# The National Streamflow Statistics Program: A Computer Program for Estimating Streamflow Statistics for Ungaged Sites

Chapter 6 of
**Book 4, Hydrologic Analysis and Interpretation**
**Section A, Statistical Analysis**


Techniques and Methods 4-A6

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

**Cover.** Photographs of an exposed streambed on the Ipswich River upstream of Rt. 28 in North Reading, Massachusetts, taken June 17, 1999 by David W. Armstrong, MA-RI Water Science Center, and flooding in Evansville, Indiana, January 2005. Flood photograph (by Vincent Pugliese, copyright The Evansville Courier and Press) shows U.S. Geological Survey hydrographers preparing to make a streamflow measurement at the White River at Petersburg streamflow-gaging station.

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# The National Streamflow Statistics Program: A Computer Program for Estimating Streamflow Statistics for Ungaged Sites

Compiled by Kernell G. Ries III

## Abstract

The National Streamflow Statistics (NSS) Program is a computer program that should be useful to engineers, hydrologists, and others for planning, management, and design applications. NSS compiles all current U.S. Geological Survey (USGS) regional regression equations for estimating streamflow statistics at ungaged sites in an easy-to-use interface that operates on computers with Microsoft Windows operating systems. NSS expands on the functionality of the USGS National Flood Frequency Program, and replaces it.

The regression equations included in NSS are used to transfer streamflow statistics from gaged to ungaged sites through the use of watershed and climatic characteristics as explanatory or predictor variables. Generally, the equations were developed on a statewide or metropolitan-area basis as part of cooperative study programs. Equations are available for estimating rural and urban flood-frequency statistics, such as the 100-year flood, for every state, for Puerto Rico, and for the island of Tutuila, American Samoa. Equations are available for estimating other statistics, such as the mean annual flow, monthly mean flows, flow-duration percentiles, and low-flow frequencies (such as the 7-day, 10-year low flow) for less than half of the states. All equations available for estimating streamflow statistics other than flood-frequency statistics assume rural (non-regulated, non-urbanized) conditions.

The NSS output provides indicators of the accuracy of the estimated streamflow statistics. The indicators may include any combination of the standard error of estimate, the standard error of prediction, the equivalent years of record, or 90-percent prediction intervals, depending on what was provided by the authors of the equations.

The program includes several other features that can be used only for flood-frequency estimation. These include the ability to generate flood-frequency plots, and plots of typical flood hydrographs for selected recurrence intervals, estimates of the probable maximum flood, extrapolation of the 500-year flood when an equation for estimating it is not available, and weighting techniques to improve flood-frequency estimates for gaging stations and ungaged sites on gaged streams.

This report describes the regionalization techniques used to develop the equations in NSS and provides guidance on the applicability and limitations of the techniques. The report also includes a users' manual and a summary of equations available for estimating basin lagtime, which is needed by the program to generate flood hydrographs. The NSS software and accompanying database, and the documentation for the regression equations included in NSS, are available on the Web at *http://water.usgs.gov/software/*.

# Introduction

By K.G. Ries III, W.O. Thomas, Jr., and M.E. Jennings

Estimates of streamflow statistics, such as the mean flow, the 100-year flood, and the 7-day, 10-year low flow, are used for a variety of design, planning, and management purposes. These estimates are often needed at ungaged sites where no observed data are available to calculate the statistics. Regression equations are commonly used for estimating streamflow statistics at ungaged sites. Regression equations are developed by statistically relating the computed streamflow statistics to the physical and climatic characteristics of the watersheds for a group of gaging stations that have virtually natural streamflow conditions within a region. Regression equations enable the transfer of streamflow statistics from gaging stations to ungaged sites simply by determining the watershed and climatic characteristics needed for the ungaged site and solving the regression equations based on these input values.

The U.S. Geological Survey (USGS) has been developing regression equations for estimating streamflow statistics at ungaged sites since at least the early 1960s. Support and justification for the applicability of these equations for estimating flood-peak discharges and frequencies for rural watersheds is given in reports by the U.S. Water Resources Council (1981) and by Newton and Herrin (1982). These reports summarize a test of nine different statistical and deterministic procedures for estimating flood frequencies for rural watersheds. The results of this test indicate that USGS-developed regression equations are unbiased, reproducible, and easy to apply.

By 1993, reports that contained regression equations for estimating flood frequencies for rural, unregulated watersheds had been published by the USGS, at least once, for every state and for the Commonwealth of Puerto Rico, and reports that contained equations for estimating urban flood frequencies were available for metropolitan areas in at least 13 States. These reports were prepared generally in cooperation with individual state Departments of Transportation, and were published either by the USGS or the state Departments of Transportation. In addition, a report that contained national regression equations for estimating urban flood frequencies had been prepared in cooperation with the Federal Highway Administration by this time (Sauer and others, 1983).

The USGS, in cooperation with the Federal Highway Administration and the Federal Emergency Management Agency, compiled all USGS-developed flood-frequency regional regression equations available as of September 1993 in the National Flood Frequency (NFF) Program, version 1.0 (Jennings and others, 1994). NFF was a MS-DOS computer program that provided engineers and hydrologists a practical tool for computing estimates of flood-peak discharges at selected recurrence intervals used for planning and design applications. NFF also provided the ability to generate flood-frequency and flood hydrograph plots for rural and (or) urban peak discharges. Version 2.0 of NFF was released in 1996 by the U.S. Forest Service, and added conversion between English and metric units of measure.

In 2002, the USGS released version 3.0 of NFF with a user-friendly Microsoft Windows user interface and updated flood-peak equations for all or parts of 36 states (Ries and Crouse, 2002). Version 3.0 of NFF also added weighting techniques to improve flood-frequency estimates for gaging stations and ungaged sites on gaged streams.

In addition to developing regression equations for estimating flood-frequency statistics, the USGS has developed numerous regression equations for estimating other streamflow statistics. For instance, Ries and Friesz (2000) developed equations for estimating flow-duration and low-flow frequency statistics for ungaged sites in Massachusetts. In addition, Hortness and Berenbrock (2001) developed equations for estimating monthly and annual mean flow and flow-duration statistics for ungaged sites in Idaho. As with the flood-frequency equations, equations for estimating other streamflow statistics usually are developed on a state-by-state basis through cooperative agreements between the USGS and local agencies. Regression equations for non-flood frequency statistics are available for fewer than half of the states.

The NFF Program has been modified to enable estimation of any streamflow statistics for which the USGS has developed compatible regression equations. Additional modifications to the program include the ability to provide region-of-influence regression estimates and to calculate prediction intervals for the estimated statistics. The software has been renamed the National Streamflow Statistics (NSS) Program to better reflect its new abilities. The version number, however, has been increased from 3.0 for the previous version of NFF to 4.0 for this initial release of NSS because NSS is considered to be an evolution of NFF.

## Purpose

The purpose of this report is to document and describe the techniques used to develop the regional regression equations and the other functionality included in the NSS Program. The report provides guidance on the applicability and limitations of the techniques, and describes how to obtain and use the program. The report also describes how to obtain information needed to solve the regression equations available for each of the individual states.

## Report Format

The main body of this report provides an overview of regionalization methods, summarizes the characteristics of the estimating techniques, and describes their applicability and limitations. Much of the material was taken verbatim from the previous NFF Program reports (Ries and Crouse, 2002; Jennings and others, 1994). Additions and revisions have been made to the report to describe additions to the capabilities of the software and changes in regionalization methods. In addition, a section that summarizes the documentation for state flood-frequency techniques is included.

This report contains two appendixes. Appendix A is a Users' Manual that explains in detail how to install and use the program. Appendix B is a summary of methods for estimating basin lagtime.

Many people contributed to the development of the computer program and this associated documentation. Authors are listed for each section of the report.

## How to Obtain the NSS Software and Documentation

USGS hydrologic analysis software is available for electronic retrieval through the World Wide Web (Web) at *http://water.usgs.gov/software/*. This Web page has links to all USGS software available for use in hydrologic analysis.

The specific Web page from which the NSS software and documentation can be retrieved is *http://water.usgs.gov/software/nss.html*. The documentation includes a digital copy of this report and information for each State, the Commonwealth of Puerto Rico, and American Samoa that contains the applicable regression equations and much of the reference information needed to solve them. This information is provided through Web links to Fact Sheets, online reports, and pages from the first NFF report (Jennings and others, 1994). A help facility also is included with the software.

New equations are developed for several areas of the Nation each year. As new equations become available, it is planned that the NSS software and documentation will be updated to include them. NSS users should check the Web site often for updates.

# History and Overview of Methods for Regionalization of Streamflow Statistics

By K.G. Ries III, and W.O. Thomas, Jr.

## Introduction

The USGS has been involved in the development of regionalization procedures for over 50 years. These regionalization procedures are used to transfer flood statistics, such as the 100-year flood-peak discharge, and other statistics, such as the mean flow and the 7-day, 10-year low flow, from gaged to ungaged sites. The USGS has traditionally used regionalization procedures that relate streamflow statistics to watershed and climatic characteristics through the use of correlation or regression techniques. Because streamflow statistics may vary substantially between regions due to differences in climate, topography, and geology, tests of regional homogeneity form an integral part of streamflow regionalization procedures.

The evolution of regionalization techniques within USGS is described by discussing the following six techniques: (1) the index-flood procedure used from the late 1940s to the 1960s, (2) the ordinary-least-squares regression procedure used in the 1970s and 1980s, (3) the weighted- and (4) generalized-least-squares regression procedures, first used in the late 1980s and still used today (2005), (5) the region-of-influence procedure, first used in the 1990s, and (6) StreamStats, an emerging automated procedure for estimating streamflow statistics.

## Index-Flood Procedures

The index-flood procedure consisted of two major parts: (1) the development of basic, dimensionless frequency curves representing the ratio of flood discharges at selected recurrence intervals to an index flood—the mean annual flood, and (2) the development of a relation between watershed and climatic characteristics and the mean annual flood to enable the mean annual flood to be predicted at any point in the region. The combination of the mean annual flood with the basic frequency curve, expressed as a ratio of the mean annual flood, provided a frequency curve for any location (Dalrymple, 1960).

The determination of the dimensionless frequency curve involved: (1) graphical determination of the frequency curve for each station using the Weibull plotting position, (2) determination of homogeneous regions using a homogeneity test on the slopes of the frequency curves, and (3) computation of the regional dimensionless frequency curve based on the median flood ratios for each recurrence interval for each station in the region. The homogeneity test used the ratio of the 10-year flood to the mean annual flood to determine whether the differences in slopes of frequency curves for all stations in a given region are greater than those attributed to chance. The 10-year flood discharge was first estimated from the regional dimensionless frequency curve. The 95-percent confidence interval for the recurrence interval of this discharge, as determined from the individual station frequency curves, was then determined as a function of record length. If the recurrence interval for a given station was within the 95-percent confidence bands, then the station was considered part of the homogeneous region. Otherwise, the station was assumed to be in another region.

The mean annual flood, as used in the index-flood procedure, was determined from the graphical frequency curve to have a recurrence interval of 2.33 years. The mean annual flood for an ungaged location was estimated from a relation that was determined by relating the mean annual flood at gaging stations to measurable watershed characteristics, such as drainage area, area of lakes and swamps, and mean altitude.

The index-flood procedure described above was used to develop a nationwide series of flood-frequency reports entitled "Magnitude and Frequency of Floods in the United States." Each report provided techniques for estimating flood magnitude and frequency for a major drainage basin or subbasin, such as the Lower Mississippi River Basin. These reports were published as USGS Water-Supply Papers 1671–1689 during the period 1964–68.

## Ordinary-Least-Squares Regression

Studies by Benson (1962a, 1962b, 1964) indicated that T-year flood-peak discharges could be estimated directly using watershed and climatic characteristics based on multiple-regression techniques. As noted by Benson (1962a), the direct estimation of T-year flood-peak discharges avoided the following deficiencies in the index-flood procedure: (1) the flood ratios for comparable streams may differ because of large differences in the index flood; (2) homogeneity of frequency-curve slope can be established at the 10-year level, but individual frequency curves commonly show wide and sometimes systematic differences at the higher recurrence levels; and (3) the slopes of the frequency curves generally vary inversely with drainage area. Benson (1962b, 1964) also showed that the flood ratios vary not only with drainage area but also with main-channel slope and climatic characteristics.

On the basis of this early work of Benson and later work by Thomas and Benson (1970), direct regression on the T-year flood using ordinary-least-squares (OLS) techniques became the standard approach of the USGS for regionalizing flood characteristics in the 1970s. OLS techniques also began to be used to estimate low-flow and other streamflow statistics beginning in the early 1970s (Lystrom, 1970; Yamanaga, 1972). In OLS regression, equal weight is given to all stations in the analysis, regardless of record length and the possible correlation of flood estimates among stations.

The flood-frequency statistics for gaging stations included in regional studies generally were computed using the guidelines described in Bulletin 15 (U.S. Water Resources Council, 1967) or some version of Bulletin 17 of the Hydrology Committee of the U.S. Water Resources Council or the U.S. Interagency Advisory Committee on Water Data (U.S. Water Resources Council, 1976, 1977, 1981; Interagency Advisory Committee on Water Data, 1982). These Bulletins prescribe estimating the T-year flood-peak discharges for gaging stations by fitting the Pearson Type III distribution to the logarithms of the annual peak discharges. The USGS computer program PEAKFQ applies the Bulletin 17B methods to estimate the flood statistics for gaging stations. The program and documentation can be downloaded from the Web at *http://water.usgs.gov/software/peakfq.html*.

Low-flow frequency statistics for gaging stations included in regional studies generally were estimated by fitting the Pearson Type III distribution to the logarithms of annual series of n-day mean flows. For instance, the 7-day, 10-year flow is estimated by fitting annual series of 7-day mean flows to the distribution and determining the 7-day mean flow that corresponds to the 10-year recurrence interval. The USGS computer program SWSTAT can be used to estimate low-flow frequency statistics, flow-duration statistics, means, minimums, maximums, medians, standard deviations, and other statistics for user-selected time periods. The SWSTAT Program and documentation can be downloaded from the Web at *http://water.usgs.gov/software/swstat.html*.

## Weighted- and Generalized-Least-Squares Regression

Research on regionalization of flow characteristics beginning in the 1980s centered on accounting for deficiencies in the assumptions of OLS regression and on developing more accurate and objective tests of regional homogeneity. OLS regression procedures do not account for variable errors in flow characteristics caused by unequal record lengths at gaging stations. Tasker (1980) proposed the use of weighted-least-squares (WLS) regression for flood characteristics where the variance of the observed flood characteristics was estimated as an inverse function of record length. Tasker and Stedinger (1986) used WLS regression to estimate regional skew of annual peak discharges with greater accuracy than results obtained using OLS regression.

Both OLS and WLS regression do not account for the possible correlation of concurrent annual peak-flow records between sites. This cross correlation of streamflows causes bias in the estimated coefficients of the parameters and in the estimated variance of the regression equations. The problem may be particularly significant where streamgages are located on the same stream, on similar and adjacent watersheds, or where streamflow statistics have been determined from a rainfall-runoff model using the same long-term rainfall record.

Generalized-least-squares (GLS) regression was proposed by Stedinger and Tasker (1985, 1986) to account for both the unequal reliability and the correlation of flood characteristics between sites. In a Monte Carlo simulation, Stedinger and Tasker (1985) showed that GLS regression procedures provided more accurate estimates of regression coefficients, better estimates of the accuracy of the regression coefficients, and better estimates of the model error than did OLS procedures. In addition, Tasker and others (1986) showed that GLS procedures provided a smaller average variance of prediction than OLS procedures for the regional 100-year flood for streams in Pima County, Arizona. Stedinger and Tasker (1985) found that the WLS procedure, which accounts for differences in record length but neglects cross correlations among concurrent flows, performs nearly as well as the GLS procedure when the cross correlations are modest (less than about 0.3) and (or) when model errors are high (model standard errors greater than about 70 percent). Equations included in the NSS Program for several of the states are based on WLS or GLS regression, although the GLS procedure is the more popular of the two techniques. A program named GLSNET that implements GLS regression is available on the Web at *http://water.usgs.gov/software/glsnet.html*.

The GLSNET program, and SWSTAT and PEAKFQ programs described above, require input data to be in a direct access file called a Watershed Data Management (WDM) file. Additional software programs are needed to import and export (IOWDM) and to manage (ANNIE) data in the WDM format. The IOWDM program and documentation can be downloaded from the Web at *http://water.usgs.gov/software/iowdm.html*. The ANNIE program and documentation can be downloaded from the Web at *http://water.usgs.gov/software/annie.html*.

## Region-Of-Influence Regression

The region-of-influence (ROI) regression procedure was first suggested by Acreman and Wiltshire (1987) and was subsequently evaluated by Burn (1990a, 1990b). The procedure was first used within the USGS by Tasker and Slade (1994). ROI regression determines a new equation each time an estimate is desired for a new ungaged site. The new equation is determined from a unique subset of streamgaging stations, referred to as the region of influence, and comprised of the set of stations nearest to the ungaged site, with nearness determined by the similarity of climatic and physical characteristics rather than the physical distance between the sites. Once the region of influence is determined for the ungaged site, the GLS regression procedure is used to develop the unique set of flood-frequency equations for the site. Predictions obtained by use of the ROI regression method generally are closer to the center of the data used to develop the equation than predictions obtained by use of more traditional regression methods. Thus, extrapolation errors and problems resulting from assumption of linearity are reduced (Ensminger, 1998).

ROI regression is still considered somewhat experimental. Results from studies that have used the procedure (Hodge and Tasker (1995) for Arkansas; Lorenz and others (1997) for Minnesota; Ensminger (1998) for Louisiana; Asquith and Slade (1999) for Texas; Pope and Tasker (1999) for North Carolina; Eash (2000) for Iowa; Feaster and Tasker (2002) for South Carolina, and Berenbrock (2002) for Idaho) indicate that errors obtained by use of the procedure usually (but not always) are lower than errors obtained by use of the GLS regression procedure. None of the authors of the studies has recommended exclusive use of the ROI regression procedure in preference to the GLS regression procedure. Berenbrock (2002) recommended that the ROI procedure not be used for Idaho because errors for the ROI are larger than those for the GLS method in Idaho.

