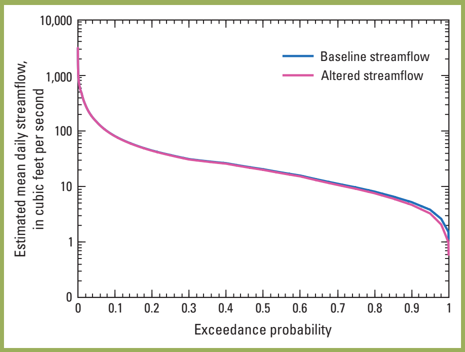
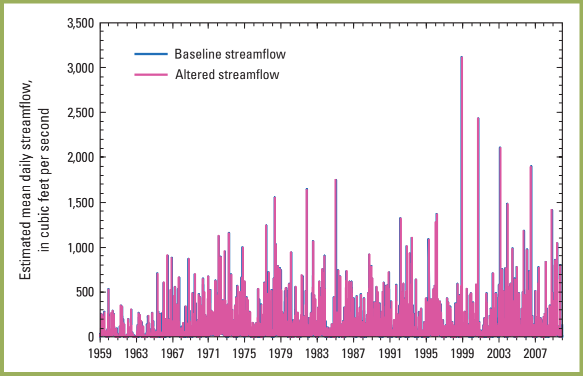
National Water Census

Estimation of Daily Mean Streamflow for Ungaged Stream Locations in the Delaware River Basin, Water Years 1960–2010





Scientific Investigations Report 2015–5157

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

Cover. Little Neshaminy Creek near Neshaminy, Pennsylvania, looking upstream. Photograph courtesy of U.S. Geological Survey Pennsylvania Water Science Center Hydrologic Surveillance Program staff, Exton office.
(Top graph) Flow-duration curve, in cubic feet per second, for ungaged site under baseline and altered flow conditions.
(Bottom graph) Baseline and altered hydrograph, in cubic feet per second, for ungaged site.

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By Marla H. Stuckey

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U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

Suggested citation:
Stuckey, M.H., 2016, Estimation of daily mean streamflow for ungaged stream locations in the Delaware River Basin, water years 1960–2010: U.S. Geological Survey Scientific Investigations Report 2015–5157, 42 p., http://dx.doi.org/10.3133/sir20155157.

ISSN 2328-0328 (online)

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Conversion Factors and Datums

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)
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 hectometers (hm^3)
inch per hour (in/h)	0.0254	meter per hour (m/h)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)

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

$$°C = (°F - 32) / 1.8$$

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

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

Estimation of Daily Mean Streamflow for Ungaged Stream Locations in the Delaware River Basin, Water Years 1960–2010

By Marla H. Stuckey

Abstract

The ability to characterize baseline streamflow conditions, compare them with current 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. The U.S. Geological Survey, through the National Water Census, has developed the Delaware River Basin Streamflow Estimator Tool (DRB-SET) to estimate baseline (minimally altered) and altered (affected by regulation, diversion, mining, or other anthropogenic activities) and altered streamflow at a daily time step for ungaged stream locations in the Delaware River Basin for water years 1960–2010. Daily mean baseline streamflow is estimated by using the QPPQ method to equate streamflow expressed as a percentile from the flow-duration curve (FDC) for a particular day at an ungaged stream location with the percentile from a FDC for the same day at a hydrologically similar gaged location where streamflow is measured. Parameter-based regression equations were developed for 22 exceedance probabilities from the FDC for ungaged stream locations in the Delaware River Basin. Water use data from 2010 is used to adjust the baseline daily mean streamflow generated from the QPPQ method at ungaged stream locations in the Delaware River Basin to reflect current, or altered, conditions. To evaluate the effectiveness of the overall QPPQ method contained within DRB-SET, a comparison of observed and estimated daily mean streamflows was performed for 109 reference streamgages in and near the Delaware River Basin. The Nash-Sutcliffe efficiency (NSE) values were computed as a measure of goodness of fit. The NSE values (using $\log_{10}$ streamflow values) ranged from 0.22 to 0.98 (median of 0.90) for 45 streamgages in the Upper Delaware River Basin and from -0.37 to 0.98 (median of 0.79) for 41 streamgages in the Lower Delaware River Basin.

Introduction

The National Water Census is a U.S. Geological Survey (USGS) research program, funded through WaterSMART, for national water availability and use that develops new water accounting tools and assesses water availability at regional and national scales. WaterSMART, which stands for Water Sustain and Manage America’s Resources for Tomorrow, is an initiative launched by the U.S. Department of the Interior in February 2010. Through the National Water Census, the USGS is integrating diverse research on water availability and use and enhancing the understanding of the connection between water quality and water availability (Alley and others, 2013). The research is designed to build the decision support capacity for water-management agencies and other natural-resource managers. The National Water Census identified three geographic Focus Areas that would benefit from cutting edge approaches to assessing water availability while also serving as pilot studies where multiple lines of research could be integrated and designed to meet stakeholders’ information needs. Each Focus Area offers unique challenges that the USGS could investigate at the scale of a large river basin. The Delaware River Basin was selected as one of these Focus Areas.

The Delaware River Basin covers more than 13,500 square miles (mi^2) in parts of four states, including New York, New Jersey, Pennsylvania, and Delaware. The population in the basin is approximately 8.3 million people. The basin has the largest inter-basin withdrawals of water east of the Mississippi River and provides drinking water to more than 15 million people (Delaware River Basin Commission, 2013). After a history of litigation, many of the water-management decisions regarding the Delaware River system are now coordinated through an interstate river basin commission known as the Delaware River Basin Commission (DRBC). In the upper parts of the basin, concerns over the effects of proposed unconventional shale gas development and the freshwater requirements for a recently discovered endangered mussel species (Lellis, 2001) have added new complexities to water management. One of the needs identified by stakeholders in the basin was the need for a scientific approach to define relations between streamflow processes and the responses of aquatic organisms in tributary streams.

Hydrologic and ecological data can be directly related to provide the basis for understanding the flow needs of aquatic species found in the tributaries in the Delaware River Basin. Because the aquatic species living in tributaries are often susceptible to minor changes in streamflow, proactive management measures incorporating the principles of ecological flow science can be implemented to promote the long-term ecological sustainability of these waters. Providing the data and tools to understand and define flow-alteration ecological-response relations will assist water-resource managers and policy makers in making water use decisions that meet the ecological flow needs of aquatic species in the Delaware River Basin.

Maintenance of 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, and assess the effects of human activities on streamflow is fundamental to water-management programs addressing water allocation, human-health issues, recreation needs, and the 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 to determine streamflow statistics that fulfill their individual needs. Typically, this information is obtainable only from a time series hydrograph. The USGS, through the National Water Census, has developed a tool to estimate streamflow at a daily time step for ungaged stream locations in the Delaware River Basin. The hydrologic information provided by this tool can be used to provide a foundation for ecological flow science in the basin.

Previous Studies

Fennessey (1994) introduced a method, termed the “QPPQ method,” to estimate streamflow statistics for an ungaged stream location. This method was used by Hughes and Smakhtin (1996), Smakhtin (1999), Smakhtin and Masse (2000), Mohamoud (2008), Archfield and others (2010), Shu and Ourda (2012), Stuckey and others (2014), and Gazoorian (2015). Archfield and Vogel (2010) developed a method for selecting an appropriate streamgage for an ungaged stream location on the basis of streamflow correlation (termed the “map correlation method”). These two methods have been successfully applied in Massachusetts (Archfield and others, 2010), the Connecticut River Basin (Archfield and others, 2012), Pennsylvania (Stuckey and others, 2014), and New York (Gazoorian, 2015) to generate daily mean streamflows for ungaged stream locations. Regression equations for estimating streamflow at 17 flow-duration exceedance probabilities from the flow-duration curve were developed for Pennsylvania in conjunction with the Baseline Streamflow Estimator Tool (Stuckey and others, 2014). Water use, including reported and estimated withdrawals and returns, for the Delaware River Basin is documented in Hutson and others, in press.

Study Area

The Delaware River Basin encompasses 13,539 mi^2, draining parts of Pennsylvania (6,422 mi^2, or 50.3 percent of the basin’s total land area), New Jersey (2,969 mi^2, or 23.3 percent), New York (2,362 mi^2, or 18.5 percent), and Delaware (1,004 mi^2, or 7.9 percent). Some subbasins within the Delaware River Basin drain directly into Delaware Bay (782 mi^2). A total of 216 tributary streams enter the Delaware River, making a total of approximately 23,700 linear stream miles in the river system (http://www.state.nj.us/drbc/basin/). The largest tributaries are the Schuylkill River and the Lehigh River in Pennsylvania, which together drain 3,281 mi^2.

Five major physiographic provinces compose the Delaware River Basin (fig. 1) (Fischer and others, 2004). The northern third of the basin is covered by the Appalachian Plateaus Physiographic Province, which is composed of gently folded sandstones, shales, and conglomerates. The Valley and Ridge Physiographic Province is adjacent and south of the Appalachian Plateau Physiographic Province and consists primarily of sandstones and shales that form ridges and valleys. Glaciation during the Pleistocene Epoch covered the upper half of the basin, extending to the New England Physiographic Province, which is an upland ridge of metamorphosed shales and carbonate rocks. The Piedmont Physiographic Province is the most highly socioeconomically developed province in the basin and is separated geographically into two sections—the Uplands Section which is composed of metamorphic and igneous rocks, and the Lowlands Section, which is primarily composed of clastic rocks. The most southern physiographic province is the Coastal Plain, which is composed of unconsolidated sediment.

The climate in the Delaware River Basin varies depending on the topography and latitude. Average annual temperature ranges from about 45 degrees Fahrenheit (°F) in the northern part of the basin to 56 °F in the southern part. Average annual precipitation ranges from about 50 inches (in.) in the north to 42 in. in the south (Jenner and Lins, 1991).

Purpose and Scope

This report presents the data and methodology used to estimate daily mean streamflow for water years[1] 1960–2010 for ungaged locations on streams in the Delaware River Basin.

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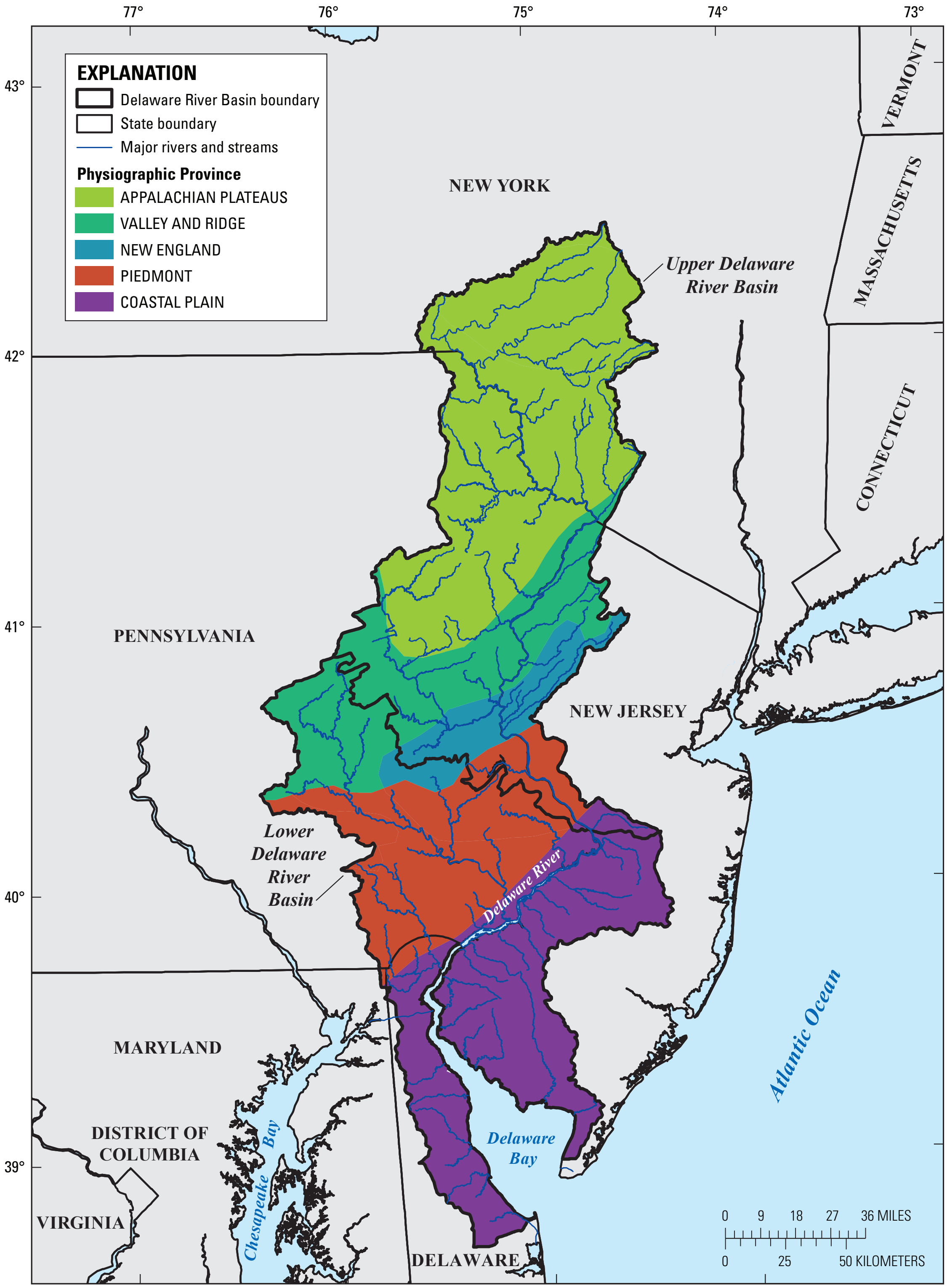
[1] Water year (WY) is defined as a 12-month period beginning October 1 and ending September 30. The water year is designated by the calendar year in which it ends.



Base modified from U.S. Geological Survey 1:100,000-scale
and 1:250,000-scale digital data

Figure 1. Physiographic provinces of the Delaware River Basin.

