# Magnitude and Frequency of Floods on Nontidal Streams in Delaware

By Kernell G. Ries III and Jonathan J.A. Dillow

Prepared in cooperation with the
Delaware Department of Transportation
and the
Delaware Geological Survey

Scientific Investigations Report 2006-5146

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

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

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

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Suggested citation:
Ries, K.G., III, and Dillow, J.J.A., 2006, Magnitude and frequency of floods on nontidal streams in Delaware: U.S. Geological Survey Scientific Investigations Report 2006-5146, 59 p.

# Contents

Abstract .......... 1
Introduction .......... 1
Physical Setting .......... 2
Methods for Estimating the Magnitude and Frequency of Floods .......... 2
Flood-Frequency Analysis at Streamgaging Stations .......... 4
Analysis of and Adjustments for Trends in Annual Peak-Flow Time Series .......... 12
Regional Skew Analysis .......... 15
Regional Flood-Frequency Relations .......... 17
Explanatory Variable Selection and Measurement .......... 17
Development of Regression Equations .......... 22
Accuracy and Limitations .......... 24
Comparison of Results with Previous Study .......... 28
Application of the Methods .......... 30
Estimation for a Gaged Location .......... 30
Estimation for a Site Upstream or Downstream from a Gaged Location .......... 31
Estimation for a Site Between Gaged Locations .......... 32
Effects of Urbanization on Floods .......... 33
StreamStats .......... 35
Summary and Conclusions .......... 35
References .......... 36

## Figures

1. Map showing study area and physiographic provinces in Delaware and surrounding states .......... 3
2. Map showing location of streamgaging stations in Delaware and surrounding states for which flood-frequency estimates were computed .......... 5
3. Example flood-frequency curve produced by the PEAKFQ program for Beaverdam Branch at Matthews, Maryland .......... 11
4. Graph showing relation between 2000 housing density and 2001 impervious surface percentage for streamgaging stations in and within 25 miles of Delaware .......... 13
5. Time-series plot showing adjustment of annual-peak flows for Stockley Branch at Stockley, Delaware for an increasing trend with time .......... 13
6. Map showing skew ranges for streamgaging stations in Delaware and surrounding states with 25 or more years of record .......... 16
7. Graph showing relation between the new ArcHydro and the traditional 10/85 method for measuring main channel slope for stations used in the regression analysis .......... 21
8. Boxplot showing percent storage measured using the National Hydrography Dataset (NHD) and a combination of the 2001 National Land Cover Dataset (NLCD) and the 2002 Delaware Land-Use Dataset (DELU) .......... 22

# Tables


1. Summary of streamgaging stations in and near Delaware for which streamflow statistics were computed ... 6
2. Description of treatment of stations with annual peak-flow time series that were affected by trends ... 14
3. Number of streamgaging stations included in the regression analyses by hydrologic region and state ... 18
4. Summary of drainage area, number of streamgaging stations, and average years of record used in the regression analyses for Delaware ... 18
5. Basin characteristics considered for use in the regression analyses ... 19
6. Climatic characteristics for stations in and near Delaware that were considered for use in the regression analyses ... 40
7. Basin characteristics for stations in and near Delaware that were considered for use in the regression analyses ... 44
8. Flood-frequency statistics for stations in and near Delaware that were considered for use in the regression analyses ... 52
9. Average standard errors of estimate and prediction and equivalent years of record for the best regression equations, by hydrologic region in Delaware ... 25
10. Values needed to determine 90-percent prediction intervals for the best regression equations, by hydrologic region in Delaware ... 26
11. Ranges of basin characteristics used to develop the regression equations ... 28
12. Mean and median percent differences between peak-flow frequency statistics computed from the systematic records for streamgaging stations included in this study and the previous study ... 29
13. Matrix of correlations between the logarithms of flood-frequency estimates at the 2- and 100-year recurrence intervals and the logarithms of the indicators of urbanization ... 34
14. Average standard errors of estimate and prediction and equivalent years of record for the urban regression equations ... 34

## Conversion Factors and Datum

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| square mile ($mi^2$) | 259.0 | hectare (ha) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Flow rate | |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

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

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

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

# Magnitude and Frequency of Floods on Nontidal Streams in Delaware

By Kernell G. Ries III and Jonathan J.A. Dillow


## Abstract

Reliable estimates of the magnitude and frequency of annual peak flows are required for the economical and safe design of transportation and water-conveyance structures. This report, done in cooperation with the Delaware Department of Transportation (DelDOT) and the Delaware Geological Survey (DGS), presents methods for estimating the magnitude and frequency of floods on nontidal streams in Delaware at locations where streamgaging stations monitor streamflow continuously and at ungaged sites. Methods are presented for estimating the magnitude of floods for return frequencies ranging from 2 through 500 years. These methods are applicable to watersheds exhibiting a full range of urban development conditions. The report also describes StreamStats, a web application that makes it easy to obtain flood-frequency estimates for user-selected locations on Delaware streams.

Flood-frequency estimates for ungaged sites are obtained through a process known as regionalization, using statistical regression analysis, where information determined for a group of streamgaging stations within a region forms the basis for estimates for ungaged sites within the region. One hundred and sixteen streamgaging stations in and near Delaware with at least 10 years of non-regulated annual peak-flow data available were used in the regional analysis. Estimates for gaged sites are obtained by combining the station peak-flow statistics (mean, standard deviation, and skew) and peak-flow estimates with regional estimates of skew and flood-frequency magnitudes. Example flood-frequency estimate calculations using the methods presented in the report are given for: (1) ungaged sites, (2) gaged locations, (3) sites upstream or downstream from a gaged location, and (4) sites between gaged locations.

Regional regression equations applicable to ungaged sites in the Piedmont and Coastal Plain Physiographic Provinces of Delaware are presented. The equations incorporate drainage area, forest cover, impervious area, basin storage, housing density, soil type A, and mean basin slope as explanatory variables, and have average standard errors of prediction ranging from 28 to 72 percent. Additional regression equations that incorporate drainage area and housing density as explanatory variables are presented for use in defining the effects of urbanization on peak-flow estimates throughout Delaware for the 2-year through 500-year recurrence intervals, along with suggestions for their appropriate use in predicting development-affected peak flows.

Additional topics associated with the analyses performed during the study are also discussed, including: (1) the availability and description of more than 30 basin and climatic characteristics considered during the development of the regional regression equations; (2) the treatment of increasing trends in the annual peak-flow series identified at 18 gaged sites, with respect to their relations with maximum 24-hour precipitation and housing density, and their use in the regional analysis; (3) calculation of the 90-percent confidence interval associated with peak-flow estimates from the regional regression equations; and (4) a comparison of flood-frequency estimates at gages used in a previous study, highlighting the effects of various improved analytical techniques.


## Introduction

Reliable estimates of the magnitude and frequency of annual peak flows, generally referred to as flood-frequency estimates, are required for the economical design of transportation and water-conveyance structures such as roads, bridges, culverts, storm sewers, dams, and levees. These estimates are also needed for the effective planning and management of land use and water resources, to protect lives and property in flood-prone areas, and to determine flood-insurance rates.

Flood-frequency estimates are needed at locations where streamgaging stations monitor streamflow continuously and at ungaged sites, where no streamflow information is available for use as a basis for determining the estimates. Estimates for ungaged sites usually are achieved through a process known as regionalization, where flood-frequency information determined for a group of streamgaging stations within a region forms the basis for estimates for ungaged sites within the region.

Methods for determining flood-frequency estimates for nontidal streams in Delaware have been provided previously in reports by: Tice (1968), Cushing, Kantrowitz, and Taylor (1973), Simmons and Carpenter (1978), and Dillow (1996). The regionalization methods described in those reports relied on fewer stations and shorter periods of record than the methods described in this report. An additional 14 years of record and improved regionalization techniques have become available since the analysis was done for the previous report by Dillow (1996).

The purpose of this report, done in cooperation with the Delaware Department of Transportation (DelDOT) and the Delaware Geological Survey (DGS), is to present methods for estimating the magnitude and frequency of floods on nontidal streams in Delaware. The report (1) describes methods used to estimate the magnitude and frequency of floods for streamgaging stations; (2) presents estimates of the magnitude of floods at the 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals determined for 116 streamgaging stations in and near Delaware; (3) describes methods used to develop regression equations for use in estimating the magnitude of floods at the same recurrence intervals for ungaged sites in Delaware; (4) describes the accuracy and limitations of the equations; (5) presents example applications of the methods; and (6) describes the StreamStats web application so that estimates can be easily obtained when needed.

## Physical Setting

The study area, comprised of the State of Delaware, is in the Mid-Atlantic coastal region of the United States. The State lies between 38°27´ and 39°51´ north latitude and 75°04´ and 75°48´ west longitude, and is bordered on the north by the State of Pennsylvania, on the west and south by the State of Maryland, and on the east by Delaware Bay (Dillow, 1996) (fig. 1). The State of New Jersey is on the eastern shore of Delaware River and Delaware Bay. Delaware has a land area of 1,954 $mi^2$ (square miles) and a 2003 population of about 817,000 (FedStats, 2005).

The climate in the study area is temperate. The mean annual temperature is about 54° F (degrees Fahrenheit), with monthly averages ranging from 31° F in January to 76° F in July (National Oceanographic and Atmospheric Administration, 2005). Mean annual precipitation is about 44 inches (Carpenter and Hayes, 1996). The precipitation is distributed fairly evenly throughout the year. Annual peak flows in the State arise from a mix of frontal storms with rain and melting snow in the spring, thunderstorms in the summer, and tropical storms and hurricanes in the summer and fall.

The study area is in two major physiographic provinces, the Coastal Plain and the Piedmont (Fenneman, 1938). The Fall Line, which crosses from the northeast corner of Delaware through about 5 mi (miles) south of the northwest corner of the State, forms the divide between the two provinces. The Piedmont Province, northwest of the Fall Line, consists of gently rolling landscape with maximum elevations generally less than 400 ft (feet) above sea level. Delaware streams in this province have fairly steep gradients, and drain to the Delaware River and Delaware Bay (Dillow, 1996). The Coastal Plain Province, southeast of the Fall Line, consists of an area of low relief adjacent to the Chesapeake and Delaware Bays, with elevations ranging from sea level to less than 100 ft. Streams in the Coastal Plain are often affected by tides for substantial distances above their mouths. The Fall Line is named as such because numerous waterfalls occur where rivers drop from the Piedmont onto the Coastal Plain.

## Methods for Estimating the Magnitude and Frequency of Floods

This report describes separate methods for estimating the magnitude and frequency of floods, hereafter referred to as flood-frequency estimates, for streamgaging stations and for ungaged sites. The general process normally followed to determine flood-frequency estimates for ungaged sites in a given region requires:

1. Selecting a group of streamgaging stations in and around the region with at least 10 years of annual peak-flow data and streamflow conditions that are generally representative of the area as a whole;
2. Computing initial flood-frequency estimates by weighting the station skews with generalized-skew values taken from "Guidelines For Determining Flood Flow Frequency" (Bulletin 17B) by the Interagency Advisory Committee on Water Data (IACWD, 1982);
3. Computing physical and climatic characteristics, hereafter termed basin characteristics, that have a conceptual relation to the generation of flood peaks for the drainage basins associated with the stations;
4. Analyzing the initial station-skew coefficients to determine new generalized-skew values for the region;
5. Re-computing the flood-frequency estimates for the stations by weighting the station skews with the new generalized-skew values;
6. Analyzing to determine if relations between flood-frequency estimates and basin characteristics are homogenous throughout the region or if the region should be divided into sub-regions;

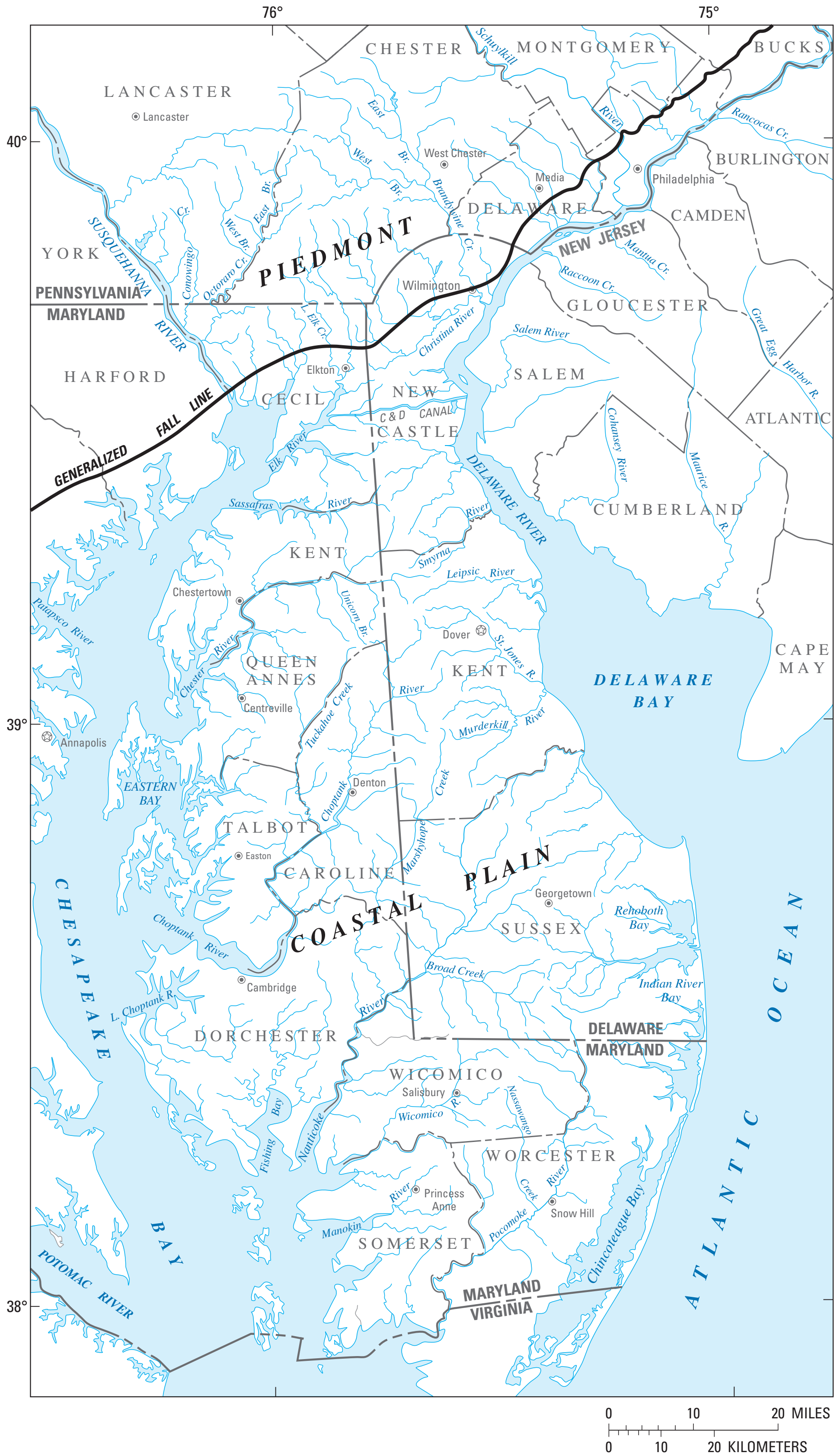


**Figure 1.** Study area and physiographic provinces in Delaware and surrounding states.

7. Using regression analysis to develop equations for use in estimating flood frequencies at ungaged sites in the region or sub-regions; and

8. Assessing and describing the accuracy associated with estimating flood frequencies for ungaged sites.

Streamgaging stations in Delaware and stations in adjacent states having drainage-basin centroids within 25 mi of the Delaware border were investigated for possible use in the regional analysis. Stations within this region were not used in the analysis if less than 10 years of annual peak-flow data were available, or if peak flows at the stations were substantially affected by dam regulations or flood-retarding reservoirs. Use of these criteria resulted in the initial selection of 116 stations for inclusion in the regional analysis (fig. 2, table 1).

The number of stations within the region was insufficient to develop separate regression equations for rural and urban basins. In addition, DelDOT was specifically interested in understanding how development can affect flood-frequency estimates. As a result, the stations were not screened based on the degree of urbanization.

## Flood-Frequency Analysis at Streamgaging Stations

Flood-frequency estimates provided later in this report for 116 unregulated streamgaging stations in the study area were computed from annual series of peak-flow data for the stations according to methods recommended in Bulletin 17B. The estimates are reported as T-year discharges, where T is a recurrence interval that indicates the average number of years between occurrences of peak discharges of the same or greater magnitude. Flood-frequency estimates can also be expressed as exceedance probabilities, which are the reciprocal of the recurrence interval. In other words, the probability that the T-year flood will be exceeded is 1/T in every year. For example, the 100-year flood has a 1 in 100 (1 percent) chance of being equaled or exceeded in any given year.

The IACWD recommends fitting the logarithms of the annual peak flows to a log-Pearson, Type III frequency distribution. Fitting the distribution requires calculating the logarithms of the mean, standard deviation, and skew coefficient of the annual peak-flow series, which describe the mid-point, slope, and curvature of the peak-flow frequency curve, respectively. Estimates of the T-year flood peaks are computed by inserting the three statistics of the frequency distribution into the equation:

$$Q_T = X + KS \tag{1}$$

where

$Q_T$ is the logarithm of the magnitude of the T-year recurrence interval discharge, in $ft^3/s$ (cubic feet per second);

$X$ is the mean of the logarithms of the annual peak streamflows;

$K$ is a factor based on the skew coefficient and the given recurrence interval, which can be obtained from a table in Bulletin 17B; and

$S$ is the standard deviation of the logarithms of the annual peak streamflows, which is a measure of the degree of variation of the annual values about the mean value.

The skew coefficient measures the symmetry of the frequency distribution and is strongly influenced by the presence of high or low outliers, annual peaks that are substantially higher or lower than other peaks in the series. The skew is positive when the mean of the annual series exceeds the median and negative when the mean is less than the median. Large positive skews are typically the result of high outliers, and large negative skews are typically the result of low outliers.

The U.S. Geological Survey (USGS) computer program PEAKFQ was used to compute the flood-frequency statistics for streamgaging stations presented in this report. PEAKFQ automates many of the analysis procedures recommended in Bulletin 17B, including identifying and adjusting for high and low outliers and historical periods, weighting of station skews with a generalized skew based on the skews of other stations within the region, and fitting a log-Pearson, Type III distribution to the streamflow data. The PEAKFQ program and associated documentation can be downloaded from the web free of charge at http://water.usgs.gov/software/peakfq.html. In conjunction with PEAKFQ, the USGS software programs ANNIE, IOWDM (Flynn and others, 1995), and SWSTAT were used for binary database management, for input and output of data to the database, and for testing annual peak-flow series for trends, respectively. The ANNIE program and accompanying documentation can be downloaded at http://water.usgs.gov/software/annie.html. The IOWDM program and accompanying documentation can be downloaded at http://water.usgs.gov/software/iowdm.html. The SWSTAT program and accompanying documentation can be downloaded at http://water.usgs.gov/software/swstat.html.

The process generally followed when computing flood-frequency estimates for streamgaging stations consisted of the following steps:

1. Retrieve the annual time series of peak flows for the station from the USGS NWIS-Web on-line database at http://nwis.waterdata.usgs.gov/usa/nwis/peak;

2. Compare the time series for the station to time series for upstream and downstream stations, and for stations in adjacent basins to determine if the records for the other stations can be used as the basis for a historical adjustment;

3. Consult the USGS data-collection manager for the State in which the station is located, do a literature search, or both, to obtain any information that can be used as the basis for historical adjustments;

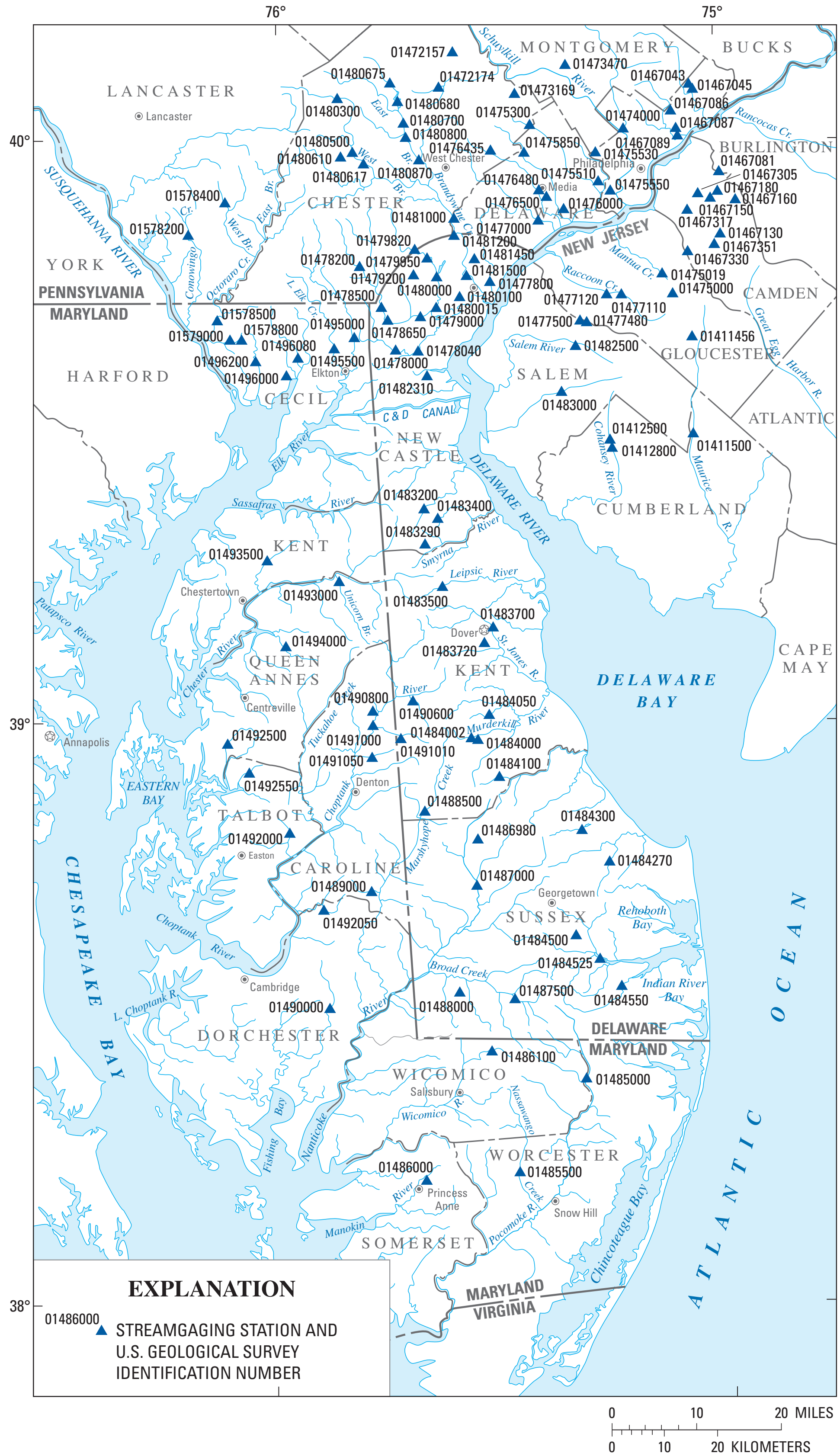


**Figure 2.** Location of streamgaging stations in Delaware and surrounding states for which flood-frequency estimates were computed.

**Table 1.** Summary of streamgaging stations in and near Delaware for which streamflow statistics were computed.

[USGS, U.S. Geological Survey, CP, Coastal Plain Physiographic Province; PD, Piedmont Coastal Plain Physiographic Province; ° ´ ˝, degrees, minutes, seconds; N, years of record]

| USGS station number | Name | Latitude ° ′ ″ | Longitude ° ′ ″ | Region | Peak-flow period | N |
|---|---|---|---|---|---|---|
| 01411456 | Little Ease Run near Clayton, NJ | 39 39 32 | 75 04 03 | CP | 1988-2004 | 17 |
| 01411500 | Maurice River at Norma, NJ | 39 29 44 | 75 04 37 | CP | 1933-2004[h] | 72 |
| 01412500 | West Branch Cohansey River at Seeley, NJ | 39 29 06 | 75 15 32 | CP | 1952-73, 1974-79, 1980-2004 | 51 |
| 01412800 | Cohansey River at Seeley NJ | 39 28 21 | 75 15 20 | CP | 1978-95, 2003-4 | 20 |
| 01467043 | Stream ‘A’ at Philadelphia, PA | 40 05 27 | 75 03 50 | PD | 1965-80 | 16 |
| 01467045 | Pennypack Creek below Veree Road at Philadelphia, PA | 40 05 04 | 75 03 34 | PD | 1964-80 | 18 |
| 01467081 | South Branch Pennsauken Creek at Cherry Hill, NJ | 39 56 30 | 75 00 04 | CP | 1968-76, 1978-2004 | 36 |
| 01467086 | Tacony Creek at County Line, Philadelphia, PA | 40 02 47 | 75 06 40 | PD | 1966-86 | 21 |
| 01467087 | Frankford Creek at Castor Ave., Philadelphia, PA | 40 00 57 | 75 05 50 | PD | 1966-2004[a] | 39 |
| 01467089 | Frankford Creek at Torresdale Ave., Philadelphia, PA | 40 00 25 | 75 05 33 | PD | 1966-81[b] | 16 |
| 01467130 | Cooper River at Kirkwood, NJ | 39 50 11 | 75 00 05 | CP | 1963-80, 2004 | 18 |
| 01467150 | Cooper River at Haddonfield, NJ | 39 54 11 | 75 01 17 | CP | 1963-2003[h] | 41 |
| 01467160 | North Branch Cooper River near Marlton, NJ | 39 53 20 | 74 58 07 | CP | 1964-78, 2004[bh] | 26 |
| 01467180 | North Branch Cooper River at Ellisburg, NJ | 39 54 27 | 75 00 41 | CP | 1964-75, 2004 | 13 |
| 01467305 | Newton Creek at Collingswood, NJ | 39 54 30 | 75 03 12 | CP | 1964-75, 1977-2004 | 40 |
| 01467317 | South Branch Newton Creek at Haddon Heights, NJ | 39 52 45 | 75 04 25 | CP | 1964-2004[c] | 41 |
| 01467330 | South Branch Big Timber Creek at Blackwood, NJ | 39 48 17 | 75 04 32 | CP | 1964-84[h] | 21 |
| 01467351 | North Branch Big Timber Creek at Laurel Rd, Laurel Springs, NJ | 39 49 07 | 75 00 55 | CP | 1975-88 | 14 |
| 01472157 | French Creek near Phoenixville, PA | 40 09 05 | 75 36 06 | PD | 1969-2004 | 36 |
| 01472174 | Pickering Creek near Chester Springs, PA | 40 05 22 | 75 37 50 | PD | 1967-83 | 17 |
| 01473169 | Valley Creek at PA Turnpike Bridge near Valley Forge, PA | 40 04 45 | 75 27 40 | PD | 1983-2004[ch] | 22 |
| 01473470 | Stony Creek at Sterigere Street at Norristown, PA | 40 07 38 | 75 20 43 | PD | 1971, 1975-94 | 21 |
| 01474000 | Wissahickon Creek at mouth, Philadelphia, PA | 40 00 55 | 75 12 26 | PD | 1966-2004[h] | 39 |
| 01475000 | Mantua Creek at Pitman, NJ | 39 44 13 | 75 06 48 | CP | 1940, 1942-94, 1999, 2003-4[ch] | 57 |
| 01475019 | Mantua Creek at Salina, NJ | 39 46 13 | 75 07 58 | CP | 1975-1988 | 14 |

**Table 1.** Summary of streamgaging stations in and near Delaware for which streamflow statistics were computed.—Continued

[USGS, U.S. Geological Survey, CP, Coastal Plain Physiographic Province; PD, Piedmont Coastal Plain Physiographic Province; ° ´ ″, degrees, minutes, seconds; N, years of record]

| USGS station number | Name | Latitude ° ′ ″ | Longitude ° ′ ″ | Region | Peak-flow period | N |
|---|---|---|---|---|---|---|
| 01475300 | Darby Creek at Waterloo Mills near Devon, PA | 40 01 21 | 75 25 20 | PD | 1972-97, 1999[h] | 27 |
| 01475510 | Darby Creek near Darby, PA | 39 55 44 | 75 16 22 | PD | 1964-90 | 27 |
| 01475530 | Cobbs Creek at U.S. Highway No. 1 at Philadelphia, PA | 39 58 29 | 75 16 49 | PD | 1965-81[h] | 17 |
| 01475550 | Cobbs Creek at Darby, PA | 39 55 02 | 75 14 52 | PD | 1964-90 | 27 |
| 01475850 | Crum Creek near Newtown Square, PA | 39 58 35 | 75 26 13 | PD | 1977-2004 | 28 |
| 01476000 | Crum Creek at Woodlyn, PA | 39 52 45 | 75 21 00 | PD | 1932-37, 1975-86 | 18 |
| 01476435 | Ridley Creek at Dutton Mill near West Chester, PA | 39 58 50 | 75 31 00 | PD | 1975-86 | 12 |
| 01476480 | Ridley Creek at Media, PA | 39 54 58 | 75 24 13 | PD | 1932-55, 1978-2004[d] | 48 |
| 01476500 | Ridley Creek at Moylan, PA | 39 54 10 | 75 23 35 | PD | 1932-55, 1978-80, 1984-85[bh] | 31 |
| 01477000 | Chester Creek near Chester, PA | 39 52 08 | 75 24 31 | PD | 1932-2004 | 73 |
| 01477110 | Raccoon Creek at Mullica Hill, NJ | 39 44 10 | 75 13 29 | CP | 1940, 1978-95, 1999[h] | 20 |
| 01477120 | Raccoon Creek near Swedesboro, NJ | 39 44 26 | 75 15 33 | CP | 1967-2004[h] | 38 |
| 01477480 | Oldmans Creek near Harrisonville, NJ | 39 41 20 | 75 18 37 | CP | 1975-95 | 21 |
| 01477500 | Oldmans Creek near Woodstown, NJ | 39 41 27 | 75 19 04 | CP | 1932-40,1967[h] | 10 |
| 01477800 | Shellpot Creek at Wilmington, DE | 39 45 39.5 | 75 31 07.3 | PD | 1945-2004[ch] | 60 |
| 01478000 | Christina River at Coochs Bridge, DE | 39 38 14.6 | 75 43 40.4 | PD | 1943-2004 | 62 |
| 01478040 | Christina River near Bear, DE | 39 38 12 | 75 40 53 | PD | 1979-83, 1985-91[h] | 12 |
| 01478200 | Middle Branch White Clay Creek near Landenberg, PA | 39 46 54 | 75 48 03 | PD | 1960-1991, 1995 | 32 |
| 01478500 | White Clay Creek above Newark, DE | 39 42 50 | 75 45 35 | PD | 1953-59, 1963-80, 1989, 1994-2004[ceh] | 37 |
| 01478650 | White Clay Creek at Newark, DE | 39 41 21.2 | 75 44 55.5 | PD | 1994-2003b | 10 |
| 01479000 | White Clay Creek near Newark, DE | 39 41 57.2 | 75 40 30.1 | PD | 1932-36, 1943-57, 1960-2004[h] | 65 |
| 01479200 | Mill Creek at Hockessin, DE | 39 46 31 | 75 41 26 | PD | 1966-75 | 10 |

**Table 1.** Summary of streamgaging stations in and near Delaware for which streamflow statistics were computed.—Continued