Because ROI computations are mathematically complex, computer programs are required to solve the equations. NSS contains the algorithms needed to perform the ROI procedure for states where the ROI method was developed; however, because of the special data requirements for the procedure, downloading a special database and separate binary files is required for each state. Information for downloading the needed files is provided at the NSS Web site at *http://water.usgs.gov/software/nss.html*. Alternately, users may choose to download custom programs that accompany the reports for each of the ROI studies. These reports generally can be located through "Publications" links from the individual Web pages operated by each USGS Water Science Center. Typically, these Web pages have the format *http://xx.water.usgs.gov*, where xx is the 2-letter postal state code. Eash (2000) did not provide a computer program to apply the ROI method for Iowa because the GLS method usually provided better results and was easier for users to apply.

# Estimating Techniques for Rural Areas

By K.G. Ries III, W.O. Thomas, Jr., and J.B. Atkins

## Introduction

The NSS Program provides equations for estimating the magnitude and frequency of flood characteristics for rural, unregulated watersheds in the 50 states, the Commonwealth of Puerto Rico, and American Samoa. NSS also provides equations for estimating other streamflow statistics for rural, unregulated watersheds in many states. These equations are taken from USGS reports that were published between 1973 and 2005.

The purpose of this section is to provide a brief overview of the rural regression equations that are presented in NSS. A summary of information needed to solve the regression equations for each state is provided in the section "Summary of State Estimating Techniques."

## Watershed and Climatic Characteristics

The rural equations in NSS are based on watershed and climatic characteristics that can be obtained from topographic maps, aerial photographs, rainfall reports and atlases, or digital map data derived from those sources. Drainage area or contributing drainage area appears in nearly all of the statewide rural regression equations given in NSS. The other most frequently used watershed and climatic characteristics are main-channel slope and mean annual precipitation. The regression equations are generally reported in the following form:

$$RQ = aX^{b}Y^{c}Z^{d},$$

where

RQ is the rural estimate of a streamflow statistic (the dependent variable),

X, Y, Z are watershed or climatic characteristics used as independent variables, and

a, b, c, d are regression coefficients.

The dependent and independent variables usually are transformed to logarithms before regression analysis is done to assure that regression residuals (differences between regression and station (observed) estimates of streamflow statistics) are normally distributed. In instances where a variable could equal zero (such as percentage of drainage area covered by lakes and ponds), a constant is added to the variable before taking the logarithms. Drainage area is the only explanatory variable in the peak-flow regression equations for several states, but it is more common to have up to four explanatory variables in the equations. The USGS has published peak-flow regression equations in many states based on channel-geometry characteristics, such as channel width; however, these equations are not provided in NSS because a site visit is required to obtain the explanatory variables.

Different names and symbols are often given to the same basin and climatic characteristics in reports that describe the regression equations for different states. For example, there are 10 different names in NSS for one of the most commonly used characteristics—the precipitation amount that occurs during 24 hours, on average, once in 2 years. In addition, main-channel slope is also referred to as channel slope or streambed slope, and is identified by symbols such as S, SL, Sc, Sb, and Sm. All of these symbols represent the slope between two points on the main channel, 85 percent and 10 percent of the channel length upstream from the streamgaging station or outlet of the watershed. NSS uses the names given to the characteristics in the original state reports to avoid differences between the program and the state documentation.

Source data (maps, aerial photographs, atlases, Geographic Information System (GIS) data layers, and graphical relations) used to measure the characteristics may vary from state to state, although the name used may be the same. It is important to use the same source data and methods to measure the characteristics for input to NSS as those that were used to develop the regression equations. Use of different source data and methods will result in estimates of streamflow statistics with unknown errors. In most cases, the data sources were the best available topographic maps or digital representations of the features on those maps. In some cases, digital map data used in the studies are available from the authors of the state reports.

Percentages, such as the percentage of the watershed in forests or lakes and ponds (when not determined by use of a GIS) are generally determined by a grid-sampling method using 20–80 points in the watershed. A transparent grid is overlain on the outline of the watershed on the most appropriate topographic map. The grid should have from 20–80 nodes within the respective watershed boundary, the number of nodes overlying green (forest) or blue (lakes and ponds) is determined, and the percentage of forest or lakes and ponds is computed as the number of node intersections (with green or blue) divided by the total nodes within the watershed. Mean basin elevation is also generally determined by the same grid-sampling method averaging elevations for 20–80 points in the watershed. The documentation for the individual states commonly contains maps of variables, such as mean annual precipitation, the 2-year 24-hour rainfall, average annual snowfall, and minimum mean January temperature.

## Hydrologic Regions

Most reports that contain regression equations for estimating streamflow statistics have a statewide geographic extent. For most of the studies described in these reports, the analysts divided their states into multiple hydrologic regions that represent areas of relatively homogeneous streamflow characteristics. The regions were usually determined by using major watershed boundaries and an analysis of the areal distribution of the regression residuals (differences between regression estimates of the streamflow statistics for the streamgaging stations used in the analysis and estimates determined from the available data for the stations). Analysis of the residuals is done to identify regions of residuals whose magnitude and algebraic sign were similar within and dissimilar between regions. Hydrologic regions were also defined by the mean elevation of the watershed in some states. These procedures for determining hydrologic region boundaries generally improve the accuracy of the estimating technique, but they are somewhat subjective. Statistical tests, such as the Wilcoxon signed-rank test, usually were used to determine if the streamflow statistics were statistically different among regions. More objective procedures for defining regions are beginning to be used, such as kriging, cluster analysis, and discriminant analysis.

On average, there are about four hydrologic regions per state; however, some states have inadequate data to define streamflow relations in some regions. For example, Florida, Georgia, and South Carolina have regions of undefined flood frequency, and regression equations are provided only for the island of Oahu, Hawaii. Regression equations for estimating flood-peak discharges for the other islands were computed as part of a nationwide network analysis (Yamanaga, 1972), but those equations are not included in NSS because that study did not focus specifically on flood-frequency analysis. Flood-peak regression equations are provided only for the island of Tutuila, American Samoa. Idaho and Massachusetts have regions where both floods and low flows are undefined. Hydrologic regions for floods and low flows are the same in some states but different in others.

## Measures of Accuracy

Estimates obtained from regression equations have a related degree of uncertainty that can be described by various measures of accuracy. Every USGS report that contains regional regression equations provides some measure of the accuracy of the equations.

Accuracy varies from site to site depending on the values of the explanatory variables (basin and climatic characteristics) for the sites. Estimates for sites with values of explanatory variables that are closer to the average values for the stations used in the regression analyses have greater accuracy than estimates for sites with values of explanatory variables that are far from the average values.

The average standard error of estimate, usually in percent, was used as the primary measure of accuracy in many of the reports that are more than about 15 years old. The average standard error of estimate is a measure of the average variation between the regression estimates and estimates derived from the station data for those stations used to develop the regression equations. About two-thirds of the regression estimates for the gaging stations used in the regression analyses have errors less than the average standard error of estimate. About one-third of the estimates have errors larger than the average standard error of estimate.

The average standard error of prediction, usually in percent, is used as the primary measure of accuracy in many recent reports. It is preferred over use of the average standard error of estimate because the average standard error of prediction is a measure of the average accuracy of the regression equations when predicting values for ungaged sites—the condition under which regression equations are most often applied. The average standard error of prediction is usually a few percent larger than the average standard error of estimate. About two-thirds of the regression estimates for ungaged sites will have errors less than the average standard errors of prediction given for the equations. NSS provides standard errors of estimate only when the standard errors of prediction were not provided in the individual statewide reports.

The average standard errors of estimate or prediction range from 30–60 percent for most of the flood-peak equations, though some equations have average standard errors near 15 percent, and some equations have standard errors greater than 100 percent. The smallest flood-peak standard errors generally are for equations developed for the eastern part of the Nation, whereas the largest standard errors generally are for flood-peak equations developed for the western and southwestern parts of the Nation. Errors generally are largest in the west and southwest because at-site variability of the flood records is greater, the network of unregulated gaging stations is less dense, and the flood records are generally shorter there than in other areas. In addition, regionalization generally is more difficult in the west and southwest than elsewhere because local climate and hydrology are sensitive to the larger variations in relief and aspect that are present in the west and southwest. In addition, the relation between natural streamflow and drainage area changes seasonally in much of this area, where streamflow often decreases with increasing drainage area as a result of high losses to evaporation, transpiration, and infiltration of water from streams to the ground.

No other streamflow statistics have equations that are available nationally, as is the case for flood-peak statistics. Because of this, errors associated with other streamflow statistics are difficult to analyze from a national perspective; however, regional conditions that favor or inhibit the accuracy of flood-peak estimates typically have similar effects on other streamflow statistics.

Previous versions of NFF did not distinguish between standard errors of estimation and prediction in the output, where they were given under a single heading named "Standard error, %." When possible, NSS now distinguishes between standard errors of estimation and prediction in the output. Standard errors of estimation are given under a heading named "Estimation error, %," and prediction errors are given under a heading named "Prediction error, %." When the type of error was not specified in the report, the "Standard error, %" heading is given.

The equivalent years of record is another measure of accuracy that is available in NSS for many flood-frequency regression equations. Equivalent years of record is defined as the number of years of actual streamflow record needed to achieve the same accuracy as the regional regression equations. This accuracy measure is related to the average standard error of prediction of the regression equations, the recurrence interval, and the average variance and skew of the annual peak flows at the gaging stations used in the analysis (Hardison, 1971).

Several reports published since the late 1980s for regional regression studies have contained information needed to calculate prediction intervals for estimates of streamflow statistics for individual sites. Prediction intervals indicate the probability that the true flow for a site is within the given bounds of flow. For example, the 90-percent prediction interval for a flow estimate at a site indicates that there is 90 percent confidence that the true flow for the site is between the given flow values.

Calculation of prediction intervals is complex. Authors of individual reports that describe methods for computing prediction intervals usually provide computer programs that can be used to compute the intervals. For example, Hodgkins (1999) describes methods for computing prediction intervals for flood-frequency estimates for ungaged sites in Maine, and he provides a computer program that can be used to compute the estimates and prediction intervals. NSS contains an algorithm described by Tasker and Driver (1988) that can be used to compute 90-percent prediction intervals for sites when report authors have provided documentation for computing them.

When estimates of streamflow statistics are determined from regression equations for an ungaged site with basin characteristics that are outside the ranges of the basin characteristics for the gaging stations used to develop the equations, the estimates are said to be extrapolated. The accuracies of extrapolated estimates are unknown. NSS allows extrapolations to be done, but users should carefully consider the possible consequences for using such estimates for planning and design purposes. The applicable ranges of basin characteristics used to develop the equations are listed in the reports from which the equations are taken, and they are also shown in the NSS user interface. NSS warns users when they have entered an explanatory variable that is outside an applicable range and asks them if they want to proceed. NSS also provides a warning in the output for these cases. Measures of accuracy are not provided for extrapolated estimates.

## Techniques for Watersheds that Span Regional/State Boundaries

NSS can estimate streamflow statistics for basins that span more than one hydrologic region within the same state. This is accomplished on the basis of percentage of drainage area in each region. The user should verify that the resultant estimates reflect the streamflow characteristics of the regions by consulting the respective state report, and in the case of flood-frequency statistics, by examining plots of the computed frequency curves.

When an ungaged site has drainage area in two or more regions, the NSS report shows the estimates from each individual region as well as the final area-weighted averaged estimates. The error measures provided for the area-weighted averaged estimates are calculated by area weighting of the error measures for the individual regions. If the estimates for any region are extrapolated, the error measures are not shown in the output for the averaged estimates. In these cases, users should consider whether to use the non-extrapolated regional estimates in preference to the averaged estimates.

Regional estimates for watersheds that span state boundaries may give different results depending on which state's equations are used. NSS is not able to weight the computations by drainage area for basins that cross state boundaries. Because of this limitation, the user must perform this procedure manually, which can be accomplished by applying NSS for each state using the basin's full drainage area. Next, the user must manually weight the estimates based on the percentage of the basin's drainage area in each state. For example, two sets of flood-frequency computations were obtained for the Sucarnoochee River at Livingston, Alabama; 320 square miles of the basin's total area of 606 square miles are in Mississippi, and 286 square miles of the basin are in Alabama. Table 1 shows the frequency computations using the full drainage area in the application of each state's equation and the weighted frequency computations.

**Table 1.** Flood-frequency computations for Sucarnoochee River at Livingston, Alabama.

[Q, discharge; (ft³/s), cubic feet per second]

| Recurrence interval (years) | Computed peak Q in Mississippi (ft³/s) | Computed peak Q in Alabama (ft³/s) | Weighted frequency estimates (ft³/s) |
|---|---|---|---|
| 2 | 16,000 | 8,750 | 12,600 |
| 5 | 27,900 | 15,400 | 22,000 |
| 10 | 36,100 | 20,700 | 28,800 |
| 25 | 47,400 | 28,800 | 38,600 |
| 50 | 58,200 | 35,700 | 47,600 |
| 100 | 63,800 | 43,400 | 55,200 |
| 200 | 74500 | 51,500 | 63,600 |
| 500 | 85,700 | 64,100 | 75,500 |

The weighted flood-frequency computations were obtained by using the following equation:

$$Q_{T(w)} = \frac{320}{606} Q_{T(MS)} + \frac{286}{606} Q_{T(AL)},$$

where

$Q_{T(MS)}$ and $Q_{T(AL)}$ are the computed T-year peak discharges, in cubic feet per second, using the Mississippi and Alabama regression equations, respectively; and

$Q_{T(w)}$ is the weighted T-year peak discharge, in cubic feet per second.

Differences between the Mississippi and the Alabama estimates are substantial. For example, the 100-year flood discharge for the Sucarnoochee River would be about 63,800 cubic feet per second if the basin was entirely within Mississippi, but only about 43,400 cubic feet per second if the basin was entirely within Alabama. The weighted estimate for the site, obtained from the equation above, is 55,200 cubic feet per second.

## Weighting of Independent Estimates of Rural Flood Frequency

Tasker (1975) demonstrated that if two independent estimates of a streamflow statistic are available, a properly weighted average of the independent estimates will provide an estimate that is more accurate than either of the independent estimates. NSS includes weighting algorithms that can produce improved flood-frequency estimates for streamgaging stations and ungaged sites. Improved flood-frequency estimates are determined for streamgaging stations by weighting regression-derived estimates with estimates determined from the systematic peak-flow record at the station. Improved estimates are determined for ungaged sites by weighting the regression-derived flood-frequency estimates for an ungaged site with estimates determined based on the flow per unit area of an upstream or downstream streamgaging station. The weighting equations provided in the following sections could, in theory, be used for many types of streamflow statistics, but weighting can only be done for flood-frequency statistics in NSS.

Some researchers have recommended different weighting methods in reports that describe the flood-frequency regression equations for individual states. Before using the weighting algorithms in NSS, users should refer to the state reports to determine if different weighting methods are recommended.

## Weighting for Streamgaging Stations

NSS includes the weighting procedure for streamgaging stations presented by the Interagency Advisory Committee on Water Data (1982), which combines flood-frequency estimates determined from log-Pearson type III analysis of the systematic annual peaks for a streamgaging station with estimates obtained for the station from regression equations. Weighting is based on the years of record for the estimates obtained from the station records and on the equivalent years of record for the regression estimates. If the two different estimates are assumed to be independent, weighted flood-frequency estimates can be computed as:

$$\log Q_{T(G)w} = \frac{N \log Q_{T(G)s} + EQ \log Q_{T(G)r}}{N + EQ} ,$$

where

$Q_{T(G)w}$ is the weighted estimate of flood-peak discharge Q for recurrence interval T at the streamgaging station,

$Q_{T(G)s}$ is the estimate of $Q_T$ derived from the systematic flood peaks,

$Q_{T(G)r}$ is the estimate of $Q_T$ derived from the regression equation,

N is the number of years of gaged record, and

EQ is the equivalent years of record determined for the regression equation.

The accuracy of the weighted estimate, in equivalent years of record, is equal to the N + EQ. No other indicators of accuracy are available for these weighted estimates. NSS cannot compute weighted estimates for streamgaging stations if the equivalent years of record are not available for the regression equations. In these cases, if NSS is used to calculate weighted estimates, the results will be identical to the estimates from the systematic flood peaks.

## Weighting for Ungaged Sites on Gaged Streams

NSS includes the weighting procedure presented by Guimaraes and Bohman (1992) and Stamey and Hess (1993) to improve flood-frequency estimates for a rural ungaged site with a drainage area that is between 0.5 and 1.5 times the drainage area of a streamgaging station that is on the same stream. To obtain a weighted peak-flow estimate $Q_T$ for recurrence interval T at the ungaged site ($Q_{T(U)w}$), the NSS program must first be used to create a scenario of weighted flow estimates for an upstream or downstream gaging station. The weighted gaging station estimate ($Q_{T(G)w}$) is then used to obtain an estimate for the ungaged site that is based on the flow per unit area at the gaging station ($Q_{T(U)g}$) by use of the equation:

$$Q_{T(U)g} = \left[\frac{A_u}{A_g}\right]^b Q_{T(G)w} ,$$

where

$A_u$ is the drainage area for the ungaged site,

$A_g$ is the drainage area for the upstream or downstream gaging station, and

b depending on the state, may be the exponent of drainage area from the appropriate regression equation, a value determined by the author of the state report, or 1 where not defined in the reports.

NSS applies the appropriate b values automatically. The weighted estimate for the ungaged site ($Q_{T(U)w}$) is then computed as:

$$Q_{T(U)w} = \frac{2\Delta A}{A_g} Q_{T(U)r} + \left[1 - \frac{2\Delta A}{A_g}\right] Q_{T(U)g}$$

where

$\Delta A$ is the absolute value of the difference between the drainage areas of the streamgaging station and the ungaged site, $|A_g - A_u|$, and

$Q_{T(U)r}$ is the peak-flow estimate for recurrence interval T at the ungaged site derived from the applicable regional equation (table 1).

The weighting algorithm gives full weight to the regression estimates when the drainage area for the gaging station is less than 0.5 or greater than 1.5 times the drainage area for the ungaged site and increasing weight to the gaging station-based estimates as the drainage area ratio approaches 1. The weighting procedure should not be applied when the drainage area is less than 0.5 or greater than 1.5.

NSS computes the equivalent years of record for the weighted estimates for an ungaged site, $EQ_{T(U)w}$. It first computes the equivalent years of record for the weighted estimate of peak discharge at the streamgaging station, $EQ_{T(U)g}$ by substituting the weighted equivalent years of record computed by NFF for $Q_{T(G)w}$ into the equation above. It then inserts $EQ_{T(U)g}$ for $Q_{T(U)g}$ and the equivalent years of record from the regression equations, $EQ_{T(U)g}$, for $Q_{T(U)g}$ into the first equation in this section to compute $EQ_{T(U)w}$. No other indicators of accuracy are available for these estimates. In theory, the standard errors for these estimates should be at least as small as those for the estimates derived from the regression equations alone.

