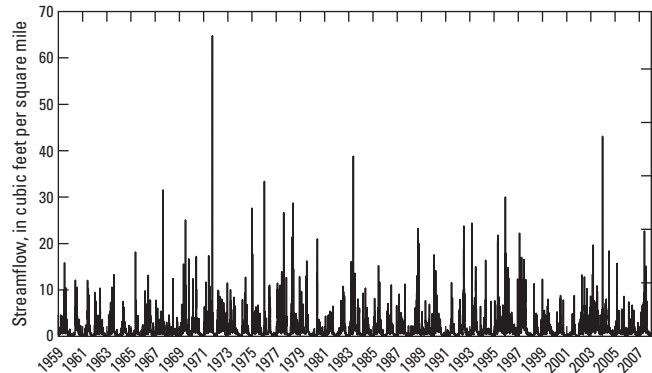
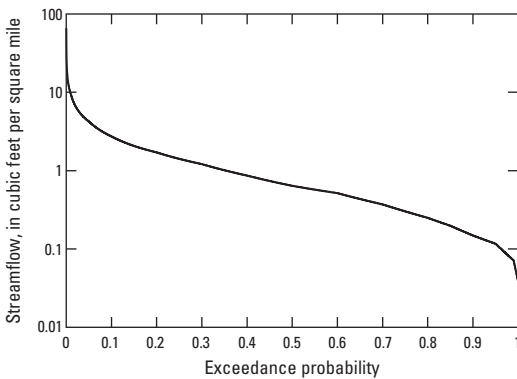
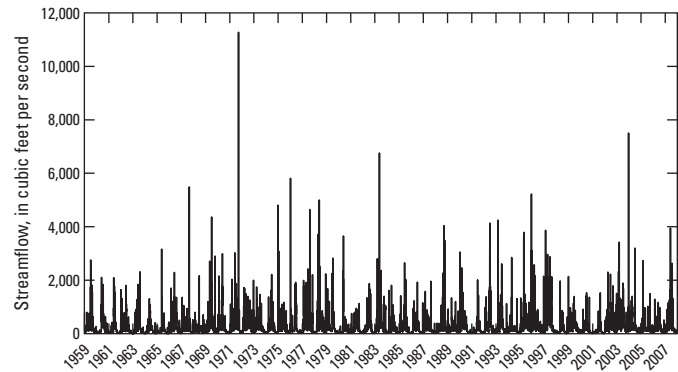
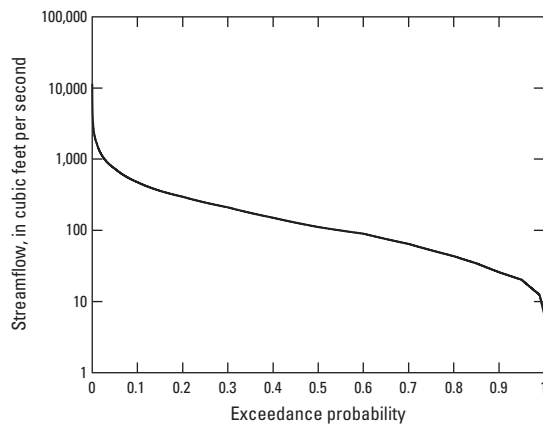


Prepared in cooperation with the Pennsylvania Department of Environmental Protection, the Susquehanna River Basin Commission, and The Nature Conservancy

Estimation of Baseline Daily Mean Streamflows for Ungaged Locations on Pennsylvania Streams, Water Years 1960–2008



Scientific Investigations Report 2012–5142
Version 1.1, August 2014

Cover. Estimated flow-duration curves and hydrographs generated by the **Baseline Streamflow Estimator**.

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By Marla Stuckey, Edward Koerkle, James Ulrich

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Version 1.1, August 2014

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

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m ²)
square mile (mi ²)	259.0	hectare (ha)
square mile (mi ²)	2.590	square kilometer (km ²)
Volume		
gallon (gal)	0.003785	cubic meter (m ³)
gallon (gal)	3.785	cubic decimeter (dm ³)
million gallons (Mgal)	3,785	cubic meter (m ³)
acre-foot (acre-ft)	1,233	cubic decimeter (dm ³)
acre-foot (acre-ft)	0.001233	cubic meter (m ³)
Flow rate		
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)
cubic foot per second per square mile [(ft ³ /s)/mi ²]	0.01093	cubic meter per second per square kilometer [(m ³ /s)/km ²]
cubic foot per day (ft ³ /d)	0.02832	cubic meter per second (m ³ /s)
gallon per day (gal/d)	0.003785	cubic meter per day (m ³ /d)
gallon per day per square mile [(gal/d)/mi ²]	1,233	cubic meter (m ³)
million gallons per day (Mgal/d)	0.001233	cubic hectometer (hm ³)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
 $^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$

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

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

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

Acronyms

BaSE	Baseline Streamflow Estimator
FDC	Flow duration curve
GIS	Geographic Information System
GNWISQ	Get NWIS WEB Streamflow Data Files
HUC	Hydrologic Accounting Unit Code
LOC	Line of organic correlation
MASYE	Massachusetts Safe Yield Estimator
MkPP	Make Plotting Position File
MOVE	Maintenance of variance
NS	Nash-Sutcliffe efficiency value
NWIS	National Water Information System
OLS	Ordinary least squares regression
P _n	nth percentile from flow duration curve
QPPQ	Methodology equating the streamflow as a percentile from a flow duration curve for a particular day at an ungaged location to the streamflow as a percentile from the flow duration curve for the same day at a reference streamgage
RMSE	Root mean square error
SREF	Streamflow Record Extension Facilitator
WLS	Weighted least squares regression
WY	Water year

Estimation of Baseline Daily Mean Streamflows for Ungaged Locations on Pennsylvania Streams, Water Years 1960–2008

By Marla H. Stuckey, Edward H. Koerkle, and James E. Ulrich

Abstract

Water-resource managers use daily mean streamflows to generate streamflow statistics and analyze streamflow conditions. An in-depth evaluation of flow regimes to promote instream ecological health often requires streamflow information obtainable only from a time series hydrograph. Historically, it has been difficult to estimate daily mean streamflow for an ungaged location. The U.S. Geological Survey, in cooperation with the Pennsylvania Department of Environmental Protection, Susquehanna River Basin Commission, and The Nature Conservancy, has developed the **Baseline Streamflow Estimator (BaSE)** to estimate baseline streamflow at a daily time scale for ungaged streams in Pennsylvania using data collected during water years 1960–2008. Baseline streamflow is minimally altered by regulation, diversion, or mining, and other anthropogenic activities. Daily mean streamflow is estimated in BaSE using a methodology that equates streamflow as a percentile from a flow duration curve for a particular day at an ungaged location with streamflow as a percentile from the flow duration curve for the same day at a reference streamgage that is considered to be hydrologically similar to the ungaged location. An appropriate reference streamgage is selected using map correlation, in which variogram models are developed that correlate streamflow at one streamgage with streamflows at all other streamgages. The percentiles from a flow duration curve for the ungaged location are converted to streamflow through the use of regression equations. Regression equations used to predict 17 flow-duration exceedance probabilities were developed for Pennsylvania using geographic information system-derived basin characteristics. The standard error of prediction for the regression equations ranged from 11 percent to 92 percent with the mean of 31 percent.

The map correlation method for estimating streamflow was tested at locations within two pilot basins, the Upper Delaware River Basin and the Lower Susquehanna River Basin, before being applied statewide. Reference streamgages

within the pilot basins were used as ungaged locations for analyzing the map correlation method. Correlation using Spearman's rho and centroid distance performed as well as, or better than, the method using the closest streamgage as a reference streamgage. Map correlation using the correlation metrics identified in the pilot basins was applied to 156 streamgages in and near Pennsylvania.

BaSE uses the map correlation method and flow-duration exceedance probability regression equations to estimate baseline daily mean streamflow for an ungaged location. The output from BaSE is a Microsoft Excel® report file that summarizes the reference streamgage and ungaged location information, including basin characteristics, percent difference in basin characteristics between the two locations, any warning associated with the basin characteristics, mean and median streamflow for the ungaged location, and a daily hydrograph of streamflow for water years 1960–2008 for the ungaged location. The daily mean streamflow for the ungaged location can be exported as a text file to be used as input into other statistical software packages. BaSE estimates daily mean streamflow for baseline conditions only, and any alterations to streamflow from regulation, large water use, or substantial mining are not reflected in the estimated streamflow.

Introduction

The natural flow regime of a stream or river is vital to the sustainability and health of aquatic freshwater ecosystems. The ability to characterize baseline, or minimally altered, streamflow conditions, compare them with current conditions, project future conditions, and assess effects of human activities on streamflow is fundamental to water-management programs addressing water allocation, human-health issues, recreation needs, and establishment of ecological flow criteria. Water-resource managers undertaking an in-depth evaluation of flow regimes to promote instream ecological health often require daily mean streamflow information obtainable only

2 Estimation of Baseline Daily Mean Streamflows for Ungaged Locations on Pennsylvania Streams, WY 1960–2008

from a time series hydrograph. Daily mean streamflow allow water-resource managers to assess streamflow and determine streamflow statistics that fulfill their individual needs.

State, Federal, and local agencies have been working collaboratively on aquatic instream flow needs and developing environmental flow criteria for water management in Pennsylvania (DePhilip and Moberg, 2010). To assist in this effort, the U.S. Geological Survey (USGS), in cooperation with the Pennsylvania Department of Environmental Protection (PaDEP), Susquehanna River Basin Commission (SRBC), and The Nature Conservancy (TNC), has developed a tool to estimate minimally altered, or baseline, streamflow at a daily time scale for ungaged streams in Pennsylvania. The Baseline Streamflow Estimator (BaSE) will provide hydrologists, ecologists, and water managers streamflow information to effectively assess baseline streamflow conditions as related to water allocation, aquatic instream-flow needs, and water availability. A range of ecologically relevant flow statistics can be computed from estimated daily mean streamflow using statistical software packages, such as Indicators of Hydrologic Alteration (IHA) (The Nature Conservancy, 2009) and Hydroecological Integrity Assessment Tool (HAT) (Henriksen and others, 2006).

Previous Studies

Fennessey (1994) introduced a method to estimate streamflow statistics for an ungaged location (termed “QPPQ” method). This method was used by Hughes and Smakhtin (1996), Smakhtin (1999), Smakhtin and Masse (2000), Mohamoud (2008), Archfield and others (2010), and Shu and Ourda (2012). Archfield and Vogel (2010) developed a method for selecting reference streamgages for an ungaged location on the basis of streamflow correlation (termed the “map correlation method”). This method has been successfully applied in Massachusetts (Archfield and others, 2010) and the Connecticut River Basin (Stacey Archfield, U.S. Geological Survey, written commun., 2012). The combination of the QPPQ method and map correlation method for selecting an appropriate reference streamgage was incorporated into the Massachusetts Sustainable-Yield Estimator (MASYE) by Archfield and others (2010). The combination of methods, or parts thereof, is being developed for applications in New York and Maryland (Ward Freeman, U.S. Geological Survey, oral commun., 2011, and Brandon Fleming, U.S. Geological Survey, oral commun., 2011). A report from The Nature Conservancy (TNC; Apse and others, 2008) for the Pennsylvania Instream Flow Technical Advisory Committee describes studies conducted to assess instream flow needs, presents methods, and describes the Ecological Limits of Hydrologic Alteration (Poff and others, 2010).

Regression equations are used to estimate streamflow characteristics where streamgage data are not available. Regression equations have not been developed for flow-duration exceedance probabilities in Pennsylvania; however,

regression equations have been developed for estimating low-flow, mean-flow, and base-flow statistics (Stuckey, 2006), as well as flood-frequency statistics (Roland and Stuckey, 2008). Flow-duration statistics for more than 500 streamgages in and near Pennsylvania are presented by Stuckey and Roland (2011). Regression estimates and streamflow statistics can be found for gaged and ungaged streams in Pennsylvania at the StreamStats web application (<http://water.usgs.gov/osw/streamstats/pennsylvania.html>) (Stuckey and Hoffman, 2010).

Purpose and Scope

This report presents the data and methodology used to estimate minimally altered (baseline) daily mean streamflow for water years¹ 1960 to 2008 for ungaged locations on streams in Pennsylvania. Parameter-based regression equations used to predict 17 exceedance probabilities from the flow duration curve (FDC) for ungaged streams in Pennsylvania are presented. Flow-duration exceedance probabilities for 162 streamgages are presented. Streamflow data from continuous-record streamgages were used to develop correlation maps of the predicted correlation of streamflow between an ungaged location and a reference streamgage. A description and instructions for the use of BaSE, a tool for estimating baseline daily mean streamflow for Pennsylvania streams, are presented.

Estimation of Baseline Daily Mean Streamflow

The BaSE tool for estimating baseline daily mean streamflow for ungaged locations on Pennsylvania streams is based on the QPPQ method (Fennessey, 1994; Hughes and Smakhtin, 1996; Smakhtin, 1999; Smakhtin and Masse, 2000; Mohamoud, 2008; Archfield and others, 2010; and Shu and Ourda, 2012), which equates streamflow expressed as a percentile from the FDC for a particular day at an ungaged location with the percentile from a FDC for the same day at a hydrologically similar location where streamflow is measured (referred to as “reference streamgage”). A graphical depiction of the QPPQ methodology is shown in figure 1. Geospatial correlation of streamflow (Archfield and others, 2010) is used to select a reference streamgage for the ungaged location. Streamflows corresponding to the flow-duration exceedance probability for the ungaged location are selected from a daily FDC constructed from points determined by regression equations. This method was successfully applied in Massachusetts and incorporated into the MASYE (Archfield and others, 2010).

The FDC for the reference streamgage is a cumulative frequency curve that shows the percentage of time that

¹ Water year (WY) is defined as a 12-month period beginning October 1 and ending September 30. The water year is designated by the calendar year in which it ends.

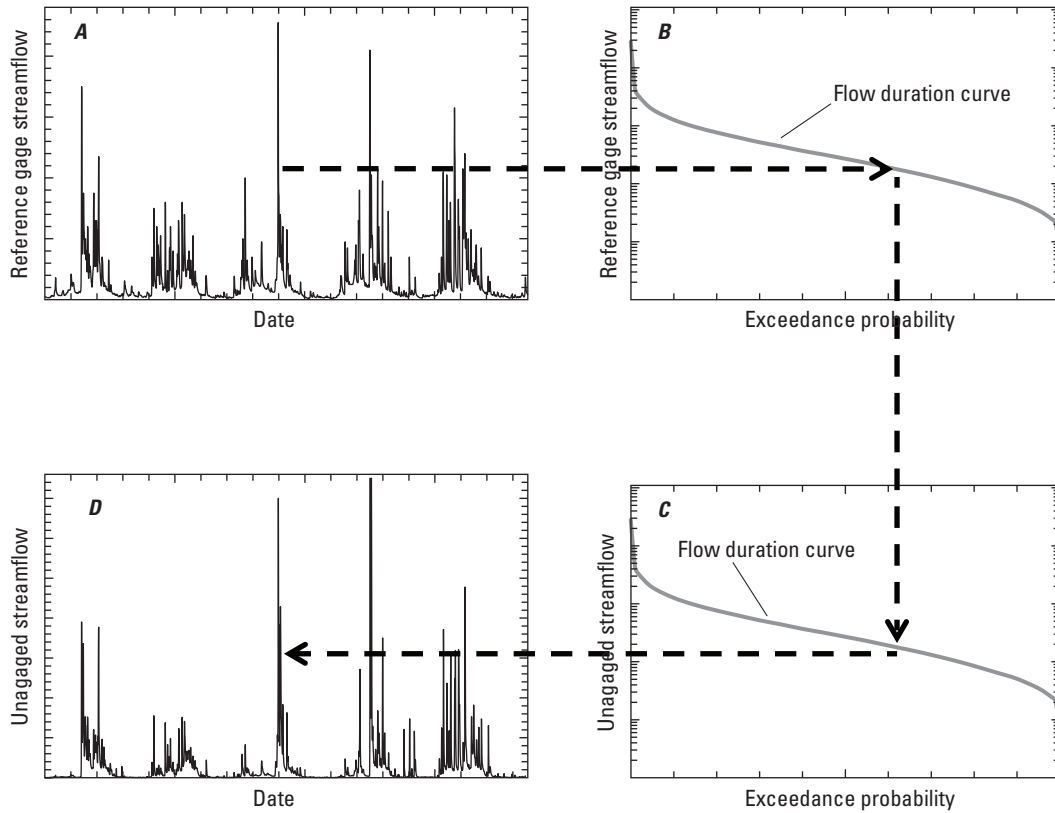


Figure 1. The QPPQ method used in the Baseline Streamflow Estimator (BaSE) showing, A, observed daily mean streamflow at a reference streamgauge, B, flow duration curve at the reference streamgauge, C, constructed flow duration curve at the ungaged location, and, D, estimated daily mean streamflow at the ungaged location. (Modified from Archfield and others, 2010)

specified streamflows are equaled or exceeded (Searcy, 1959). It is constructed by arranging observed streamflow values for a given period of time by magnitude and the percentage of time observed daily streamflow values equaled or exceeded a specific streamflow. For this report, the percentage of time that the streamflow is equaled or exceeded is “exceedance probability” and is used when discussing statistics. An individual exceedance probability is “percentile” for this report and is used when discussing methodology associated with a generic FDC.

The FDC for an ungaged location is constructed from estimates of streamflow for 17 percentiles. Streamflow is estimated for each of the 17 percentiles by use of regression equations developed using basin characteristics and streamflow data from a subset of reference streamgages. Streamflow for all other percentiles is determined by interpolation. Interpolation of streamflow between exceedance probabilities determined from the 17 regression equations yields a continuous daily hydrograph consisting of 17,898 streamflow values (one value for each day in water years 1960–2008) for the ungaged location.

A critical consideration in estimating baseline daily mean streamflow is the selection of the reference streamgauge that results in the best estimate of daily streamflow at the ungaged location. Selection of a reference streamgauge is performed using map correlation (Archfield and others, 2010; Archfield and Vogel, 2010). Map correlation is a geostatistical procedure for determining the streamgauge with streamflow that exhibits the strongest correlation with streamflow at an ungaged location.

Reference Streamgages in Pennsylvania and Surrounding States

A reference streamgauge constitutes a composite of the upstream land cover, geology, and hydrologic characteristics and can be used to represent ungaged basins with similar characteristics. Reference streamgages are used by water-resource managers for a variety of purposes, including regulatory decisions, drought and flood forecasting, and long-term baseline

4 Estimation of Baseline Daily Mean Streamflows for Ungaged Locations on Pennsylvania Streams, WY 1960–2008

data collection. Data on observed streamflows at reference streamgages are used in this analysis to develop regression equations for estimating exceedance probabilities and for development of correlation maps.

Criteria

Reference streamgages selected for this baseline analysis had streamflow that was minimally altered by regulation, diversion, or mining, and other anthropogenic activities, and had at least 10 years of continuous record; however, one streamgage with 8 years of record was included to increase spatial coverage. Most of the streamgages (152) had 15 or more years of record; the average number of years of record is 46 years. Substantial regulation for this analysis is represented by upstream reservoir impoundments that control at least 10 percent of the contributing drainage area at the streamgage. Streamgages with questionable regulation were further evaluated graphically by comparing the range and median of the streamflows before and after construction of the impoundment and were evaluated statistically by using a two-sample Kolmogorov-Smirnov goodness of fit test (TIBCO Software Inc., 2008). For streamgages with at least 10 years of unregulated flow data recorded before the impoundment was constructed, only the period prior to the start of regulation was used in the analysis. Information on diversions and mining affects were obtained from USGS Annual Water Data Reports, available on-line only since 2006 at <http://wdr.water.usgs.gov/> and in paper format prior to 2006 on file at the USGS Pennsylvania Water Science Center. There were 168 streamgages that potentially met the above criteria—143 in Pennsylvania, 10 in New York, 6 in Maryland, 2 in West Virginia, and 7 in Ohio (fig. 2). A complete listing of streamgages used in the analysis is presented in appendix 1.

The percentage of impervious area within a basin was used to limit the number of streamgages with potential anthropogenic effects on streamflow. However, in large urban/suburban areas, such as in the southeastern part of the State, some streamgages with a high percentage of impervious area were retained for improved spatial coverage. The average percentage of impervious area for the streamgages selected for the analysis is 2.5; with a maximum of 29 percent allowed in southeastern Pennsylvania.

Water use in Pennsylvania, including registered withdrawals, estimated withdrawals, and discharges for 2003 (Stuckey, 2008), were used to evaluate the selected streamgages. Because of uncertainties associated with the water-use data, including lack of verification or adjustment for storage, pass-by flows, or other drought-specific requirements, the data were not used independently to exclude streamgages but rather as a check of streamgages that exhibited unusual streamflow characteristics. The net water use (total discharges – total withdrawals) normalized to the drainage area associated with the selected streamgages within Pennsylvania is shown in figure 3. Positive values in the normalized net water use indicate more water is being returned to the basin than is being

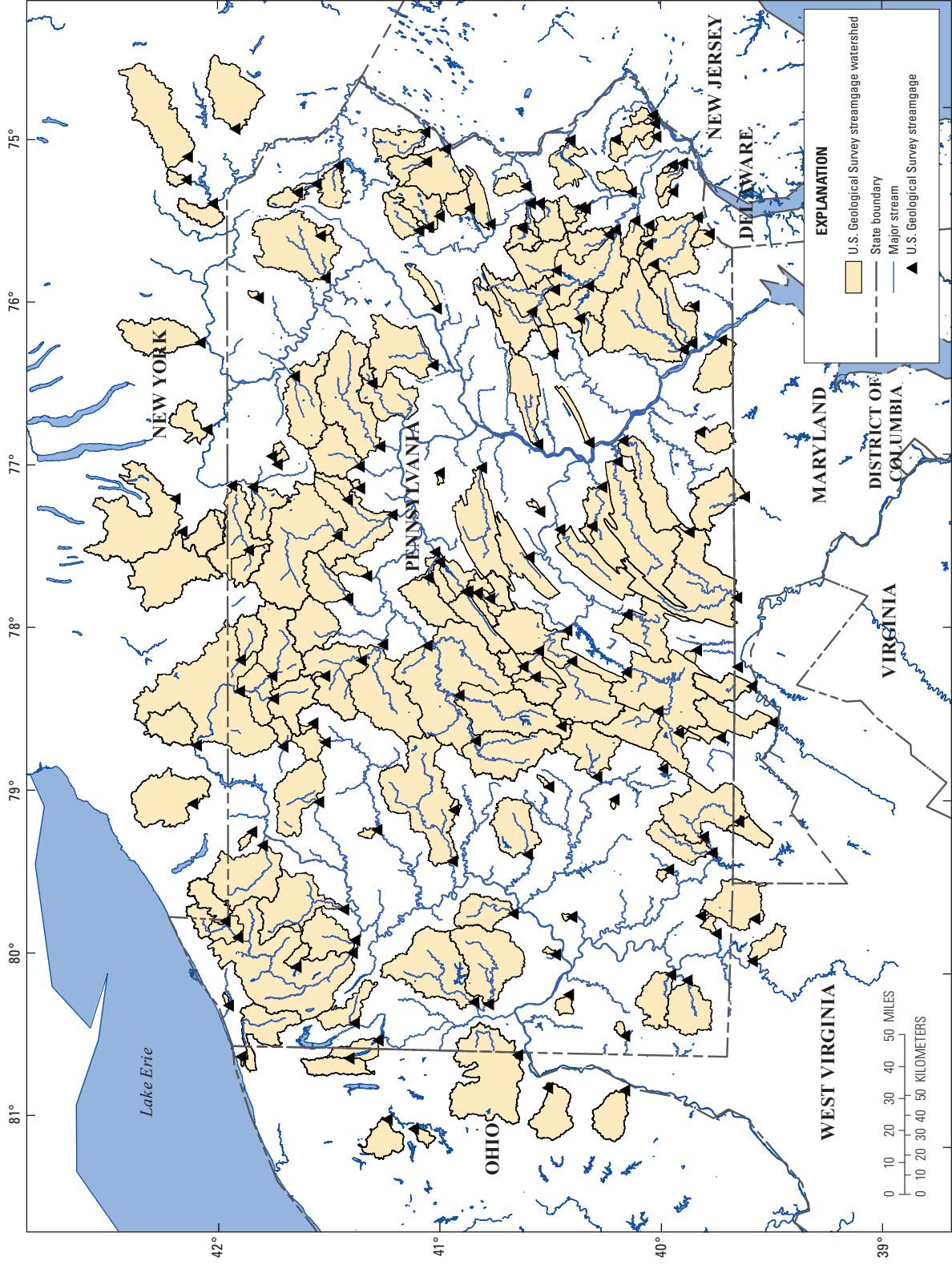
withdrawn, either through discharges, such as wastewater-sewage-treatment plants, or importation of water from outside the basin. Negative values indicate more water is being withdrawn for multiple purposes or being exported out of the basin than is being returned. Streamgages in the combined Upper and Lower Delaware River Basins had the highest normalized water use per square mile overall with more water being consumed or exported in the Upper Delaware River Basin and more water being discharged or imported in the Lower Delaware (fig. 3).

Record Extension

Estimation of daily mean streamflow using the QPPQ method for WY 1960 to 2008 for any ungaged stream location requires that all reference streamgages have a complete daily streamflow record for the same period. Of the selected reference streamgages, 67 had a complete record with unregulated flow for WY 1960 to 2008. The remaining streamgages had record lengths of 8 to 48 years. Streamflow records shorter than 49 years were extended to complete the 1960–2008 WY period using the Streamflow Record Extension Facilitator (SREF) (Granato, 2009). The average number of incomplete years of record during WY 1960–2008 that required record extension was 25 years, with a range of 1 year to 44 years. No estimated streamflow data from the record extension analysis were used in the development of regression equations or correlation maps.

The methodology used for the SREF relies on the assumption that long-term streamflow records from hydrologically similar streamgages can be used to estimate a missing record at a streamgage of interest (Granato, 2009). The SREF program produces estimated daily mean streamflow for the purpose of extending or augmenting the streamflow record at streamgages with limited data (Granato, 2009). Record extension in SREF uses the line of organic correlation (LOC) regression as part of a maintenance of variance (MOVE) method. A valuable characteristic of the LOC for streamflow record extension is the prediction of flows with variance and probability distribution that can closely estimate those of the observed record (Helsel and Hirsch, 1992, p. 276–278). The MOVE.1 method (Hirsch, 1982, Vogel and Stedinger, 1985) was used for this analysis.

The streamflows were log transformed prior to LOC regression. This transformation resulted in undefined logarithms when zero-flow values were present. SREF offers four options to address zero flows in the streamflow record. Three of the options substitute constants for zero-flow days. The fourth option, and the one selected for this application, applies a streamflow-recession constant beginning with the last nonzero streamflow value prior to the zero-flow sequence. This procedure creates a series of streamflow values that decrease with each successive zero-flow day. This option was chosen to avoid imposing an arbitrary constant flow value over a potentially substantial period of low-flow values that would result in a flatline hydrograph for streamgages at their



Base from U.S. Geological Survey 1:2,000,000 and 1:100,000 digital data

Figure 2. Location of U.S. Geological Survey reference streamgages in and near Pennsylvania.