Parameter-based regression equations used to predict streamflows at 22 exceedance probabilities from the flow-duration curve (FDC) for ungaged stream locations in the Delaware River Basin are presented. Flow-duration exceedance probabilities for 109 streamgages are presented. Streamflow data from continuous-record streamgages were used to develop correlation maps of the predicted correlation of streamflow between an ungaged stream location and a reference streamgage. A brief description of the Delaware River Basin Streamflow Estimator Tool (DRB-SET), a tool for estimating baseline and altered daily mean streamflow for ungaged stream locations in the Delaware River Basin, is presented.

Estimation of Baseline Daily Mean Streamflow

Daily mean streamflow can be estimated using the QPPQ method (Fennessey, 1994), which equates streamflow expressed as a percentile from the FDC for a particular day at an ungaged stream location with that from the FDC for the same day at a hydrologically similar gaged location where streamflow is measured (referred to as a “reference streamgage”). Streamflow corresponding to the flow-duration exceedance probability for the ungaged stream location are selected from a daily FDC constructed from points determined by regression equations. Geospatial correlation of streamflow, termed map correlation, (Archfield and others, 2010) is used to select a reference streamgage for the ungaged stream location. A graphical depiction of the QPPQ methodology is shown in figure 2.

For this study, observed streamflow and basin characteristics from 109 reference streamgages (fig. 3) with unaltered streamflow were used to develop regression equations to predict streamflow corresponding to 22 exceedance probabilities from the FDC. The FDC for a reference streamgage is a cumulative frequency curve that shows the percentage of time that specified streamflows are equaled or exceeded (Searcy, 1960). 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 term “exceedance probability” refers to the percentage of time that each streamflow value in the record is equaled or exceeded and is used when discussing statistics; the term “percentile” refers to an

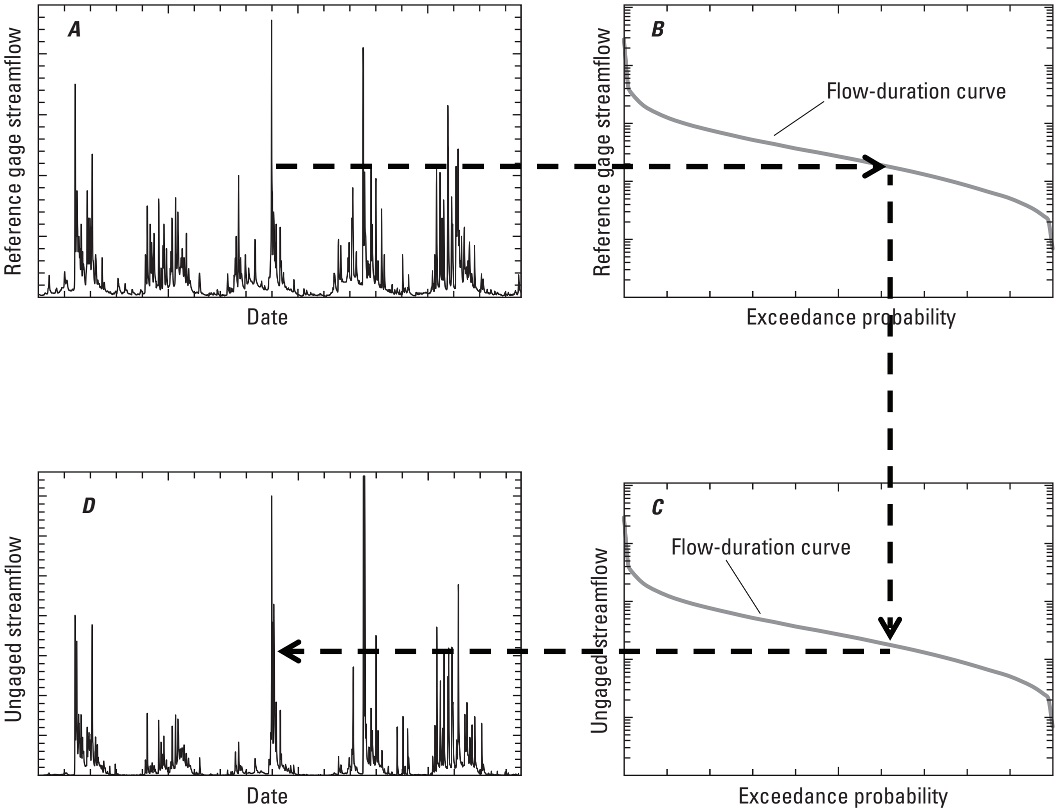
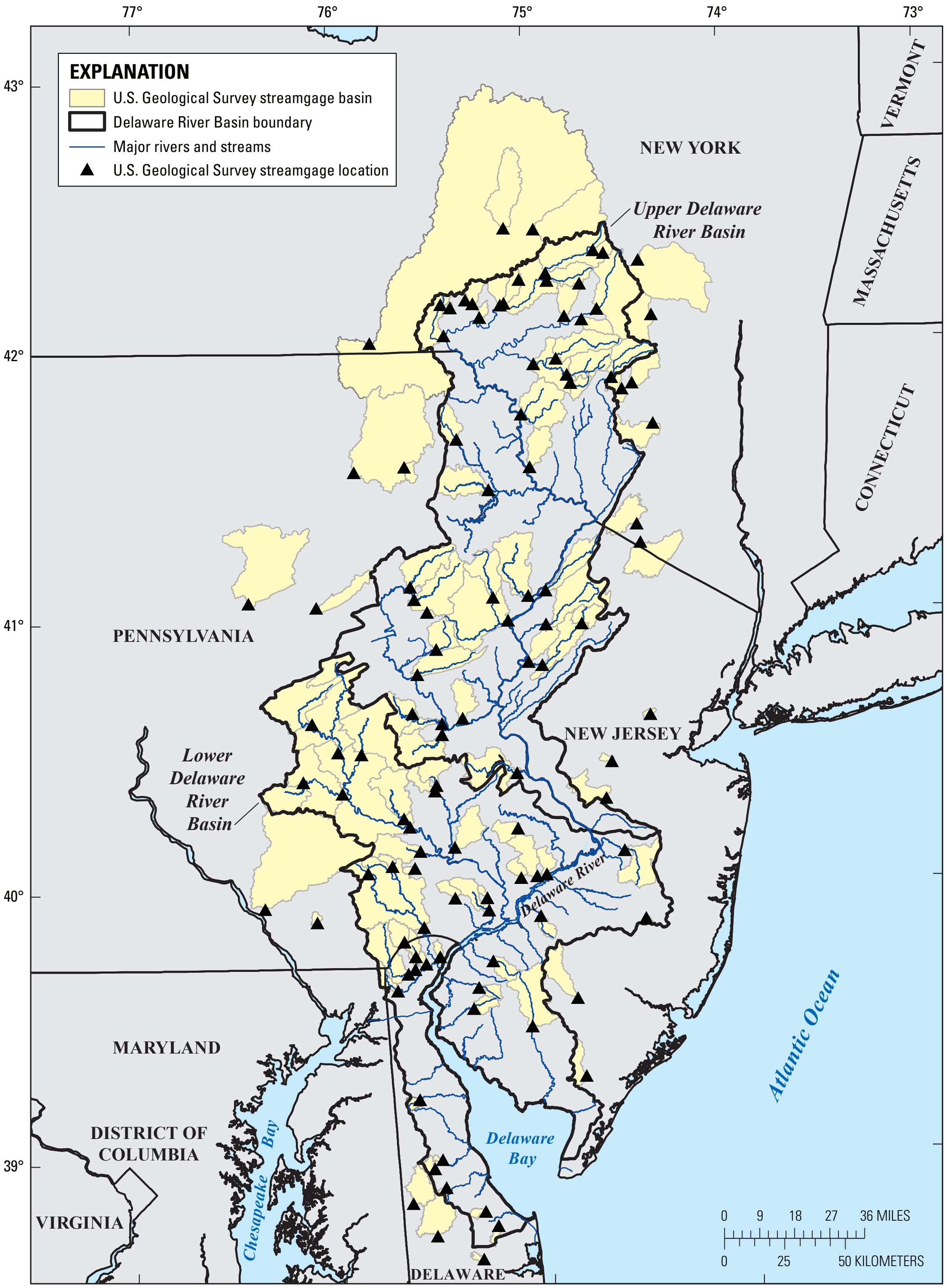


Figure 2. Graphical representation of the QPPQ methodology, showing *A*, observed daily mean streamflow at a reference streamgage, *B*, flow-duration curve at the reference streamgage, *C*, constructed flow-duration curve at the ungaged stream location, and *D*, estimated daily mean streamflow at the ungaged stream location. (Modified from Archfield and others, 2010; Stuckey and others, 2014.)



Base modified from U.S. Geological Survey 1:100,000-scale and 1:250,000-scale digital data

Figure 3. Location of U.S. Geological Survey reference streamgages in or near the Delaware River Basin.

individual exceedance probability and is used when discussing methodology associated with a generic FDC.

The FDC for an ungaged stream location is constructed from estimates of streamflow. Streamflow at the ungaged stream location is estimated using the equivalent exceedance probabilities (22 percentiles for this study) from regression equations developed using basin characteristics and streamflow data from reference streamgages. Interpolation between exceedance probabilities of the 22 regression equations is used to determine all other streamflow percentiles. The conjunction of interpolation and regression equations yields a continuous daily hydrograph consisting of 18,628 streamflow values (one value for each day in water years 1960–2010) for the ungaged stream location.

A critical consideration in estimating baseline daily mean streamflow is the selection of the reference streamgage that results in the best estimate of daily streamflow at the ungaged stream location. Selection of a reference streamgage is performed in DRB-SET by default using map correlation (Archfield and others, 2010; Archfield and Vogel, 2010), although selection of the closest streamgage and selection by the user of a streamgage are also supported. Map correlation is a geostatistical procedure for determining the streamgage with streamflow that exhibits the strongest correlation with streamflow at an ungaged stream location.

Reference Streamgages in the Delaware River Basin

The streamflow at a reference streamgage constitutes a composite of the upstream land cover, geology, and hydrologic characteristics that 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 data collection. Data on observed streamflows at reference streamgages are used in this analysis to develop regression equations for estimating streamflows at 22 exceedance probabilities and for development of correlation maps.

Reference Streamgage Criteria

Reference streamgages selected for this analysis had streamflow that was minimally altered by regulation, diversion, mining, or other anthropogenic activities and had at least 10 years of continuous record. Substantial regulation for this analysis is defined by upstream reservoir impoundments that control at least 10 percent of the contributing drainage area at the streamgage. Information on diversions and mining effects were obtained from USGS Annual Water Data Reports, available online from 2006 through 2014 at http://wdr.water.usgs.gov/ and in paper format prior to 2006. Streamgages with questionable regulation in Pennsylvania 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). If the results of this evaluation indicated that the streamflow at the streamgage was affected by regulation, the streamflow data were excluded from the overall analysis. The unaltered part of the record at streamgages that yield flow records altered by upstream regulation was included in the study if there was at least 10 years of unaltered flow before the impoundment was constructed. Streamgages outside of Pennsylvania were also reviewed for suitability as a reference streamgage by personnel in the respective USGS Water Science Center. There were 109 streamgages in or near the Delaware River Basin that met the above criteria—44 in Pennsylvania, 33 in New York, 17 in New Jersey, and 15 in Delaware (fig. 3). Of the 109 streamgages, 24 were outside the Delaware River Basin but were included for a more regional spatial coverage. The average number of years of record is 47 years for the 109 reference streamgages selected for use in this study. A complete listing of streamgages used in the analysis is presented in table 1.

The percentage of impervious area within a basin was used to identify streamgages with potential anthropogenic effects on streamflow (Fry and others, 2011). In most of the study area, baseline conditions were defined using data from reference streamgages with less than 10 percent of the upstream area covered by impervious surfaces. However, in large urban/suburban areas, such as in and around the Philadelphia/Camden, New Jersey area, some streamgages with a high percentage of impervious area were retained for improved spatial coverage. Historical maps indicate that much of the Philadelphia area has not undergone significant change in impervious area since the early 1900s (http://www.philageohistory.org/tiles/viewer/). The percent impervious area upstream from streamgages used in the analysis ranged from 0.0 to 32 percent, with 11 reference streamgages having more than 10 percent impervious area (fig. 4).

Record Extension

Estimation of daily mean streamflow using the QPPQ method for WY 1960–2010 for any ungaged stream location requires that all reference streamgages have a complete daily mean streamflow record for the same period. Of the 109 reference streamgages, 36 had a complete daily mean streamflow record with unaltered flow for the study period. The remaining streamgages had record lengths of 9–50 years during the study period. Streamflow records that were incomplete over the study period were extended to the complete period using the Streamflow Record Extension Facilitator (SREF) (Granato, 2009). The average number of years of record during the study period that required record extension was 24 years, with a range of 1–42 years (fig. 5). Estimated streamflow data from the record extension analysis were not used in the development of regression equations or correlation maps.

Table 1. U.S. Geological Survey reference streamgages in and near the Delaware River Basin.