# Urban Flood-Frequency Estimating Techniques

By V.B. Sauer

## Introduction

The NSS Program provides equations for estimating the magnitude and recurrence intervals for floods in urbanized areas throughout the conterminous United States and Hawaii. The seven-parameter nationwide equations described in USGS Water-Supply Paper (WSP) 2207 (Sauer and others, 1983), are based on urban runoff data from 199 basins in 56 cities and 31 states. These equations have been thoroughly tested and proven to give reasonable estimates for floods having recurrence intervals between 2 and 500 years. A later study by Sauer (1985) of urban data at 78 additional sites in the southeastern United States verified the seven-parameter equations as unbiased and having standard errors equal to or better than those reported in WSP 2207.

Additional equations for urban areas in some states have been included in the NSS program as optional methods to estimate and compare urban flood frequency. These equations were developed for local use within their designated urban area and should not be used for other urban areas.

## Nationwide Urban Flood-Frequency Equations

The following seven-parameter equations and definitions are excerpted from Sauer and others (1983). The equations are based on multiple regression analysis of urban flood-frequency data from 199 urbanized basins,

$$UQ2 = 2.35\ A^{.41}\ SL^{.17}\ (RI2+3)^{2.04}\ (ST+8)^{-.65}\ (13\text{-}BDF)^{-.32}\ IA^{.15}\ RQ2^{.47}$$
standard error of estimate is 38 percent

$$UQ5 = 2.70\ A^{.35}\ SL^{.16}\ (RI2+3)^{1.86}\ (ST+8)^{-.59}\ (13\text{-}BDF)^{-.31}\ IA^{.11}\ RQ5^{.54}$$
standard error of estimate is 37 percent

$$UQ10 = 2.99\ A^{.32}\ SL^{.15}\ (RI2+3)^{1.75}\ (ST+8)^{-.57}\ (13\text{-}BDF)^{-.30}\ IA^{.09}\ RQ10^{.58}$$
standard error of estimate is 38 percent

$$UQ25 = 2.78\ A^{.31}\ SL^{.15}\ (RI2+3)^{1.76}\ (ST+8)^{-.55}\ (13\text{-}BDF)^{-.29}\ IA^{.07}\ RQ25^{.60}$$
standard error of estimate is 40 percent

$$UQ50 = 2.67\ A^{.29}\ SL^{.15}\ (RI2+3)^{1.74}\ (ST+8)^{-.53}\ (13\text{-}BDF)^{-.28}\ IA^{.06}\ RQ50^{.62}$$
standard error of estimate is 42 percent

$$UQ100 = 2.50\ A^{.29}\ SL^{.15}\ (RI2+3)^{1.76}\ (ST+8)^{-.52}\ (13\text{-}BDF)^{-.28}\ IA^{.06}\ RQ100^{.63}$$
standard error of estimate is 44 percent

$$UQ500 = 2.27\ A^{.29}\ SL^{.16}\ (RI2+3)^{1.86}\ (ST+8)^{-.54}\ (13\text{-}BDF)^{-.27}\ IA^{.05}\ RQ500^{.63}$$
standard error of estimate is 49 percent

where

UQ2, UQ5,...UQ500 are the urban peak discharges, in cubic feet per second, for the 2-, 5-, ... 500-year recurrence intervals;

A is the contributing drainage area, in square miles, as determined from the best available topographic maps; in urban areas, drainage systems sometimes cross topographic divides. Such drainage changes should be accounted for when computing A;

SL is the main channel slope, in feet per mile (ft/mi), measured between points that are 10 percent and 85 percent of the main channel length upstream from the study site (for sites where SL is greater than 70 ft/mi, 70 ft/mi is used in the equations);

RI2 is the rainfall, in inches, for the 2-hour, 2-year recurrence interval, determined from U.S. Weather Bureau Technical Paper 40 (1961) (eastern United States), or from National Oceanic and Atmospheric Administration Atlas 2 (Miller and others, 1973) (western United States);

ST is basin storage, the percentage of the drainage basin occupied by lakes, reservoirs, swamps, and wetlands; in-channel storage of a temporary nature, resulting from detention ponds or roadway embankments, should not be included in the computation of ST;

BDF is the basin development factor, an index of the prevalence of the urban drainage improvements;

IA is the percentage of the drainage basin occupied by impervious surfaces, such as houses, buildings, streets, and parking lots; and

RQT are the peak discharges, in cubic feet per second, for an equivalent rural drainage basin in the same hydrologic area as the urban basin, for a recurrence interval of T years; equivalent rural peak discharges are computed from the rural equations for the appropriate state, in the NSS program, and are automatically transferred to the urban computations.

The basin development factor (BDF) is a highly significant variable in the equations, and provides a measure of the efficiency of the drainage basin. It can easily be determined from drainage maps and field inspections of the drainage basin. The basin is first divided into upper, middle, and lower thirds on a drainage map, as shown in figures 1A–C. Each third should contain about one-third of the contributing drainage area, and stream lengths of two or more streams should be approximately the same in each third. Stream lengths of different thirds, however, can be different. For instance, in figure 1C, the stream distances of the lower third are all about equal, but are longer than those in the middle third. Precise definition of the basin thirds is not considered necessary because it will not have much effect on the final value of BDF. Therefore, the boundaries between basin thirds can be drawn by eye without precise measurements.

Within each third of the basin, four characteristics of the drainage system must be evaluated and assigned a code of 0 or 1. Summation of the 12 codes (four codes in each third of the basin) yields the BDF. The following guidelines should not be considered as requiring precise measurements. A certain amount of subjectivity will necessarily be involved, and field checking should be performed to obtain the best estimates.

1. Channel improvements.—If channel improvements such as straightening, enlarging, deepening, and clearing are prevalent for the main drainage channels and principal tributaries (those that drain directly into the main channel), then a code of 1 is assigned. To be considered prevalent, at least 50 percent of the main drainage channels and principal tributaries must be improved to some degree over natural conditions. If channel improvements are not prevalent, then a code of 0 is assigned.

2. Channel linings.—If more than 50 percent of the length of the main channels and principal tributaries has been lined with an impervious surface, such as concrete, then a code of 1 is assigned to this characteristic; otherwise, a code of 0 is assigned. The presence of channel linings would obviously indicate the presence of channel improvements as well. Therefore, this is an added factor and indicates a more highly developed drainage system.

3. Storm drains or storm sewers.—Storm drains are defined as those enclosed drainage structures (usually pipes), commonly used on the secondary tributaries where the drainage is received directly from streets or parking lots. Many of these drains empty into open channels; however, in some basins they empty into channels enclosed as box and pipe culverts. Where more than 50 percent of the secondary tributaries within a subarea (third) consists of storm drains, then a code of 1 is assigned to this aspect; otherwise, a code of 0 is assigned.

4. Curb-and-gutter streets.—If more than 50 percent of the subarea (third) is urbanized (covered with residential, commercial, and/or industrial development), and if more than 50 percent of the streets and highways in the subarea are constructed with curbs and gutters, then a code of 1 is assigned to this aspect; otherwise, a code of 0 is assigned. Drainage from curb- and-gutter streets commonly empties into storm drains.

Estimates of urban flood-frequency values should not be made using the seven-parameter equations under certain conditions. For instance, the equations should not be used for basins where flow is controlled by reservoirs, or where detention storage is used to reduce flood peaks. The equations also should not be used if the rural equations for the region of interest contain independent variables, such as basin development factor, percentage of impervious area, percentage of urban development, or an urbanization index. Though classified in NSS as rural equations, estimates obtained from equations that contain these types of variables already reflect the effects of urbanization.

The urban equations should not be used if any of the values of the seven parameters are outside the range of values used in the original regression study (except for SL, which is limited to 70 ft/mi). These ranges are provided in the NSS Program, and the user is warned by the program anytime a variable value exceeds the range. The program will compute urban estimates even though a parameter may be outside the range; however, the standard error of estimate may be greater than the value given for each equation.

## Local Urban Flood-Frequency Equations

The NSS Program includes additional equations for some cities and metropolitan areas that were developed for local use in those designated areas only. These local urban equations can be used in lieu of the nationwide urban equations, or they can be used for comparative purposes. It would be highly coincidental for the local equations and the nationwide equations to give identical results. Therefore, the user should compare results of the two (or more) sets of urban equations, and compare the urban results to the equivalent rural results. Ultimately, it is the user's decision as to which urban results to use.

The local urban equations are described in the individual summaries of state flood-frequency techniques for states that use the same equations as those that appeared in the previous version of NSS. The local urban equations are described in Fact Sheets for states that have updated either their rural or urban equations since the previous version of NSS was released (Jennings and others, 1994). In addition, some of the rural reports contain estimation techniques for urban watersheds. Several of the rural reports suggest the use of the nationwide equations given by Sauer and others (1983) and described above.

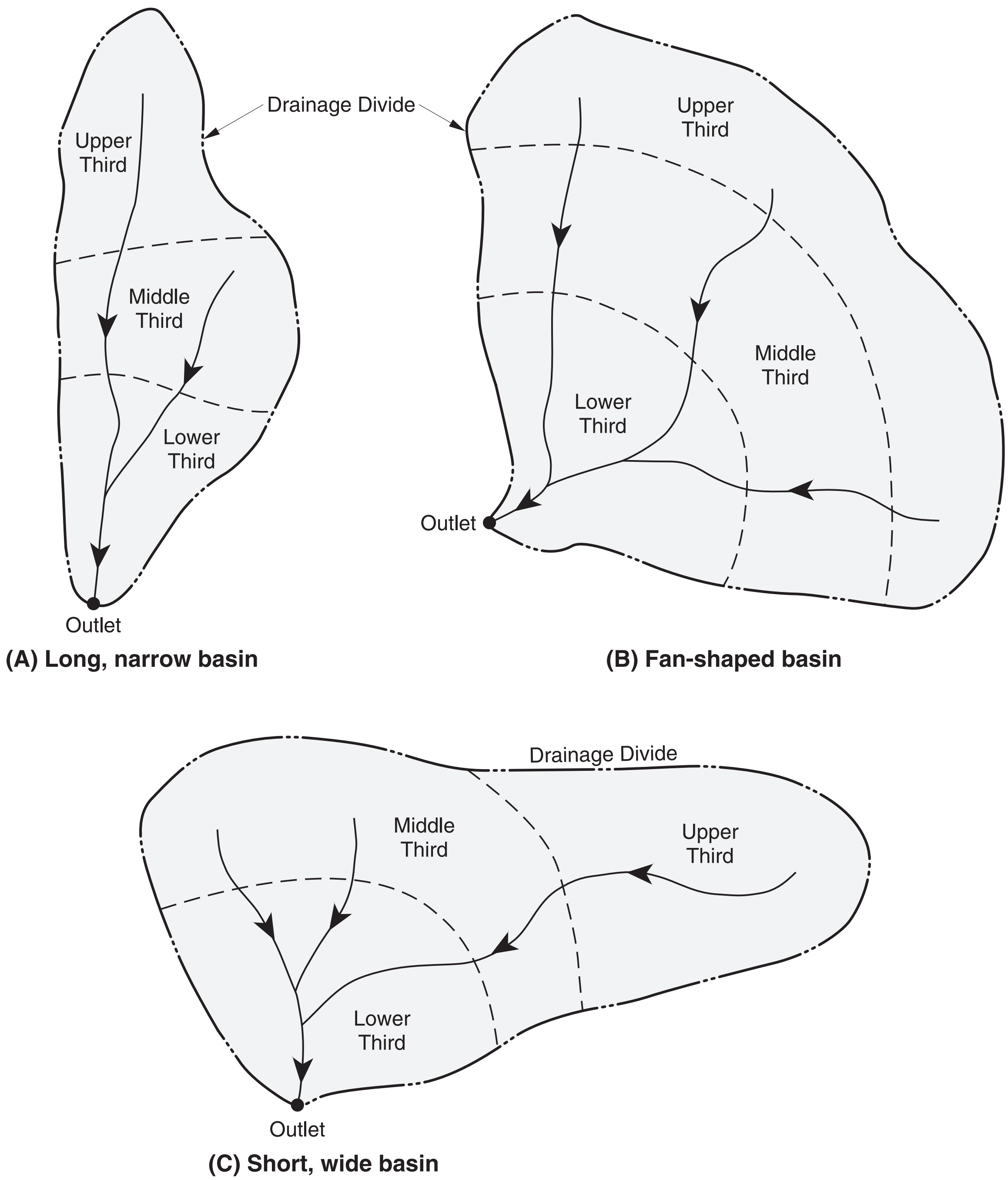


**Figure 1.** Schematic of typical drainage basin shapes and subdivision into basin thirds. (Note that stream-channel distances within any given third of a basin in the examples are approximately equal, but between basin thirds the distances are not equal, to compensate for the relative basin width of the thirds.) (from Jennings and others, 1994).

# Flood Hydrograph Estimation

## By V.B. Sauer

The NSS Program contains a procedure for computing a typical hydrograph that represents average runoff for a specified peak discharge. It should be emphasized that this is an average hydrograph, and is not necessarily representative of any particular rainfall distribution. The average, or typical, hydrograph could be considered a design hydrograph for some applications.

The procedure used in NSS to compute the average hydrograph is known as the dimensionless-hydrograph method. Stricker and Sauer (1982) developed the method for urban basins using theoretical techniques. Inman (1987) used actual streamflow data for both urban and rural streams in Georgia, and confirmed the theoretical, dimensionless hydrograph developed by Stricker and Sauer. Other investigators have since developed similar dimensionless hydrographs for numerous other states (Sauer, 1989). Except in some relatively flat-topography, slow-runoff areas, the same dimensionless hydrograph seems to apply with reasonable accuracy. The dimensionless-hydrograph approach, however, is not applicable to snowmelt runoff or for estimating more complex double-peaked hydrographs.

The dimensionless-hydrograph method has three essential parts: (1) the peak discharge for which a hydrograph is desired, (2) the basin lagtime, and (3) the dimensionless-hydrograph ordinates. In order to compute the average, or design hydrograph using the NSS procedures, the user selects the peak discharge from the NSS frequency output. The user must also provide an estimate of the basin lagtime. The NSS Program then computes the hydrograph using the dimensionless ordinates of the hydrograph developed by Inman (1987), which are stored in the program.

Basin lagtime (LT) is defined as the elapsed time, in hours, from the center of mass of rainfall excess to the center of mass of the resultant runoff hydrograph. This is the most difficult estimate to make for the hydrograph computations. For rural basins, the user must make an estimate of lagtime, independent of the NSS Program, because there are no lagtime equations currently available in NSS for rural watersheds. However, Sauer (1989) summarized basin lagtime equations that have been developed for rural and urban watersheds in several states. The following statewide equations computed for rural Georgia streams by Inman (1987) are an example:

$$LT = 4.64A^{.49}\,SL^{-.21} \text{(north of Fall Line)}$$
$$LT = 13.6A^{.43}\,SL^{-.31} \text{(south of Fall Line)},$$

where

LT is basin lagtime, in hours,

A is drainage area, in square miles, and

SL is channel slope, in feet per mile, as defined earlier.

Appendix B provides a summary of equations for estimating basin lagtime as given by Sauer (1989), in addition to a few other known studies.

The following generalized equation was developed by Sauer and others (1983) for urban basins for use on a nationwide basis:

$$LT = 0.003L^{.71}(13-BDF)^{.34}(ST+10)^{2.53}\,RI2^{-.44}\,IA^{-.20}\,SL^{-.14},$$

where

L is the length, in miles, of the main channel from the point of interest to the extension of the main channel to the basin divide, and

BDF, ST, RI2, IA, and SL are described in the section "Urban Flood Frequency Estimating Techniques."

The standard error for the above lagtime equation is plus or minus 61 percent, based on regression analysis for 170 stations on a nationwide basis. For urban basins, the user has a choice of using the nationwide lagtime equation given above, or inputting an independent estimate of lagtime.

# Estimation of Extreme Floods

By W.O. Thomas, Jr., and W.H. Kirby

## Measures of Extreme Floods

Very large or extreme floods can be characterized in several ways. Some examples are the Probable Maximum Flood (PMF), envelope curve values based on maximum observed floods (Crippen and Bue, 1977; Crippen, 1982), and probabilistic floods, such as the 500-year flood, which has only a 0.2 percent chance of being exceeded in any given year.

The PMF is defined as the most severe flood that is considered reasonably possible at a site as a result of hydrologic and meteorologic conditions (Cudworth, 1989; Hansen and others, 1982). The estimation of the PMF involves three steps: (1) determination of the Probable Maximum Precipitation (PMP) from reports published by the National Weather Service (e.g., Hansen and others, 1982), (2) determination of infiltration and other losses, and (3) the conversion of the excess precipitation to runoff. In step (2), it is general practice to assume that an antecedent storm of sufficient magnitude has reduced water losses, such as interception, evaporation, and surface depression storage, to negligible levels. In step (3), the conversion of precipitation excess to runoff is accomplished by one of a number of techniques or models ranging from detailed watershed models to a less detailed unit-hydrograph approach. Most Federal construction and regulatory agencies use the less detailed unit-hydrograph approach that is based on the principle of linear superposition of hydrographs as originally described by Sherman (1932).

The words “probable” and “likely” in the definition of the PMF and PMP do not refer to any specific quantitative measures of probability or likelihood of occurrence. Moreover, an interagency work group of the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data decided “It is not within the state of the art to calculate the probability of PMF-scale floods within definable confidence or error bounds” (Interagency Advisory Committee on Water Data, 1986).

The definition of another type of large or extreme flood is based on the maximum observed flood for a given size watershed. Crippen and Bue (1977) and Crippen (1982) developed flood-envelope curves by plotting the maximum known flood discharges against drainage area for 17 flood regions of the conterminous United States. These flood-envelope curves approximate the maximum flood-peak discharge that has been regionally experienced for a given size watershed. Like the PMF, these flood-envelope values do not have an associated probability of exceedance.

In general, the largest flood having a defined probability of exceedance that is used for planning, management, and design is the 500-year flood. This flood discharge has a 0.2 percent chance of being exceeded in any given year or, stated another way, will be exceeded at intervals of time averaging 500 years in length. The 500-year flood is the most extreme flood discharge computed in flood-frequency programs of the USGS (Kirby, 1981) and the U.S. Army Corps of Engineers (1982) that implement Federal Interagency Bulletin 17B guidelines for flood frequency (Interagency Advisory Committee on Water Data, 1982). These two computer programs are the ones most frequently used by the hydrologic community.