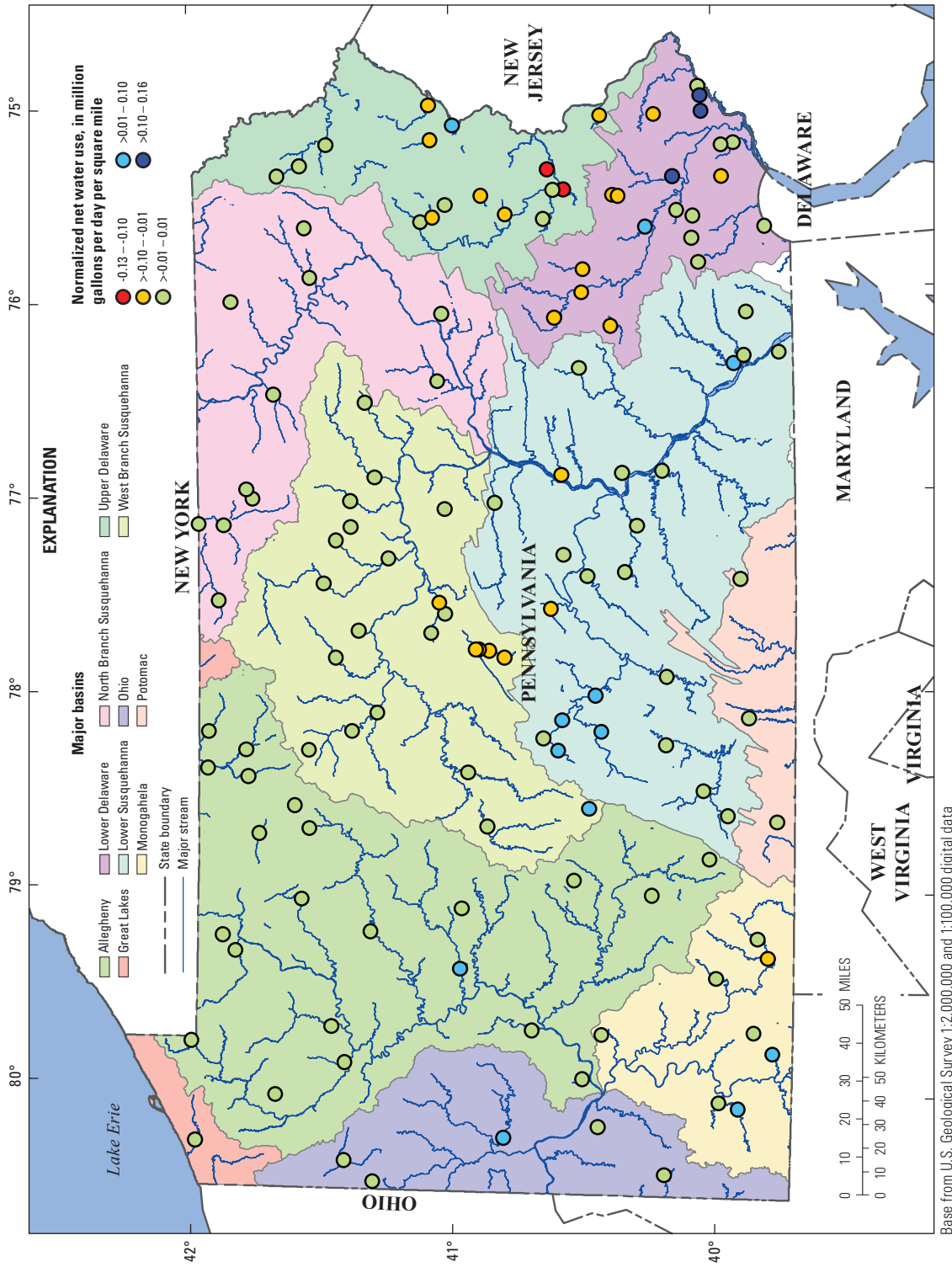


Figure 3. Normalized net water use in selected U.S. Geological Survey streamgauge basins in Pennsylvania, 2003. (>, greater than)

zero-flow threshold. For example, in an upstream-downstream pairing, streamflow at the downstream streamgage, although strongly correlated with the upstream streamgage, does not recede to zero flow as quickly or as often owing to a larger drainage area. The daily rate of decrease is determined by the streamflow-recession constant and ranges from 0 to 1. On the basis of a sampling of low-flow recession rates for the reference streamgages, a recession constant of 0.9 was selected.

The streamgages used to extend the record of a streamgage with an incomplete period of record during WY 1960–2008 are termed “index streamgages.” Ten years was considered the minimum streamflow record length for an acceptable application of MOVE.1. Eleven reference streamgages had 10-year periods of record of observed streamflows or less during WY 1960–2008. For those streamgages, a period of record from 1950 to 2008 was used to obtain the requisite 10 years of concurrent observed streamflows. After the streamflow record extensions were completed, records were trimmed back to the 1960 to 2008 period. A maximum of three streamgages was used for record extension (appendix 2). Selection of index streamgages was based on period of available concurrent record, strength of correlation, and distribution of LOC residuals. The concurrent records were evaluated graphically and statistically using correlations and the R^2 statistic to ensure a good fit between the index streamgage and a streamgage with an incomplete period of record. Record extension correlations ranged from 0.75 to 0.98, with a mean of 0.92. A listing of streamgages with record extension techniques applied is provided in appendix 2.

Regression Equations for Estimating Flow-Duration Exceedance Probabilities

Regression equations were developed for 17 percentiles along the FDC using observed streamflow data from 162 of the 168 reference streamgages in Pennsylvania and surrounding states from the beginning of observed record through the 2008 WY (appendix 1). Values for basin characteristics with possible effects on a range of streamflow, such as land cover and soil properties, were determined for the streamgages, and exceedance probabilities were computed for the streamgages using the entire period of unregulated flow. The observed exceedance probabilities (dependent variable) were related to the basin characteristics (independent or explanatory variables) using regression techniques.

Streamgages and Basin Characteristics Used in Regression Analysis

Daily streamflow values for the selected streamgages were retrieved from the National Water Information System (NWIS) web application (<http://waterdata.usgs.gov/nwis>) using the program Get NWIS WEB Streamflow Files

(GNWISQ) (Granato, 2009). This program allows for batch downloads from NWISweb and formats the retrieved files for further analysis. After the downloaded data were reviewed for completeness and accuracy, the data were entered into the Make Plotting Position File (MkPP) (Granato, 2009) to compute the flow-duration exceedance probabilities. The Weibull plotting position option was used. Only the period of record for observed unregulated flow at the streamgage was used to compute the exceedance probabilities for use in the regression analysis.

A list of 28 climatologic, geologic, hydrologic, and physiographic basin characteristics with possible effects on a range of streamflows was compiled from various geographic information system (GIS) sources (table 1). Only basin characteristics derived using GIS methods were evaluated during the regression analysis. The use of GIS-derived basin characteristics improves the consistency, reproducibility, and ease-of-use of the resulting regression equations. Many of the basin characteristics evaluated were used in previous regression analyses (Stuckey, 2006; Roland and Stuckey, 2008; Risser and others, 2008) and can be determined using the StreamStats web application for Pennsylvania (Stuckey and Hoffman, 2010).

Regression Analysis and Resulting Flow-Duration Exceedance Probability Regression Equations

The exceedance probabilities for observed streamflows were related to basin characteristics using exploratory ordinary least squares (OLS) and weighted least squares (WLS) regression techniques. The exceedance probabilities were weighted using the following expression for the WLS regression techniques to account for different periods of record: (number of years of record at streamgage \times number of streamgages) / sum of years of record of all streamgages. Regression iterations were performed using the statistical package Spotfire S+ (TIBCO Software Inc., 2008). Regression diagnostics used to evaluate the resulting regressions include graphical relations, multicollinearity, prediction error sum of squares (PRESS) statistic, standard error, and coefficient of determination (R^2) (Helsel and Hirsch, 1992, p. 245–253; p. 300–315).

Data from 162 streamgages in and near Pennsylvania were used to develop regression equations for estimating the 1-, 5-, 10-, 15-, 20-, 30-, 40-, 50-, 60-, 70-, 80-, 85-, 90-, 95-, and 99-percent exceedance probabilities (P1, P5, P10, P15, P20, P30, P40, P50, P60, P70, P80, P90, P95, and P99, respectively). Two additional regression equations were developed for the 0.0056- and 99.9944-percent flow-duration exceedances (P0.0056 and P99.9944, respectively) to represent the ends of the FDC for the period from 1960 to 2008 (49 years). Because only observed data were used in the regression analysis, the streamgages used to develop the regression equations for the lower and upper ends of the FDC were limited to those with at least 49 years of record. As a result, 67 streamgages

8 Estimation of Baseline Daily Mean Streamflows for Ungaged Locations on Pennsylvania Streams, WY 1960–2008

Table 1. Basin characteristics used in the development of regression equations for flow-duration exceedance probabilities for Pennsylvania streams.

Basin characteristic	Source	Reference
Basin slope (degrees)	Digital Elevation Model (DEM)	U.S. Geological Survey (2000a)
Mean basin elevation (feet)	Digital Elevation Model (DEM)	U.S. Geological Survey (2000a)
Forested (percent of basin area)	National Land Cover Dataset (NLCD); and enhanced version (NLCDe)	Homer and others (2004); Price and others (2003)
Glaciated (percent of basin area)	From modified geology maps	Pennsylvania Dept. of Conservation and Natural Resources (1997); Environmental Resources Research Institute (1996)
Lakes and open water (percent of basin area)	National Land Cover Dataset (NLCD); and enhanced version (NLCDe); digitized from USGS quadrangle maps 1:24000 scale	Homer and others (2004); Price and others (2003)
Longest drainage path (mile)	National Hydrography Dataset (NHD), 1:24000 scale	U.S. Geological Survey (2000b)
Stream density (length mile/basin area square miles)	National Hydrography Dataset (NHD), 1:24000 scale	U.S. Geological Survey (2000b)
Channel slope (feet per mile)	Digital Elevation Model (DEM)	U.S. Geological Survey (2000a)
Soil infiltration index (unit less 1=well to 4=poor)	State Soil Geographic (STATSGO) database	U.S. Department of Agriculture (1994)
Mean annual precipitation, 1971–2000 (inches)	Parameter-elevation Regressions on Independent Slopes Model (PRISM)	Daly (1996)
Drainage area (square mile)	Digital Elevation Model (DEM)	U.S. Geological Survey (2000a)
Soil depth to bedrock (feet)	State Soil Geographic (STATSGO) database	U.S. Department of Agriculture (1994)
Drainage runoff number (unit less 1=well to 7=poor)	State Soil Geographic (STATSGO) database	U.S. Department of Agriculture (1994)
Soil available water content (percent)	State Soil Geographic (STATSGO) database	U.S. Department of Agriculture (1994)
Soil permeability (inches per hour)	State Soil Geographic (STATSGO) database	U.S. Department of Agriculture (1994)

Table 1. Basin characteristics used in the development of regression equations for flow-duration exceedance probabilities for Pennsylvania streams.—Continued

Basin characteristic	Source	Reference
Urbanized area (percent of basin area)	National Land Cover Dataset (NLCD); and enhanced version (NLCDe)	Homer and others (2004); Price and others (2003)
Residential area (percent of basin area)	National Land Cover Dataset enhanced version (NLCDe)	Price and others (2003)
Mined area (percent of basin area)	National Land Cover Dataset enhanced version (NLCDe)	Price and others (2003)
Commercial, industrial, and transportation area (percent of basin area)	National Land Cover Dataset enhanced version (NLCDe)	Price and others (2003)
Wetlands (percent of basin area)	National Land Cover Dataset (NLCD); and enhanced version (NLCDe)	Homer and others (2004); Price and others (2003)
Mean basin elevation minus minimum elevation (feet)	Digital Elevation Model (DEM)	U.S. Geological Survey (2000a)
Shape factor (unitless) is a measure of the shape of a basin computed as the ratio of length of the basin to its computed area	Digital Elevation Model (DEM)	U.S. Geological Survey (2000a)
Carbonate bedrock (percent of basin area)	From modified geology maps	Pennsylvania Dept. of Conservation and Natural Resources (1997); Environmental Resources Research Institute (1996)
Impervious surface area (percent of basin area)	National Land Cover Dataset (NLCD)	Homer and others (2004)
Mean maximum daily temperature, 1971-2000 (degrees Fahrenheit)	Parameter-elevation Regressions on Independent Slopes Model (PRISM)	Daly (1996)
Longitude and latitude of basin outlet (decimal degrees)		
Latitude and longitude of basin centroid (decimal degrees)		
Percentage of sand in soil	State Soil Geographic (STATSGO) database	U.S. Department of Agriculture (1994)

¹Referred to as soil thickness in report by Stuckey (2006)

with sufficient period of record were used to develop regression equations for estimating the P0.0056 and P99.9944 exceedance probabilities. Outliers and streamgages with high leverage and (or) influence were removed from individual regression analysis only if sufficient data or information was found to support the removal of the streamgages, such as high water use in the basin (including withdrawals and discharges), abnormal basin characteristics or streamflow, or poor or estimated daily streamflow computations during low- or high-flow periods.

The possibility of dividing the State into regions was evaluated during exploratory regression analysis using OLS and WLS. Basic statewide regression equations were initially developed, and residual standard errors were mapped to determine if regionalization was appropriate. Although no pattern was observed in the residuals, previously defined low-flow and peak-flow regions (Stuckey, 2006; Roland and Stuckey, 2008) were used to regionalize the State during the exploratory regression analysis to possibly improve regression diagnostics. The resulting standard errors, coefficient of determination (R^2), residuals, PRESS statistic, and other regression diagnostics were compared to the statewide initial regression equations. The exploratory regressions resulting from using previously defined low-flow regions lowered the standard error of prediction for the lower exceedance probabilities but increased the standard error of prediction for the higher exceedance probabilities. There was no noticeable improvement in error when using the previously defined peak-flow regions. The statewide regression equations consistently produced a range of the exceedance probabilities with more accuracy than regression equations using either set of regions. Also an attempt was made to create new regions on the basis of the statewide residuals, hydrologic unit code (HUC) 8 boundaries, physiographic provinces, and (or) major basins, but no overall improvement was noted. As a result, regression equations for the suite of exceedance probabilities were developed on a statewide scale. WLS was used to generate the final statewide regression equations.

The following independent variables were found to be significant at the 95-percent confidence level for one or more regression equations: longitude at the outlet, drainage area, mean annual precipitation, mean maximum daily temperature, depth to bedrock, drainage runoff number, and percentages of carbonate bedrock and impervious surface area (table 2). The basin characteristics values associated with the streamgages used in the analysis are listed in appendix 3. To form a near-linear relation between the flow-duration exceedance probabilities and basin characteristics, all independent and dependent variables were log-transformed (base 10) prior to regression analysis. Because percentages can have a value of zero, 1.0 was added to the decimal form of the percentages of carbonate bedrock and impervious surface area.

The regression model took the following form, in log units:

$$\log \hat{Q}_p = A + b \log Long + c \log DA + d \log Ppt + e \log MaxT + f \log Thk + g \log Drn + h \log(1 + 0.01 \times Carb) + i \log(1 + 0.01 \times Imp)$$

or in arithmetic space:

$$\hat{Q}_p = 10^A (Long)^b (DA)^c (Ppt)^d (MaxT)^e (Thk)^f (Drn)^g (1 + 0.01 \times Carb)^h (1 + 0.01 \times Imp)^i,$$

where

Log	= log to base 10;
\hat{Q}_p	= flow-duration exceedance probability, in cubic feet per second;
A	= the intercept;
$Long$	= longitude of the outlet of the basin, in decimal degrees;
DA	= drainage area, in square miles;
Ppt	= mean annual precipitation, in inches;
$MaxT$	= mean maximum daily temperature, in degrees Fahrenheit;
Thk	= soil depth to bedrock, in feet;
Drn	= drainage runoff number, unitless;
$Carb$	= basin underlain by carbonate bedrock, in percent;
Imp	= impervious surface area in basin, in percent; and

$b, c, d, e, f, g, h,$ and i = independent variable coefficients of regression estimated by WLS.

Standard errors of prediction for the regression equations provide an estimate of reliability of the predicted exceedance probabilities (table 2) (Helsel and Hirsch, 1992, p.35). The standard error of prediction for the flow-duration exceedance probability regression equation ranged from 0.05 to 0.34 in log units (11 percent to 92 percent; table 2); mean standard error over the entire suite of flow-duration equations equals 31 percent. The regression equations used to estimate the lower ends of the FDC have the highest errors; the extreme low-flow exceedance probability of P99.9944 has an error of 92 percent, and P99 and P95 have errors of 64 percent and 47 percent, respectively. For comparison, the most recent regression equations developed for estimating the 7-day, 10-year low flow for streams in Pennsylvania have errors ranging from 51 percent to 66 percent (Stuckey, 2006). The coefficient of determination (R^2) provides a way of estimating the uncertainty associated with the regression. For example, the R^2 for P60 is 0.97, indicating the basin characteristics selected for use in the P60 regression equation describe about 97 percent of the influence that all basin characteristics have on predicting the 60-percent

Table 2. Regression coefficients for use with flow-duration exceedance probability regression equations for Pennsylvania streams.

[--, basin characteristic not significant]

Flow duration exceedance	Intercept	Longitude	Basin characteristic coefficients							Coefficient of determination (R ²)			Standard error of prediction	
			Drainage area	Mean annual precipitation	Mean maximum daily temperature	Depth to bedrock	Drainage runoff number	Percent carbonate bedrock	Percent Impervious Area	Log units	Percent			
P0.0056	19.4870	-9.2666	0.9467	--	--	--	--	--	--	-1.0541	--	0.93	0.12	29
P1	1.3859	--	0.9790	0.8532	-0.9410	--	--	--	--	-1.1890	--	0.98	0.07	16
P5	2.3635	--	1.0174	1.2290	-2.0862	--	--	--	--	-0.8718	--	0.99	0.05	12
P10	3.0648	--	1.0320	1.5437	-2.9012	--	--	--	--	-0.5003	--	0.99	0.05	11
P15	3.1570	--	1.0351	1.7714	-3.2373	--	--	--	--	-0.2491	--	0.99	0.05	11
P20	3.7262	--	1.0348	2.0031	-3.7308	--	--	-0.3174	--	--	--	0.99	0.05	12
P30	2.9371	--	1.0288	2.3264	-3.6074	--	--	-0.4800	--	--	--	0.99	0.06	13
P40	4.4846	-2.2014	1.0289	2.5671	-2.5667	--	--	--	--	--	--	0.99	0.07	17
P50	6.4550	-3.8133	1.0312	2.8468	-2.2881	--	--	--	--	--	--	0.98	0.09	21
P60	4.3767	-5.0540	1.0339	2.8911	--	0.7184	-0.5143	--	--	--	-0.4900	0.97	0.11	25
P70	8.5970	-7.5624	1.0578	3.0510	--	1.2641	-1.0775	--	--	--	0.4131	0.96	0.13	31
P80	11.8916	-9.4846	1.0773	3.0311	--	1.9057	-1.5886	--	--	--	1.6540	0.94	0.15	37
P85	12.5831	-9.8562	1.0783	2.8778	--	2.2722	-1.7499	--	--	--	2.4188	0.93	0.17	40
P90	12.8246	-10.2618	1.0927	3.0113	--	2.6396	-1.9053	--	--	--	3.0786	0.92	0.19	46
P95	14.8563	-11.1128	1.0950	2.6659	--	3.0603	-2.4097	--	--	--	3.3086	0.92	0.19	47
P99	16.5197	-12.3238	1.1478	2.6429	--	4.2131	-3.2166	--	--	--	5.1089	0.88	0.25	64
P99.9944	16.5036	-12.9899	1.1441	3.1975	--	5.8935	-5.0895	--	--	--	--	0.75	0.34	92

exceedance value (table 2). A lower R^2 for P99.9944 (0.75) indicates that additional variables may help to better define this extreme low-flow prediction. Flow-duration exceedance probabilities computed from streamflow data (observed) and regression equations (predicted) for streamgages used in the regression analysis can be found in appendix 4.

Selection of Reference Streamgages for Estimating Baseline Daily Mean Streamflow

An important consideration in applying the QPPQ method is the selection of a reference streamgage. A typical approach has been to select the closest reference streamgage to the ungaged location as the preferred reference gage. Choosing the closest streamgage as the most appropriate (best) reference streamgage is based on the assumption that similarity in the conditions determining streamflow increases with decreasing distance between two locations. However, there are many instances where conditions at the closest streamgage are neither physically or hydrologically similar to those at the ungaged location. Archfield and Vogel (2010) showed that the closest reference streamgage is not always the best choice and introduced the map correlation method as an alternative.

Map Correlation

Map correlation is a geostatistical approach to selecting a reference streamgage where streamflow exhibits the strongest correlation with that at an ungaged location. First, each reference streamgage is assigned a unique map of correlation estimate developed from a model of the spatial correlation structure, or variogram, between it and all other available reference streamgages in Pennsylvania and surrounding states (fig. 4). Ordinary kriging (Isaaks and Srivastava, 1989) is used to estimate the expected correlation at the ungaged location.

Selecting the most appropriate (best) reference streamgage is accomplished by choosing the streamgage whose map has the highest correlation coefficient at the coordinates of the ungaged location. Map correlation may be a unique application of geostatistical models in that many models need to be compared as part of the reference streamgage selection process. Selecting the best model is, therefore, dependent in part on all models being fit in a consistent manner to avoid biasing one or more models. Variogram model fitting can involve a substantial amount of trial and error (Isaaks and Srivastava, 1989; Archfield and Vogel, 2010) and subjectivity as well. When the models are fit interactively, it is likely to result in many parameters having few similarities. One model may perform better than another simply because more time was given to finding the best parameters. Considering the small differences in correlation coefficients among many reference streamgages, minimization of subjectivity in model fitting is an important consideration. In an attempt to minimize subjectivity, the variogram models were developed in

the Geostatistical Analyst extension in ArcMAP 9.3 (Environmental Systems Research Institute, Inc., 2009) using default automated parameter estimation.

Application of Map Correlation in Two Pilot Basins

The map correlation method was originally developed using streamflow data from streamgages in and near Massachusetts and had not been previously tested for use in Pennsylvania. Because of this, the map correlation method was applied and evaluated for two pilot basins situated primarily in Pennsylvania (fig. 5) in anticipation of extending map correlation to the entire State and as a means of exploring possible improvements to the method. The objective of the pilot basin analysis was to compare the relative efficiency of the widely used closest streamgage method to the map correlation method as used by Archfield and others (2010) and to determine if modifications could improve the method's use in Pennsylvania. Pennsylvania is hydrologically diverse, in large part, because of its varied geology and topography. The first pilot basin, Lower Susquehanna River Basin, is located in south-central Pennsylvania and northern Maryland and is bounded by HUC 020503. The Lower Susquehanna River Basin covers approximately 9,200 square miles (mi^2) in the Susquehanna River Basin. Twenty USGS streamgages within HUC 020503 were selected as reference gages (table 3). The second pilot basin, the Upper Delaware River Basin, is bounded by HUC 020401 and drains approximately 6,900 mi^2 of the Delaware River Basin in parts of New York, New Jersey, and Pennsylvania. Eighteen reference streamgages were selected within HUC 020401 (table 3). The reference streamgages selected had minimally altered hydrology from human activities. The period of available daily streamflow record ranged from 13 to 59 years.

The modifications to Archfield and others (2010) method, applied for the pilot basins in Pennsylvania, include (1) using Spearman's ρ in place of Pearson's r for streamflow correlations, (2) using basin centroid locations in place of basin outlet locations when defining correlation models, and (3) adding anisotropy parameters to the correlation models. For this analysis, anisotropy is measured by observing the directional orientation in the shape of stream basins and stream channels.

Correlation Metrics

The map correlation method defines a spatial correlation structure of daily streamflow among a set of reference streamgages. Archfield and others (2010) chose Pearson's r of the logarithms of daily streamflow at reference streamgages as the correlation metric. Pearson's r is a parametric measure of the linear association between two variables (Helsel and Hirsch, 1992, p.218–219). It assumes a bivariate normal distribution, is sensitive to outliers, and is insensitive to strong associations that are nonlinear. Daily streamflow data generally follow a lognormal distribution, and taking the logarithms prior to computing Pearson's r improves the results as Archfield and others (2010) noted.

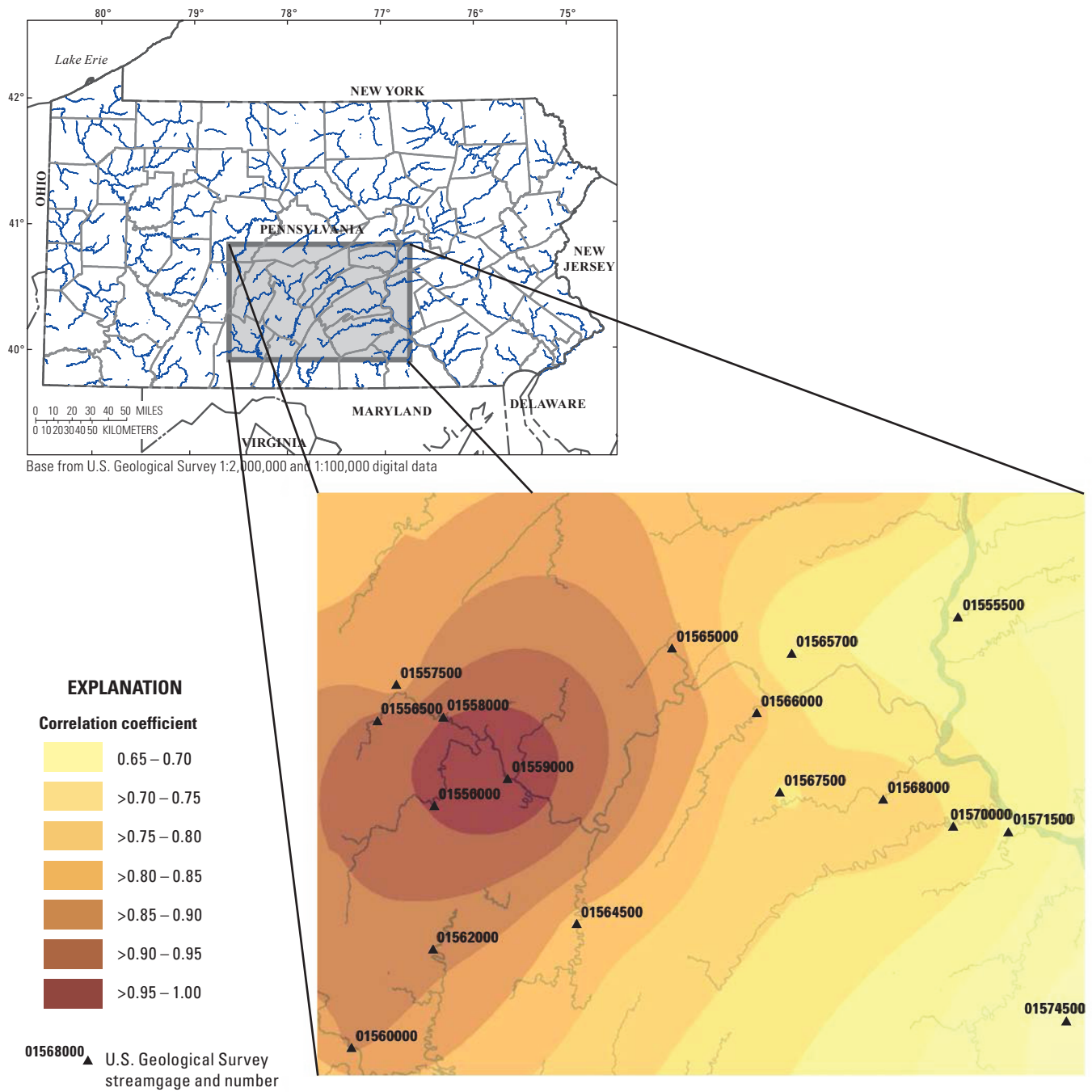


Figure 4. Example correlation map for U.S. Geological Survey streamgauge 01559000, Juniata River at Huntingdon, Pa. (>, greater than)

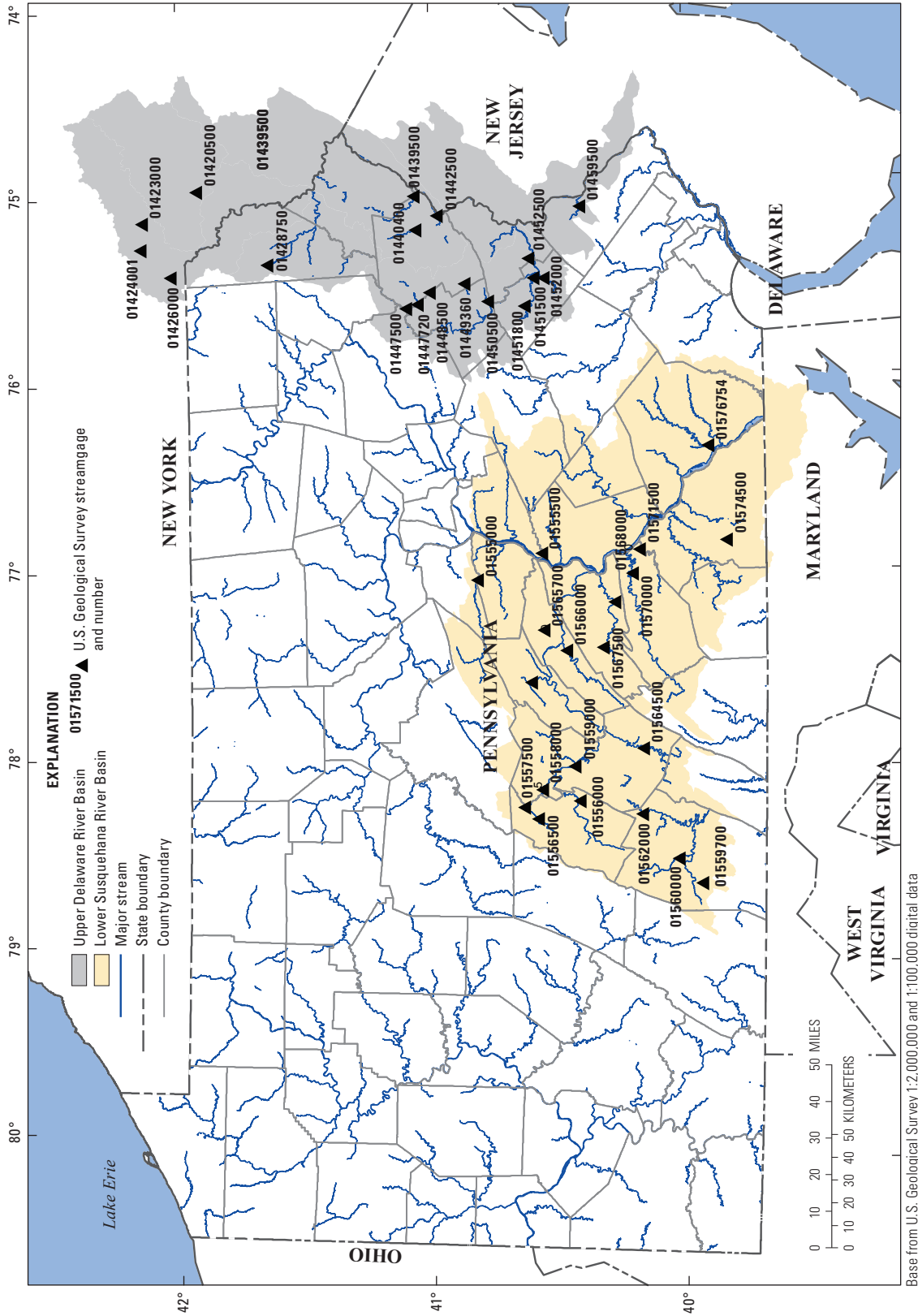


Figure 5. Location of pilot test basins in Pennsylvania and reference streamgages for the map correlation method.