[USGS, U.S. Geological Survey, CP, Coastal Plain Physiographic Province; PD, Piedmont Coastal Plain Physiographic Province; ° ´ ˝, degrees, minutes, seconds; N, years of record]

| USGS station number | Name | Latitude ° ′ ″ | Longitude ° ′ ″ | Region | Peak-flow period | N |
|---|---|---|---|---|---|---|
| 01479820 | Red Clay Creek near Kennett Square, PA | 39 49 00 | 75 41 31 | PD | 1988-2004[h] | 17 |
| 01479950 | Red Clay Creek Tributary near Yorklyn, DE | 39 47 50 | 75 39 33 | PD | 1966-75 | 10 |
| 01480000 | Red Clay Creek at Wooddale, DE | 39 45 46.1 | 75 38 11.4 | PD | 1943-2004[h] | 62 |
| 01480015 | Red Clay Creek near Stanton, DE | 39 42 56.7 | 75 38 23.8 | PD | 1989-2004[h] | 16 |
| 01480100 | Little Mill Creek at Elsmere, DE | 39 44 05 | 75 35 14 | PD | 1964-80,1989 | 18 |
| 01480300 | West Branch Brandywine Creek near Honey Brook, PA | 40 04 22 | 75 51 40 | PD | 1960-2004 | 45 |
| 01480500 | West Branch Brandywine Creek at Coatesville, PA | 39 59 08 | 75 49 40 | PD | 1942,1944-50, 1970-2004[h] | 44 |
| 01480610 | Sucker Run near Coatesville, PA | 39 58 20 | 75 51 03 | PD | 1964-2004 | 41 |
| 01480617 | West Branch Brandywine Creek at Modena, PA | 39 57 42 | 75 48 06 | PD | 1970-2004[b] | 35 |
| 01480675 | Marsh Creek near Glenmoore, PA | 40 05 52 | 75 44 31 | PD | 1967-2004[b] | 38 |
| 01480680 | Marsh Creek near Lyndell, PA | 40 03 58 | 75 43 38 | PD | 1960-71[b] | 12 |
| 01480700 | East Branch Brandywine Creek near Downingtown, PA | 40 02 05 | 75 42 32 | PD | 1966-2004[h] | 39 |
| 01480800 | East Branch Brandywine Creek at Downingtown, PA | 40 00 20 | 75 42 20 | PD | 1942, 1958-68[bh] | 12 |
| 01480870 | East Branch Brandywine Creek below Downingtown, PA | 39 58 07 | 75 40 25 | PD | 1972-2004[fh] | 33 |
| 01481000 | Brandywine Creek at Chadds Ford, PA | 39 52 11 | 75 35 37 | PD | 1912-53, 1954-5, 1963-2004[bh] | 85 |
| 01481200 | Brandywine Creek tributary near Centerville, DE | 39 50 08 | 75 35 57 | PD | 1966-75 | 10 |
| 01481450 | Willow Run at Rockland, DE | 39 47 32 | 75 33 16 | PD | 1966-75 | 10 |
| 01481500 | Brandywine Creek at Wilmington, DE | 39 46 09.9 | 75 34 25.0 | PD | 1912-2004[g] | 93 |
| 01482310 | Doll Run at Red Lion, DE | 39 35 53 | 75 39 43 | CP | 1966-75[b] | 10 |
| 01482500 | Salem River at Woodstown, NJ | 39 38 36 | 75 19 51 | CP | 1940-95, 2003-4[h] | 58 |
| 01483000 | Alloway Creek at Alloway, NJ | 39 33 56 | 75 21 38 | CP | 1953-72 | 20 |
| 01483200 | Blackbird Creek at Blackbird, DE | 39 21 58.6 | 75 40 09.8 | CP | 1952-2004 | 52 |
| 01483290 | Paw Paw Branch tributary near Clayton, DE | 39 18 41 | 75 40 08 | CP | 1966-75[h] | 10 |
| 01483400 | Sawmill Branch tributary near Blackbird, DE | 39 20 57 | 75 38 31 | CP | 1966-75 | 10 |
| 01483500 | Leipsic River near Cheswold, DE | 39 13 58 | 75 37 57 | CP | 1943-75 | 33 |
| 01483700 | St. Jones River at Dover, DE | 39 09 49.4 | 75 31 08.7 | CP | 1958-2004 | 47 |
| 01483720 | Puncheon Branch at Dover, DE | 39 08 25 | 75 32 20 | CP | 1966-75 | 10 |

**Table 1.** Summary of streamgaging stations in and near Delaware for which streamflow statistics were computed.—Continued

[USGS, U.S. Geological Survey, CP, Coastal Plain Physiographic Province; PD, Piedmont Coastal Plain Physiographic Province; ° ´ ˝, degrees, minutes, seconds; N, years of record.]

| USGS station number | Name | Latitude ° ′ ″ | Longitude ° ′ ″ | Region | Peak-flow period | N |
|---|---|---|---|---|---|---|
| 01484000 | Murderkill River near Felton, DE | 38 58 33 | 75 34 03 | CP | 1932-3, 1960-85, 1997-99[h] | 31 |
| 01484002 | Murderkill River tributary near Felton, DE | 38 58 19 | 75 33 31 | CP | 1966-75[h] | 10 |
| 01484050 | Pratt Branch near Felton, DE | 39 00 37 | 75 31 46 | CP | 1966-75[h] | 10 |
| 01484100 | Beaverdam Branch at Houston, DE | 38 54 20.8 | 75 30 45.9 | CP | 1958-2004 | 47 |
| 01484270 | Beaverdam Creek near Milton, DE | 38 45 41 | 75 16 03 | CP | 1966-80, 2002-3[bh] | 18 |
| 01484300 | Sowbridge Branch near Milton, DE | 38 48 51 | 75 19 39 | CP | 1957-78 | 22 |
| 01484500 | Stockley Branch at Stockley, DE | 38 38 19.9 | 75 20 31.1 | CP | 1943-2004[c] | 62 |
| 01484525 | Millsboro Pond outlet at Millsboro, DE | 38 35 40.4 | 75 17 27.7 | CP | 1987-8, 1992-2004 | 15 |
| 01484550 | Pepper Creek at Dagsboro, DE | 38 32 50 | 75 14 40 | CP | 1960-75[b] | 16 |
| 01485000 | Pocomoke River near Willards, MD | 38 23 20.0 | 75 19 28.0 | CP | 1950-2004[ch] | 55 |
| 01485500 | Nassawango Creek near Snow Hill, MD | 38 13 44.1 | 75 28 17.2 | CP | 1950-2004[c] | 55 |
| 01486000 | Manokin Branch near Princess Anne, MD | 38 12 50.0 | 75 40 17.0 | CP | 1951-71, 1975-2004 | 50 |
| 01486100 | Andrews Branch near Delmar, MD | 38 26 15 | 75 31 46 | CP | 1967-76 | 10 |
| 01486980 | Toms Dam Branch near Greenwood, DE | 38 48 04 | 75 33 28 | CP | 1966-75 | 10 |
| 01487000 | Nanticoke River near Bridgeville, DE | 38 43 42.0 | 75 33 42.7 | CP | 1943-2004[ch] | 62 |
| 01487500 | Trap Pond outlet near Laurel, DE | 38 31 40.4 | 75 28 56.7 | CP | 1952-75, 2001-4 | 27 |
| 01488000 | Holly Ditch near Laurel, DE | 38 32 20 | 75 35 55 | CP | 1951-56, 1959-61, 1967-75 | 18 |
| 01488500 | Marshyhope Creek near Adamsville, DE | 38 50 58.9 | 75 40 23.2 | CP | 1943-68, 1973-2003[ch] | 59 |
| 01489000 | Faulkner Branch at Federalsburg, MD | 38 42 44 | 75 47 34 | CP | 1950-91[bh] | 42 |
| 01490000 | Chicamacomico River near Salem, MD | 38 30 42.0 | 75 52 47.7 | CP | 1951-80, 2003[h] | 31 |
| 01490600 | Meredith Branch near Sandtown, DE | 39 02 23 | 75 41 52 | CP | 1966-75[h] | 10 |
| 01490800 | Oldtown Branch at Goldsboro, MD | 39 01 23 | 75 47 16 | CP | 1967-76[h] | 10 |
| 01491000 | Choptank River near Greensboro, MD | 38 59 49.9 | 75 47 08.9 | CP | 1948-2004[h] | 57 |
| 01491010 | Sangston Prong near Whiteleysburg, DE | 38 58 25 | 75 43 32 | CP | 1966-75[h] | 10 |
| 01491050 | Spring Branch near Greensboro, MD | 38 56 34 | 75 47 25 | CP | 1967-76[h] | 10 |

**Table 1.** Summary of streamgaging stations in and near Delaware for which streamflow statistics were computed.—Continued

[USGS, U.S. Geological Survey, CP, Coastal Plain Physiographic Province; PD, Piedmont Coastal Plain Physiographic Province; ° ´ ˝, degrees, minutes, seconds; N, years of record]

| USGS station number | Name | Latitude ° ′ ″ | Longitude ° ′ ″ | Region | Peak-flow period | N |
|---|---|---|---|---|---|---|
| 01492000 | Beaverdam Branch at Matthews, MD | 38 48 41 | 75 58 15 | CP | 1950-81[h] | 32 |
| 01492050 | Gravel Run at Beulah, MD | 38 40 54 | 75 53 53 | CP | 1966-76[h] | 11 |
| 01492500 | Sallie Harris Creek near Carmichael, MD | 38 57 53.6 | 76 06 31.8 | CP | 1952-81, 2001-4 | 34 |
| 01492550 | Mill Creek near Skipton, MD | 38 55 00 | 76 03 42 | CP | 1966-76[h] | 11 |
| 01493000 | Unicorn Branch near Millington, MD | 39 14 58.9 | 75 51 40.7 | CP | 1948-2003[c] | 56 |
| 01493500 | Morgan Creek near Kennedyville, MD | 39 16 48.1 | 76 00 52.4 | CP | 1951-2004[h] | 54 |
| 01494000 | Southeast Creek at Church Hill, MD | 39 07 57 | 75 58 51 | CP | 1952-59, 1961-65 | 13 |
| 01495000 | Big Elk Creek at Elk Mills, MD | 39 39 25.4 | 75 49 20.5 | PD | 1884, 1932-2004[h] | 73 |
| 01495500 | Little Elk Creek at Childs, MD | 39 38 30 | 75 52 00 | PD | 1949-58, 1989,1999 | 12 |
| 01496000 | Northeast Creek at Leslie, MD | 39 37 40 | 75 56 40 | PD | 1949-84, 1999[h] | 37 |
| 01496080 | Northeast River tributary near Charlestown, MD | 39 35 53 | 75 58 37 | PD | 1967-75 | 10 |
| 01496200 | Principio Creek near Principio Furnace, MD | 39 37 34 | 76 02 27 | PD | 1967-92, 1999[h] | 27 |
| 01578200 | Conowingo Creek near Buck, PA | 39 50 35 | 76 11 45 | PD | 1963-89, 1991-2004 | 41 |
| 01578400 | Bowery Run near Quarryville, PA | 39 53 41 | 76 06 50 | PD | 1963-81 | 19 |
| 01578500 | Octoraro Creek near Rising Sun, MD | 39 41 24 | 76 07 43 | PD | 1884,1918, 1932-58, 1963, 1965-77, 1999[h] | 44 |
| 01578800 | Basin Run at West Nottingham, MD | 39 39 23 | 76 04 30 | PD | 1967-76 | 10 |
| 01579000 | Basin Run at Liberty Grove, MD | 39 39 30 | 76 06 10 | PD | 1949-76, 1999[bh] | 23 |

[a] 1966-1981 estimated based on record for station 01467089.

[b] Station not used in regression analysis.

[c] Peak-flow record adjusted for trends.

[d] 1932-55,1978-80,1984-85 estimated based on record for station 01476480.

[e] 1994-2004 estimated based on records for stations 01478245, 01478650, and 01479000.

[f] 1958-68 estimated based on records for station 01480800, 1969-71 estimated based on records for stations 01480800 and 01481000, historical period based on records for station 01481500.

[g] 1912-46 estimated based on records from station 01481000.

[h] Peak-flow record adjusted for historical period.

4. Plot the annual time series to look for unusual observations that will require further investigation and to visually detect monotonic or step trends;

5. Run SWSTAT to perform a Kendall's tau test on the time series to determine if monotonic trends are statistically significant (Helsel and Hirsch, 1992);

6. If necessary, adjust the time series for trends or eliminate the station from further analysis;

7. Run PEAKFQ, applying any necessary historical adjustments, to obtain initial flood-frequency estimates for the station, using the default generalized-skew values provided by the program, which are derived from the Bulletin 17B skew map;

8. Plot the initial flood-frequency curve to determine if it adequately fits the data or if low- or high-outlier thresholds or other adjustments need to be made for the curve to better fit the data (fig. 2); and

9. If necessary, re-run PEAKFQ to apply any adjustments to obtain a satisfactory flood-frequency curve.

Completion of the steps described above resulted in flood-frequency estimates that were based on weighting of the station skew and the Bulletin 17B generalized skew. The station skews from these initial analyses were used to develop an improved method for computing generalized-skew values for the stations used in the study. PEAKFQ was then rerun for each station with the new generalized-skew values replacing the Bulletin 17B skew values to obtain the final flood-frequency estimates for the stations. The following two sections describe methods for handling stations with trends and developing new generalized-skew values, respectively.

Simmons and Carpenter (1978) previously determined flood-frequency statistics for 21 of the stations used in this study by weighting estimates determined from the systematic records for the stations with estimates determined from a rainfall-runoff model. The rainfall-runoff model simulated a longer period of record than the one actually available for the stations. The weighted flood-frequency estimates were also used in the previous regression analysis done by Dillow (1996). Although none of the stations had additional record since either of the two previous reports were published, the weighted flood-frequency estimates were not used in this

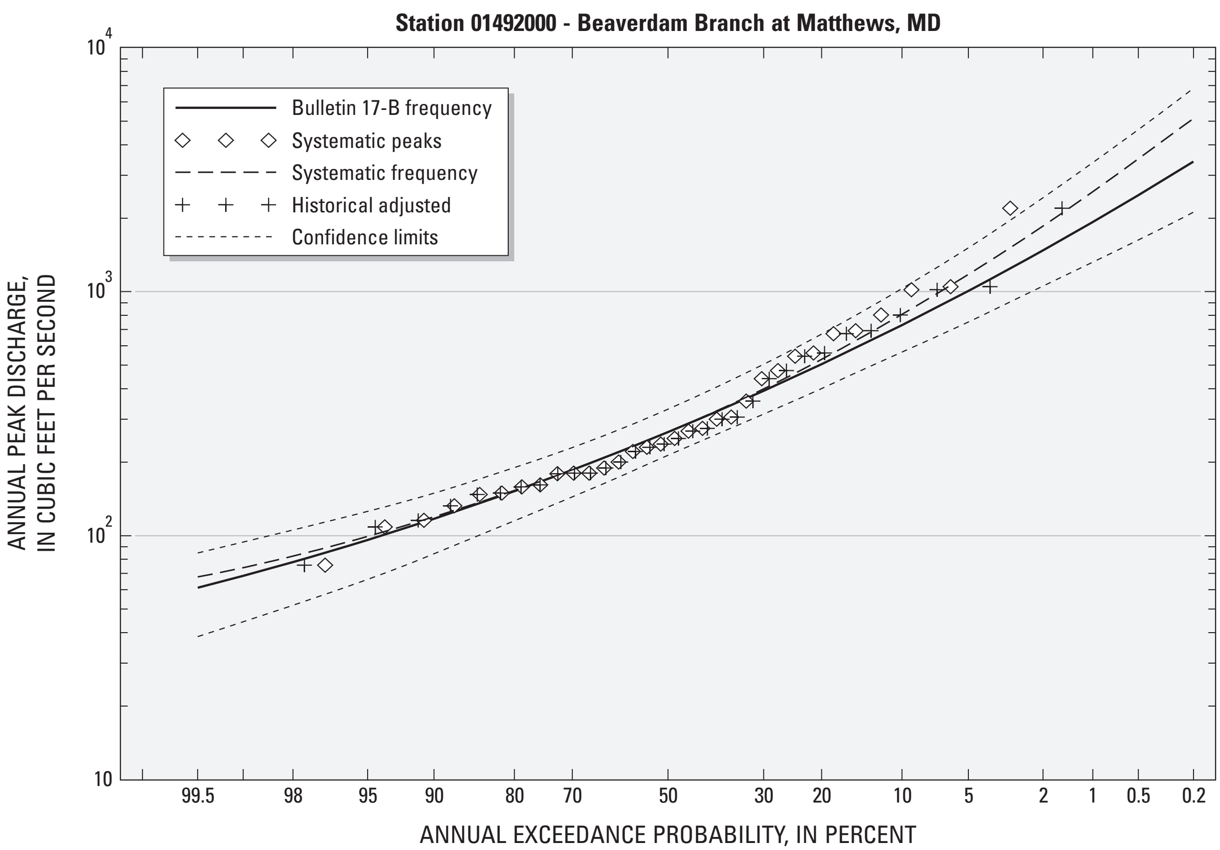


**Figure 3.** Example flood-frequency curve produced by the PEAKFQ program for Beaverdam Branch at Matthews, Maryland.

analysis because the previous estimates were not determined using the revised generalized-skew values determined for this report.

## Analysis of and Adjustments for Trends in Annual Peak-Flow Time Series

Trends in the annual peak flows at a station can affect the reliability and interpretation of the flood-frequency estimates. Plots of the peak-flow time series for a station can show evidence of (1) gradual upward or downward trends, known as monotonic trends; (2) sudden jumps from one condition to another, known as step trends; or (3) trends with more complex patterns. Visual inspection of the plots indicated no stations with step trends or obvious complex patterns, but monotonic trends were evident for several stations.

Kendall's tau tests for monotonic trends (Helsel and Hirsch, 1992) were done on the annual series of peak flows for all stations considered for use in this study. The two primary outputs from the test are the tau value and the probability (p-value) associated with accepting the null hypothesis that there is no trend when, in fact, a trend exists. The tau value measures the strength of the correlation between the annual peak-flow values and time. Positive values of tau indicate increasing trends and negative values indicate decreasing trends. Trends are considered to be significant when the p-value is less than or equal to 0.05. At this p-value, there is a 5-percent likelihood that the test will detect a significant trend when there is no actual trend present.

Usually only a small percentage of stations considered for use in similar regional flood-frequency studies are found to have trends. Because of this, any stations with trends usually are excluded from further analysis to avoid the effort required to treat the trends and to avoid confusion over how to interpret the resulting de-trended statistics. Usually, there are plenty of stations left over to use for regression analyses after the stations with trends are excluded.

The trend tests done for this study identified 18 stations with statistically significant trends (p-values <= 0.05). All stations with significant trends had positive tau values, indicating that peak flows were increasing with time. About half of the trend-affected stations were in and around southern Delaware. The remaining trend-affected stations were distributed throughout the region of study. Removal of the stations with trends from the regional analysis would leave an inadequate dataset to define regional peak-flow frequencies in southern Delaware. As a result, the annual-peak-flow records for stations with trends were further analyzed to determine if climate, land use, or other data could be used as the basis for de-trending the peak-flow data.

First, relations between annual series of peak flows and maximum 24-hour precipitation were examined for the trend-affected stations. Annual series of maximum 24-hour precipitation were obtained for 11 precipitation stations in and around Delaware from the National Oceanic and Atmospheric Administration web site at http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_series.html (Bonnin and others, 2004), and Kendall's tau trend tests were performed using these data. Tau values for 9 of the 11 precipitation stations were negative, in contrast to the positive tau values for the trend-affected streamgaging stations during the same time period, but no precipitation trends were statistically significant. From this analysis, it was concluded that the increasing trends in the streamflow data were not related to similar increasing trends in maximum 24-hour rainfall.

Second, relations between annual series of peak flows and housing density were examined for the trend-affected streamgaging stations. Geographic Information System (GIS) coverages of housing-density data for 1960, 1970, 1980, 1990, and 2000 were obtained from The Nature Conservancy (Theobald, 2001). These data were derived from U.S. Census Bureau (2001) data. Average housing density, in homes per acre, was determined for each station for each decadal sample by using GIS to overlay drainage boundaries for the stations on the housing data. Linear interpolation between years of known housing density was then used to estimate average housing density for each year between 1960 and 2000 for each station. Values for 2001 through 2004 were extrapolated based on the rate of change between 1990 and 2000. The annual series of average housing density was related to the annual series of peak flows for each of the 18 streamgaging stations with significant trends in the peak-flow series using scatterplots and regression analyses. The regression analyses indicated statistically significant relations between the two time series for 8 of the 18 trend-affected stations.

As further described in the Explanatory Variable Selection and Measurement section, several GIS datasets were available to indicate the degree of urbanization in the study area. Housing density and population data were the only data that were readily available in 10-year snapshots, enabling interpolation to annual time series and relation to the annual peak-flow time series. The housing density data were considered superior to the population data for use as an indicator of urbanization in Delaware because of the large concentration of vacation homes in coastal areas. Housing density was considered more likely to reflect the existence of these vacation homes and their effect on peak flows than population density, which was not measured for this study. The housing density data are strongly related to the percentage of impervious surfaces, as determined from the impervious cover dataset developed by the USGS as part of the 2001 National Land Cover Dataset (NLCD) (Yang and others, 2003). The impervious data can be downloaded from the web at http://gisdata.usgs.net/website/MRLC/.

The relation between 2000 housing density and 2001 impervious area percentage determined for the streamgaging stations used in this study is shown in figure 4. A polynomial equation fit through the data has an $R^2$ value of 0.9144. The dependent y variable in the equation in figure 4 is 2000 housing density in homes per acre, and the explanatory x variable is 2001 impervious percentage. The $R^2$ value, known as the

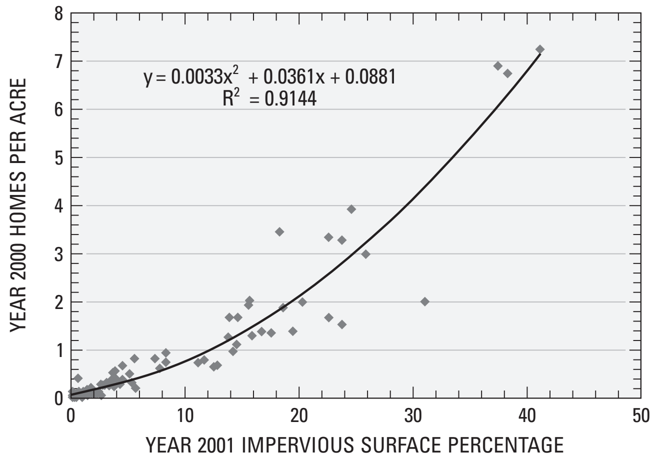


**Figure 4.** Relation between 2000 housing density and 2001 impervious surface percentage for streamgaging stations in and within 25 miles of Delaware.

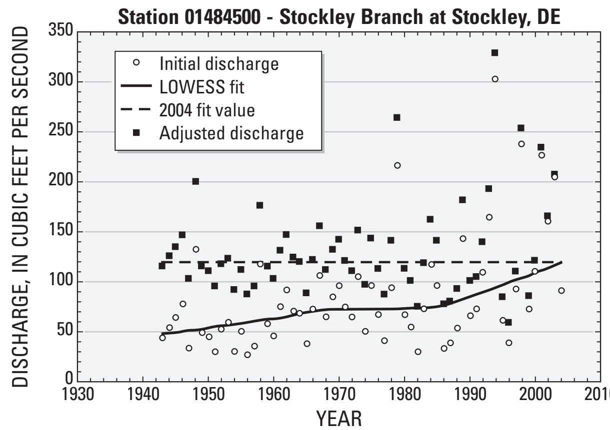


**Figure 5.** Time-series plot showing adjustment of annual-peak flows for Stockley Branch at Stockley, Delaware for an increasing trend with time.

coefficient of determination, indicates the proportion of the variation in the dependent variable that is explained by the explanatory variable. The standard error of estimate of this relation is 0.38 homes per acre, meaning that two thirds of the estimated homes per acre determined from the equation for stations used in the analysis were within the given standard error of the measured homes per acre for the stations.

Use of the relations between the annual series of peak flows and housing density to de-trend the peak-flow time series would give unsatisfactory results for the stations where the relations were not significant. Although it was not tried, it is also possible that use of only the housing density data to de-trend the peak-flow data would not result in complete removal of the peak-flow trends for these stations. Resources to further investigate other possible physical or climatic mechanisms for the trends were not available.

The peak-flow time series for 11 of the trend-affected stations were adjusted on the basis of time alone. Trend-adjusted peaks were determined for each year by (1) fitting a curve through the actual annual values by use of a LOWESS, or Locally-Weighted Scatterplot Smoothing, algorithm (Helsel and Hirsch, 1992), (2) computing the differences between the actual peaks and the corresponding values from the curve, and (3) subtracting the difference for each year from the 2004 value from the smoothed curve. The adjusted values were then subjected to the standard Bulletin 17B flood-frequency analysis to obtain de-trended estimates of flood frequencies and magnitudes for the trend-affected stations.

An example scatterplot that illustrates the treatment of trends for station 01484500 is shown in figure 5. The original annual time series of peak-flow values are shown as open circles. A solid line is fit through the data by use of the LOWESS algorithm. The trend-adjusted peaks are shown as black squares, with a dashed baseline equal to the 2004 value from the smoothed trend curve.

Information for stations that were affected by trends is provided in table 2. For the 11 stations that were treated for trends, table 2 provides the 2- through 500-year flood-frequency estimates, means, standard deviations, and skew values of the logarithms of the annual peak flows before and after the time series for the stations were treated for trends. In addition, the table provides the change per year for the last 10 years of the trend, in cubic feet per second and in percent, the base discharge used in the analysis, and the percentage change in housing density during the period of record at the station or from 1960 to the end of record for stations with record that precedes 1960. The base discharge is the 2004 value from the smoothed curve through the annual peak-flow values for all stations except station 01488500, where record ended in 2002. The change-per-year values were determined by fitting a regression line through the last 10 values of the time series. These values are useful for evaluating the future reliability of the flood-frequency estimates for the trend-adjusted stations. The time series for 7 of the 18 stations with trends were not adjusted for various reasons. A description of how the seven stations that were not adjusted for trends were treated is also provided in table 2. Asterisks in front of the period-of-record housing density change percentages for 8 of the 18 stations indicate that the relation between the unadjusted annual peak flows and housing density is statistically significant at the 95-percent probability (p-value <= 0.05) for those stations.

In all 11 cases where the time series were adjusted for trends, the adjustments resulted in larger means and smaller standard deviations of the logarithms of the annual-peak flows. The skews were smaller in absolute value for 4 of the

**Table 2.** Description of treatment of stations with annual peak-flow time series that were affected by trends.

[Recurrence intervals, changes per year, and base discharges are in cubic feet per second; station statistics are in logarithms, base 10; std. dev. is standard deviation; base discharge is trend line value for 2004 except 01488500, which is value for 2002; POR HD change is period-of-record housing density change, in percent; * development-related trend]

| Station number | Scenario | Recurrence interval | | | | | | | | Station statistics | | | Change per year | Percent per year | Base dis-charge | POR HD change |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 5 | 10 | 25 | 50 | 100 | 200 | 500 | Mean | Std. dev. | Skew | | | | |
| **Stations for which trends were adjusted before use in the regression analysis** | | | | | | | | | | | | | | | | |
| 01467317 | Initial | 69 | 147 | 217 | 327 | 425 | 537 | 665 | 859 | 1.836 | 0.393 | -0.193 | | | | |
| | Adjusted | 210 | 259 | 294 | 342 | 379 | 419 | 460 | 520 | 2.329 | 0.115 | 0.115 | 8.67 | 4.09 | 212 | *6.5 |
| 01473169 | Initial | 1,230 | 1,930 | 2,510 | 3,360 | 4,100 | 4,930 | 5,870 | 7,310 | 3.115 | 0.240 | 0.803 | | | | |
| | Adjusted | 2,040 | 2,620 | 3,050 | 3,650 | 4,150 | 4,680 | 5,260 | 6,110 | 3.317 | 0.165 | 0.504 | 73.9 | 3.56 | 2,078 | 69.7 |
| 01475000 | Initial | 114 | 220 | 331 | 537 | 755 | 1,050 | 1,430 | 2,140 | 2.090 | 0.282 | 0.423 | | | | |
| | Adjusted | 211 | 291 | 353 | 444 | 521 | 607 | 703 | 848 | 2.347 | 0.164 | 1.044 | 7.49 | 3.64 | 206 | 619 |
| 01477800 | Initial | 1,590 | 2,710 | 3,670 | 5,160 | 6,510 | 8,070 | 9,890 | 12,800 | 3.220 | 0.261 | 0.533 | | | | |
| | Adjusted | 2,440 | 3,480 | 4,320 | 5,560 | 6,650 | 7,880 | 9,280 | 11,400 | 3.402 | 0.182 | 0.618 | 37.6 | 1.56 | 2,397 | 36.4 |
| 01478500 | Initial | 3,450 | 5,720 | 7,550 | 10,200 | 12,500 | 15,100 | 18,000 | 22,200 | 3.523 | 0.278 | -0.583 | | | | |
| | Adjusted | 4,830 | 6,710 | 8,190 | 10,400 | 12,200 | 14,300 | 16,600 | 20,100 | 3.655 | 0.246 | -1.820 | 17.9 | 0.38 | 4,757 | *227 |
| 01484500 | Initial | 70 | 115 | 151 | 207 | 256 | 312 | 375 | 472 | 1.862 | 0.242 | 0.465 | | | | |
| | Adjusted | 120 | 160 | 190 | 231 | 264 | 299 | 338 | 393 | 2.093 | 0.140 | 0.722 | 2.54 | 2.12 | 120 | *290 |
| 01485000 | Initial | 711 | 1,020 | 1,270 | 1,640 | 1,970 | 2,330 | 2,740 | 3,370 | 2.869 | 0.193 | 0.399 | | | | |
| | Adjusted | 832 | 1,130 | 1,360 | 1,700 | 1,980 | 2,300 | 2,650 | 3,180 | 2.935 | 0.163 | 0.510 | 3.32 | 0.40 | 831 | *200 |
| 01485500 | Initial | 584 | 966 | 1,250 | 1,640 | 1,960 | 2,290 | 2,640 | 3,130 | 2.763 | 0.262 | -0.166 | | | | |
| | Adjusted | 827 | 1,180 | 1,430 | 1,770 | 2,040 | 2,330 | 2,640 | 3,070 | 2.925 | 0.176 | 0.274 | 11.3 | 1.38 | 818 | *340 |
| 01487000 | Initial | 630 | 1,100 | 1,500 | 2,100 | 2,630 | 3,240 | 3,930 | 4,990 | 2.811 | 0.278 | 0.269 | | | | |
| | Adjusted | 1,000 | 1,440 | 1,780 | 2,290 | 2,720 | 3,200 | 3,740 | 4,550 | 3.019 | 0.177 | 0.802 | 21.4 | 2.17 | 989 | 120 |
| 01488500 | Initial | 1,040 | 1,940 | 2,630 | 3,560 | 4,290 | 5,050 | 5,820 | 6,880 | 2.992 | 0.334 | -0.555 | | | | |
| | Adjusted | 2,160 | 2,830 | 3,260 | 3,780 | 4,160 | 4,540 | 4,900 | 5,390 | 3.330 | 0.135 | -0.251 | 38.7 | 1.82 | 2,131 | *100 |
| 01493000 | Initial | 334 | 627 | 878 | 1,260 | 1,600 | 1,990 | 2,440 | 3,110 | 2.529 | 0.320 | 0.076 | | | | |
| | Adjusted | 622 | 879 | 1,080 | 1,390 | 1,650 | 1,940 | 2,280 | 2,790 | 2.805 | 0.189 | -0.007 | 18.3 | 2.93 | 625 | 230 |
| **Stations with trends that were not used in the regression analysis and reasons for not using them** | | | | | | | | | | | | | | | | |
| 01467089 | Combined with upstream station 01467087; 1966-80 peaks at station 01467087 estimated based on flow per unit area at station 01467089. | | | | | | | | | | | | | | | 1.6 |
| 01467160 | No record since 1988 to indicate if trend adjustment is still appropriate. | | | | | | | | | | | | | | | 609 |
| 01482310 | Development-related trend with no record since 1975 to indicate if trend adjustment is still appropriate. | | | | | | | | | | | | | | | 97.0 |
| 01484270 | Large break in record results in uncertainty in appropriateness of trend adjustment. | | | | | | | | | | | | | | | *345 |
| 01484550 | Development-related trend with no record since 1975 to indicate if trend adjustment is still appropriate. | | | | | | | | | | | | | | | *35.0 |
| 01489000 | No record since 1991 to indicate if trend adjustment is still appropriate. | | | | | | | | | | | | | | | 100 |
| 01579000 | Large break in record and no record since 1999 to indicate if trend adjustment is still appropriate. | | | | | | | | | | | | | | | 113 |

11 stations after adjustment. The trend-adjusted flood-frequency estimates were all higher in discharge for recurrence intervals of 2 years or less and lower in discharge for the 200- and 500-year recurrence intervals than the non-trend-adjusted estimates. Trend-adjusted flood-frequency estimates for recurrence intervals between 5 and 100 years were sometimes lower and sometimes higher in discharge than those for the non-trend-adjusted estimates.