[USGS, U.S. Geological Survey; HUC8, 8-digit hydrologic unit code; water year, the 12-month period starting October 1, and ending September 30 of the following year]

USGS streamgage number	Latitude (decimal degrees)	Longitude (decimal degrees)	Hydrologic Unit Code (HUC8)	Period of record used in analysis (water year)	Station name
01350000	42.319444	-74.436667	2020005	1904–2010	Schoharie Creek at Prattsville, N.Y.
01362200	42.116944	-74.380278	2020006	1964–2010	Esopus Creek at Allaben, N.Y.
01365000	41.866389	-74.487222	2020007	1937–2010	Rondout Creek near Lowes Corners, N.Y.
01365500	41.845000	-74.539444	2020007	1939–1987; 1999–2010	Chestnut Creek at Grahamsville, N.Y.
01366650	41.714167	-74.389167	2020007	1957–1977	Sandburg Creek at Ellenville, N.Y.
01368500	41.344444	-74.487778	2020007	1944–1968	Rutgers Creek at Gardnerville, N.Y.
01369000	41.275556	-74.471667	2020007	1938–1979	Pochuck Creek near Pine Island, N.Y.
01401000	40.333056	-74.681944	2030105	1954–2010	Stony Brook at Princeton, N.J.
01401650	40.468056	-74.648889	2030105	1980–2010	Pike Run at Belle Mead, N.J.
01403540	40.636389	-74.451389	2030105	1975–2010	Stony Brook at Watchung, N.J.
01411000	39.594722	-74.851667	2040302	1926–2010	Great Egg Harbor River at Folsom, N.J.
01411300	39.306944	-74.820556	2040302	1970–2010	Tuckahoe River at Head of River, N.J.
01411500	39.495556	-75.076944	2040206	1933–2010	Maurice River at Norma, N.J.
01413500	42.144722	-74.653611	2040102	1937–2010	East Branch Delaware River at Margaretville, N.Y.
01414500	42.106111	-74.730556	2040102	1937–2010	Mill Brook near Dunraven, N.Y.
01415000	42.120000	-74.818611	2040102	1937–2010	Tremper Kill near Andes, N.Y.
01418500	41.963056	-74.866944	2040102	1937–1970	Beaver Kill at Craigie Clair, N.Y.
01419500	41.903333	-74.812778	2040102	1938–1970	Willowemoc Creek near Livingston Manor, N.Y.
01420000	41.872778	-74.797222	2040102	1925–1981	Little Beaver Kill near Livingston Manor, N.Y.
01420500	41.946389	-74.979722	2040102	1914–2010	Beaver Kill at Cooks Falls, N.Y.
01421614	42.349444	-74.611111	2040101	1999–2009	Town Brook Tributary Southeast of Hobart, N.Y.
01421618	42.361111	-74.662222	2040101	1998–2010	Town Brook Southeast of Hobart, N.Y.
01421900	42.280278	-74.907222	2040101	1937–1970; 1997–2010	West Branch Delaware River upstream from Delhi, N.Y.
01422389	42.238611	-74.736111	2040101	1998–2009	Coulter Brook near Bovina Center, N.Y.
01422500	42.252222	-74.901667	2040101	1938–1970; 1997–2010	Little Delaware River near Delhi, N.Y.
01422738	42.259444	-75.041944	2040101	1999–2009	Wolf Creek at Mundale, N.Y.
01422747	42.172778	-75.121389	2040101	1999–2010	East Brook East of Walton, N.Y.
01423000	42.166111	-75.140000	2040101	1951–2010	West Branch Delaware River at Walton, N.Y.
01423500	42.121944	-75.246944	2040101	1953–1968	Dryden Brook near Granton, N.Y.
0142400103	42.173611	-75.279444	2040101	1953–1967; 1997–2010	Trout Creek near Trout Creek, N.Y.
01424108	42.187778	-75.315556	2040101	1998–2007	Sherruck Brook Tributary near Trout Creek, N.Y.
01425500	42.161111	-75.392778	2040101	1935–1968	Cold Spring Brook at China, N.Y.
01425675	42.174444	-75.440000	2040101	1970–1981	Oquaga Creek near North Sanford, N.Y.
01426000	42.058611	-75.428056	2040101	1941–1973	Oquaga Creek at Deposit, N.Y.
01427500	41.760833	-75.048333	2040101	1941–1982	Callicoon Creek at Callicoon, N.Y.
01428000	41.563889	-75.014444	2040101	1946–1973	Tenmile River at Tusten, N.Y.
01428750	41.674530	-75.376013	2040103	1987–2010	West Branch Lackawaxen River near Aldenville, Pa.
01431000	41.484811	-75.221842	2040103	1946–1960	Middle Creek near Hawley, Pa.

Table 1. U.S. Geological Survey reference streamgages in and near the Delaware River Basin.—Continued

[USGS, U.S. Geological Survey; HUC8, 8-digit hydrologic unit code; water year, the 12-month period starting October 1, and ending September 30 of the following year]

USGS streamgage number	Latitude (decimal degrees)	Longitude (decimal degrees)	Hydrologic Unit Code (HUC8)	Period of record used in analysis (water year)	Station name
01435000	41.890000	-74.590000	2040104	1938–2010	Neversink River near Claryville, N.Y.
01439500	41.088151	-75.037675	2040104	1909–2010	Bush Kill at Shoemakers, Pa.
01440000	41.106111	-74.952500	2040104	1924–2010	Flat Brook near Flatbrookville, N.J.
01440400	41.084815	-75.214625	2040104	1958–2010	Brodhead Creek near Analomink, Pa.
01442500	40.998706	-75.142679	2040104	1951–2010	Brodhead Creek at Minisink Hills, Pa.
01443500	40.980833	-74.953333	2040105	1922–2010	Paulins Kill at Blairstown, N.J.
01445000	40.980833	-74.776389	2040105	1940–2010	Pequest River at Huntsville, N.J.
01445500	40.830556	-74.977778	2040105	1922–2010	Pequest River at Pequest, N.J.
01446000	40.843333	-75.046389	2040105	1923–2010	Beaver Brook near Belvidere, N.J.
01447500	41.130363	-75.625467	2040106	1944–2010	Lehigh River at Stoddartsville, Pa.
01447720	41.084808	-75.605467	2040106	1962–1984	Tobyhanna Creek near Blakeslee, Pa.
01448500	41.035643	-75.543243	2040106	1949–1996	Dilldown Creek near Long Pond, Pa.
01449360	40.897592	-75.502408	2040106	1967–2010	Pohopoco Creek at Kresgeville, Pa.
01450500	40.806205	-75.597964	2040106	1940–2010	Aquashicola Creek at Palmerton, Pa.
01451500	40.582320	-75.482961	2040106	1946–2010	Little Lehigh Creek near Allentown, Pa.
01451800	40.661762	-75.626854	2040106	1967–2010	Jordan Creek near Schnecksville, Pa.
01452000	40.623153	-75.482405	2040106	1945–2010	Jordan Creek at Allentown, Pa.
01452500	40.641209	-75.379347	2040106	1949–2010	Monocacy Creek at Bethlehem, Pa.
01459500	40.433715	-75.116561	2040105	1936–1973	Tohickon Creek near Pipersville, Pa.
01464500	40.137222	-74.600000	2040201	1938–2010	Crosswicks Creek at Extonville, N.J.
01464907	40.229275	-75.119616	2040201	1999–2010	Little Neshaminy Creek at Valley Road, Pa.
01465798	40.057056	-74.985169	2040202	1966–2010	Poquessing Creek at Grant Ave. at Philadelphia, Pa.
01466500	39.885000	-74.505278	2040202	1954–2010	McDonalds Branch in Byrne State Forest, N.J.
01467048	40.050111	-75.032671	2040202	1966–2010	Pennypack Creek at Lower Rhawn St. Bdg., Phila., Pa.
01467086	40.046500	-75.110730	2040202	1966–2010	Tacony Creek at County Line, Philadelphia, Pa.
01467150	39.903056	-75.021389	2040202	1964–2010	Cooper River at Haddonfield, N.J.
01468500	40.629258	-76.124662	2040203	1948–1953; 1964–1965; 1974–2010	Schuylkill River at Landingville, Pa.
01470500	40.522593	-75.998268	2040203	1948–2008	Schuylkill River at Berne, Pa.
01470756	40.514261	-75.882982	2040203	1974–1995	Maiden Creek at Virginville, Pa.
01470779	40.413426	-76.171613	2040203	1975–2008	Tulpehocken Creek near Bernville, Pa.
01471000	40.368982	-75.979102	2040203	1951–1978	Tulpehocken Creek near Reading, Pa.
01471980	40.272873	-75.679910	2040203	1975–2004	Manatawny Creek near Pottstown, Pa.
01472000	40.241763	-75.651575	2040203	1928–1978	Schuylkill River at Pottstown, Pa.
01472157	40.151491	-75.601305	2040203	1969–2008	French Creek near Phoenixville, Pa.
01472174	40.089548	-75.630203	2040203	1967–1983	Pickering Creek near Chester Springs, Pa.
01472198	40.393988	-75.515459	2040203	1982–2008	Perkiomen Creek at East Greenville, Pa.
01472199	40.373988	-75.522403	2040203	1982–2008	West Branch Perkiomen Creek at Hillegass, Pa.
01473120	40.164550	-75.433239	2040203	1967–1994	Skippack Creek near Collegeville, Pa.

Table 1. U.S. Geological Survey reference streamgages in and near the Delaware River Basin.—Continued

[USGS, U.S. Geological Survey; HUC8, 8-digit hydrologic unit code; water year, the 12-month period starting October 1, and ending September 30 of the following year]

USGS streamgage number	Latitude (decimal degrees)	Longitude (decimal degrees)	Hydrologic Unit Code (HUC8)	Period of record used in analysis (water year)	Station name
01475510	39.929002	-75.272406	2040202	1965–1990	Darby Creek near Darby, Pa.
01475530	39.974835	-75.279907	2040202	1965–2008	Cobbs Creek at U.S. Highway No. 1 at Philadelphia, Pa.
01475850	39.976499	-75.436586	2040202	1982–2008	Crum Creek near Newtown Square, Pa.
01477120	39.740556	-75.259167	2040202	1967–2010	Raccoon Creek near Swedesboro, N.J.
01477800	39.760972	-75.518694	2040205	1945–2010	Shellpot Creek at Wilmington, Del.
01478000	39.637389	-75.727889	2040205	1943–2010	Christina River at Coochs Bridge, Del.
01479000	39.699222	-75.675028	2040205	1932–2010	White Clay Creek near Newark, Del.
01479820	39.816777	-75.691601	2040205	1988–2008	Red Clay Creek near Kennett Square, Pa.
01480000	39.762806	-75.636500	2040205	1943–2010	Red Clay Creek at Wooddale, Del.
01480015	39.715750	-75.639944	2040205	1989–2010	Red Clay Creek near Stanton, Del.
01480100	39.734835	-75.586869	2040205	1964–1981	Little Mill Creek at Elsmere, Del.
01480300	40.072879	-75.860774	2040205	1961–2008	West Branch Brandywine Creek near Honey Brook, Pa.
01480675	40.097879	-75.741599	2040205	1967–2008	Marsh Creek near Glenmoore, Pa.
01481000	39.869833	-75.593262	2040205	1912–1953; 1963–1973	Brandywine Creek at Chadds Ford, Pa.
01482500	39.643889	-75.330278	2040206	1941–1984; 2002–2010	Salem River at Woodstown, N.J.
01483000	39.565556	-75.360556	2040206	1953–1972	Alloway Creek at Alloway, N.J.
01483500	39.232889	-75.632150	2040207	1943–1975	Leipsic River near Cheswold, Del.
01484000	38.975947	-75.567147	2040207	1932–2009	Murderkill River near Felton, Del.
01484100	38.905778	-75.512750	2040207	1958–2010	Beaverdam Branch at Houston, Del.
01484270	38.761501	-75.267134	2040207	1971–2005	Beaverdam Creek near Milton, Del.
01484300	38.814279	-75.327137	2040207	1957–1978	Sowbridge Branch near Milton, Del.
01484500	38.638861	-75.341972	2060010	1943–2004	Stockley Branch at Stockley, Del.
01487000	38.728333	-75.561861	2060008	1935–2010	Nanticoke River near Bridgeville, Del.
01488500	38.849694	-75.673111	2060008	1935–2003; 2005–2010	Marshyhope Creek near Adamsville, Del.
01498500	42.445000	-74.963611	2050101	1938–1975	Charlotte Creek at West Davenport, N.Y.
01499000	42.450833	-75.114722	2050101	1941–1968	Otego Creek near Oneonta, N.Y.
01503000	42.035278	-75.803056	2050101	1913–2010	Susquehanna River at Conklin, N.Y.
01533950	41.574802	-75.641855	2050106	1961–1978	South Branch Tunkhannock Creek near Montdale, Pa.
01534000	41.558410	-75.894642	2050106	1914–2010	Tunkhannock Creek near Tunkhannock, Pa.
01538000	41.059250	-76.093540	2050107	1920–2010	Wapwallopen Creek near Wapwallopen, Pa.
01539000	41.078141	-76.431056	2050107	1936–2010	Fishing Creek near Bloomsburg, Pa.
01576754	39.946489	-76.367739	2050306	1985–2010	Conestoga River at Conestoga, Pa.
01578400	39.894826	-76.113564	2050306	1963–1981	Bowery Run near Quarryville, Pa.

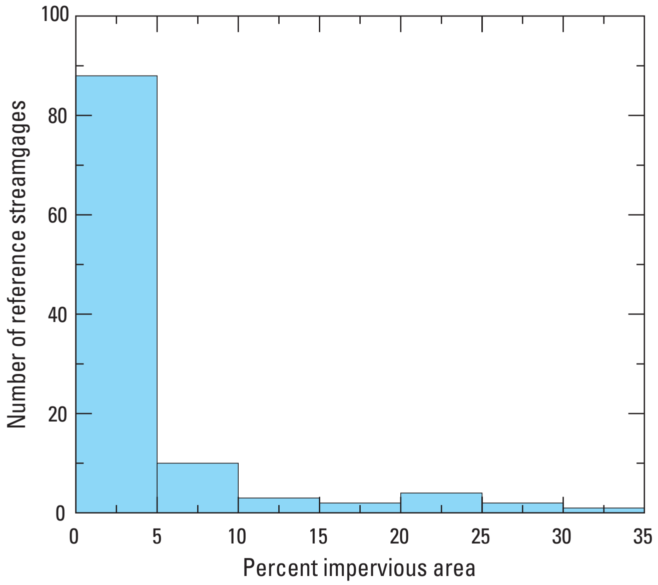


Figure 4. Histogram showing percent impervious area in the reference streamgage subbasins within the Delaware River Basin.

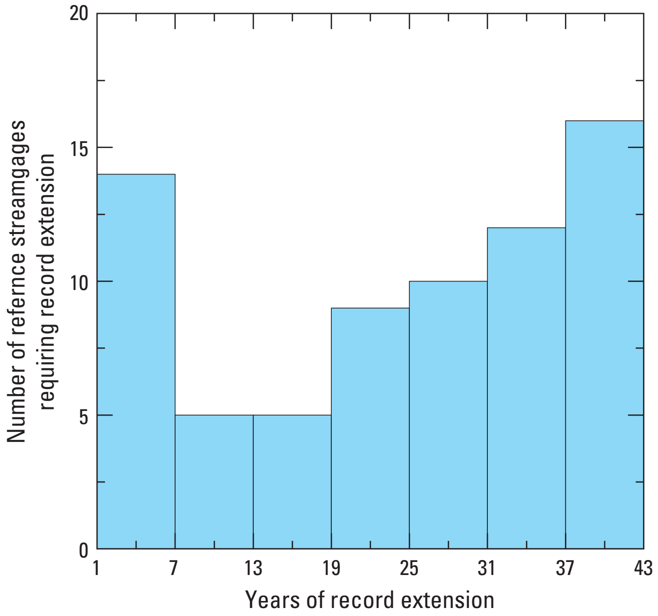


Figure 5. Histogram showing the number of reference streamgages requiring record extension and the number of years of record extension, Delaware River Basin.