Estimates of 500-year flood discharges are used in defining flood plains for the flood insurance studies of the Federal Emergency Management Agency (FEMA), as well as by the National Park Service for defining flood plains in National Parks. Flood-plain boundaries based on the 500-year flood are used mostly for planning purposes to identify areas that would be inundated by an extreme flood. Prompted by a number of bridge failures beginning in the late 1980s that resulted from excessive scour, the Federal Highway Administration (FHWA) has developed procedures for evaluating scour at bridges. As part of this program, the FHWA advised the state Departments of Transportation nationwide to evaluate the risk of their bridges being subjected to scour damage during floods on the order of 100- to 500-year or greater average return periods. Therefore, there is a defined need for estimates of flood discharges having return periods on the order of 500 years.

## Extrapolation for the 500-Year Flood

Before 1989, USGS policy prohibited publication of at-site estimates of the 500-year flood and regional regression equations for estimating the 500-year flood at ungaged sites. Therefore, only USGS statewide reports published since 1989 contain regression equations or at-site estimates for the 500-year flood. A procedure is given in the NSS Program for extrapolating the regional regression equations in any state to the 500-year flood. The extrapolation procedure basically consists of fitting a log-Pearson Type III curve to the 2- to 100-year flood discharges given by NSS and extrapolating this curve to the 500-year flood discharge. The procedure consists of the following steps for a given watershed.

1. Determine the flood-peak discharges for selected return periods from the appropriate regional regression equations given in NSS. At least three points are needed to define the skew coefficient required in a subsequent step. Use of additional points improves the definition of the frequency curve that is defined by the regional equations, and helps to average out any minor irregularities that may exist in the relations among the regional equations. The NSS program uses all available regional equations for selected return periods to define the frequency curve.

2. Fit a quadratic curve to the selected points on log-probability paper using least-squares regression computations. The variables used in the regression computations are the logarithms of the selected discharges and the standard normal deviates associated with the corresponding probabilities. The purpose of this quadratic curve is to obtain a smooth curve through the selected flood-peak discharges from step 1 above. The quadratic curve is an approximation of the log-Pearson Type III curve that will be computed.

3. Determine the skew coefficient of the log-Pearson Type III frequency curve that passes through the 2-, 10-, and 100-year floods defined by the quadratic curve. The skew coefficient is defined approximately by the formula (Interagency Advisory Committee on Water Data, 1982):

$$G = -2.50 + 3.12 \log\left[\frac{Q_{100}}{Q_{10}}\right] \Big/ \log\left[\frac{Q_{10}}{Q_2}\right]$$

4. Replot (conceptually) the selected discharges and return periods using a Pearson Type III probability scale defined such that a frequency curve with the computed skew plots as a straight line. This scale is defined by plotting probability values *p* at positions *x* on the probability axis, where *x* is defined by the standardized Pearson Type III deviate (K values) for the given skew and probability. A Wilson-Hilferty approximation (Kirby, 1972) is used to compute the K value.

5. Fit a straight line by least-squares regression to the points plotted in step 4, and extrapolate this line to the 500-year flood-peak discharge. The variables used in the least-squares computation are the logarithms of the selected discharges and the Pearson Type III K values associated with the corresponding probabilities.

An example of a flood-frequency curve computed by this procedure for the Fenholloway River at Foley, Florida is shown in figure 2. The solid triangles are the regional flood-frequency values as estimated by the equations given by Bridges (1982), which are incorporated in the NSS Program. The 500-year value, shown as a solid circle (12,800 cubic feet per second), is estimated using the extrapolation procedure described above. Note that the extrapolated 500-year value is a reasonable extension (see dashed line) of the regional frequency curve.

The solid triangle (fig. 2) (11,500 cubic feet per second) for the 500-year value is the regional value as obtained directly from the 500-year equation given in Bridges (1982). The 500-year flood for the Fenholloway River can be estimated without extrapolation since Florida is one of the states for which 500-year regression equations have been published. The difference

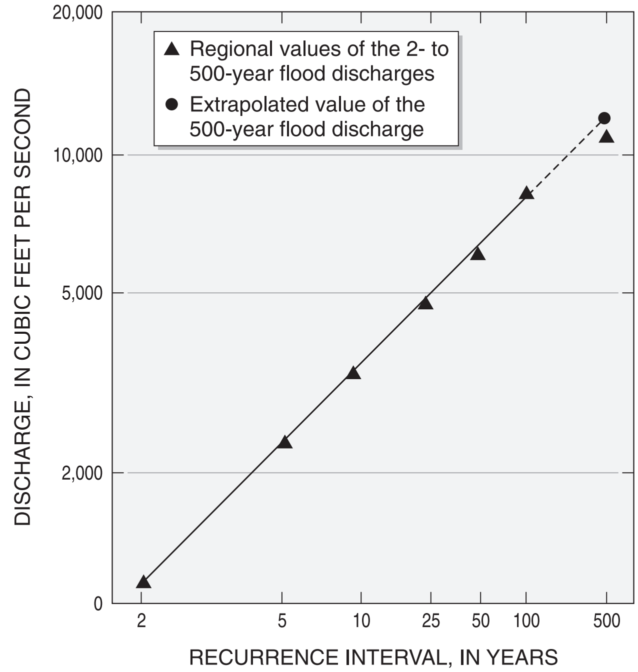


**Figure 2.** Regional flood-frequency curve for the Fenholloway River at Foley, Florida (from Jennings and others, 1994).

between the two 500-year values is 11.3 percent. This is typical of several comparisons of extrapolated 500-year floods to published regional equations made by Jennings and others (1994), which mostly agree within plus or minus 15 percent.

For comparison with and evaluation of extrapolated 500-year flood values, the NSS Program can display the maximum flood-envelope curve values given by Crippen and Bue (1977) and Crippen (1982). Because there is no frequency of occurrence associated with envelope-curve estimates, the comparison of these values to the extrapolated 500-year floods is merely a qualitative evaluation. In general, one would expect the extrapolated 500-year flood-peak discharges to be less than the envelope-curve values, assuming that several watersheds in a given region have experienced at least one flood exceeding the 500-year value during the period of data collection. For the Fenholloway River at Foley, Florida, estimates of the 500-year flood range from 11,500 to 12,800 cubic feet per second. The envelope-curve value from Crippen and Bue (1977) and Crippen (1982) is 101,000 cubic feet per second given that the watershed is in Region 3 as defined by Crippen and Bue (1977) and Crippen (1982). A map of the conterminous United States showing the flood-region boundaries (fig. 3) from Crippen and Bue (1977) can be displayed within NSS so the user can determine the appropriate flood region for a site of interest.

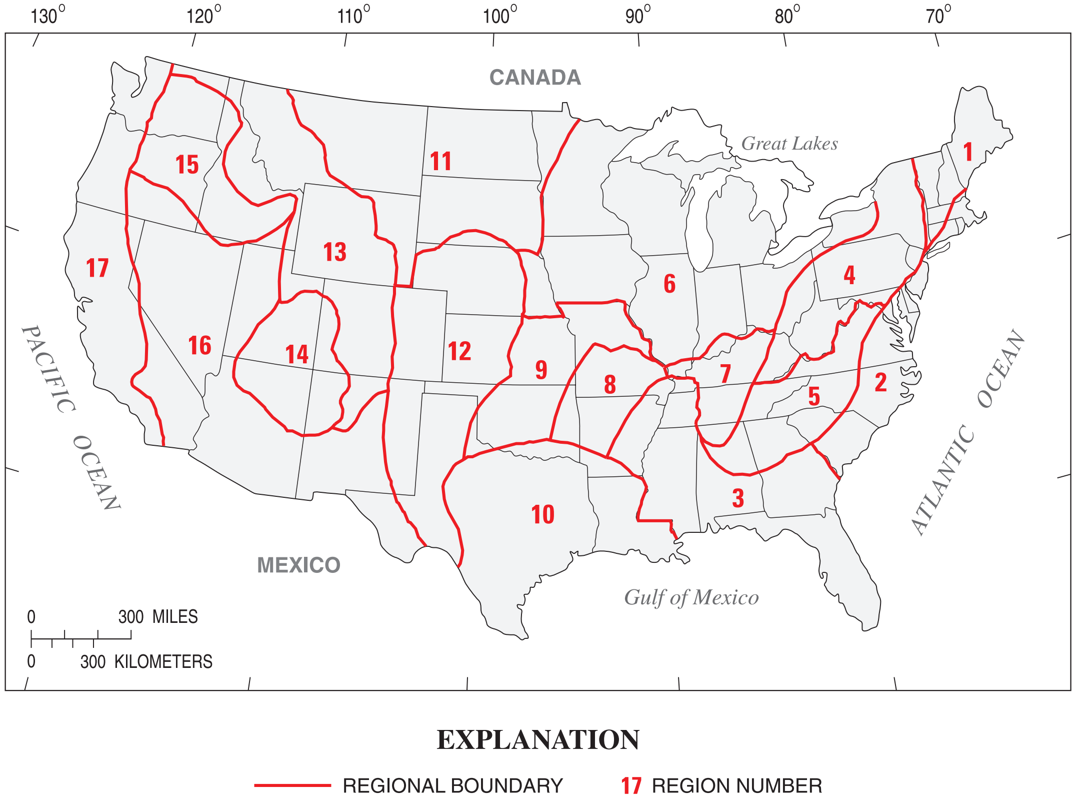


**Figure 3.** Map of the conterminous United States showing flood-region boundaries (modified from Crippen and Bue, 1977).

# Testing and Validation of Techniques

By K.G. Ries III

The algorithms in the original version of the NFF Program were tested extensively before the initial release of the software. Flood-frequency estimates were obtained using NFF for three to five gaged sites from each hydrologic region in each state, using watershed and climatic data obtained for the sites from published flood-frequency reports or provided by local USGS Water Science Centers. These estimates were compared to the published regional regression-equation estimates for the sites to confirm the reliability of the software. Particular emphasis was placed on testing the accuracy of the 500-year extrapolation procedure described in the previous section of this report. The testing process indicated that the extrapolation procedure for the 500-year flood was reasonable and gave estimates similar to those based on station data and regional equations developed by regression analysis. Jennings and others (1994) described the tests and results in detail.

Although the operating environment changed from MS-DOS for the initial version of the software to MS Windows for NFF version 3.0, most of the underlying algorithms did not change. There also were few changes to the basic algorithms with this new update to NSS version 4.0. As a result, rigorous testing before releasing the present version was done only for the algorithms that were changed. Emphasis was placed on assuring that the equations for each region in each state were correct, and that estimates obtained from NSS for tested gaged sites agreed with the regional regression-equation estimates for the sites that were published in the state reports. At least one test was made of the equations for each region in each state. These tests were done primarily by personnel from the USGS offices in which the state reports originated.

# Applicability and Limitations

By J.B. Atkins, and K.G. Ries III

The regression equations in the NSS Program are applicable and representative of the data used to derive them. Because the user of NSS is responsible for the assessment and interpretation of the computed results, the following limitations of NSS should be observed.

1. Estimates from the regression equations in NSS reflect natural flow conditions. The estimates do not account for the effects of water diversions, dams, flood-detention structures, and other manmade works. The equations can be used to obtain estimates of natural flow conditions on streams that do not have natural flows. The equations should not be used to obtain estimates of streamflow statistics under existing conditions if the streams do not have natural flows. Users should carefully assess the degree to which flows may be modified at their selected sites. A flood-retention reservoir on a stream may have a large effect on peak flows but no effect on low flows. Likewise, a diversion of a few million gallons per day may have a large effect on low flows but an insignificant effect on peak flows.

2. The rural flood-frequency equations and all equations for estimating other types of streamflow statistics in NSS can be used to obtain estimates of natural flow conditions on urbanized streams. The equations should not be used to obtain estimates of existing streamflow statistics on urbanized streams unless the equations contain independent variables, such as basin development factor, percentage of impervious area, percentage of urban development, or an urbanization index that accounts for the effects of urbanization. NSS users should refer to the reports that document the equations to determine the extent of regulations, diversions, or urbanization that is allowable for use of the rural equations.

3. The user is cautioned that the magnitude of the true standard errors of estimates for ungaged sites will be larger than the reported average standard errors if the equations in NSS are used to estimate flood magnitudes for streams with explanatory variables near the ranges identified in NSS. The errors for ungaged sites with explanatory variables beyond the ranges identified in NSS are unknown.

4. Drainage area must always be determined because NSS requires a value. Although a hydrologic region may not include drainage area as a variable in the prediction equation to compute a frequency curve, NSS requires the use of a watershed's drainage area for other computations, such as determining the maximum flood-envelope discharge from Crippen and Bue (1977) and (or) Crippen (1982), and weighting of flood-frequency curves for watersheds in more than one region.

5. Flood-frequency curves for watersheds contained in more than one region cannot be computed if the regions involved do not have corresponding T-year equations. Failure to observe this limitation of NSS will lead to erroneous results. Frequency curves are weighted by the percentage of drainage area in each region within a given state. No provision is provided in the software for weighting frequency curves for watersheds in different states.

6. In some instances, the maximum flood-envelope value might be less than some T-year computed peak discharges for a given watershed. The T-year peak discharge is the discharge that will be exceeded as an annual maximum peak discharge, on average, every T years. The user should carefully determine which maximum flood region contains the watershed being analyzed (fig. 3), and is encouraged to consult Crippen and Bue (1977) and (or) Crippen (1982) for guidance and interpretation.

7. The NSS Program allows the weighting of the logarithms of the estimated and observed peak discharges for streamgaging stations using the equivalent years of record of the regression estimate and the number of years of observed record as the weighting factors. If NSS has determined the 500-year flood for the site of interest by extrapolation, then the equivalent years of record of the 100-year regression equation and the extrapolated 500-year flood are used in the weighting calculation. If the equivalent years of record are not available for the 2- through 200-year floods, NSS cannot compute weighted estimates, and it uses the observed peak discharges as the final estimates.

8. The NSS Program allows the weighting of regression estimates for ungaged sites with estimates based on the flow per unit area of an upstream or downstream streamgaging station to determine improved estimates for the ungaged site. The drainage area for the ungaged site should be within 0.5 and 1.5 times the drainage area for the streamgaging station; otherwise, only the regression estimates should be used.

9. Some hydrologic regions do not have prediction equations for peak discharges as large as or larger than the 100-year peak discharge. The user is responsible for the assessment and interpretation of any interpolated or any extrapolated T-year peak discharges. Examination of plots of the frequency curves computed by NSS is highly desirable.

10. Hydrographs of flood flows, computed by procedures in NSS, are not applicable to watersheds where flood hydrographs are typically derived from snowmelt runoff, or to watersheds that typically exhibit double-peaked hydrographs. Furthermore, the flood-hydrograph estimation procedure might not be applicable to watersheds in the semi-arid/arid regions of the Nation because the procedure is based on data from Georgia (Inman, 1987).

# Summary of Estimating Techniques

## By K.G. Ries III, H.C. Riggs, and W.O. Thomas, Jr.

Full documentation of the equations and information necessary to solve them is provided in the individual reports for each state. Many of the state reports are available for download from the Web. In addition, USGS Fact Sheets are available that summarize the flood-frequency reports for 20 states with new or corrected equations developed since the release of NFF version 1.0. Summaries of the equations for estimating flood flows from the original NFF report (Jennings and others, 1994) are available online for the states that have not developed new equations since the release of NFF version 1.0.

The NSS Web site (*http://water.usgs.gov/software/nss.html*) provides links to the online reports, the Fact Sheets, and the state summaries that document the equations in NSS. These sites will be updated as new equations become available. Specific documentation on the state equations is not provided in this report because several new sets of equations are developed each year, and the documentation would quickly become obsolete. It is recommended that users check the NSS Web site periodically to determine if new equations have been developed for areas of interest to them. Users should obtain an updated version of the database and new documentation when new equations are available.

Figures and maps needed to determine the input variables are included in the Fact Sheets and state summaries when they could be easily digitized, though often they are of smaller scale than the maps provided in the statewide flood-frequency reports. In some cases, the user will need to consult the original reports to obtain some of the input variables for the regression equations. StreamStats should be used to measure the input variables and solve the regression equations for areas where it is implemented.

The regression equations are provided in the same format in the Fact Sheets and summaries as in the original reports. In the application of these equations, it is often necessary to add constants to input variables that might equal zero. These constants are not always shown in the equations. The user should enter the actual value of the variable and the necessary constants will be applied in the computer program.

Brief descriptions of each variable used in the regression equations are provided in the documentation. It is assumed that the user is knowledgeable with regard to determination of many of the routine watershed characteristics, such as drainage area and channel length, from topographic maps. The applicable range of all variables is given in the NSS Program so the user will know if estimates are being made outside the range of data used in developing the regression equations. Users should exercise caution when extrapolating the flood estimates beyond the data used to develop the equations.

# StreamStats

## By K.G. Ries III

The USGS has developed a Web application named StreamStats that automates the process of computing streamflow statistics for ungaged sites and provides previously computed streamflow statistics for USGS data-collection stations. StreamStats provides a map-based user interface that appears in a Web-browser window. Users can obtain estimates of streamflow statistics for ungaged sites by clicking on site locations in the interface. A GIS program determines boundaries of the drainage basins for the ungaged sites, measures the physical characteristics of the drainage basins, and inserts the characteristics into the NSS program to solve the regression equations that estimate the streamflow statistics for the sites, which appear in a pop-up Web browser window. This process for measuring the basin characteristics is much faster, more accurate, and more consistent than previous manual methods. Users also can obtain previously published streamflow statistics and other information for USGS data-collection stations by clicking on station locations in the user interface.

Because of the ease of use and accuracy of the results, StreamStats should be used to obtain estimates for sites located in areas where the application is available. A map on the StreamStats Web page at *http://streamstats.usgs.gov/* shows the states where the application is available and provides a link to the application and documentation of the regression equations for each state. The StreamStats Web site also provides a description of the application, user instructions, definitions of terms, answers to frequently asked questions, a description of limitations, links to presentations, and contact information. A Fact Sheet on StreamStats (Ries and others, 2004) is available on the Web at *http://md.water.usgs.gov/publications/fs-2004-3115/*.

StreamStats currently does not incorporate all of the functionality of NSS, such as the ability to generate flood-frequency plots and flood hydrographs, and to analyze the sensitivity of the estimates to changes in basin characteristics.