Table 3. Description of selected U.S. Geological Survey reference streamgages in the Upper Delaware River Basin and the Lower Susquehanna River Basin in Pennsylvania.

[ddmmss, degrees, minutes, seconds; mi², square miles]

U.S. Geological Survey streamgage number	Name	Latitude (ddmmss)	Longitude (ddmmss)	Drainage area (mi ²)	Period of record
Upper Delaware River Basin					
0142400103	Trout Creek near Trout Creek, NY	421025	751647	20.2	1952–67, 1996–1999
01420500	Beaver Kill at Cooks Falls, NY	415647	745848	241	1913–2008
01423000	West Branch Delaware River at Walton, NY	420958	750825	332	1950–2008
01426000	Oquaga Creek at Deposit NY	420331	752542	67.6	1941–73, 2004–2005
01428750	West Branch Lackawaxen River near Aldenville, PA	414028	752235	40.6	1987–2002
01439500	Bush Kill at Shoemakers, PA	410517	750217	117	1909–2008
01440400	Brodhead Creek near Analomink, PA	410505	751254	65.9	1958–2008
01442500	Brodhead Creek at Minisink Hills, PA	405955	750835	259	1950–2008
01447500	Lehigh River at Stoddartsville, PA	410749	753733	91.7	1944–2008
01447720	Tobyhanna Creek near Blakeslee, PA	410505	753621	118	1961–1984
01448500	Dilldown Creek near Long Pond, PA	410208	753237	2.39	1949–1996
01449360	Pohopoco Creek at Kresgeville, PA	405351	753010	49.9	1966–2008
01450500	Aquashicola Creek at Palmerton, PA	404822	753554	76.7	1939–2008
01451500	Little Lehigh Creek near Allentown, PA	403456	752900	80.8	1946–2008
01451800	Jordan Creek near Schnecksville, PA	403942	753738	53.0	1966–2008
01452000	Jordan Creek at Allentown, PA	403723	752858	75.8	1945–2008
01452500	Monocacy Creek at Bethlehem, PA	403828	752247	44.5	1948–2008
01459500	Tohickon Creek near Pipersville, PA	402601	750701	97.4	1937–1973
Lower Susquehanna River Basin					
01555000	Penns Creek at Penns Creek, PA	405200	770255	301	1930–2008
01555500	East Mahantango Creek near Dalmatia, PA	403640	765444	162	1930–2008
01556000	Frankstown Br Juniata River at Williamsburg, PA	402747	781200	291	1917–2008
01556500	Little Juniata River at Tipton, PA	403740	781738	93.7	1946–1962
01557500	Bald Eagle Creek at Tyrone, PA	404101	781402	44.1	1953–2008
01558000	Little Juniata River at Spruce Creek, PA	403645	780827	220	1939–2008
01559000	Juniata River at Huntingdon, PA	402905	780109	816	1942–2008
01559700	Sulphur Springs Creek near Manns Choice, PA	395840	783708	5.28	1962–1978
01560000	Dunning Creek at Belden, PA	400418	782934	172	1939–2008
01562000	Raystown Branch Juniata River at Saxton, PA	401257	781556	756	1912–2008
01564500	Aughwick Creek near Three Springs, PA	401245	775532	205	1938–2008
01565000	Kishacoquillas Creek at Reedsville, PA	403917	773500	164	1940–70, 1984–85, 2001–2008
01565700	Little Lost Creek at Oakland Mills, PA	403619	771842	6.52	1964–1981
01566000	Tuscarora Creek near Port Royal, PA	403055	772510	214	1913–58, 2002–2008
01567500	Bixler Run near Loysville, PA	402215	772409	15.0	1954–2008
01568000	Sherman Creek at Shermans Dale, PA	401924	771009	207	1930–2008
01570000	Conodoguinet Creek near Hogestown, PA	401508	770117	470	1930–58, 1967–2008
01571500	Yellow Breeches Creek near Camp Hill, PA	401329	765354	216	1954–2008
01574500	Codorus Creek at Spring Grove, PA	395243	765113	75.5	1929–1964
01576754	Conestoga River at Conestoga, PA	395647	762205	470	1985–2002

Although it is straightforward to compute Pearson's r of the logarithm of streamflow, Pearson's r for several reasons may not be an optimal choice when the map correlation method is used in conjunction with the QPPQ method. First, measuring the correlation of FDC percentiles directly may improve the results. When applied as part of the QPPQ method, the Pearson's r correlation of log transformed streamflow functions acts as a surrogate for the correlation of FDC percentiles between the ungaged and reference gage locations. The QPPQ method relies on the assumption of equivalence of percentiles between an ungaged location and a reference streamgage (Waldron and Archfield, 2006) and measures equivalence in the relation between streamflows.

Second, Pearson's r is a measure of a linear association (Helsel and Hirsh, 1992, p. 218–219) and daily mean streamflow seldom fit a log normal distribution exactly. Records from different streamgages often yield non-linear correlations with a poor Pearson's r . The relation between streamflow at different streamgages does not need to be linear, but can have a strong rank-based correlation. FDCs are typically built around rank-based quantiles (Vogel and Fennessey, 1994; Helsel and Hirsch, 1992). In many instances FDC exceedance values are calculated using a formula derived from the general form

$$p = (i - a) / (n + 1 - 2a),$$

where

- p = flow-duration exceedance probability,
- i = rank of an observation,
- a = constant, and
- n = number of observations.

Given that a and n are constants for a specific FDC, p will retain the rank order of the observations. As a result, the association between FDCs is equivalent to a streamflow rank-order correlation.

A third issue is the occurrence of undefined logarithms when zero streamflow values are present. A common but less than desirable work-around is replacing the undefined logarithms with a small value. For the pilot basin analyses, 0.001 cubic feet per second was substituted for zero streamflow values when computing logarithms. Archfield and Vogel (2010) reported that Kendall's τ , a non-parametric rank-based correlation coefficient, could be used as alternative to Pearson's r in areas with zero streamflow values, therefore, eliminating undefined logarithms. Although Kendall's τ is widely applied in hydrology, Spearman's ρ is another non-parametric measure of correlation that can be used. Spearman's ρ is similar in derivation and scale to Pearson's r , whereas Kendall's τ yields a smaller coefficient for most correlations (Helsel and Hirsch, 1992, p. 212–218). Although both Kendall's τ and Spearman's ρ handle zero streamflow values and monotonic associations, they present different fits to the data. During exploratory analysis, it was found that Spearman's ρ exhibits a more linear association with distance than Kendall's τ when the value is greater

than about 0.7. A linear correlation to distance relation is advantageous when fitting a variogram model of the spatial correlation.

Distance Metrics

Archfield and Vogel (2010) applied ordinary kriging with a spherical variogram model to estimate cross-correlations of daily streamflows between a reference streamgage and ungaged locations anywhere within a study area. Those estimates are based on Euclidean distances between basin outlets (streamgage locations) at the reference and ungaged locations. Huang and Yang (1998) and Skoien and Blöschl (2007) use the centroid of the basin area for distance measures. They note that streamflow at a basin outlet actually represents local streamflows integrated over the entire basin area and imply that the centroid location better represents the basin area. Centroid distances were examined and compared for their performance in identifying the best reference gage in the map correlation method.

Anisotropy

The directional orientation observed in the shape of stream basins and stream channels is "anisotropy" and can be mirrored in the correlation of streamflow at streamgages located in the basin. Streamgages located along the same reach share the same directional orientation and exhibit higher magnitudes of correlation between streamflow and persistence of correlation with distance than streamgages located on different reaches. Streamgages on tributaries intersecting the mainstem in an orthogonal orientation are more likely to include independent tributary streamflow or streamflow similar to that of an adjacent basin. To determine if anisotropy information would improve selection of the best correlated reference streamgage, an anisotropy component was added to the spatial correlation models. Spatial correlation models with and without anisotropy were compared to determine whether the inclusion of anisotropy improved map correlation in the pilot basins.

Anisotropy parameters were used to define a set of orthogonal major and minor axes whose orientation and magnitudes were best fit to corresponding orientation-dependent variations in the correlation variograms. The Upper Delaware River and Lower Susquehanna River pilot basins trend north to south and west to east, respectively. Moreover, the length to width ratio and streamflow patterns are quite different. For example, the Upper Delaware River pilot basin is four times longer than wide, and the mainstem and major tributaries have prominent north to south components (fig. 5). The Lower Susquehanna River pilot basin is approximately two times longer than wide. Although there is an overall west to east orientation, there is great variation in reach orientation, and many of the tributaries flow in opposing directions. These characteristics indicate stronger anisotropy in the Upper Delaware River pilot basin than in the Lower Susquehanna River pilot basin.

Analysis and Results of Map Correlation in Two Pilot Basins

The process of selecting the best reference streamgauge using map correlation in the pilot basins treated each reference streamgauge as an ungauged location using a leave-one-out cross-validation procedure. Each reference streamgauge was removed, in turn, from each variogram dataset, and the correlation was estimated for that location. In this way, each reference streamgauge location represents a sample ungauged location. The variogram model whose origin was the sample ungauged location was dropped from consideration. Thus, each reference streamgauge location yielded $n - 1$ correlation estimates, where n is the number of reference streamgages.

The pilot basin analysis was intended to answer two questions. First, how well did the various map correlation models reproduce the correlation coefficients for the reference streamgages? Second, how successful was map correlation in picking the most correlated reference streamgauge? These questions were examined during the multiple trials of map correlation and modifications for the pilot basins.

Direct comparison of the correlation coefficients among the trials was not feasible because of computational differences in r and ρ . Therefore, the Nash-Sutcliffe (NS) efficiency value, suitable for comparisons across the different correlation coefficient types, was used. The NS efficiency value ranges from negative infinity to 1. A perfect prediction of the observed data yields an efficiency of 1. An efficiency of 0 indicates predictions no better than the mean of the data. A negative efficiency implies the data mean is a better predictor than the modeled data because of lower variance. Considering that all correlation maps need to perform similarly if the best

reference streamgauge is to be selected consistently, it follows that the trial with the highest average and lowest range in efficiencies is preferred.

NS efficiencies for the Lower Susquehanna River pilot basin correlation maps were not markedly different among the various trials (fig. 6). Median NS efficiencies ranged from 0.57 to 0.63. Higher efficiencies were observed when the basin centroids rather than basin outlets were used to identify reference streamgauge locations. Neither Pearson's r nor Spearman's ρ correlations performed consistently better. Map correlation using Spearman's correlation, in combination with basin centroid locations and anisotropy, had the highest median and smallest range in efficiency, except for a single outlier.

NS efficiencies for the Upper Delaware River pilot basin were generally lower than those for the Lower Susquehanna River pilot basin (fig. 6). Median NS efficiencies ranged from 0.27 to 0.69. An efficiency advantage was not observed for either basin outlet or basin centroid locations. Pearson's and Spearman's correlations performed similarly well. Anisotropy, however, when used with basin centroids resulted in a substantial improvement in efficiencies. Both Pearson's r and Spearman's ρ correlations with basin centroid distance yielded nearly identical median efficiencies of 0.69 and 0.67 when combined with anisotropy.

The other question associated with the pilot basin analysis is: How successfully did the map correlation method select the most highly correlated streamgauge? An initial assumption was that higher NS efficiencies would indicate improved chances of selecting the best correlated reference streamgauge. Higher efficiencies indicate correlation map estimates are closer to the observed data. The best correlated reference streamgauge was determined for each ungauged location by

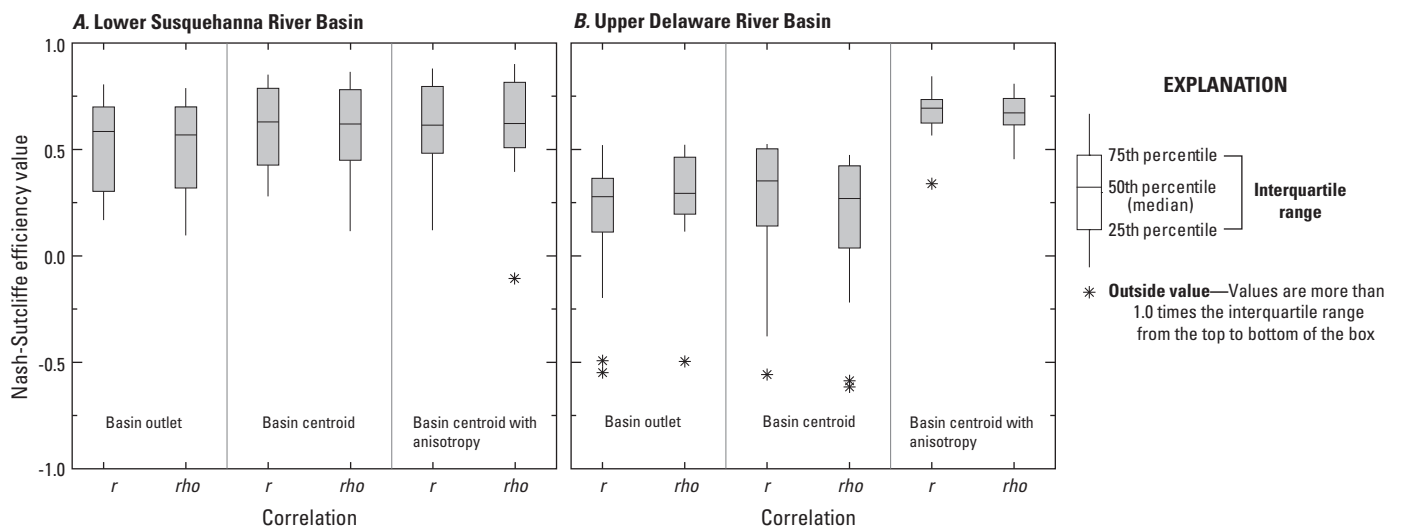


Figure 6. Distribution of Nash-Sutcliffe efficiency values computed from observed and estimated correlations of daily mean streamflows at selected U.S. Geological Survey streamgages in, *A*, the Lower Susquehanna River Basin and, *B*, the Upper Delaware River Basin in Pennsylvania. (r , Pearson's correlation; ρ , Spearman's correlation)

selecting the highest correlation value from among all cross-validation estimates for a selected ungaged location. The percentage of time during the map correlation method trials that the best correlated streamgauge was selected is presented in figure 7 along with two closest reference streamgauge selection methods.

Success rates for selection of the best correlated reference streamgauge in the Lower Susquehanna River pilot basin ranged from 25 to 60 percent (fig. 7). Map correlation performed better than other selection methods when basin centroids, Spearman's correlation, and anisotropy were used. Selection of the closest reference streamgauge by basin outlet was the least successful, but substituting closest basin centroids for basin outlet locations improved the outcome by almost double. This trial essentially matched the success rate of map correlation using basin centroids. Basin centroids consistently improved selection results, whereas the choice of Pearson's r or Spearman's ρ did not. The addition of anisotropy for centroid-based correlation maps increased the success rate for selecting the best correlated reference streamgauge when using Spearman's ρ , whereas use of Pearson's r led to a decrease in success rate. In general, the success rate for selecting the best correlated streamgauge increased with an increase in the NS efficiency.

The Upper Delaware River pilot basin trials showed minimal differences in the success rates for selection of the best correlated reference streamgauge. Success rates ranged from 50 to 61 percent across all trials (fig. 7). Selection of the closest

reference streamgauge by basin outlet location and map correlation selection using centroid location performed best, with a success rate of 61 percent. Using the basin centroid distance metric improved the map correlation selection outcome, but the rate of successful selection decreased when basin centroid was substituted for outlet location in the closest streamgauge selection method. In only one trial (map correlation selection using basin outlet locations) did the choice of Pearson's r or Spearman's ρ have an effect on the success rates. Anisotropy reduced the success rate of map correlation using basin centroids from 61 to 50 percent. For the Lower Susquehanna River pilot basin, there was no clear association between the NS efficiencies and success rates for selecting the best correlated streamgauge. This can be seen in the map correlation with anisotropy trials where NS efficiencies have the highest values of all trials (fig. 6), yet have the lowest success rates in selection of the best correlated reference streamgauge.

The pilot basin trials demonstrate that modifications to the map correlation method of Archfield and others (2010) can improve the probability of selecting the most highly correlated streamgauge as a reference streamgauge for an ungaged location. The results from the trials in the two basins are summarized in table 4. The modified map correlation method performed as well as, or better than, the commonly used method of selecting the closest streamgauge as a reference. The most useful modification is use of the basin centroid in place of basin outlet when determining distances in the correlation models, which consistently improved selection outcomes. Although the inclusion of anisotropy in map correlation improved selection outcomes in only one of the trials in the Lower Susquehanna River Basin, this may be an area for exploration in the future.

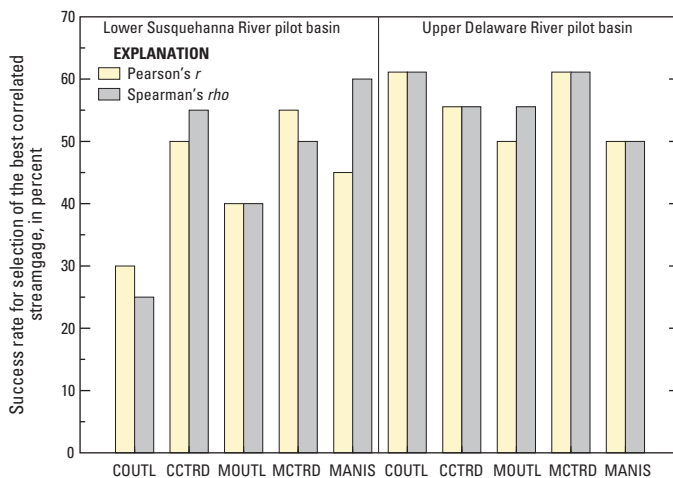


Figure 7. Success rate for selection of the best correlated streamgauge by using distance and map correlation methods applied in the pilot basins. (COUTL, closest streamgauge using outlet distance; CCTRD, closest streamgauge using centroid distance; MOU TL, map correlation using outlet distance; MCTRD, map correlation using centroid distance; MANIS, map correlation with anisotropy using centroid distance)

Statewide Map Correlation Development

Variogram models were developed for 156 reference streamgages in and near Pennsylvania with minimally altered streamflow and at least 10 years of continuous record during 1960–2008 water years and for 1 reference streamgauge with 8 years of record that was selected to improve spatial coverage. The streamgages used in the map correlation development are listed in appendix 1 and labeled MAP. From the complete list of reference streamgages found in appendix 1, 12 of the streamgages were not included in the map correlation development because of insufficient unregulated streamflow record, insufficient streamflow record during 1960–2008, or invalid correlations related to limited concurrent years of record.

The spherical variogram model was selected to describe the spatial structure within the correlation of daily streamflow for several reasons. First, out of several model forms, it produced the best fit to the data. Additional trial fitting using exponential and Bessel function models was also explored. The trials confirmed that the spherical form produced the best fits averaged for all reference streamgages. Second, the spherical model exhibited a good match to the correlation to separation distance relation of the observed data at distances near the

Table 4. Summary of map correlation application in two pilot basins in Pennsylvania.

[--, not applicable]

Trial	Lower Susquehanna River Basin		Upper Delaware River Basin	
	Median Nash-Sutcliffe efficiency value	Selection of best correlated streamgage (percent)	Median Nash-Sutcliffe efficiency value	Selection of best correlated streamgage (percent)
Closest streamgage using outlet distance with Pearson correlation	--	30	--	61
Closest streamgage using outlet distance with Spearman's correlation	--	25	--	60
Closest streamgage using centroid distance with Pearson correlation	--	50	--	56
Closest streamgage using centroid distance with Spearman's correlation	--	55	--	56
Map correlation with Pearson correlation using outlet distance	0.58	40	0.28	50
Map correlation with Spearman's correlation using outlet distance	0.57	40	0.29	56
Map correlation with Pearson correlation using centroid distance	0.63	55	0.35	61
Map correlation with Spearman's correlation using centroid distance	0.62	50	0.27	61
Map correlation with anisotropy and Pearson correlation using centroid distance	0.61	45	0.69	50
Map correlation with anisotropy and Spearman's correlation using centroid distance	0.62	60	0.67	50

origin. Although not strictly equivalent, the variogram and the correlation to separation distance relation of the observed data in this application are similar in their representation of spatial continuity. Model fit is improved where there is similarity between the linear form of the spherical model near the origin and the correlation to distance relation of the observed data. The near origin behavior is an important consideration in the choice of model (Isaaks and Srivastava, 1989), and Pearson's r and Spearman's ρ for the reference streamgages have reasonably linear relations with distance, critically in the region nearest the origin. Lastly, the spherical model is perhaps the most broadly applied variogram function.

It is desirable that the period of streamflow record common to the reference streamgages be sufficiently long to represent as broad a range of streamflow values as possible. Short common periods of record can produce misleading correlation coefficients which may affect the spatial correlation relation and the choice of reference streamgage. Streamflow records of short duration often exhibit a restricted range of streamflows and are candidates for deletion from the dataset owing to limited usefulness for estimating a representative hydrograph for

20 years or more. As a practical matter, retaining these short period of record correlation pairs was deemed useful because the performance of map correlation (kriging) is contingent on data density (Archfield and Vogel, 2010; Skoien and Blöschl, 2007), and data obtained from short common periods of record have value for defining the spatial correlation structure. All reference streamgage correlations used in the variogram development were significant at the 0.05 level.

The mean correlation resulting from the map correlation method for the reference streamgages statewide is 0.93 (table 5). Mean correlations are shown in table 5 by drainage area and major basin. As the drainage area of the gaged basins increases, the mean correlation increases as well. Basins with small drainage areas tend to have unique hydrologic characteristics that can be more difficult to correlate with other basins. Lake Erie/Genesee River Basin had the lowest mean correlation, most likely because of the limited number of streamgages and lower density of streamgages than in other parts of the State. The Lower Susquehanna and Upper Delaware River Basins, in which the pilot analyses were conducted, had mean correlations of 0.94 and 0.95, respectively.

Table 5. Mean streamflow correlations for reference streamgages used in the map correlation method for Pennsylvania streams, by drainage area and major basin.

Area/basin	Number of reference streamgages	Mean streamflow correlation
By drainage area (in square miles)		
Less than 15	29	0.91
15–49	23	0.93
50–149	39	0.94
150–499	49	0.95
Greater than or equal to 500	16	0.96
By major basin		
Upper Delaware	18	0.95
Lower Delaware	20	0.94
Upper Susquehanna	15	0.93
West Branch Susquehanna	23	0.96
Lower Susquehanna	20	0.94
Potomac	7	0.92
Lake Erie/Genesee	2	0.88
Allegheny	28	0.94
Monongahela	11	0.93
Upper Ohio	12	0.92
Statewide	156	0.93

Use of BaSE for Estimating Baseline Daily Mean Streamflow for Ungaged Locations

The **Baseline Streamflow Estimator (BaSE)** is a tool for simulating minimally altered streamflow at a daily time step for an ungaged location in Pennsylvania for WY 1960 to 2008. BaSE is a user-friendly and time-saving tool used to assist water-resource managers in determining water-allocation, ecological-flow, and human-health needs. BaSE is modeled after the MASYE (Archfield and others, 2010), but parts of the MASYE code have been modified for use in this application and written as a stand-alone application on a visual basic.net (VB.NET) platform with the use of Microsoft Excel®. Output from the program consists of reference streamgage information, baseline daily mean streamflow, mean and median streamflow, FDCs, and hydrographs.

Basin characteristic information for the ungaged location is manually entered by the user or obtained in StreamStats (<http://water.usgs.gov/osw/streamstats/pennsylvania.html>). BaSE can read in the geodatabase file downloaded from StreamStats and auto-populate the opening screen with the

required information. BaSE selects an appropriate reference streamgage for a user-entered ungaged location by default; the default is based on maximizing the estimated streamflow correlation. The user has the option of manually selecting a different reference streamgage. After the initial information is entered into BaSE, the Compute Baseline Daily Streamflows function computes the baseline daily mean streamflows for the ungaged location for WY 1960 to 2008.

A report output file, a Microsoft Excel® spreadsheet, is generated and summarizes the reference streamgage and ungaged location information, including basin characteristics, percent difference in basin characteristics between the two locations, and any warnings associated with the basin characteristics (fig. 8). Mean and median streamflows are computed for the ungaged location. FDCs and hydrographs are presented for the ungaged location in cubic feet per second and cubic feet per second per square mile. The estimated daily flows for the ungaged location can be easily exported to a text file that can be used as input into a statistical software package to determine additional streamflow statistics, such as low-flow frequencies or monthly flow-duration exceedance probabilities. More detailed information, instructions for use, and all related links to files for the BaSE tool are in appendix 5.

Accuracy and Limitations of Estimated Baseline Streamflows

Accuracy of estimated baseline daily streamflows for ungaged locations is dependent on the uncertainties associated with the multiple steps which compose the overall process. These steps include (1) measurement of streamflow at reference streamgages, (2) streamflow record extension at reference streamgages, (3) selection of a reference streamgage using the map correlation method, (4) transfer of exceedance probabilities from reference streamgage to the ungaged location, and (5) estimation of the flow duration curve for an ungaged location on the basis of regression equations and basin characteristics.

The accuracy of measured streamflow data is documented for each reference streamgage in annual data reports. In Pennsylvania, most of the published streamflow records are rated as fair to good. These ratings specify that 95 percent of the data are within 10 (good) to 15 (fair) percent of their true values.