Housing density increased from 1960 to 2000 for all 116 stations considered for use in this study except for 2 stations, where housing density was constant. The average increase in housing density, over the period of record for the stations or between 1960 and the end of the period of record for stations with record prior to 1960, was 121 percent. The maximum increase was 619 percent at station 01475000, and the standard deviation was 130 percent. Interestingly, the relation between the unadjusted annual peak flows and housing density was not statistically significant at station 01475000, but the relation was statistically significant at station 01467317, which had an increase in housing density of only 6.5 percent.

Several other investigators have hypothesized a strong relation between the magnitude of peak flows and the degree of urbanization (for example, Beighley and Moglen, 2003; National Resources Conservation Service, 1986; and Sauer and others, 1983), so it is somewhat surprising that only 17 of the 116 stations considered for use in this study had statistically significant trends in annual peak flows, and that only 8 of those trends could be attributed to urbanization. Numerous other USGS peak-flow studies have found similarly small numbers of stations with trends in annual peak-flow time series, however. For instance, recent flood-frequency studies for Illinois (Soong and others, 2004), Ohio (Koltun, 2003), Vermont (Olson, 2002), and West Virginia (Wiley and others, 2000) found 50 of 288 stations, 34 of 305 stations, 0 of 138 stations, and 10 of 160 stations affected by positive trends, respectively. Although the other studies did not compare the annual peak-flow time series to annual time series of housing density or other indicators of development, the generally very small percentage of stations with trends may indicate that either better methods are needed to detect trends that are actually present or the relation between the magnitude of peak flows and the degree of urbanization needs further investigation.

## Regional Skew Analysis

As mentioned previously, the skew coefficient describes the curvature of the peak-flow frequency curve used to describe the annual peak-flow series from a streamgaging station. The value of skew is highly influenced by large events, and the addition of a single large value to the annual peak-flow time series for a station with a short record length can have a large influence on the skew. Also, a localized large event can have a large influence on the skew for an individual station. This causes large variations in skew between stations. Because of this, it is advantageous to improve the accuracy of the skew coefficient for any station by considering not only data from that station, but also information from other nearby stations. For the purpose of discussion, the station skew is defined as the skew calculated using the annual peak-flow series from that station alone. The generalized skew is defined as a skew coefficient associated with a defined region, calculated using the station skews from all stations in the region. A weighted skew, calculated using the station skew and a generalized skew, is used to calculate the flood-frequency statistics used in regression analyses to produce the peak-flow estimation equations for ungaged sites presented in this report.

The calculations of the station skew and the weighted skew are performed using the peak-flow series for an individual station and the equations and methods given in Bulletin 17B. Generalized skew can also be obtained from a national map of generalized-skew values included in Bulletin 17B; however, that map was prepared at a national scale using data and methods that are now more than 30 years old. It is generally preferable for regional studies of flood frequency to include a regional analysis of station skews to either confirm the reasonableness of using the Bulletin 17B skew map or to generate more accurate generalized-skew values using the latest available station skews (Interagency Advisory Committee on Water Data, 1982, Plate 1). Bulletin 17B provides the following recommendations with regard to the data and methods to be used for a generalized-skew analysis:

1. Data from at least 40 stations, or all stations within a 100-mi radius of the study region should be used in the analysis;

2. Each station providing data for the analysis should have at least 25 years of peak-flow record;

3. The recognized analytical methods for calculating generalized skew, in order of preference, are (a) development of skew isolines, (b) development of skew prediction equations, and (c) calculation of the mean station-skew value.

A generalized-skew analysis using these guidelines was performed as part of the study. The steps followed, as well as the results, are discussed below.

From the dataset of 116 stations considered for use in this flood-frequency study, 53 of them had 25 or more years of peak-flow record and were suitable for use in the initial skew analysis. Graphical analysis indicated that the station-skew data associated with these sites is unbiased and approximately normally distributed.

The station skews for the 53 stations were plotted on a map (fig. 6), which was visually inspected for spatial patterns in the skew values. To create the map, the stations were separated into six bins based on the magnitude of the skew value. The three bins with the smallest skew values were shown on the map with circular symbols in shades of red, with the size of the circle and the intensity of the color increasing as the skew value decreased. The three bins with the largest skew values were shown on the map with circular symbols

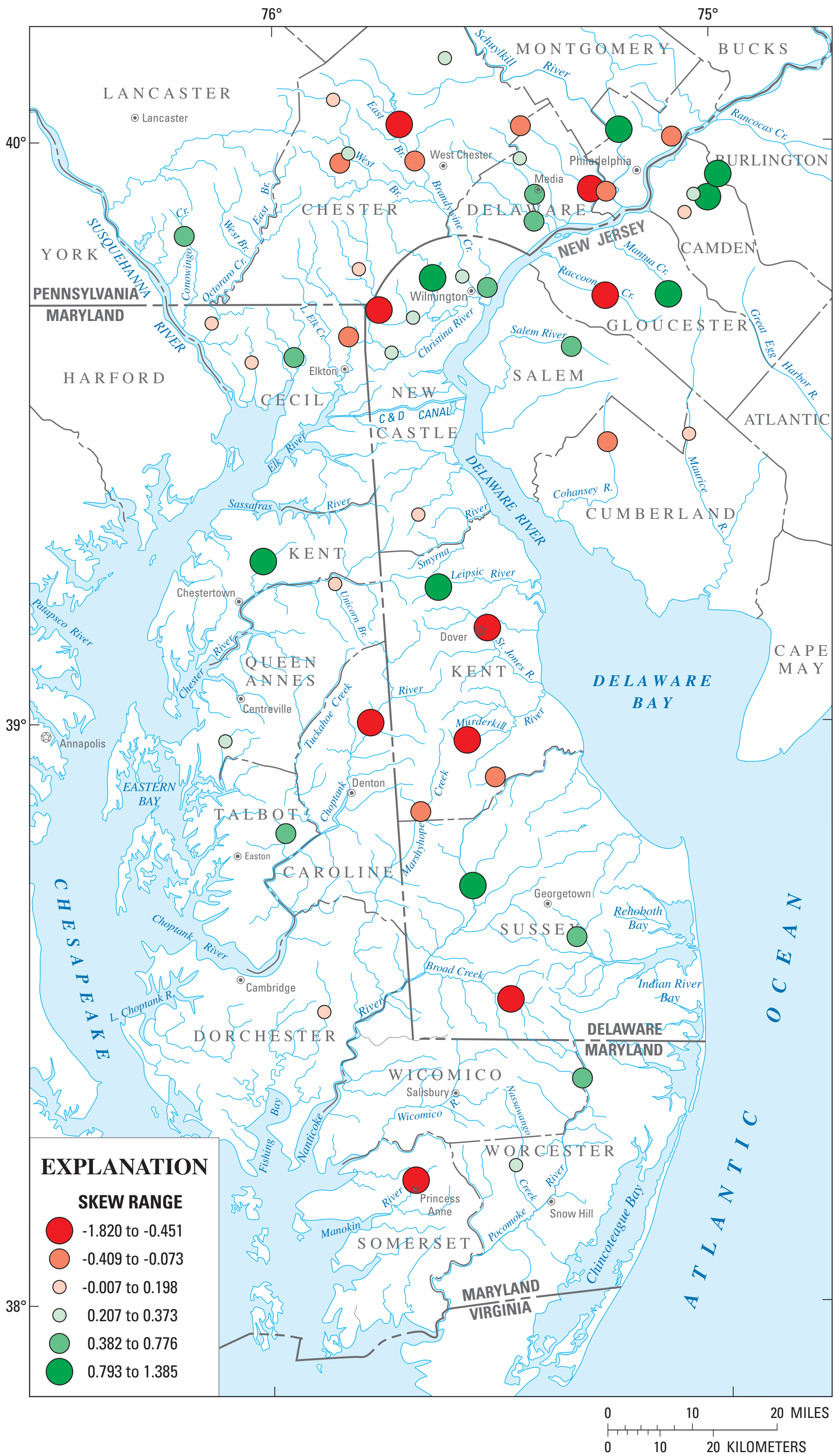


**Figure 6.** Skew ranges for streamgaging stations in Delaware and surrounding states with 25 or more years of record.

in shades of green, with the size of the circle and the intensity of the color increasing as the skew value increased. As a result, the more extreme values of skew, in either direction, had larger, darker circles, and appeared more prominently on the map. An examination of the map indicated that the skew values in the northern part of the study area were, on average, higher than the values in the southern part of the study area. The variation between sites was too large to allow the development of meaningful skew isolines, however. Consequently, an attempt was then made to develop prediction equations for station skew.

Weighted least-squares (WLS) regressions were performed using station skew as the response variable. All available basin-characteristic and climatic variables (Peter Steeves, USGS, written commun., 2005) were tested as explanatory variables. The weighting scheme used in the WLS analysis was the one proposed by Stedinger and Tasker (1986). The explanatory variables found to have the strongest linear relations with station skew were storage and development intensity; however, the coefficients of determination ($R^2$) for both relations were less than 0.03, indicating that each relation explained less than 3 percent of the variation in station skew. No relations were statistically significant at the 95-percent confidence level, the level generally considered to be the minimum acceptable for statistical estimation. Neither of the identified relations predicted the value of station skew with enough accuracy to be useful in calculating the generalized skew.

When isolines and regression equations do not prove useful as means of developing generalized skews, as was the case for this study, Bulletin 17B recommends determining the generalized skew by computing the mean and variance of the station skews for all stations in the region having 25 or more years of record. As resources were not available to attempt more sophisticated techniques, the Bulletin 17B recommendations were followed. The mean and variance of the station skews for 53 stations in the study region were determined to obtain initial generalized skew and variance values for Delaware of 0.156 and 0.327, respectively.

Previous studies performed in this region have found that physiography was a significant factor in estimating flood frequency, so this issue was considered in the regional skew analysis as well. The dataset was split initially by physiographic province to determine whether physiography was a significant factor in determining station skew. Of the 53 sites used, 27 were in the Coastal Plain subset and 26 were in the Piedmont subset. The mean and variance of the station skews for the Piedmont were 0.107 and 0.348, whereas the mean and variance for the Coastal Plain were 0.204 and 0.314, respectively. The means of the Coastal Plain and Piedmont station-skew subsets were each compared to the mean station skew for the entire data set using t-tests. The means of the two subsets were also compared to each other directly. Results from all comparisons indicate that neither subset has a mean that is significantly different from the whole dataset, nor were the two subsets significantly different from each other at the 95-percent confidence level.

A further test was done to determine if use of separate mean skews for each region would result in improved accuracy of the generalized-skew estimates over use of a single mean skew value for the entire study area. Variances were computed for each region using the mean skew value determined from all 53 stations rather than using the regional means, as described above. The resulting variances were 0.350 for the Piedmont and 0.317 for the Coastal Plain. Because the variances determined using the regional means are lower than those determined using the mean skew of all 53 sites, the accuracy of the generalized-skew estimate will be greater if the estimate is made based on the physiographic subsets. Therefore, generalized-skew values used in the flood-frequency analyses done for this study were based on the mean skews for each physiographic region, 0.107 for the Piedmont and 0.204 for the Coastal Plain.

## Regional Flood-Frequency Relations

Regression analysis was used to develop separate sets of equations for use in estimating the magnitude and frequency of floods for unregulated, ungaged sites in two hydrologic regions of Delaware. The hydrologic regions correspond to the Coastal Plain and Piedmont physiographic regions, as discussed below. The equations statistically relate the 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year floods computed from available records for data-collection stations (streamgaging and peak-flow partial-record stations) in each of the regions to measured physical and climatic characteristics of the drainage basins for the stations. A database for the regional analysis was developed using active and discontinued streamgaging stations, and populated with flood-frequency estimates for selected recurrence intervals for the streamgaging stations and the hydrologic characteristics of the basins upstream from each station. The total number of stations included in the regression analyses by hydrologic region and state, and the number of stations with 25 years or more of record for each grouping are shown in table 3. The number of stations and the average years of record for given ranges of drainage area, by hydrologic region and for all stations, are listed in table 4.

### Explanatory Variable Selection and Measurement

Basin characteristics were selected for use as potential explanatory variables in the regression analyses on the basis of their theoretical relation to flood flows, results of previous studies in similar hydrologic regions, and the ability to measure the basin characteristics using digital datasets and GIS technology. The ability to measure the basin characteristics by use of a GIS was important to facilitate eventual automation of the process for measuring the basin characteristics and solving the regression equations for ungaged sites. The automation

**Table 3.** Number of streamgaging stations included in the regression analyses by hydrologic region and state.

[POR, period of record; >=, greater than or equal to; DE, Delaware; MD, Maryland; NJ, New Jersey; PA, Pennsylvania]

| Region | | State | | | | |
|---|---|---|---|---|---|---|
| | | DE | MD | NJ | PA | Total |
| Coastal Plain | | | | | | |
| | Total stations | 20 | 15 | 20 | 0 | 55 |
| | POR >= 25 | 9 | 9 | 9 | 0 | 27 |
| Piedmont | | | | | | |
| | Total stations | 13 | 7 | 0 | 27 | 47 |
| | POR >= 25 | 6 | 4 | 0 | 16 | 26 |
| All | | | | | | |
| | Total stations | 33 | 22 | 20 | 27 | 102 |
| | POR >= 25 | 15 | 13 | 9 | 16 | 53 |

**Table 4.** Summary of drainage area, number of streamgaging stations, and average years of record used in the regression analyses for Delaware.

[--, not applicable]

| Drainage area (square miles) | Number of streamgaging stations | | | Average years of observed record | | |
|---|---|---|---|---|---|---|
| | Coastal Plain | Piedmont | Total | Coastal Plain | Piedmont | Total |
| 0 - 1 | 3 | 2 | 5 | 20.3 | 10.0 | 16.2 |
| 1 - 2 | 2 | 4 | 6 | 25.0 | 11.5 | 16.0 |
| 2 - 5 | 12 | 3 | 15 | 24.1 | 22.7 | 23.8 |
| 5 - 10 | 13 | 8 | 21 | 27.4 | 27.6 | 27.5 |
| 10 - 20 | 14 | 4 | 18 | 29.2 | 31.5 | 29.7 |
| 20 - 50 | 6 | 15 | 21 | 40.0 | 31.1 | 33.6 |
| 50 - 10 | 3 | 9 | 12 | 44.0 | 45.7 | 45.3 |
| 100 - 200 | 2 | 1 | 3 | 64.5 | 44.0 | 57.7 |
| 200 - 500 | 0 | 1 | 1 | -- | 93.0 | 93.0 |
| Total | 55 | 47 | 102 | 30.3 | 31.8 | 31.0 |

process is described later in the StreamStats section. The name, units of measure, method of measurement, and source data for each measured basin characteristic are listed in table 5. The climatic and basin characteristics measured for each station considered for use in the regression analyses are listed in tables 6 and 7, respectively, at the back of the report.

Drainage-basin boundaries were needed for each station before their basin characteristics could be measured. A GIS and a Digital Elevation Model (DEM) can be used to measure basin boundaries; however, boundaries determined from DEMs can sometimes be inaccurate, especially in low-lying coastal areas, such as those in much of Delaware. To improve boundary delineations and to facilitate implementation of the StreamStats web application (discussed on page 35) for areas in or that drain into Delaware, processing was done to make the 10-meter resolution National Elevation Dataset (NED) (U.S. Geological Survey, 1999a) DEM conform to the streams in the National Hydrography Dataset (NHD) (U.S. Geological

**Table 5.** Basin characteristics considered for use in the regression analyses.

| Name | Units | Method | Source data |
|---|---|---|---|
| 24-hour, 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year maximum precipitation | Inches | Area average | U.S. National Oceanographic and Atmospheric Administration Atlas 14, Volume 2 (http://hdsc.nws.noaa.gov/hdsc/pfds/index.html) |
| Average soil permeability | Inches per hour | Area average of maximum and minimum values of permeability of the surface soil layer | State Soil Geographic (STATSGO) Data (http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/) |
| Basin relief | Feet | Maximum - minimum basin elevation | National Elevation Dataset elevation grid, 10- and 30-meter resolution (http://ned.usgs.gov/) |
| Basin shape factor | Dimension-less | Main channel length squared divided by drainage area | National Hydrography Dataset, 1:24,000 scale (http://nhd.usgs.gov/), and National Elevation Dataset, 10- and 30-meter resolution (http://ned.usgs.gov/) |
| Development intensity | Percent | ((.10*A21+.25*A22+.65*A23+.90*A24)/ drainage area)*100, where A21 through A24 are land-use classes defined at http://www.mrlc.gov/nlcd_definitions.asp | National Land-Cover Dataset 2001 (http://www.mrlc.gov/mrlc2k_nlcd.asp) and Delaware Land-Use Cover 2003 (http://datamil.delaware.gov) |
| Drainage area | Square miles | ArcHydro method | National Elevation Dataset elevation grid, conditioned to conform with National Hydrography Dataset streams, 1:24,000 scale (http://nhd.usgs.gov/), and Watershed Boundary Dataset drainage boundaries (http://www.ncgc.nrcs.usda.gov/products/datasets/watershed/) |
| Station elevation | Feet | Point elevation from grid at the streamgaging station | National Elevation Dataset elevation grid, 30-meter resolution (http://ned.usgs.gov/) |
| Housing density | Homes per acre | Area average for centroid year of record | Derived from Theobald, 2001 |
| Hydrologic soil type A | Percent | (Area of type A soil/drainage area)*100; type A is high infiltration-rate soils | State Soil Geographic (STATSGO) Data (http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/index.html) |
| Hydrologic soil type D | Percent | (Area of type D soil/drainage area)*100; type D is very slow infiltration-rate soils | State Soil Geographic (STATSGO) Data (http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/index.html) |
| Main channel length | Miles | ArcHydro method using longest flow path extended to basin divide | National Hydrography Dataset, 1:24,000 scale (http://nhd.usgs.gov/) |
| Mean annual precipitation | Inches | Area average | DAYMET (http://www.daymet.org/) |
| Mean basin elevation | Feet | Area average | National Elevation Dataset, 10-meter resolution (http://ned.usgs.gov/) |
| Mean basin slope | Percent | Mean of slope grid values within the drainage area | National Elevation Dataset slope grid, 10-meter resolution (http://ned.usgs.gov/) |

**Table 5.** Basin characteristics considered for use in the regression analyses.—Continued

| Name | Units | Method | Source data |
|---|---|---|---|
| Mean stream slope | Feet per mile | ArcHydro method for computing the mean of the slope grid values for all cells that intersect the stream channel from the site to the basin divide | National Hydrography Dataset, 1:24,000 scale (http://nhd.usgs.gov/), and National Elevation Dataset slope grid, 10- and 30-meter resolution (http://ned.usgs.gov/) |
| Percent developed | Percent | (Sum of areas of classes A21-A24/drainage area)*100, where land-use classes are defined at http://www.mrlc.gov/nlcd_definitions.asp | National Land-Cover Dataset 2001 (http://www.mrlc.gov/mrlc2k_nlcd.asp) and Delaware Land-Use Cover 2003 (http://datamil.delaware.gov) |
| Percent forest | Percent | (Sum of areas of classes A42-A43, A92, A93/drainage area)*100, where land-use classes are defined at http://www.mrlc.gov/nlcd_definitions.asp | National Land-Cover Dataset 2001 (http://www.mrlc.gov/mrlc2k_nlcd.asp) and Delaware Land-Use Cover 2003 (http://datamil.delaware.gov) |
| Percent impervious | Percent | (Impervious area/drainage area)*100 | National Land-Cover Dataset 2001 Imperviousness (http://www.mrlc.gov/mrlc2k_nlcd.asp) |
| Percent storage NHD | Percent | (Sum of areas of wetlands and open water/drainage area)*100 | National Hydrography Dataset, 1:24,000 scale (http://nhd.usgs.gov/) |
| Percent storage NLCD/DE | Percent | (Sum of areas of classes A10, A91-A99/drainage area)*100, where land-use classes are defined at http://www.mrlc.gov/nlcd_definitions.asp | National Land-Cover Dataset 2001 (http://www.mrlc.gov/mrlc2k_nlcd.asp) and Delaware Land-Use Cover 2003 (http://datamil.delaware.gov) |
| Stream slope, 10/85 method | Feet per mile | ArcHydro method of computing stream slope from points 10- and 85-percent of the distance from the site to the basin divide | National Hydrography Dataset, 1:24,000 scale (http://nhd.usgs.gov/), and National Elevation Dataset elevation grid, 10- and 30-meter resolution (http://ned.usgs.gov/) |

Survey, 1999b) and to watershed boundaries in the Watershed Boundary Dataset (WBD) (Natural Resources Conservation Service, 2004). This process was developed by Peter Steeves (2002), and was done using the ArcHydro Tools (Environmental Systems Research Institute, Inc., 2005). The resulting conditioned DEM was used only for basin-boundary delineations. The original DEM was used to measure all other basin characteristics for the study that required elevation information.

As a means of quality assurance, the drainage areas computed by use of the GIS and the conditioned DEM were compared to the previously published drainage areas for the stations and to Digital Raster Graphics (DRG) scanned images of USGS topographic maps for the area of interest (U.S. Geological Survey, 2005). The measured and published drainage areas agreed closely for most stations, but several differences of greater than 5 percent were found. In most of these cases, the published drainage areas were determined from older topographic maps with 10-ft contour intervals, whereas the conditioned 10-m (meter) NED from which the boundaries were determined using a GIS was derived from newer topographic maps with 5-ft contours. In all cases, the boundaries determined from the GIS were considered superior in accuracy to the previously published figures. The drainage areas shown in table 7 are those determined for this study by use of the GIS. Asterisks appear in table 7 beside the drainage areas for several stations. The official drainage areas for these stations have been revised to agree with the GIS measurements.

For stations with drainage areas that were entirely outside of Delaware, the 30-m resolution NED was used to determine elevation-dependent basin characteristics. Digital drainage boundaries for these stations were determined by USGS personnel from the offices for the states where the stations were located, and provided for use in this study.

Four basin characteristics were measured for this study as possible indicators of urbanization: (1) housing density, (2) percent developed, (3) development intensity, and (4) percent imperviousness. The methods and source data used to measure these characteristics are presented in table 5. As mentioned above, annual series of housing density were determined for each station by interpolation from GIS coverages of housing density for 1960, 1970, 1980, 1990, and 2000 (Theobald, 2001). In addition, housing density was computed for the centroids of the periods of record for each station from the annual values. A few stations had centroids of their periods of record that were before 1960. The 1960 values were used for those stations.

Development intensity is a surrogate measurement of the percentage of impervious surfaces in a basin that is derived from the NLCD land-cover dataset rather than from the NLCD impervious-cover dataset. Development intensity was computed by multiplying the area of each NLCD land-cover class for developed land (classes 21-24 at http://www.mrlc.gov/nlcd_definitions.asp) within a basin by the average proportion of impervious surfaces attributed to the class by Bird and others (2002), summing these amounts, dividing the sum by the drainage area, and then multiplying the result by 100 to obtain percentages.

The ArcHydro Tools were used to measure main channel lengths and slopes. The ArcHydro Tools method for measuring main channel length uses the longest flow path from the NHD stream network, and then extends the flow path from the upstream end of the NHD stream to the highest elevation that contributes drainage to the main channel. Two methods were used to measure main channel slope. One method determines the distances for points at 10 and 85 percent of the distance along the main channel from the NHD and the corresponding elevations from the DEM, and then divides the difference in elevation between the two points by 0.75 times the main channel length. This is the ArcHydro Tools implementation of the traditional channel slope method recommended by the Interagency Advisory Committee on Water Data (1977), often referred to as the 10/85 method.

The other method for measuring main channel slope takes the average value of slopes computed for each grid cell in the DEM that has spatial correspondence with the NHD main stream channel. This new method in the ArcHydro Tools should be a more accurate measure of main channel slope than the method recommended by the Interagency Advisory Committee on Water Data (1977) because the slope is determined from an average of the elevations along the stream rather than from only two points along the stream channel. On average, 926 elevations were used to determine main channel slope for the stations used in this study.

The two methods for measuring main channel slope gave results that were highly correlated. A graph of the relation between the results of the two slope-measurement methods, with a regression line fit through the data is shown in figure 7. The $R^2$ value for the relation is 0.938. The exponent of the 10/85 slope (the x variable) in the equation in

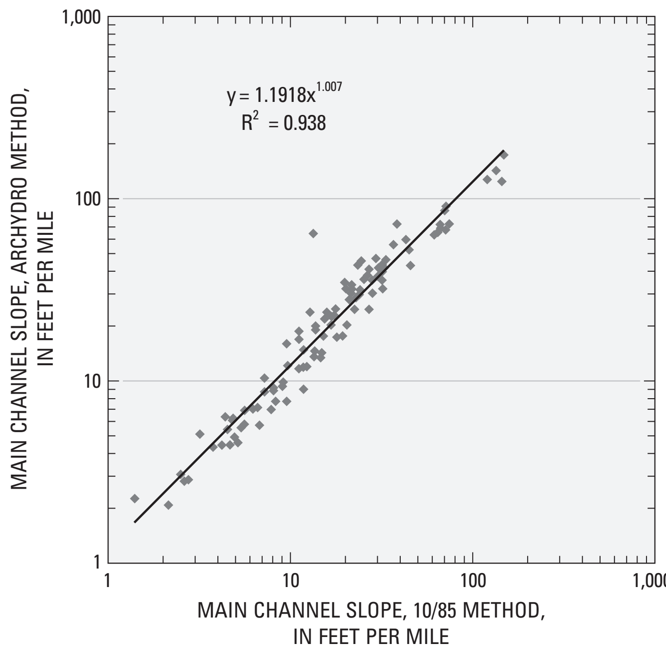


**Figure 7.** Relation between the new ArcHydro and the traditional 10/85 method for measuring main channel slope for stations used in the regression analysis.

figure 7 is nearly one, thus the ArcHydro slope can be reasonably approximated from the 10/85 slope by adding 19 percent to the 10/85 slope value. Tests in other areas would be needed to determine if this relation between the two methods is consistent everywhere. Overall, however, this relation indicates that the traditional 10/85 slope method yields results for most stations in and around Delaware that are very similar to those obtained from the much more data-intensive ArcHydro method.

The land-use variables development intensity, percent developed, percent forest, and percent storage were measured using a dataset that combined the 2001 NLCD in areas outside of Delaware and a land-use dataset that was developed for Delaware from 2002 aerial photography. Metadata for the Delaware land-use dataset is available online at http://maps.udel.edu/metadata/full_metadata.jsp?docId=%7BDEA492B3-17AA-4AD3-957F-3CA3F384A0AF%7D&loggedIn=false.

For comparative purposes, percent storage was also measured using the NHD. Differences between percent storage measured from the combined land-use dataset (NLCD.DELU) and from the NHD were substantial. Percent storage determined from the NHD reflects all areas of lakes, ponds, reservoirs, wide rivers, and wetlands, as shown on USGS 1:24,000-scale topographic maps. Percent storage determined from the NLCD.DELU dataset reflects all areas of open water and wetland land-use categories. Except for one station, stor-

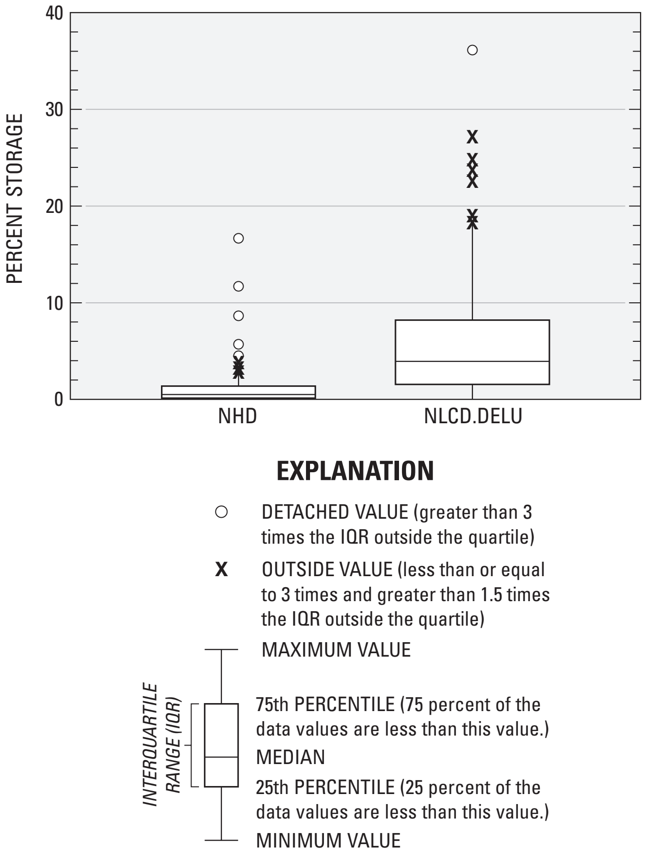


**Figure 8.** Percent storage measured using the National Hydrography Dataset (NHD) and a combination of the 2001 National Land Cover Dataset (NLCD) and the 2002 Delaware Land-Use Dataset (DELU).

age values determined from NLCD.DELU were larger than those from the NHD.

Boxplots of the two storage measurements are shown in figure 8. The boxplots show how the data are distributed (Tukey, 1977). The horizontal line inside the box shows the location of the median value. The top and bottom of the box indicate the quartiles, which are the values that are exceeded 75 and 25 percent of the time. The vertical lines extending upward and downward from the box are known as the whiskers. They encompass all values that are within 1.5 times the length of the box (1.5 times the interquartile range). Values that are within the upper and lower whiskers are indicated in the explanation as within the upper and lower adjacent regions of the boxplots, respectively. Values that are outside the whiskers are shown individually. Values shown with an “x” in the boxplot are referred to as outside values. These values are within 3 times the interquartile range in either direction from the median. The values shown with an “o” in the boxplot are referred to as detached values. These values are more than 3 times the interquartile range in either direction from the median. The boxplots show that the 75$^{th}$ percentile of the NHD values is approximately equal to the 25$^{th}$ percentile of the NLCD.DELU values.

Percent storage values from the NLCD.DELU were much more highly correlated with flood frequencies than the values from the NHD, indicating that NLCD.DELU storage is a better individual predictor of flood frequencies than NHD storage. As discussed in the next section, however, when used in conjunction with other explanatory variables, the inclusion of NHD storage provided regression equations with the greater accuracy in predicting flood magnitudes of specified frequency. Correlation coefficients between the logarithms of NLCD.DELU values and the logarithms of the T-year floods ranged from -0.338 for the 2-year flood to -0.396 for the 500-year flood. Correlation coefficients for the NHD values ranged from 0.003 for the 10-year flood to -0.039 for the 500-year flood.

Much of the land area of southern Delaware has been ditched to provide drainage for agriculture. One issue of concern for DelDOT was that the NHD representation of streams would inadequately capture the ditches that are actually present on the landscape, and there would be errors in drainage boundaries and basin characteristics determined for some selected streams because of this. Consequently, a GIS was used to compare the NHD streams to county-mapped ditches, and to determine if incorporation of the ditches into the NHD would be necessary. The comparison indicated that the NHD incorporated the great majority of the ditches. Some areas had ditches that were not included in the NHD, and drainage boundaries determined for these areas could be in error. In general, however, the affected areas are small (less than 1 $mi^2$). It was determined that adding all missing ditches into the NHD would be too large a task for inclusion in this study, and it would generally provide little benefit.

## Development of Regression Equations

Regression equations were developed for use in estimating peak flows associated with the 2- through 500-year recurrence intervals at both ungaged and gaged locations for the two hydrologic regions in Delaware. All response (T-year peak flows) and explanatory variables (basin characteristics) were transformed to logarithms, base 10, prior to the regression analyses to obtain linear relations between the response variables and the explanatory variables, and to achieve equal variance about the regression line. A one (1) was added to all basin characteristics given as percentages to facilitate transformation to logarithms.