Users can insert the basin characteristics measured by StreamStats into the NSS Program to take advantage of its additional functionality. It also should be noted that StreamStats cannot be used to obtain flood-peak estimates for urban streams using the national urban equations described previously in this report because the basin development factor used as an independent variable in those equations cannot be measured by a GIS.

It is a goal of the USGS to eventually have StreamStats implemented throughout the Nation. Implementation for individual states usually requires cooperative funding agreements between the USGS and one or more Federal, State, or local agencies, whereby the other agency or agencies pay for at least half of the implementation cost. Because of this reliance on funding from other agencies, full national implementation may take several years.

## Acknowledgments

NSS was developed by Aqua Terra Consultants, Inc., through a contract with the USGS. Craig Perl, previously of the USGS, populated much of the NSS database. Robert Mason, of the USGS Office of Surface Water, and several hydrologists from the USGS Washington Water Science Center coauthored many of the USGS Fact Sheets that describe the regression equations. Scientists from the Mississippi and Washington USGS Water Science Centers created many of the graphics used in this report and in the supporting Fact Sheets. Hydrologists from each Water Science Center verified results from NSS for their respective states. The Publication Staff at the Maryland-Delaware-D.C. and New Hampshire USGS Water Science Centers provided illustrations, layout, and editorial review for this report.

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# Appendix A. National Streamflow Statistics Program Users' Manual

By P.R. Hummel[2], M. Gray[2], R. Dusenbury[2], and K.G. Ries III[1]

[1] U.S. Geological Survey, Baltimore, Maryland.

[2] Aqua Terra Consultants, Inc.

Version 4.0 of the National Streamflow Statistics (NSS) computer program solves regression equations for estimating T-year flood-peak discharges for rural and urban watersheds throughout the United States, and it solves regression equations for other types of streamflow statistics that are available in many areas of the Nation. The program also provides methods for (1) plotting flood-frequency curves, (2) estimating a typical flood hydrograph corresponding to a given T-year peak discharge, (3) weighting flood-peak estimates obtained from regression equations for streamgaging stations with estimates computed from the annual peak flows at the stations, and (4) weighting flood-peak estimates obtained from regression equations for ungaged sites with estimates obtained by applying the peak flow per unit area for an upstream or downstream gaging station to the ungaged site.

The NSS computer program has four components—a user interface, a calculation routine, a Microsoft Access database, and a help facility. The NSS user interface allows users to control the operation of the software and presents results. The calculation routine calculates streamflow statistics using basin and climatic characteristics entered by the user and provides tabling and graphing capabilities. The Access database contains the regression coefficients, standard errors, and other information, for more than 2,000 multiple regression equations. The help facility contains an electronic copy of this report, a link to the NSS Web page, and version information. The NSS Program is written in the Visual Basic programming language.

This users' manual provides instructions for downloading, installing, and using NSS. The provided instructions assume a general basic knowledge of the Windows operating systems. In the discussion that follows, the names of windows that appear on the users' desktop are shown in *italics*, and the names of text boxes, menu items, and command buttons are shown in **bold**.

## Downloading and Installing the Program

NSS can be run on a variety of personal computers (PCs). It requires a computer running Windows 98/NT version 4.0 or higher with service pack 5 or higher. For optimal performance, a processor running at 400 megahertz or faster with at least 64 megabytes (Mb) of memory is recommended. A VGA or better color monitor also is recommended.

NSS can be downloaded from the Web at *http://water.usgs.gov/software/nss.html*. Users will need to download at least two files— NSSv4.exe, which contains the NSS Setup Wizard and the NSS computer program (about 8 Mb), and NSSv4_YYYY-MM-DD.mdb, which is the database (about 14 Mb), where YYYY is the year, MM is the month, and DD is the day of the most recent release. To download and install NSS by either facility, users should follow these steps:

1. Double click with the left mouse button on the file names or icons for the files shown in the Web browser window.
2. Specify a directory and save both files to the local-hard drive.
3. Locate NSSv4.exe on the hard drive using *Windows Explorer* or *My Computer*.
4. Double click with the left mouse button on the file name (NSSv4.exe) to start the NSS Setup Wizard.
5. Click on the **Next** button in the Setup Wizard *Welcome* window.
6. At the prompt, specify the directory in which NSS will be installed. A default path name, C:\Program Files\NSS, will be displayed, and is recommended. Alternately, the user can browse to select a different directory or type in the path name.

7. At the prompt, select the **Start** menu folder in which to place the program's shortcut. The default folder name is USGS. It is suggested that this folder name be used if other USGS software is or will be installed on the user's PC. If not, the user may wish to name the folder NSS or to select another folder that is already available.
8. Choose whether or not to create a desktop icon for the program.
9. Click on the **Install** button.
10. When the Wizard provides notification that the installation is complete, click on the **Finish** button to close the Wizard.
11. Copy the NSSv4_YYYY-MM-DD.mdb file to the NSS directory. (The default location is C:\Program Files\NSS).
12. When installation is complete, start NSS to assure that the installation was successful and the program works.
13. If NSS works correctly, delete the downloaded file, NSSv4.exe, from its original saved location.

For basic installation, the NSS directory should contain seven files: (1) current.nss, which is a text file that contains instructions provided to NSS by the user during the previous and current sessions, (2 and 3) unin000.dat and unins000.exe, which are used to uninstall the program, (4) NSS.exe, which is the executable program file, (5) NSS.chm, which is the help facility, (6) NSSv4_YYYY-MM-DD.mdb, which is the database, and (7) ATCoRend.mdb, which is an Access database of colors used for graphics. To run NSS, double click on NSS.exe in *Windows Explorer* or *My Computer*. Alternately, the program may be started by clicking on the NSS entry in the **Start** menu, or if an icon has been created on the computer desktop, by double-clicking on the icon. To run the help facility, double click on NSS.chm. The help facility may also be started by clicking on the **Manual** menu item of the **Help** menu in the NSS user interface. To uninstall NSS, double click on unins0000.exe.

Region-Of-Influence (ROI) regression is available for use in estimating peak-flow statistics for several states. If users want to obtain ROI estimates for a state, they must download one or two binary files of data needed to run ROI for each individual state. These files can be downloaded from the above-mentioned Web and FTP sites. The file names are formatted as SS.ttt.bin, where SS is the 2-letter postal abbreviation for the state; ttt is the data type, rec, or rho; and bin indicates the file has a binary format. Most states have two binary files, and users must download both files to obtain ROI estimates.

## Starting the Program

NSS can be started by double-clicking on the desktop icon, if one was created during installation, by clicking on the NSS listing in the **Start** menu (by default under USGS), or by double-clicking on NSS.exe in the NSS directory. Starting the program will cause a small *NSS* window to appear. Buttons in this window allow the user to choose whether **English** or **Metric** units will be used during the session (fig. A-1). If users enter their name in the **User** text box, their name will be included in any reports generated during the session.

The **Project** text box specifies the path and file name to a project status file, which saves the selections made during a previous session of NSS. The default status file name is current.nss, which is saved in the root directory of the application. This file will reset the user selections to those made during the most recent session of NSS. Alternatively, the user may type in a pathname or click on the **Browse** button to locate a different status file that was saved during an older session of NSS. Once the desired entries have been made in the *NSS* startup window, press the **Run** button to begin the session. Clicking on the **Quit** button will terminate the session.

## Main Window

After the **Run** button is pressed in the *NSS* startup window, that window will disappear and the *National Streamflow Statistics Program (NSS)* main window will appear. This window (fig. A-2) features pull-down menus, small input text boxes, two large frames with large text boxes for display of input parameters and output, and several command buttons.

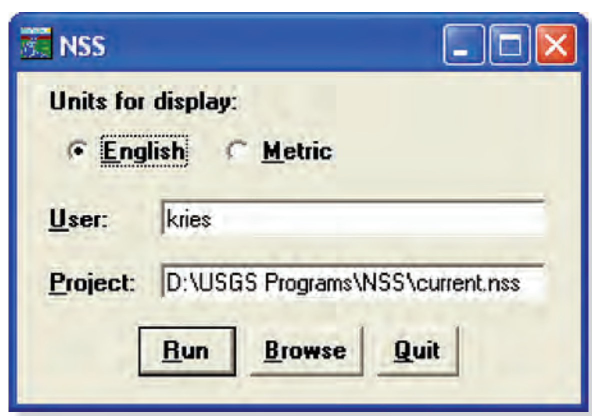



**Figure A-1.** View of the National Streamflow Statistics Program start-up window, which allows selection of the system of units for input and output, specification of a user name, and selection of a project status file.

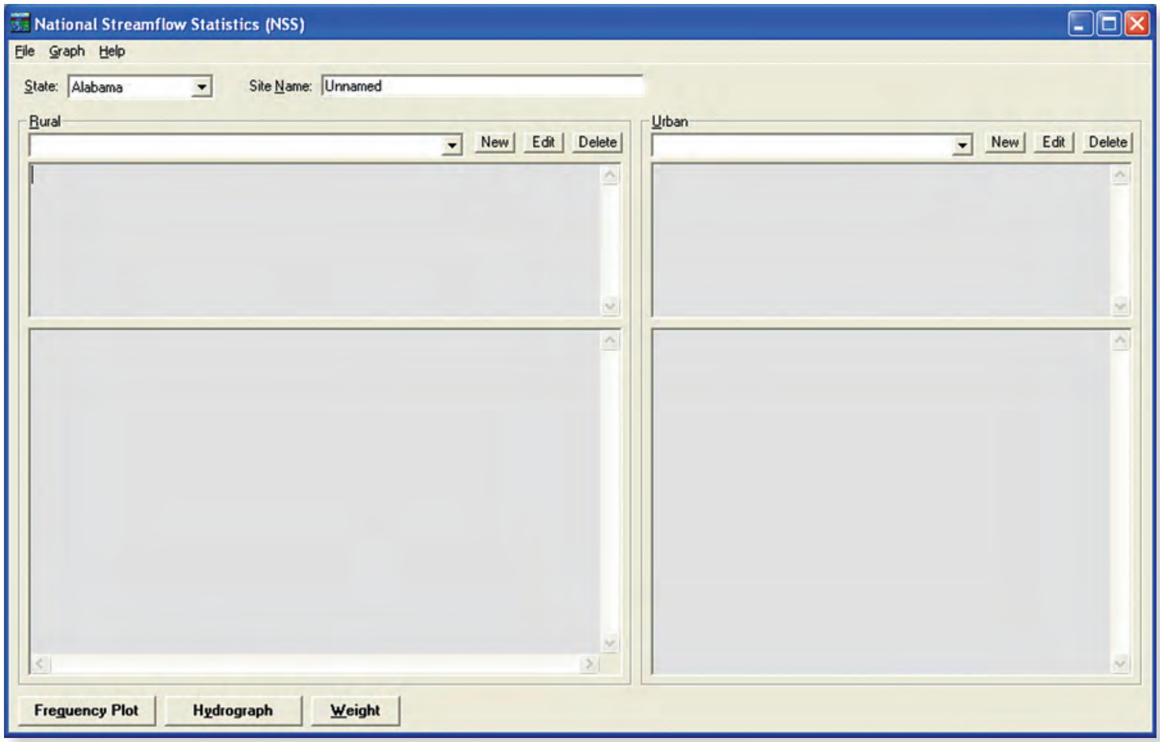



**Figure A-2.** The main window of the National Streamflow Statistics Program at start-up.

The **File**, **Graph**, and **Help** pull-down menus are at the top left of the main window. These menus provide additional utilities to the user, and are described later. Directly below the pull-down menus are a pair of boxes that allow the user to select the state in which the site of interest is located, and to name the site. A state must be chosen before estimates can be obtained. Selection is accomplished by clicking on the downward-pointing arrow at the right side of the **State** box. Clicking will cause a list of state names to appear along with a scroll bar at the right of the list that allows moving to a state of interest (fig. A-3). Clicking on an individual state will cause its name to appear in the box. Alternately, users may type the first letter of the state name to select their state of interest. When more than one state has the same first letter, typing the first letter again will advance to the next one in alphabetical order. When selecting a new state, any results from the current state will be cleared, so care should be taken to save any desired results before selecting a new state.

Use of the **Site Name** text box is optional. If a name is entered in the box, the name will appear in saved reports for the site. If no name is entered, the site name “Unnamed” will be used by default.

Two large frames, one for rural estimates and the other for urban estimates, fill the center of the main window. A box at the top left of each frame shows the name of the current scenario (a scenario is a set of input parameters and estimates for a site). To the right of the boxes are the **New**, **Edit**, and **Delete** buttons that allow the user to create, edit, or delete scenarios, respectively. When multiple scenarios have been created for a selected state, the scenarios can be selected from the scroll-down list for viewing, editing, and deleting.

Below the buttons are a pair of text boxes. The top box shows input parameters used to evaluate the regression equations for the selected rural or urban scenario (fig. A-4). The bottom box shows the output. The first column lists the recurrence intervals for peak-flow estimates or the names of the statistics for other statistic types. The second column lists the estimated flows. Ensuing columns list whatever measures of the accuracy of the estimates are available. These always include the average standard errors of estimate or prediction, and may include 90-percent prediction intervals or the equivalent years of record, or both. When both rural and urban estimates have been computed, input and output for both types of estimates are shown at the same time.

When a rural or urban scenario has been computed, the physical characteristics used as explanatory variables in the computation are displayed in the top text box and the computed flow statistics and error indicators associated with the

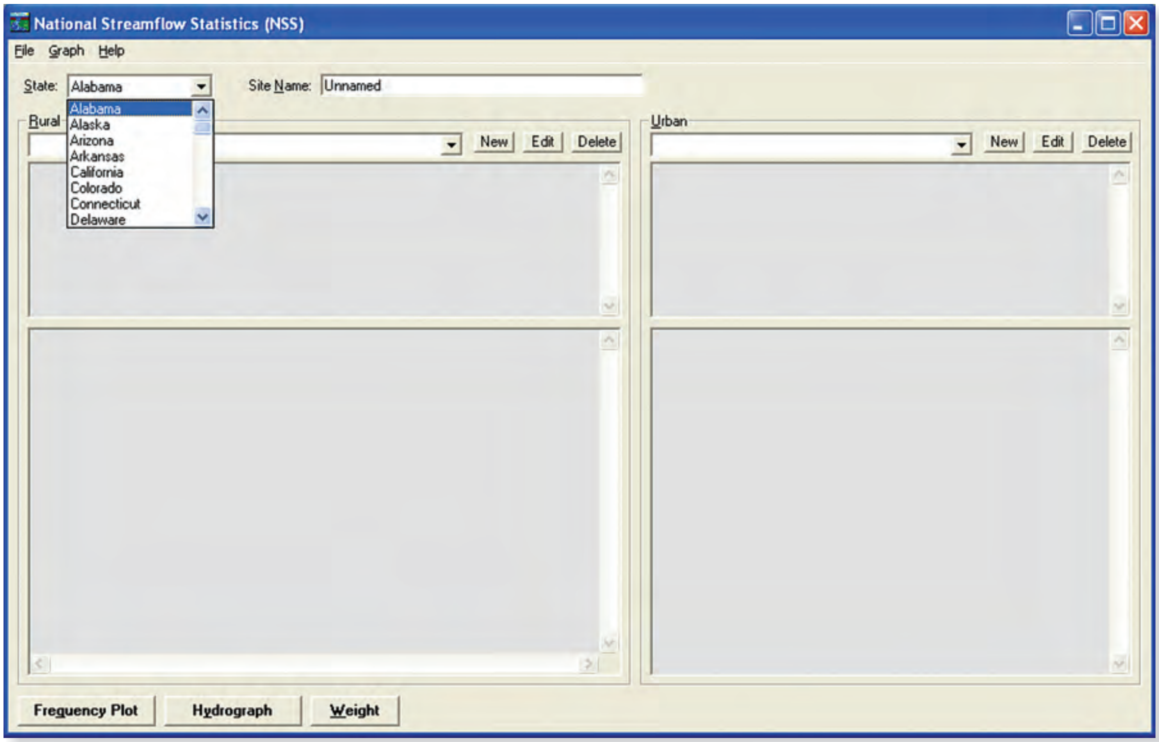



**Figure A-3.** The main window of the National Streamflow Statistics Program showing the State selection scroll-down list.

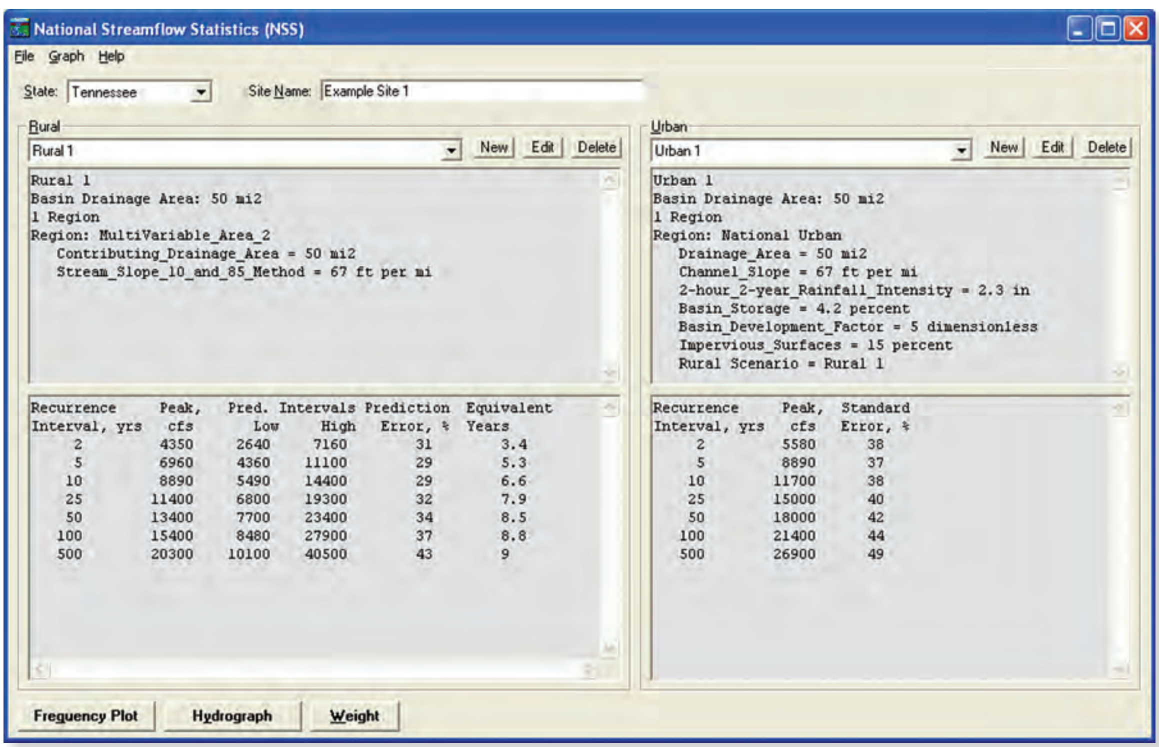



**Figure A-4.** The main window of the National Streamflow Statistics Program showing results of rural and urban peak-flow computations for an example site in Tennessee.

estimates are displayed in the bottom text box. When both types of estimates (rural or urban) have been computed, both sets of estimates are displayed at the same time.