Streamflow record extension introduces uncertainty to baseline streamflow estimates, which is difficult to quantify. Because the length of record requiring extension varied by streamgage from none to 75 percent of the record, the uncertainty introduced to the overall record also varies. A general sense of the accuracy of these estimates can be obtained by observing the correlation coefficients, which range from 0.75 to 0.98 (with a perfect correlation equal to 1). Factoring in the part of the record that required no extension will decrease the overall uncertainty. When the relation between the logarithm of streamflow at a streamgage requiring record extension and

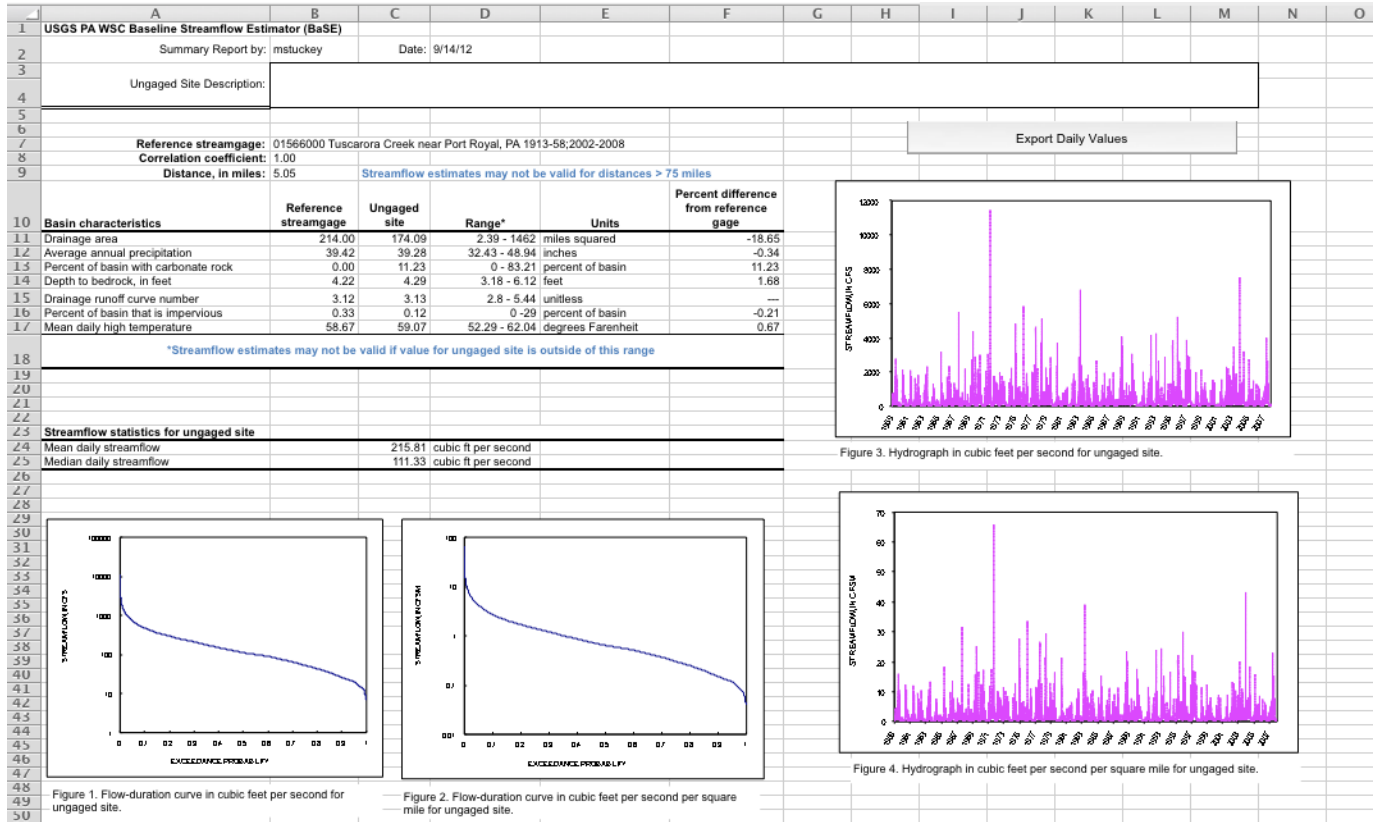


Figure 8. Screen capture of report generated by the BaSE tool showing flow duration curves and a hydrograph.

the logarithm of streamflow at the reference streamgage is non-linear, the correlations, and associated uncertainties, are less likely to agree. Thus, the overall uncertainty introduced by record extension is a combination of the length of extension period, strength of reference streamgage correlation, and quality of the relation between daily streamflow and daily exceedance probabilities when streamflow is used as a surrogate for exceedance probability

The selection of a reference streamgage by map correlation affects the uncertainty in the baseline streamflow estimates by way of the accuracy with which the best correlated reference streamgage is selected. Even when the best correlated reference streamgage is selected, uncertainty is introduced into the daily exceedance probabilities for the ungaged location because the reference streamgage would still not be perfectly correlated. Additional uncertainty would be introduced if map correlation did not select the best correlated reference streamgage. In the pilot basin trials, cross-validation experiments permitted comparison of the accuracy between the map correlation methods and alternate means in the selection of the best reference streamgage. The pilot basin trials showed that 50 to 60 percent of the time, map correlation selected the best correlated streamgage. However, the

accuracy of map correlation when extrapolated to ungaged locations across Pennsylvania remains unknown.

The transfer of streamflow exceedance probabilities from reference streamgage to an ungaged location relies on the assumption that both locations experience identical exceedance probabilities at identical times. Although this assumption is more likely to be true for locations in proximity to the reference streamgage, its validity for ungaged locations at the distances common statewide is unknown. Other than in the pilot basin trials presented in this report, this assumption is untested in Pennsylvania.

Uncertainties in the constructed FDC for the ungaged locations consist of errors in the regression estimates of the 17 specified exceedance probabilities and uncertainties introduced through interpolation of the remaining unspecified exceedance probabilities of the FDC. Prediction errors for the regression estimates range from 11 to 92 percent (table 2). All other exceedance probabilities are interpolated. Archfield and others (2010) noted “hook” features when plotting observed and estimated daily mean streamflows at the highest and lowest streamflows and attributed that to an artifact of the log-linear interpolation between the exceedance probabilities that were used in Massachusetts. This hook feature

was also prevalent in plots of observed and estimated streamflow for streamgages in Pennsylvania. A FDC for streamgage 01548500 using log-linear interpolation is shown in figure 9A; hook features are circled in red. Use of log-log interpolation smoothed out the hook features in the higher flows (fig. 9B). Other interpolations were examined to smooth the lower hook features, but without consistent results. The remaining hook features affect mainly the extreme low streamflows (well below P99) observed over the 49-year period, typically resulting in underprediction of extreme low flows.

To evaluate the effectiveness of the overall QPPQ method contained within BaSE, a comparison of observed and estimated daily mean streamflows was performed for all the streamgages in the pilot basins. Estimated streamflows were produced using the BaSE tool and the best correlated reference streamgage within the same pilot basin. Only periods with observed daily mean streamflows were compared. The comparison is intended to show how the BaSE tool can be expected to perform over the range of basin characteristics found across the State. Overall, the pilot basin streamgages are representative of the range of basin characteristics used in the development of the regression equations. With the exception of impervious land cover, more than 50 percent of the range of basin characteristics is represented by the pilot

basin streamgages. NS efficiency values and percent root-mean-square-error (RMSE) were computed as a measure of goodness of fit. Median NS efficiencies ranged from 0.54 to 0.96 (median of 0.82) for the Lower Susquehanna River pilot basin and from 0.47 to 0.91 (median of 0.79) for the Upper Delaware River pilot basin (fig. 10A). RMSE ranged from 27 to 256 percent (median of 93 percent) for the Lower Susquehanna River pilot basin and from 43 to 228 percent (median of 65 percent) for the Upper Delaware River pilot basin (fig. 10B).

Hydrographs and FDCs generated in BaSE for streamgages 01556000, Frankstown Branch Juniata River at Williamsburg, Pa., and 01452500, Monocacy Creek at Bethlehem, Pa., are shown in figures 11A and 11B, respectively. These streamgages represent the best (01556000) and worst (01452500) correlations for streamgages in the pilot basins with observed streamflow for WY 1960 to 2008. Streamgage 01556000 was associated with reference streamgage 01559000 with a correlation of 0.97, and streamgage 01452500 was associated with reference streamgage 01451500 with a correlation of 0.90 for estimates of daily mean flow. The low-flow period from 1998 to 2002 is shown in the hydrographs in figure 11. Although both hydrographs show good general fit between the estimated and observed streamflow, the hydrograph for

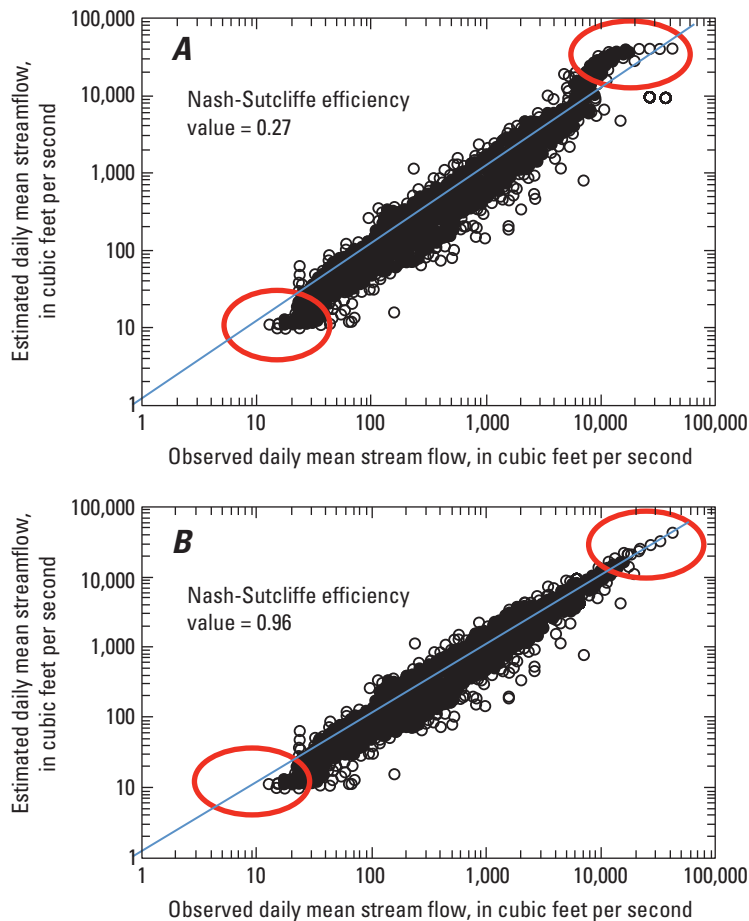


Figure 9. Observed and estimated daily mean streamflow for U.S. Geological Survey streamgage 01548500 Pine Creek at Cedar Run, Pa., using, *A*, log-linear interpolation and, *B*, log-log interpolation.

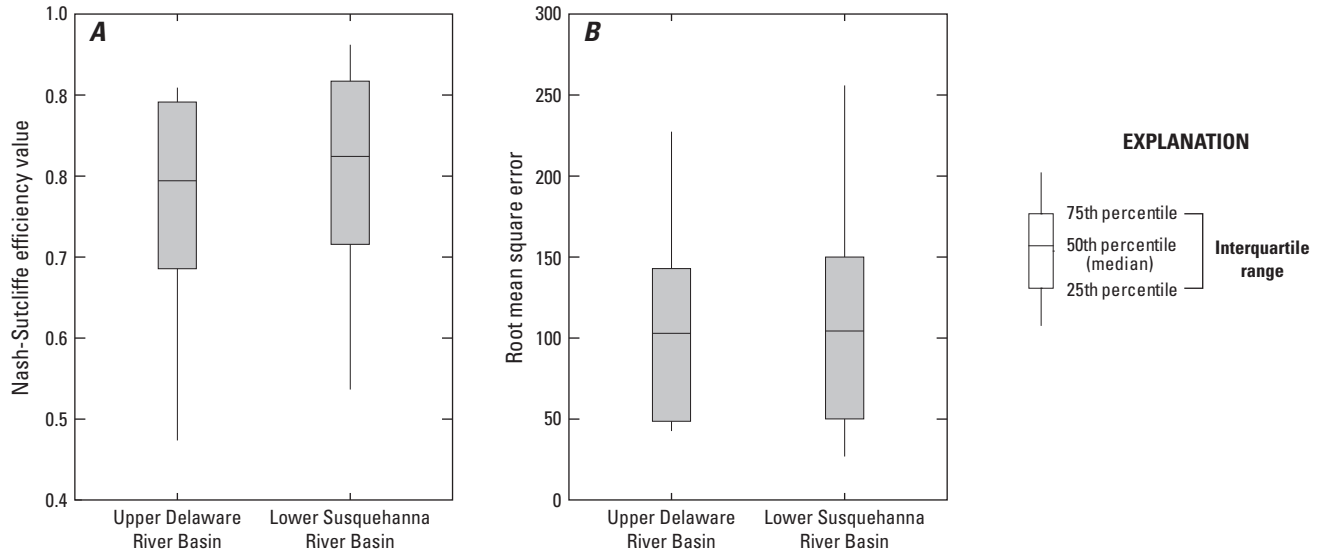


Figure 10. Distribution of, *A*, Nash-Sutcliffe efficiency values and, *B*, root mean square error obtained from comparison between observed and estimated daily mean streamflows in the two pilot basins in Pennsylvania.

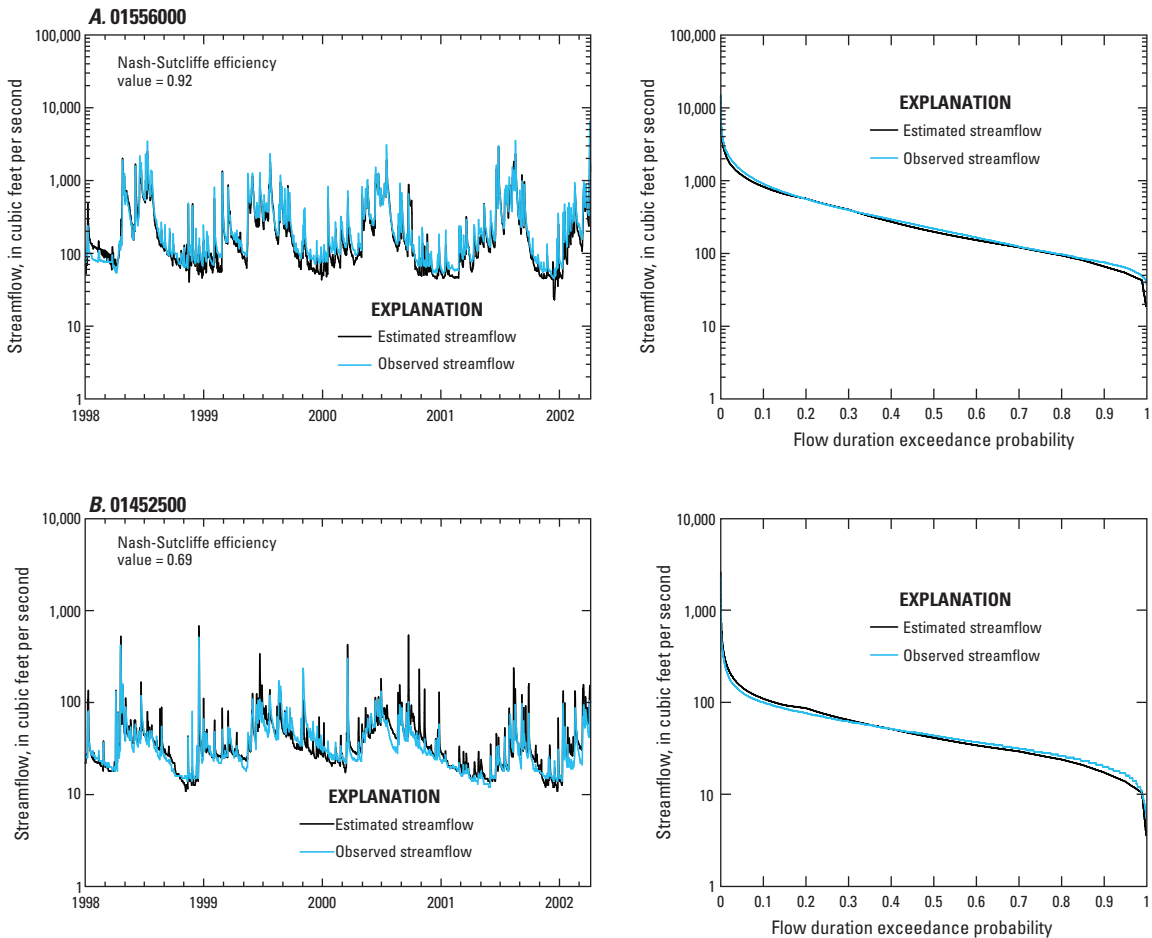


Figure 11. Hydrographs and flow duration curves showing estimated and observed daily mean flows for U.S. Geological Survey streamgages, *A*, 01556000, Frankstown Branch Juniata River at Williamsburg, Pa., and, *B*, 01452500, Monocacy Creek at Bethlehem, Pa.

01452500 shows more variance, which is reflected in the lower NS value of 0.69.

BaSE relies on estimates of streamflow derived from regression equations, and as such, it is not to be used for streams with basin characteristics outside the range used to develop the equations. Estimates of streamflow for streams with basin characteristics outside this range may not be valid. The range of basin characteristics used in the development of the regression equations is shown in table 6. Alterations to streamflow by regulation, mining, or other large water uses are not reflected in the estimated streamflows generated by BaSE, which are estimates of unaffected streamflows under baseline conditions. If groundwater and surface-water divides are not coincident, which can occur in areas with karst topography or mining, results from the regression equations and BaSE also may not be valid.

Summary

The ability to generate daily mean streamflow for any location on a stream in Pennsylvania is critical for water-resource managers. Water-allocation decisions, recreation resource decisions, and in-depth evaluation of flow regimes to promote instream ecological health often require streamflow information obtainable only from a time series hydrograph. Daily mean streamflow is not readily available for ungaged streams in Pennsylvania. The U.S. Geological Survey, in cooperation with the Pennsylvania Department of Environmental Protection, Susquehanna River Basin Commission, and The Nature Conservancy, has developed the Baseline Streamflow Estimator (BaSE) to estimate minimally altered or “baseline” daily mean streamflow for ungaged streams in Pennsylvania for water years 1960 to 2008. BaSE uses a modified QPPQ approach that equates the streamflow as a percentile from the flow duration curve (FDC) for a particular day at an ungaged

location with the streamflow as a percentile for the same day at a reference streamgage. Correlation of streamflow is used to select an appropriate reference streamgage for the ungaged location. Streamflows corresponding to the percentile for the ungaged location are selected from a daily FDC constructed from points determined by regression equations using basin characteristics.

Flow-duration exceedance probability regression equations were developed for 17 percentiles along the FDC using data from 162 streamgages from the 1960 water year through the 2008 water year. The standard errors of prediction for the flow-duration regression equations range from 11 percent to 92 percent, with the average standard error over the entire suite of equations equal to 31 percent.

The map correlation method was tested in two pilot basins—the Lower Susquehanna River Basin and the Upper Delaware River Basin—to confirm applicability for use in Pennsylvania. The map correlation method performed as well as, or better than, the closest centroid method for selecting reference sites in the basins and offers consistency and reliability in the approach. Therefore, variogram models were developed for a subset of the reference streamgage dataset with minimally altered streamflow in and near Pennsylvania using a spherical distribution model.

The BaSE tool estimates the daily mean streamflow for an ungaged location by first selecting a reference streamgage using the map correlation method as a default. An option is available for a manual choice by the user. After selecting a reference streamgage, BaSE then equates the percentiles at the gaged site for a particular day with percentiles at the ungaged location for the same day. The percentiles are converted to streamflow at the ungaged location using regression equations and interpolation. BaSE outputs a report file in Microsoft Excel® summarizing the reference streamgage and ungaged location information, including basin characteristics, percent difference in basin characteristics between the two sites, any warning associated with the basin characteristics, mean and

Table 6. Basin characteristics with minimum, maximum, and mean values used in development of regression equations to estimate flow-duration exceedance probabilities with BaSE for basins in Pennsylvania.

Basin characteristic	Minimum	Maximum	Mean
Longitude (decimal degrees)	74.9856	80.9953	77.6276
Drainage area (square mile)	2.39	1,462	171
Percent impervious area	0.02	29.2	2.5
Percent carbonate bedrock	0	83.2	6.9
Mean annual precipitation (inches)	32.4	48.9	42
Mean maximum daily temperature (degrees Fahrenheit)	52.3	62.0	57.3
Soil depth to bedrock (feet)	3.18	6.12	4.64
Drainage runoff number ¹	2.80	5.44	3.57

¹Unit less 1 = well to 7 = poor

median streamflows, and hydrographs for the ungaged location. The daily mean streamflow for the ungaged location can be exported as a text file to be used as input into separate statistical software for further analysis.

Accuracy of estimated baseline daily mean streamflow for ungaged locations is affected by the uncertainties introduced by the multiple steps involved in the process. Uncertainty is introduced during the selection of the reference streamgage, estimation of exceedance probabilities for the ungaged location, and the QPPQ process. It is difficult to quantify the overall uncertainty associated with the estimated daily mean flows at the ungaged location because of the number of potential sources. Observed and estimated daily mean flows for reference streamgages in the two pilot basins were examined for accuracy. Median Nash-Sutcliffe efficiency values ranged from 0.47 to 0.96, and root mean square errors ranged from 27 to 256 percent for the streamgages in the pilot basins. BaSE is not to be used to estimate daily mean streamflow in basins with basin characteristics outside the range used to develop the equations. Alterations to streamflow by regulation, mining, or other large water uses are not reflected in the estimated streamflow values generated by BaSE. If the groundwater and surface-water divides are not coincident, which can occur in areas with karst topography or mining, results from the regression equations and BaSE may not be valid.

References Cited

- Apse, C., Dephily, M., Zimmerman, J., and Smith, M.P., 2008, Developing instream flow criteria to support ecologically sustainable water resource planning and management: Harrisburg, Pa: The Nature Conservancy, p. 195
- Archfield, S.A., Vogel, R.M., Steeves, P.A., Brandt, S.L., Weiskel, P.K., and Garabedian, S.P., 2010, The Massachusetts Sustainable-Yield Estimator: A decision-support tool to assess water availability at ungaged stream locations in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2009–5227, 41 p., plus CD-ROM.
- Archfield, S. A., and R. M. Vogel, 2010, Map correlation method: Selection of a reference streamgage to estimate daily streamflow at ungaged catchments: *Water Resources Research*, no. 46, W10513, doi:10.1029/2009WR008481.
- Daly, Christopher, 1996, Overview of the PRISM Model, accessed December 7, 2011, at <http://www.ocs.orst.edu/prism/overview.html>.
- DePhilip, M., and Moberg, T., 2010, Ecosystem Flow Recommendations for the Susquehanna River Basin: The Nature Conservancy, 96 p.
- Environmental Resources Research Institute, 1996, Areas of carbonate lithology: Pennsylvania Department of Environmental Protection, accessed December 7, 2011, at <http://www.pasda.psu.edu/>.
- Environmental Systems Research Institute, Inc., 2009, accessed August 4, 2009, at <http://www.esri.com/>.
- Fennessey, N.M., 1994, A hydro-climatological model of daily streamflow for the northeast United States: Medford, Mass., Tufts University, Ph.D. dissertation [variously paged].
- Granato, G.E., 2009, Computer programs for obtaining and analyzing daily mean streamflow data from the U.S. Geological Survey National Water Information System Web Site: U.S. Geological Survey Open-File Report 2008–1362, 123 p. on CD-ROM, 5 append.
- Helsel, D.R., and Hirsch, R.M., 1992, *Statistical methods in environmental science 49—Statistical methods in water resources*: Amsterdam, Elsevier, 522 p.
- Henriksen, J.A., Heasley, J., Kennen, J.G., and Nieswand, S., 2006, Users' manual for the Hydroecological Integrity Assessment Process software (including the New Jersey Assessment Tools): U.S. Geological Survey Open-File Report 2006–1093, 72 p.
- Hirsch, R.M., 1982, A comparison of four streamflow record extension techniques: *Water Resources Research*, v. 18, no. 4, p. 1081–1088.
- Homer, C., Huang, C., Yang, L., Wylie, B., and Coan, M., 2004, Development of a 2001 National Landcover Database for the United States: *Photogrammetric Engineering and Remote Sensing*, v. 70, no. 7, July 2004, p. 829–840, accessed December 7, 2011, at http://www.mrlc.gov/mrlc2k_publications.asp.
- Huang, W-C., and Yang, F-T., 1998, Streamflow estimation using kriging: *Water Resources Research*, v. 34, no. 6, p. 1599–1608.
- Hughes, D.A., and Smakhtin, V.U., 1996, Daily flow time series patching or extension: a spatial interpolation approach based on flow duration curves: *Journal of Hydrological Sciences*, v. 41, no. 6, p. 851–871.
- Isaaks, E.H., and Srivastava, R.M., 1989, *An Introduction to Applied Geostatistics*: New York and Oxford, Oxford University Press, 561 p.
- Mohamoud, Y. M., 2008, Prediction of daily flow duration curves and streamflow for ungauged catchments using regional flow duration curves: *Journal of Hydrological Sciences*, v. 53, no. 4, p. 706–724.

- Pennsylvania Department of Conservation and Natural Resources, 1997, *Glacial deposits of Pennsylvania: Bureau of Topographic and Geologic Survey*, accessed December 7, 2011, at <http://www.dcnr.state.pa.us/topogeo/field/glacial.aspx>.
- Poff, N.L., Richter, B., Arthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P., Freeman, M., Henriksen, J., Jacobson, R.B., Kennen, J., Merritt, D.M., O’Keefe, J., Olden, J.D., Rogers, K., Tharme, R.E., and Warner, A., 2010, *The Ecological Limits of Hydrologic Alteration (ELOHA): a new framework for developing regional environmental flow standards: Freshwater Biology*, no. 55, p. 147–170.
- Price, C., Nakagaki, N., Hitt, K., and Clawges, R., 2003, *Mining GIRAS: Improving on a national treasure of land use data: ESRI International User Conference 2003 Proceedings*, accessed December 7, 2011, at <http://gis.esri.com/library/userconf/proc03/p0904.pdf>.
- Risser, D.W., Thompson, R.E., and Stuckey, M.H., 2008, *Regression method for estimating long-term mean annual ground-water recharge rates from base flow in Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2008–5185*, 23 p.
- Roland, M.A., and Stuckey, M.H., 2008, *Regression equations for estimating magnitude and frequency of peak flows for ungaged streams in Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2008–5102*, 76 p.
- Searcy, J. K., 1959, *Flow-duration curves: U.S. Geological Survey Water-Supply Paper 1542-A*, p. 1–33.
- Searcy, J.K., 1960, *Graphical correlation of gaging-station records: U.S. Geological Survey Water-Supply Paper 1541-C*, p. 67–100.
- Shu, C., and Ourda, T.B.M.J., 2012, *Improved methods for daily streamflow estimates at ungauged sites: Water Resources Research*, v. 48, W02523, doi:10.1029/2011WR011501.
- Skøien, J.O., and Blöschl, G., 2007, *Spatiotemporal topological kriging of runoff time series: Water Resources Research*, 43, W09419, doi:10.1029/2006WR005760.
- Smakhtin, V.U., 1999, *Generation of natural daily flow time series in regulated rivers using nonlinear spatial interpolation technique: Regulated Rivers Research and Management* v. 15, 12 p.
- Smakhtin, V.U., and Masse, B., 2000, *Continuous daily hydrograph simulation using duration curves of a precipitation index: Hydrological Processes*, v. 14, p. 1,083–1,100.
- Stuckey, M.H., 2006, *Low-flow, base-flow, and mean-flow regression equations for Pennsylvania streams: U.S. Geological Survey Scientific Investigations Report 2006–5130*, 84 p.
- Stuckey, M.H., 2008, *Development of the Water-Analysis Screening Tool used in the initial screening for the Pennsylvania State Water Plan update of 2008: U.S. Geological Survey Open-File Report 2008–1106*, 9 p.
- Stuckey, M.H., and Hoffman, S.A., 2010, *Pennsylvania StreamStats: A web-based application for obtaining water-resource-related information: U.S. Geological Survey Fact Sheet 2010–3086*, 2 p.
- Stuckey, M.H., and Roland, M.A., 2011, *Selected streamflow statistics for streamgage locations in and near Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2011–1070*, 88 p.
- The Nature Conservancy, 2009, *Indicators of Hydrologic Alteration Version 7.1 User’s Manual: The Nature Conservancy*, April 2009, 76 p.
- TIBCO Software Inc., 2008, *TIBCO Spotfire S+ 8.1 Guide to Packages: Palo Alto, Calif.*, 77 p.
- U.S. Department of Agriculture, 1994, *State Soil Geographic (STATSGO) Data Base: Washington D.C.: Miscellaneous Publication Number 1492*, 33 p., accessed June 19, 2012, at http://dbwww.essc.psu.edu/dbtop/doc/statsgo/statsgo_info.html.
- U.S. Geological Survey, 2000a, *U.S. GeoData Digital Elevation Models: U.S. Geological Survey Fact Sheet 040–00*, 3 p., accessed December 7, 2011, at <http://erg.usgs.gov/isb/pubs/factsheets/fs04000.html>.
- U.S. Geological Survey, 2000b, *NHD User Guide*, accessed December 7, 2011, at <http://nhd.usgs.gov/userguide.html>.
- Vogel, R.M., and Fennessey, N.M., 1994, *Flow-duration curves I: A new interpretation and confidence intervals: ASCE Journal of Water Resources Planning and Management*, v. 120, no. 4, p. 485–504.
- Vogel, R.M., and Stedinger, J.R., 1985, *Minimum variance streamflow record augmentation procedures: Water Resources Research*, v. 21, no. 5, p. 715–723.
- Waldron, M.C., and Archfield, S.A., 2006, *Factors affecting firm yield and the estimation of firm yield for streamflow-dominated drinking-water-supply reservoirs in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2006–5044*, 39 p.