The methodology used for the SREF relies on the assumption that long-term streamflow records from hydrologically similar streamgages can be used to estimate missing record for 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 the 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, 2002). The MOVE.1 method (Hirsch, 1982) was used for this analysis.

The daily mean 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 applies a streamflow-recession constant beginning with the last nonzero streamflow value prior to the zero-flow sequence. This option was selected for the analysis of the reference streamgages to avoid imposing an arbitrary constant flow value over a potentially substantial period of low-flow values that would result in a flat line hydrograph for streamgages at their zero-flow threshold. A recession constant of 0.9 was selected on the basis of prior sampling of low-flow recession rates in Pennsylvania (Stuckey and others, 2014).

The streamgages used to extend the record of a streamgage with an incomplete period of record during WY 1960–2010 are termed “index streamgages.” Ten years was considered the minimum streamflow record length for an acceptable application of MOVE.1. A maximum of three streamgages was used for record extension to cover the incomplete study period (Appendix 1). Selection of index streamgages was based on period of available concurrent record, strength of correlation, and distribution of LOC residuals (Granato, 2009). Record prior to 1960 was used when necessary to establish the relation between streamgages with an incomplete period of record and the index streamgage. The concurrent records were evaluated graphically and statistically using correlation to ensure a good fit between the index streamgage and a streamgage with an incomplete period of record. Record extension correlations ranged from 0.742 to 0.988, with a mean of 0.894. A maximum correlation of 1.0 indicates a perfect linear relation. A listing of streamgages with record extension techniques applied is provided in Appendix 1.

Regression Equations for Estimating Streamflow at Flow-Duration Exceedance Probabilities

Regression equations were developed for 22 percentiles along the FDC using observed streamflow data from reference streamgages in and near the Delaware River Basin from the beginning of observed record through WY 2010. Values for basin characteristics with possible effects on a range of streamflows, 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 unaltered flow. The observed exceedance probability discharges (dependent variable) were related to the basin characteristics (independent or explanatory variables) using regression techniques.

Flow-Duration Exceedance Probabilities and Basin Characteristics for Reference Streamgages

Daily streamflow values for the selected reference streamgages were retrieved from the National Water Information System web application (NWISWeb) (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 governing equations and statistical methods utilized in MkPP are documented by Granato (2009). The Weibull plotting position option was used. Only the period of record for observed unaltered flow at the reference streamgage was used to compute the exceedance probabilities for use in the regression analysis. No extended streamflow record was used to compute the exceedance probabilities.

A list of 43 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 2). 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. National datasets were emphasized and utilized whenever available to limit issues pertaining to State and local boundaries.

Regression Analysis and Resulting Flow-Duration Exceedance Probability Regression Equations

The exceedance probability discharges for observed streamflows were related to basin characteristics using exploratory ordinary least squares (OLS) and weighted least squares (WLS) regression techniques. The exceedance probabilities associated with each reference streamgage were weighted using the following expression for the WLS regression techniques to account for differing periods of record: *(number of years of record at streamgage*number of streamgages)/sum of years of record of all streamgages*. Regression analyses were performed using the statistical package Spotfire S+ (TIBCO Software Inc., 2008). Regression diagnostics used to evaluate the resulting regressions included graphical relations, multicollinearity, prediction error sum of squares (PRESS) statistic, standard error, and coefficient of determination (R^2) (Helsel and Hirsch, 2002).

Streamflow data from reference streamgages in and near the Delaware River Basin were used to develop regression equations for estimating the 1-, 2-, 5-, 10-, 15-, 20-, 25-, 30-, 40-, 50-, 60-, 70-, 75-, 80-, 85-, 90-, 95-, 98-, and 99-percent exceedance probability discharges (designated as P1, P2, P5, P10, P15, P20, P25, P30, P40, P50, P60, P70, P75, P80, P85, P90, P95, P98, and P99, respectively). Two additional regression equations were developed for the 0.0054- and 99.9946-percent flow-duration exceedances (P0.0054 and P99.9946, respectively) to represent the ends of the FDC for the period from 1960 to 2010 (51 years), and an equation was developed for the 99.95-percent flow-duration exceedance (P99.95) to further define the low end of the FDC. Because only observed data were used in the regression analysis and those extreme exceedances require additional years of record (data points) to compute, the streamgages used to develop the regression equations for the lower and upper ends of the FDC were limited to those with at least 51 years of record. As a result, 40 streamgages had a sufficient period of record, regardless of whether this period was contained within the study period, and were used to develop regression equations for estimating the P0.0054, P99.9946, and P99.95 exceedance probability discharges.

Outliers and streamgages with high leverage and (or) influence were removed from an individual regression analysis only if sufficient data or information were found to support the removal of the streamgages, such as high water use in the basin (including withdrawals and discharges), basin characteristic or streamflow values well outside the normal or expected range for that variable, or poor or estimated daily streamflow computations during low- or high-flow periods. Three streamgages with a P99.9946 exceedance probability discharge equaling zero and one streamgage with a P99.95 exceedance probability discharge equaling zero were excluded from the regression analysis for those particular exceedance probabilities.

During exploratory regression analysis, regression models were developed for the entire basin using different regions that were based on physiographic province, hydrologic unit code (HUC) 8 boundaries, and residual standard errors. The results of these models were then compared to each other using standard errors, coefficient of determination (R^2), residuals, PRESS statistic, and other regression diagnostics. Insufficient data were available, owing to the small number of streamgages in some physiographic provinces, to develop robust regression models by region that would have adequately predicted streamflows for all 22 exceedance probabilities, even when some physiographic provinces were combined to make larger regions. The basin-wide regression model

Table 2. Basin characteristics used in the development of regression equations for flow-duration exceedance probabilities for streams in the Delaware River Basin.

[>, greater than]

Variable	Source	Reference	Unit
Drainage area	Digital Elevation Model (DEM)	Gesch and others (2002)	Square miles
Basin slope	Digital Elevation Model (DEM)	Gesch and others (2002)	Degrees
Channel slope	Digital Elevation Model (DEM)	Gesch and others (2002)	Feet/mile
Mean basin elevation	Digital Elevation Model (DEM)	Gesch and others (2002)	Feet
Maximum basin elevation	Digital Elevation Model (DEM)	Gesch and others (2002)	Feet
Shape factor	Digital Elevation Model (DEM)	Gesch and others (2002)	Unitless
Percent of basin >1,200	Digital Elevation Model (DEM)	Gesch and others (2002)	Percent
Soil thickness	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Feet
Sand in soil	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Percent
Clay in soil	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Percent
Hydrologic group A	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Percent
Hydrologic group B	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Percent
Hydrologic group C	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Percent
Hydrologic group D	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Percent
Percent coarse fragments	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Percent
Poorly drained	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Percent
Well drained	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Percent
Saturated hydraulic conductivity	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Micrometers/second
Till/glacial	Soil Survey Geographic dataset (SSURGO)	Soil Survey Staff, Natural Resources Conservation Service	Percent
Mean annual precipitation	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2010	Daly and others (1994)	Inches
Winter mean precipitation (Dec., Jan., Feb.)	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2010	Daly and others (1994)	Inches
Spring mean precipitation (Mar., Apr., May)	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2010	Daly and others (1994)	Inches
Summer mean precipitation (June, July, Aug.)	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2010	Daly and others (1994)	Inches
Fall mean precipitation (Sep., Oct., Nov.)	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2010	Daly and others (1994)	Inches

Table 2. Basin characteristics used in the development of regression equations for flow-duration exceedance probabilities for streams in the Delaware River Basin.—Continued

[>, greater than]

Variable	Source	Reference	Unit
Low-flow season precipitation (July, Aug., Sep.)	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2015	Daly and others (1994)	Inches
Mean annual temperature	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2016	Daly and others (1994)	Degrees Fahrenheit
Mean daily maximum temperature	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2017	Daly and others (1994)	Degrees Fahrenheit
Winter mean temperature (Dec., Jan., Feb.)	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2018	Daly and others (1994)	Degrees Fahrenheit
Spring mean temperature (Mar., Apr., May)	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2019	Daly and others (1994)	Degrees Fahrenheit
Summer mean temperature (June, July, Aug.)	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2020	Daly and others (1994)	Degrees Fahrenheit
Fall mean temperature (Sep., Oct., Nov.)	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2021	Daly and others (1994)	Degrees Fahrenheit
Low-flow season temperature (July, Aug., Sep.)	Parameter-elevation Regressions on Independent Slopes Model (PRISM) 1981–2022	Daly and others (1994)	Degrees Fahrenheit
Imperviousness	National Land Cover Dataset 2006 (NLCD 2006)	Fry and others (2011)	Percent
Forested area (classes 41, 42, 43)	National Land Cover Dataset 2006 (NLCD 2006)	Fry and others (2011)	Percent
Evergreen (class 42)	National Land Cover Dataset 2006 (NLCD 2006)	Fry and others (2011)	Percent
Urban (classes 23, 24)	National Land Cover Dataset 2006 (NLCD 2006)	Fry and others (2011)	Percent
Developed (classes 21, 22, 23, 24)	National Land Cover Dataset 2006 (NLCD 2006)	Fry and others (2011)	Percent
Open water (class 11)	National Land Cover Dataset 2006 (NLCD 2006)	Fry and others (2011)	Percent
Storage (classes 11, 90, 95)	National Land Cover Dataset 2006 (NLCD 2006)	Fry and others (2011)	Percent
Longitude at outlet			Decimal degrees
Latitude at outlet			Decimal degrees
Longitude at centroid			Decimal degrees
Latitude at centroid			Decimal degrees

performed as well as, if not better than, the other regionalization models generated during the exploratory analysis, and it was used to develop the suite of 22 exceedance probability regression equations. WLS was used to generate the final basin-wide regression equations.

The following independent variables were found to be significant at the 95-percent confidence level for one or more regression equations: latitude at the outlet, drainage area, mean annual precipitation (1981–2010), mean winter precipitation (December–February; 1981–2010), saturated hydraulic conductivity, and percentages of poorly drained soil and sand in soil (table 3). The values for basin characteristics associated with the streamgages used in the analysis are listed in Appendix 2. 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, a value of 1.0 was added to the decimal form of the percentages of poorly drained soil and sand in soil before the variables were log transformed.

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

$$\begin{aligned} Log\widehat{Q}_p &= A + bLogDA + cLogLat + dLogPPT.ANN \\ &+ eLogPPT.WIN + fLog\left(1+.01*POOR\right) \\ &+ gLog\left(1+.01*SAND\right) + hLog\left(KSAT\right) \end{aligned} \tag{1}$$

or in arithmetic space:

$$\begin{aligned} \widehat{Q}_p &= 10^A \left(DA\right)^b \left(Lat\right)^c \left(PPT.ANN\right)^d \left(PPT.WIN\right)^e \\ &\left(1+.01*POOR\right)^f \left(1+.01*SAND\right)^g \left(KSAT\right)^h \end{aligned} \tag{2}$$

where

Log = log to base 10;
$\widehat{Q}_p$ = discharge at flow-duration exceedance probability, in cubic feet per second (ft^3/s);
A = the intercept, estimated by WLS;
DA = drainage area, in square miles;
Lat = latitude of the outlet of the basin, in decimal degrees;
$PPT.ANN$ = mean annual precipitation, in inches;
$PPT.WIN$ = mean winter precipitation, in inches;
$POOR$ = poorly drained soil, in percent;
$SAND$ = sand in soil, in percent;
$KSAT$ = saturated hydraulic conductivity, in micrometers per second; and
$b, c, d, e, f,$ $g,$ and h = independent variable coefficients of regression estimated by WLS.

The coefficients for the resulting regression equations are listed in table 3. All basin characteristic coefficients were checked for continuity issues and expected effect on flow. Generally, the coefficients did not have any continuity issues, except where changes occurred to the suite of regressions or where exceedances were closer together than elsewhere along the FDC. These continuity issues did not appear to affect the performance of the regressions. All basin characteristic coefficients reflected expected signage, and resulting changes to streamflow were reasonable. For example, as the percentage of poorly drained soil increased, discharge decreased for low and medium flows; for high flows, as the percentage of poorly drained soil increased, discharge also increased. This is because for low and medium flows, water infiltrating through the poorly drained soils is hindered from entering the groundwater, which would result in a lower base-flow contribution to the stream. During high flows, the poorly drained soil acts as an impervious surface, increasing overland flow and runoff, which would result in higher streamflows.

Flow-duration exceedance probability discharges computed from streamflow data (observed) and regression equations (predicted) for streamgages used in the regression analysis are listed in Appendix 3. The predicted exceedance probability discharges computed from the regression equations for the reference streamgages were checked for continuity, and no issues or problems were found.

Standard errors of prediction (Helsel and Hirsch, 2002) for regression equations provide an estimate of reliability of the predicted variable, in this case, streamflow at 22 exceedance probabilities (table 3). The standard error of prediction is a measure of the average accuracy of the regression equations when predicting values for ungaged stream locations; about two-thirds of the regression estimates for ungaged stream locations will have errors less than the average standard errors of prediction given for the equations (Ries, 2007). The standard error of prediction for the flow-duration exceedance probability regression equation ranges from 0.05 to 0.30 in log units (11 percent to 79 percent; table 3); median and mean standard error over the entire suite of flow-duration equations is 24 and 32 percent, respectively. The regression equations used to estimate the lower ends of the FDC have the highest errors; the extreme low-flow exceedance probability of P99.9946 has an error of 79 percent, and P99.95 and P99 have errors of 69 percent and 64 percent, respectively. Regressions to estimate extreme low-flow statistics typically have higher associated errors because low flows are dependent on multifaceted factors such as underlying geology and evapotranspiration, which can be difficult to capture as independent parameters in a regression model.