The **Frequency Plot**, **Hydrograph,** and **Weight** command buttons at the bottom of the main window work only for peak-flow scenarios. The **Frequency Plot** and **Hydrograph** buttons can be used to create the indicated types of graphs. The **Weight** button at the bottom of the main window can be used to obtain improved estimates for streamgaging stations and ungaged sites. The plotting and weighting functions are described in separate sections.

## Menu Items

The **File**, **Graph**, and **Help** menus at the top left of the main window provide additional utilities to the user. The menus are accessed by clicking on their titles. The menu items that appear can be selected by clicking on them.

## File Menu

The File menu has four options: **Open**, **Save As…**, **Report**, and **Exit**. Selecting the **Open**, **Save As…**, and **Report** menu items causes a file dialogue form to appear that allows users to browse their PC, select, and name files. Clicking on the **Open** command button in the *Open Status File* window causes the selected file to be used. Clicking on the **Save** command button in the *Save Status File* or the *Save Report* window causes the selected file to be saved. Clicking on the **Cancel** command button in any of these windows causes no changes to be made.

The **Open** option allows users to open an NSS status file, which contains information on results of previous work (fig. A-5).

The **Save As…** option allows the user to save work in a new status file (fig. A-6).

The **Report** option is used to create reports that can be saved and printed (fig. A-7).

The **Exit** option lets the user exit the program.

Reports are saved as text files. An example report is shown in figure A-8 for an ungaged site in Tennessee for which both rural and urban estimates have been obtained.

The **Exit** option lets the user exit the program. The state of the system will be saved to the default status file name, *current.NSS*.

## Graph Menu

The **Graph** menu allows users to create flood-frequency plots and flood hydrographs. These functions are duplicated by the **Frequency Plot** and **Hydrograph** command buttons at the bottom of the NSS main window. The functions are discussed in the Frequency Plots and Hydrographs sections.

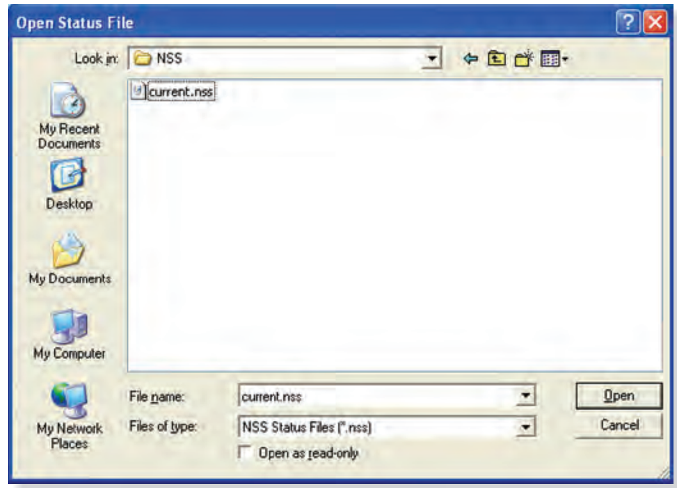



**Figure A-5.** The Open Status File window of the National Streamflow Statistics Program.

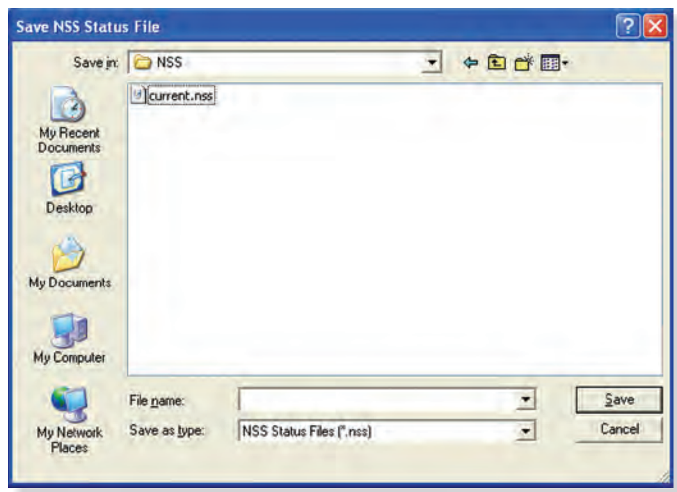



**Figure A-6.** The Save Status File window of the National Streamflow Statistics Program.

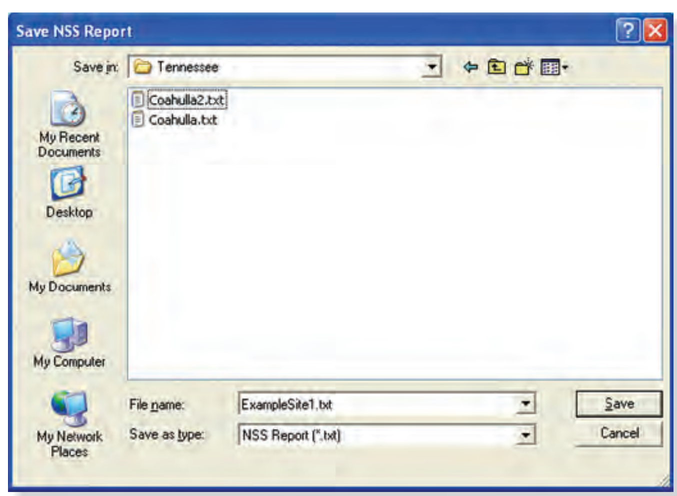



**Figure A-7.** The Save Report File window of the National Streamflow Statistics Program.

## Help Menu

The **Help** menu contains three items: **Manual**, **Web Site**, and **About**. The **Manual** item is used to bring up a window for accessing the NSS help file. The **Web Site** item provides access to the NSS Web site. The **About** item provides information about the NSS program.

### Manual

The NSS help file contains all of the information in this report. The user can move through the help file by navigating the hierarchical structure (fig. A-9), by navigating the index of help topics (fig. A-10), or by use of the search facility (fig. A-11).

To navigate the help file using the hierarchical structure, click on the **Contents** tab to bring it to the front in the left frame of the window. When this is done, the headings from this report will appear in the frame. Double-click on a heading to make the information for that heading appear in the right frame of the window.

To navigate the help file using the index of help topics, click on the **Index** tab to bring it to the front in the left frame of the window. When this is done, an alphabetical list of subjects will be displayed in the frame. Double-click on any of the subjects to make the information for that subject appear in the right frame of the window.

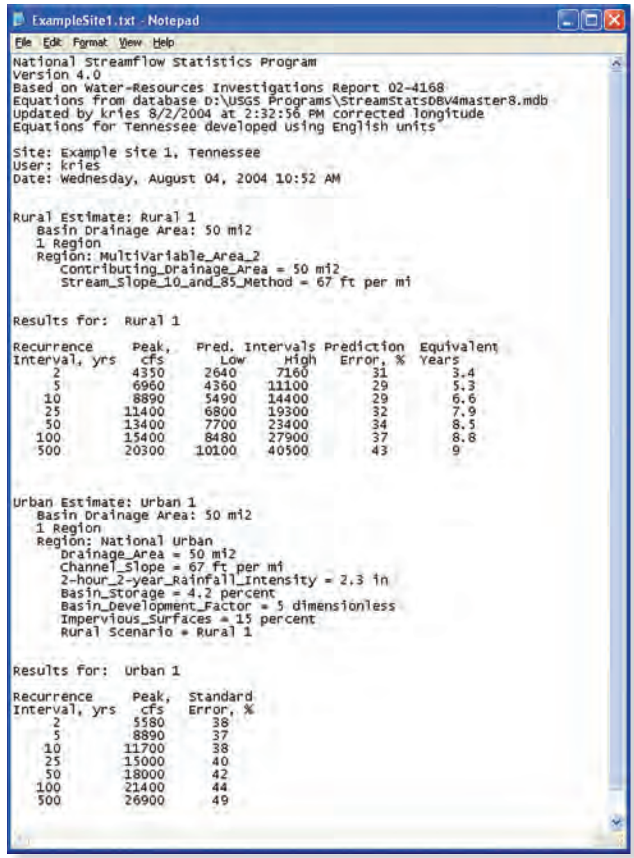
To navigate the Help file using the search facility, click on the **Search** tab to bring it to the front in the left frame of the window. When this is done, a text box will appear in which the user can type in the keyword to be used for searching. After the keyword is typed in, the user should click on the **List Topics** command button directly below the text box. This will cause a list of topics to appear in the frame below the button. Double-click on a topic to make information for the topic appear in the right frame of the window. The keywords will be highlighted in blue in the right frame.

### Web Site

Clicking on the **Web Site** item allows users to access the NSS Web site, which contains a brief description of NSS, links for downloading the software and database, and links to the documentation, including documentation for the individual states. An Internet connection must be available to connect to the Web site. Users should access the Web site often to check whether an updated version of the database is available for downloading.

### About

Clicking on the **About** item causes a small window to open that displays the version information for the program (fig. A-12). Clicking the **System info…** command button causes the Microsoft System Information window to appear. This window allows users to obtain information on the availability and configuration of hardware and software installed on their PCs. Clicking on **OK** closes the window.



```
ExampleSite1.txt - Notepad
File Edit Format View Help
National Streamflow Statistics Program
Version 4.0
Based on Water-Resources Investigations Report 02-4168
Equations from database D:\USGS Programs\StreamStatsDBV4master8.mdb
Updated by kries 8/2/2004 at 2:32:56 PM corrected longitude
Equations for Tennessee developed using English units

Site: Example Site 1, Tennessee
User: kries
Date: Wednesday, August 04, 2004 10:52 AM


Rural Estimate: Rural 1
   Basin Drainage Area: 50 mi2
   1 Region
   Region: MultiVariable_Area_2
      Contributing_Drainage_Area = 50 mi2
      Stream_Slope_10_and_85_Method = 67 ft per mi


Results for:  Rural 1

Recurrence     Peak,   Pred. Intervals Prediction  Equivalent
Interval, yrs   cfs        Low     High   Error, %  Years
      2         4350     2640     7160       31         3.4
      5         6960     4360    11100       29         5.3
     10         8890     5490    14400       29         6.6
     25        11400     6800    19300       32         7.9
     50        13400     7700    23400       34         8.5
    100        15400     8480    27900       37         8.8
    500        20300    10100    40500       43         9


Urban Estimate: Urban 1
   Basin Drainage Area: 50 mi2
   1 Region
   Region: National Urban
      Drainage_Area = 50 mi2
      Channel_Slope = 67 ft per mi
      2-hour_2-year_Rainfall_Intensity = 2.3 in
      Basin_Storage = 4.2 percent
      Basin_Development_Factor = 5 dimensionless
      Impervious_Surfaces = 15 percent
      Rural Scenario = Rural 1


Results for:  Urban 1

Recurrence     Peak,  Standard
Interval, yrs   cfs   Error, %
      2         5580     38
      5         8890     37
     10        11700     38
     25        15000     40
     50        18000     42
    100        21400     44
    500        26900     49
```

**Figure A-8.** Example report file output.

## Edit Scenario Window

When a rural or urban **New** button is pressed in the NSS main window, the *Edit Scenario* window opens (fig. A-13). A name for the scenario can be specified in the **Scenario** text box. If a name is not specified, NSS will name the scenario "Rural X," where X is one more than the previous number of rural scenarios that have been created.

Available regions are listed in the **Regions** box on the left side of the window. When a region is selected by clicking on a region name or number in the **Regions** box, the variables for that region appear in the table to the right. Note that the variables in the *Edit Scenario* window will vary depending on the state and region selected.

Values for each variable are entered in the data entry boxes to the right of the variable names. Values that are not yet entered or are outside the recommended range for a variable are highlighted in yellow. When values within the recommended range are entered, the yellow highlighting is removed. The recommended range for the current variable is displayed beneath the table of values.

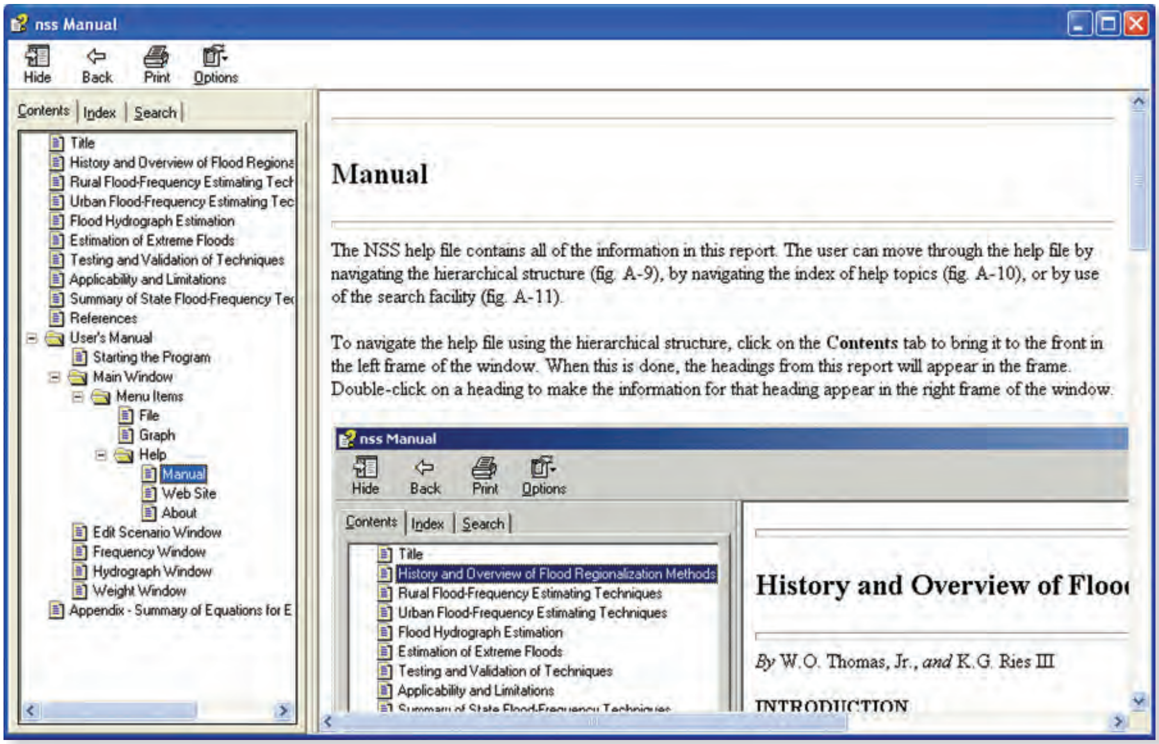



**Figure A-9.** The National Streamflow Statistics Program Users' Manual window showing navigation by hierarchical structure.

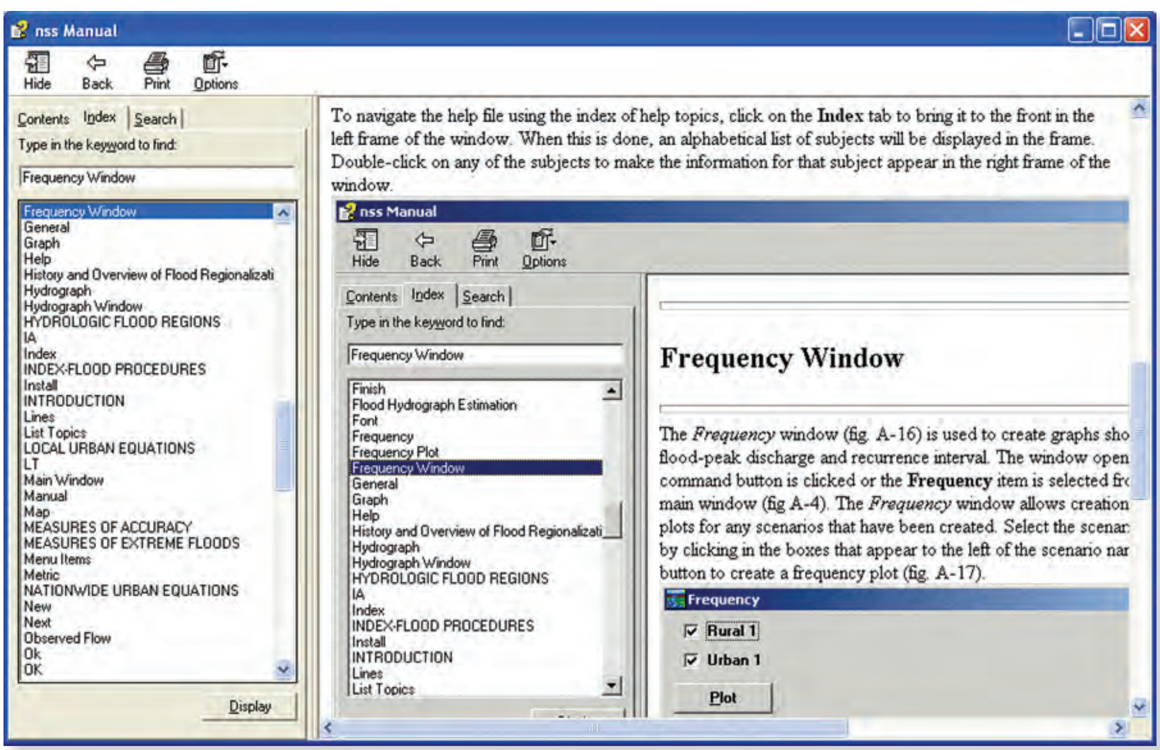



**Figure A-10.** The National Streamflow Statistics Program Users' Manual window showing navigation by use of the index of help topics.