Equation development was done in three phases. The first phase used weighted all-possible-subsets (APS) regression methods to identify possible optimal combinations of explanatory variables. The second phase used WLS regression to test the adequacy of candidate explanatory variable subsets for violations of regression analysis assumptions and to determine if separate sets of equations were needed for each physiographic region. The third phase used Estimated-Generalized-Least-Squares (EGLS) regression methods to determine the final regression equations.

In APS regression (Neter and others, 1985, p. 421-429), all possible combinations of explanatory variables were tested to identify a small set of possible best combinations of explanatory variables for further testing with WLS regression methods. Weighting was applied in the APS regressions to correct for differences in record length by dividing the number of years of systematic data available for each station by the mean record length for all stations. As a result, stations with longer records were given greater weight in the analysis than stations with shorter records. The Mallow's $C_p$ criterion was used for selecting best subset combinations (Neter and others, 1985, p. 426-428).

The WLS analyses were used for detailed testing of candidate models identified through the APS analyses. Weights used in the WLS analyses were the same as those used for the APS analyses. WLS results were examined to identify potential undesirable statistical characteristics, and to select the final combinations of variables to be included in the EGLS analysis. Possible undesirable statistical characteristics that could lead to elimination of a set of candidate explanatory variables included (1) geographic bias of the potential equations, (2) extreme influence of flood-frequency values or high leverage of the basin characteristics for individual stations, (3) high correlation (multicollinearity) among potential explanatory variables, or (4) lack of statistical significance of the explanatory variables at the 95-percent probability level. The WLS analyses indicated that developing separate sets of regression equations for the Coastal Plain and Piedmont hydrologic regions would result in more accurate relations than developing a single set of equations for the entire State.

EGLS was used to determine the final regression equations because the EGLS algorithm is able to assign weights to the stations used in the analysis to adjust not only for differences in record length, as in WLS, but also for cross-correlation of the annual time series on which the peak-flow statistics for the stations are based, and for spatial correlation among the stations (Stedinger and Tasker, 1985). Because the WLS and EGLS weighting schemes were not the same, it was necessary to test several combinations of explanatory variables identified through the APS/WLS process to determine the best EGLS equations for the 2- through 500-year recurrence intervals in each of the two hydrologic regions. The combinations of explanatory variables that met all requirements with regard to leverage, influence, and multicollinearity while also providing the lowest estimation error for each recurrence interval in each region, were selected for inclusion in the final regression equations.

The results of the analyses described above are separate sets of the best regression equations for the Piedmont and Coastal Plain regions, which can be used to estimate peak flows of known accuracy with recurrence intervals between 2 and 500 years for gaged and ungaged streams in Delaware. The final equations were developed for the Piedmont using 47 stations, and for the Coastal Plain using 55 stations. Fourteen sites that were considered for use were excluded from regression equation development—7 with unadjustable trends in their annual peak-flow series, 5 that are in close proximity on the same stream to sites that were included, and 2 that exerted undue leverage on the form of the regression equations caused by basin characteristic values that are atypical of streams in Delaware. The best equations are as follows:

Piedmont region

$$PK2 = 1{,}320 DRNAREA^{0.684}(FOREST+1)^{-0.540}(SOILA+1)^{-0.219}(IMPNLCD01+1)^{0.101} \quad (2)$$

$$PK5 = 3{,}080 DRNAREA^{0.662}(FOREST+1)^{-0.568}(SOILA+1)^{-0.224} \quad (3)$$

$$PK10 = 2{,}190 DRNAREA^{0.674}(FOREST+1)^{-0.447}(STORNHD+1)^{-0.346} \quad (4)$$

$$PK25 = 2{,}580 DRNAREA^{0.675}(FOREST+1)^{-0.391}(STORNHD+1)^{-0.445} \quad (5)$$

$$PK50 = 2{,}840 DRNAREA^{0.679}(FOREST+1)^{-0.353}(STORNHD+1)^{-0.520} \quad (6)$$

$$PK100 = 3{,}090 DRNAREA^{0.684}(FOREST+1)^{-0.316}(STORNHD+1)^{-0.594} \quad (7)$$

$$PK200 = 3{,}310 DRNAREA^{0.689}(FOREST+1)^{-0.282}(STORNHD+1)^{-0.668} \quad (8)$$

$$PK500 = 3{,}600 DRNAREA^{0.698}(FOREST+1)^{-0.239}(STORNHD+1)^{-0.765} \quad (9)$$

Coastal Plain region

$$PK2 = 92.8 DRNAREA^{0.710} BSLDEM10M^{0.303}(SOILA+1)^{-0.301} \quad (10)$$

$$PK5 = 157 DRNAREA^{0.710} BSLDEM10M^{0.292}(SOILA+1)^{-0.310} \quad (11)$$

$$PK10 = 210 DRNAREA^{0.709} BSLDEM10M^{0.289}(SOILA+1)^{-0.316} \quad (12)$$

$$PK25 = 288 DRNAREA^{0.711} BSLDEM10M^{0.292}(SOILA+1)^{-0.323} \quad (13)$$

$$PK50 = 353 DRNAREA^{0.712} BSLDEM10M^{0.297}(SOILA+1)^{-0.328} \quad (14)$$

$$PK100 = 425 DRNAREA^{0.715} BSLDEM10M^{0.303}(SOILA+1)^{-0.332} \quad (15)$$

$$PK200 = 505 DRNAREA^{0.717} BSLDEM10M^{0.310}(SOILA+1)^{-0.337} \quad (16)$$

$$PK500 = 623 DRNAREA^{0.720} BSLDEM10M^{0.320}(SOILA+1)^{-0.344} \quad (17)$$

where

*PK2*, *PK5*,…, *PK500* are the peak discharges for floods with recurrence intervals of 2 years, 5 years,…, 500 years, in $ft^3/s$;

*DRNAREA* is the drainage area, in $mi^2$;

*FOREST* is percent forest;

*IMPNLCD01* is percent impervious determined from the 2001 NLCD impervious dataset;

*STORNHD* is percent storage from NHD, in percent;

*BSLDEM10M* is mean basin slope determined from a 10-m DEM, in percent, and;

*SOILA* is hydrologic soil type A, in percent, high infiltration-rate soils.

The methods and source data used to calculate the variables in equations (2) through (17) are identified in table 5. Discharge estimates calculated by use of the equations are in units of cubic feet per second, but they may be converted to other measurement systems by applying the appropriate conversion factor. Systematic record, regression equation, and weighted estimates of the flood-frequency statistics for each station considered for use in the regression analyses are shown in table 8. The method for determining the weighted estimates is described below.

Normally, allowing the equation for each recurrence interval to contain the best variables for estimating flood discharge for that interval without regard to variables used for other recurrence intervals improves the accuracy of the equations. The drawback to this approach, however, is that equations that contain different variables for successive recurrence intervals may provide estimated discharge magnitudes that do not increase with increasing recurrence interval. The 2-year recurrence interval flood discharge estimate for a particular site may be larger than the 5-year estimate for the same site, for example.

The initial set of best equations developed for each region had explanatory variables that differed among the recurrence intervals. Tests of these equations indicated a high incidence of estimated flood flows that did not increase with increasing recurrence interval. To avoid these irregularities, the housing density explanatory variable that was found significant for the 2-, 5-, and 10-year recurrence intervals for the Coastal Plain was replaced by the mean basin slope explanatory variable for these recurrence intervals to avoid reductions in flow between the 10- and 25-year recurrence intervals when housing density was included in the equations. Dropping of housing density from the Coastal Plain equations lowered the accuracy of the affected equations somewhat, but eliminated irregularities in estimated flows with increasing recurrence intervals.

The percent storage explanatory variable was allowed to remain in the equation for estimating the 10-year peak discharge for the Piedmont, and the percent forest explanatory variable was allowed to remain in the equation for estimating the 500-year peak discharge for the Piedmont region even though their statistical significance in the relations did not meet the standard criterion used for variable selection. These substitutions of variables reduced irregularities in the estimated flows with increasing recurrence intervals, but some irregularities can still occur between flow estimates for the 5- and 10-year recurrence intervals when the percent forest for an ungaged site is less than about 15 percent.

## Accuracy and Limitations

The accuracy of a regression equation depends on the model error and the sampling error. Model error measures the ability of a set of explanatory variables to estimate the values of peak-flow characteristics calculated from the station records used to develop the equation. Sampling error measures the ability of a finite number of stations with a finite number of recorded annual peak flows to describe the true peak-flow characteristics of the entire peak-flow record for a station. Model error depends on the number and predictive power of the explanatory variables in a regression equation. Sampling error depends on the number and record length of stations used in the analysis, and decreases as the number of stations and record lengths increases.

Traditional measures of the accuracy of peak-discharge regression equations are the standard errors of estimate and prediction, and the equivalent years of record. The standard error of estimate is derived from the model error, and is a measure of how well the estimated peak discharges generated using an equation agree with the peak-flow statistics generated from station records that were used to create the equation. Approximately two thirds of the estimates obtained from the equations for the stations used in the regression analysis have errors less than the noted standard errors of estimate. The standard error of prediction is derived from the sum of the model error and the sampling error, and is a measure of how accurately the estimated peak discharges generated using an equation will be able to predict the true value of peak discharge for the selected recurrence interval. Approximately two thirds of the estimates obtained from the equations for ungaged sites will have errors less than than the noted standard errors of prediction. The equivalent years of record is an estimate of the number of years of station record that would be needed at a given ungaged site to produce peak-discharge estimates with an accuracy equal to that of the associated regression equation. The equivalent years of record is derived from a relation between the standard error of estimate and the measure of variability of the observed peak discharges used to develop an equation. Average standard errors of estimate and prediction and equivalent years of record associated with equations (2) through (17) are shown in table 9.

Prediction intervals are another useful indicator of the uncertainty inherent in use of the regression equations when applied to ungaged sites. A prediction interval is given as a minimum and maximum value within which there is a stated probability that the true value of the response variable exists. As an example, the minimum and maximum values given in a 90-percent prediction interval for the 100-year peak for an ungaged site should be interpreted to mean that there is 90-percent confidence that the true value of the 100-year peak is within the prediction interval.

Tasker and Driver (1988) have shown that a 100(1- α) prediction interval for the true value of a streamflow statistic obtained for an ungaged site from a regression equation can be computed by

$$Q/T < Q < TQ \qquad (18)$$

where

Q is the streamflow statistic for the site and T is computed as:

$$T = 10^{\left[t_{(\alpha/2,n-p)}S_i\right]} \qquad (19)$$

In equation (19), $t_{(\alpha\ /2,n-p)}$ is the critical value from the students t-distribution at alpha-level α (α = 0.10 for 90-percent prediction intervals); *n-p* is the degrees of freedom with n stations (*n*=55 for the Coastal Plain and *n*=47 for the Piedmont) used in the regression analysis and *p* parameters in the equation (the number of basin characteristics plus one); and $S_i$ is computed from equation (20) below. Critical values from the students *t*-distribution are contained in many introductory statistics textbooks. Other prediction intervals can be calculated by changing α to obtain the desired percentage.

The value of $S_i$ is computed using the equation

$$S_i = \left[\gamma^2 + x_i U x_i'\right]^{0.5} \qquad (20)$$

where

$\gamma^2$ is the model error variance;

$x_i$ is a row vector of the logarithms of the basin characteristics for site *i*, augmented by a 1 as the first element;

*U* is the covariance matrix for the regression coefficients; and

$x_i'$ is the transpose of $x_i$ (Ludwig and Tasker, 1993).

The values of $t_{(\alpha\ /2,n-p)}$, $\gamma^2$, and *U* needed to determine prediction intervals for estimates obtained from the regression equations are presented in table 10.

The procedure necessary to obtain the estimates is explained below with an example computation of the 50-year peak discharge for a hypothetical ungaged site on the Christina River near Newark, Delaware. First, the necessary basin characteristics for the site are measured from the various GIS data layers. Values for drainage area, percent forest, and percent storage are 8.00 mi$^2$, 30.00 percent, and 0.60 percent, respectively. Substituting these values into equation (6) to predict the 50-year peak discharge yields

$$PK50 = 2{,}840(8.00)^{0.679}(30.00+1)^{-0.353}(0.60+1)^{-0.520} = 2{,}720 \text{ ft}^3/\text{s}.$$

**Table 9.** Average standard errors of estimate and prediction and equivalent years of record for the best regression equations, by hydrologic region in Delaware.

| Recurrence interval (years) | Piedmont | | | Coastal Plain | | |
|---|---|---|---|---|---|---|
| | Average standard errors | | Equivalent years of record (years) | Average standard errors | | Equivalent years of record (years) |
| | Estimate (percent) | Prediction (percent) | | Estimate (percent) | Prediction (percent) | |
| 2 | 26.6 | 28.9 | 4.1 | 64.3 | 67.4 | 0.8 |
| 5 | 26.0 | 28.1 | 6.7 | 57.1 | 60.1 | 1.6 |
| 10 | 27.4 | 29.9 | 8.4 | 55.3 | 58.5 | 2.4 |
| 25 | 28.3 | 31.0 | 11.3 | 55.5 | 59.0 | 3.5 |
| 50 | 29.8 | 32.7 | 12.7 | 57.0 | 60.8 | 4.2 |
| 100 | 31.8 | 35.1 | 13.5 | 59.3 | 63.4 | 4.8 |
| 200 | 34.4 | 38.0 | 13.8 | 62.4 | 66.9 | 5.2 |
| 500 | 38.2 | 48.3 | 13.7 | 67.3 | 72.3 | 5.6 |

**Table 10.** Values needed to determine 90-percent prediction intervals for the best regression equations, by hydrologic region in Delaware.

[t, the critical value from the Student's t distribution used in equation 19; 2, the regression model error variance used in equation 20; U, the covariance matrix used in equation 20]

| Recurrence interval (years) | Piedmont | | | | | | |
|---|---|---|---|---|---|---|---|
| | t | $\gamma^2$ | U | | | | |
| 2 | 1.682 | 0.0129 | 0.032399 | 0.000256 | -0.015862 | -0.008039 | -0.006372 |
| | | | 0.000256 | 0.001094 | -0.000897 | -0.000551 | -0.000209 |
| | | | -0.015862 | -0.000897 | 0.009974 | 0.002040 | 0.002671 |
| | | | -0.008039 | -0.000551 | 0.002040 | 0.007052 | 0.001515 |
| | | | -0.006372 | -0.000209 | 0.002671 | 0.001515 | 0.002657 |
| 5 | 1.681 | 0.0123 | 0.018606 | -0.000293 | -0.010122 | -0.004813 | |
| | | | -0.000293 | 0.001139 | -0.000715 | -0.000458 | |
| | | | -0.010122 | -0.000715 | 0.007731 | 0.000596 | |
| | | | -0.004813 | -0.000458 | 0.000596 | 0.006605 | |
| 10 | 1.681 | 0.0137 | 0.020045 | -0.001710 | -0.013381 | 0.008815 | |
| | | | -0.001710 | 0.001841 | 0.000092 | -0.004745 | |
| | | | -0.013381 | 0.000092 | 0.010790 | -0.008049 | |
| | | | 0.008815 | -0.004745 | -0.008049 | 0.042291 | |
| 25 | 1.681 | 0.0145 | 0.023753 | -0.001963 | -0.015881 | 0.010301 | |
| | | | -0.001963 | 0.002131 | 0.000089 | -0.005454 | |
| | | | -0.015881 | 0.000089 | 0.012815 | -0.009442 | |
| | | | 0.010301 | -0.005454 | -0.009442 | 0.048422 | |
| 50 | 1.681 | 0.0160 | 0.027642 | -0.002241 | -0.018531 | 0.011950 | |
| | | | -0.002241 | 0.002448 | 0.000097 | -0.006257 | |
| | | | -0.018531 | 0.000097 | 0.014957 | -0.010975 | |
| | | | 0.011950 | -0.006257 | -0.010975 | 0.055508 | |
| 100 | 1.681 | 0.0182 | 0.032334 | -0.002587 | -0.021740 | 0.013985 | |
| | | | -0.002587 | 0.002836 | 0.000116 | -0.007254 | |
| | | | -0.021740 | 0.000116 | 0.017545 | -0.012862 | |
| | | | 0.013985 | -0.007254 | -0.012862 | 0.064376 | |
| 200 | 1.681 | 0.0211 | 0.037763 | -0.002997 | -0.025458 | 0.016371 | |
| | | | -0.002997 | 0.003289 | 0.000146 | -0.008428 | |
| | | | -0.025458 | 0.000146 | 0.020538 | -0.015074 | |
| | | | 0.016371 | -0.008428 | -0.015074 | 0.074865 | |
| 500 | 1.681 | 0.0257 | 0.045988 | -0.003629 | -0.031101 | 0.020027 | |
| | | | -0.003629 | 0.003980 | 0.000202 | -0.010230 | |
| | | | -0.031101 | 0.000202 | 0.025073 | -0.018465 | |
| | | | 0.020027 | -0.010230 | -0.018465 | 0.091042 | |

**Table 10.** Values needed to determine 90-percent prediction intervals for the best regression equations, by hydrologic region in Delaware.—Continued

[t, the critical value from the Student's t distribution used in equation 19; 2, the regression model error variance used in equation 20; U, the covariance matrix used in equation 20]

| Recurrence interval (years) | Coastal Plain | | | | | |
|---|---|---|---|---|---|---|
| | t | $\gamma^2$ | U | | | |
| 2 | 1.675 | 0.0652 | 0.014305 | -0.004551 | -0.004712 | -0.008147 |
| | | | -0.004551 | 0.004659 | 0.000261 | -0.000044 |
| | | | -0.004712 | 0.000261 | 0.017005 | 0.004016 |
| | | | -0.008147 | -0.000044 | 0.004016 | 0.008181 |
| 5 | 1.675 | 0.0532 | 0.012706 | -0.004072 | -0.004172 | -0.006940 |
| | | | -0.004072 | 0.004069 | 0.000284 | -0.000062 |
| | | | -0.004172 | 0.000284 | 0.015025 | 0.003457 |
| | | | -0.006940 | -0.000062 | 0.003457 | 0.007005 |
| 10 | 1.675 | 0.0504 | 0.012851 | -0.004115 | -0.004178 | -0.006867 |
| | | | -0.004115 | 0.004068 | 0.000294 | -0.000086 |
| | | | -0.004178 | 0.000294 | 0.015252 | 0.003446 |
| | | | -0.006867 | -0.000086 | 0.003446 | 0.006968 |
| 25 | 1.675 | 0.0507 | 0.013878 | -0.004422 | -0.007297 | -0.004438 |
| | | | -0.004422 | 0.004344 | -0.000127 | 0.000296 |
| | | | -0.007297 | -0.000127 | 0.007454 | 0.003690 |
| | | | -0.004438 | 0.000296 | 0.003690 | 0.016605 |
| 50 | 1.675 | 0.0531 | 0.015112 | -0.004793 | -0.007900 | -0.004777 |
| | | | -0.004793 | 0.004705 | -0.000163 | 0.000297 |
| | | | -0.007900 | -0.000163 | 0.008105 | 0.004010 |
| | | | -0.004777 | 0.000297 | 0.004010 | 0.018187 |
| 100 | 1.675 | 0.0569 | 0.016674 | -0.005268 | -0.008696 | -0.005222 |
| | | | -0.005268 | 0.005176 | -0.000203 | 0.000300 |
| | | | -0.008696 | -0.000203 | 0.008952 | 0.004426 |
| | | | -0.005222 | 0.000300 | 0.004426 | 0.020161 |
| 200 | 1.675 | 0.0620 | 0.018532 | -0.005839 | -0.009660 | -0.005764 |
| | | | -0.005839 | 0.005746 | -0.000247 | 0.000307 |
| | | | -0.009660 | -0.000247 | 0.009972 | 0.004926 |
| | | | -0.005764 | 0.000307 | 0.004926 | 0.022483 |
| 500 | 1.675 | 0.0704 | 0.021407 | -0.006729 | -0.011172 | -0.006618 |
| | | | -0.006729 | 0.006640 | -0.000311 | 0.000323 |
| | | | -0.011172 | -0.000311 | 0.011562 | 0.005705 |
| | | | -0.006618 | 0.000323 | 0.005705 | 0.026044 |

To determine a 90-percent prediction interval for this estimate, the $\boldsymbol{x}_i$ vector is

$$x_i = \{1, \log_{10}(8.00). \log_{10}(31.00), \log_{10}(1.60)\}$$

the model error variance from table 10 is $\gamma^2 = 0.0160$, and the covariance matrix, $U$, for the 50-year peak discharge in the Piedmont hydrologic region is

$$U = \begin{matrix} 0.027642 & -0.002241 & -0.018531 & 0.011950 \\ -0.002241 & 0.002448 & 0.000097 & -0.006257 \\ -0.018531 & 0.000097 & 0.014957 & -0.010975 \\ 0.011950 & -0.006257 & -0.010975 & 0.055508 \end{matrix}$$

The standard error of prediction computed using equation (20) is $S_i$=(0.0160+0.00205)^0.5=0.1344, and T computed from equation (19) is T=10^(1.681*0.1344)=1.682. The 90-percent prediction interval is estimated from equation (18) as (2,720/1.682)< PK50<(2,720*1.682), or, 1,620< PK50< 4,580.

The regression equations can be used to estimate peak-flow frequencies for ungaged sites with natural flow conditions in Delaware. The equations should not be applied to streams with substantial flood-retention storage upstream from sites of interest.

The accuracy of the equations is known only within the range of the basin characteristics used to develop the equations. The equations can be applied for ungaged sites with basin characteristics that are not within the ranges of applicability, but the accuracy of the estimates will be unknown. Also, it is possible that discharge estimates for lower-recurrence-interval floods can be larger than discharge estimates for higher-recurrence-interval floods when basin characteristics for an ungaged site are substantially beyond the ranges of applicability. The ranges of basin characteristics used to develop the equations are provided in table 11.

## Comparison of Results with Previous Study

A comparison was made between estimates obtained from the systematic records and the regression equations in this report and those from the previous Delaware flood-frequency report (Dillow, 1996) for stations that were used in both reports. Mean and median percent differences between the flood-frequency estimates obtained from the systematic record from the previous study and from this study were computed for all stations and by region, and are shown in table 12. Differences for the 200-year recurrence interval are not shown in the table because discharges for this recurrence interval were not computed for the previous study.

Estimates determined from the systematic record for this study are, on average, larger in discharge than those from the previous study for the lowest recurrence intervals, and they are smaller than those from the previous study for the highest recurrence intervals when all stations are considered as a group. Mean differences in percent range from positive 9.9 percent for the 2-year recurrence interval to negative 18.5 percent for the 500-year recurrence interval. Median

**Table 11.** Ranges of basin characteristics used to develop the regression equations.

[NHD, National Hydrography Dataset]

| | Piedmont region | | Coastal Plain region | |
|---|---|---|---|---|
| **Basin characteristic** | **Minimum** | **Maximum** | **Minimum** | **Maximum** |
| Drainage area (square miles) | 0.31 | 319 | 0.51 | 117 |
| Forest cover (percent) | 4.07 | 84.9 | -- | -- |
| Impervious area (percent) | 0.10 | 38.3 | -- | -- |
| Storage (NHD) (percent) | 0.00 | 2.92 | -- | -- |
| Housing density (homes/acre) | 0.06 | 6.84 | 0.01 | 3.42 |
| Hydrologic soil type A (percent) | 0.00 | 7.22 | 0.53 | 60.0 |
| Mean basin slope (percent) | -- | -- | 0.30 | 3.69 |

differences in percent range from positive 2.9 percent for the 2-year recurrence interval to negative 22.3 percent for the 500-year recurrence interval. Many stations within the study area experienced major flooding since completion of the previous study, which could lead to the expectation that flood-frequency estimates would increase rather than decrease. The decrease in the higher recurrence-interval estimates, however, can mostly be explained by (1) additional record for many of the stations, (2) the improved generalized-skew values used for this study, which are substantially lower than the previous values taken from Bulletin 17B, and account for lowering of the 100-year peaks by an average of about 4 percent, (3) the use of more historical adjustments than were used for the previous study, and (4) adjustments for trends in the annual peak-flow time series at some stations.

As indicated in table 12, differences between the estimates from the previous and current studies vary substantially depending on the region and whether or not additional data were collected. When all stations are considered, percent differences generally are much larger in the Coastal Plain than in the Piedmont, and stations with no record since the previous study have very small positive mean changes for smaller peaks and large negative mean changes for larger peaks, whereas stations with additional record since the previous study have large positive mean changes for smaller peaks and small negative mean changes for larger peaks. For the Coastal Plain, stations with no additional record have small negative mean changes for smaller peaks and large negative mean changes for larger peaks, whereas stations with additional record have large positive mean changes for smaller peaks and large

**Table 12.** Mean and median percent differences between peak-flow frequency statistics computed from the systematic records for streamgaging stations included in this study and the previous study (Dillow, 1996).

| Recurrence interval | All stations | | Coastal Plain | | Piedmont | |
|---|---|---|---|---|---|---|
| | Mean percent difference | Median percent difference | Mean percent difference | Median percent difference | Mean percent difference | Median percent difference |
| All stations | | | | | | |
| 2 | 9.9 | 2.9 | 16.0 | 2.9 | 4.7 | 2.8 |
| 5 | 3.5 | 1.4 | 3.4 | -0.7 | 3.7 | 1.9 |
| 10 | -0.9 | -1.5 | -3.8 | -6.5 | 1.9 | -1.0 |
| 25 | -5.9 | -5.9 | -11.2 | -8.4 | -0.6 | -4.7 |
| 50 | -9.5 | -9.3 | -16.2 | -14.0 | -2.6 | -8.3 |
| 100 | -12.6 | -13.6 | -20.5 | -18.6 | -4.5 | -13.1 |
| 500 | -18.5 | -22.3 | -28.8 | -30.1 | -8.0 | -20.5 |
| Stations with no record since last study | | | | | | |
| 2 | 0.9 | 2.9 | -2.4 | -2.1 | 4.2 | 3.2 |
| 5 | -4.7 | 1.4 | -11.1 | -10.5 | 1.8 | 0.7 |
| 10 | -9.1 | -1.5 | -16.8 | -12.4 | -1.5 | -2.4 |
| 25 | -14.6 | -5.9 | -23.0 | -17.7 | -6.2 | -6.3 |
| 50 | -18.9 | -9.3 | -27.3 | -23.6 | -10.6 | -9.8 |
| 100 | -22.8 | -13.6 | -31.0 | -29.7 | -14.5 | -14.0 |
| 500 | -31.0 | -22.3 | -38.5 | -41.4 | -23.4 | -22.3 |
| Stations with additional record since last study | | | | | | |
| 2 | 24.3 | 6.7 | 48.1 | 13.4 | 5.7 | 2.3 |
| 5 | 14.6 | 7.8 | 27.0 | 13.4 | 4.9 | 5.4 |
| 10 | 9.5 | 6.6 | 16.6 | 11.5 | 4.0 | 2.7 |
| 25 | 4.5 | 2.7 | 6.5 | 7.6 | 2.9 | -1.7 |
| 50 | 1.4 | -3.3 | 0.0 | -3.3 | 2.5 | -5.2 |
| 100 | -1.1 | -8.8 | -5.3 | -8.8 | 2.2 | -9.0 |
| 500 | -4.9 | -17.4 | -15.2 | -20.1 | 3.2 | -17.4 |

negative mean changes for larger peaks. For the Piedmont, stations with no additional record have small positive mean changes for smaller peaks and large negative mean changes for larger peaks, whereas stations with additional record have small positive mean changes for all peaks.

Adjustments for trends for some stations also contribute to increasing the low recurrence-interval estimates and decreasing the high recurrence-interval estimates. Because the annual peak flows tend to be smaller for the trend-affected stations during earlier parts of the periods of record than during later parts, the trend adjustments generally have the effect of increasing the lower flows more than the higher flows, and lowering the standard deviations of the annual series. This results in higher discharge estimates for the lower recurrence intervals and lower discharge estimates for the higher recurrence intervals.

Errors associated with the regression equations cannot be directly compared between the two studies because the same stations and explanatory variables were not used; however, some comparison is justified to understand differences between the results. Average standard errors of prediction associated with the regression equations for the Piedmont are somewhat larger for this study (28 to 48 percent) than for the previous study (23 to 45 percent). Average standard errors of prediction associated with the regression equations for the Coastal Plain are substantially larger for this study (58 to 72 percent) than for the previous study (38 to 43 percent).

The large differences in error between the two studies were not expected and they cannot be fully explained, but it is likely that the new average standard errors of prediction give a more precise indication of the true errors associated with estimates from the regression equations than the average standard errors of prediction given for the previous equations. The regression methods used in the two studies were essentially the same. The peak-flow statistics for the stations used in this study are considered more precise than those used in the previous study because of (1) improved generalized-skew values, (2) longer periods of record for many stations, and (3) corrections for trends that were not made previously. In addition, the basin characteristics used as explanatory variables in the equations were generally measured with more precision than those from the previous study.

A possible explanation for the increased error in the equations is that many of the long-term streamgaging stations used in the analysis have experienced large peaks since the previous study was completed. These large peaks may have increased the uncertainty in systematic flood-frequency estimates used as the dependent variables in the regression analyses. Percent differences in discharge between estimates obtained from the previous study and this study, as shown in table 12, are larger for the Coastal Plain, where average standard errors of estimate have increased the most, than for the Piedmont. The Coastal Plain also has the largest differences between the percent changes for stations with and without additional record. The pattern of changes for the Coastal Plain stations with and without new record is substantially different, indicating that more recent events are causing the differences in the changes.

This study included 21 stations in the Coastal Plain of southern New Jersey that were not included in the previous study. There was some concern that differences in the physiography of southern New Jersey and the Coastal Plain in Delaware were large enough that the addition of the New Jersey stations was causing the increased errors. A test set of regression analyses was run excluding the New Jersey stations. Average prediction errors decreased a few percentage points when this was done, but the decision was made to include the New Jersey stations in the final analyses to extend the range of applicability of the resulting regression equations.

# Application of the Methods

The best estimates of flood frequencies for a site are often obtained through a weighted combination of estimates produced from more than one method. 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. Improved flood-frequency estimates can be determined for Delaware streamgaging stations by weighting estimates determined from the systematic peak-flow record at the station with estimates obtained from the regression equations provided in this report. Improved estimates can be determined for ungaged sites in Delaware by weighting the estimates obtained from the regression equations with estimates determined based on the flow per unit area of an upstream or downstream streamgaging station.

The sections below describe the weighting process for streamgaging stations and ungaged sites in more detail, and provide example calculations. The methods presented are those incorporated into the USGS National Flood Frequency Program (NFF) (Ries and Crouse, 2002), a computer program that can be used to solve all of the USGS flood-frequency equations in the Nation, including those from this report, given user input of basin characteristics. NFF can be downloaded from the web at http://water.usgs.gov/software/nff.html, along with complete documentation on how to use it. NFF can also be used to perform the weighting functions described below for estimation at a gaged location and for an ungaged site upstream or downstream from a gaged location, but not for an ungaged site between gaged locations. The StreamStats program (described later in the StreamStats section) does not currently (2006) include the weighting functionality that is in NFF.

## Estimation for a Gaged Location

The Interagency Advisory Committee on Water Data (1982) recommends that the best estimates of flood-frequency statistics for a streamgaging station can be obtained by combining the estimates determined from log-Pearson type III analysis of the systematic annual peaks with estimates obtained for the station from regression equations. Note that the symbols used to explain this method in the source publication have been preserved in the discussion below, and that the equivalent expressions used in this report are identified in the variable definitions that accompany each equation.

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

$$\log Q_{T(G)w} = \frac{N \log Q_{T(G)s} + EQ \log Q_{T(G)r}}{N + EQ} \qquad (21)$$

where

$Q_{T(G)w}$ is the weighted estimate of flood-peak discharge for any recurrence interval (*PK2, PK5, ...,PK500*) at the streamgaging station,

$Q_{T(G)s}$ is the estimate of (*PK2, PK5,…, PK500*) derived from the systematic flood peaks,

$Q_{T(G)r}$ is the estimate of (*PK2, PK5,…, PK500*) 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, $EQ_{T(G)w}$, is equal to the $N + EQ$. No other indicators of accuracy are available for these weighted estimates.