The coefficient of determination (R^2) provides a way to estimate the uncertainty associated with the regression. For example, the R^2 for P60 is 0.98, indicating the basin characteristics selected for use in the P60 regression equation accounted for 98 percent of the variability in streamflow for the 60-percent exceedance value (table 3). A lower R^2 for P99.9946 (0.81) indicates that other variables may help to better define this extreme low-flow prediction. Multicollinearity between the basin characteristics was evaluated for significance in each regression equation using variance inflation factor (VIF) and correlation. The maximum VIF between the independent variables is 1.5, and the maximum correlation is 0.5, indicating no issues with multicollinearity.

Table 3. Regression coefficients for use with flow-duration exceedance probability regression equations for streams in the Delaware River Basin.

[--, not applicable]

Flow-duration exceedance probability	Intercept	Basin characteristic coefficients							Coefficient of determination (R^2)	Standard error of prediction	
		Drainage area (square miles)	Latitude at outlet (decimal degrees)	Mean annual precipitation (inches)	Mean winter precipitation (inches)	Poorly drained soil (percent)	Sand in soil (percent)	Saturated hydraulic conductivity (micrometers/second)		Log units	Percent
P99.9946	-4.3959	1.1307	--	--	4.5049	-4.3049	--	0.5645	0.81	0.30	79
P99.95	-4.1035	1.1029	--	--	4.1949	-4.0969	--	0.5835	0.83	0.27	69
P99	33.2029	1.1222	-26.2694	4.6408	--	-5.0778	2.1644	--	0.87	0.25	64
P98	32.8459	1.1007	-25.6730	4.3760	--	-4.7792	1.8673	--	0.89	0.23	57
P95	28.7833	1.0832	-22.7789	4.1294	--	-4.0698	1.6034	--	0.91	0.19	48
P90	23.2624	1.0675	-18.9841	3.8737	--	-3.5848	1.4931	--	0.93	0.17	41
P85	18.3160	1.0608	-15.6972	3.7318	--	-3.1822	1.4620	--	0.94	0.15	37
P80	13.6808	1.0579	-12.5158	3.4956	--	-2.7438	1.3804	--	0.95	0.14	33
P75	9.4482	1.0524	-9.6371	3.3041	--	-2.4207	1.3624	--	0.96	0.12	29
P70	6.1189	1.0443	-7.2406	3.0352	--	-2.1952	1.3583	--	0.97	0.11	27
P60	2.3600	1.0313	-4.3327	2.5920	--	-1.8559	1.0845	--	0.98	0.09	21
P50	-1.7188	1.0295	-1.4696	2.3424	--	-1.4160	1.0029	--	0.98	0.08	19
P40	-5.4898	1.0312	1.1582	2.1301	--	-1.0043	0.9059	--	0.99	0.07	17
P30	-9.8871	1.0337	4.1007	1.9550	--	-0.6564	1.1918	--	0.99	0.07	16
P25	-11.3858	1.0326	5.1642	1.8740	--	-0.4601	1.0580	--	0.99	0.06	15
P20	-12.8310	1.0336	6.1718	1.8212	--	-0.2563	0.8658	--	0.99	0.06	13
P15	-14.0886	1.0277	7.0563	1.7975	--	-0.0051	0.5907	--	0.99	0.05	12
P10	-14.5510	1.0159	7.5043	1.7536	--	0.2450	0.1710	--	0.99	0.05	11
P5	-13.7837	0.9881	7.3916	1.6065	--	0.5542	-0.6415	--	0.99	0.05	13
P2	-12.5259	0.9564	6.9088	1.5536	--	0.9765	-1.5405	--	0.98	0.08	18
P1	-11.6455	0.9442	6.5207	1.5436	--	1.2985	-2.0901	--	0.98	0.09	21
P0.0054	-1.0797	0.9347	--	2.0318	--	--	-2.3815	--	0.92	0.15	37

Selection of Reference Streamgages for Estimating Daily Mean Streamflow

An important consideration in applying the QPPQ method is the selection of a reference streamgage. A traditional approach has been to select the closest streamgage to the ungaged stream location as the representative reference gage. Choosing the closest streamgage as the most appropriate reference streamgage is based on the assumption that similarity in the conditions determining streamflow increases with decreasing distance between two locations (Stuckey and others, 2014). However, there are instances where conditions at the closest streamgage are neither physically nor hydrologically similar to those at the ungaged stream location. Map correlation based on kriging is an alternative to using the closest reference streamgage (Archfield and Vogel, 2010). These methods for selecting a reference streamgage were compared using observed streamflow correlations to indicate what the “best,” or most appropriate representative reference streamgage should be.

Closest Streamgage

The closest reference streamgage approach was evaluated to determine how successful the method was in selecting the reference streamgage with streamflows most highly correlated to those of the ungaged stream location. The closest reference streamgage was defined as the streamgage with the shortest distance from the centroid of the basin of the reference streamgage to the outlet of the ungaged stream location; this method was found to perform best in Pennsylvania by Stuckey and others (2014). Observed streamflow correlations using Spearman’s rho were calculated among the 86 streamgages within the Delaware River Basin to evaluate whether using the closest streamgage identifies the most appropriate, or best, streamgage. The reference streamgage with the highest observed correlations and shortest distance to the ungaged stream location was the same 48 percent of the time, and 94 percent of the time, the closest streamgage was in the top five streamgages.

Map Correlation

Map correlation is a geostatistical approach to selecting a reference streamgage where streamflow exhibits the strongest correlation with streamflow at an ungaged stream location. First, each reference streamgage is assigned a unique map of correlation estimates developed from a model of the spatial correlation structure, or variogram, between it and all other available reference streamgages in and near the Delaware River Basin (fig. 6). Ordinary kriging (Isaaks and Srivastava, 1989) is used to estimate the predicted correlation at the ungaged stream location.

Selection of the most appropriate representative reference streamgage is accomplished using the map correlation method by choosing the streamgage whose map has the highest estimated correlation coefficient at the coordinates of the ungaged stream 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 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. 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.

Variogram models were developed for 109 reference streamgages in and near the Delaware River Basin with minimally altered streamflow and at least 10 years of continuous record during WY1960–2010. In an attempt to minimize subjectivity, the variogram models were developed in the Free R Software (http://www.r-project.org/) using default automated parameter estimation. The spherical variogram model was used to describe the spatial structure within the correlation of daily streamflow. Spearman’s rho, a non-parametric rank-based correlation coefficient, was used to define the correlation between the reference streamgages. Stuckey and others (2014) found that Spearman’s rho performed as well as if not better than Kendall’s tau in two pilot basins in Pennsylvania. All reference streamgage correlations used in the variogram development were significant at the 0.05 level.

Map correlation results were evaluated to determine how accurately map correlation reproduced the correlation coefficient for the reference streamgages and how often the streamgage with the highest estimated correlation was the same as the streamgage with the highest observed correlation. Observed and estimated correlations among streamgages were compared for goodness of fit to evaluate the effectiveness of the map correlation model. Root mean square error (RMSE) values between the observed and estimated streamflow correlations were computed for each of the streamgages using observed and estimated correlations. RMSE values ranged from 0.031 to 0.081 with a median value of 0.048 (fig. 7). When plotted spatially (fig. 7), the highest RMSE values (values within the upper quartile range) were generally in the northern and central parts of the basin, whereas the lowest RMSE values were found in south-central part of the basin. This does not necessarily dictate how map correlation overall will perform, but shows how well the correlation coefficient at each reference streamgage was reproduced. The correlations for the 86 streamgages within the Delaware River Basin were also evaluated to determine whether the same streamgage had the highest observed and estimated correlations. Streamgages had the highest observed and estimated correlations 30 percent of the time, and streamgages with the highest observed correlation were within the top five estimated correlations 80 percent of the time. Although these percentages are lower than those found using the closest streamgage, variations of the correlation coefficients for many streamgages with the highest correlations were quite small, on the order of magnitude 0.001.

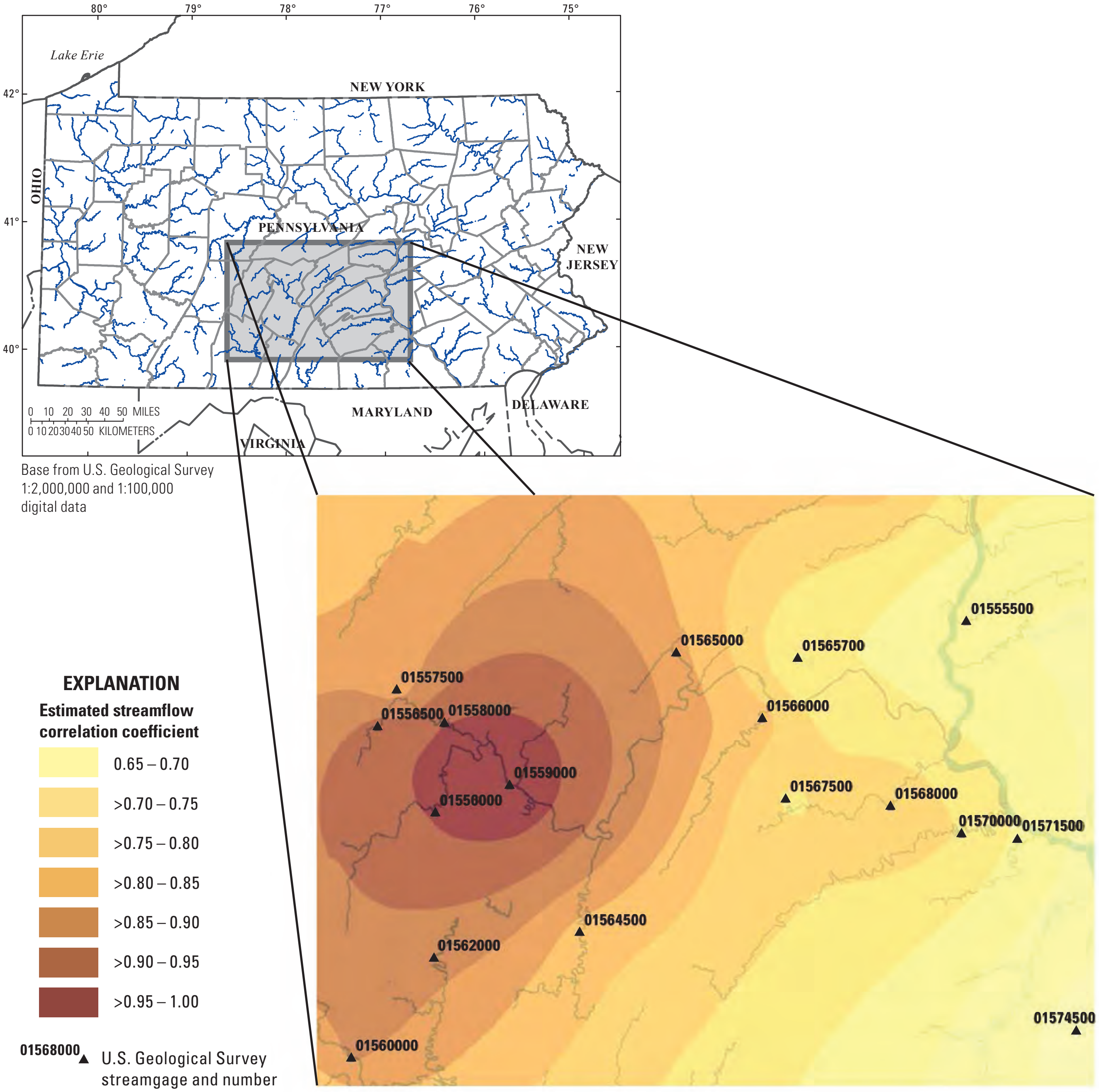
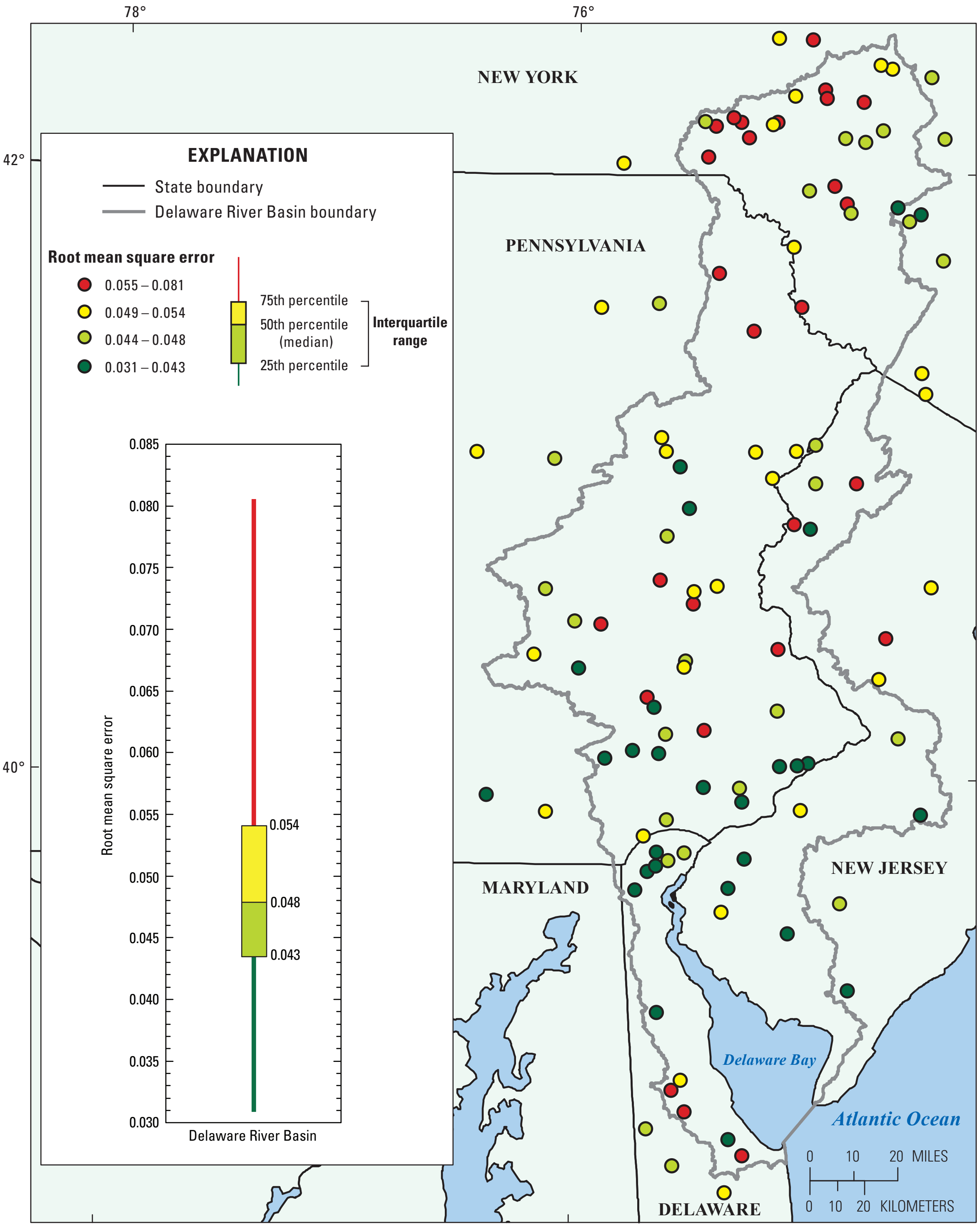


Figure 6. Example streamflow correlation map for U.S. Geological Survey streamgage 01559000, Juniata River at Huntingdon, Pa. (from Stuckey and others, 2014).