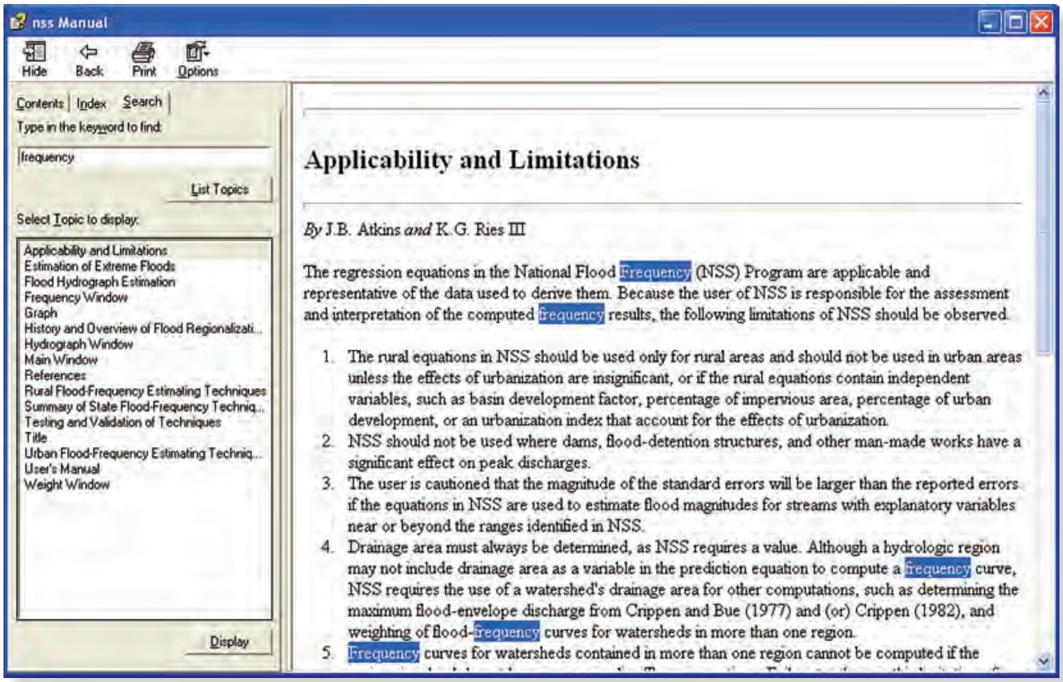



**Figure A-11.** The National Streamflow Statistics Program Users' Manual window showing navigation by use of the search facility.

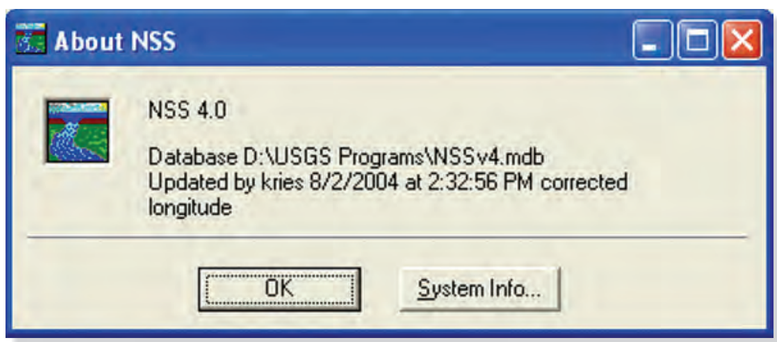



**Figure A-12.** The National Streamflow Statistics Program About NSS window.

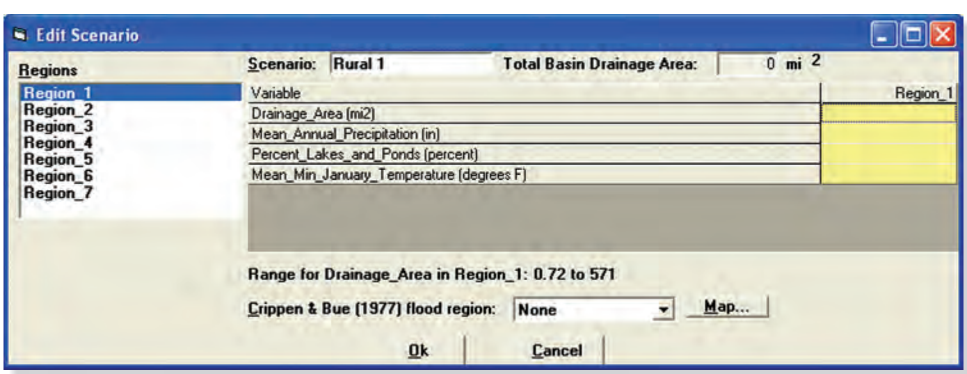



**Figure A-13.** The National Streamflow Statistics Program Edit Scenario window showing the variables that need to be entered to solve the equation for the selected Region 1.

For rural computations, it is possible to select more than one region for cases where the drainage area for the site of interest spans regional boundaries (fig. A-14). Recommended value ranges for the same variable are commonly different for different regions, so it is important to continually reference the suggested values if more than one region is selected. The drainage area associated with each individual region is entered in the drainage area box for each region, whereas the other variables entered in the boxes should reflect the entire drainage area encompassed by all regions. The basin total drainage area is shown above the data entry table in a box that is not editable.

Probable maximum flood estimates determined by the Crippen and Bue (1977) method can be obtained for the current scenario by selecting one of the 17 flood regions from the drop-down list near the bottom of the window. Users can view the map showing the Crippen and Bue regions (fig. 3 in the main body of the report) by clicking on the **Map** button.

When a set of urban estimates is being computed (fig. A-15), only one regional or national set of equations can be selected. Some urban equations depend on the results of rural calculations. These equations will only be available if a rural estimate was computed before the urban **New** button is pressed.

When all of the selections and data entry are complete, click the **Ok** button to calculate the new estimates and display the results on the main window. Click the **Cancel** button at any time to close the compute window without calculating a new estimate.

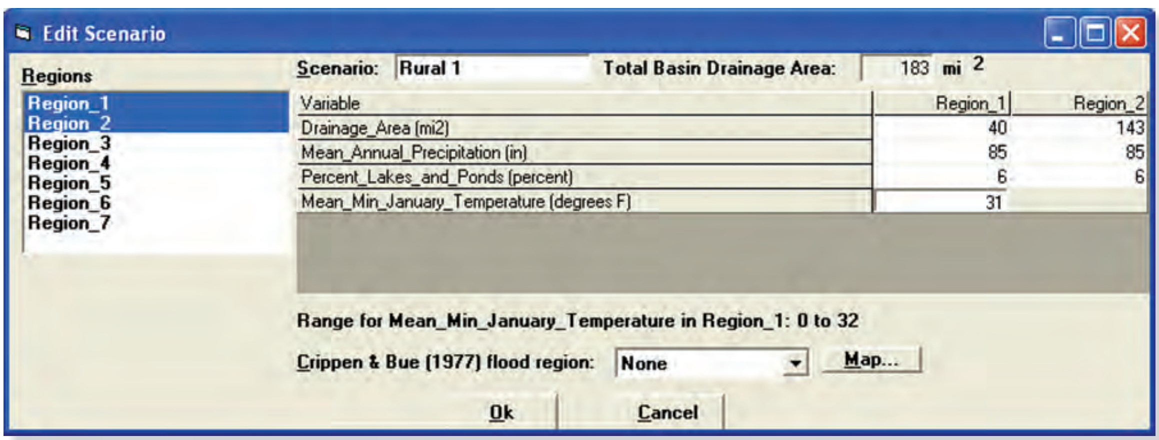



**Figure A-14.** The National Streamflow Statistics Program Edit Scenario window showing the variables that need to be entered to solve the equations for a site with drainage area in both selected Regions 1 and 2.

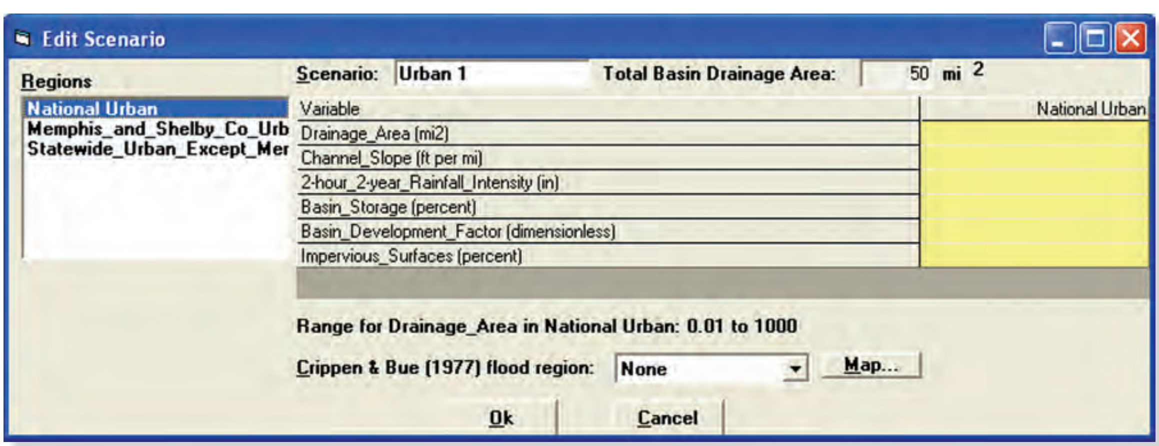



**Figure A-15.** The National Streamflow Statistics Program Edit Scenario window showing the variables that need to be entered to solve the national urban equations.

## Frequency Window

The *Frequency* window (fig. A-16) is used to create graphs showing the relation between flood-peak discharge and recurrence interval. The window opens when the **Frequency Plot** command button is clicked or the **Frequency** item is selected from the **Graph** menu in the main window (fig A-4). The *Frequency* window allows creation of peak-flow frequency plots for any scenarios that have been created. Select the scenarios to include on the graph by clicking in the boxes that appear to the left of the scenario names, then press the **Plot** button to create a frequency plot (fig. A-17).

The *Frequency Plot* window (fig. A-17) contains **File**, **Edit**, and **View** pull-down menus. The **File** menu contains **Print**, **Save**, **Open Specification**, and **Close** items. The **Print** item allows users to send the plot to a printer. The **Save** item allows users to save the plot as a Windows bitmap (.bmp) file and to save selected specifications for the current graph, such as curve and axis properties, and legend locations, in a Windows metafile (.grf) file. Saving the specifications allows users to create a series of graphs with the same specifications. The **Open Specification** item allows users to select a saved specifications file for use in the plots. The **Close** item clears the plot from the desktop.

The **Edit** menu contains the **Axes**, **Titles**, **Curves**, **Lines**, **General**, **Font**, and **Copy to Clipboard** items. Clicking on any of the first five items causes the *Graph Edit* window (fig. A-18) to open, with the selected item tab shown in the

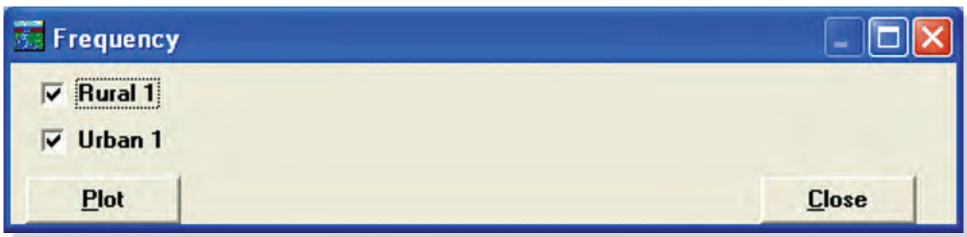



**Figure A-16.** The National Streamflow Statistics Program Frequency window with a rural and an urban scenario selected for plotting.

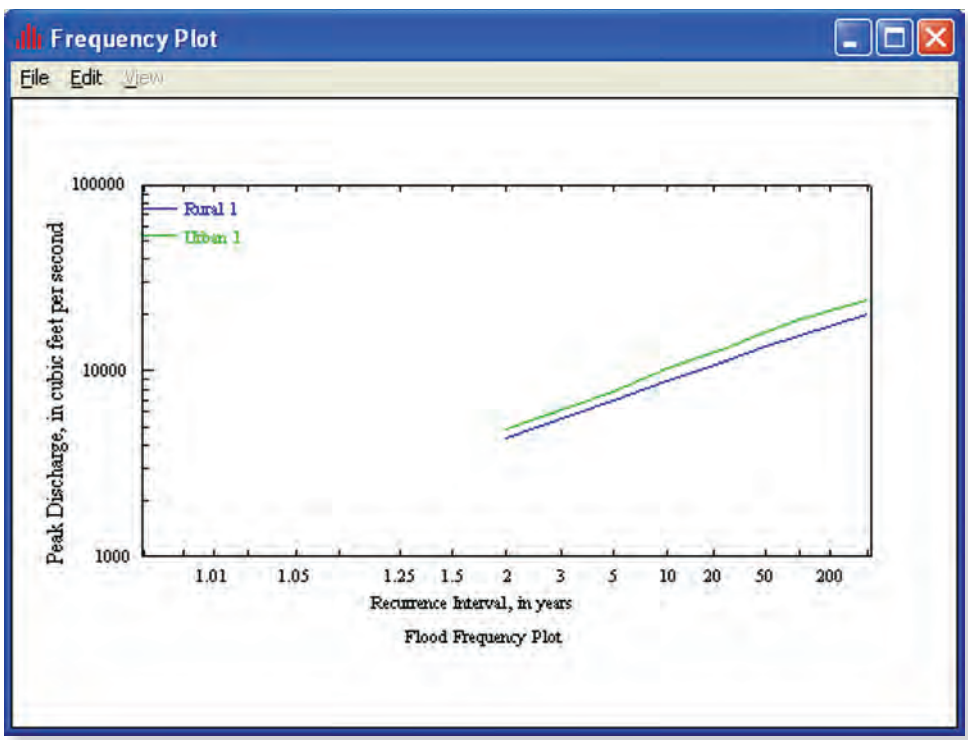



**Figure A-17.** The National Streamflow Statistics Program Frequency Plot window showing rural and urban frequency plots for a sample site.

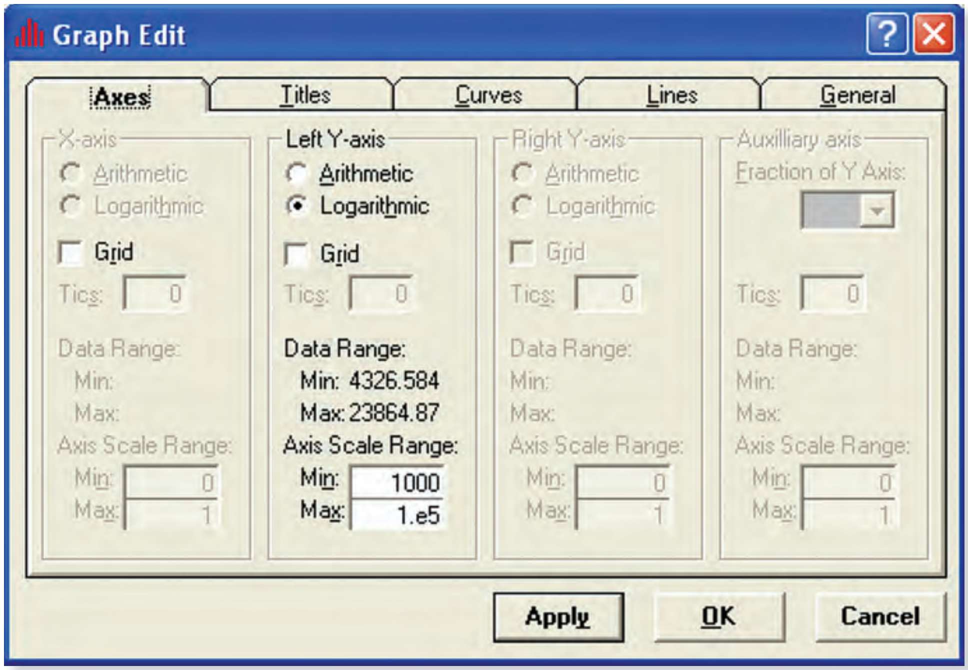



**Figure A-18.** The National Streamflow Statistics Program Graph Edit window showing the Axes tab on top.

front. The **Axes** tab allows specifying arithmetic or logarithmic scales, minimum and maximum axis values, and for arithmetic scales the number of ticks. The **Titles** tab allows specifying the plot title and the axes titles. The **Curves** tab allows specifying the placement of the scale (left, right, auxiliary, bottom), the curve thickness, the point markers, the curve colors, and the name for the curve that appears in the legend. The **Lines** tab is not used. The **General** tab allows specifying the legend location and entry and placement of any additional text desired by the user. Clicking the **Apply** command button at the bottom of the *Graph Edit* window applies any selected changes to the plot. Clicking the **Ok** command button closes the window with any applied changes saved. Clicking the **Cancel** command button closes the window without saving the changes. The **Font** menu item opens the *Font* window (fig. A-19), which allows changes to the font type, style, and size of the text that appears in the plot. The **Copy to Clipboard** menu item copies the plot to the Windows clipboard, from which the plot can be pasted into other Windows applications.

The View menu appears in gray rather than black letters in the *Frequency Plot* window. This menu normally is used to list data shown in a plot, but it has been disabled in NSS because its listing features are duplicated elsewhere in the program.

## Hydrograph Window

The *Hydrograph* window (fig. A-20) is used to create graphs showing how discharge changes over time during an average flood of specified recurrence interval and basin lagtime for the user-selected hydrologic region. The *Hydrograph* window opens when the **Hydrograph** command button is clicked or when the **Hydrograph** item is selected from the **Graph** menu in the main window (fig. A-4). The *Hydrograph* window allows creation of hydrographs for any scenarios that have been created. A recurrence interval must be selected from the scroll-down list near the top left of the window. The scenarios to include on the graph are selected by clicking in the boxes that appear to the left of the scenario names. If the national urban equations have been used to create an urban scenario, basin lagtime can be computed by NSS if the basin length is known. Click on the check box at the top left of the *Hydrograph* window and enter the basin length in the box at the top right of the window to automatically calculate lagtime for the urban estimates. If the national urban equations were not used for the scenarios, lagtimes determined by the user must be entered for each scenario in the boxes to the right of the scenario names. Appendix B provides a summary of available equations for manually estimating basin lagtime.