Appendixes 1–4

Appendix 1. Description of reference streamgages used in the development of BaSE for Pennsylvania with period of record and use of data.[ddmms, degrees, minutes, seconds; m², square miles]

U.S. Geological Survey streamgage number	Name	Latitude (ddmms)	Longitude (ddmms)	Drainage area (mi ²)	Period of record ¹	Use of daily streamflow data ²
01420500	Beaver Kill at Cooks Falls, NY	415647	745848	242	1913–2008	MAP, PILOT
01423000	West Branch Delaware River at Walton, NY	420958	750825	332	1950–2008	MAP, PILOT
0142400103	Trout Creek near Trout Creek, NY	421025	751647	20.2	1952–67, 1996–1999	REG, MAP, PILOT
01426000	Oquaga Creek at Deposit, NY	420331	752542	67.7	1941–73, 2004–2005	MAP, PILOT
01428750	West Branch Lackawaxen River near Aldenville, PA	414028	752235	40.6	1987–2008	REG, MAP, PILOT
01429000	West Branch Lackawaxen River at Prompton, PA	413514	751938	59.7	1945–2008	REG
01431000	Middle Creek near Hawley, PA	412905	751320	78.4	1946–1960	REG
01439500	Bush Kill at Shoemakers, PA	410517	750217	117	1909–2008	REG, MAP, PILOT
01440400	Brodhead Creek near Analomink, PA	410505	751254	65.9	1958–2008	REG, MAP, PILOT
01442500	Brodhead Creek at Minisink Hills, PA	405955	750835	259	1950–2008	REG, MAP, PILOT
01447500	Lehigh River at Stoddartsville, PA	410749	753733	91.7	1944–2008	REG, MAP, PILOT
01447720	Tobyhanna Creek near Blakeslee, PA	410505	753621	118	1961–1984	REG, MAP, PILOT
01448500	Dilldown Creek near Long Pond, PA	410208	753237	2.39	1949–1996	REG, MAP, PILOT
01449360	Pohopoco Creek at Kresgeville, PA	405351	753010	49.9	1966–2008	REG, MAP, PILOT
01450500	Aquashicola Creek at Palmerton, PA	404822	753554	76.7	1939–2008	REG, MAP, PILOT
01451500	Little Lehigh Creek near Allentown, PA	403456	752900	80.8	1946–2008	REG, MAP, PILOT
01451800	Jordan Creek near Schnecksville, PA	403942	753738	53.0	1966–2008	REG, MAP, PILOT
01452000	Jordan Creek at Allentown, PA	403723	752858	75.8	1945–2008	REG, MAP, PILOT
01452500	Monocacy Creek at Bethlehem, PA	403828	752247	44.5	1948–2008	REG, MAP, PILOT
01459500	Tohickon Creek near Pipersville, PA	402601	750701	97.4	1937–1973	REG, MAP, PILOT
01464907	Little Neshaminy Creek at Valley Road near Neshaminy PA	401345	750712	26.8	1998–2008	REG, MAP
01465798	Poquessing Creek at Grant Avenue at Philadelphia, PA	400325	745908	21.4	1966–2008	REG
01467048	Pennypack Creek at Lower Rhawn Street Bridge, Philadelphia, PA	400300	750159	49.8	1965–2008	REG, MAP
01467086	Taony Creek above Adams Avenue, Philadelphia, PA	400247	750640	16.7	1966–70;1974–86;2006–08	REG
01468500	Schuylkill River at Landingsville, PA	403745	760730	133	1948–53;1963–65;1974–2008	REG, MAP
01470500	Schuylkill River at Berne, PA	403121	755955	355	1949–2008	REG, MAP
01470756	Maiden Creek at Virginville, PA	403051	755300	159	1973–1995	REG, MAP
01470779	Tulpehocken Creek near Bernville, PA	402448	761019	66.5	1975–2002	REG, MAP
01471000	Tulpehocken Creek near Reading, PA	402208	755846	211	1951–1979	REG, MAP
01471980	Manatawny Creek near Pottstown, PA	401622	754049	85.5	1975–2004	REG, MAP

Appendix 1. Description of reference streamgages used in the development of BaSE for Pennsylvania with period of record and use of data.—Continued[ddmss, degrees, minutes, seconds; mi², square miles]

U.S. Geological Survey streamgage number	Name	Latitude (ddmss)	Longitude (ddmss)	Drainage area (mi ²)	Period of record ¹	Use of daily streamflow data ²
01472000	Schuylkill River at Pottstown, PA	401430	753907	1147	1928–1979	REG, MAP
01472157	French Creek near Phoenixville, PA	400905	753606	59.1	1969–2008	REG, MAP
01472174	Pickering Creek near Chester Springs, PA	400522	753750	5.98	1967–1983	REG, MAP
01472198	Perkiomen Creek at East Greenville, PA	402338	753057	38.0	1982–2008	REG, MAP
01472199	West Branch Perkiomen Creek at Hillgass, PA	402226	753122	23.0	1982–2008	REG, MAP
01473120	Skippack Creek near Collegeville, PA	400952	752601	53.7	1966–1994	REG, MAP
01475510	Darby Creek near Darby, PA	395544	751622	37.4	1964–1990	REG, MAP
01475530	Cobbs Creek at U.S. Highway No. 1 at Philadelphia, PA	395829	751649	4.78	1965–81;2005–08	REG
01475850	Crum Creek near Newtown Square, PA	395835	752613	15.8	1981–2008	REG, MAP
01479820	Red Clay Creek near Kennett Square, PA	394900	754131	28.3	1988–2008	REG, MAP
01480300	West Branch Brandywine Creek near Honey Brook, PA	400422	755140	18.7	1961–2008	REG, MAP
01480675	Marsh Creek near Glenmoore, PA	400552	754431	8.57	1967–2008	REG, MAP
01481000	Brandywine Creek at Chadds Ford, PA	395211	753537	287	1912–1953;1962–1973	REG, MAP
01514000	Owego Creek near Owego, NY	420745	761615	185	1930–1978	REG, MAP
01516500	Corey Creek near Mainesburg, PA	414727	770054	12.2	1954–2008	REG, MAP
01517000	Elk Run near Mainesburg, PA	414854	765755	10.2	1955–1978	REG, MAP
01518500	Crooked Creek at Tioga, PA	415408	770855	122	1954–1974	REG, MAP
01518862	Cowanesque River at Westfield, PA	415523	773156	90.6	1984–2008	REG, MAP
01520000	Cowanesque River near Lawrenceville, PA	415948	770825	298	1952–1979	REG, MAP
01525500	Canisteo River at West Cameron, NY	421320	772505	340	1931;1937–1970;	REG, MAP
01529500	Cohocton River near Campbell, NY	421509	771301	470	1919–2008	REG, MAP
01530500	Newtown Creek at Elmira, NY	420616	764754	77.5	1938–1989	REG, MAP
01532000	Towanda Creek near Monroeton, PA	414225	762906	215	1915–2008	REG, MAP
01532850	Middle Branch Wyalusing Creek near Birchardville, PA	415145	760026	5.67	1965–1979	REG, MAP
01533950	South Branch Tunkhannock Creek near Montdale, PA	413429	753832	12.6	1961–1978	REG, MAP
01534000	Tunkhannock Creek near Tunkhannock, PA	413330	755342	383	1915–2008	REG, MAP
01538000	Wapwallopen Creek near Wapwallopen, PA	410333	760538	43.8	1920–2008	REG, MAP
01539000	Fishing Creek near Bloomsburg, PA	410441	762553	274	1939–2008	REG, MAP
01541000	West Branch Susquehanna River at Bower, PA	405349	784038	315	1914–2008	REG, MAP
01541308	Bradley Run near Ashville, PA	403033	783502	6.77	1967–1980	REG, MAP

Appendix 1. Description of reference streamgages used in the development of BaSE for Pennsylvania with period of record and use of data.—Continued[ddmms, degrees, minutes, seconds; mi², square miles]

U.S. Geological Survey streamgage number	Name	Latitude (ddmms)	Longitude (ddmms)	Drainage area (mi ²)	Period of record ¹	Use of daily streamflow data ²
01541500	Clearfield Creek at Dimeling, PA	405818	782422	371	1914–2008	REG
01542500	West Branch Susquehanna River at Karthaus, PA	410703	780633	1462	1941–1964	REG, MAP
01542810	Waldy Run near Emporium, PA	413444	781734	5.24	1965–2008	REG, MAP
01543000	Driftwood Br Sinnemahoning Creek at Sterling Run, PA	412448	781150	272	1914–2008	REG, MAP
01543500	Sinnemahoning Creek at Sinnemahoning, PA	411902	780612	685	1939–2008	REG, MAP
01544500	Kettle Creek at Cross Fork, PA	412833	774934	136	1941–2008	REG, MAP
01545600	Young Womans Creek near Renovo, PA	412322	774128	46.2	1965–2008	REG, MAP
01546400	Spring Creek at Houserville, PA	405001	774940	58.5	1985–2008	REG, MAP
01546500	Spring Creek near Axemann, PA	405323	774740	87.2	1941–2008	REG, MAP
01547100	Spring Creek at Milesburg, PA	405554	774709	142	1968–2008	REG, MAP
01547200	Bald Eagle Creek below Spring Creek at Milesburg, PA	405635	774712	265	1956–2008	REG, MAP
01547700	Marsh Creek at Blanchard, PA	410334	773622	44.1	1956–2008	REG, MAP
01547950	Beech Creek at Monument, PA	410642	774209	152	1969–2008	REG, MAP
01548005	Bald Eagle Creek near Beech Creek Station, PA	410451	773259	562	1912–1970	REG, MAP
01548500	Pine Creek at Cedar Run, PA	413118	772652	604	1919–2008	REG, MAP
01549500	Blockhouse Creek near English Center, PA	412825	771352	37.7	1941–2008	REG, MAP
01549700	Pine Creek below Little Pine Creek near Waterville, PA	411625	771928	944	1958–2008	REG, MAP
01549780	Larrys Creek at Cogan House, PA	412504	770946	6.80	1961–1978	REG, MAP
01550000	Lycoming Creek near Trout Run, PA	412506	770159	173	1914–2008	REG, MAP
01552000	Loyalsock Creek at Loyalsockville, PA	411930	765446	435	1926–2008	REG, MAP
01552500	Muncy Creek near Sonestown, PA	412125	763206	23.8	1941–2008	REG, MAP
01553130	Sand Spring Run near White Deer, PA	410331	770437	4.93	1968–1980	REG, MAP
01555000	Penns Creek at Penns Creek, PA	405200	770255	301	1930–2008	REG, MAP, PILOT
01555500	East Mahantango Creek near Dalmatia, PA	403640	765444	162	1930–2008	REG, MAP, PILOT
01556000	Frankstown Branch Juniata River at Williamsburg, PA	402747	781200	291	1917–2008	REG, MAP, PILOT
01556500	Little Juniata River at Tipton, PA.	403740	781738	93.7	1946–1962	REG, PILOT
01557500	Bald Eagle Creek at Tyrone, PA	404101	781402	44.1	1953–2008	REG, MAP, PILOT
01558000	Little Juniata River at Spruce Creek, PA	403645	780827	220	1939–2008	REG, MAP, PILOT
01559000	Juniata River at Huntingdon, PA	402905	780109	816	1942–2008	REG, MAP, PILOT
01559700	Sulphur Springs Creek near Manns Choice, PA	395840	783708	5.28	1962–1978	REG, MAP, PILOT

Appendix 1. Description of reference streamgages used in the development of BaSE for Pennsylvania with period of record and use of data.—Continued[ddmss, degrees, minutes, seconds; mi², square miles]

U.S. Geological Survey streamgage number	Name	Latitude (ddmss)	Longitude (ddmss)	Drainage area (mi ²)	Period of record ¹	Use of daily streamflow data ²
01560000	Dunning Creek at Belden, PA	400418	782934	172	1939–2008	REG, MAP, PILOT
01562000	Raystown Branch Juniata River at Saxton, PA	401257	781556	756	1912–2008	REG, MAP, PILOT
01564500	Aughwick Creek near Three Springs, PA	401245	775532	205	1938–2008	REG, MAP, PILOT
01565000	Kishacoquillas Creek at Reedsville, PA	403917	773500	164	1940–70;1984–85;2001–08	REG, MAP, PILOT
01565700	Little Lost Creek at Oakland Mills, PA	403619	771842	6.52	1964–1981	REG, MAP, PILOT
01566000	Tuscarora Creek near Port Royal, PA	403055	772510	214	1913–58;2002–08	REG, MAP, PILOT
01567500	Bixler Run near Loysville, PA	402215	772409	15.0	1954–2008	REG, MAP, PILOT
01568000	Sherman Creek at Shermans Dale, PA	401924	771009	207	1930–2008	REG, MAP, PILOT
01569000	Stony Creek near Dauphin, PA	402247	765427	33.2	1938–45;1967–74	REG
01570000	Conodoguinet Creek near Hogestown, PA	401508	770116	470	1930–58;1967–2008	REG, MAP, PILOT
01571500	Yellow Breeches Creek near Camp Hill, PA	401329	765354	216	1954–2008	REG, MAP, PILOT
01572000	Lower Little Swatara Creek at Pine Grove, PA	403215	762240	34.3	1920–32;1981–84	REG
01574500	Codorus Creek at Spring Grove, PA	395243	765113	75.5	1929–1964	REG, MAP, PILOT
01576754	Conestoga River at Conestoga, PA	395647	762205	470	1985–2002	REG, MAP, PILOT
01576787	Pequea Creek at Martic Forge, PA	395421	761943	148	1977–81;1993–95;2005–08	REG
01577500	Muddy Creek at Castle Fin, PA	394621	761858	133	1929–38;1968–71	REG
01578400	Bowery Run near Quarryville, PA	395341	760650	5.98	1964–1981	REG, MAP, PILOT
01603500	Evitts Creek near Centerville, PA	394723	783848	30.2	1934–1982	REG, MAP
01609000	Town Creek near Oldtown, MD	393312	783318	148	1967–81;2001–04;2007–2008	REG, MAP
01610155	Sideling Hill Creek near Bellegrove, MD	393858	782039	102	1967–77;1999–2008	REG, MAP
01612500	Little Tonoloway Creek near Hancock, MD	394245	781355	16.9	1948–1963	REG
01613050	Tonoloway Creek near Needmore, PA	395354	780757	10.7	1966–2008	REG, MAP
01614090	Conococheague Creek near Fayetteville, PA	395548	772623	5.05	1961–1981	REG, MAP
01614500	Conococheague Creek at Fairview, MD	394259	774929	494	1930–2008	REG, MAP
01639000	Monocacy River at Bridgeport, MD	394044	771404	173	1942–2008	REG, MAP
03007800	Allegheny River at Port Allegany, PA	414907	781735	248	1975–2008	REG, MAP
03009680	Potato Creek at Smethport, PA	414835	782550	160	1975–1995	REG, MAP
03010500	Allegheny River at Eldred, PA	415748	782311	550	1939–2008	REG, MAP
03010655	Oswayo Creek at Shinglehouse, PA	415742	781154	98.7	1975–2008	REG, MAP
03011020	Allegheny River at Salamanca, NY	420923	784256	1608	1904–2008	MAP

Appendix 1. Description of reference streamgages used in the development of BaSE for Pennsylvania with period of record and use of data.—Continued[ddmms, degrees, minutes, seconds; mi², square miles]

U.S. Geological Survey streamgage number	Name	Latitude (ddmms)	Longitude (ddmms)	Drainage area (mi ²)	Period of record ¹	Use of daily streamflow data ²
03011800	Kinzua Creek near Guffey, PA	414559	784308	38.8	1967–2008	REG, MAP
03013000	Conewango Creek at Waterboro, NY	421015	790410	290	1938–1993	REG, MAP
03015280	Jackson Run near North Warren, PA	415410	791418	12.8	1963–1978	REG, MAP
03015500	Brokenstraw Creek at Youngsville, PA	415109	791903	321	1911–2008	REG, MAP
03017500	Tionesta Creek at Lynch, PA	413607	790301	233	1939–1979	REG, MAP
03020500	Oil Creek at Rouseville, PA	412854	794144	300	1934–2008	REG, MAP
03021350	French Creek near Wattsburg, PA	420055	794658	92.0	1975–2008	REG, MAP
03021500	French Creek at Carters Corners, PA	415723	795238	208	1911–1971	REG, MAP
03022540	Woodcock Creek at Blooming Valley, PA	414126	800254	31.1	1976–1995	REG, MAP
03024000	French Creek at Utica, PA	412615	795722	1028	1934–1970	REG, MAP
03025000	Sugar Creek at Sugarcreek, PA	412543	795248	166	1934–1979	REG, MAP
03026500	Sevenmile Run near Rasselas, PA	413752	783437	7.84	1953–2008	REG, MAP
03028000	West Branch Clarion River at Wilcox, PA	413431	784133	63.0	1955–2008	REG, MAP
03029400	Toms Run at Cooksburg, PA	412016	791250	12.6	1961–1978	REG, MAP
03031950	Big Run near Sprinkle Mills, PA	405930	790526	7.38	1965–1981	REG, MAP
03032500	Redbank Creek at St. Charles, PA	405940	792340	528	1920–2008	REG, MAP
03038000	Crooked Creek at Idaho, PA	403917	792056	191	1939–1967	REG, MAP
03039200	Clear Run near Buckstown, PA	400249	784958	3.68	1965–1978	REG, MAP
03039925	North Fork Bens Creek at North Fork Reservoir, PA	401558	790101	3.45	1985;1988–1998	REG, MAP
03041000	Little Conemaugh River at East Conemaugh, PA	402045	785258	186	1939–1995	MAP
03042200	Little Yellow Creek near Strongstown, PA	403345	785644	7.36	1962–1988	REG, MAP
03049000	Buffalo Creek near Freeport, PA	404257	794159	137	1942–2008	REG, MAP
03049800	Little Pine Creek near Etna, PA	403113	795618	5.78	1963–2008	REG, MAP
03062500	Deckers Creek at Morgantown, WV	393745	795710	63.2	1946–69; 2002–2008	REG, MAP
03070500	Big Sandy Creek at Rockville, WV	393718	794216	200	1909–2008	MAP
03072590	Georges Creek at Smithfield, PA	394744	794747	16.3	1964–1978	REG, MAP
03072840	Tennile Creek near Clarksville, PA	395951	800231	133	1969–1979	REG, MAP
03073000	South Fork Tennile Creek at Jefferson, PA	395523	800422	180	1932–1995	REG, MAP
03074300	Lick Run at Hopwood, PA	395204	794140	3.80	1967–1978	REG, MAP
03078000	Casselman River at Grantsville, MD	394208	790811	62.5	1947–2008	REG, MAP

Appendix 1. Description of reference streamgages used in the development of BaSE for Pennsylvania with period of record and use of data.—Continued

[ddmms, degrees, minutes, seconds; mi², square miles]

U.S. Geological Survey streamgage number	Name	Latitude (ddmms)	Longitude (ddmms)	Drainage area (mi ²)	Period of record ¹	Use of daily streamflow data ²
03079000	Casselman River at Markleton, PA	395135	791340	382	1922–2008	REG, MAP
03080000	Laurel Hill Creek at Ursina, PA	394913	791918	121	1919–2008	REG, MAP
03082200	Poplar Run near Normalville, PA	400059	792533	9.27	1963–1978	REG, MAP
03084000	Abers Creek near Murrysville, PA	402701	794250	4.39	1949–1993	REG, MAP
03085956	Montour Run at Scott Station near Imperial, PA	402723	801034	25.4	2000–2008	REG, MAP
03092000	Kale Creek near Pricetown, OH	410823	805943	21.9	1941–1993	REG, MAP
03093000	Eagle Creek at Phalanx Station, OH	411540	805716	97.6	1926–34, 1938–2008	REG, MAP
03102500	Little Shenango River at Greenville, PA	412519	802235	104	1914–2008	REG, MAP
03102950	Pymatuning Creek at Kinsman, OH	412634	803518	96.7	1966–1994	REG, MAP
03103000	Pymatuning Creek near Orangeville, PA	411840	802840	169	1915–1963	REG, MAP
03106000	Connoquenessing Creek near Zellenople, PA	404901	801433	356	1920–2008	REG, MAP
03106500	Slippery Rock Creek at Wurttemberg, PA	405302	801402	398	1913–1969	REG, MAP
03109500	Little Beaver Creek near East Liverpool, OH	404033	803227	496	1916–2008	REG, MAP
03110000	Yellow Creek near Hammondsville, OH	403216	804331	147	1941–2008	REG, MAP
03111150	Brush Run near Buffalo, PA	401154	802428	10.3	1961–78; 1983–85	REG, MAP
03111500	Short Creek near Dillonvale, OH	401136	804404	123	1942–2008	REG, MAP
04213000	Conneaut Creek at Conneaut, OH	415537	803615	175	1922–36; 1950–61; 1962–2008	REG, MAP
04213075	Brandy Run near Girard, PA	415931	801729	4.45	1986–2008	REG, MAP

¹Period of record is in water years, defined as the 12-month period beginning October 1 and ending September 30. The water year is designated by the calendar year in which it ends.

²REG, regression analysis; MAP, map correlation; PILOT, pilot basin streamgage.

Appendix 2. Reference streamgages with record extension techniques applied.

U.S. Geological Survey streamgage number	Name	Portion of record extended	Index streamgage(s) used to extend record	Correlation coefficient between log-transformed flow records
0142400103	Trout Creek near Trout Creek, NY	Jul 1967–Nov 1996	WBr Delaware River at Walton, NY (01423000)	0.96
01426000	Oquaga Creek at Deposit, NY	Oct 1973–Sep 2008	WBr Delaware River at Walton, NY (01423000)	0.86
01428750	West Branch Lackawaxen River near Aldenville, PA	Oct 1959–Sept 1987	Tunkhannock Creek near Tunkhannock, PA (01534000)	0.93
01447720	Tobyhanna Creek near Blakeslee, PA	Oct 1959–Sept 1960 Oct 1985–Sept 2008	Lehigh River at Stoddartsville, PA (01447500)	0.95
01448500	Dilldown Creek near Long Pond, PA	Oct 1996–Sept 2008	Brodhead Creek at Minisink Hills, PA (01442500) Pohopoco Creek at Kresgeville, PA (01449360)	0.93 0.92
01449360	Pohopoco Creek at Kresgeville, PA	Oct 1959–Sept 1966	Aquashicola Creek at Palmerton, PA (01450500)	0.96
01451800	Jordan Creek near Schnecksville, PA	Oct 1959–Jan 1966	Jordan Creek at Allentown, PA (01452000)	0.98
01459500	Tohickon Creek near Pipersville, PA	Dec 1973–Sep 2008	Skippack Creek near Collegeville, PA (01473120) Jordan Creek near Schnecksville, PA (01451800)	0.89 0.87
01464907	Little Neshaminy Creek at Valley Rd, PA	Oct 1959–Nov 1998	Pennypack Creek at Lower Rhawn St, Philadelphia, PA (01467048) French Creek near Phoenixville, PA (01472157) Jordan Creek at Allentown, PA (01452000)	0.90 0.87 0.78
01467048	Pennypack Creek at Lower Rhawn Street Bridge, Philadelphia, PA	Oct 1959–Sep 1965	Tohickon Creek near Pipersville, PA (01459500)	0.75
01468500	Schuylkill River at Landingville, PA	Oct 1959–Sep 1963 Oct 1965–Jul 1973	Schuylkill River at Berne, PA (01470500)	0.98

Appendix 2. Reference streamgages with record extension techniques applied.—Continued

U.S. Geological Survey streamgage number	Name	Portion of record extended	Index streamgage(s) used to extend record	Correlation coefficient between log-transformed flow records
01470756	Maiden Creek at Virginville, PA	Oct 1995–Sep 2008	Jordan Creek at Allentown, PA (01452000)	0.96
01470779	Tulpehocken Creek near Bernville, PA	Oct 1959–Nov 1974	Tulpehocken Creek near Reading, PA (01471000)	0.92
01471000	Tulpehocken Creek near Reading, PA	Apr 1979–Sep 2008	Schuylkill River at Berne, PA (01470500)	0.92
01471980	Manatawny Creek near Pottstown, PA	Oct 1959–Jul 1974 Oct 2004–Sep 2008	West Branch Perkiomen Creek at Hillegass, PA (01472199) Jordan Creek at Allentown, PA (01452000)	0.96 0.86
01472000	Schuylkill River at Pottstown, PA	Apr 1979–Sep 2008	Schuylkill River at Berne, PA (01470500)	0.97
01472157	French Creek near Phoenixville, PA	Oct 1959–Sep 1968	Brandywine Creek at Chadds Ford, PA (01481000) Tohickon Creek near Pipersville, PA (01459500)	0.95 0.85
01472174	Pickering Creek near Chester Springs, PA	Oct 1959–Dec 1966 Oct 1983–Sep 2008	Brandywine Creek at Chadds Ford, PA (01481000) French Creek near Phoenixville, PA (01472157) Little Lehigh Creek near Allentown, PA (01451500)	0.92 0.91 0.77
01472198	Perkiomen Creek at East Greenville, PA	Oct 1959–Aug 1981	French Creek near Phoenixville, PA (01472157) Jordan Creek at Allentown, PA (01452000)	0.92 0.87
01472199	West Branch Perkiomen Creek at Hillegass, PA	Oct 1959–Sep 1981	Manatawny Creek near Pottstown, PA (01471980) Jordan Creek at Allentown, PA (01452000)	0.96 0.87
01473120	Skippack Creek near Collegeville, PA	Oct 1959–Apr 1966 Oct 1994–Sep 2008	French Creek near Phoenixville, PA (01472157) Jordan Creek at Allentown, PA (01452000)	0.86 0.79
01475510	Darby Creek near Darby, PA	Oct 1959–Sep 1964 Oct 1990–Sep 2008	Crum Creek near Newtown Square, PA (01475850) Tohickon Creek near Pipersville, PA (01459500)	0.91 0.75

Appendix 2. Reference streamgages with record extension techniques applied.—Continued