Base modified from U.S. Geological Survey 1:100,000-scale and 1:250,000-scale digital data

Figure 7. Distribution of root mean square error between the observed and estimated streamflow correlations, resulting from map correlation, for 109 streamgages in and near the Delaware River Basin.

Estimation of Altered Daily Mean Streamflow

Streamflow is a source of drinking water supply for more than 15 million people in the Delaware River Basin. Other water uses also affect the amount of water flowing in the streams in the basin on any given day. Estimated baseline daily mean streamflow generated using the QPPQ method for the Delaware River Basin was adjusted using compiled water use information to reflect current, or altered, conditions. Withdrawals were compiled and reviewed for accuracy by water use category as part of the National Water Census (Susan Hutson, U.S. Geological Survey, oral commun., 2013). The categories of withdrawals are water supply, self-supplied domestic, industrial, irrigation, livestock, mining, power/hydroelectric, remediation, sewage treatment, aquaculture, commercial, and thermoelectric. More information on the types of water use categories is presented in Hutson and others, in press. Return flows were not categorized by sector because of insufficient information. The water use data were compiled for all states within the Delaware River Basin for 2010. In addition, water use data were compiled for each year from 2005 through 2010 for the parts of the Delaware River Basin within Pennsylvania and New Jersey. Estimated daily mean streamflows were adjusted to incorporate water use using average withdrawals and returns, by month rather than annually, to capture seasonal and monthly variation in water use.

Use of DRB-SET for Estimating Baseline and Altered Daily Mean Streamflow at Ungaged Stream Locations

DRB-SET is a tool for simulating streamflow at a daily time step for an ungaged stream location in the Delaware River Basin for WY 1960–2010. DRB-SET is a user friendly and time saving tool used to assist water-resource managers in determining water allocation, ecological flow, and water for human-health needs. DRB-SET is modeled after the BaSE (Stuckey and others, 2014) and MASYE (Archfield and others, 2010) and is 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 basin characteristic information, reference streamgage information, baseline and altered daily mean streamflow, mean and median streamflow statistics, FDCs, and hydrographs.

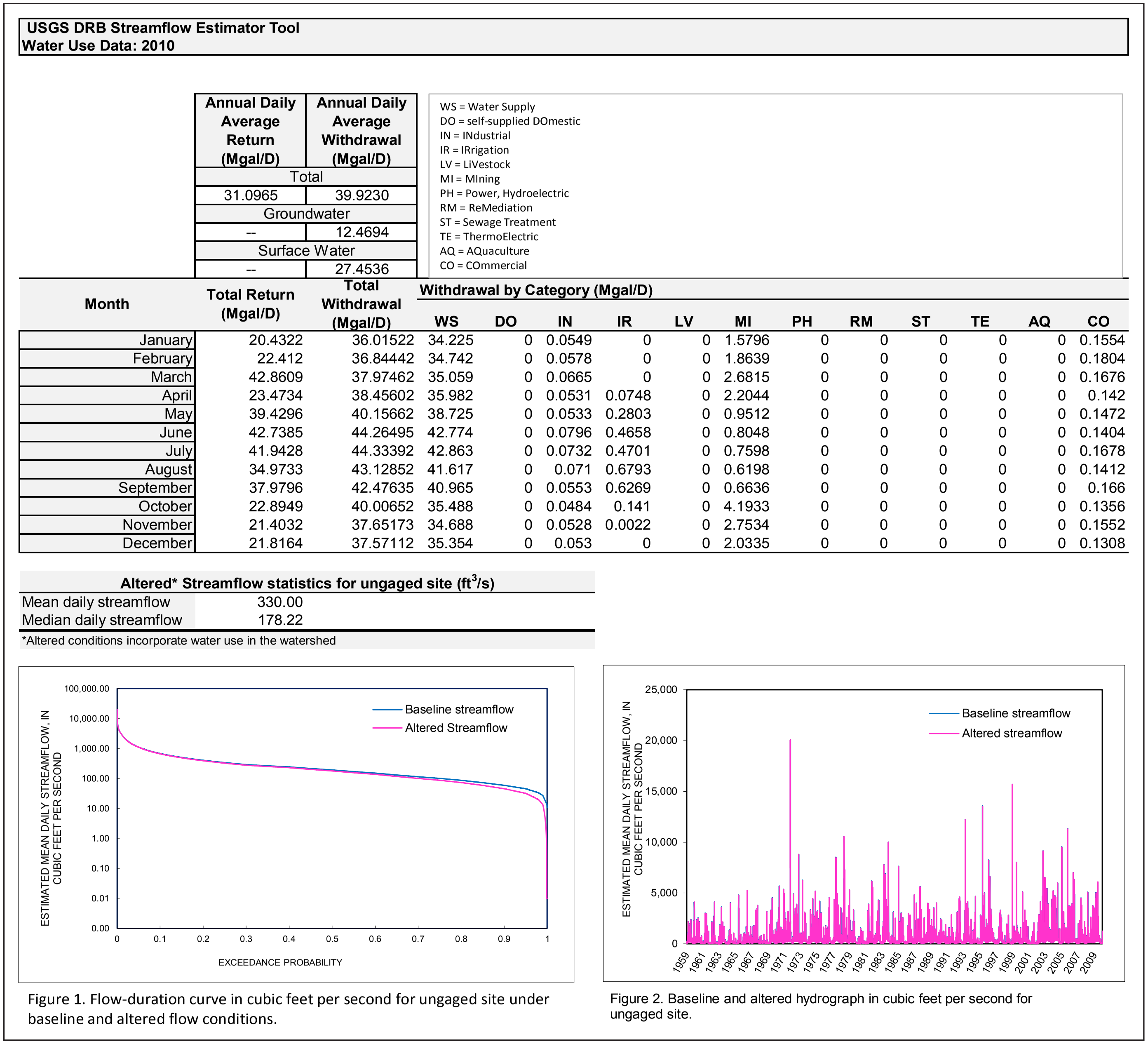
Within DRB-SET the user can utilize an interactive map to select a location of interest (the ungaged stream location). Basin characteristic information for the ungaged stream location can be obtained from the interactive map through StreamStats Web services (Ries and others, 2008) or entered manually. By default, DRB-SET selects an appropriate reference streamgage for a user-entered ungaged stream location by maximizing the estimated streamflow correlation (map correlation). The user has the option of manually selecting a different reference streamgage or using the closest reference streamgage to the ungaged stream location. After the initial information is entered into DRB-SET, the Compute Daily Streamflows function computes the baseline and altered (based on water use in the basin, if applicable) daily mean streamflows for the ungaged stream location for WY 1960–2010. Any altered streamflow incorporates compiled upstream water use into the baseline daily streamflow for the basin by subtracting any withdrawals and adding any return flows.

A report output file, in the form of a Microsoft Excel® spreadsheet, is generated and summarizes the reference streamgage and ungaged stream location information, including basin characteristics and percent difference in basin characteristics between the two locations (fig. 8). Mean and median statistics are computed for the ungaged stream location. FDCs and hydrographs are presented for the ungaged stream location in cubic feet per second (ft^3/s) and cubic feet per second per square mile [$(ft^3/s)/mi^2$]. The water use within the basin (if any) is summarized by category in the Water Use report. The estimated daily flows for the ungaged stream location, both baseline and altered, 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 information and detailed instructions on the use of DRB-SET can be found in Stuckey and Ulrich, in press.

Accuracy and Limitations of Estimated Streamflow

Accuracy of estimated daily streamflows for ungaged stream locations is dependent on the uncertainties associated with the multiple steps that compose the overall process. Stuckey and others (2014) outlined the following steps: measurement of streamflow at reference streamgages, streamflow record extension at reference streamgages, estimation of the streamflow for an ungaged stream location on the basis of regression equations, the use of basin characteristics outside the range used to develop the equations, selection of a reference streamgage using the map correlation method, and transfer of exceedance probabilities from the reference streamgage to the ungaged stream location.

The accuracy of measured streamflow data depends on several factors, including the stability of the stage-discharge relation, accuracy of measurements of discharge, and interpretation of streamflow records. Records are rated as excellent, good, fair, or poor. These ratings specify that 95 percent of the daily discharges are within 5 percent (excellent), 10 percent (good), or 15 percent (fair) of their true values. The accuracy of measured streamflow data is documented for each reference



USGS DRB Streamflow Estimator Tool
Water Use Data: 2010

Annual Daily Average Return (Mgal/D)	Annual Daily Average Withdrawal (Mgal/D)
Total	
31.0965	39.9230
Groundwater	
--	12.4694
Surface Water	
--	27.4536

WS = Water Supply
DO = self-supplied DOmestic
IN = INdustrial
IR = IRrigation
LV = LiVestock
MI = MIning
PH = Power, Hydroelectric
RM = ReMediation
ST = Sewage Treatment
TE = ThermoElectric
AQ = AQuaculture
CO = COmmercial

Month	Total Return (Mgal/D)	Total Withdrawal (Mgal/D)	Withdrawal by Category (Mgal/D)											
			WS	DO	IN	IR	LV	MI	PH	RM	ST	TE	AQ	CO
January	20.4322	36.01522	34.225	0	0.0549	0	0	1.5796	0	0	0	0	0	0.1554
February	22.412	36.84442	34.742	0	0.0578	0	0	1.8639	0	0	0	0	0	0.1804
March	42.8609	37.97462	35.059	0	0.0665	0	0	2.6815	0	0	0	0	0	0.1676
April	23.4734	38.45602	35.982	0	0.0531	0.0748	0	2.2044	0	0	0	0	0	0.142
May	39.4296	40.15662	38.725	0	0.0533	0.2803	0	0.9512	0	0	0	0	0	0.1472
June	42.7385	44.26495	42.774	0	0.0796	0.4658	0	0.8048	0	0	0	0	0	0.1404
July	41.9428	44.33392	42.863	0	0.0732	0.4701	0	0.7598	0	0	0	0	0	0.1678
August	34.9733	43.12852	41.617	0	0.071	0.6793	0	0.6198	0	0	0	0	0	0.1412
September	37.9796	42.47635	40.965	0	0.0553	0.6269	0	0.6636	0	0	0	0	0	0.166
October	22.8949	40.00652	35.488	0	0.0484	0.141	0	4.1933	0	0	0	0	0	0.1356
November	21.4032	37.65173	34.688	0	0.0528	0.0022	0	2.7534	0	0	0	0	0	0.1552
December	21.8164	37.57112	35.354	0	0.053	0	0	2.0335	0	0	0	0	0	0.1308

Altered* Streamflow statistics for ungaged site (ft^3/s)	
Mean daily streamflow	330.00
Median daily streamflow	178.22

*Altered conditions incorporate water use in the watershed

Figure 1. Flow-duration curve in cubic feet per second for ungaged site under baseline and altered flow conditions.

Figure 2. Baseline and altered hydrograph in cubic feet per second for ungaged site.

Figure 8. Screen capture of an example report generated by the Delaware River Basin Streamflow Estimator Tool (DRB-SET) showing water use, a flow-duration curve, and a hydrograph.

streamgage in annual data reports (http://wdr.water.usgs.gov/) through WY2013. Most of the published streamflow records for the Delaware River Basin are rated good to fair.

Streamflow record extension introduces uncertainty to baseline streamflow estimates, which is difficult to quantify. Because the length of record requiring extension varied by streamgage (0 to 82 percent of the record), the uncertainty introduced into the overall record also varies. A general sense of the accuracy of these streamflow estimates can be obtained by observing the correlation coefficients. A maximum correlation of 1.0 indicates a perfect linear relation. In this study, correlation coefficients range from 0.742 to 0.988. The correlation coefficients are included in Appendix 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 the logarithm of streamflow at the reference streamgage is non-linear, the correlations are likely to decrease, and the associated uncertainties are likely to increase. 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.

Uncertainties in the constructed FDC for the ungaged stream locations consist of errors in the regression estimates of the streamflows at the 22 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 79 percent. The median and mean predictive errors are 24 and 32 percent, respectively. All other exceedance probabilities that are not predicted from regression equations are log-log interpolated.

DRB-SET relies on estimates of streamflow derived from regression equations and is not meant 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 4. The maximum percent impervious for watersheds to be used in DRB-SET generally should be less than 10 percent. For watersheds with percent imperviousness greater than this value, results from DRB-SET need to be evaluated very carefully before use. 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 DRB-SET also may not be valid.

The selection of a reference streamgage by map correlation affects the uncertainty in the 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 by map correlation, uncertainty is introduced into the daily exceedance probabilities for the ungaged stream 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. A comparison between streamflow estimates resulting from DRB-SET using map correlation and the closest streamgage method to select a reference streamgage was performed using NSE with the logs (base10) of the streamflow. A perfect match of modeled to the

Table 4. Range of basin characteristics used in the development of regression equations to estimate flow-duration exceedance probability discharges for ungaged stream locations within the Delaware River Basin.