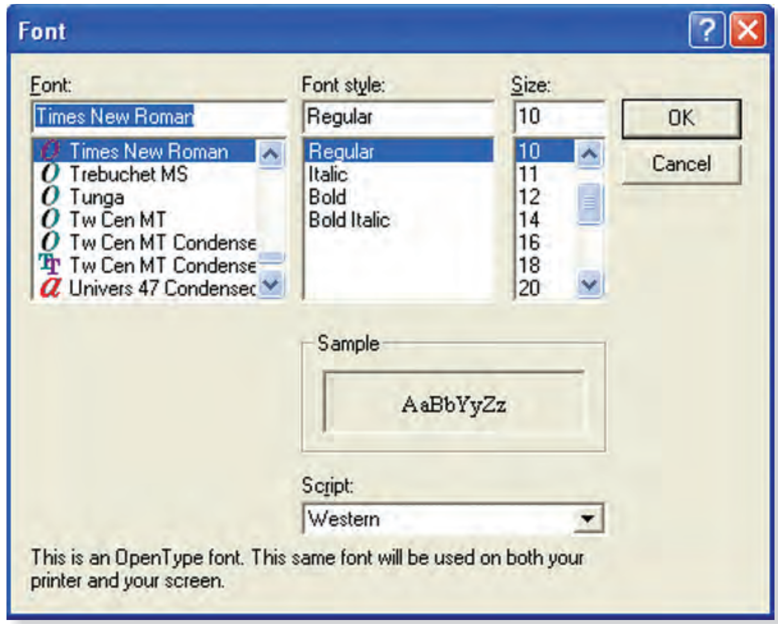



**Figure A-19.** The National Streamflow Statistics Program Font window.

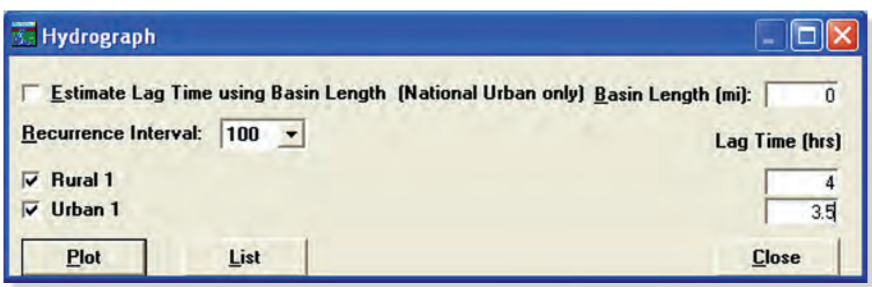



**Figure A-20.** The National Streamflow Statistics Program Hydrograph window with a recurrence interval of 10 years and rural and urban scenarios selected for plotting.

After the scenarios have been selected and the lagtimes have been entered, clicking on the **Plot** command button will cause the hydrographs to appear in the *Hydrograph Plot* window (fig. A-21). Clicking on the **List** command button will cause the Hydrograph List window to appear (fig. A-22). Clicking on the **Close** command button will cause the window to disappear. The Hydrograph Plot window has **File**, **Edit**, and **View** pull-down menus with exactly the same functions as those for the pull-down menus in the *Frequency Plot* window.

## Weight Window

The *Weight* window allows users to produce improved flood-frequency estimates for rural streamgaging stations and ungaged sites. Users must compute rural estimates for a streamgaging station and have the appropriate scenario selected in the NSS main window before weighted estimates can be obtained for the station. For an ungaged site, users must first compute weighted estimates for an upstream or down-stream streamgaging station to be used in the weighting, and then they must compute rural estimates for the ungaged site before weighted estimates can be obtained for the ungaged site. After the required rural scenarios have been computed, clicking the **Weight** command button at the bottom of the main NSS window will cause the *Weight* window to open (fig. A-23).

Upon opening the form, the button to **Weight for gaged site using observed data** is selected by default. A text box near the top of the form is used for entering the **Years of observed data**, which is used by NSS as the weight for the observed flow estimates. The equivalent years of record, which

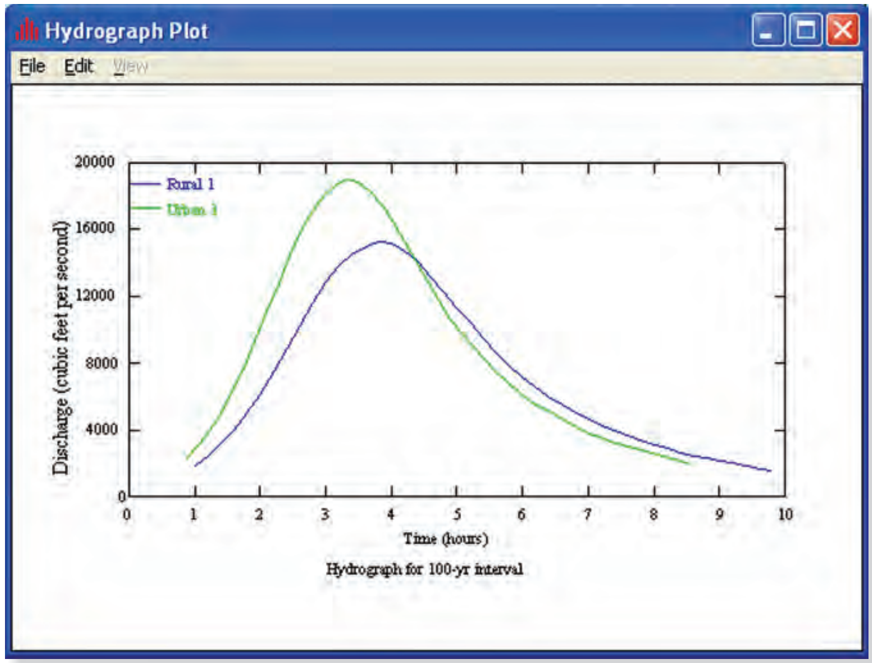
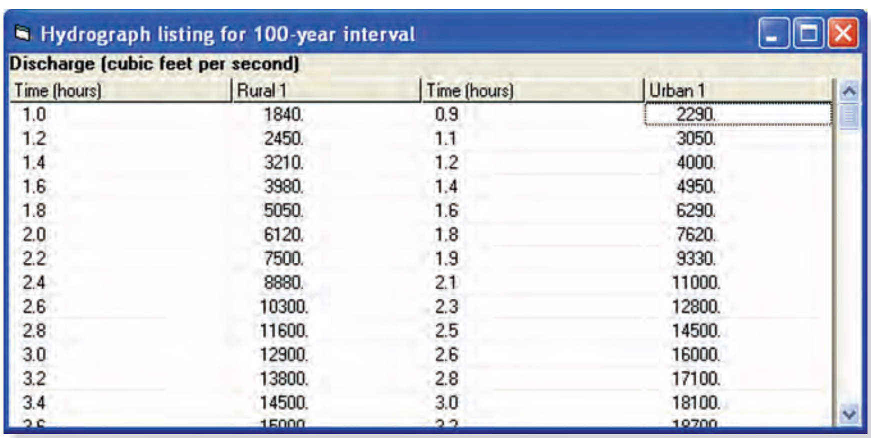



**Figure A-21.** The National Streamflow Statistics Program Hydrograph Plot window showing rural and urban hydrograph plots for a sample site, with a lagtime set a 5 hours for the rural hydrograph and at 4 hours for the urban hydrograph.



Hydrograph listing for 100-year interval

Discharge (cubic feet per second)

| Time (hours) | Rural 1 | Time (hours) | Urban 1 |
|---|---|---|---|
| 1.0 | 1840. | 0.9 | 2290. |
| 1.2 | 2450. | 1.1 | 3050. |
| 1.4 | 3210. | 1.2 | 4000. |
| 1.6 | 3980. | 1.4 | 4950. |
| 1.8 | 5050. | 1.6 | 6290. |
| 2.0 | 6120. | 1.8 | 7620. |
| 2.2 | 7500. | 1.9 | 9330. |
| 2.4 | 8880. | 2.1 | 11000. |
| 2.6 | 10300. | 2.3 | 12800. |
| 2.8 | 11600. | 2.5 | 14500. |
| 3.0 | 12900. | 2.6 | 16000. |
| 3.2 | 13800. | 2.8 | 17100. |
| 3.4 | 14500. | 3.0 | 18100. |

**Figure A-22.** The National Streamflow Statistics Program Hydrograph List window showing rural and urban hydrograph lists for a sample site.

are stored in the database, are used by NSS as the weights for the regression equation estimates. The user must manually enter the **Observed Flow** for each recurrence interval. As the **Observed Flow** values are entered, the **Weighted Flow** values shown in the right-hand column of the form change automatically from being the same as the Estimated Flow values to values somewhere between the observed and estimated flows. If the equivalent years of record are not available for the regression estimates, the weighted estimates will equal the observed estimates. Click on the **Apply** command button to save the weighted estimates as a scenario. This scenario will have the same name as the original scenario, except that weighted, in parentheses, will be appended to the name (i.e. "Rural 1 (weighted)"). Click on the **Cancel** button to return to the main form without creating a new scenario.

To obtain weighted estimates for an ungaged site, click on the **Weight** command button in the main NSS window, then click on the radio button in the top right of the form to **Weight for ungaged site using weighted gaged values** (fig. A-24). Choose the scenario containing the weighted gaged values from the **Select scenario containing weighted gaged values** drop-down list beneath the radio button. The regression-based estimates for the ungaged site, the weighted estimates for the streamgaging station, and the weighted estimates for the ungaged site will automatically appear on the form. Click on the **Apply** button to save the weighted estimates for the ungaged site as a scenario. This scenario will have the same name as the original scenario, except that weighted, in parentheses, will be appended to the name (i.e. "Rural 2 (weighted)"). Click on the **Cancel** button to return to the main form without creating a new scenario.

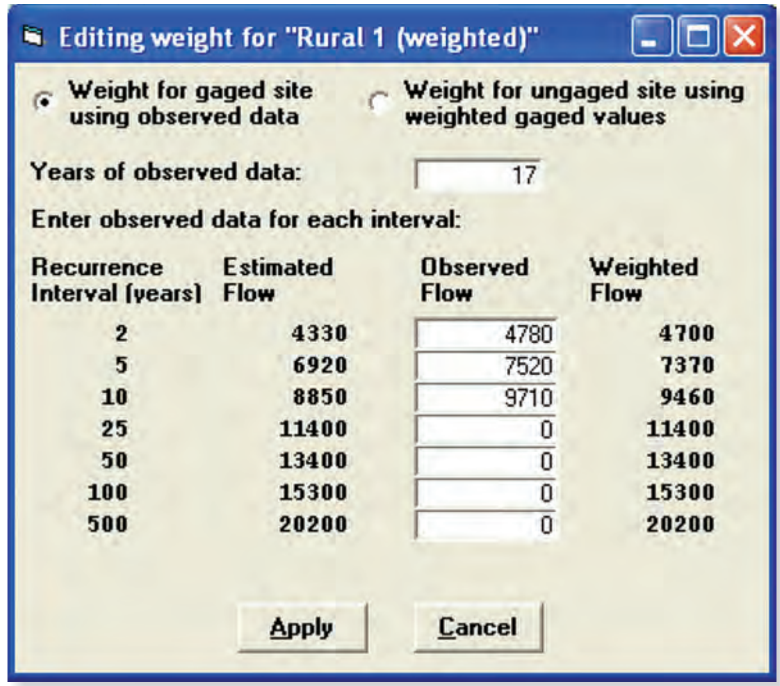



**Figure A-23.** The National Streamflow Statistics Program Weight window showing weighting for a streamgaging station.

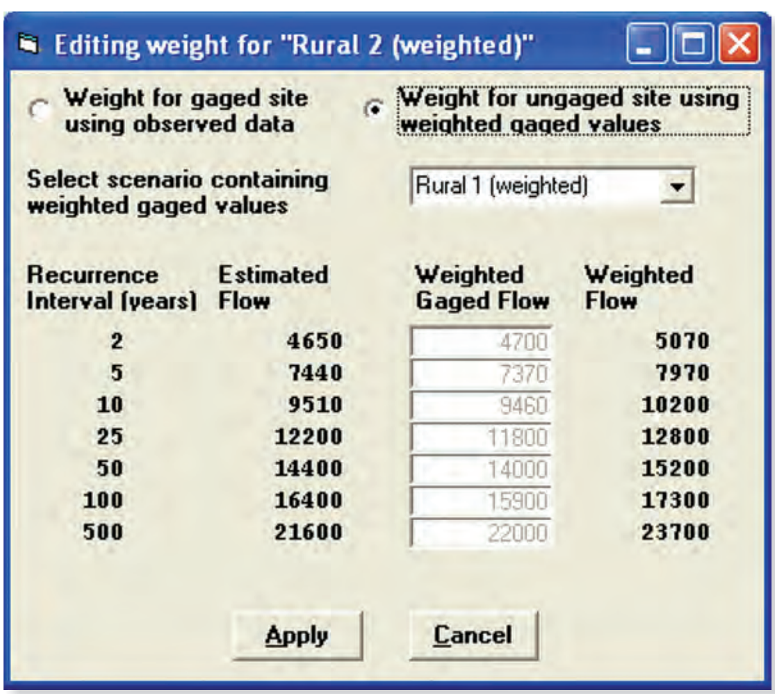



**Figure A-24.** The National Streamflow Statistics Program Weight window showing weighting for an ungaged site.

# Appendix B. Summary of Equations for Estimating Basin Lagtime.

[LT, basin lagtime, in hours]

| State/Area/Region | Equation | Standard error, in percent |
|---|---|---|
| | **Alabama** | |
| North of Fall Line | $LT = 2.66A^{.46} S^{-.08}$ | 32 |
| South of Fall Line | $LT = 5.06A.^{50} S^{-.20}$ | 31 |
| Statewide, urban | $LT = 2.85A^{.295} S^{-.183} IA^{-.122}$ | 31 |
| | **Arkansas** | |
| Rural | $LT = 256A^{.90} (P\text{-}30)^{.61} Q100^{-.65} Q_p^{-.16} S^{-.25}$ | 33 |
| Memphis, urban | $LT = 2.05A^{.35} C^{-.87} IA^{-.22}$ | 24 |
| | **Georgia** | |
| North of Fall Line | $LT = 4.64A^{.49} S^{-.21}$ | 31 |
| South of Fall Line | $LT = 13.6A^{.43} S^{-.231}$ | 25 |
| Atlanta, urban | $LT = 161A^{.22} S^{-.66} IA^{-.67}$ | 19 |
| Regions 1, 2, and 3, urban | $LT = 7.86A^{.35} TIA^{-.22} S^{-.31}$ | 30 |
| Region 3, urban | $LT = 6.10A^{.35} TIA^{-.22} S^{-.31}$ | 30 |
| | **Missouri, rural** | |
| Equation 1 | $LT = 2.79L^{.39} S^{-.195}$ | 26 |
| Equation 2 | $LT = 1.46A^{.27}$ | 26 |
| | **Missouri, urban** | |
| Equation 1 | $LT = 0.87L^{.60} S^{-.30} (13\text{-}BDF)^{.45}$ | 23 |
| Equation 2 | $LT = 0.32A^{.50} (13\text{-}BDF)^{.37}$ | 22 |
| | **Montana** | |
| Statewide, rural | $LT = 0.393A^{.58}$ | 40 |
| | **Nationwide, urban** | |
| Equation 1 | $LT = 0.85L^{.67} S^{-.31} (13\text{-}BDF)^{.47}$ | 76 |
| Equation 2 | $LT = 0.003L^{.71} (13\text{-}BDF)^{.34} (ST+10)^{2.53} RI2^{-.44} IA^{-.20} S^{-.14}$ | 22 |
| | **New Mexico** | |
| Statewide, rural | $LT = 0.04L^{.606} Sh^{.253}$ | 56 |
| | **Ohio** | |
| Small, rural | $LT = 16.4S^{-.78} (F+10)^{.38} (ST+1)^{.31}$ | 35 |
| Small, urban | $LT = 1.13(L/SL^{0.5})^{.57} (13\text{-}BDF)^{.46}$ | 53 |
| | **Oklahoma** | |
| Statewide, rural | $LT = 0.206A^{.239} S^{-.280} RI24^{2.54}$ | 40 |

# Appendix B. Summary of Equations for Estimating Basin Lagtime.—Continued

[LT, basin lagtime, in hours]

| State/Area/Region | Equation | Standard error, in percent |
|---|---|---|
| South Carolina (average basin LT) | | |
| Blue Ridge | $LT = 3.71A^{.265}$ | 7 |
| Piedmont | $LT = 2.66A^{.460}$ | 26 |
| Inner Coastal Plain | $LT = 6.10A^{.417}$ | 34 |
| Lower Coastal Plain | | |
| Region 1 | $LT = 6.62A^{.341}$ | 26 |
| Region 2 | $LT = 10.88A^{.341}$ | 26 |
| Statewide, urban | $LT = 20.2(L/S^{0.5})^{.623}\ TIA^{-.919}\ RI2^{1.129}$ | 24 |
| South Carolina (Qp adjusted LT) | | |
| Blue Ridge | $LT = 7.21A^{.322}\ Q_p^{-.112}$ | -- |
| Piedmont | $LT = 3.30A^{.614}\ Q_p^{-.120}$ | -- |
| Inner Coastal Plain | $LT = 7.03A^{.375}\ Q_p^{-.010}$ | -- |
| Lower Coastal Plain | | |
| Region 1 | $LT = 6.95A^{.348}\ Q_p^{-.022}$ | -- |
| Region 2 | $LT = 11.7A^{.348}\ Q_p^{-.022}$ | -- |
| Tennessee | | |
| East | $LT = 1.26L^{.825}$ | 47 |
| Central | $LT = 0.94L^{.868}$ | 39 |
| Central, urban | $LT = 1.64A^{.49}\ IA^{-.16}$ | 16 |
| West | $LT = 0.707A^{.73}$ | 43 |
| West, urban | $LT = 2.65A^{.348}\ IA^{-.357}$ | 39 |

A = drainage area, in square miles.
S = main channel slope, in feet per mile.
L = main channel length, in miles.
$Q_p$ = peak discharge, in cubic feet per second.
F = percent forest area.
ST = percent of surface storage in basin.
Sh = basin width per stream length, in feet per mile.
P = mean annual precipitation, in inches.
Q100 = 100-year recurrence interval peak discharge, in cubic feet per second.
IA = percent of basin covered by impervious surfaces.
BDF = basin development factor.
RI2 = 2-year 2-hour rainfall intensity.
RI24 = 2-year 24-hour rainfall.
TIA = total percentage of basin covered by impervious area.
C = channel condition (unpaved 1, full paved 2).
SL = main channnel slope, in feet per mile, determined as the difference in elevation between points 10 percent and 85 percent along the stream from the site of interest to the basin boundary, divided by the distance between the points.

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