U.S. Geological Survey streamgage number	Name	Portion of record extended	Index streamgage(s) used to extend record	Correlation coefficient between log-transformed flow records
01475850	Crum Creek near Newtown Square, PA	Oct 1959–Sep 1981	Darby Creek near Darby, PA (01475510) West Branch Brandywine Creek near Honey Brook, PA (01480300) Little Lehigh Creek near Allentown, PA (01451500)	0.91 0.87 0.75
01479820	Red Clay Creek near Kennett Square, PA	Oct 1959–Dec 1987	Darby Creek near Darby, PA (01475510) Little Lehigh Creek near Allentown, PA (01451500)	0.88 0.76
01480300	West Branch Brandywine Creek near Honey Brook, PA	Oct 1959–May 1960	Tohickon Creek near Pipersville, PA (01459500)	0.82
01480675	Marsh Creek near Glenmoore, PA	Oct 1959–Jul 1966	Brandywine Creek at Chadds Ford, PA (01481000) Tohickon Creek near Pipersville, PA (01459500)	0.93 0.86
01481000	Brandywine Creek at Chadds Ford, PA	Oct 1959–Sep 1962 Nov 1973–Sep 2008	French Creek near Phoenixville, PA (01472157) Schuylkill River at Pottstown, PA (01472000)	0.95 0.86
01514000	Owego Creek near Owego, NY	Nov 1978–Sep 2008	Unadilla River at Rockdale, NY (01502500) Pine Creek at Cedar Run, PA (01548500)	0.92 0.89
01517000	Elk Run near Mainesburg, PA	Oct 1978–Sep 2008	Corey Creek near Mainesburg, PA (01516500)	0.97
01518500	Crooked Creek at Tioga, PA	Oct 1974–Sep 2008	Pine Creek at Cedar Run, PA (01548500)	0.95
01518862	Cowanesque River at Westfield, PA	Oct 1959–Jul 1983	Pine Creek at Cedar Run, PA (01548500)	0.94
01520000	Cowanesque River near Lawrenceville, PA	Dec 1979–Sep 2008	Pine Creek at Cedar Run, PA (01548500)	0.95
01525500	Canistota River at West Cameron, NY	Oct 1970–Sep 2008	Cohocton River near Campbell, NY (01529500)	0.96

Appendix 2. Reference streamgages with record extension techniques applied.—Continued

U.S. Geological Survey streamgage number	Name	Portion of record extended	Index streamgage(s) used to extend record	Correlation coefficient between log-transformed flow records
01530500	Newtown Creek at Elmira, NY	Aug 1989–Sep 2008	Cohocton River near Campbell, NY (01529500)	0.89
01532850	Middle Branch Wyalusing Creek near Birchardville, PA	Oct 1959–Aug 1965 Oct 1979–Sep 2008	Tunkhannock Creek near Tunkhannock, PA (01534000)	0.89
01533950	South Branch Tunkhannock Creek near Montdale, PA	Oct 1959–Aug 1960 Oct 1978–Sep 2008	Tunkhannock Creek near Tunkhannock, PA (01534000)	0.94
01541308	Bradley Run near Ashville, PA	Oct 1959–Sep 1967 Feb 1980–Sep 2008	Frankstown Branch Juniata River at Williamsburg, PA (01556000)	0.91
01542500	West Branch Susquehanna River at Karthaus, PA	Nov 1965–Sep 2008	West Branch Susquehanna River at Bower, PA (01541000)	0.96
01542810	Waldy Run near Emporium, PA	Oct 1959–Aug 1964	Driftwood Branch Sinnemahoning Creek at Sterling Run, PA (01543000)	0.96
01545600	Young Womans Creek near Renovo, PA	Oct 1959–Nov 1964	Kettle Creek at Cross Fork, PA (01544500)	0.96
01546400	Spring Creek at Houserville, PA	Oct 1959–Aug 1984	Bald Eagle Creek below Spring Creek at Milesburg, PA (01547200)	0.92
01547100	Spring Creek at Milesburg, PA	Oct 1959–Sep 1967	Spring Creek near Axemann, PA (01546500)	0.98
01547950	Beech Creek at Monument, PA	Oct 1959–Sep 1968	Marsh Creek at Blanchard, PA (01547700)	0.95
01548005	Bald Eagle Creek near Beech Creek Station, PA	Mar 1971–Sep 2008	Little Juniata River at Spruce Creek, PA (01558000)	0.95

Appendix 2. Reference streamgages with record extension techniques applied.—Continued

U.S. Geological Survey streamgage number	Name	Portion of record extended	Index streamgage(s) used to extend record	Correlation coefficient between log-transformed flow records
01549780	Larrys Creek at Cogan House, PA	Oct 1959–Sep 1960 Oct 1978–Sep 2008	Lycoming Creek near Trout Run, PA (01550000)	0.94
01552000	Loyalsock Creek at Loyalsockville, PA	Oct 1974–Sep 1975	Lycoming Creek near Trout Run, PA (01550000)	0.95
01553130	Sand Spring Run near White Deer, PA	Oct 1959–Dec 1968 Apr 1981–Sep 2008	Penns Creek at Penns Creek, PA (01555000) Beech Creek at Monument, PA (01547950)	0.91 0.89
01559700	Sulphur Springs Creek near Mamms Choice, PA	Oct 1959–Sep 1961 Oct 1978–Sep 2008	Dunning Creek at Belden, PA (01560000)	0.91
01565000	Kishacoquillas Creek at Reedsville, PA	Oct 1970–Sep 1983 Oct 1985–Sep 2001	Penns Creek at Penns Creek, PA (01555000)	0.97
01565700	Little Lost Creek at Oakland Mills, PA	Oct 1959–Aug 1963 Apr 1981–Sep 2008	Bixler Run near Loysville, PA (01567500)	0.89
01566000	Tuscarora Creek near Port Royal, PA	Oct 1959–Sep 2001	Sherman Creek at Shermans Dale, PA (01568000)	0.97
01570000	Conodoguinet Creek near Hogestown, PA	Oct 1959–Jun 1967	Conococheague Creek at Fairview, MD (01614500)	0.95
01574500	Codorus Creek at Spring Grove, PA	Oct 1964–Oct 1965 Oct 1967–Sep 2008	Yellow Breeches Creek near Camp Hill, PA (01571500)	0.88
01576754	Conestoga River at Conestoga, PA	Oct 1959–Sep 1984	French Creek near Phoenixville, PA (01472157) Schuylkill River at Berne, PA (01470500)	0.90 0.86
01578400	Bowery Run near Quarryville, PA	Oct 1959–Sep 1962 Apr 1981–Sep 2008	West Branch Brandywine Creek near Honey Brook, PA (01480300) Codorus Creek at Spring Grove, PA (01574500)	0.83 0.75

Appendix 2. Reference streamgages with record extension techniques applied.—Continued

U.S. Geological Survey streamgage number	Name	Portion of record extended	Index streamgage(s) used to extend record	Correlation coefficient between log-transformed flow records
01603500	Evitts Creek near Centerville, PA	Oct 1982–Sep 2008	Town Creek near Oldtown, MD (01609000) Raystown Branch Juniata River at Saxton, PA (01562000)	0.94 0.92
01609000	Town Creek near Oldtown, MD	Oct 1959–May 1967 Oct 1981–Apr 2001	Evitts Creek near Centerville, PA (01603500) Raystown Branch Juniata River at Saxton, PA (01562000)	0.94 0.93
01610155	Sideling Hill Creek at Bellegrove, MD	Oct 1959–Jun 1967 Oct 1977–Mar 1999	Aughwick Creek near Three Springs, PA (01564500)	0.90
01613050	Tonoloway Creek near Needmore, PA	Oct 1959–Sep 1965	Aughwick Creek near Three Springs, PA (01564500)	0.91
01614090	Conococheague Creek near Fayetteville, PA	Oct 1959–Aug 1960 Apr 1981–Sep 2008	Aughwick Creek near Three Springs, PA (01564500)	0.87
03007800	Allegheny River at Port Allegany, PA	Oct 1959–Sep 1974	Allegheny River at Eldred, PA (03010500)	0.98
03009680	Potato Creek at Smethport, PA	Oct 1959–Sep 1974 Oct 1995–Sep 2008	Allegheny River at Eldred, PA (03010500) Kinzua Creek near Guffey, PA (03011800)	0.96 0.96
03010655	Oswayo Creek at Shinglehouse, PA	Oct 1959–Sep 1974	Allegheny River at Eldred, PA (03010500) Allegheny River at Salamanca, NY (03011020)	0.95 0.94
03011800	Kinzua Creek near Guffey, PA	Oct 1959–Sep 1965	West Branch Clarion River at Wilcox, PA (03028000)	0.95
03013000	Conewango Creek at Waterboro, NY	Oct 1993–Sep 2008	French Creek at Carters Corners, PA (03021500) Allegheny River at Salamanca, NY (03011020)	0.93 0.91
03015280	Jackson Run near North Warren, PA	Oct 1959–Sep 1962 Oct 1978–Sep 2008	Brokenstraw Creek at Youngsville, PA (03015500)	0.94

Appendix 2. Reference streamgages with record extension techniques applied.—Continued

U.S. Geological Survey streamgage number	Name	Portion of record extended	Index streamgage(s) used to extend record	Correlation coefficient between log-transformed flow records
03017500	Tionesta Creek at Lynch, PA	Oct 1979–Sep 2008	West Branch Clarion River at Wilcox, PA (03028000)	0.96
03021350	French Creek near Wattsburg, PA	Oct 1959–Sep 1974	Oil Creek at Rouseville, PA (03020500)	0.89
03021500	French Creek at Carters Corners, PA	Oct 1971–Sep 2008	Brokenstraw Creek at Youngsville, PA (03015500) Conneaut Creek at Conneaut, OH (04213000)	0.95 0.92
03022540	Woodcock Creek at Blooming Valley, PA	Oct 1959–Sep 1974 Oct 1995–Sep 2008	Oil Creek at Rouseville, PA (03020500)	0.91
03024000	French Creek at Utica, PA	Jul 1970–Sep 2008	Brokenstraw Creek at Youngsville, PA (03015500) Conneaut Creek at Conneaut, OH (04213000) Conewango Creek at Waterboro, NY (03013000)	0.96 0.93 0.94
03025000	Sugar Creek at Sugarcreek, PA	Nov 1979–Sep 2008	Oil Creek at Rouseville, PA (03020500)	0.96
03029400	Toms Run at Cooksburg, PA	Dec 1978–Sep 2008	West Branch Clarion River at Wilcox, PA (3028000)	0.90
03031950	Big Run near Sprankle Mills, PA	Oct 1959–Sep 1963 Apr 1981–Sep 2008	Redbank Creek at St. Charles, PA (03032500)	0.90
03038000	Crooked Creek at Idaho, PA	Jul 1967–Sep 2008	Little Yellow Creek near Strongstown, PA (03042200) Buffalo Creek near Freeport, PA (03049000)	0.94 0.92
03039200	Clear Run near Buckstown, PA	Sep 1959–Aug 1964 Dec 1978–Sep 2008	Casselman River at Markleton, PA (03079000) Casselman River at Grantsville, MD (03078000)	0.92 0.90
03039925	North Fork Bens Creek at North Fork Reservoir, PA	Oct 1959–Sep 1984 Oct 1998–Sep 2008	Casselman River at Markleton, PA (03079000)	0.88

Appendix 2. Reference streamgages with record extension techniques applied.—Continued

U.S. Geological Survey streamgage number	Name	Portion of record extended	Index streamgage(s) used to extend record	Correlation coefficient between log-transformed flow records
03041000	Little Conemaugh River at East Conemaugh, PA	Oct 1995–Sep 2003 Jul 2004–Sep 2008	Casselman River at Markleton, PA (03079000)	0.88
03042200	Little Yellow Creek near Strongstown, PA	Oct 1959–Aug 1960 Dec 1978–Sep 1986 Oct 1988–Sep 2008	West Branch Susquehanna River at Bower, PA (01541000) Laurel Hill Creek at Ursina, PA (03080000)	0.91 0.86
03049800	Little Pine Creek near Etna, PA	Oct 1959–Sep 1962	Crooked Creek at Idaho, PA (03038000) Buffalo Creek near Freeport, PA (03049000)	0.89 0.84
03062500	Deckers Creek at Morgantown, WV	Oct 1969–Sep 2002	Lick Run at Hopwood, PA (03074300) Casselman River at Grantsville, MD (03078000)	0.935 0.895
03072590	Georges Creek at Smithfield, PA	Oct 1959–Sep 1963 Dec 1978–Sep 2008	Deckers Creek at Morgantown, WV (03062500) South Fork Tenmile Creek at Jefferson, PA (03073000) Laurel Hill Creek at Ursina, PA (03080000)	0.92 0.90 0.87
03072840	Tennmile Creek near Clarksville, PA	Oct 1959–Nov 1968 Oct 1979–Sep 2008	South Fork Tenmile Creek at Jefferson, PA (03073000) Yellow Creek near Hammondsville, OH (03110000)	0.94 0.84
03073000	South Fork Tenmile Creek at Jefferson, PA	Oct 1995–Sep 2008	Deckers Creek at Morgantown, WV (03062500) Laurel Hill Creek at Ursina, PA (03080000)	0.89 0.86
03074300	Lick Run at Hopwood, PA	Oct 1959–Sep 1966 Dec 1978–Sep 2008	Deckers Creek at Morgantown, WV (03062500) Laurel Hill Creek at Ursina, PA (03080000)	0.94 0.88
03082200	Poplar Run near Normalville, PA	Oct 1959–Aug 1961 Dec 1978–Sep 2008	Laurel Hill Creek at Ursina, PA (03080000)	0.92
03084000	Abers Creek near Murrysville, PA	Nov 1993–Sep 2008	Little Pine Creek near Etna, PA (03049800) Buffalo Creek near Freeport, PA (03049000)	0.84 0.81
03085956	Montour Run at Scott Station near Imperial, PA	Oct 1959–Sep 2000	Little Pine Creek near Etna, PA (03049800) Short Creek near Dillonvale, OH (03111500)	0.87 0.83

Appendix 2. Reference streamgages with record extension techniques applied.—Continued

U.S. Geological Survey streamgage number	Name	Portion of record extended	Index streamgage(s) used to extend record	Correlation coefficient between log-transformed flow records
03092000	Kale Creek near Pricetown, OH	Oct 1993–Sep 2008	Little Shenango River at Greenville, PA (03102500)	0.85
03102950	Pymatuning Creek at Kinsman, OH	Oct 1959–Sep 1965 Oct 1994–Sep 2008	Rock Creek near Rock Creek, OH (04211000) Conneaut Creek at Conneaut, OH (04213000)	0.90 0.82
03103000	Pymatuning Creek near Orangeville, PA	Oct 1964–Sep 2008	Little Shenango River at Greenville, PA (03102500) Conneaut Creek at Conneaut, OH (04213000)	0.94 0.87
03106500	Slippery Rock Creek at Wurttemberg, PA	May 1969–Sep 2008	Little Beaver Creek near East Liverpool, OH (03109500)	0.94
03111150	Brush Run near Buffalo, PA	Oct 1959–Sep 1960 Dec 1978–Sep 1982 Oct 1985–Sep 2008	Yellow Creek near Hammondsville, OH (03110000) South Fork Tenmile Creek at Jefferson, PA (03073000)	0.85 0.85
04213075	Brandy Run near Girard, PA	Oct 1959–May 1986	Conneaut Creek at Conneaut, OH (04213000)	0.81

Appendix 3. Basin characteristics used in the development of flow-duration regression equations.

U.S. Geological Survey streamgage number	Longitude (decimal degrees)	Drainage area (square miles)	Percent impervious area	Percent carbonate bedrock	Mean annual precipitation (inches)	Mean maximum daily temperature (degrees Fahrenheit)	Soil depth to bedrock (feet)	Drainage runoff number (unitless)
0142400103	75.280	20.2	0.38	0	43.2	53.2	4.76	3.63
01428750	75.376	40.6	0.28	0	45.4	52.3	4.46	4.06
01429000	75.327	59.7	0.29	0	44.8	52.8	4.57	4.04
01431000	75.222	78.4	0.48	0	42.9	54.7	4.65	3.96
01439500	75.038	117	0.35	0	43.4	55.1	5.05	3.95
01440400	75.215	65.9	0.39	0	44.5	54.3	4.66	3.97
01442500	75.143	259	2.71	0.06	46.3	56.2	4.81	3.93
01447500	75.626	91.7	0.59	0	46.0	53.1	4.88	3.97
01447720	75.606	118	1.67	0	47.6	52.9	5.07	4.10
01448500	75.544	2.39	0.27	0	48.9	53.1	4.75	3.80
01449360	75.503	49.9	2.49	0	47.4	57.2	4.55	3.26
01450500	75.598	76.7	1.70	4.91	45.8	58.5	4.51	3.24
01451500	75.483	80.8	8.24	63.7	45.2	59.9	5.11	3.22
01451800	75.627	53.0	1.62	0	45.6	59.8	3.38	3.10
01452000	75.483	75.8	3.56	11.3	45.4	59.9	3.65	3.11
01452500	75.380	44.5	8.55	62.8	44.6	59.7	4.50	3.19
01459500	75.117	97.4	2.91	0	45.0	60.3	4.43	4.32
01464907	75.120	26.8	13.8	0	45.0	61.7	4.20	4.48
01465798	74.986	21.4	29.2	1.03	47.0	62.0	4.18	4.15
01467048	75.033	49.8	22.7	1.43	45.6	61.9	4.79	3.64
01467086	75.111	16.2	24.5	0	45.0	62.0	5.12	3.29
01468500	76.125	133	4.16	0	48.7	57.2	4.45	3.15
01470500	75.999	355	2.83	0.12	48.7	57.7	4.47	3.13
01470756	75.883	159	1.51	10.8	46.8	59.8	3.84	3.13
01470779	76.172	66.5	4.12	83.2	43.3	60.0	5.16	3.23
01471000	75.979	211	3.29	41.3	44.7	59.8	4.40	3.20
01471980	75.680	85.5	0.94	26.1	46.0	60.3	5.13	3.33
01472000	75.652	1,147	3.85	18.7	46.5	58.6	4.43	3.22
01472157	75.602	59.1	0.47	0.62	44.9	60.2	4.90	3.39
01472174	75.631	5.98	3.65	0	45.0	60.3	5.09	3.30
01472198	75.516	38.0	1.72	3.35	45.3	60.3	4.83	3.44
01472199	75.523	23.0	1.01	4.76	46.2	60.3	4.85	3.47
01473120	75.434	53.7	9.60	0	43.1	61.8	4.13	3.93
01475510	75.273	37.4	15.7	0	44.7	61.6	4.85	3.57
01475530	75.280	4.78	22.8	0	45.0	61.9	5.03	3.36
01475850	75.437	15.8	3.62	0	45.0	60.7	4.93	3.71
01479820	75.692	28.3	3.73	11.1	45.0	60.8	5.13	3.29
01480300	75.861	18.7	1.37	3.36	45.0	59.8	5.08	3.28
01480675	75.742	8.57	0.64	0.39	45.0	60.0	5.09	3.30
01481000	75.594	287	3.40	7.63	45.0	60.5	5.11	3.36
01514000	76.271	185	0.35	0	37.0	53.8	4.44	3.78
01516500	77.015	12.2	0.39	0	34.8	54.2	4.64	4.05

Appendix 3. Basin characteristics used in the development of flow-duration regression equations.—Continued

U.S. Geological Survey streamgage number	Longitude (decimal degrees)	Drainage area (square miles)	Percent impervious area	Percent carbonate bedrock	Mean annual precipitation (inches)	Mean maximum daily temperature (degrees Fahrenheit)	Soil depth to bedrock (feet)	Drainage runoff number (unitless)
01517000	76.965	10.2	0.27	0	35.7	54.0	4.48	4.09
01518500	77.149	122	0.29	0	33.1	55.3	4.38	3.75
01518862	77.532	90.6	0.31	0	36.3	54.6	4.50	3.77
01520000	77.140	298	0.26	0	34.1	55.2	4.53	3.80
01525500	77.418	340	0.71	0	34.9	54.5	4.57	3.80
01529500	77.217	470	0.61	0	32.4	54.8	4.65	3.63
01530500	76.798	77.5	3.49	0	34.5	55.6	4.24	3.86
01532000	76.485	215	0.30	0	36.2	54.8	4.54	4.04
01532850	76.007	5.67	0.14	0	40.1	53.8	4.87	3.99
01533950	75.642	12.6	0.84	0	42.3	54.3	3.98	3.77
01534000	75.895	383	0.76	0	40.3	55.1	4.47	4.00
01538000	76.094	43.8	3.08	0	43.7	56.0	4.47	4.00
01539000	76.431	274	0.42	0	42.1	56.2	4.50	3.84
01541000	78.677	315	0.69	0	44.3	56.2	4.50	3.57
01541308	78.584	6.77	3.58	0	47.7	55.0	4.79	3.11
01541500	78.406	371	0.52	0	41.7	56.3	4.46	3.58
01542500	78.109	1,462	0.74	0	41.9	55.6	4.52	3.52
01542810	78.293	5.24	0.02	0	43.1	55.0	4.68	3.59
01543000	78.197	272	0.24	0	43.4	55.3	4.66	3.65
01543500	78.103	685	0.20	0	43.4	53.9	4.60	3.65
01544500	77.826	136	0.05	0	39.9	54.8	4.58	3.49
01545600	77.691	46.2	0.02	0	41.7	54.8	4.77	3.16
01546400	77.828	58.5	5.63	75.1	39.4	57.2	5.25	3.16
01546500	77.794	87.2	6.19	83.1	38.8	57.6	5.39	3.16
01547100	77.787	142	5.01	78.3	38.5	57.9	5.40	3.16
01547200	77.787	265	3.08	46.0	38.2	57.5	4.75	3.11
01547700	77.606	44.1	0.45	0.35	39.0	57.2	4.01	2.99
01547950	77.703	152	0.29	0	40.1	55.9	4.75	3.18
01548005	77.550	562	1.81	27.4	39.0	55.8	4.63	3.11
01548500	77.448	604	0.23	0	36.3	53.8	4.40	3.67
01549500	77.231	37.7	0.55	0	36.2	54.3	4.38	4.02
01549700	77.324	944	0.20	0	36.9	54.3	4.47	3.55
01549780	77.163	6.80	0.35	0	41.9	54.9	4.50	3.83
01550000	77.033	173	0.13	0	36.7	53.3	4.14	3.84
01552000	76.913	435	0.20	0	39.8	54.6	4.36	3.95
01552500	76.535	23.8	0.15	0	45.4	53.5	4.42	4.03
01553130	77.077	4.93	0.74	0	45.0	54.9	4.78	3.10
01555000	77.049	301	0.54	24.0	43.7	57.5	4.86	3.16
01555500	76.912	162	0.86	0	42.7	58.3	4.62	3.11
01556000	78.200	291	3.79	21.0	39.6	57.8	4.69	3.13
01556500	78.294	93.7	4.25	5.13	40.5	56.2	4.40	3.10
01557500	78.234	44.1	1.03	5.04	38.9	56.4	4.11	3.05

Appendix 3. Basin characteristics used in the development of flow-duration regression equations.—Continued

U.S. Geological Survey streamgage number	Longitude (decimal degrees)	Drainage area (square miles)	Percent impervious area	Percent carbonate bedrock	Mean annual precipitation (inches)	Mean maximum daily temperature (degrees Fahrenheit)	Soil depth to bedrock (feet)	Drainage runoff number (unitless)
01558000	78.141	220	2.67	20.5	39.6	56.0	4.58	3.10
01559000	78.019	816	2.33	32.6	39.2	56.4	4.79	3.12
01559700	78.619	5.28	0.22	1.73	39.0	58.2	4.04	3.10
01560000	78.493	172	0.96	4.27	38.7	57.4	4.01	3.08
01562000	78.266	756	1.09	14.2	38.0	57.8	4.30	3.06
01564500	77.926	205	0.73	4.46	38.3	59.0	3.93	3.04
01565000	77.583	164	1.22	24.8	41.2	58.5	4.90	3.13
01565700	77.312	6.52	1.82	47.8	41.3	59.8	4.26	3.12
01566000	77.419	214	0.33	0	39.4	58.7	4.22	3.12
01567500	77.403	15.0	0.63	0	39.9	59.4	5.40	3.24
01568000	77.169	207	0.65	0	39.6	58.8	4.83	3.19
01569000	76.908	33.2	0.12	0	43.2	57.9	4.79	3.10
01570000	77.021	470	2.99	38.1	39.1	61.0	4.61	3.18
01571500	76.898	216	4.10	34.2	40.5	60.2	5.23	3.35
01572000	76.378	34.3	0.75	0	46.6	58.5	4.22	3.10
01574500	76.854	75.5	2.60	16.8	39.8	61.9	4.46	2.95
01576754	76.368	470	6.97	59.0	42.4	60.3	5.02	3.30
01576787	76.329	148	2.13	57.5	41.7	60.0	5.28	3.24
01577500	76.316	133	0.48	0.33	41.6	61.4	5.09	3.30
01578400	76.114	5.98	0.24	25.4	41.0	59.9	5.09	3.30
01603500	78.647	30.2	0.53	21.8	38.0	58.9	4.68	3.15
01609000	78.555	148	0.35	0	37.1	60.6	3.90	3.00
01610155	78.344	102	0.51	0	37.0	60.3	3.18	2.80
01612500	78.232	16.9	1.22	0	37.0	61.6	3.33	2.90
01613050	78.133	10.7	0.31	0	38.5	59.2	4.03	2.95
01614090	77.440	5.05	0.09	0	45.0	59.1	5.00	3.20
01614500	77.825	494	2.86	0	40.3	60.3	4.67	3.15
01639000	77.235	173	1.14	0	41.4	61.6	4.42	3.60
03007800	78.293	248	0.37	0	40.4	54.0	4.71	3.64
03009680	78.431	160	0.25	0	44.4	53.9	4.65	3.67
03010500	78.386	550	0.31	0	42.0	53.0	4.69	3.67
03010655	78.198	98.7	0.12	0	39.1	54.4	4.54	3.48
03011800	78.719	38.8	0.46	0	45.0	53.1	4.63	3.57
03013000	79.069	290	0.44	0	43.7	54.8	4.73	3.97
03015280	79.238	12.8	0.39	0	45.2	54.9	5.86	4.41
03015500	79.318	321	0.48	0	46.8	55.5	5.65	4.23
03017500	79.050	233	0.29	0	44.1	54.1	4.69	3.50
03020500	79.696	300	0.48	0	44.5	55.5	5.87	4.15
03021350	79.783	92.0	0.46	0	47.0	55.9	5.18	4.44
03021500	79.877	208	0.52	0	46.5	55.9	5.29	4.42
03022540	80.048	31.1	0.41	0	45.0	56.3	6.08	4.63
03024000	79.956	1,028	1.16	0	45.0	56.1	5.76	4.53

Appendix 3. Basin characteristics used in the development of flow-duration regression equations.—Continued

U.S. Geological Survey streamgage number	Longitude (decimal degrees)	Drainage area (square miles)	Percent impervious area	Percent carbonate bedrock	Mean annual precipitation (inches)	Mean maximum daily temperature (degrees Fahrenheit)	Soil depth to bedrock (feet)	Drainage runoff number (unitless)
03025000	79.880	166	0.45	0	43.8	56.3	5.94	4.04
03026500	78.577	7.84	0.14	0	45.0	53.1	4.63	3.56
03028000	78.693	63.0	0.32	0	45.0	53.4	4.63	3.62
03029400	79.214	12.6	0.15	0	45.0	55.9	4.72	3.93
03031950	79.091	7.38	0.56	0	45.0	57.0	4.61	4.01
03032500	79.394	528	1.31	0	43.2	55.9	4.31	3.78
03038000	79.349	191	1.08	0	44.3	58.8	3.40	3.14
03039200	78.833	3.68	0.29	0	42.7	54.5	4.69	3.21
03039925	79.017	3.45	0.03	0	45.9	54.6	4.69	3.21
03042200	78.946	7.36	0.27	0	46.3	55.8	4.66	3.26
03049000	79.700	137	0.85	0	41.0	59.4	3.71	3.21
03049800	79.938	5.78	4.56	0	39.0	60.0	3.95	3.45
03062500	79.953	63.2	3.28	0	47.9	60.0	3.72	3.20
03072590	79.796	16.3	4.94	0	44.1	60.0	4.29	3.34
03072840	80.042	133	0.59	0	39.0	59.8	4.78	3.62
03073000	80.073	180	0.97	0	39.5	60.0	4.78	3.64
03074300	79.694	3.80	1.35	0	46.8	56.9	4.53	3.06
03078000	79.136	62.5	0.42	0	42.2	55.6	3.67	3.37
03079000	79.228	382	0.92	0	41.7	55.7	4.22	3.40
03080000	79.322	121	0.40	0	46.2	55.5	4.47	3.33
03082200	79.426	9.27	0.71	0	45.0	56.6	4.60	3.33
03084000	79.714	4.39	23.7	0	39.0	60.1	3.69	3.29
03085956	80.176	25.4	17.9	0	37.0	59.8	3.93	3.35
03092000	80.990	21.9	1.08	0	37.0	59.0	4.86	4.83
03093000	80.950	97.6	1.62	0	38.4	58.9	4.61	4.52
03102500	80.376	104	1.06	0	40.5	58.0	6.12	4.56
03102950	80.590	96.7	0.82	0	39.6	58.4	5.27	4.69
03103000	80.478	169	0.79	0	39.4	58.5	5.61	4.47
03106000	80.243	356	3.70	0	39.1	59.3	4.33	3.58
03106500	80.234	398	1.42	0	40.7	58.8	5.51	3.96
03109500	80.540	496	1.83	0	37.0	59.9	5.05	3.69
03110000	80.730	147	0.34	0	38.0	59.8	3.81	3.16
03111150	80.408	10.3	0.47	0	39.0	60.0	4.82	3.60
03111500	80.730	123	1.09	0	38.9	60.0	4.80	3.63
04213000	80.600	175	1.25	0	42.1	56.5	5.34	5.13
04213075	80.291	4.45	3.09	0	42.9	56.5	5.04	5.44

Appendix 4. Flow-duration exceedance probabilities, observed and computed from streamflow data, and regression equations for streamgages used in regression analysis.