Basin characteristic	Mean	Median	Minimum	Maximum
Latitude at outlet (decimal degrees)	40.760392	40.636665	38.638861	42.450968
Drainage area (square miles)	81.2	45.7	0.61	1,147
Mean annual precipitation (inches)	47.3	46.6	42.6	59.2
Mean winter precipitation (inches)	3.28	3.30	2.69	4.29
Poorly drained soil (percent)	7.06	4.26	0.00	47.8
Sand in soil (percent)	42.1	38.4	17.6	86.5
Saturated hydraulic conductivity (micrometers/second)	24.9	14.3	3.52	121

observed data would result in a NSE value of 1.0. The results are shown in figure 9. Both methods for selecting a reference streamgage produce streamflow estimates in good agreement with the observed streamflow; however, those resulting from map correlation perform slightly better, as indicated by more points falling below the line of equal NSE (fig. 9). Those points that fall on the line of equal NSE represent instances where both methods for selecting the best streamgage selected the same reference streamgage.

The median NSE values resulting from the use of map correlation and the closest gage are 0.85 and 0.83, respectively. The greatest discrepancy between the two methods is shown by streamgage 01426000, Oquaga Creek at Deposit, N.Y., with a drainage area 67.6 mi^2. The use of map correlation resulted in the selection of 01425675, Oquaga Creek near North Sanford, N.Y. (drainage area 4.69 mi^2) as the most representative reference streamgage with a NSE value of 0.87; the use of the closest gage resulted in the selection of 01425500, Cold Spring Brook at China, N.Y. (drainage area 1.50 mi^2) as the most representative reference streamgage with a NSE value of -0.27. In this example, the closest gage (01425500) is in a neighboring watershed, whereas the streamgage with the highest estimated correlation (01425675) is in the headwaters of the same watershed. Both streamgages are well outside the range of suggested drainage area ratios (Roland and Stuckey, 2008), however, the other basin characteristics for 01426000 and 01425675 are similar whereas some of the basin characteristics differ between 01426000 and 01425500 (Appendix 2). This difference in basin characteristics, especially percent of poorly drained soil, likely contributed to the lower NSE value seen with the use of the closest gage.

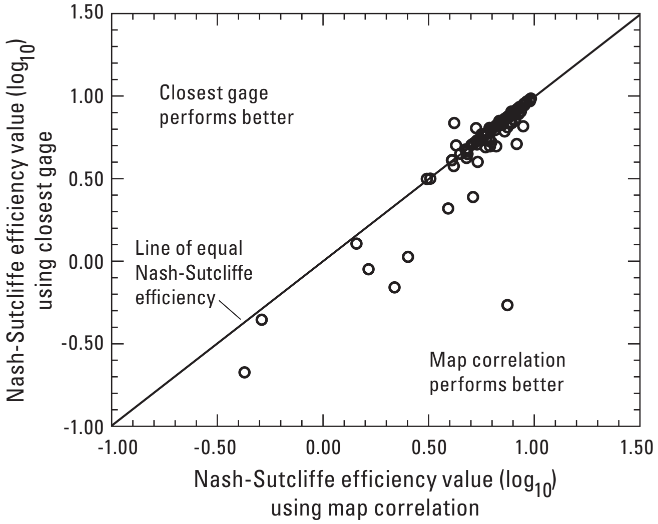


Figure 9. Nash-Sutcliffe efficiency values determined using the closest streamgage and map correlation in the Delaware River Basin Streamflow Estimator Tool.

The transfer of streamflow exceedance probabilities from a reference streamgage to an ungaged stream location using the QPPQ method relies on the assumption that both locations experience identical exceedance probabilities at identical times. Isolated storm events frequently occur that affect one subbasin but not other nearby subbasins. This is especially true when the ungaged subbasin has a much smaller or larger drainage area than the reference streamgage subbasin.

To evaluate how well DRB-SET estimates daily mean streamflow, a comparison of observed and estimated daily mean streamflows was performed for all the reference streamgages within the Delaware River Basin. The reference streamgages were run through DRB-SET as ungaged stream locations, and the estimated streamflow was compared to the observed using NSE ($\log_{10}$) values as a measure of goodness of fit. Reference streamgages were selected using the default map correlation method. NSE ($\log_{10}$) values ranged from 0.22 to 0.98 (median of 0.90) for the Upper Delaware River Basin and from -0.37 to 0.98 (median of 0.79) for the Lower Delaware River Basin (table 5 and fig. 10). The lowest NSE value (-0.37) is from 01466500, McDonalds Branch in Byrne State Forest, N.J., with a drainage area of 2.34 mi^2; the percent sand in soil is 86.5 percent, which is the maximum used in the overall analysis. The spatial distribution of the NSE values determined for each reference streamgage within the Delaware River Basin is shown in figure 11. Two of the three remaining reference streamgages with NSE values less than or equal to zero are located to the west of the Delaware Bay in Delaware and have small drainage areas (fig. 11). The final reference streamgage with an NSE value less than or equal to zero is located in the western part of the basin on the Tulpehocken Creek (fig. 11).

Hydrographs and FDCs generated from DRB-SET for streamgages 01420500, Beaver Kill at Cooks Falls, N.Y., and 01464500, Crosswicks Creek at Extonville, N.J., are shown in figures 12*A* and 12*B*, respectively. Streamgage 01420500 was associated with reference streamgage 01418500 with an estimated streamflow correlation (using map correlation) of 0.99, and streamgage 01464500 was associated with reference streamgage 01401000 with an estimated streamflow correlation (using map correlation) of 0.86 for estimates of daily mean flow. While both of these estimated streamflow correlations are fairly high, they represent the best (01420500) and worst (01464500) estimated streamflow correlations for reference streamgages with measured streamflow for WY 1960–2010. The low-flow period from WY 1998 to 2002 is shown in the hydrographs in figure 12. Although both hydrographs show good general fit between the estimated and observed streamflows, the hydrograph for 01464500 shows more variance, which is reflected in the lower NSE ($\log_{10}$) value of 0.59 in comparison to the NSE ($\log_{10}$) value of 0.98 associated with 01420500.

Table 5. Nash-Sutcliffe efficiency values between observed and estimated daily mean streamflows in the Delaware River Basin.

Location	Number of streamgages	Minimum Nash-Sutcliffe efficiency value ($\log_{10}$)	Maximum Nash-Sutcliffe efficiency value ($\log_{10}$)	Mean Nash-Sutcliffe efficiency value ($\log_{10}$)	Median Nash-Sutcliffe efficiency value ($\log_{10}$)
Upper Delaware River Basin	45	0.22	0.98	0.86	0.90
Lower Delaware River Basin	41	-0.37	0.98	0.72	0.79
Entire Delaware River Basin	86	-0.37	0.98	0.78	0.86
Outside Delaware River Basin	24	0.49	0.96	0.80	0.83

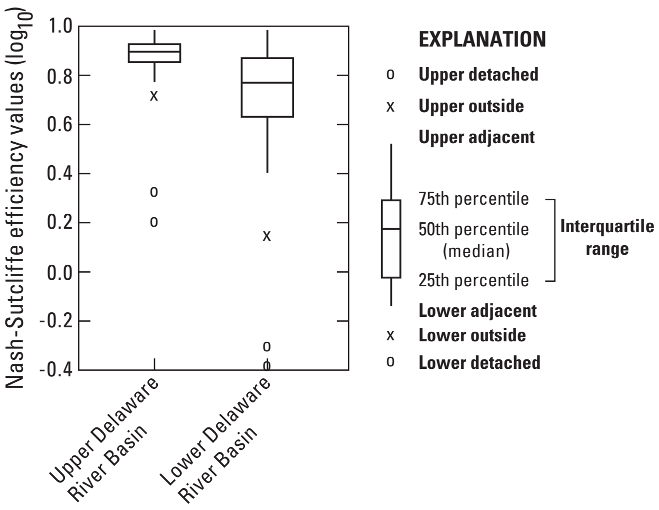
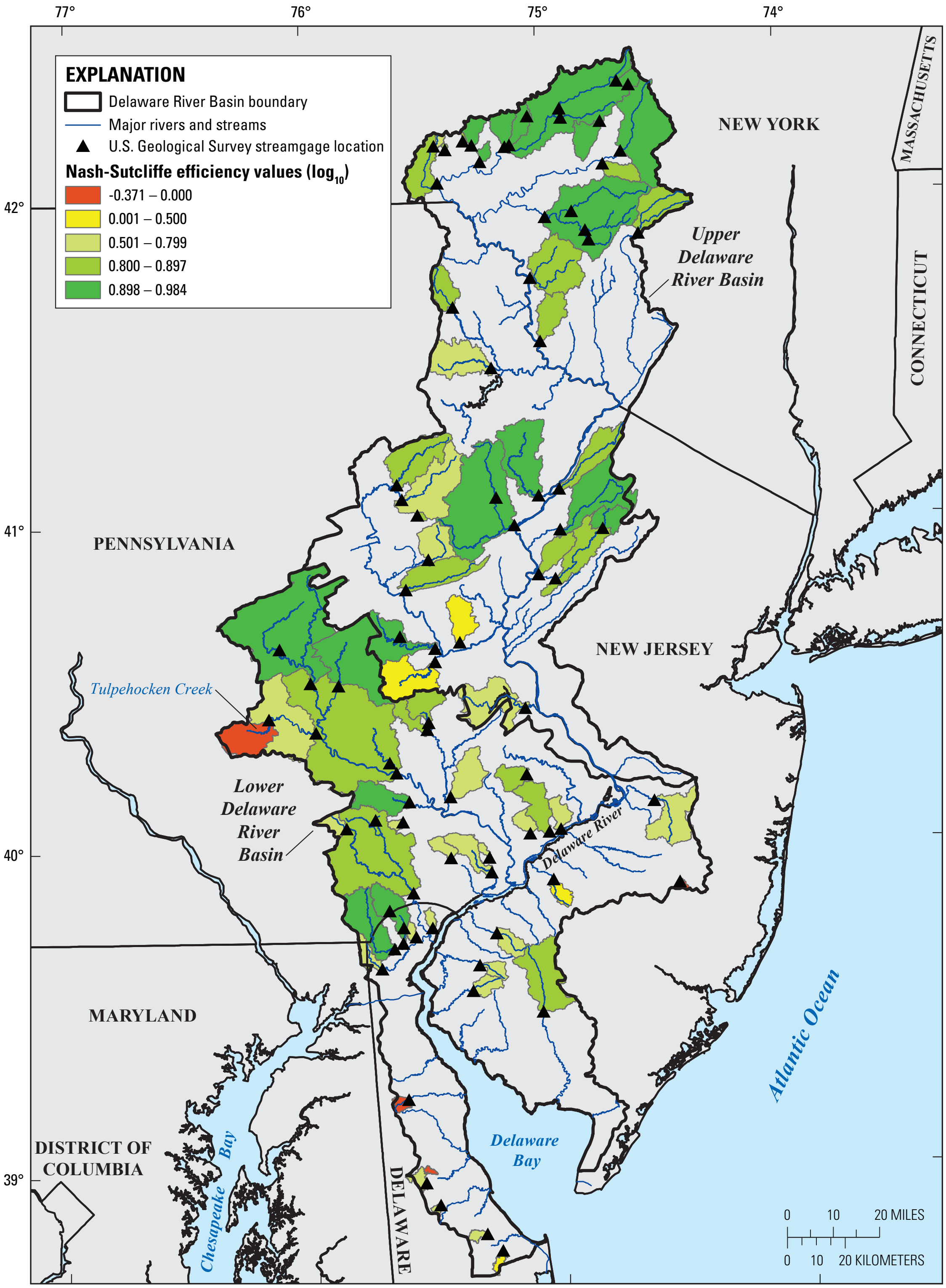


Figure 10. Distribution of Nash-Sutcliffe efficiency values between observed and estimated daily mean streamflows in the Upper and Lower Delaware River Basin.



Base modified from U.S. Geological Survey 1:100,000-scale
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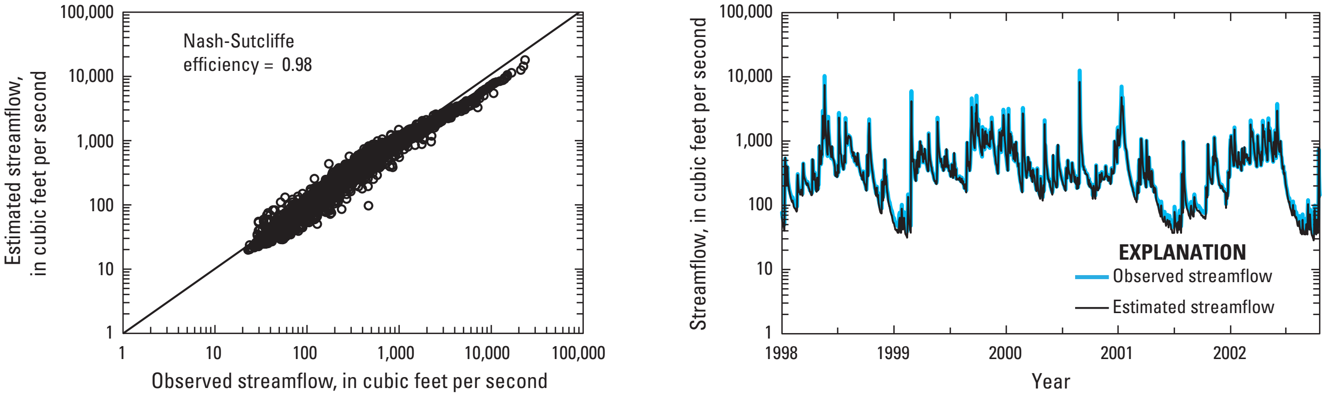
Figure 11. Spatial distribution of Nash-Sutcliffe efficiency values for reference streamgage basins in the Delaware River Basin.