An example of the application of the procedure described above is the computation of the weighted 100-year flood-peak discharge for the site on Little Mill Creek at Elsmere, Delaware (station number 01480100):

1. Obtain the estimate of the 100-year discharge at the site based on the systematic flood peaks from table 8; $PK100_{(G)s}$ = 6,370 ft$^3$/s,
2. Obtain drainage area, percent forest, and percent storage from table 7, and the number of years of gaged record from table 1; *DRNAREA*=6.67 mi$^2$, *FOREST*= 13.76 percent, *STORNHD*=0.35 percent, and *N*=18 years,
3. Compute $PK100_{(G)r}$ = $3{,}090(6.67)^{0.684}(13.76+1)^{-0.316}(0.35+1)^{-0.594}$ =4,040 ft$^3$/s,
4. Obtain the equivalent years of record for the 100-year peak-discharge regression equation for the Piedmont region from table 9; EQ=13.5 years, and
5. Compute the weighted 100-year flood-peak discharge for the site;
log $PK100_{(G)w}$=((18)(log6,370)+(13.5)(log4,040))/(18+13.5)=3.7194, and $PK100_{(G)w}$=5,240 ft$^3$/s.

## Estimation for a Site Upstream or Downstream from a Gaged Location

Guimaraes and Bohman (1992) and Stamey and Hess (1993) presented the following method to improve flood-frequency estimates for an 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. As in the previous section, the symbols used to explain this method in the source publications have been preserved in the discussion below, and the equivalent expressions used in this report are identified in the variable definitions that accompany each equation.

To obtain a weighted peak-flow estimate ($Q_{T(U)w}$) for recurrence interval T at the ungaged site, the weighted flow estimate for an upstream or downstream streamgaging station ($Q_{T(G)w}$) must first be determined using the equation provided in the previous section. The weighted streamgaging station estimate is then used to obtain an estimate for the ungaged site that is based on the flow per unit area at the streamgaging station ($Q_{T(U)g}$) by use of the equation

$$Q_{T(U)g} = \left(\frac{Au}{Ag}\right)^b Q_{T(G)w} \qquad (22)$$

where

$A_u$ is the drainage area ($DRNAREA_u$) for the ungaged site,

$A_g$ is the drainage area ($DRNAREA_g$) for the upstream or downstream streamgaging station, and

$b$ is 0.60 in the Piedmont and 0.70 in the Coastal Plain, as determined by computing the mean of the drainage-area exponents for all recurrence intervals from regressions of flood-frequencies against drainage area as the only explanatory variable, and where the equation constant is forced to be zero.

The weighted estimate for the ungaged site ($Q_{T(U)w}$) is then computed as

$$Q_{T(U)w} = \frac{2\Delta A}{A_g} Q_{T(U)r} + \left(1 - \frac{2\Delta A}{A_g}\right) Q_{T(U)g} \qquad (23)$$

where

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

$Q_{T(U)r}$ is the peak-flow estimate for recurrence interval (*PK2, PK5,…,PK500*) at the ungaged site derived from the applicable regional equation given above.

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

The equivalent years of record for the weighted estimate for an ungaged site, $EQ_{T(U)w}$, can be computed. This is done by first substituting the equivalent years of record for the weighted estimate of peak discharge at the streamgaging station, $EQ_{T(G)w}$, in place of $Q_{T(G)w}$ in equation (22) above to obtain an estimate of the weighted equivalent years of record for the streamgaging station that is adjusted to the drainage area for the ungaged site, $EQ_{T(U)g}$. As noted above, $EQ_{T(G)w}$ is equal to $N + EQ$ from equation (21). The area-adjusted equivalent years of record based on the gaged site, $EQ_{T(U)g}$, is then substituted for $Q_{T(U)g}$, and the equivalent years of record for the ungaged site based on the regression equation, $EQ_{T(U)r}$, is substituted for $Q_{T(U)r}$ in equation (23) to compute the final weighted equivalent years of record for the ungaged site, $EQ_{T(U)w}$. 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.

An example of the application of the procedure described above is the computation of the weighted 100-year flood-peak discharge, and its associated equivalent years of record, for a hypothetical site on Little Mill Creek located above the USGS station at Elsmere, Delaware (station number 01480100) cited in the previous section:

1. Calculate the value of $PK100_{(G)w}$ (see example in previous section); $PK100_{(G)w}$=5,240 ft$^3$/s,

2. Obtain the drainage areas for both the gaged and ungaged sites; $DRNAREA_g$ =6.67 mi$^2$, and $DRNAREA_u$=4.44 mi$^2$,

3. Use equation (22) and b=0.6 for stations in the Piedmont, to calculate the 100-year peak discharge based on station data; $PK100_{(U)g}$= (4.44/6.67)$^{0.6}$(5,240) = 4,100 ft$^3$/s,

4. Compute $\Delta A$, where $\Delta A$=6.67-4.44=2.23 mi$^2$,

5. Compute $PK100_{(U)r}$ for the ungaged site using equation (7) with *FOREST*= 8.00 percent and *STORNHD*= 0.10 percent; $PK100_{(U)r}$ =3,090$(4.44)^{0.684}(8.00+1)^{-0.316}(0.10+1)^{-0.594}$=4,040 ft$^3$/s,

6. Compute the weighted estimate for the ungaged site, $Q_{T(U)w}$, using equation (23);

7. $PK100_{(U)w}$=[((2*2.23)/6.67)*4,040]+[(1-((2*2.23)/6.67))* 3,490]=3,860 ft$^3$/s, and finally,

8. Compute the equivalent years of record for the weighted estimate of the 100-year peak discharge for the ungaged site using equations (22) and (23) and substituting $EQ_{T(G)w}$ in place of $Q_{T(G)w}$, $EQ_{T(U)g}$, in place of $Q_{T(U)g}$, $EQ_{T(U)r}$ in place of $Q_{T(U)r,}$ and $EQ_{T(U)w}$ in place of $Q_{T(U)w}$; giving:

   From equation (22), $EQ_{100(U)g}$=(4.44/6.67)$^{0.6}$(31.5)= 24.7 years,
   From table 9, $EQ_{100(U)r}$=13.5 years, and
   From equation (23), $EQ_{100(U)w}$=[((2*2.23)/6.67)*13.5]+ [(1-((2*2.23)/6.67))*18]=15.0 years.

## Estimation for a Site Between Gaged Locations

In the case where a flood-frequency estimate is needed for a site that is located between two gaged locations on a stream, the estimate may be obtained by use of the procedure presented above for calculating weighted estimates for a gaged location, with the following procedural alteration. For consistency, the symbology used below is the same as that used in the previous section, and the equivalent expressions used elsewhere in this report are identified in the variable definitions that accompany each equation.

Because the site is ungaged, a direct determination of the flow at the site for the selected recurrence interval is not possible. An interpolated value can be obtained by use of the equation:

$$Q_{Tu} = [\frac{A_u - A_{gu}}{A_{gd} - A_{gu}} * \left(\frac{Q_{Tgd}}{A_{gd}} - \frac{Q_{Tgu}}{A_{gu}}\right) + \frac{Q_{Tgu}}{A_{gu}}] * A_u \qquad (24)$$

where

$A_u$ is the drainage area ($DRNAREA_u$) for the ungaged site,

$A_{gu}$ is the drainage area ($DRNAREA_{gu}$) for the upstream gaged location,

$A_{gd}$ is the drainage area ($DRNAREA_{gd}$) for the downstream gaged location,

$Q_{Tu}$ is the discharge at the T-year recurrence interval (*PK2, PK5,…, PK500*) for the ungaged site,

$Q_{Tgu}$ is the discharge at the T-year recurrence interval (*PK2, PK5,…, PK500*) for the upstream gaged location, and

$Q_{Tgd}$ is the discharge at the T-year recurrence interval (*PK2, PK5,…, PK500*) for the downstream gaged locations.

The value of $Q_{Tu}$ from equation (24) may be used in equation (21) in place of $Q_{T(G)s}$.

The value of *N* for use in equation (21) may be calculated by determining the arithmetically weighted average of the number of years of record for the upstream and downstream gaged locations, using the difference in the two drainage areas as the weighting factor. The calculation can be done using the equation:

$$N_u = \frac{N_{gd}(A_u - A_{gu}) + N_{gu}(A_{gd} - A_u)}{A_{gd} - A_{gu}} \qquad (25)$$

where,

$A_u$, $A_{gu}$, and $A_{gd}$ are as defined immediately above, and

$N_u$, $N_{gu}$, and $N_{gd}$ are the number of years of record for the ungaged site and the upstream and downstream gaged locations, respectively.

The value determined for $N_u$ from equation (25) may be inserted in place of the value of $N$ in equation (21) to solve that equation, thus obtaining a weighted estimate of the T-year flood for the ungaged site located between an upstream and downstream gaged location.

An example of the application of the procedure described above is the computation of the weighted 5-year flood-peak discharge, and its associated equivalent years of record, for a hypothetical site on Brandywine Creek, with a drainage area of 300 mi$^2$, percent forest of 31.60 percent and percent hydrologic soil type A of 5.00, located between the USGS gages at Chadds Ford, Pennsylvania (station number 01481000) and Wilmington, Delaware (station number 01481500):

1. Use equation (24) to calculate $PK5_u$ with the information given above, gaged drainage areas associated with the two stations from table 7, and the appropriate discharge characteristics from table 8; $DRNAREA_u$=300 mi$^2$, $DRNAREA_{gu}$=288 mi$^2$, $DRNAREA_{gd}$=319 mi$^2$, $PK5_{gu}$= 11,000 ft$^3$/s, and $PK5_{gd}$=12,400 ft$^3$/s, so $PK5_u$={[(300-288)/(319-288)]*[(12,400/319)-(11,000/288)]+(11,000/288)}*300=11,500 ft$^3$/s,

2. Use equation (25) to calculate $N_{u,}$ with drainage areas as defined in the previous step and the years of record for the upstream (station number 01481000) and downstream (station number 01481500) gages as given in table 1; $N_{gu}$=84 years, and $N_{gd}$=93 years, so $N_u$ =(93*(300.00-288.17)+84*(318.54-300.00))/(318.54-288.17)= 87.5 years,

3. After computing the regression equation estimate for the ungaged site and determining the associated equivalent years of record from table 9, calculate the weighted peak discharge estimate of the ungaged site using equation (21) with $PK5_{(G)s}$=11,500 ft$^3$/s, $PK5_{(G)r}$=12,400 ft$^3$/s, *N*=87.5 years, and EQ=6.7 years, so log $PK5_{(G)w}$=((87.5)(log11,500)+(6.7)(log12,400))/(87.5+ .7)=4.0630, and $PK5_{(G)w}$=11,600 ft$^3$/s.

## Effects of Urbanization on Floods

The design of structures that can withstand future floods and protection of life and property in floodplains in urbanizing basins requires an understanding of the effects of urbanization on flood peaks. Engineers and planners often need to consider the potential effects on streamflow of full-build-out scenarios in their design and planning efforts. The section above on the Analysis of and Adjustments for Trends in Annual Peak-Flow Time Series presents some findings on the effects of urbanization on annual flood peaks at streamgaging stations in and near Delaware. This section describes an analysis that was done to develop regression equations that could be used to estimate the effects of future development on flood frequencies.

A matrix of correlations between the logarithms of flood-frequency estimates at the 2- and 100-year recurrence intervals and the logarithms of drainage area and the measured indicators of urbanization for stations used in the regression analyses is presented in table 13. Correlations among the indicators of urbanization were very high. In addition, note that the correlations between the indicators of urbanization and the 2-year peak flow were higher than those for the 100-year peak flow. Although only the 2- and 100-year peak flows are shown in the correlation matrix for simplicity, additional tests showed that correlations with the indicators of urbanization decreased consistently with increasing recurrence interval.

Development intensity was computed for this study primarily as a basis for comparing how closely this measure of impervious surface percentage agrees with impervious percentage obtained directly from the 2001 NLCD imperviousness dataset. The matrix indicates that the correlation of peak flows with development intensity is less than half of the correlation with percent impervious, which has the highest individual correlation with the peak flows of the urbanization indicators. In addition, development intensity actually had slightly lower correlations with peak flows than percent developed. Development intensity was derived by applying weights to the same land-use categories as those used to compute percent developed. This indicates that the application of weights to the land-use categories was actually counterproductive when attempting to explain more of the variation in peak flows.

Regressions of peak flows against the individual urbanization indicators had very high average standard errors of prediction. As a result, regressions that also included

**Table 13.** Matrix of correlations between the logarithms of flood-frequency estimates at the 2- and 100-year recurrence intervals and the logarithms of the indicators of urbanization.

| | 2-year peak flow | 100-year peak flow | Drainage area | 2000 Housing density | Centroid year housing density | Percent impervious | Percent developed |
|---|---|---|---|---|---|---|---|
| 2-year peak flow | 1 | | | | | | |
| 100-year peak flow | 0.952 | 1 | | | | | |
| Drainage area | 0.769 | 0.738 | 1 | | | | |
| 2000 housing density | 0.423 | 0.314 | 0.057 | 1 | | | |
| Centroid year housing density | 0.352 | 0.291 | 0.038 | 0.704 | 1 | | |
| Percent impervious | 0.431 | 0.315 | 0.130 | 0.900 | 0.651 | 1 | |
| Percent developed | 0.212 | 0.095 | -0.013 | 0.822 | 0.512 | 0.817 | 1 |
| Development intensity | 0.194 | 0.076 | -0.025 | 0.807 | 0.467 | 0.823 | 0.989 |

drainage area as an explanatory variable were done to increase the accuracy of the equations. The combination of drainage area and centroid housing density provided the regression equations with the lowest errors. Regressions that included an indicator variable to differentiate between the Piedmont and the Coastal Plain were also tested, but the indicators were statistically insignificant. The equations that are most useful for developing scenarios of the effects of future urbanization on flood-frequency relations are:

$$UPK2 = 51.4DRNAREA^{0.798}(HOMEDENS+1)^{1.09} \quad (26)$$

$$UPK5 = 91.8DRNAREA^{0.783}(HOMEDENS+1)^{0.950} \quad (27)$$

$$UPK10 = 126DRNAREA^{0.775}(HOMEDENS+1)^{0.870} \quad (28)$$

$$UPK25 = 179DRNAREA^{0.767}(HOMEDENS+1)^{0.780} \quad (29)$$

$$UPK50 = 225DRNAREA^{0.762}(HOMEDENS+1)^{0.719} \quad (30)$$

$$UPK100 = 277DRNAREA^{0.758}(HOMEDENS+1)^{0.663} \quad (31)$$

$$UPK200 = 334DRNAREA^{0.754}(HOMEDENS+1)^{0.611} \quad (32)$$

$$UPK500 = 420DRNAREA^{0.751}(HOMEDENS+1)^{0.546} \quad (33)$$

where

UPK2 through UPK500 are the estimates of urban flood frequency for the 2- through 500-year recurrence intervals, in cubic feet per second, and HOMEDENS is the housing density, in homes per acre. Housing-density values used in the analysis were those associated with the centroid of the period of record for each station. The average standard errors of estimate and prediction and the equivalent years of record associated with the urban equations above are presented in table 14. The ranges of applicability for equations (26) through (33) are equivalent to the combined ranges for both regions given in table 11.

**Table 14.** Average standard errors of estimate and prediction and equivalent years of record for the urban regression equations.

| Recurrence interval (years) | Average standard errors of | | Equivalent years of record (years) |
|---|---|---|---|
| | Estimate (percent) | Prediction (percent) | |
| 2 | 88.6 | 90.6 | 0.54 |
| 5 | 88.8 | 91.1 | 0.85 |
| 10 | 89.5 | 91.9 | 1.19 |
| 25 | 91.0 | 93.6 | 1.68 |
| 50 | 92.6 | 95.4 | 2.06 |
| 100 | 94.7 | 97.6 | 2.42 |
| 200 | 97.2 | 100 | 2.76 |
| 500 | 101 | 105 | 3.17 |

Because the errors associated with the urban equations are much higher than those for the best equations, it is recommended that the urban equations be applied only for the purpose of evaluating the effects of increased urbanization on peak flows. First, the best estimates of peak flows for a site should be determined using equations (2) through (17). Next, housing density should be determined under different land-use conditions and the different values of housing density should be applied using equations (26) through (33) to obtain estimates of peak flows for the different land-use scenarios. Finally, the percentage change between the peak-flow estimates for the different scenarios should be applied to the estimates obtained from equations (3) through (17) to obtain the best estimates of peak flows for the scenarios. These scenarios can be computed easily by using the NFF program, which includes both the best and the urban equations. Because the 2-year best equation for the Piedmont (equation 2) already contains the percent of impervious surfaces as a variable it is preferable to do build-out scenarios with the best equation for the 2-year recurrence interval for the Piedmont region rather than using equation 26 above. The urban equations can be incorporated into the methods used to develop build-out scenarios in the Coastal Plain region.

## StreamStats

StreamStats is a map-based USGS web application that makes it easy for users to obtain streamflow statistics and basin characteristics for USGS streamflow data-collection stations and ungaged sites of interest. It uses digital map data and a GIS to automatically determine the basin characteristics for ungaged sites. Ries and others (2004) provide a detailed description of the application. Although it is designed to eventually be a national application, Streamstats is being implemented on a state-by-state basis, usually through cooperative funding agreements between the USGS and local partners.

StreamStats has been developed for Delaware. Users can access all of the flood-frequency statistics and basin characteristics published in this report for the stations used in this study by selecting a station location on the map shown in the StreamStats user interface. Users can also obtain estimates for ungaged sites in Delaware by selecting the location of a site of interest on the map.

Complete instructions for using StreamStats are provided through links on the StreamStats web site at http://streamstats.usgs.gov. The web site also provides links to (1) general limitations of the application, (2) other State applications, (3) definitions of terms, (4) answers to frequently asked questions, (5) downloadable talks and other technical information about the application, (6) information that can be accessed only by USGS employees, and (7) contact information.

Due to software limitations, the StreamStats implementation for Delaware does not include the ability to solve the urban equations presented above for ungaged sites. Readers who are interested in using the urban equations can use StreamStats to obtain the basin characteristics needed to solve both the best equations and the urban equations, and they can get flood-frequency estimates based on the best equations. The basin characteristics obtained from StreamStats can then be used in the NFF program to obtain urban estimates for different development scenarios. StreamStats measures housing density for ungaged sites from the 2000 housing-density dataset (Theobald, 2001). Users will need to determine the appropriate housing-density values for other times.

## Summary and Conclusions

This study was done by the U.S. Geological Survey in cooperation with the Delaware Geological Survey and the Delaware Department of Transportation. The report presents estimates of flood-frequency statistics and basin characteristics for 116 stations in and within 25 miles of Delaware. It also describes methods for estimating flood frequencies for streamgaging stations and for ungaged sites in Delaware.

Statistically significant upward trends were found in the annual time series of peak flows for 18 of the 116 streamgaging stations analyzed for this study. Additional analyses were done to determine if these trends were related to corresponding increases in annual maximum precipitation or housing density, or both. The analyses revealed that annual maximum precipitation has not been increasing in the study area, but statistically significant relations were found between annual peak flows and corresponding annual values of housing density for 8 of the 18 stations.

Adjustments for trends in the annual peak-flow time series were made on the basis of time only for 11 of the 18 stations with significant trends before final flood-frequency analyses were completed for the stations. When compared to the original flood-frequency estimates for the trend-adjusted stations, the adjustments had the effect of increasing the magnitude of peak discharges for floods at recurrence intervals of up to 2 years, and decreasing the peak discharges for the 200- and 500-year recurrence intervals for all of the stations. Results varied for recurrence intervals between 5 and 100 years. For various reasons, the time series for seven of the trend-affected stations were not adjusted. These stations were not used in the regional flood-frequency analyses.

An analysis of station skews resulted in new generalized-skew values defined for each of two hydrologic regions in Delaware -- the Piedmont and Coastal Plain regions. The Piedmont includes the area north of the Fall Line, in northern Delaware, and the Coastal Plain includes the area to the south. The new generalized skew values are 0.107 for the Piedmont and 0.204 for the Coastal Plain, and are substantially lower than skew values taken from Bulletin 17B for the previous flood-frequency study. These new generalized-skew values were used to determine the flood-frequency values from the systematic records for the streamgaging stations presented in this report.

Discharge estimates determined from the systematic record for this study were, on average, larger than those from the previous study for the lowest recurrence intervals, and they were smaller than those from the previous study for the highest recurrence intervals when all stations are considered as a group. The changes are much larger in the Coastal Plain than in the Piedmont. The changes are due in large part to the longer periods of record and the improved generalized-skew values used for this study, and the adjustment of annual time series for some stations to eliminate trends.

Two sets of regression equations are presented for estimating flood discharges at the 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals at ungaged sites in Delaware. One set of equations is the best set of regression equations that could be developed for estimating flood discharges in the study area. Separate sets of best equations were developed for the Coastal Plain and the Piedmont hydrologic regions. A second set of equations was developed for use in estimating the effects of urbanization on flood discharges. The explanatory variables in the best equations for the Coastal Plain include drainage area, percent of drainage basin covered by soil type A, and mean basin slope. The explanatory variables in the best equations for the Piedmont include drainage area, percent of basin covered by forest, percent of basin covered by impervious surfaces (2-year recurrence interval only), percent of basin covered by hydrologic soil type A (2-year and 5-year recurrence intervals), and percent storage (areas of wetlands and waterbodies) determined from the National Hydrography Dataset (10- to 500-year recurrence intervals). The explanatory variables used in the urban equations included drainage area and housing density. The report presents the equations, indicators of the errors associated with use of the equations, and a discussion of the limitations for their use.

Average standard errors of prediction for the best regression equations ranged from 28 to 48 percent for the Piedmont, and from 58 to 72 percent for the Coastal Plain. Although they are not directly comparable because of differences in the stations used and their lengths of record, the errors associated with the new equations are higher than those presented in the previous report, which ranged from 23 to 45 percent for the Piedmont, and from 38 to 43 percent for the Coastal Plain. The differences in error cannot be fully explained, but it is likely that the new average standard errors of prediction give a more precise indication of the true errors associated with estimates from the regression equations than the average standard errors of prediction given for the previous equations. A possible explanation for the increased error in the equations is that many of the long-term streamgaging stations used in the analysis have experienced large peaks since the previous study was completed. These large peaks lead to greater uncertainty in the flood-frequency estimates for the streamgaging stations used in the study.

Estimates of housing density under different land-use scenarios can be used with the urban equations to evaluate the changes in flood magnitude as a result of the land-use changes. The average standard errors of prediction for the urban equations range from 91 to 105 percent. Consequently, these equations should be used only to compute the percentage change for different scenarios.

The best equations and the urban equations developed during this study have been incorporated into the National Flood Frequency (NFF) and StreamStats programs of the USGS. The National Flood Frequency program is a desktop program that solves regression equations for all states in the Nation, and requires user input of the basin characteristics. The StreamStats program is a web application that can provide the streamflow statistics and basin characteristics published in this report for streamgaging stations when users select a station location in the user interface. StreamStats can also compute basin characteristics and provide estimates of streamflow statistics for ungaged sites when users select the location of a site along any stream in Delaware.

This report describes methods for obtaining improved flood-frequency estimates for streamgaging stations and ungaged sites. Improved estimates for streamgaging stations are obtained by computing the weighted average of the estimates obtained from the systematic record and the estimates obtained from the regression equations, with weighting based on the years of systematic record and the equivalent years of record for the regression estimates. Improved estimates for ungaged sites can be obtained by combining the estimates from regression equations with estimates determined by applying the flow per unit area for an upstream or downstream streamgaging station to the drainage area for the ungaged site, and weighting the estimates according to the difference in drainage area between the ungaged site and the streamgaging station. The NFF program can be used to obtain these improved estimates.

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# Tables 6 through 8

**Table 6.** Climatic characteristics for stations in and near Delaware that were considered for use in the regression analyses.

[USGS, U.S. Geological Survey]

| USGS station number | Mean annual precipitation (inches) | Recurrence interval of 24-hour maximum precipitation (inches) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 200-year | 500-year |
| 01411456 | 46.59 | 3.30 | 4.28 | 5.13 | 6.41 | 7.54 | 8.79 | 10.21 | 12.37 |
| 01411500 | 46.06 | 3.29 | 4.27 | 5.12 | 6.41 | 7.54 | 8.81 | 10.23 | 12.42 |
| 01412500 | 45.27 | 3.26 | 4.24 | 5.08 | 6.36 | 7.48 | 8.75 | 10.18 | 12.35 |
| 01412800 | 45.53 | 3.27 | 4.24 | 5.08 | 6.37 | 7.49 | 8.76 | 10.18 | 12.35 |
| 01467043 | 50.86 | 3.31 | 4.20 | 4.95 | 6.07 | 7.04 | 8.09 | 9.25 | 10.98 |
| 01467045 | 50.11 | 3.30 | 4.17 | 4.90 | 5.98 | 6.92 | 7.90 | 9.00 | 10.62 |
| 01467081 | 47.36 | 3.33 | 4.24 | 5.01 | 6.15 | 7.15 | 8.22 | 9.42 | 11.19 |
| 01467086 | 50.56 | 3.30 | 4.17 | 4.90 | 5.97 | 6.89 | 7.87 | 8.96 | 10.57 |
| 01467087 | 49.96 | 3.30 | 4.16 | 4.89 | 5.96 | 6.87 | 7.85 | 8.93 | 10.52 |
| 01467130 | 47.17 | 3.31 | 4.24 | 5.04 | 6.24 | 7.28 | 8.43 | 9.71 | 11.63 |
| 01467150 | 47.12 | 3.30 | 4.23 | 5.02 | 6.21 | 7.23 | 8.36 | 9.61 | 11.50 |
| 01467160 | 47.34 | 3.32 | 4.24 | 5.03 | 6.21 | 7.23 | 8.35 | 9.60 | 11.46 |
| 01467180 | 47.22 | 3.32 | 4.24 | 5.02 | 6.18 | 7.19 | 8.30 | 9.52 | 11.35 |
| 01467305 | 46.63 | 3.29 | 4.21 | 4.98 | 6.14 | 7.15 | 8.24 | 9.47 | 11.29 |
| 01467317 | 46.27 | 3.29 | 4.20 | 4.98 | 6.15 | 7.17 | 8.27 | 9.51 | 11.37 |
| 01467330 | 46.78 | 3.30 | 4.26 | 5.08 | 6.32 | 7.42 | 8.62 | 9.98 | 12.04 |
| 01467351 | 47.24 | 3.30 | 4.25 | 5.05 | 6.27 | 7.34 | 8.51 | 9.82 | 11.80 |
| 01472157 | 47.23 | 3.23 | 4.05 | 4.72 | 5.70 | 6.52 | 7.40 | 8.35 | 9.74 |
| 01472174 | 46.81 | 3.24 | 4.06 | 4.73 | 5.72 | 6.53 | 7.42 | 8.37 | 9.75 |
| 01473169 | 47.05 | 3.23 | 4.05 | 4.73 | 5.72 | 6.54 | 7.43 | 8.39 | 9.78 |
| 01473470 | 47.48 | 3.25 | 4.08 | 4.77 | 5.76 | 6.60 | 7.49 | 8.46 | 9.87 |
| 01474000 | 48.61 | 3.28 | 4.12 | 4.82 | 5.84 | 6.71 | 7.63 | 8.65 | 10.12 |
| 01475000 | 46.72 | 3.30 | 4.27 | 5.10 | 6.37 | 7.48 | 8.72 | 10.11 | 12.23 |
| 01475019 | 46.66 | 3.29 | 4.24 | 5.07 | 6.31 | 7.42 | 8.61 | 9.97 | 12.04 |
| 01475300 | 48.16 | 3.25 | 4.08 | 4.77 | 5.77 | 6.62 | 7.52 | 8.50 | 9.93 |
| 01475510 | 48.12 | 3.26 | 4.10 | 4.80 | 5.81 | 6.67 | 7.59 | 8.59 | 10.05 |
| 01475530 | 49.21 | 3.27 | 4.11 | 4.81 | 5.82 | 6.67 | 7.59 | 8.58 | 10.03 |
| 01475550 | 48.02 | 3.26 | 4.10 | 4.80 | 5.81 | 6.66 | 7.58 | 8.57 | 10.02 |
| 01475850 | 47.97 | 3.25 | 4.08 | 4.77 | 5.78 | 6.63 | 7.53 | 8.52 | 9.96 |
| 01476000 | 47.72 | 3.25 | 4.09 | 4.79 | 5.82 | 6.68 | 7.61 | 8.62 | 10.11 |
| 01476435 | 47.56 | 3.25 | 4.07 | 4.76 | 5.76 | 6.60 | 7.49 | 8.47 | 9.89 |
| 01476480 | 47.42 | 3.25 | 4.09 | 4.79 | 5.81 | 6.68 | 7.60 | 8.62 | 10.10 |
| 01477000 | 47.12 | 3.25 | 4.10 | 4.81 | 5.85 | 6.73 | 7.68 | 8.72 | 10.24 |
| 01477110 | 46.52 | 3.27 | 4.21 | 5.02 | 6.24 | 7.33 | 8.49 | 9.82 | 11.83 |
| 01477120 | 46.37 | 3.26 | 4.20 | 5.01 | 6.22 | 7.29 | 8.45 | 9.76 | 11.75 |
| 01477480 | 46.18 | 3.26 | 4.21 | 5.02 | 6.24 | 7.32 | 8.50 | 9.84 | 11.86 |

**Table 6.** Climatic characteristics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey]

| USGS station number | Mean annual precipitation (inches) | Recurrence interval of 24-hour maximum precipitation (inches) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 200-year | 500-year |
| 01477500 | 46.07 | 3.26 | 4.21 | 5.02 | 6.24 | 7.31 | 8.50 | 9.83 | 11.84 |
| 01477800 | 46.77 | 3.27 | 4.13 | 4.84 | 5.89 | 6.77 | 7.73 | 8.77 | 10.30 |
| 01478000 | 45.86 | 3.25 | 4.07 | 4.77 | 5.78 | 6.62 | 7.53 | 8.52 | 9.96 |
| 01478040 | 45.08 | 3.24 | 4.08 | 4.78 | 5.80 | 6.67 | 7.59 | 8.61 | 10.08 |
| 01478200 | 47.83 | 3.25 | 4.08 | 4.77 | 5.76 | 6.60 | 7.50 | 8.47 | 9.88 |
| 01478500 | 47.39 | 3.26 | 4.08 | 4.77 | 5.77 | 6.61 | 7.51 | 8.48 | 9.89 |
| 01479000 | 46.97 | 3.26 | 4.08 | 4.77 | 5.78 | 6.62 | 7.52 | 8.49 | 9.91 |
| 01479200 | 48.07 | 3.27 | 4.10 | 4.79 | 5.80 | 6.64 | 7.55 | 8.53 | 9.96 |
| 01479820 | 47.68 | 3.27 | 4.10 | 4.79 | 5.79 | 6.63 | 7.53 | 8.50 | 9.91 |
| 01479950 | 47.47 | 3.27 | 4.11 | 4.80 | 5.81 | 6.66 | 7.57 | 8.56 | 9.99 |
| 01480000 | 47.69 | 3.27 | 4.10 | 4.80 | 5.80 | 6.64 | 7.55 | 8.52 | 9.94 |
| 01480015 | 47.53 | 3.27 | 4.10 | 4.80 | 5.80 | 6.65 | 7.55 | 8.53 | 9.95 |
| 01480100 | 45.84 | 3.27 | 4.12 | 4.81 | 5.83 | 6.68 | 7.60 | 8.60 | 10.05 |
| 01480300 | 47.81 | 3.21 | 4.02 | 4.70 | 5.68 | 6.49 | 7.37 | 8.32 | 9.70 |
| 01480500 | 47.76 | 3.22 | 4.03 | 4.71 | 5.69 | 6.51 | 7.39 | 8.34 | 9.72 |
| 01480610 | 47.25 | 3.24 | 4.05 | 4.73 | 5.72 | 6.54 | 7.43 | 8.38 | 9.77 |
| 01480675 | 47.58 | 3.24 | 4.06 | 4.74 | 5.72 | 6.54 | 7.42 | 8.38 | 9.77 |
| 01480680 | 47.29 | 3.24 | 4.06 | 4.74 | 5.72 | 6.54 | 7.43 | 8.38 | 9.77 |
| 01480700 | 47.24 | 3.24 | 4.05 | 4.73 | 5.71 | 6.53 | 7.42 | 8.37 | 9.75 |
| 01480870 | 47.11 | 3.24 | 4.06 | 4.74 | 5.72 | 6.54 | 7.42 | 8.38 | 9.76 |
| 01481000 | 47.25 | 3.25 | 4.07 | 4.75 | 5.74 | 6.56 | 7.45 | 8.41 | 9.80 |
| 01481200 | 47.94 | 3.28 | 4.12 | 4.82 | 5.83 | 6.68 | 7.60 | 8.59 | 10.02 |
| 01481450 | 47.62 | 3.28 | 4.13 | 4.84 | 5.87 | 6.73 | 7.67 | 8.70 | 10.18 |
| 01481500 | 47.29 | 3.25 | 4.07 | 4.75 | 5.74 | 6.57 | 7.46 | 8.43 | 9.83 |
| 01482310 | 43.93 | 3.22 | 4.10 | 4.83 | 5.92 | 6.88 | 7.88 | 9.01 | 10.68 |
| 01482500 | 46.06 | 3.26 | 4.22 | 5.04 | 6.29 | 7.39 | 8.60 | 9.97 | 12.05 |
| 01483000 | 45.48 | 3.26 | 4.23 | 5.06 | 6.32 | 7.42 | 8.65 | 10.05 | 12.16 |
| 01483200 | 44.41 | 3.20 | 4.14 | 4.94 | 6.17 | 7.24 | 8.43 | 9.77 | 11.81 |
| 01483290 | 44.55 | 3.21 | 4.15 | 4.96 | 6.19 | 7.27 | 8.47 | 9.82 | 11.88 |
| 01483400 | 44.34 | 3.20 | 4.14 | 4.95 | 6.18 | 7.25 | 8.45 | 9.80 | 11.85 |
| 01483500 | 44.51 | 3.25 | 4.22 | 5.05 | 6.32 | 7.43 | 8.67 | 10.07 | 12.21 |
| 01483700 | 44.62 | 3.27 | 4.25 | 5.10 | 6.39 | 7.53 | 8.79 | 10.23 | 12.42 |
| 01483720 | 44.56 | 3.30 | 4.29 | 5.14 | 6.45 | 7.60 | 8.88 | 10.35 | 12.57 |
| 01484000 | 44.86 | 3.31 | 4.30 | 5.16 | 6.47 | 7.63 | 8.92 | 10.38 | 12.60 |
| 01484002 | 44.83 | 3.33 | 4.33 | 5.20 | 6.52 | 7.68 | 8.98 | 10.46 | 12.70 |
| 01484050 | 44.80 | 3.33 | 4.33 | 5.19 | 6.51 | 7.67 | 8.97 | 10.44 | 12.69 |
| 01484100 | 44.94 | 3.35 | 4.36 | 5.23 | 6.56 | 7.73 | 9.04 | 10.51 | 12.77 |
| 01484270 | 45.37 | 3.41 | 4.43 | 5.32 | 6.67 | 7.86 | 9.19 | 10.70 | 13.00 |