[--, no data; P_n, n probability exceedance]

U.S. Geological Survey streamgage number		Type	Flow-duration exceedance, in cubic feet per second																
			P99.9944	P99	P95	P90	P85	P80	P70	P60	P50	P40	P30	P20	P15	P10	P05	P01	P0.0056
0142400103	Observed	--	0.40	0.80	1.40	2.20	3.30	7.00	11.0	18.0	25.0	35.0	50.0	63.0	83.0	122	270	--	
	Predicted	0.98	1.88	3.31	4.41	5.80	7.24	10.7	14.7	22.4	29.1	38.8	54.3	65.5	84.8	126	272	2,150	
01428750	Observed	--	5.80	8.00	10.0	13.0	16.0	24.0	33.0	45.0	59.0	77.0	108	136	181	292	664	--	
	Predicted	0.97	2.49	5.00	7.36	9.94	13.0	21.1	31.3	55.0	70.8	90.3	128	156	198	283	572	4,110	
01429000	Observed	--	8.20	11.0	15.0	19.0	23.0	33.0	44.0	60.0	84.0	115	160	194	252	379	848	--	
	Predicted	1.73	4.25	8.09	11.7	15.6	20.2	31.7	45.9	77.4	100	126	179	221	282	404	818	5,960	
01431000	Observed	--	3.61	6.70	9.80	13.0	17.0	29.0	42.0	60.0	86.0	125	180	224	299	452	1,127	--	
	Predicted	2.55	6.06	10.9	15.2	20.1	25.6	38.9	55.1	83.6	107	133	191	241	314	468	994	7,820	
01439500	Observed	2.63	9.00	17.0	27.0	38.0	52.0	85.0	120	160	210	271	362	428	526	706	1,270	8,840	
	Predicted	7.17	14.6	23.2	31.3	39.8	49.1	70.0	92.9	130	165	202	288	364	473	703	1,475	11,680	
01440400	Observed	5.11	7.60	12.0	17.0	23.0	30.0	48.0	66.0	87.0	111	143	196	237	301	435	918	6,040	
	Predicted	2.37	5.48	10.0	14.1	18.6	23.8	36.3	51.3	79.0	101	125	177	220	284	417	871	6,640	
01442500	Observed	30.0	50.0	73.0	95.0	119	145	207	274	356	454	590	805	966	1,220	1,750	3,500	29,040	
	Predicted	16.4	39.1	60.9	85.0	106	132	187	242	337	419	498	697	872	1,120	1,640	3,330	24,450	
01447500	Observed	7.04	14.0	23.0	32.0	42.5	53.0	78.0	102	130	162	205	270	320	394	551	1,100	15,830	
	Predicted	4.71	10.1	17.1	24.1	31.0	39.2	58.3	80.2	126	162	206	290	355	449	639	1,270	8,630	
01447720	Observed	--	30.0	42.0	54.0	67.0	81.0	110	141	179	220	275	360	436	545	783	1,580	--	
	Predicted	7.50	16.5	26.8	38.0	47.7	59.5	86.3	116	182	231	288	403	494	619	866	1,670	10,980	
01448500	Observed	0.25	0.42	0.66	0.89	1.20	1.40	1.90	2.50	3.20	4.00	5.10	6.70	7.80	9.6	14.0	30.0	153	
	Predicted	0.09	0.18	0.38	0.54	0.74	0.95	1.51	2.23	3.52	4.46	5.71	7.64	9.08	11.5	16.9	37.6	276	
01449360	Observed	--	15.0	22.0	28.0	32.0	38.0	49.0	61.0	76.0	93.0	113	144	168	204	278	520	--	
	Predicted	4.77	8.55	13.4	17.7	22.5	28.0	38.8	49.0	62.4	77.5	99.4	132	156	202	305	668	4,920	
01450500	Observed	9.21	18.0	27.0	35.0	42.0	49.0	64.0	80.0	100	125	158	206	246	306	440	900	4,340	
	Predicted	6.70	11.8	18.6	24.3	31.0	38.7	54.0	68.8	83.4	104	132	178	211	274	415	914	6,950	
01451500	Observed	23.0	28.0	35.0	41.0	45.0	50.0	60.0	70.0	82.0	95.0	112	136	151	175	224	420	4,540	
	Predicted	14.9	29.3	35.2	42.7	49.9	56.5	66.9	74.8	80.4	100	124	167	180	211	277	547	4,630	
01451800	Observed	--	3.50	7.20	11.0	15.0	19.0	27.0	36.0	49.0	65.0	89.0	127	159	212	325	749	--	
	Predicted	0.99	2.61	5.62	8.12	11.5	15.8	26.2	38.6	53.5	66.6	84.6	112	135	179	283	658	5,130	
01452000	Observed	0.00	3.70	7.70	12.0	17.0	22.0	33.0	45.0	62.0	83.0	112	157	194	253	389	937	6,640	
	Predicted	2.33	5.99	11.2	15.5	21.0	27.8	42.3	58.0	76.6	95.0	120	160	188	242	367	818	6,550	
01452500	Observed	5.27	11.0	17.0	21.0	24.0	26.0	31.0	36.0	42.0	50.0	60.0	75.0	85.0	99.0	127	238	2,090	
	Predicted	3.64	8.86	12.5	15.9	19.6	23.1	29.7	35.7	42.3	52.7	66.0	88.7	95.7	113	150	304	2,680	
01459500	Observed	--	0.90	2.10	3.80	5.40	7.40	14.0	24.0	37.0	56.0	87.0	145	204	325	610	1,790	--	
	Predicted	1.87	6.25	12.1	18.2	24.2	31.4	49.7	73.0	96.8	119	126	179	240	319	506	1,170	9,720	

Appendix 4. Flow-duration exceedance probabilities, observed and computed from streamflow data, and regression equations for streamgages used in regression analysis.—Continued

[—, no data; P_n, n probability exceedance]

U.S. Geological Survey streamgage number	Type	Flow-duration exceedance, in cubic feet per second																		
		P99.9944	P99	P95	P90	P85	P80	P70	P60	P50	P40	P30	P20	P15	P10	P05	P01	P0.0056		
01464907	Observed	--	1.60	2.60	4.40	6.20	7.90	11.0	14.0	19.0	25.0	34.0	49.0	65.0	97.0	196	668	--		
	Predicted	0.26	1.70	3.22	4.93	6.40	7.89	11.9	17.3	24.3	29.8	30.4	42.7	58.7	79.0	130	324	2,860		
01465798	Observed	--	1.70	3.20	4.20	5.20	6.00	7.80	9.70	12.0	15.0	19.0	28.0	39.0	61.0	125	409	--		
	Predicted	0.34	3.58	5.16	7.51	8.85	9.87	12.3	15.3	21.6	26.1	27.0	37.0	49.1	65.4	107	265	2,330		
01467048	Observed	--	13.0	17.0	21.0	24.0	27.0	34.0	42.0	50.0	61.0	75.0	99.0	121	169	285	810	--		
	Predicted	3.49	18.1	21.0	27.0	30.4	32.7	36.7	40.5	47.6	57.8	64.4	87.5	112	150	243	588	5,130		
01467086	Observed	--	4.00	6.00	7.20	8.10	9.00	11.0	13.0	16.0	19.0	23.0	29.0	35.3	48.0	81.0	202	--		
	Predicted	2.27	9.38	9.61	11.4	12.4	12.7	13.0	13.3	14.3	17.5	20.6	27.5	34.3	46.3	77.1	197	1,780		
01468500	Observed	--	46.0	62.0	75.0	89.0	102	129	160	197	242	303	391	455	557	756	1,500	--		
	Predicted	14.9	28.1	41.1	54.4	67.5	83.7	113	139	179	224	295	389	452	580	855	1,780	11,540		
01470500	Observed	40.8	91.0	127	158	191	223	289	364	458	577	741	998	1,200	1,490	2,100	4,230	32,480		
	Predicted	49.9	86.6	121	160	196	245	326	392	487	604	789	1,040	1,220	1,560	2,280	4,620	29,650		
01470756	Observed	--	17.0	30.0	42.0	52.0	64.0	88	115	150	190	250	348	434	570	856	2,050	--		
	Predicted	7.22	15.5	27.5	38.2	50.9	67.4	102	138	176	218	276	367	428	548	814	1,740	12,640		
01470779	Observed	--	27.0	34.0	42.0	47.0	52.0	61.0	73.0	85.0	99.0	117	142	159	188	254	515	--		
	Predicted	9.65	15.8	20.6	25.0	30.2	35.1	44.3	52.8	56.0	71.4	91.2	124	132	152	195	381	3,140		
01471000	Observed	--	50.0	65.0	85.0	98.0	113.0	140	171	212	265	335	430	501	607	833	1,700	--		
	Predicted	16.9	33.7	49.8	64.9	81.8	101.3	139	174	206	259	329	446	499	606	831	1,660	12,640		
01471980	Observed	--	21.0	28.0	34.0	39.0	44.0	56.0	69.0	85.0	105	129	169	197	246	369	889	--		
	Predicted	14.1	20.3	28.2	35.6	43.6	52.5	69.1	83.8	87.2	108	131	177	206	257	372	795	6,280		
01472000	Observed	175	260	367	457	545	636	820	1,030	1,300	1,630	2,070	2,690	3,160	3,850	5,200	9,830	70,260		
	Predicted	144	289	383	502	609	752	979	1,150	1,410	1,740	2,210	3,000	3,440	4,280	5,930	11,280	78,480		
01472157	Observed	--	11.0	16.0	20.0	24.0	27.0	36.0	46.0	58.0	72.0	90.0	116	136	173	256	625	--		
	Predicted	6.06	9.62	14.7	19.0	24.0	29.4	40.6	51.8	56.3	70.1	85.0	115	143	190	303	712	5,670		
01472174	Observed	--	1.60	2.40	2.80	3.20	3.6	4.40	5.40	6.60	8.00	9.50	12.0	13.0	17.0	26.0	93.6	--		
	Predicted	0.63	1.04	1.59	1.99	2.50	3.0	3.95	4.99	5.31	6.65	8.16	10.8	13.4	17.9	29.6	76.2	650		
01472198	Observed	--	8.70	13.0	15.0	18.0	20.0	25.0	32.0	40.0	50.0	61.1	79.0	92.0	115	171	442	--		
	Predicted	3.25	5.75	9.04	11.8	15.0	18.4	25.6	33.0	36.6	45.4	54.3	73.3	90.8	120	190	450	3,670		
01472199	Observed	--	4.80	6.70	8.00	9.40	11.0	14.0	19.0	25.0	31.0	38.0	49.0	58.0	74.0	111	281	--		
	Predicted	1.89	3.22	5.29	7.00	8.97	11.1	15.8	20.7	23.0	28.4	33.7	45.2	55.7	73.0	115	275	2,250		
01473120	Observed	--	2.20	4.60	6.48	8.10	9.8	14.0	20.0	28.0	40.0	54.0	79.0	101	144	293	1,060	--		
	Predicted	0.84	3.74	6.72	9.68	12.7	15.7	23.4	33.0	43.0	53.6	59.2	82.9	111	150	248	614	5,320		
01475510	Observed	--	12.0	17.0	20.0	23.0	26.0	31.0	37.0	45.0	52.0	61.0	75.0	86.0	107	172	443	--		
	Predicted	2.70	9.87	12.6	16.1	18.9	21.0	25.1	29.2	33.4	41.1	47.1	64.2	82.2	111	181	446	3,850		

Appendix 4. Flow-duration exceedance probabilities, observed and computed from streamflow data, and regression equations for streamgages used in regression analysis.—Continued

[--, no data; P_n, n probability exceedance]

U.S. Geological Survey streamgage number		Type	Flow-duration exceedance, in cubic feet per second																
			P99.9944	P99	P95	P90	P85	P80	P70	P60	P50	P40	P30	P20	P15	P10	P05	P01	P0.0056
01475530	Observed	--	1.50	1.80	2.20	2.50	2.80	3.20	3.90	4.40	5.10	5.80	7.40	8.90	12.0	23.0	65.1	--	
	Predicted	0.44	1.81	2.12	2.57	2.91	3.04	3.34	3.66	4.03	4.98	5.84	7.75	9.74	13.2	22.3	59.6	549	
01475850	Observed	--	2.70	4.50	5.90	7.10	8.40	11.0	13.0	15.0	18.0	22.0	27.0	32.0	40.0	62.9	182	--	
	Predicted	0.91	1.96	3.24	4.34	5.53	6.72	9.52	12.7	14.4	17.8	20.4	27.8	35.7	47.8	78.4	196	1,670	
01479820	Observed	--	5.31	11.0	13.0	15.0	17.0	20.0	24.0	29.0	34.0	40.0	49.0	54.0	64.0	95.7	324	--	
	Predicted	3.94	6.43	8.94	11.1	13.6	15.9	20.6	24.9	25.8	32.2	39.2	52.6	63.4	82.6	129	305	2,520	
01480300	Observed	1.00	3.20	5.60	6.80	7.80	8.80	11.0	13.0	15.0	18.0	22.0	27.0	32.0	42.0	77.0	257	1,620	
	Predicted	2.28	3.34	5.01	6.29	7.90	9.48	12.8	16.2	17.3	21.8	27.2	36.4	44.3	58.6	93.4	225	1,800	
01480675	Observed	--	0.72	1.50	2.10	2.60	3.20	4.40	6.00	7.90	9.90	12.0	16.0	19.0	25.0	42.0	97.0	--	
	Predicted	0.94	1.33	2.11	2.65	3.38	4.08	5.65	7.29	7.75	9.73	12.0	16.1	19.7	26.4	43.1	108	898	
01481000	Observed	41.4	69.0	100	118	138	158	193	231	274	325	393	498	575	700	985	2,240	9,540	
	Predicted	49.5	84.0	106	133	158	187	234	272	285	353	427	583	712	928	1,410	3,080	23,600	
01514000	Observed	8.90	11.0	14.0	18.0	23.0	29.0	49.0	79.0	117	170	250	374	484	680	1,100	2,420	9,550	
	Predicted	3.43	8.83	15.7	20.9	28.3	35.6	55.0	80.8	131	180	249	374	476	636	969	2,060	15,500	
01516500	Observed	0.00	0.06	0.26	0.50	0.74	1.00	1.80	2.90	4.60	6.90	10.0	16.0	21.0	28.0	47.0	123	1,910	
	Predicted	0.10	0.28	0.59	0.79	1.12	1.41	2.35	3.87	6.34	9.04	12.4	18.9	25.0	34.3	55.7	136	1,080	
01517000	Observed	--	0.00	0.00	0.14	0.40	0.60	1.10	2.10	3.40	5.10	8.00	13.0	18.0	26.0	44.0	115	--	
	Predicted	0.07	0.21	0.46	0.64	0.91	1.16	2.00	3.37	5.75	8.14	11.1	16.8	22.1	30.1	48.4	117	917	
01518500	Observed	--	2.60	4.30	6.10	8.00	10.0	14.0	22.0	34.0	54.0	88.0	145	191	266	442	1,110	--	
	Predicted	1.23	3.42	6.34	8.25	11.5	14.4	23.0	35.8	56.1	80.4	114	176	233	322	523	1,220	9,400	
01518862	Observed	--	1.60	3.30	5.30	7.3	9.9	18.0	29.0	47.0	69.8	100	153	194	257	402	1,020	--	
	Predicted	1.27	3.23	5.96	7.96	10.9	13.7	22.0	34.0	53.9	76.2	108	162	209	282	443	994	6,770	
01520000	Observed	--	3.00	6.20	10.0	15.0	21.0	36.0	60.0	95.0	150	230	370	490	694	1,200	3,000	--	
	Predicted	4.33	11.4	19.7	25.6	34.7	43.2	66.8	100	155	219	307	473	624	854	1,350	3,000	21,910	
01525500	Observed	--	20.0	25.0	31.0	36.0	42.0	58.0	82.0	120	175	261	427	565	806	1,340	3,340	--	
	Predicted	5.42	14.3	24.1	31.6	42.4	52.7	81.0	121	191	272	387	593	774	1,050	1,630	3,520	24,010	
01529500	Observed	8.48	27.0	39.0	51.0	64.0	76.0	110	155	218	302	424	640	820	1,120	1,700	3,610	21,910	
	Predicted	9.00	21.9	34.2	42.3	56.2	68.0	100	144	216	312	457	713	934	1,290	2,050	4,520	33,420	
01530500	Observed	1.70	6.70	9.80	13.0	15.0	17.0	23.0	29.0	39.0	51.0	71.0	106	135	188	307	792	3,030	
	Predicted	0.64	2.24	4.26	5.73	7.94	9.9	15.8	24.6	39.8	55.9	76.3	116	154	212	343	805	6,380	
01532000	Observed	0.78	3.60	8.90	14.0	21.0	30.0	52.0	80.0	120	170	246	377	482	662	1,080	2,670	24,620	
	Predicted	2.98	8.47	15.4	21.0	28.5	35.9	56.7	86.1	137	190	252	384	507	684	1,060	2,310	17,410	
01532850	Observed	--	0.20	0.43	0.63	0.90	1.20	2.00	3.00	4.20	6.00	8.00	12.0	15.0	21.0	34.0	107	--	
	Predicted	0.11	0.26	0.52	0.70	0.96	1.20	1.92	2.95	4.62	6.22	8.15	11.8	15.0	19.8	30.9	73.0	591	

Appendix 4. Flow-duration exceedance probabilities, observed and computed from streamflow data, and regression equations for streamgages used in regression analysis.—Continued

[—, no data; P_n, n probability exceedance]

U.S. Geological Survey streamgage number		Type	Flow-duration exceedance, in cubic feet per second																
			P99.9944	P99	P95	P90	P85	P80	P70	P60	P50	P40	P30	P20	P15	P10	P05	P01	P0.0056
01533950	Observed	--	0.30	0.90	1.40	1.90	2.30	3.50	5.10	7.10	9.6	14.0	21.0	27.0	37.0	63.0	175	--	
	Predicted	0.14	0.41	0.95	1.38	1.97	2.63	4.50	7.14	12.2	16.0	20.9	29.4	36.5	47.8	73.0	165	1,320	
01534000	Observed	7.10	21.0	35.0	51.0	66.0	85.0	132	191	270	370	520	767	957	1,270	1,930	4,330	25,730	
	Predicted	8.63	23.7	41.7	58.4	77.4	99.0	153	220	344	454	577	850	1,100	1,440	2,150	4,430	32,310	
01538000	Observed	1.57	4.50	6.70	9.10	12.0	14.0	22.0	31.0	41.0	53.0	70.0	94.0	112	140	200	422	2,600	
	Predicted	0.90	2.65	5.03	7.26	9.68	12.4	19.4	28.8	44.0	57.0	70.3	99.5	127	166	253	559	4,050	
01539000	Observed	8.40	19.0	35.0	54.0	76.0	100.0	150	208	278	369	498	692	846	1,080	1,570	3,210	25,580	
	Predicted	7.84	19.1	33.2	46.5	61.4	78.8	121	174	255	334	426	613	780	1,020	1,540	3,250	22,040	
01541000	Observed	16.0	29.0	48.0	63.0	80.0	99.0	146	207	290	400	551	795	987	1,290	1,910	4,010	20,310	
	Predicted	10.9	23.1	38.9	54.7	71.4	92.0	144	210	305	413	574	803	986	1,280	1,900	3,890	19,230	
01541308	Observed	--	1.40	2.00	2.50	3.00	3.60	4.80	6.20	7.70	9.8	13.0	17.0	21.0	26.0	40.0	89.0	--	
	Predicted	0.50	0.81	1.32	1.74	2.23	2.72	3.96	5.44	7.56	10.2	15.1	19.8	22.6	29.0	43.6	98.4	513	
01541500	Observed	--	23.0	41.0	54.0	68.0	86.0	130	190	278	398	575	850	1,060	1,380	2,010	4,350	--	
	Predicted	10.6	23.6	39.7	54.7	72.0	92.3	144	211	308	421	588	841	1,050	1,380	2,080	4,330	23,180	
01542500	Observed	--	147	200	250	310	400	620	916	1,260	1,800	2,588	3,740	4,560	5,770	8,100	15,000	--	
	Predicted	63.6	136	205	277	354	449	664	916	1,340	1,820	2,570	3,690	4,550	5,930	8,650	16,850	87,960	
01542810	Observed	--	0.10	0.24	0.43	0.62	0.85	1.50	2.40	3.60	5.20	7.50	11.0	15.0	21.0	35.0	84.0	--	
	Predicted	0.12	0.23	0.47	0.65	0.89	1.13	1.87	2.95	4.42	6.08	8.58	11.9	14.5	19.1	29.7	70.2	416	
01543000	Observed	0.46	6.80	17.0	26.0	38.0	52.0	92.0	142	210	294	430	652	815	1,100	1,680	3,660	17,550	
	Predicted	10.2	21.0	34.8	48.3	62.8	80.1	123	178	263	357	495	700	863	1,120	1,650	3,360	17,710	
01543500	Observed	1.74	22.0	44.0	71.0	105.0	152.0	262	404	580	808	1,160	1,720	2,140	2,780	4,100	8,200	42,030	
	Predicted	27.9	58.6	93.8	130	168	215	326	462	728	989	1,400	2,000	2,440	3,130	4,450	8,508	42,940	
01544500	Observed	1.20	6.60	11.0	17.0	23.0	32.0	53.0	80.0	111	159	223	330	411	543	812	1,730	9,670	
	Predicted	4.24	8.54	14.4	19.1	25.3	31.8	48.7	70.6	106	146	211	304	375	495	750	1,600	9,600	
01545600	Observed	--	2.00	3.80	6.20	9.10	13.0	21.0	31.0	42.0	56.0	77.0	109	133	170	248	489	--	
	Predicted	3.09	4.66	7.32	9.21	12.0	14.7	21.2	28.8	39.6	54.0	80.7	112	132	173	264	578	3,510	
01546400	Observed	--	16.0	19.0	22.0	25.0	28.0	34.0	41.0	50.0	60.0	73.0	92.0	108	132	178	375	--	
	Predicted	5.79	10.2	12.8	15.0	18.2	20.5	25.9	32.1	38.5	52.9	76.8	108	115	135	175	342	2,390	
01546500	Observed	20.0	25.0	35.0	41.0	45.0	48.0	55.0	63.0	74.0	87.0	104	128	145	169	216	392	2,720	
	Predicted	10.2	17.8	21.0	24.1	28.8	32.0	39.2	47.2	54.9	75.5	109	155	164	191	245	470	3,340	
01547100	Observed	--	104	120	129	137	143	155	172	192	215	248	290	322	370	471	793	--	
	Predicted	17.6	29.1	34.2	39.2	46.8	52.3	64.1	77.1	87.9	121	175	248	266	312	404	774	5,470	
01547200	Observed	79.0	92.6	121	135	146	157	186	221	265	325	410	541	638	799	1,170	2,310	14,880	
	Predicted	17.9	32.6	43.8	52.5	65.9	77.9	104	133	166	229	335	479	536	660	909	1,800	12,180	

Appendix 4. Flow-duration exceedance probabilities, observed and computed from streamflow data, and regression equations for streamgages used in regression analysis.—Continued

[—, no data; P_n, n probability exceedance]

U.S. Geological Survey streamgage number		Type	Flow-duration exceedance, in cubic feet per second																
			P99.9944	P99	P95	P90	P85	P80	P70	P60	P50	P40	P30	P20	P15	P10	P05	P01	P0.0056
01547700	Observed	0.00	0.82	2.10	3.40	4.80	6.60	11.0	18.0	26.0	38.0	56.0	86.0	107	142	223	500	4,460	
	Predicted	1.15	2.21	4.02	5.16	7.12	9.11	14.2	20.6	28.4	39.0	57.9	80.9	97.3	132	211	499	3,380	
01547950	Observed	--	15.0	23.0	34.0	47.0	60.0	93.0	125	164	218	292	391	468	590	833	1,550	--	
	Predicted	10.0	16.0	23.8	29.5	37.9	46.3	65.3	87	116	158	233	330	398	528	811	1,760	10,830	
01548005	Observed	80.0	117	142	160	181	201	252	324	430	575	784	1,100	1,350	1,700	2,440	4,980	18,440	
	Predicted	40.2	71.1	96.5	118	148	179	241	308	413	567	848	1,214	1,380	1,730	2,400	4,640	29,460	
01548500	Observed	8.71	30.0	47.0	66.0	89.0	118.0	190	283	406	578	825	1,240	1,570	2,050	3,050	6,380	38,440	
	Predicted	11.3	28.5	47.9	63.5	85.1	107.5	166	244	400	564	821	1,240	1,580	2,100	3,160	6,480	41,220	
01549500	Observed	0.02	1.10	2.40	3.70	5.50	7.70	13.0	19.0	28.0	39.0	54.0	81.0	101	133	205	495	3,110	
	Predicted	0.30	0.90	1.87	2.61	3.69	4.73	8.01	13.2	22.4	31.6	43.4	65.5	86.0	116	184	423	3,060	
01549700	Observed	23.0	43.0	75.0	112	156	205	342	500	700	973	1,360	2,010	2,530	3,350	5,140	10,700	74,190	
	Predicted	26.4	60.1	94.2	122	161	201	298	420	650	908	1,320	1,980	2,480	3,310	4,970	10,060	63,840	
01549780	Observed	--	0.30	0.60	1.00	1.50	1.80	2.70	3.80	5.20	7.00	10.0	15.0	19.0	24.0	38.0	87.0	--	
	Predicted	0.10	0.24	0.52	0.73	1.03	1.33	2.24	3.59	5.66	7.67	10.3	14.5	18.2	24.0	37.6	88.7	610	
01550000	Observed	4.00	9.54	17.0	25.0	35.0	46.0	71.0	101	144	203	284	410	509	665	986	2,180	13,410	
	Predicted	1.67	4.97	9.88	13.8	19.3	25.1	41.8	66	118	166	235	354	452	603	915	1,940	13,260	
01552000	Observed	11.3	26.0	44.6	70.0	103.0	137.0	210	300	411	555	750	1,070	1,300	1,680	2,530	5,680	42,280	
	Predicted	7.40	20.5	37.4	53.0	71.4	92.6	148	224	366	496	661	979	1,250	1,650	2,460	5,003	32,210	
01552500	Observed	0.20	1.50	2.70	4.40	6.40	8.80	13.0	19.0	26.0	35.0	47.0	66.0	80.0	103	156	375	3,510	
	Predicted	0.42	1.09	2.31	3.46	4.75	6.29	10.6	16.7	28.5	37.4	48.3	67.7	83.8	107	157	332	2,150	
01553130	Observed	--	1.10	1.60	2.00	2.20	2.50	3.50	4.80	6.40	8.00	9.80	13.0	15.0	18.0	25.0	56.2	--	
	Predicted	0.38	0.54	0.91	1.16	1.52	1.87	2.72	3.71	5.00	6.63	9.63	12.8	14.8	19.2	29.5	68.8	454	
01555000	Observed	21.3	40.0	55.0	68.0	83.0	99.0	142	200	267	350	470	645	776	981	1,390	2,790	20,560	
	Predicted	38.3	56.0	76.5	95.8	118.5	144.4	194	242	290	378	522	717	814	1,010	1,410	2,790	17,820	
01555500	Observed	1.53	7.60	15.0	23.0	32.0	41.0	63.0	90.0	121	162	220	308	382	497	760	1,710	31,140	
	Predicted	14.2	22.6	33.2	41.7	53.0	65.2	90.3	116	139	182	249	342	413	548	854	1,900	12,650	
01556000	Observed	31.4	48.0	63.0	73.0	81.0	93.0	118	157	210	284	390	556	682	888	1,320	2,780	20,930	
	Predicted	18.6	35.8	48.6	59.7	74.7	89.0	120	156	196	269	393	556	650	833	1,220	2,540	15,450	
01556500	Observed	--	12.0	14.0	16.0	19.0	23.0	35.0	55.0	80.5	116	164	227	272	342	473	960	--	
	Predicted	3.89	8.22	12.6	16.0	20.7	25.2	36.1	49.3	69.3	95.8	144	201	238	313	475	1,040	6,060	
01557500	Observed	1.41	3.60	5.20	7.00	9.00	12.0	20.0	30.0	41.0	54.0	74.0	105	130	169	252	538	2,800	
	Predicted	1.06	2.12	3.81	4.91	6.73	8.55	13.3	19.7	28.2	39.4	60.1	84	100	134	208	478	2,990	
01558000	Observed	31.4	64.0	74.0	83.0	92.0	103	130	172	225	296	393	540	648	815	1,170	2,260	18,830	
	Predicted	12.6	23.4	33.4	41.4	52.7	63.8	88.6	117	160	221	334	473	542	689	986	2,000	11,990	

Appendix 4. Flow-duration exceedance probabilities, observed and computed from streamflow data, and regression equations for streamgages used in regression analysis.—Continued

[—, no data; P_n, n probability exceedance]

U.S. Geological Survey streamgage number		Type	Flow-duration exceedance, in cubic feet per second																
			P99.9944	P99	P95	P90	P85	P80	P70	P60	P50	P40	P30	P20	P15	P10	P05	P01	P0.0056
01559000	Observed	43.6	173	228	266	297	330	414	520	668	866	1,150	1,580	1,880	2,380	3,410	6,500	45,950	
	Predicted	69.6	120	154	186	230	274	363	456	588	810	1,210	1,730	1,960	2,430	3,330	6,340	38,020	
01559700	Observed	--	0.10	0.20	0.28	0.35	0.40	0.70	1.20	2.00	3.10	4.80	7.30	9.9	14.0	22.5	48.0	--	
	Predicted	0.07	0.15	0.32	0.42	0.60	0.78	1.31	2.12	2.91	4.08	6.04	8.35	10.2	13.9	23.2	60.5	396	
01560000	Observed	6.40	11.0	16.0	20.0	25.0	31.0	46.0	68.0	100	142	209	320	413	572	900	1,970	9,000	
	Predicted	3.90	8.33	14.5	19.0	25.9	33.2	51.8	76.3	107	150	224	318	384	513	801	1,790	10,610	
01562000	Observed	39.6	68.0	98.0	118	140	163	220	304	428	599	860	1,290	1,640	2,200	3,330	7,200	49,370	
	Predicted	32.4	62.0	91.2	114	148	184	264	358	467	648	967	1,390	1,650	2,160	3,220	6,690	40,200	
01564500	Observed	0.83	5.40	9.80	14.0	19.0	24.0	40.0	64.0	100	147	216	330	428	593	953	2,160	17,640	
	Predicted	4.85	10.3	17.9	23.2	31.7	40.8	63.0	91.3	121	165	240	340	415	560	893	2,050	13,370	
01565000	Observed	--	19.0	26.0	31.0	38.0	44.0	64.0	90.0	125	174	239	330	398	489	660	1,230	--	
	Predicted	15.8	24.0	33.2	40.6	50.8	60.9	82.4	105.3	122	163	228	317	366	465	676	1,430	9,350	
01565700	Observed	--	0.40	0.73	1.10	1.30	1.60	2.20	2.80	3.90	5.20	6.90	9.8	12.0	16.0	23.0	63.9	--	
	Predicted	0.19	0.36	0.68	0.89	1.22	1.53	2.37	3.48	4.26	5.67	7.72	10.5	11.7	14.5	21.0	48.8	381	
01566000	Observed	2.20	8.60	18.0	25.0	32.0	39.0	57.0	81.4	120	167	236	350	445	600	949	2,260	22,050	
	Predicted	8.02	15.3	25.0	32.0	42.7	54.0	80.3	112	142	191	269	380	469	635	1015	2,320	15,490	
01567500	Observed	1.21	2.40	3.10	3.60	4.10	4.50	5.80	7.60	10.0	13.0	18.0	25.0	30.0	40.0	62.0	153	2,030	
	Predicted	1.41	1.91	2.77	3.29	4.16	4.85	6.58	8.65	9.2	12.4	16.9	23.5	29.4	40.2	67.3	172	1,250	
01568000	Observed	9.93	17.0	25.0	31.0	38.0	47.0	69.0	103	145	200	280	400	500	653	978	2,370	16,750	
	Predicted	16.2	26.0	36.8	45.0	56.9	68.6	93.7	121	140	188	259	366	454	615	983	2,250	15,460	
01569000	Observed	--	4.40	7.40	9.30	12.0	14.0	22.0	31.0	40.0	51.0	65.0	86.0	103	125	166	317	--	
	Predicted	3.03	4.29	6.64	8.28	10.7	13.1	18.4	24.1	28.5	37.3	51.5	69.8	84	111	175	409	2,820	
01570000	Observed	--	63.0	96.0	115	137	159	207	267	336	428	563	777	949	1,190	1,720	35,404	--	
	Predicted	31.4	61.3	83.6	103	129	154	207	262	290	384	509	723	846	1,070	1,550	3,260	24,340	
01571500	Observed	67.4	90.0	104	117	128	138	159	186	217	259	311	387	448	535	723	1,410	12,280	
	Predicted	23.8	42.8	53.7	64.9	78.3	90.2	114	139	150	197	256	360	425	536	778	1,650	12,200	
01572000	Observed	--	2.00	3.90	5.60	7.40	9.20	14.0	21.0	30.0	41.0	56.0	80.0	100	133	200	453	--	
	Predicted	2.09	3.60	6.32	8.47	11.2	14.4	21.6	29.2	36.7	46.4	61.4	81.1	96	126	195	446	3,100	
01574500	Observed	--	8.20	11.0	14.0	16.0	18.0	24.0	32.0	41.0	53.0	71.0	99.0	118	150	222	520	--	
	Predicted	5.10	8.82	13.0	15.7	20.3	24.5	33.4	43.0	45.2	59.3	79.7	110	131	174	277	665	5,250	
01576754	Observed	--	94.0	141	180	215	249	313	386	470	565	694	884	1,020	1,250	1,780	4,250	--	
	Predicted	62.7	131	154	188	221	254	308	355	388	497	631	879	981	1,170	1,560	2,990	22,700	
01576787	Observed	--	31.0	54.0	67.0	79.0	87.0	106	127	151	177	207	243	276	330	469	1,330	--	
	Predicted	23.6	34.7	43.8	52.3	63.2	73.4	92.4	110	114	147	191	264	294	354	480	967	7,720	

Appendix 4. Flow-duration exceedance probabilities, observed and computed from streamflow data, and regression equations for streamgages used in regression analysis.—Continued

[—, no data; P_n, n probability exceedance]

U.S. Geological Survey streamgage number		Type	Flow-duration exceedance, in cubic feet per second																
			P99.9944	P99	P95	P90	P85	P80	P70	P60	P50	P40	P30	P20	P15	P10	P05	P01	P0.0056
01577500	Observed	--	28.0	38.6	47.0	56.0	69.0	86.0	105	122	140	160	193	219	267	354	846	--	
	Predicted	15.1	22.6	31.4	38.5	57.2	76.2	95.2	96.2	123	154	214	271	369	605	1,450	11,240	--	
01578400	Observed	--	1.60	2.10	2.60	3.00	3.40	4.00	4.80	5.40	6.20	7.30	8.88	10.0	13.0	19.0	66.2	--	
	Predicted	0.43	0.63	1.03	1.27	1.65	1.98	2.79	3.75	4.03	5.24	6.71	9.20	10.9	14.1	22.0	54.0	483	
01603500	Observed	1.00	2.00	2.70	3.40	4.00	4.80	7.00	11.0	15.0	22.0	31.0	45.0	56.0	73.0	110	259	1,980	
	Predicted	1.09	1.84	3.02	3.74	4.98	6.08	9.07	13.1	15.8	22.2	32.4	45.8	54.5	71.3	111	260	1,700	
01609000	Observed	--	4.60	6.80	11.2	15.0	21.0	38.0	63.0	101	142	207	323	422	625	993	2,480	--	
	Predicted	2.78	5.85	10.5	13.5	18.7	24.1	38.2	57.2	71.5	100	145	206	258	359	604	1,490	9,540	
01610155	Observed	--	0.02	0.40	1.50	2.70	4.80	11.0	22.0	36.0	57.0	88.5	141	191	269	450	1,080	--	
	Predicted	0.79	2.08	4.53	6.12	9.09	12.5	21.7	35.1	49.5	68.9	104	145	178	248	417	1,040	6,880	
01612500	Observed	--	0.00	0.00	0.10	0.20	0.40	1.00	2.00	3.80	6.90	12.0	19.0	26.0	37.0	66.0	170	--	
	Predicted	0.11	0.30	0.70	0.94	1.41	1.90	3.36	5.57	7.41	10.27	14.8	20.6	25.8	36.3	64.0	174	1,270	
01613050	Observed	--	0.00	0.11	0.30	0.55	0.88	1.80	3.30	5.00	7.50	12.0	18.0	24.0	33.0	53.0	121	--	
	Predicted	0.22	0.41	0.79	1.01	1.43	1.83	2.93	4.46	5.69	7.87	11.6	16.0	19.6	27.0	45.8	120	834	
01614090	Observed	--	0.40	0.70	0.99	1.20	1.50	2.20	3.20	4.50	6.10	8.20	11.0	13.0	16.0	22.0	42	--	
	Predicted	0.40	0.55	0.92	1.18	1.53	1.88	2.75	3.79	4.26	5.58	7.48	9.9	12.0	16.0	26.0	66	445	
01614500	Observed	25.3	56.0	84.0	103	120	140	187	252	338	450	602	843	1,030	1,320	1,930	4,220	24,260	
	Predicted	36.3	67.2	90.7	112	140	169	228	291	330	442	606	852	1,060	1,440	2,310	5,220	32,580	
01639000	Observed	0.01	1.80	4.90	7.90	11.0	16.0	27.0	43.0	65.0	95.0	141	223	297	450	867	2,590	16,320	
	Predicted	4.85	11.3	19.5	26.7	35.3	45.0	69.1	100	118	154	190	268	350	477	784	1,870	12,950	
03007800	Observed	--	18.0	32.0	48.0	66.0	86.0	130	185	250	334	450	643	801	1,030	1,590	3,360	--	
	Predicted	7.77	16.4	26.8	36.1	47.2	59.2	90.4	132	205	286	416	603	746	976	1,440	2,950	16,050	
03009680	Observed	--	8.6	25.0	35.0	48.0	62.0	97.0	135	180	236	315	437	539	698	1,010	2,100	--	
	Predicted	5.56	11.4	19.7	27.8	36.4	46.7	73.3	108	171	233	332	466	565	724	1,040	2,090	10,430	
03010500	Observed	16.5	37.0	59.0	87.0	122.0	164.0	263	380	535	728	1,020	1,440	1,760	2,290	3,330	5,810	53,800	
	Predicted	20.3	42.8	68.2	93.5	120.6	152.7	232	332	541	751	1,100	1,590	1,930	2,490	3,540	6,780	33,740	
03010655	Observed	--	6.20	10.0	15.0	20.0	27.0	44.0	65.0	88.0	119	163	228	276	361	523	1,200	--	
	Predicted	2.51	5.18	8.98	11.9	15.9	20.1	31.3	46.5	71.6	101	149	215	265	352	536	1,160	6,780	
03011800	Observed	--	5.10	8.40	12.0	15.0	19.0	28.0	39.0	51.0	65.2	85.0	113	136	171	240	458	--	
	Predicted	1.22	2.40	4.40	6.18	8.22	10.6	16.9	25.6	41.8	57.7	84.8	117	140	178	258	535	2,640	
03013000	Observed	22.0	34.0	44.0	55.0	70.0	87.0	134	203	291	400	549	850	1,080	1,400	1,900	3,160	8,100	
	Predicted	6.93	16.5	29.0	42.2	55.3	71.4	116	178	282	389	535	766	963	1,240	1,810	3,640	16,980	
03015280	Observed	--	1.10	1.70	2.30	3.00	3.70	5.70	8.30	12.0	16.0	23.0	32.0	40.0	52.0	78.0	181	--	
	Predicted	0.44	0.86	1.52	2.17	2.79	3.41	5.43	8.49	12.2	16.9	22.0	31.1	40.1	51.9	78.5	176	868	

Appendix 4. Flow-duration exceedance probabilities, observed and computed from streamflow data, and regression equations for streamgages used in regression analysis.—Continued

[—, no data; Pn, n probability exceedance]

U.S. Geological Survey streamgage number		Type	Flow-duration exceedance, in cubic feet per second																
			P99.9944	P99	P95	P90	P85	P80	P70	P60	P50	P40	P30	P20	P15	P10	P05	P01	P0.0056
03015500	Observed	21.2	36.0	52.0	68.0	86.0	107.0	160	227	310	420	589	852	1,080	1,440	2,170	4,200	4,200	13,650
	Predicted	19.1	36.9	55.5	79.3	97.5	120.4	181	260	364	493	643	910	1,160	1,480	2,120	4,200	4,200	18,160
03017500	Observed	--	20.0	30.0	42.0	57.0	74.0	117	168	240	330	464	652	794	1,000	1,410	2,720	2,720	--
	Predicted	10.1	19.0	30.9	42.4	54.9	69.7	107	155	237	327	483	677	811	1,040	1,500	2,990	2,990	13,840
03020500	Observed	23.0	34.0	47.0	63.0	81.0	102.0	155	220	300	397	536	750	924	1,220	1,880	3,930	3,930	15,420
	Predicted	19.7	35.3	50.5	69.4	84.7	102.2	149	213	289	400	539	772	987	1,270	1,860	3,770	3,770	16,300
03021350	Observed	--	5.40	11.0	17.0	23.0	31.0	52.0	78.0	104	140	192	292	375	530	875	1,940	1,940	--
	Predicted	2.03	4.92	9.2	14.0	18.3	23.6	39.8	64.4	97.8	134	171	242	313	401	591	1,230	1,230	5,270
03021500	Observed	4.38	11.0	18.0	26.0	35.0	46.0	77.0	125	188	270	390	585	752	1,020	1,580	3,300	3,300	13,830
	Predicted	5.64	13.3	23.1	34.8	44.6	56.9	93.0	146	218	300	387	550	713	915	1,340	2,710	2,710	11,280
03022540	Observed	--	2.80	4.40	6.60	8.40	11.0	17.0	22.0	30.0	38.0	51.0	73.0	92.0	121	190	421	421	--
	Predicted	1.01	2.07	3.53	5.11	6.48	7.90	12.6	20.0	27.3	38.1	48.3	69.1	91.8	120	183	408	408	1,830
03024000	Observed	--	73.0	104	141	185	233	387	600	898	1,270	1,840	2,690	3,360	4,360	6,180	11,000	11,000	--
	Predicted	45.7	103	151	219	266	327	493	724	1,020	1,410	1,810	2,630	3,470	4,470	6,460	12,560	12,560	50,750
03025000	Observed	--	18.0	25.0	32.0	40.0	50.0	72.0	103	142	197	273	384	470	617	933	1,970	1,970	--
	Predicted	11.4	19.1	27.3	36.8	45.0	53.8	78.2	111	144	201	272	388	497	648	973	2,060	2,060	9,110
03026500	Observed	0.07	0.27	0.64	1.10	1.60	2.20	3.90	5.90	8.20	11.0	15.0	21.0	25.0	32.0	48.0	104	104	456
	Predicted	0.20	0.39	0.78	1.09	1.49	1.92	3.17	4.97	8.12	11.2	16.4	22.5	26.7	34.3	50.9	112	112	590
03028000	Observed	4.51	7.20	11.0	15.0	20.0	26.0	39.0	56.0	76.0	100	133	185	224	290	418	816	816	2,860
	Predicted	1.99	4.00	7.23	10.2	13.5	17.4	27.9	42.1	68.3	94	136	189	227	290	419	856	856	4,180
03029400	Observed	--	0.70	1.10	1.40	1.80	2.40	4.00	6.00	9.00	14.0	21.0	29.0	36.0	47.0	70.0	140	140	--
	Predicted	0.21	0.48	1.00	1.48	2.02	2.63	4.55	7.51	11.42	15.7	21.2	29.5	37.0	48.3	74.1	170	170	858
03031950	Observed	--	0.50	0.90	1.30	1.60	2.10	3.40	4.90	6.90	9.40	13.0	18.0	22.0	29.0	47.0	109	109	--
	Predicted	0.09	0.23	0.51	0.77	1.06	1.40	2.49	4.23	6.33	8.65	11.3	15.6	20.0	26.2	41.3	99	99	524
03032500	Observed	20.7	40.0	62.0	85.0	112.0	143.0	229	335	470	660	920	1,330	1,630	2,130	3,090	5,990	5,990	27,030
	Predicted	9.36	25.1	45.2	66.4	88.4	116.3	192	299	476	659	921	1,320	1,650	2,140	3,160	6,350	6,350	28,830
03038000	Observed	--	6.00	10.0	14.0	19.0	26.0	46.0	75.0	115	172	254	390	503	691	1,060	2,330	2,330	--
	Predicted	2.01	5.52	11.9	17.8	25.5	35.7	63.8	104	159	216	311	422	508	671	1,040	2,280	2,280	11,070
03039200	Observed	--	0.10	0.20	0.38	0.55	0.79	1.40	2.40	3.30	4.40	6.00	8.50	11.0	14.0	23.0	52	52	--
	Predicted	0.13	0.20	0.38	0.50	0.68	0.85	1.34	2.04	2.97	4.16	6.38	8.68	10.2	13.4	20.9	50	50	280
03039925	Observed	--	0.32	0.58	1.00	1.40	1.80	2.50	3.70	4.90	6.30	8.40	11.0	13.0	17.0	24.0	44	44	--
	Predicted	0.14	0.22	0.42	0.56	0.76	0.96	1.54	2.34	3.39	4.66	7.05	9.36	10.8	14.0	21.4	50	50	257
03042200	Observed	--	0.30	0.60	0.90	1.30	1.80	3.10	4.60	6.50	9.00	12.0	18.0	23.0	30.0	46.0	104	104	--
	Predicted	0.32	0.51	0.94	1.28	1.72	2.18	3.47	5.19	7.23	9.83	14.4	19.1	22.4	29.1	44.5	103	103	532

Appendix 4. Flow-duration exceedance probabilities, observed and computed from streamflow data, and regression equations for streamgages used in regression analysis.—Continued

[--, no data; P_n, n probability exceedance]

U.S. Geological Survey streamgage number		Flow-duration exceedance, in cubic feet per second																		
Type	P99.9944	P99	P95	P90	P85	P80	P70	P60	P50	P40	P30	P20	P15	P10	P05	P01	P0.0056			
03049000	Observed	1.30	4.70	8.30	12.0	17.0	23.0	41.0	65.0	95.0	135	190	273	343	456	698	1,450	7,530		
	Predicted	1.53	3.90	7.94	11.3	16.0	21.6	37.5	61.0	87.1	121	176	245	304	410	659	1,530	7,760		
03049800	Observed	--	0.04	0.20	0.35	0.53	0.71	1.20	1.80	2.70	4.00	5.90	8.60	11.0	15.0	24.0	55.0	--		
	Predicted	0.03	0.11	0.24	0.34	0.49	0.63	1.12	1.95	2.79	3.98	5.61	7.88	10.2	14.1	24.2	65.4	377		
03062500	Observed	--	1.40	3.20	5.00	7.00	9.90	19.0	34.0	52.0	74.0	104	151	190	255	391	825	--		
	Predicted	1.02	2.68	5.46	8.17	11.3	15.3	26.3	41.9	58.8	78.8	110	144	174	227	355	810	3,620		
03072590	Observed	--	0.13	0.37	0.67	1.10	1.80	3.70	5.60	8.3	12.0	17.0	27.0	34.0	45.0	70.0	159	--		
	Predicted	0.32	0.80	1.49	2.09	2.80	3.55	5.70	8.82	11.6	15.9	22.0	29.7	36.9	49.5	80.8	200	1,020		
03072840	Observed	--	3.50	7.17	9.8	14.0	19.0	31.0	51.0	74.0	105	150	213	265	350	556	1,330	--		
	Predicted	2.87	6.09	10.3	13.9	18.4	23.0	36.5	56.6	71.1	101	140	202	265	362	594	1,420	7,250		
03073000	Observed	0.10	0.59	1.60	3.20	6.00	9.80	20.0	38.0	66.0	105	163	260	346	490	819	2,040	8,710		
	Predicted	4.08	8.88	14.8	20.0	26.3	32.9	51.8	79.7	100	141	194	279	365	498	813	1,920	9,620		
03074300	Observed	--	0.11	0.25	0.42	0.60	0.85	1.50	2.20	3.30	4.70	6.90	10.0	13.0	16.0	25.0	55.0	--		
	Predicted	0.16	0.25	0.47	0.63	0.85	1.08	1.72	2.60	3.48	4.77	7.16	9.3	10.8	14.1	22.1	53.3	261		
03078000	Observed	0.04	1.90	4.80	8.2	12.0	16.0	30.0	46.0	68.0	93.0	127	176	219	282	420	854	3,400		
	Predicted	0.55	1.50	3.34	4.9	7.1	9.77	17.6	29.7	50.5	70.5	105	146	177	232	354	775	3,940		
03079000	Observed	11.0	20.0	37.0	57.0	77.0	101.0	162	242	343	482	677	958	1,180	1,540	2,330	4,930	22,900		
	Predicted	9.03	20.5	35.4	49.1	65.5	85.0	136	203	313	437	648	918	1,120	1,470	2,190	4,500	21,630		
03080000	Observed	2.35	6.30	12.0	20.0	30.0	40.0	69.0	102	148	200	278	393	485	639	938	1,840	6,400		
	Predicted	5.11	9.32	16.0	22.3	29.2	37.8	59.5	87.2	128	175	256	348	411	528	774	1,600	7,210		
03082200	Observed	--	0.10	0.30	0.75	1.25	1.90	3.70	6.10	9.00	13.0	18.0	26.0	33.0	45.0	70.0	158	--		
	Predicted	0.29	0.52	0.97	1.34	1.81	2.31	3.74	5.76	8.02	11.0	16.1	21.6	25.9	33.9	52.9	124	626		
03084000	Observed	--	0.00	0.20	0.39	0.57	0.76	1.20	1.80	2.50	3.50	5.00	7.30	9.20	13.0	20.0	44	--		
	Predicted	0.02	0.17	0.29	0.40	0.53	0.61	0.89	1.34	2.12	3.02	4.32	6.01	7.64	10.6	18.3	50	298		
03085956	Observed	--	2.52	3.50	4.80	5.80	7.00	9.50	13.0	17.0	23.0	30.1	42.4	52.0	70.0	113	307	--		
	Predicted	0.17	0.98	1.61	2.14	2.81	3.28	4.82	7.28	11.0	16.0	23.4	33.5	43.3	60.3	103	267	1,490		
03092000	Observed	0.00	0.04	0.10	0.24	0.40	0.60	1.20	2.10	3.90	6.60	11.0	20.0	30.0	50.0	105	353	1,780		
	Predicted	0.07	0.25	0.58	0.89	1.28	1.65	3.16	6.17	9.38	13.9	17.7	27.0	38.9	53.9	91	234	1,180		
03093000	Observed	1.02	7.00	11.0	14.0	16.0	19.0	25.0	34.0	46.0	64.0	90.0	137	182	265	471	1,130	5,060		
	Predicted	0.43	1.57	3.36	5.13	7.18	9.37	17.3	32.0	48.9	71.4	93.2	140	196	268	438	1,050	4,870		
03102500	Observed	2.91	5.80	9.40	13.0	16.0	21.0	32.0	48.0	69.0	96.0	133	196	246	336	551	1,210	5,550		
	Predicted	3.07	6.66	10.3	14.3	17.9	21.3	32.7	50.7	64.7	92.5	118	176	242	325	515	1,180	5,530		
03102950	Observed	--	0.84	3.00	5.50	8.20	12.0	23.0	37.0	55.0	83.0	124	199	260	352	517	882	--		
	Predicted	0.91	2.67	5.10	7.57	10.1	12.8	22.1	38.4	54.8	79.1	101	151	211	285	459	1,070	5,030		

Appendix 4. Flow-duration exceedance probabilities, observed and computed from streamflow data, and regression equations for streamgages used in regression analysis.—Continued

[--, no data; P_n, n probability exceedance]

U.S. Geological Survey streamgage number	Type	Flow-duration exceedance, in cubic feet per second																
		P99.9944	P99	P95	P90	P85	P80	P70	P60	P50	P40	P30	P20	P15	P10	P05	P01	P0.0056
03103000	Observed	--	2.10	4.70	6.90	9.30	12.0	21.0	38.0	64.0	106	181	315	412	546	813	1,690	--
	Predicted	3.17	7.71	12.8	18.0	23.1	28.3	45.3	72.8	96.1	138	179	267	369	500	801	1,840	8,650
03106000	Observed	6.54	13.0	22.0	33.0	44.0	58.0	94.0	146	216	310	448	659	831	1,100	1,700	3,830	21,170
	Predicted	5.13	14.8	25.0	34.6	46.0	58.1	92.8	144	200	285	402	583	757	1,028	1,650	3,750	17,990
03106500	Observed	20.2	34.0	47.0	58.0	68.0	81.0	115	167	248	355	523	818	1,040	1,390	1,990	4,120	16,470
	Predicted	16.4	33.2	47.8	64.1	79.8	96.0	142	207	256	362	487	709	938	1,260	1,980	4,360	20,015
03109500	Observed	12.0	25.0	39.0	53.0	68.0	85.0	125	182	258	361	503	730	920	1,240	1,890	4,160	17,910
	Predicted	12.6	28.0	41.5	54.0	69.2	83.7	126	188	231	335	472	700	935	1,290	2,110	4,900	23,800
03110000	Observed	0.80	3.00	6.90	11.0	16.0	21.0	34.0	52.2	80.0	113	161	235	294	390	595	1,290	7,350
	Predicted	1.38	3.37	6.71	9.25	13.2	17.5	30.5	50.9	70.8	103	156	222	280	385	636	1,530	7,360
03111150	Observed	--	0.00	0.00	0.20	0.40	0.61	1.40	2.40	3.90	6.00	9.00	13.0	17.0	22.0	35.0	87.0	--
	Predicted	0.16	0.32	0.62	0.83	1.14	1.43	2.39	3.96	4.95	7.13	9.98	14.2	18.5	25.6	43.6	115	617
03111500	Observed	2.87	12.0	18.0	23.0	28.0	33.0	45.0	60.0	80.0	106	138	186	219	270	385	852	3,750
	Predicted	2.34	5.13	8.72	11.8	15.7	19.5	31.3	49.5	62.4	90	126	182	240	328	542	1,300	6,220
04213000	Observed	0.30	3.10	6.80	11.0	15.0	21.0	39.0	66.0	100	150	221	353	480	700	1,190	2,610	10,680
	Predicted	1.49	5.02	9.77	15.4	20.4	26.1	46.2	81.5	130	185	230	345	483	636	969	2,080	8,820
04213075	Observed	--	0.36	0.73	1.00	1.20	1.40	2.00	2.60	3.50	4.60	6.10	8.60	11.0	14.0	23.0	58.6	--
	Predicted	0.01	0.06	0.15	0.25	0.35	0.46	0.91	1.82	3.14	4.48	5.33	7.87	11.1	14.8	23.6	58.1	282

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