**Table 6.** Climatic characteristics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey]

| USGS station number | Mean annual precipitation (inches) | Recurrence interval of 24-hour maximum precipitation (inches) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 200-year | 500-year |
| 01477500 | 46.07 | 3.26 | 4.21 | 5.02 | 6.24 | 7.31 | 8.50 | 9.83 | 11.84 |
| 01477800 | 46.77 | 3.27 | 4.13 | 4.84 | 5.89 | 6.77 | 7.73 | 8.77 | 10.30 |
| 01478000 | 45.86 | 3.25 | 4.07 | 4.77 | 5.78 | 6.62 | 7.53 | 8.52 | 9.96 |
| 01478040 | 45.08 | 3.24 | 4.08 | 4.78 | 5.80 | 6.67 | 7.59 | 8.61 | 10.08 |
| 01478200 | 47.83 | 3.25 | 4.08 | 4.77 | 5.76 | 6.60 | 7.50 | 8.47 | 9.88 |
| 01478500 | 47.39 | 3.26 | 4.08 | 4.77 | 5.77 | 6.61 | 7.51 | 8.48 | 9.89 |
| 01479000 | 46.97 | 3.26 | 4.08 | 4.77 | 5.78 | 6.62 | 7.52 | 8.49 | 9.91 |
| 01479200 | 48.07 | 3.27 | 4.10 | 4.79 | 5.80 | 6.64 | 7.55 | 8.53 | 9.96 |
| 01479820 | 47.68 | 3.27 | 4.10 | 4.79 | 5.79 | 6.63 | 7.53 | 8.50 | 9.91 |
| 01479950 | 47.47 | 3.27 | 4.11 | 4.80 | 5.81 | 6.66 | 7.57 | 8.56 | 9.99 |
| 01480000 | 47.69 | 3.27 | 4.10 | 4.80 | 5.80 | 6.64 | 7.55 | 8.52 | 9.94 |
| 01480015 | 47.53 | 3.27 | 4.10 | 4.80 | 5.80 | 6.65 | 7.55 | 8.53 | 9.95 |
| 01480100 | 45.84 | 3.27 | 4.12 | 4.81 | 5.83 | 6.68 | 7.60 | 8.60 | 10.05 |
| 01480300 | 47.81 | 3.21 | 4.02 | 4.70 | 5.68 | 6.49 | 7.37 | 8.32 | 9.70 |
| 01480500 | 47.76 | 3.22 | 4.03 | 4.71 | 5.69 | 6.51 | 7.39 | 8.34 | 9.72 |
| 01480610 | 47.25 | 3.24 | 4.05 | 4.73 | 5.72 | 6.54 | 7.43 | 8.38 | 9.77 |
| 01480675 | 47.58 | 3.24 | 4.06 | 4.74 | 5.72 | 6.54 | 7.42 | 8.38 | 9.77 |
| 01480680 | 47.29 | 3.24 | 4.06 | 4.74 | 5.72 | 6.54 | 7.43 | 8.38 | 9.77 |
| 01480700 | 47.24 | 3.24 | 4.05 | 4.73 | 5.71 | 6.53 | 7.42 | 8.37 | 9.75 |
| 01480870 | 47.11 | 3.24 | 4.06 | 4.74 | 5.72 | 6.54 | 7.42 | 8.38 | 9.76 |
| 01481000 | 47.25 | 3.25 | 4.07 | 4.75 | 5.74 | 6.56 | 7.45 | 8.41 | 9.80 |
| 01481200 | 47.94 | 3.28 | 4.12 | 4.82 | 5.83 | 6.68 | 7.60 | 8.59 | 10.02 |
| 01481450 | 47.62 | 3.28 | 4.13 | 4.84 | 5.87 | 6.73 | 7.67 | 8.70 | 10.18 |
| 01481500 | 47.29 | 3.25 | 4.07 | 4.75 | 5.74 | 6.57 | 7.46 | 8.43 | 9.83 |
| 01482310 | 43.93 | 3.22 | 4.10 | 4.83 | 5.92 | 6.88 | 7.88 | 9.01 | 10.68 |
| 01482500 | 46.06 | 3.26 | 4.22 | 5.04 | 6.29 | 7.39 | 8.60 | 9.97 | 12.05 |
| 01483000 | 45.48 | 3.26 | 4.23 | 5.06 | 6.32 | 7.42 | 8.65 | 10.05 | 12.16 |
| 01483200 | 44.41 | 3.20 | 4.14 | 4.94 | 6.17 | 7.24 | 8.43 | 9.77 | 11.81 |
| 01483290 | 44.55 | 3.21 | 4.15 | 4.96 | 6.19 | 7.27 | 8.47 | 9.82 | 11.88 |
| 01483400 | 44.34 | 3.20 | 4.14 | 4.95 | 6.18 | 7.25 | 8.45 | 9.80 | 11.85 |
| 01483500 | 44.51 | 3.25 | 4.22 | 5.05 | 6.32 | 7.43 | 8.67 | 10.07 | 12.21 |
| 01483700 | 44.62 | 3.27 | 4.25 | 5.10 | 6.39 | 7.53 | 8.79 | 10.23 | 12.42 |
| 01483720 | 44.56 | 3.30 | 4.29 | 5.14 | 6.45 | 7.60 | 8.88 | 10.35 | 12.57 |
| 01484000 | 44.86 | 3.31 | 4.30 | 5.16 | 6.47 | 7.63 | 8.92 | 10.38 | 12.60 |
| 01484002 | 44.83 | 3.33 | 4.33 | 5.20 | 6.52 | 7.68 | 8.98 | 10.46 | 12.70 |
| 01484050 | 44.80 | 3.33 | 4.33 | 5.19 | 6.51 | 7.67 | 8.97 | 10.44 | 12.69 |
| 01484100 | 44.94 | 3.35 | 4.36 | 5.23 | 6.56 | 7.73 | 9.04 | 10.51 | 12.77 |
| 01484270 | 45.37 | 3.41 | 4.43 | 5.32 | 6.67 | 7.86 | 9.19 | 10.70 | 13.00 |
| 01484300 | 45.11 | 3.39 | 4.40 | 5.29 | 6.62 | 7.80 | 9.12 | 10.62 | 12.90 |

**Table 6.** Climatic characteristics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey]

| USGS station number | Mean annual precipitation (inches) | Recurrence interval of 24-hour maximum precipitation (inches) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 200-year | 500-year |
| 01484500 | 45.61 | 3.42 | 4.45 | 5.34 | 6.69 | 7.88 | 9.22 | 10.73 | 13.03 |
| 01484525 | 45.52 | 3.42 | 4.45 | 5.34 | 6.69 | 7.88 | 9.22 | 10.73 | 13.03 |
| 01484550 | 45.65 | 3.42 | 4.44 | 5.33 | 6.68 | 7.86 | 9.20 | 10.71 | 13.00 |
| 01485000 | 45.49 | 3.44 | 4.47 | 5.37 | 6.73 | 7.93 | 9.27 | 10.79 | 13.11 |
| 01485500 | 45.33 | 3.47 | 4.51 | 5.41 | 6.79 | 7.99 | 9.35 | 10.89 | 13.22 |
| 01486000 | 44.90 | 3.35 | 4.35 | 5.22 | 6.54 | 7.71 | 9.02 | 10.49 | 12.74 |
| 01486100 | 45.38 | 3.45 | 4.49 | 5.39 | 6.75 | 7.95 | 9.30 | 10.82 | 13.15 |
| 01486980 | 44.98 | 3.36 | 4.37 | 5.25 | 6.58 | 7.76 | 9.07 | 10.55 | 12.81 |
| 01487000 | 44.98 | 3.36 | 4.37 | 5.25 | 6.58 | 7.75 | 9.06 | 10.54 | 12.80 |
| 01487500 | 45.35 | 3.44 | 4.47 | 5.36 | 6.72 | 7.91 | 9.25 | 10.77 | 13.08 |
| 01488000 | 44.67 | 3.42 | 4.45 | 5.34 | 6.69 | 7.88 | 9.22 | 10.73 | 13.03 |

**Table 7.** Basin characteristics for stations in and near Delaware that were considered for use in the regression analyses.

[USGS, U.S. Geological Survey; $mi^2$, square miles; ft/mi, NHD, National Hydrography Dataset; NLCD.DE, 2001 National Land Cover Dataset and 2003 Delaware land cover dataset combined; feet per mile; mi, miles; in/hr, inches per hour; ft, feet]

| USGS station number | Drainage area ($mi^2$) | Mean stream slope (ft/mi) | 10/85 stream slope (ft/mi) | Mean basin slope (percent) | Storage (NHD) (percent) | Storage (NLCD.DE) (percent) | Forest cover (percent) | Main channel length (mi) | Basin shape factor | Hydrologic soil type A (percent) |
|---|---|---|---|---|---|---|---|---|---|---|
| 01411456 | 9.78 | 8.84 | 8.07 | 0.72 | 12.3 | 18.8 | 59.9 | 5.40 | 2.98 | 12.5 |
| 01411500 | 112 | 6.16 | 4.84 | 0.99 | 9.27 | 11.7 | 50.8 | 19.7 | 3.46 | 13.6 |
| 01412500 | 2.55 | 25.0 | 22.6 | 2.09 | 0.06 | 1.39 | 4.87 | 3.36 | 4.43 | 0.53 |
| 01412800 | 28.0 | 11.6 | 11.2 | 1.93 | 1.27 | 4.53 | 16.3 | 8.58 | 2.63 | 4.55 |
| 01467043 | 1.20 | 71.8 | 67.1 | 4.39 | 0.00 | 0.57 | 13.4 | 2.13 | 3.80 | 6.25 |
| 01467045 | 43.1 | 20.4 | 16.7 | 4.75 | 0.47 | 0.96 | 19.1 | 14.7 | 5.02 | 2.82 |
| 01467081 | 8.98 | 12.2 | 9.72 | 1.88 | 0.31 | 5.81 | 17.3 | 8.64 | 8.31 | 5.39 |
| 01467086 | 16.2 | 38.3 | 26.9 | 5.23 | 0.33 | 1.49 | 13.5 | 9.40 | 5.46 | 5.98 |
| 01467087 | 30.0 | 31.8 | 21.8 | 4.41 | 0.36 | 1.29 | 9.43 | 12.9 | 5.57 | 6.31 |
| 01467089 | 33.8 | 30.9 | 20.8 | 4.11 | 0.33 | 1.20 | 8.44 | 13.8 | 5.59 | 6.56 |
| 01467130 | 5.03 | 32.5 | 20.0 | 2.71 | 2.47 | 11.2 | 44.2 | 4.11 | 3.36 | 30.0 |
| 01467150 | 17.1 | 18.3 | 11.2 | 2.69 | 1.25 | 7.58 | 29.9 | 9.92 | 5.75 | 11.7 |
| 01467160 | 5.32 | 24.0 | 12.8 | 2.57 | 0.34 | 8.22 | 29.8 | 6.16 | 7.13 | 3.22 |
| 01467180 | 10.5 | 18.9 | 11.1 | 2.64 | 0.33 | 9.55 | 32.1 | 9.18 | 8.01 | 3.64 |
| 01467305 | 1.33 | 41.8 | 30.3 | 1.21 | 0.31 | 3.49 | 21.1 | 2.31 | 4.04 | 6.00 |
| 01467317 | 0.62 | 43.5 | 45.5 | 1.51 | 0.28 | 2.38 | 11.0 | 1.46 | 3.44 | 6.00 |
| 01467330 | 20.8 | 20.6 | 20.4 | 3.19 | 3.80 | 7.91 | 31.2 | 8.44 | 3.42 | 5.17 |
| 01467351 | 7.16 | 24.8 | 27.3 | 3.69 | 2.66 | 6.81 | 36.7 | 5.63 | 4.43 | 35.3 |
| 01472157 | 59.0 | 36.1 | 25.1 | 9.53 | 0.73 | 2.44 | 53.1 | 19.0 | 6.08 | 5.43 |
| 01472174 | 5.98 | 73.4 | 38.6 | 8.00 | 0.48 | 2.01 | 30.7 | 4.74 | 3.77 | 6.25 |
| 01473169 | 20.8 | 47.3 | 29.7 | 8.72 | 0.37 | 3.60 | 29.8 | 9.93 | 4.73 | 1.97 |
| 01473470 | 20.8 | 35.6 | 28.1 | 4.39 | 0.24 | 0.24 | 16.3 | 7.87 | 2.97 | 0.00 |
| 01474000 | 63.7 | 64.3 | 13.3 | 5.45 | 0.57 | 1.17 | 24.0 | 25.4 | 10.1 | 1.26 |
| 01475000 | 6.05 | 17.7 | 19.2 | 2.07 | 2.58 | 5.23 | 19.2 | 4.50 | 3.35 | 4.03 |
| 01475019 | 14.1 | 17.3 | 17.9 | 2.59 | 2.42 | 5.87 | 23.4 | 8.02 | 4.56 | 2.66 |
| 01475300 | 5.18 | 56.2 | 36.8 | 5.59 | 0.36 | 1.01 | 30.5 | 4.08 | 3.21 | 3.47 |
| 01475510 | 37.6 | 28.2 | 21.0 | 6.90 | 0.46 | 1.00 | 24.7 | 18.3 | 8.94 | 6.21 |
| 01475530 | 4.78 | 63.7 | 61.7 | 4.42 | 0.15 | 1.26 | 11.2 | 4.71 | 4.64 | 6.46 |
| 01475550 | 21.8 | 35.4 | 32.2 | 4.08 | 0.27 | 1.17 | 8.17 | 11.8 | 6.34 | 7.36 |
| 01475850 | 15.8 | 43.6 | 32.0 | 6.56 | 0.43 | 1.74 | 36.8 | 8.67 | 4.75 | 1.95 |
| 01476000 | 33.7 | 27.6 | 22.0 | 7.77 | 2.30 | 3.92 | 35.1 | 20.1 | 12.0 | 3.25 |
| 01476435 | 9.71 | 40.8 | 32.7 | 5.54 | 0.56 | 1.31 | 24.9 | 6.42 | 4.24 | 3.16 |
| 01476480 | 30.2 | 29.3 | 23.4 | 7.79 | 0.58 | 0.93 | 41.1 | 16.8 | 9.35 | 1.74 |
| 01476500 | 31.6 | 28.4 | 22.3 | 7.88 | 0.59 | 0.96 | 40.8 | 18.2 | 10.4 | 1.94 |
| 01477000 | 60.7 | 27.9 | 22.7 | 7.67 | 0.92 | 1.80 | 32.2 | 20.9 | 7.19 | 3.35 |
| 01477110 | 14.6 | 14.4 | 15.1 | 2.65 | 2.17 | 5.42 | 29.6 | 8.17 | 4.57 | 7.32 |
| 01477120 | 25.9 | 13.4 | 14.8 | 2.84 | 1.77 | 5.70 | 29.5 | 10.3 | 4.10 | 5.19 |

**Table 7.** Basin characteristics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; mi², square miles; ft/mi, NHD, National Hydrography Dataset; NLCD.DE, 2001 National Land Cover Dataset and 2003 Delaware land cover dataset combined; feet per mile; mi, miles; in/hr, inches per hour; ft, feet]

| Hydrologic soil type D (percent) | Average soil permeability (in/hr) | Impervious area (percent) | Basin relief (ft) | Mean basin elevation (ft) | Gage elevation (ft) | Development intensity (percent) | Developed area (percent) | Centroid year housing density (homes/acre) | 2000 Housing density (homes/acre) | USGS station number |
|---|---|---|---|---|---|---|---|---|---|---|
| 8.09 | 6.91 | 4.22 | 48.6 | 134 | 112 | 4.25 | 15.8 | 0.26 | 0.28 | 01411456 |
| 7.08 | 6.86 | 3.27 | 131 | 115 | 48.7 | 3.21 | 13.9 | 0.15 | 0.26 | 01411500 |
| 0.00 | 1.83 | 0.13 | 93.3 | 105 | 47.9 | 0.06 | 0.46 | 0.06 | 0.07 | 01412500 |
| 0.74 | 2.84 | 0.80 | 114 | 103 | 27.4 | 0.76 | 2.87 | 0.07 | 0.08 | 01412800 |
| 7.29 | 1.23 | 25.8 | 154 | 207 | 96.9 | 22.5 | 80.6 | 2.92 | 2.99 | 01467043 |
| 5.67 | 1.12 | 20.3 | 364 | 251 | 69.2 | 19.7 | 69.4 | 1.56 | 1.99 | 01467045 |
| 0.53 | 2.67 | 31.0 | 106 | 63.1 | 17.0 | 29.1 | 77.6 | 1.80 | 1.98 | 01467081 |
| 6.97 | 1.23 | 24.6 | 366 | 254 | 63.8 | 23.7 | 79.2 | 3.80 | 3.94 | 01467086 |
| 7.69 | 1.23 | 38.3 | 417 | 220 | 18.3 | 37.3 | 85.6 | 6.70 | 6.74 | 01467087 |
| 8.32 | 1.23 | 41.1 | 430 | 206 | 3.28 | 40.0 | 87.0 | 7.16 | 7.25 | 01467089 |
| 4.47 | 6.99 | 14.2 | 145 | 104 | 56.5 | 13.2 | 41.6 | 0.52 | 0.97 | 01467130 |
| 2.68 | 3.82 | 19.4 | 193 | 84.9 | 5.80 | 18.4 | 60.7 | 1.22 | 1.39 | 01467150 |
| 3.37 | 2.61 | 16.7 | 157 | 91.6 | 33.7 | 15.2 | 59.5 | 0.35 | 1.38 | 01467160 |
| 2.26 | 2.52 | 17.6 | 183 | 78.0 | 8.92 | 16.6 | 60.6 | 0.57 | 1.35 | 01467180 |
| 0.00 | 2.64 | 18.2 | 103 | 70.2 | 18.9 | 17.4 | 78.1 | 3.42 | 3.47 | 01467305 |
| 0.00 | 2.64 | 23.8 | 64.8 | 73.4 | 37.9 | 22.7 | 89.0 | 3.28 | 3.28 | 01467317 |
| 2.53 | 3.96 | 14.4 | 180 | 112 | 9.15 | 13.4 | 47.0 | 0.62 | 1.12 | 01467330 |
| 5.25 | 7.83 | 15.5 | 182 | 114 | 19.1 | 14.5 | 50.2 | 1.92 | 1.94 | 01467351 |
| 7.00 | 1.65 | 0.45 | 838 | 529 | 167 | 0.44 | 2.03 | 0.08 | 0.10 | 01472157 |
| 7.29 | 1.23 | 3.70 | 355 | 437 | 277 | 3.33 | 14.0 | 0.06 | 0.24 | 01472174 |
| 2.33 | 1.24 | 12.7 | 635 | 354 | 117 | 12.5 | 38.6 | 0.58 | 0.66 | 01473169 |
| 8.07 | 1.06 | 15.8 | 412 | 283 | 78.8 | 14.8 | 52.3 | 1.02 | 1.29 | 01473470 |
| 6.89 | 1.07 | 13.8 | 469 | 283 | 20.6 | 13.6 | 54.7 | 1.53 | 1.68 | 01474000 |
| 2.58 | 4.20 | 14.6 | 90.1 | 128 | 69.6 | 13.4 | 49.0 | 0.45 | 1.67 | 01475000 |
| 2.79 | 3.64 | 13.8 | 150 | 105 | 11.7 | 12.7 | 46.6 | 0.68 | 1.25 | 01475019 |
| 12.0 | 0.95 | 8.25 | 245 | 434 | 316 | 9.01 | 42.3 | 0.78 | 0.93 | 01475300 |
| 10.7 | 1.15 | 15.7 | 531 | 325 | 28.3 | 15.0 | 56.9 | 1.90 | 2.03 | 01475510 |
| 7.85 | 1.23 | 22.6 | 311 | 319 | 126 | 21.5 | 81.4 | 3.19 | 3.33 | 01475530 |
| 10.3 | 1.23 | 37.5 | 426 | 209 | 17.1 | 36.0 | 87.6 | 6.84 | 6.89 | 01475550 |
| 14.6 | 0.79 | 3.56 | 382 | 419 | 218 | 4.10 | 20.6 | 0.49 | 0.53 | 01475850 |
| 13.6 | 0.90 | 7.24 | 561 | 336 | 35.4 | 7.30 | 32.3 | 0.47 | 0.82 | 01476000 |
| 12.6 | 0.91 | 5.48 | 270 | 472 | 342 | 5.51 | 28.9 | 0.40 | 0.83 | 01476435 |
| 15.0 | 0.77 | 3.83 | 499 | 373 | 110 | 3.82 | 19.5 | 0.20 | 0.57 | 01476480 |
| 14.7 | 0.79 | 4.42 | 523 | 367 | 87.3 | 4.42 | 20.8 | 0.21 | 0.66 | 01476500 |
| 12.3 | 0.93 | 7.74 | 586 | 338 | 24.6 | 7.78 | 29.8 | 0.30 | 0.62 | 01477000 |
| 5.35 | 4.98 | 1.60 | 140 | 115 | 31.0 | 1.60 | 8.13 | 0.12 | 0.15 | 01477110 |
| 3.86 | 3.93 | 1.67 | 163 | 102 | 10.6 | 1.56 | 7.78 | 0.11 | 0.14 | 01477120 |

**Table 7.** Basin characteristics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; mi², square miles; ft/mi, NHD, National Hydrography Dataset; NLCD.DE, 2001 National Land Cover Dataset and 2003 Delaware land cover dataset combined; feet per mile; mi, miles; in/hr, inches per hour; ft, feet]

| USGS station number | Drainage area (mi²) | Mean stream slope (ft/mi) | 10/85 stream slope (ft/mi) | Mean basin slope (percent) | Storage (NHD) (percent) | Storage (NLCD.DE) (percent) | Forest cover (percent) | Main channel length (mi) | Basin shape factor | Hydrologic soil type A (percent) |
|---|---|---|---|---|---|---|---|---|---|---|
| 01477480 | 13.8 | 14.5 | 13.5 | 2.47 | 1.31 | 5.33 | 31.8 | 9.16 | 6.09 | 5.45 |
| 01477500 | 18.5 | 13.7 | 13.5 | 2.67 | 0.99 | 5.31 | 28.8 | 9.87 | 5.26 | 6.44 |
| 01477800 | 7.34 | 65.3 | 65.4 | 3.70 | 0.13 | 0.23 | 7.29 | 6.10 | 5.07 | 1.56 |
| 01478000 | 20.8 | 30.5 | 21.7 | 4.71 | 0.43 | 2.26 | 23.7 | 13.4 | 8.67 | 2.61 |
| 01478040 | 40.6 | 23.2 | 17.6 | 3.38 | 1.06 | 4.71 | 25.1 | 18.1 | 8.08 | 1.33 |
| 01478200 | 12.7 | 36.8 | 27.5 | 6.63 | 0.18 | 0.66 | 15.9 | 11.0 | 9.53 | 6.23 |
| 01478500 | 66.4 | 25.2 | 17.7 | 8.16 | 0.36 | 1.54 | 25.7 | 19.5 | 5.70 | 5.90 |
| 01478650 | 68.6 | 23.3 | 16.7 | 8.22 | 0.41 | 1.59 | 26.5 | 21.7 | 6.86 | 5.82 |
| 01479000 | 88.9 | 20.0 | 13.9 | 7.69 | 0.42 | 1.56 | 25.1 | 27.2 | 8.32 | 5.12 |
| 01479200 | 4.29 | 60.1 | 42.8 | 6.39 | 0.33 | 0.76 | 10.7 | 3.38 | 2.67 | 6.25 |
| 01479820 | 27.6 | 32.8 | 20.9 | 6.90 | 0.64 | 1.76 | 19.6 | 10.8 | 4.22 | 5.84 |
| 01479950 | 0.38 | 173 | 149 | 14.7 | 0.00 | 0.00 | 35.2 | 1.40 | 5.14 | 6.25 |
| 01480000 | 47.2 | 23.8 | 15.9 | 8.58 | 1.36 | 2.07 | 25.1 | 19.3 | 7.88 | 6.01 |
| 01480015 | 52.5 | 22.3 | 15.4 | 8.34 | 1.31 | 2.03 | 23.8 | 23.7 | 10.7 | 5.88 |
| 01480100 | 6.67 | 46.2 | 33.4 | 4.08 | 0.35 | 0.53 | 13.8 | 6.55 | 6.44 | 7.22 |
| 01480300 | 18.7 | 44.9 | 24.4 | 5.23 | 0.26 | 3.15 | 22.0 | 9.22 | 4.56 | 5.36 |
| 01480500 | 46.1 | 33.6 | 22.0 | 6.75 | 0.69 | 3.27 | 34.3 | 20.7 | 9.31 | 2.42 |
| 01480610 | 2.61 | 124 | 145 | 9.96 | 0.23 | 4.74 | 31.8 | 2.65 | 2.68 | 3.74 |
| 01480617 | 55.3 | 31.1 | 21.5 | 7.48 | 0.67 | 3.83 | 33.9 | 23.7 | 10.1 | 2.64 |
| 01480675 | 8.54 | 41.3 | 26.9 | 7.11 | 6.04 | 5.46 | 46.3 | 6.01 | 4.23 | 6.25 |
| 01480680 | 17.6 | 39.9 | 31.6 | 7.80 | 5.15 | 5.57 | 39.1 | 9.13 | 4.72 | 6.25 |
| 01480700 | 60.1 | 43.8 | 23.5 | 7.49 | 2.92 | 4.62 | 37.5 | 17.9 | 5.30 | 5.99 |
| 01480800 | 81.8 | 40.3 | 22.0 | 7.61 | 2.26 | 4.22 | 35.5 | 20.2 | 4.97 | 5.39 |
| 01480870 | 89.8 | 35.0 | 19.9 | 7.95 | 2.14 | 4.27 | 36.2 | 24.1 | 6.46 | 5.36 |
| 01481000 | 288 | 19.4 | 13.8 | 8.53 | 1.15 | 3.28 | 31.5 | 43.6 | 6.59 | 4.65 |
| 01481200 | 1.05* | 142 | 134 | 15.2 | 0.19 | 0.26 | 48.2 | 1.93 | 3.53 | 6.25 |
| 01481450 | 0.31* | 72.1 | 74.7 | 3.11 | 0.00 | 0.00 | 4.07 | 0.92 | 2.69 | 0.00 |
| 01481500 | 319 | 17.2 | 11.2 | 8.63 | 1.21 | 3.26 | 31.8 | 54.4 | 9.28 | 4.59 |
| 01482310 | 1.05 | 32.1 | 32.0 | 2.22 | 0.82 | 4.92 | 13.3 | 1.81 | 3.10 | 0.00 |
| 01482500 | 14.6 | 15.0 | 11.7 | 2.55 | 1.71 | 4.13 | 17.9 | 8.11 | 4.51 | 3.88 |
| 01483000 | 20.4 | 13.8 | 13.6 | 2.86 | 2.83 | 5.29 | 39.0 | 9.35 | 4.29 | 11.6 |
| 01483200 | 4.06* | 14.4 | 14.8 | 1.76 | 4.39 | 17.7 | 30.7 | 4.19 | 4.33 | 3.07 |
| 01483290 | 1.2* | 11.9 | 11.7 | 1.16 | 1.67 | 10.4 | 7.34 | 2.40 | 4.79 | 3.06 |
| 01483400 | 0.51* | 30.3 | 28.2 | 1.70 | 2.59 | 18.0 | 7.44 | 1.08 | 2.3 | 3.06 |
| 01483500 | 9.15 | 9.04 | 8.22 | 1.46 | 0.89 | 11.3 | 9.40 | 5.86 | 3.75 | 3.6 |
| 01483700 | 31.0 | 4.87 | 4.95 | 1.06 | 4.28 | 16.1 | 14.0 | 13.7 | 6.04 | 3.71 |
| 01483720 | 2.54* | 14.0 | 14.3 | 1.01 | 0.06 | 3.33 | 9.95 | 2.53 | 2.51 | 3.06 |

**Table 7.** Basin characteristics for stations in and near Delaware that were considered for use in the regression analyses—Continued.

[USGS, U.S. Geological Survey; mi², square miles; ft/mi, NHD, National Hydrography Dataset; NLCD.DE, 2001 National Land Cover Dataset and 2003 Delaware land cover dataset combined; feet per mile; mi, miles; in/hr, inches per hour; ft, feet]

| Hydrologic soil type D (percent) | Average soil permeability (in/hr) | Impervious area (percent) | Basin relief (ft) | Mean basin elevation (ft) | Gage elevation (ft) | Development intensity (percent) | Developed area (percent) | Centroid year housing density (homes/acre) | 2000 Housing density (homes/acre) | USGS station number |
|---|---|---|---|---|---|---|---|---|---|---|
| 23.8 | 4.06 | 0.33 | 148 | 109 | 17.2 | 0.34 | 1.76 | 0.05 | 0.05 | 01477480 |
| 19.4 | 4.34 | 0.31 | 150 | 105 | 13.0 | 0.31 | 1.57 | 0.02 | 0.05 | 01477500 |
| 19.1 | 0.66 | 18.6 | 400 | 275 | 21.9 | 31.5 | 90.7 | 1.74 | 1.87 | 01477800 |
| 7.98 | 1.25 | 11.0 | 412 | 191 | 28.6 | 16.3 | 40.0 | 0.50 | 0.74 | 01478000 |
| 6.61 | 1.38 | 11.6 | 423 | 135 | 17.0 | 20.5 | 47.4 | 0.59 | 0.80 | 01478040 |
| 7.27 | 1.23 | 1.03 | 414 | 452 | 235 | 1.09 | 6.18 | 0.10 | 0.16 | 01478200 |
| 6.88 | 1.23 | 1.64 | 582 | 376 | 70.4 | 2.19 | 9.79 | 0.12 | 0.20 | 01478500 |
| 6.92 | 1.23 | 1.84 | 597 | 369 | 55.5 | 2.54 | 10.7 | 0.21 | 0.21 | 01478650 |
| 7.19 | 1.23 | 5.10 | 636 | 324 | 16.2 | 8.06 | 23.1 | 0.15 | 0.50 | 01479000 |
| 7.29 | 1.23 | 8.22 | 226 | 313 | 214 | 23.7 | 76.8 | 0.20 | 0.72 | 01479200 |
| 6.81 | 1.23 | 3.75 | 361 | 370 | 190 | 3.83 | 15.8 | 0.30 | 0.31 | 01479820 |
| 7.29 | 1.23 | 0.56 | 269 | 305 | 147 | 8.94 | 37.8 | 0.15 | 0.42 | 01479950 |
| 7.01 | 1.23 | 2.55 | 467 | 336 | 84.7 | 5.82 | 24.8 | 0.18 | 0.29 | 01480000 |
| 7.08 | 1.23 | 3.90 | 536 | 320 | 15.7 | 8.09 | 30.7 | 0.37 | 0.38 | 01480015 |
| 14.2 | 1.13 | 22.6 | 304 | 155 | 49.7 | 34.1 | 83.0 | 1.64 | 1.67 | 01480100 |
| 6.3 | 1.47 | 1.35 | 463 | 726 | 590 | 1.24 | 4.33 | 0.10 | 0.15 | 01480300 |
| 11.5 | 1.10 | 1.47 | 743 | 663 | 306 | 1.31 | 5.95 | 0.09 | 0.20 | 01480500 |
| 5.86 | 1.17 | 4.38 | 331 | 543 | 354 | 4.17 | 20.7 | 0.33 | 0.38 | 01480610 |
| 10.5 | 1.12 | 3.82 | 783 | 632 | 266 | 3.56 | 11.3 | 0.30 | 0.35 | 01480617 |
| 7.29 | 1.23 | 0.60 | 381 | 598 | 452 | 0.57 | 2.79 | 0.06 | 0.08 | 01480675 |
| 7.29 | 1.23 | 1.33 | 494 | 557 | 336 | 1.21 | 6.53 | 0.03 | 0.12 | 01480680 |
| 6.98 | 1.31 | 1.66 | 795 | 558 | 261 | 1.48 | 6.42 | 0.12 | 0.19 | 01480700 |
| 6.53 | 1.32 | 3.08 | 826 | 531 | 228 | 2.82 | 11.6 | 0.07 | 0.32 | 01480800 |
| 6.48 | 1.31 | 3.71 | 855 | 516 | 199 | 3.47 | 13.2 | 0.27 | 0.35 | 01480870 |
| 7.79 | 1.21 | 3.38 | 901 | 489 | 154 | 3.23 | 12.4 | 0.11 | 0.34 | 01481000 |
| 7.29 | 1.23 | 0.40 | 282 | 327 | 157 | 8.57 | 34.5 | 0.07 | 0.11 | 01481200 |
| 18.0 | 0.59 | 23.7 | 70.7 | 355 | 312 | 34.8 | 95.9 | 1.51 | 1.51 | 01481450 |
| 8.11 | 1.19 | 3.45 | 987 | 472 | 67.3 | 3.91 | 14.4 | 0.19 | 0.34 | 01481500 |
| 2.15 | 1.76 | 5.57 | 58.8 | 58.1 | 21.4 | 13.8 | 25.7 | 0.08 | 0.21 | 01482310 |
| 4.47 | 3.03 | 0.89 | 133 | 110 | 31.0 | 0.99 | 4.34 | 0.04 | 0.06 | 01482500 |
| 3.79 | 3.29 | 0.13 | 151 | 82.2 | 10.1 | 0.14 | 0.92 | 0.03 | 0.04 | 01483000 |
| 3.05 | 2.87 | 0.05 | 63.1 | 62.8 | 19.8 | 2.25 | 9.91 | 0.03 | 0.04 | 01483200 |
| 3.06 | 2.87 | 0.14 | 34.6 | 64.0 | 45.6 | 2.99 | 13.4 | 0.02 | 0.06 | 01483290 |
| 3.06 | 2.87 | 0.94 | 33.8 | 52.9 | 36.2 | 13.6 | 29.1 | 0.02 | 0.06 | 01483400 |
| 3.06 | 2.98 | 0.56 | 56.1 | 58.7 | 20.0 | 3.31 | 14.9 | 0.02 | 0.07 | 01483500 |
| 2.70 | 2.78 | 5.30 | 67.7 | 51.4 | 12.6 | 11.0 | 31.4 | 0.22 | 0.31 | 01483700 |
| 3.06 | 2.87 | 12.4 | 36.0 | 45.3 | 24.1 | 22.2 | 36.6 | 0.33 | 0.64 | 01483720 |

**Table 7.** Basin characteristics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; mi², square miles; ft/mi, NHD, National Hydrography Dataset; NLCD.DE, 2001 National Land Cover Dataset and 2003 Delaware land cover dataset combined; feet per mile; mi, miles; in/hr, inches per hour; ft, feet]

| USGS station number | Drainage area (mi²) | Mean stream slope (ft/mi) | 10/85 stream slope (ft/mi) | Mean basin slope (percent) | Storage (NHD) (percent) | Storage (NLCD.DE) (percent) | Forest cover (percent) | Main channel length (mi) | Basin shape factor | Hydrologic soil type A (percent) |
|---|---|---|---|---|---|---|---|---|---|---|
| 01484000 | 12.9* | 7.00 | 6.23 | 0.69 | 0.71 | 18.0 | 14.4 | 6.91 | 3.7 | 36.8 |
| 01484002 | 0.88* | 13.9 | 14.6 | 1.00 | 0.19 | 3.91 | 10.3 | 2.29 | 5.92 | 60.0 |
| 01484050 | 2.91* | 11.9 | 12.3 | 1.20 | 0.14 | 4.74 | 10.2 | 3.49 | 4.19 | 60.0 |
| 01484100 | 3.02* | 6.40 | 4.42 | 0.48 | 0.95 | 17.9 | 21.5 | 3.15 | 3.29 | 49.8 |
| 01484270 | 6.85* | 5.69 | 6.85 | 0.86 | 2.27 | 5.35 | 29.0 | 7.01 | 7.17 | 51.0 |
| 01484300 | 6.99 | 7.70 | 8.29 | 0.81 | 3.10 | 9.18 | 30.4 | 5.69 | 4.64 | 43.9 |
| 01484500 | 5.20 | 4.45 | 4.19 | 0.57 | 0.00 | 19.5 | 10.9 | 4.98 | 4.76 | 38.4 |
| 01484525 | 61.7* | 4.45 | 4.62 | 0.66 | 2.30 | 14.1 | 27.9 | 12.2 | 2.42 | 45.7 |
| 01484550 | 8.31* | 4.37 | 3.76 | 0.59 | 0.00 | 24.3 | 8.15 | 7.34 | 6.47 | 6.77 |
| 01485000 | 58.2 | 2.10 | 2.14 | 0.48 | 17.3 | 25.4 | 22.8 | 16.7 | 4.77 | 8.53 |
| 01485500 | 44.8 | 5.07 | 3.18 | 0.41 | 6.42 | 8.22 | 66.0 | 13.3 | 3.91 | 18.2 |
| 01486000 | 4.69 | 7.13 | 6.62 | 0.35 | 0.02 | 9.98 | 56.1 | 3.68 | 2.89 | 6.01 |
| 01486100 | 4.84* | 8.63 | 7.24 | 0.57 | 0.00 | 1.11 | 57.1 | 4.88 | 4.93 | 7.17 |
| 01486980 | 6.48 | 2.27 | 1.41 | 0.36 | 0.10 | 25.2 | 26.3 | 4.47 | 3.08 | 17.6 |
| 01487000 | 74.0 | 2.81 | 2.60 | 0.53 | 1.59 | 17.9 | 16.8 | 15.1 | 3.07 | 17.9 |
| 01487500 | 16.0 | 4.62 | 5.14 | 0.43 | 1.38 | 16.2 | 40.1 | 9.00 | 5.06 | 46.2 |
| 01488000 | 2.89* | 5.39 | 4.53 | 0.30 | 0.00 | 7.23 | 3.73 | 3.30 | 3.77 | 59.5 |
| 01488500 | 46.8* | 3.03 | 2.49 | 0.53 | 0.02 | 27.7 | 8.3 | 12.3 | 3.21 | 8.55 |
| 01489000 | 7.33 | 6.84 | 5.56 | 1.20 | 0.00 | 1.64 | 19.8 | 6.06 | 5.01 | 4.70 |
| 01490000 | 15.3 | 6.09 | 4.75 | 0.63 | 0.00 | 4.22 | 33.6 | 7.87 | 4.05 | 6.8 |
| 01490600 | 8.90* | 5.52 | 5.33 | 0.50 | 1.03 | 36.6 | 11.9 | 6.00 | 4.05 | 10.2 |
| 01490800 | 4.00 | 6.95 | 7.85 | 0.64 | 0.00 | 3.97 | 37.7 | 4.24 | 4.49 | 4.98 |
| 01491000 | 117 | 2.87 | 2.75 | 0.72 | 1.50 | 23.1 | 21.0 | 22.0 | 4.15 | 10.0 |
| 01491010 | 2.11* | 4.42 | 4.22 | 0.55 | 0.00 | 16.7 | 11.9 | 3.33 | 5.24 | 27.9 |
| 01491050 | 3.51* | 6.06 | 4.76 | 0.50 | 0.00 | 1.00 | 25.5 | 4.34 | 5.37 | 10.2 |
| 01492000 | 5.88 | 9.03 | 11.7 | 0.65 | 0.00 | 2.96 | 27.0 | 4.72 | 3.79 | 3.59 |
| 01492050 | 8.73 | 9.46 | 9.01 | 1.12 | 0.26 | 1.50 | 15.3 | 5.57 | 3.55 | 4.08 |
| 01492500 | 7.97 | 9.84 | 9.12 | 0.89 | 0.00 | 4.16 | 24.5 | 5.87 | 4.32 | 0.76 |
| 01492550 | 4.44 | 17.7 | 15.2 | 0.70 | 0.20 | 2.55 | 5.56 | 3.62 | 2.95 | 3.79 |
| 01493000 | 19.7 | 5.74 | 5.57 | 0.89 | 1.32 | 8.56 | 29.9 | 11.2 | 6.34 | 3.72 |
| 01493500 | 12.4 | 7.67 | 9.48 | 0.98 | 0.72 | 3.59 | 6.33 | 6.36 | 3.27 | 1.09 |
| 01494000 | 12.8 | 10.4 | 7.20 | 0.86 | 0.06 | 4.13 | 23.6 | 5.93 | 2.75 | 2.34 |
| 01495000 | 53.2 | 22.8 | 16.6 | 7.26 | 0.50 | 1.64 | 23.2 | 25.0 | 11.8 | 6.14 |
| 01495500 | 26.7 | 28.5 | 23.3 | 5.95 | 0.39 | 1.61 | 23.4 | 17.3 | 11.3 | 4.41 |
| 01496000 | 24.2 | 31.5 | 24.4 | 3.83 | 0.53 | 1.85 | 19.9 | 14.2 | 8.38 | 4.06 |
| 01496080 | 1.73 | 127 | 121 | 7.02 | 0.70 | 8.80 | 84.9 | 2.83 | 4.63 | 0.00 |

**Table 7.** Basin characteristics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; mi$^2$, square miles; ft/mi, NHD, National Hydrography Dataset; NLCD.DE, 2001 National Land Cover Dataset and 2003 Delaware land cover dataset combined; feet per mile; mi, miles; in/hr, inches per hour; ft, feet]

| Hydrologic soil type D (percent) | Average soil permeability (in/hr) | Impervious area (percent) | Basin relief (ft) | Mean basin elevation (ft) | Gage elevation (ft) | Development intensity (percent) | Developed area (percent) | Centroid year housing density (homes/acre) | 2000 Housing density (homes/acre) | USGS station number |
|---|---|---|---|---|---|---|---|---|---|---|
| 4.31 | 2.92 | 0.84 | 52.0 | 55.0 | 21.3 | 3.68 | 13.5 | 0.04 | 0.09 | 01484000 |
| 6.00 | 3.15 | 0.69 | 32.6 | 54.3 | 28.1 | 1.40 | 2.19 | 0.03 | 0.08 | 01484002 |
| 5.99 | 3.15 | 2.01 | 48.5 | 52.8 | 22.9 | 7.40 | 22.6 | 0.02 | 0.08 | 01484050 |
| 5.25 | 3.05 | 0.01 | 25.8 | 53.1 | 37.5 | 1.49 | 6.33 | 0.03 | 0.06 | 01484100 |
| 4.91 | 2.90 | 0.72 | 51.2 | 34.5 | 4.19 | 4.08 | 13.3 | 0.05 | 0.08 | 01484270 |
| 4.76 | 3.37 | 0.50 | 45.8 | 37.1 | 8.33 | 1.99 | 7.55 | 0.02 | 0.05 | 01484300 |
| 3.05 | 2.60 | 2.62 | 29.4 | 43.8 | 26.8 | 8.17 | 19.0 | 0.03 | 0.07 | 01484500 |
| 4.29 | 2.95 | 1.48 | 62.0 | 39.7 | 1.00 | 5.58 | 15.4 | 0.08 | 0.09 | 01484525 |
| 10.1 | 3.93 | 1.34 | 35.9 | 33.7 | 9.08 | 3.76 | 11.9 | 0.03 | 0.05 | 01484550 |
| 13.0 | 4.00 | 0.16 | 55.8 | 41.1 | 19.2 | 0.87 | 3.63 | 0.02 | 0.03 | 01485000 |
| 6.09 | 4.49 | 0.12 | 74.8 | 44.3 | 14.3 | 0.12 | 0.66 | 0.02 | 0.04 | 01485500 |
| 2.00 | 3.22 | 0.12 | 35.3 | 28.6 | 17.5 | 0.10 | 0.62 | 0.01 | 0.02 | 01486000 |
| 1.35 | 2.15 | 0.03 | 40.3 | 59.3 | 39.2 | 0.03 | 0.13 | 0.01 | 0.06 | 01486100 |
| 2.91 | 2.74 | 0.38 | 39.6 | 51.9 | 44.1 | 2.96 | 11.0 | 0.01 | 0.03 | 01486980 |
| 3.49 | 3.04 | 0.87 | 65.6 | 48.6 | 18.8 | 3.35 | 11.2 | 0.02 | 0.04 | 01487000 |
| 4.89 | 3.21 | 0.05 | 49.4 | 48.7 | 28.8 | 1.22 | 5.12 | 0.02 | 0.03 | 01487500 |
| 5.96 | 3.16 | 0.01 | 17.9 | 37.0 | 28.6 | 2.10 | 8.93 | 0.01 | 0.04 | 01488000 |
| 2.45 | 2.93 | 0.12 | 38.9 | 55.8 | 31.2 | 1.37 | 6.23 | 0.02 | 0.04 | 01488500 |
| 2.58 | 2.91 | 0.14 | 42.6 | 44.4 | 17.5 | 0.11 | 0.53 | 0.02 | 0.04 | 01489000 |
| 3.19 | 3.57 | 0.11 | 49.1 | 29.2 | 2.72 | 0.11 | 0.36 | 0.02 | 0.02 | 01490000 |
| 2.87 | 3.15 | 0.04 | 34.1 | 58.1 | 36.6 | 1.56 | 7.03 | 0.01 | 0.04 | 01490600 |
| 2.02 | 2.62 | 0.86 | 29.9 | 57.2 | 35.7 | 0.80 | 3.13 | 0.02 | 0.04 | 01490800 |
| 2.80 | 3.10 | 0.28 | 103 | 57.1 | 11.4 | 2.24 | 9.60 | 0.03 | 0.06 | 01491000 |
| 4.94 | 4.68 | 0.03 | 18.0 | 58.5 | 46.7 | 0.28 | 2.11 | 0.01 | 0.02 | 01491010 |
| 2.66 | 3.08 | 0.10 | 26.3 | 56.5 | 39.2 | 0.12 | 0.68 | 0.02 | 0.06 | 01491050 |
| 2.28 | 2.34 | 0.18 | 43.2 | 52.3 | 16.9 | 0.21 | 1.26 | 0.01 | 0.03 | 01492000 |
| 3.82 | 3.55 | 0.18 | 57.7 | 40.2 | 2.19 | 0.19 | 0.75 | 0.02 | 0.04 | 01492050 |
| 2.26 | 1.85 | 0.27 | 60.8 | 55.1 | 18.7 | 0.36 | 2.21 | 0.02 | 0.04 | 01492500 |
| 2.52 | 2.73 | 0.27 | 66.8 | 51.1 | 14.3 | 0.23 | 1.13 | 0.01 | 0.03 | 01492550 |
| 3.07 | 2.99 | 0.26 | 69.2 | 59.9 | 10.4 | 0.28 | 1.28 | 0.02 | 0.03 | 01493000 |
| 4.50 | 1.75 | 0.26 | 63.8 | 56.5 | 16.9 | 0.28 | 1.24 | 0.01 | 0.01 | 01493500 |
| 3.06 | 2.71 | 0.32 | 64.3 | 62.3 | 18.0 | 0.31 | 1.61 | 0.01 | 0.03 | 01494000 |
| 6.90 | 1.26 | 0.92 | 583 | 409 | 68.5 | 0.91 | 3.98 | 0.05 | 0.13 | 01495000 |
| 6.99 | 1.26 | 1.12 | 504 | 366 | 67.2 | 1.17 | 5.29 | 0.05 | 0.14 | 01495500 |
| 7.62 | 1.19 | 1.08 | 451 | 404 | 119 | 1.11 | 4.16 | 0.03 | 0.11 | 01496000 |
| 6.66 | 0.88 | 2.49 | 365 | 225 | 58.8 | 2.28 | 6.94 | 0.02 | 0.06 | 01496080 |

**Table 7.** Basin characteristics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; $mi^2$, square miles; ft/mi, NHD, National Hydrography Dataset; NLCD.DE, 2001 National Land Cover Dataset and 2003 Delaware land cover dataset combined; feet per mile; mi, miles; in/hr, inches per hour; ft, feet]

| USGS station number | Drainage area ($mi^2$) | Mean stream slope (ft/mi) | 10/85 stream slope (ft/mi) | Mean basin slope (percent) | Storage (NHD) (percent) | Storage (NLCD.DE) (percent) | Forest cover (percent) | Main channel length (mi) | Basin shape factor | Hydrologic soil type A (percent) |
|---|---|---|---|---|---|---|---|---|---|---|
| 01496200 | 8.96 | 38.1 | 30.1 | 5.25 | 0.25 | 0.52 | 15.8 | 6.71 | 5.02 | 3.79 |
| 01578200 | 5.53 | 91.0 | 71.2 | 7.43 | 0.11 | 0.74 | 18.0 | 4.76 | 4.09 | 6.25 |
| 01578400 | 6.03 | 86.6 | 70.7 | 7.10 | 0.06 | 0.96 | 18.1 | 4.36 | 3.15 | 6.25 |
| 01578500 | 192 | 16.3 | 9.50 | 7.74 | 0.93 | 2.26 | 20.2 | 41.9 | 9.14 | 5.52 |
| 01578800 | 1.37* | 66.7 | 71.2 | 3.87 | 0.78 | 1.54 | 13.0 | 1.76 | 2.27 | 5.89 |
| 01579000 | 5.26 | 52.8 | 45.2 | 4.90 | 0.48 | 1.79 | 20.5 | 3.87 | 2.85 | 5.33 |

* Indicates that drainage area has been revised as a result of this study.

**Table 7.** Basin characteristics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; mi², square miles; ft/mi, NHD, National Hydrography Dataset; NLCD.DE, 2001 National Land Cover Dataset and 2003 Delaware land cover dataset combined; feet per mile; mi, miles; in/hr, inches per hour; ft, feet]

| Hydrologic soil type D (percent) | Average soil permeability (in/hr) | Impervious area (percent) | Basin relief (ft) | Mean basin elevation (ft) | Gage elevation (ft) | Development intensity (percent) | Developed area (percent) | Centroid year housing density (homes/acre) | 2000 Housing density (homes/acre) | USGS station number |
|---|---|---|---|---|---|---|---|---|---|---|
| 8.19 | 1.18 | 0.19 | 274 | 381 | 207 | 0.17 | 0.67 | 0.08 | 0.11 | 01496200 |
| 7.29 | 1.23 | 1.18 | 434 | 656 | 472 | 1.13 | 3.28 | 0.08 | 0.11 | 01578200 |
| 7.29 | 1.23 | 0.23 | 406 | 654 | 478 | 0.20 | 0.83 | 0.03 | 0.09 | 01578400 |
| 7.70 | 1.19 | 0.69 | 839 | 500 | 84.0 | 0.63 | 2.62 | 0.04 | 0.09 | 01578500 |
| 5.52 | 1.39 | 0.10 | 142 | 367 | 299 | 0.11 | 0.55 | 0.09 | 0.15 | 01578800 |
| 5.93 | 1.37 | 0.61 | 269 | 356 | 218 | 0.62 | 3.23 | 0.07 | 0.15 | 01579000 |

**Table 8.** Flood-frequency statistics for stations in and near Delaware that were considered for use in the regression analyses.

[USGS, U.S. Geological Survey; discharges are in cubic feet per second; G is estimated from the systematic record at the streamgaging station, R is estimated from the regression equation, and W is the weighted estimate]

| USGS station number | 2-year Recurrence interval | | | 5-year Recurrence interval | | | 10-year Recurrence interval | | | 25-year Recurrence interval | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | G | R | W | G | R | W | G | R | W | G | R | W |
| 01411456 | 70 | 194 | 76 | 113 | 321 | 130 | 143 | 423 | 175 | 182 | 571 | 243 |
| 01411500 | 504 | 1,180 | 509 | 820 | 1,930 | 837 | 1,100 | 2,540 | 1,130 | 1,540 | 3,440 | 1,610 |
| 01412500 | 109 | 198 | 110 | 237 | 332 | 240 | 356 | 441 | 360 | 548 | 605 | 552 |
| 01412800 | 424 | 721 | 434 | 868 | 1,190 | 892 | 1,260 | 1,570 | 1,300 | 1,880 | 2,140 | 1,920 |
| 01467043 | 290 | 321 | 296 | 475 | 490 | 480 | 608 | 749 | 656 | 786 | 1,030 | 882 |
| 01467045 | 2,830 | 3,490 | 2,940 | 4,010 | 5,000 | 4,260 | 4,850 | 6,310 | 5,280 | 5,970 | 8,510 | 6,850 |
| 01467081 | 550 | 306 | 541 | 768 | 504 | 751 | 936 | 665 | 911 | 1,180 | 904 | 1,140 |
| 01467086 | 2,420 | 1,900 | 2,330 | 3,400 | 2,750 | 3,220 | 4,010 | 3,910 | 3,980 | 4,760 | 5,230 | 4,920 |
| 01467087 | 6,290 | 3,590 | 5,940 | 8,370 | 4,950 | 7,680 | 9,660 | 6,820 | 9,020 | 11,200 | 8,940 | 10,600 |
| 01467089 | 6,750 | 4,090 | 6,090 | 8,510 | 5,620 | 7,530 | 9,580 | 7,800 | 8,930 | 10,800 | 10,200 | 10,500 |
| 01467130 | 150 | 141 | 150 | 244 | 228 | 243 | 317 | 298 | 315 | 422 | 400 | 419 |
| 01467150 | 779 | 438 | 769 | 1,230 | 715 | 1,200 | 1,610 | 939 | 1,560 | 2,200 | 1,270 | 2,100 |
| 01467160 | 225 | 327 | 228 | 330 | 434 | 335 | 414 | 572 | 426 | 538 | 782 | 562 |
| 01467180 | 469 | 417 | 465 | 677 | 688 | 679 | 825 | 908 | 839 | 1,020 | 1,240 | 1,070 |
| 01467305 | 180 | 67 | 177 | 221 | 111 | 215 | 248 | 147 | 240 | 281 | 199 | 273 |
| 01467317 | 210 | 42 | 204 | 259 | 70 | 247 | 294 | 92 | 276 | 342 | 125 | 316 |
| 01467330 | 424 | 659 | 431 | 732 | 1,080 | 753 | 1,020 | 1,420 | 1,060 | 1,510 | 1,940 | 1,570 |
| 01467351 | 284 | 190 | 279 | 424 | 305 | 411 | 518 | 398 | 500 | 637 | 535 | 617 |
| 01472157 | 2,440 | 1,730 | 2,350 | 4,430 | 3,130 | 4,170 | 6,120 | 4,740 | 5,810 | 8,730 | 6,660 | 8,150 |
| 01472174 | 669 | 528 | 636 | 1,330 | 906 | 1,190 | 1,870 | 1,360 | 1,670 | 2,660 | 1,870 | 2,300 |
| 01473169 | 2,040 | 1,700 | 1,970 | 2,620 | 2,570 | 2,620 | 3,050 | 3,270 | 3,120 | 3,650 | 4,550 | 3,970 |
| 01473470 | 5,410 | 3,010 | 4,960 | 9,470 | 4,550 | 8,100 | 12,700 | 4,390 | 9,310 | 17,400 | 5,960 | 11,900 |
| 01474000 | 3,690 | 4,380 | 3,760 | 5,770 | 6,440 | 5,870 | 7,580 | 7,290 | 7,520 | 10,400 | 9,900 | 10,300 |
| 01475000 | 211 | 256 | 211 | 291 | 422 | 294 | 353 | 558 | 360 | 444 | 759 | 459 |
| 01475019 | 398 | 549 | 406 | 530 | 907 | 561 | 612 | 1,200 | 677 | 711 | 1,640 | 844 |
| 01475300 | 709 | 572 | 687 | 1,240 | 922 | 1,160 | 1,670 | 1,270 | 1,560 | 2,330 | 1,770 | 2,140 |
| 01475510 | 2,920 | 2,360 | 2,840 | 4,070 | 3,450 | 3,940 | 4,830 | 5,170 | 4,910 | 5,800 | 7,070 | 6,150 |
| 01475530 | 769 | 887 | 790 | 1,400 | 1,340 | 1,380 | 1,970 | 1,950 | 1,970 | 2,900 | 2,620 | 2,790 |
| 01475550 | 2,520 | 2,990 | 2,570 | 3,540 | 4,180 | 3,660 | 4,230 | 5,950 | 4,570 | 5,080 | 7,800 | 5,740 |
| 01475850 | 1,140 | 1,130 | 1,140 | 1,890 | 1,910 | 1,900 | 2,500 | 2,450 | 2,480 | 3,380 | 3,430 | 3,400 |
| 01476000 | 1,000 | 1,910 | 1,130 | 1,550 | 2,980 | 1,860 | 1,930 | 3,110 | 2,220 | 2,430 | 4,000 | 2,890 |
| 01476435 | 588 | 958 | 674 | 761 | 1,590 | 1,010 | 865 | 2,020 | 1,250 | 985 | 2,750 | 1,660 |
| 01476480 | 1,320 | 1,710 | 1,350 | 2,400 | 2,820 | 2,450 | 3,390 | 3,510 | 3,410 | 5,020 | 4,900 | 5,000 |
| 01476500 | 1,060 | 1,750 | 1,120 | 1,690 | 2,850 | 1,850 | 2,240 | 3,600 | 2,480 | 3,120 | 5,020 | 3,630 |
| 01477000 | 2,990 | 2,990 | 2,990 | 5,320 | 4,590 | 5,250 | 7,420 | 5,800 | 7,220 | 10,900 | 7,840 | 10,400 |

**Table 8.** Flood-frequency statistics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; discharges are in cubic feet per second; G is estimated from the systematic record at the streamgaging station, R is estimated from the regression equation, and W is the weighted estimate]

| 50-year Recurrence interval | | | 100-year Recurrence interval | | | 200-year Recurrence interval | | | 500-year Recurrence interval | | | USGS station number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G | R | W | G | R | W | G | R | W | G | R | W | |
| 211 | 694 | 298 | 240 | 827 | 355 | 270 | 973 | 415 | 309 | 1,190 | 497 | 01411456 |
| 1,960 | 4,200 | 2,050 | 2,460 | 5,050 | 2,580 | 3,050 | 5,980 | 3,210 | 4,020 | 7,370 | 4,220 | 01411500 |
| 724 | 745 | 725 | 929 | 901 | 926 | 1,170 | 1,080 | 1,160 | 1,540 | 1,340 | 1,510 | 01412500 |
| 2,430 | 2,630 | 2,470 | 3,060 | 3,170 | 3,080 | 3,780 | 3,780 | 3,780 | 4,870 | 4,700 | 4,830 | 01412800 |
| 922 | 1,260 | 1,060 | 1,060 | 1,500 | 1,250 | 1,200 | 1,770 | 1,450 | 1,400 | 2,160 | 1,730 | 01467043 |
| 6,850 | 10,400 | 8,140 | 7,770 | 12,400 | 9,510 | 8,730 | 14,700 | 11,000 | 10,100 | 18,100 | 13,000 | 01467045 |
| 1,380 | 1,110 | 1,340 | 1,600 | 1,330 | 1,560 | 1,850 | 1,580 | 1,810 | 2,220 | 1,960 | 2,170 | 01467081 |
| 5,290 | 6,320 | 5,670 | 5,800 | 7,500 | 6,440 | 6,300 | 8,790 | 7,220 | 6,950 | 10,700 | 8,280 | 01467086 |
| 12,300 | 10,700 | 11,800 | 13,400 | 12,500 | 13,100 | 14,400 | 14,600 | 14,400 | 15,700 | 17,500 | 16,200 | 01467087 |
| 11,700 | 12,100 | 11,900 | 12,500 | 14,300 | 13,300 | 13,400 | 16,400 | 14,700 | 14,400 | 19,800 | 16,700 | 01467089 |
| 508 | 487 | 505 | 603 | 583 | 600 | 706 | 688 | 703 | 856 | 843 | 854 | 01467130 |
| 2,730 | 1,560 | 2,580 | 3,350 | 1,880 | 3,140 | 4,080 | 2,230 | 3,790 | 5,220 | 2,760 | 4,810 | 01467150 |
| 645 | 958 | 682 | 765 | 1,160 | 816 | 901 | 1,380 | 968 | 1,110 | 1,710 | 1,200 | 01467160 |
| 1,180 | 1,520 | 1,260 | 1,340 | 1,840 | 1,470 | 1,510 | 2,200 | 1,690 | 1,740 | 2,730 | 2,020 | 01467180 |
| 306 | 242 | 299 | 331 | 289 | 326 | 356 | 341 | 354 | 391 | 417 | 394 | 01467305 |
| 379 | 152 | 348 | 419 | 181 | 384 | 460 | 214 | 423 | 520 | 261 | 479 | 01467317 |
| 1,990 | 2,390 | 2,050 | 2,590 | 2,890 | 2,640 | 3,340 | 3,450 | 3,360 | 4,620 | 4,300 | 4,550 | 01467330 |
| 725 | 652 | 709 | 813 | 782 | 806 | 901 | 925 | 907 | 1,020 | 1,140 | 1,050 | 01467351 |
| 11,000 | 8,340 | 10,200 | 13,700 | 10,300 | 12,600 | 16,700 | 12,400 | 15,300 | 21,400 | 15,700 | 19,600 | 01472157 |
| 3,320 | 2,310 | 2,820 | 4,030 | 2,780 | 3,390 | 4,800 | 3,300 | 4,020 | 5,900 | 4,070 | 4,950 | 01472174 |
| 4,150 | 5,660 | 4,710 | 4,680 | 6,900 | 5,520 | 5,260 | 8,290 | 6,400 | 6,110 | 10,400 | 7,670 | 01473169 |
| 21,400 | 7,300 | 14,100 | 25,800 | 8,780 | 16,700 | 30,500 | 10,400 | 19,700 | 37,500 | 12,900 | 24,300 | 01473470 |
| 13,100 | 12,100 | 12,800 | 16,200 | 14,600 | 15,800 | 20,000 | 17,300 | 19,200 | 26,000 | 21,400 | 24,600 | 01474000 |
| 521 | 931 | 544 | 607 | 1,120 | 639 | 703 | 1,330 | 745 | 848 | 1,650 | 904 | 01475000 |
| 782 | 2,020 | 979 | 851 | 2,440 | 1,120 | 918 | 2,920 | 1,270 | 1,000 | 3,640 | 1,470 | 01475019 |
| 2,910 | 2,190 | 2,640 | 3,560 | 2,660 | 3,200 | 4,300 | 3,170 | 3,840 | 5,420 | 3,930 | 4,820 | 01475300 |
| 6,510 | 8,710 | 7,160 | 7,230 | 10,500 | 8,210 | 7,950 | 12,500 | 9,300 | 8,920 | 15,600 | 10,800 | 01475510 |
| 3,770 | 3,160 | 3,500 | 4,800 | 3,750 | 4,310 | 6,040 | 4,390 | 5,250 | 8,040 | 5,300 | 6,700 | 01475530 |
| 5,720 | 9,300 | 6,640 | 6,350 | 10,900 | 7,560 | 6,990 | 12,600 | 8,480 | 7,840 | 15,200 | 9,710 | 01475550 |
| 4,120 | 4,280 | 4,180 | 4,950 | 5,230 | 5,060 | 5,860 | 6,290 | 6,030 | 7,210 | 7,900 | 7,480 | 01475850 |
| 2,810 | 4,690 | 3,410 | 3,190 | 5,400 | 3,920 | 3,580 | 6,130 | 4,430 | 4,100 | 7,130 | 5,110 | 01476000 |
| 1,070 | 3,350 | 1,980 | 1,150 | 4,010 | 2,300 | 1,220 | 4,720 | 2,610 | 1,320 | 5,750 | 3,010 | 01476435 |
| 6,570 | 6,100 | 6,460 | 8,440 | 7,460 | 8,190 | 10,700 | 8,980 | 10,300 | 14,400 | 11,300 | 13,600 | 01476480 |
| 3,930 | 6,240 | 4,610 | 4,890 | 7,660 | 5,740 | 6,040 | 9,150 | 7,030 | 7,900 | 11,500 | 9,060 | 01476500 |
| 14,100 | 9,560 | 13,200 | 17,900 | 11,500 | 16,600 | 22,600 | 13,500 | 20,700 | 30,200 | 16,600 | 27,300 | 01477000 |

**Table 8.** Flood-frequency statistics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; discharges are in cubic feet per second; G is estimated from the systematic record at the streamgaging station, R is estimated from the regression equation, and W is the weighted estimate]

| USGS station number | 2-year Recurrence interval | | | 5-year Recurrence interval | | | 10-year Recurrence interval | | | 25-year Recurrence interval | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | G | R | W | G | R | W | G | R | W | G | R | W |
| 01477110 | 328 | 443 | 331 | 633 | 726 | 638 | 910 | 955 | 914 | 1,360 | 1,300 | 1,350 |
| 01477120 | 717 | 743 | 718 | 1,180 | 1,220 | 1,180 | 1,510 | 1,610 | 1,520 | 1,950 | 2,190 | 1,970 |
| 01477480 | 391 | 449 | 393 | 574 | 738 | 585 | 699 | 972 | 724 | 861 | 1,320 | 917 |
| 01477500 | 655 | 543 | 649 | 1,200 | 891 | 1,170 | 1,720 | 1,170 | 1,640 | 2,620 | 1,600 | 2,400 |
| 01477800 | 2,440 | 1,820 | 2,380 | 3,480 | 2,810 | 3,400 | 4,320 | 3,120 | 4,130 | 5,560 | 4,100 | 5,280 |
| 01478000 | 1,810 | 1,810 | 1,810 | 2,730 | 2,780 | 2,740 | 3,430 | 3,550 | 3,450 | 4,410 | 4,860 | 4,490 |
| 01478040 | 1,980 | 3,080 | 2,150 | 2,920 | 4,640 | 3,300 | 3,620 | 4,810 | 3,960 | 4,580 | 6,370 | 5,210 |
| 01478200 | 990 | 1,140 | 1,010 | 1,680 | 2,130 | 1,760 | 2,240 | 3,230 | 2,420 | 3,060 | 4,400 | 3,380 |
| 01478500 | 4,830 | 2,870 | 4,580 | 6,710 | 4,970 | 6,410 | 8,190 | 7,650 | 8,090 | 10,400 | 10,600 | 10,400 |
| 01478650 | 4,340 | 2,900 | 3,860 | 8,480 | 5,010 | 6,870 | 12,100 | 7,640 | 9,810 | 17,700 | 10,500 | 13,400 |
| 01479000 | 3,820 | 3,950 | 3,830 | 6,070 | 6,270 | 6,090 | 7,840 | 9,260 | 7,990 | 10,400 | 12,700 | 10,700 |
| 01479200 | 557 | 770 | 617 | 900 | 1,280 | 1,040 | 1,190 | 1,760 | 1,430 | 1,630 | 2,320 | 1,970 |
| 01479820 | 1,850 | 1,920 | 1,860 | 3,480 | 3,220 | 3,410 | 4,980 | 4,450 | 4,800 | 7,420 | 5,940 | 6,800 |
| 01479950 | 47 | 67 | 52 | 84 | 136 | 102 | 117 | 228 | 159 | 169 | 329 | 240 |
| 01480000 | 2,200 | 2,360 | 2,210 | 3,490 | 4,010 | 3,540 | 4,560 | 5,080 | 4,620 | 6,170 | 6,640 | 6,240 |
| 01480015 | 2,840 | 2,710 | 2,820 | 5,500 | 4,440 | 5,170 | 7,770 | 5,620 | 7,000 | 11,300 | 7,340 | 9,520 |
| 01480100 | 963 | 984 | 967 | 1,760 | 1,460 | 1,670 | 2,490 | 2,120 | 2,360 | 3,730 | 2,830 | 3,330 |
| 01480300 | 1,220 | 1,310 | 1,230 | 2,160 | 2,380 | 2,190 | 2,930 | 3,570 | 3,040 | 4,080 | 4,930 | 4,260 |
| 01480500 | 1,940 | 2,220 | 1,960 | 3,530 | 3,900 | 3,580 | 4,900 | 4,900 | 4,900 | 7,030 | 6,730 | 6,970 |
| 01480610 | 342 | 327 | 340 | 601 | 565 | 594 | 805 | 815 | 807 | 1,100 | 1,150 | 1,110 |
| 01480617 | 2,620 | 2,660 | 2,620 | 4,600 | 4,370 | 4,560 | 6,150 | 5,600 | 6,040 | 8,360 | 7,690 | 8,180 |
| 01480675 | 243 | 485 | 260 | 409 | 914 | 461 | 538 | 844 | 584 | 722 | 1,020 | 781 |
| 01480680 | 659 | 903 | 714 | 851 | 1,620 | 1,070 | 978 | 1,550 | 1,180 | 1,140 | 1,880 | 1,450 |
| 01480700 | 2,400 | 2,210 | 2,380 | 3,860 | 3,790 | 3,850 | 4,890 | 4,230 | 4,780 | 6,240 | 5,380 | 6,060 |
| 01480800 | 3,680 | 2,950 | 3,480 | 4,800 | 4,860 | 4,820 | 5,640 | 5,670 | 5,650 | 6,800 | 7,300 | 7,040 |
| 01480870 | 3,490 | 3,180 | 3,460 | 5,060 | 5,120 | 5,070 | 6,070 | 6,050 | 6,070 | 7,320 | 7,850 | 7,410 |
| 01481000 | 6,980 | 7,700 | 7,010 | 11,000 | 12,300 | 11,100 | 14,100 | 16,100 | 14,300 | 18,500 | 21,500 | 18,800 |
| 01481200 | 110 | 112 | 110 | 227 | 223 | 226 | 336 | 372 | 352 | 516 | 537 | 527 |
| 01481450 | 247 | 342 | 270 | 371 | 565 | 432 | 466 | 480 | 472 | 600 | 619 | 609 |
| 01481500 | 7,810 | 8,260 | 7,840 | 12,400 | 13,100 | 12,500 | 16,100 | 17,000 | 16,200 | 21,300 | 22,700 | 21,500 |
| 01482310 | 130 | 122 | 129 | 209 | 205 | 208 | 274 | 274 | 274 | 369 | 376 | 371 |
| 01482500 | 667 | 513 | 664 | 1,370 | 846 | 1,350 | 2,050 | 1,120 | 2,000 | 3,220 | 1,520 | 3,080 |
| 01483000 | 519 | 506 | 519 | 948 | 826 | 938 | 1,300 | 1,080 | 1,280 | 1,830 | 1,470 | 1,770 |
| 01483200 | 147 | 195 | 148 | 268 | 324 | 270 | 371 | 429 | 373 | 529 | 584 | 533 |
| 01483290 | 138 | 73 | 132 | 220 | 121 | 204 | 290 | 160 | 261 | 402 | 217 | 347 |

**Table 8.** Flood-frequency statistics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; discharges are in cubic feet per second; G is estimated from the systematic record at the streamgaging station, R is estimated from the regression equation, and W is the weighted estimate]

| 50-year Recurrence interval | | | 100-year Recurrence interval | | | 200-year Recurrence interval | | | 500-year Recurrence interval | | | USGS station number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G | R | W | G | R | W | G | R | W | G | R | W | |
| 1,780 | 1,590 | 1,750 | 2,280 | 1,920 | 2,220 | 2,870 | 2,290 | 2,760 | 3,820 | 2,840 | 3,620 | 01477110 |
| 2,280 | 2,690 | 2,320 | 2,620 | 3,260 | 2,680 | 2,960 | 3,900 | 3,060 | 3,420 | 4,850 | 3,580 | 01477120 |
| 983 | 1,620 | 1,070 | 1,110 | 1,960 | 1,240 | 1,230 | 2,340 | 1,410 | 1,400 | 2,900 | 1,640 | 01477480 |
| 3,490 | 1,960 | 3,100 | 4,590 | 2,370 | 3,950 | 5,960 | 2,820 | 4,970 | 8,300 | 3,500 | 6,650 | 01477500 |
| 6,650 | 4,900 | 6,270 | 7,880 | 5,740 | 7,390 | 9,280 | 6,650 | 8,670 | 11,400 | 7,950 | 10,600 | 01477800 |
| 5,220 | 5,970 | 5,360 | 6,080 | 7,200 | 6,300 | 7,020 | 8,560 | 7,320 | 8,380 | 10,600 | 8,800 | 01478000 |
| 5,370 | 7,640 | 6,220 | 6,200 | 9,010 | 7,290 | 7,100 | 10,500 | 8,430 | 8,400 | 12,600 | 10,000 | 01478040 |
| 3,750 | 5,400 | 4,180 | 4,520 | 6,500 | 5,060 | 5,380 | 7,710 | 6,020 | 6,650 | 9,510 | 7,440 | 01478200 |
| 12,200 | 13,100 | 12,400 | 14,300 | 16,000 | 14,700 | 16,600 | 19,300 | 17,200 | 20,100 | 24,300 | 21,100 | 01478500 |
| 22,800 | 13,000 | 16,700 | 28,500 | 15,900 | 20,400 | 35,100 | 19,000 | 24,600 | 45,200 | 24,000 | 31,300 | 01478650 |
| 12,600 | 15,800 | 13,000 | 15,000 | 19,200 | 15,600 | 17,600 | 23,100 | 18,500 | 21,600 | 28,900 | 22,700 | 01479000 |
| 2,020 | 2,760 | 2,420 | 2,480 | 3,240 | 2,900 | 3,010 | 3,730 | 3,420 | 3,830 | 4,440 | 4,180 | 01479200 |
| 9,710 | 7,180 | 8,540 | 12,500 | 8,520 | 10,500 | 15,700 | 9,980 | 12,800 | 21,100 | 12,100 | 16,400 | 01479820 |
| 217 | 415 | 311 | 273 | 512 | 390 | 339 | 618 | 478 | 443 | 778 | 612 | 01479950 |
| 7,600 | 7,890 | 7,640 | 9,220 | 9,220 | 9,220 | 11,100 | 10,600 | 11,000 | 14,000 | 12,600 | 13,700 | 01480000 |
| 14,300 | 8,720 | 11,600 | 17,800 | 10,200 | 14,000 | 21,700 | 11,800 | 16,600 | 27,700 | 14,000 | 20,500 | 01480015 |
| 4,910 | 3,400 | 4,190 | 6,370 | 4,040 | 5,240 | 8,160 | 4,700 | 6,340 | 11,100 | 5,660 | 8,180 | 01480100 |
| 5,070 | 6,090 | 5,310 | 6,180 | 7,390 | 6,480 | 7,410 | 8,840 | 7,770 | 9,260 | 11,000 | 9,710 | 01480300 |
| 8,940 | 8,300 | 8,780 | 11,100 | 10,000 | 10,900 | 13,700 | 12,000 | 13,200 | 17,600 | 14,900 | 16,900 | 01480500 |
| 1,340 | 1,430 | 1,370 | 1,610 | 1,740 | 1,650 | 1,900 | 2,090 | 1,950 | 2,310 | 2,610 | 2,400 | 01480610 |
| 10,200 | 9,470 | 9,990 | 12,100 | 11,500 | 11,900 | 14,200 | 13,700 | 14,100 | 17,200 | 17,100 | 17,200 | 01480617 |
| 873 | 1,130 | 932 | 1,040 | 1,240 | 1,090 | 1,210 | 1,330 | 1,240 | 1,470 | 1,440 | 1,460 | 01480675 |
| 1,260 | 2,110 | 1,640 | 1,380 | 2,330 | 1,820 | 1,500 | 2,510 | 1,980 | 1,660 | 2,750 | 2,170 | 01480680 |
| 7,260 | 6,260 | 7,030 | 8,310 | 7,150 | 8,030 | 9,370 | 8,060 | 9,040 | 10,800 | 9,280 | 10,400 | 01480700 |
| 7,760 | 8,580 | 8,170 | 8,780 | 9,990 | 9,400 | 9,890 | 11,300 | 10,600 | 11,500 | 13,300 | 12,500 | 01480800 |
| 8,220 | 9,280 | 8,410 | 9,090 | 10,800 | 9,410 | 9,950 | 12,400 | 10,400 | 11,100 | 14,600 | 11,700 | 01480870 |
| 22,100 | 26,100 | 22,600 | 26,100 | 31,400 | 26,800 | 30,500 | 36,800 | 31,300 | 36,900 | 45,500 | 38,000 | 01481000 |
| 683 | 679 | 681 | 883 | 839 | 858 | 1,120 | 1,020 | 1,060 | 1,500 | 1,290 | 1,370 | 01481200 |
| 711 | 724 | 717 | 831 | 829 | 830 | 962 | 936 | 947 | 1,150 | 1,080 | 1,110 | 01481450 |
| 25,700 | 27,500 | 26,000 | 30,400 | 32,900 | 30,900 | 35,700 | 38,800 | 36,300 | 43,500 | 47,600 | 44,200 | 01481500 |
| 451 | 463 | 455 | 542 | 560 | 548 | 645 | 670 | 653 | 800 | 833 | 812 | 01482310 |
| 4,360 | 1,870 | 4,110 | 5,770 | 2,260 | 5,370 | 7,510 | 2,700 | 6,900 | 10,400 | 3,360 | 9,430 | 01482500 |
| 2,290 | 1,800 | 2,190 | 2,800 | 2,170 | 2,660 | 3,370 | 2,580 | 3,180 | 4,210 | 3,200 | 3,960 | 01483000 |
| 670 | 715 | 674 | 831 | 862 | 834 | 1,020 | 1,020 | 1,020 | 1,300 | 1,260 | 1,300 | 01483200 |
| 504 | 265 | 423 | 625 | 318 | 510 | 769 | 376 | 611 | 1,000 | 460 | 771 | 01483290 |

**Table 8.** Flood-frequency statistics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; discharges are in cubic feet per second; G is estimated from the systematic record at the streamgaging station, R is estimated from the regression equation, and W is the weighted estimate]

| USGS station number | 2-year Recurrence interval | | | 5-year Recurrence interval | | | 10-year Recurrence interval | | | 25-year Recurrence interval | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | G | R | W | G | R | W | G | R | W | G | R | W |
| 01483400 | 24 | 44 | 25 | 32 | 74 | 36 | 38 | 97 | 45 | 46 | 132 | 58 |
| 01483500 | 217 | 317 | 219 | 415 | 526 | 420 | 606 | 695 | 612 | 937 | 946 | 938 |
| 01483700 | 517 | 680 | 520 | 856 | 1,130 | 866 | 1,100 | 1,500 | 1,120 | 1,420 | 2,040 | 1,460 |
| 01483720 | 145 | 118 | 143 | 270 | 198 | 259 | 375 | 262 | 351 | 533 | 356 | 482 |
| 01484000 | 307 | 171 | 302 | 575 | 280 | 555 | 790 | 367 | 749 | 1,100 | 491 | 1,020 |
| 01484002 | 19 | 25 | 19 | 32 | 40 | 33 | 44 | 52 | 46 | 66 | 70 | 67 |
| 01484050 | 63 | 61 | 63 | 112 | 99 | 110 | 157 | 129 | 152 | 233 | 172 | 217 |
| 01484100 | 51 | 50 | 51 | 81 | 82 | 81 | 103 | 107 | 103 | 133 | 143 | 134 |
| 01484270 | 36 | 106 | 38 | 55 | 173 | 60 | 69 | 226 | 79 | 91 | 302 | 111 |
| 01484300 | 36 | 110 | 37 | 56 | 180 | 60 | 72 | 236 | 81 | 97 | 315 | 114 |
| 01484500 | 120 | 84 | 119 | 160 | 137 | 160 | 190 | 180 | 189 | 231 | 241 | 231 |
| 01484525 | 562 | 482 | 555 | 970 | 786 | 939 | 1,300 | 1,030 | 1,240 | 1,800 | 1,380 | 1,670 |
| 01484550 | 269 | 192 | 265 | 402 | 321 | 394 | 495 | 423 | 485 | 616 | 574 | 608 |
| 01485000 | 832 | 676 | 829 | 1,130 | 1,130 | 1,130 | 1,360 | 1,490 | 1,370 | 1,700 | 2,010 | 1,720 |
| 01485500 | 827 | 434 | 818 | 1,180 | 719 | 1,160 | 1,430 | 946 | 1,400 | 1,770 | 1,270 | 1,730 |
| 01486000 | 142 | 113 | 142 | 246 | 189 | 243 | 326 | 251 | 321 | 438 | 339 | 431 |
| 01486100 | 97 | 128 | 99 | 144 | 213 | 152 | 178 | 281 | 194 | 222 | 380 | 255 |
| 01486980 | 39 | 107 | 42 | 60 | 177 | 69 | 74 | 234 | 93 | 93 | 314 | 127 |
| 01487000 | 1,000 | 673 | 995 | 1,440 | 1,110 | 1,430 | 1,780 | 1,460 | 1,770 | 2,290 | 1,970 | 2,270 |
| 01487500 | 208 | 162 | 206 | 332 | 266 | 327 | 425 | 348 | 417 | 554 | 465 | 541 |
| 01488000 | 9 | 40 | 10 | 25 | 66 | 27 | 42 | 86 | 46 | 74 | 114 | 79 |
| 01488500 | 2,160 | 597 | 2,120 | 2,830 | 992 | 2,740 | 3,260 | 1,310 | 3,130 | 3,780 | 1,770 | 3,600 |
| 01489000 | 471 | 239 | 465 | 724 | 397 | 708 | 930 | 524 | 901 | 1,240 | 714 | 1,190 |
| 01490000 | 232 | 302 | 233 | 376 | 502 | 381 | 488 | 664 | 499 | 651 | 899 | 672 |
| 01490600 | 221 | 172 | 217 | 315 | 286 | 311 | 394 | 377 | 390 | 512 | 509 | 511 |
| 01490800 | 177 | 127 | 173 | 278 | 212 | 268 | 352 | 280 | 337 | 452 | 380 | 432 |
| 01491000 | 1,850 | 1,200 | 1,840 | 3,310 | 1,980 | 3,250 | 4,450 | 2,620 | 4,340 | 6,070 | 3,540 | 5,860 |
| 01491010 | 63 | 48 | 61 | 130 | 79 | 121 | 204 | 104 | 180 | 354 | 139 | 281 |
| 01491050 | 63 | 89 | 65 | 105 | 148 | 110 | 144 | 195 | 153 | 212 | 263 | 224 |
| 01492000 | 266 | 181 | 263 | 504 | 303 | 492 | 728 | 402 | 698 | 1,110 | 546 | 1,030 |
| 01492050 | 88 | 275 | 96 | 143 | 456 | 167 | 190 | 604 | 236 | 262 | 820 | 349 |
| 01492500 | 222 | 330 | 225 | 462 | 556 | 466 | 690 | 740 | 694 | 1,080 | 1,010 | 1,070 |
| 01492550 | 113 | 150 | 115 | 184 | 251 | 192 | 250 | 332 | 263 | 361 | 451 | 381 |
| 01493000 | 622 | 466 | 619 | 879 | 776 | 876 | 1,080 | 1,030 | 1,080 | 1,390 | 1,400 | 1,390 |
| 01493500 | 377 | 441 | 378 | 856 | 740 | 852 | 1,390 | 985 | 1,370 | 2,420 | 1,350 | 2,330 |

**Table 8.** Flood-frequency statistics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; discharges are in cubic feet per second; G is estimated from the systematic record at the streamgaging station, R is estimated from the regression equation, and W is the weighted estimate]

| 50-year Recurrence interval | | | 100-year Recurrence interval | | | 200-year Recurrence interval | | | 500-year Recurrence interval | | | USGS station number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G | R | W | G | R | W | G | R | W | G | R | W | |
| 51 | 162 | 69 | 57 | 194 | 80 | 63 | 229 | 92 | 70 | 281 | 109 | 01483400 |
| 1,260 | 1,160 | 1,250 | 1,680 | 1,400 | 1,640 | 2,190 | 1,660 | 2,110 | 3,080 | 2,050 | 2,890 | 01483500 |
| 1,660 | 2,500 | 1,730 | 1,910 | 3,010 | 2,010 | 2,160 | 3,580 | 2,300 | 2,510 | 4,420 | 2,700 | 01483700 |
| 670 | 435 | 591 | 822 | 521 | 712 | 993 | 616 | 846 | 1,250 | 756 | 1,050 | 01483720 |
| 1,360 | 594 | 1,240 | 1,640 | 706 | 1,470 | 1,940 | 826 | 1,720 | 2,380 | 1,000 | 2,090 | 01484000 |
| 87 | 84 | 86 | 114 | 99 | 109 | 147 | 115 | 137 | 205 | 138 | 181 | 01484002 |
| 306 | 208 | 275 | 395 | 246 | 343 | 504 | 287 | 421 | 687 | 347 | 546 | 01484050 |
| 157 | 172 | 158 | 182 | 203 | 184 | 208 | 236 | 211 | 245 | 283 | 249 | 01484100 |
| 109 | 364 | 137 | 128 | 433 | 165 | 151 | 506 | 198 | 184 | 609 | 245 | 01484270 |
| 119 | 381 | 143 | 144 | 452 | 176 | 172 | 529 | 214 | 217 | 639 | 270 | 01484300 |
| 264 | 290 | 266 | 299 | 343 | 303 | 338 | 401 | 343 | 393 | 483 | 400 | 01484500 |
| 2,230 | 1,670 | 2,030 | 2,700 | 1,990 | 2,420 | 3,240 | 2,330 | 2,860 | 4,040 | 2,840 | 3,510 | 01484525 |
| 708 | 696 | 705 | 802 | 833 | 809 | 898 | 981 | 918 | 1,030 | 1,190 | 1,070 | 01484550 |
| 1,980 | 2,450 | 2,020 | 2,300 | 2,930 | 2,350 | 2,650 | 3,460 | 2,730 | 3,180 | 4,240 | 3,280 | 01485000 |
| 2,040 | 1,550 | 2,000 | 2,330 | 1,840 | 2,280 | 2,640 | 2,160 | 2,580 | 3,070 | 2,630 | 3,020 | 01485500 |
| 530 | 411 | 519 | 629 | 488 | 614 | 734 | 572 | 716 | 885 | 694 | 863 | 01486000 |
| 257 | 462 | 306 | 292 | 550 | 359 | 329 | 647 | 415 | 380 | 787 | 494 | 01486100 |
| 108 | 379 | 156 | 123 | 449 | 187 | 139 | 524 | 218 | 160 | 632 | 261 | 01486980 |
| 2,720 | 2,400 | 2,690 | 3,200 | 2,860 | 3,170 | 3,740 | 3,370 | 3,700 | 4,550 | 4,110 | 4,500 | 01487000 |
| 659 | 561 | 643 | 772 | 664 | 752 | 892 | 774 | 869 | 1,060 | 933 | 1,040 | 01487500 |
| 106 | 137 | 111 | 147 | 161 | 149 | 197 | 186 | 195 | 283 | 222 | 269 | 01488000 |
| 4,160 | 2,160 | 3,960 | 4,540 | 2,590 | 4,320 | 4,900 | 3,050 | 4,690 | 5,390 | 3,740 | 5,190 | 01488500 |
| 1,510 | 870 | 1,440 | 1,820 | 1,050 | 1,720 | 2,170 | 1,240 | 2,040 | 2,710 | 1,520 | 2,530 | 01489000 |
| 787 | 1,100 | 818 | 936 | 1,310 | 979 | 1,100 | 1,540 | 1,160 | 1,340 | 1,890 | 1,410 | 01490000 |
| 618 | 618 | 618 | 739 | 735 | 738 | 880 | 863 | 874 | 1,100 | 1,050 | 1,080 | 01490600 |
| 531 | 462 | 510 | 614 | 552 | 593 | 701 | 650 | 683 | 823 | 793 | 812 | 01490800 |
| 7,400 | 4,330 | 7,090 | 8,830 | 5,200 | 8,420 | 10,400 | 6,150 | 9,850 | 12,600 | 7,570 | 11,900 | 01491000 |
| 523 | 167 | 380 | 761 | 198 | 503 | 1,100 | 231 | 660 | 1,760 | 277 | 936 | 01491010 |
| 277 | 319 | 289 | 359 | 379 | 366 | 462 | 444 | 456 | 640 | 538 | 602 | 01491050 |
| 1,480 | 666 | 1,340 | 1,930 | 797 | 1,720 | 2,490 | 941 | 2,170 | 3,420 | 1,150 | 2,910 | 01492000 |
| 327 | 1,000 | 452 | 403 | 1,210 | 569 | 491 | 1,430 | 702 | 630 | 1,760 | 904 | 01492050 |
| 1,440 | 1,240 | 1,420 | 1,890 | 1,500 | 1,830 | 2,430 | 1,780 | 2,320 | 3,320 | 2,200 | 3,120 | 01492500 |
| 467 | 550 | 489 | 598 | 658 | 616 | 761 | 776 | 765 | 1,040 | 949 | 1,000 | 01492550 |
| 1,650 | 1,710 | 1,660 | 1,940 | 2,060 | 1,960 | 2,280 | 2,440 | 2,290 | 2,790 | 3,010 | 2,810 | 01493000 |
| 3,560 | 1,650 | 3,340 | 5,110 | 2,000 | 4,690 | 7,220 | 2,380 | 6,460 | 11,200 | 2,940 | 9,700 | 01493500 |

**Table 8.** Flood-frequency statistics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; discharges are in cubic feet per second; G is estimated from the systematic record at the streamgaging station, R is estimated from the regression equation, and W is the weighted estimate]

| USGS station number | 2-year Recurrence interval | | | 5-year Recurrence interval | | | 10-year Recurrence interval | | | 25-year Recurrence interval | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | G | R | W | G | R | W | G | R | W | G | R | W |
| 01494000 | 477 | 377 | 470 | 839 | 631 | 813 | 1,150 | 838 | 1,100 | 1,650 | 1,140 | 1,520 |
| 01495000 | 2,940 | 2,500 | 2,910 | 4,970 | 4,500 | 4,930 | 6,610 | 6,650 | 6,620 | 9,030 | 9,060 | 9,040 |
| 01495500 | 1,780 | 1,660 | 1,750 | 2,600 | 3,020 | 2,760 | 3,240 | 4,270 | 3,660 | 4,170 | 5,860 | 4,970 |
| 01496000 | 1,540 | 1,710 | 1,560 | 2,530 | 3,140 | 2,620 | 3,380 | 4,150 | 3,510 | 4,710 | 5,580 | 4,900 |
| 01496080 | 290 | 198 | 262 | 496 | 353 | 440 | 653 | 359 | 505 | 869 | 516 | 671 |
| 01496200 | 1,090 | 934 | 1,070 | 2,140 | 1,860 | 2,080 | 3,080 | 2,510 | 2,930 | 4,580 | 3,400 | 4,170 |
| 01578200 | 455 | 612 | 471 | 874 | 1,150 | 917 | 1,260 | 1,790 | 1,360 | 1,920 | 2,470 | 2,050 |
| 01578400 | 636 | 610 | 631 | 1,300 | 1,220 | 1,280 | 1,980 | 1,920 | 1,960 | 3,230 | 2,660 | 3,000 |
| 01578500 | 4,560 | 6,480 | 4,660 | 9,540 | 11,600 | 9,720 | 14,200 | 15,300 | 14,400 | 22,000 | 20,300 | 21,800 |
| 01578800 | 447 | 262 | 381 | 707 | 551 | 636 | 890 | 681 | 789 | 1,130 | 879 | 991 |
| 01579000 | 598 | 549 | 590 | 1,040 | 1,070 | 1,050 | 1,400 | 1,490 | 1,420 | 1,900 | 2,000 | 1,950 |

**Table 8.** Flood-frequency statistics for stations in and near Delaware that were considered for use in the regression analyses.—Continued

[USGS, U.S. Geological Survey; discharges are in cubic feet per second; G is estimated from the systematic record at the streamgaging station, R is estimated from the regression equation, and W is the weighted estimate]

| 50-year Recurrence interval | | | 100-year Recurrence interval | | | 200-year Recurrence interval | | | 500-year Recurrence interval | | | USGS station number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G | R | W | G | R | W | G | R | W | G | R | W | |
| 2,110 | 1,400 | 1,900 | 2,640 | 1,680 | 2,330 | 3,270 | 2,000 | 2,820 | 4,260 | 2,460 | 3,590 | 01494000 |
| 11,100 | 11,100 | 11,100 | 13,400 | 13,400 | 13,400 | 16,000 | 15,900 | 16,000 | 19,800 | 19,700 | 19,800 | 01495000 |
| 4,960 | 7,210 | 6,080 | 5,830 | 8,720 | 7,310 | 6,810 | 10,400 | 8,660 | 8,290 | 12,900 | 10,600 | 01495500 |
| 5,910 | 6,780 | 6,120 | 7,310 | 8,090 | 7,520 | 8,960 | 9,520 | 9,110 | 11,600 | 11,600 | 11,600 | 01496000 |
| 1,040 | 651 | 815 | 1,230 | 801 | 975 | 1,420 | 967 | 1,150 | 1,690 | 1,210 | 1,410 | 01496080 |
| 5,940 | 4,140 | 5,250 | 7,520 | 4,950 | 6,480 | 9,350 | 5,840 | 7,900 | 12,200 | 7,140 | 10,100 | 01496200 |
| 2,540 | 3,040 | 2,670 | 3,290 | 3,680 | 3,400 | 4,210 | 4,380 | 4,260 | 5,730 | 5,430 | 5,640 | 01578200 |
| 4,520 | 3,300 | 3,960 | 6,220 | 4,000 | 5,130 | 8,410 | 4,790 | 6,560 | 12,300 | 5,960 | 8,960 | 01578400 |
| 29,400 | 24,400 | 28,500 | 38,200 | 28,900 | 36,400 | 48,800 | 33,800 | 45,800 | 65,900 | 41,100 | 60,600 | 01578500 |
| 1,310 | 1,030 | 1,150 | 1,500 | 1,180 | 1,310 | 1,680 | 1,330 | 1,470 | 1,940 | 1,540 | 1,700 | 01578800 |
| 2,320 | 2,420 | 2,380 | 2,780 | 2,890 | 2,840 | 3,270 | 3,370 | 3,330 | 3,990 | 4,080 | 4,040 | 01579000 |