***A.* 1420500 Beaver Kill at Cooks Falls, N.Y.**

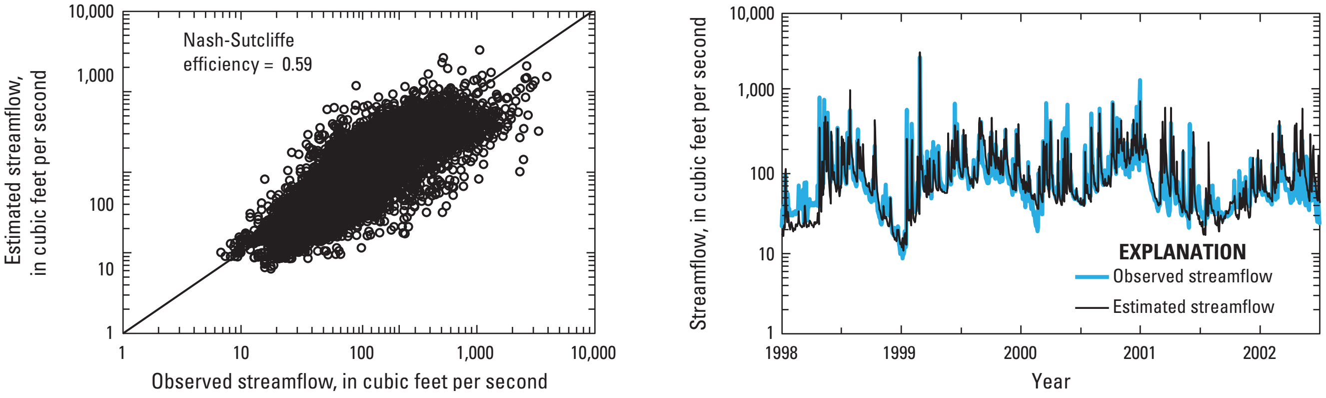

***B.* 1464500 Crosswicks Creek at Extonville, N.J.**

Figure 12. Estimated and observed daily mean streamflows for U.S. Geological Survey streamgages *A*, 01420500, Beaver Kill at Cooks Falls, New York, water years 1999–2002, and *B*, 01464500, Crosswicks Creek at Extonville, New Jersey, water years 1999–2002.

Summary

The Delaware River Basin encompasses more than 13,500 square miles in parts of four states—New York, New Jersey, Pennsylvania, and Delaware—and has a population of approximately 8.3 million. In the upper parts of the basin, concerns over the effects of new natural gas development and the freshwater requirements for a recently discovered endangered mussel species have added new complexities to water management in the basin. Hydrologic and ecological data can be directly related to provide the basis for understanding the flow needs of aquatic species found in the tributaries of the Delaware River Basin. Providing the data and tools to understand and define flow-alteration ecological-response relations will assist water-resource managers and policy makers in meeting the ecological flow needs of aquatic species in the Delaware River Basin.

The U.S. Geological Survey, through the National Water Census, has developed a tool to estimate streamflow at a daily time step for ungaged stream locations in the Delaware River Basin. The Delaware River Basin Streamflow Estimator Tool (DRB-SET) is a tool for simulating streamflow at a daily time step for an ungaged stream location in the Delaware River Basin for water years (WY) 1960–2010. Daily mean streamflow is estimated using the QPPQ method, which equates streamflow expressed as a percentile from the flow-duration curve (FDC) for a particular day at an ungaged stream location with the percentile from a FDC for the same day at a hydrologically similar location where streamflow is observed. Parameter-based regression equations were developed for 22 exceedance probabilities from the FDC for ungaged stream locations in the Delaware River Basin. Prediction errors for the 22 regression estimates ranged from 11 to 79 percent. Streamflow data from continuous-record streamgages were used to develop correlation maps of the predicted correlation of streamflow between an ungaged stream location and a reference streamgage. Water use data from 2010 were used to adjust the baseline daily mean streamflow generated from the QPPQ method at ungaged stream locations in the Delaware River Basin to reflect non-baseline conditions which may be affected by anthropogenic water usage.

To evaluate the effectiveness of the overall QPPQ method contained within DRB-SET, a comparison of observed and estimated daily mean streamflows was performed for 109 reference streamgages in and near the Delaware River Basin. The Nash-Sutcliffe efficiency (NSE) values were computed as a measure of goodness of fit; a maximum value of 1.0 would indicate a perfect match of modeled and observed data. The NSE values (using $\log_{10}$ streamflow values) ranged from 0.22 to 0.98 (median of 0.90) for the Upper Delaware River Basin and from -0.37 to 0.98 (median of 0.79) for the Lower Delaware River Basin.

The accuracy of estimated daily streamflows for ungaged stream locations is dependent on the uncertainties associated with the multiple steps that compose the overall process. These steps include measurement of streamflow at reference streamgages, streamflow record extension at reference streamgages, estimation of the FDC for an ungaged stream location on the basis of regression equations and basin characteristics, selection of a reference streamgage using the map correlation method, and transfer of exceedance probabilities from reference streamgage to the ungaged stream location.

Acknowledgments

The author thanks Martyn Smith of the U.S. Geological Survey (USGS) for providing assistance with the geographic information systems and StreamStats that was necessary for the completion of the project. The author also thanks Stacey Archfield, USGS, for her assistance in running the map correlations and her expertise in the QPPQ process. Other USGS colleagues also made substantive contributions: Jeffrey Fischer provided helpful feedback pertaining to the overall National Water Census and technical reviews were provided by Thomas Over and Mark Roland.

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Appendixes 1–3

Appendix 1. Reference streamgages with record extension techniques applied.

[USGS, U.S. Geological Survey]

USGS streamgage number	Name	Portion of record extended	Index station 1 (station number)	Correlation coefficient	Index station 2 (station number)	Correlation coefficient	Index station 3 (station number)	Correlation coefficient
01362200	Esopus Creek at Allaben, N.Y.	Oct. 1959–Sep. 1963	East Branch Delaware River at Margaretville, N.Y. (01413500)	0.961				
01365500	Chestnut Creek at Grahamsville, N.Y.	Apr. 1987–Sep. 1998	Roundout Creek near Lowes Corners, N.Y. (01365000)	0.945				
01366650	Sandburg Creek at Ellenville, N.Y.	Oct. 1977–Sep. 2010	Roundout Creek near Lowes Corners, N.Y. (01365000)	0.919				
01368500	Rutgers Creek at Gardnerville, N.Y.	Oct. 1968–Sep. 2010	Flat Brook near Flatbrookville, N.J. (01440000)	0.941				
01369000	Pochuck Creek near Pine Island, N.Y.	Oct. 1977–Sep. 2010	Paulins Kill at Blairstown, N.J. (01443500)	0.924				
01401650	Pike Run at Belle Mead, N.J.	Oct. 1959–June 1980	Stony Brook at Princeton, N.J. (01401000)	0.897				
01403540	Stony Brook at Watchung, N.J.	Oct. 1959–Sep. 1974	Stony Brook at Princeton, N.J. (01401000)	0.873				
01411300	Tuckahoe River at Head of River, N.J.	Oct 1959-Dec 1969	Great Egg Harbor River at Folsom, N.J. (01411300)	0.880				
01418500	Beaver Kill at Craigie Clair, N.Y.	Oct. 1970–Sep. 2010	Beaver Kill at Cooks Falls, N.Y. (01420500)	0.985				
01419500	Willowemoc Creek near Livingston Manor, N.Y.	Oct. 1970–Sep. 2010	Beaver Kill at Cooks Falls, N.Y. (01420500)	0.984				
01420000	Little Beaver Kill near Livingston Manor, N.Y.	Oct. 1981–Sep. 2010	Beaver Kill at Cooks Falls, N.Y. (01420500)	0.964				
01421614	Town Brook Tributary southeast of Hobart, N.Y.	Oct. 1959–Sep. 1998; Nov. 2009–Sep. 2010	West Branch Delaware River at Walton, N.Y. (01423000)	0.915				
01421618	Town Brook Tributary southeast of Hobart, N.Y.	Oct. 1959–Sep. 1997	East Branch Delaware River at Margaretville, N.Y. (01413500)	0.942				
01421900	West Branch Delaware River upstream from Delhi, N.Y.	Sep. 1970–Dec. 1996	West Branch Delaware River at Walton, N.Y. (01423000)	0.988				
01422389	Coulter Brook near Bovina Center, N.Y.	Oct. 1959–Sep. 1997; Oct. 2009–Oct. 2010	West Branch Delaware River at Walton, N.Y. (01423000)	0.914				
01422500	Little Delaware River near Delhi, N.Y.	Oct. 1970–Jan. 1997	West Branch Delaware River at Walton, N.Y. (01423000)	0.977				
01422738	Wolf Creek at Mundale, N.Y.	Oct. 1959–Sep. 1998; June 2009–Oct. 2010	West Branch Delaware River at Walton, N.Y. (01423000)	0.931				
01422747	East Brook east of Walton, N.Y.	Oct. 1959–Sep. 1998	West Branch Delaware River at Walton, N.Y. (01423000)	0.966				
01423500	Dryden Brook near Granton, N.Y.	June 1967–Sep. 2010	West Branch Delaware River at Walton, N.Y. (01423000)	0.956				
0142400103	Trout Creek near Trout Creek, N.Y.	July 1967–Nov. 1996	West Branch Delaware River at Walton, N.Y. (01423000)	0.959				
01424108	Sherruck Brook Tributary near Trout Creek, N.Y.	Oct. 1959–Sep. 1997; Sep. 2007–Sep. 2010	West Branch Delaware River at Walton, N.Y. (01423000)	0.937				

Appendix 1. Reference streamgages with record extension techniques applied.—Continued

[USGS, U.S. Geological Survey]

USGS streamgage number	Name	Portion of record extended	Index station 1 (station number)	Correlation coefficient	Index station 2 (station number)	Correlation coefficient	Index station 3 (station number)	Correlation coefficient
01425500	Cold Spring Brook at China, N.Y.	Oct. 1968–Sep. 2010	Susquehanna River at Conklin, N.Y. (01503000)	0.917				
01425675	Oquaga Creek near North Sanford, N.Y.	Oct. 1959–Sep. 1969; Oct. 1981–Sep. 2010	Susquehanna River at Conklin, N.Y. (01503000)	0.869				
01426000	Oquaga Creek at Deposit, N.Y.	Oct. 1973–Sep. 2010	West Branch Delaware River at Walton, N.Y. (01423000)	0.924				
01427500	Callicoon Creek at Callicoon, N.Y.	Oct. 1982–Sep. 2010	Beaver Kill at Cooks Falls, N.Y. (0142500)	0.943				
01428000	Tenmile River at Tusten, N.Y.	Oct. 1973–Sep. 2010	Bush Kill at Shoemakers, Pa. (01439500)	0.913				
01428750	West Branch Lackawaxen River near Aldenville, Pa.	Oct. 1959–Sep. 1987	Tunkhannock Creek near Tunkhannock, Pa. (01534000)	0.927				
01431000	Middle Creek near Hawley, Pa.	Sep. 1960–Sep. 2010	Lehigh River at Stoddartsville, Pa. (01447500)	0.920				
01445000	Pequest River at Huntsville, N.J.	Oct. 1962–Sept. 2002	Flat Brook near Flatbrookville, N.J. (01440000)	0.920				
01447720	Tobyhanna Creek near Blakeslee, Pa.	Oct. 1959–Sep. 1960; Oct. 1985–Sep. 2010	Lehigh River at Stoddartsville, Pa. (01447500)	0.950				
01448500	Dilldown Creek near Long Pond, Pa.	Oct. 1996–Sep. 2010	Brodhead Creek at Minisink Hills, Pa. (01442500)	0.926	Pohopoco Creek at Kresgeville, Pa. (01449360)	0.924		
01449360	Pohopoco Creek at Kresgeville, Pa.	Oct. 1959–Sep. 1966	Aquashicola Creek at Palmerton, Pa. (01450500)	0.958				
01451800	Jordan Creek near Schnecksville, Pa.	Oct. 1959–Jan. 1966	Jordan Creek at Allentown, Pa. (01452000)	0.975				
01459500	Tohickon Creek near Pipersville, Pa.	Dec. 1973–Sep. 2010	Skippack Creek near Collegeville, Pa. (01473120)	0.897	Jordan Creek near Schnecksville, Pa. (01451800)	0.872		
01464907	Little Neshaminy Creek at Valley Road, Pa.	Oct. 1959–Nov. 1998	Pennypack Creek at Lower Rhawn St, Philadelphia, Pa. (01467048)	0.902	French Creek near Phoenixville, Pa. (01472157)	0.871		
01465798	Poquessing Creek at Grant Ave. at Philadelphia, Pa.	Oct. 1959–Jul. 1965	Shellpot Creek at Wilmington, Del. (01477800)	0.821				
01467048	PennyPack Creek at Lower Rhawn Street Bridge, Philadelphia, Pa.	Oct. 1959–Sep. 1965	Tohickon Creek near Pipersville, Pa. (01459500)	0.748				
01467086	Tacony Creek at County Line, Philadelphia, Pa.	Oct. 1959–July 1965	Shellpot Creek at Wilmington, Del. (01477800)	0.821				
01467150	Cooper River at Haddonfield, N.J.	Oct. 1959–Sep. 1963	Christina River at Coochs Bridge, Del. (01478000)	0.753				
01468500	Schuylkill River at Landingville, Pa.	Oct. 1959–Sep. 1963; Oct. 1965–July 1973	Schuylkill River at Berne, Pa. (01470500)	0.975				
01470756	Maiden Creek at Virginville, Pa.	Oct. 1960–Jan. 1973; Oct. 1995–Sep. 2010	Jordan Creek at Allentown, Pa. (01452000)	0.955				

Appendix 1. Reference streamgages with record extension techniques applied.—Continued

[USGS, U.S. Geological Survey]

USGS streamgage number	Name	Portion of record extended	Index station 1 (station number)	Correlation coefficient	Index station 2 (station number)	Correlation coefficient	Index station 3 (station number)	Correlation coefficient
01470779	Tulpehocken Creek near Bernville, Pa.	Oct. 1959–Nov. 1974	Tulpehocken Creek near Reading, Pa. (01471000)	0.849				
01471000	Tulpehocken Creek near Reading, Pa.	Apr. 1979–Sep. 2010	Schuylkill River at Berne, Pa. (01470500)	0.853				
01471980	Manatawny Creek near Pottstown, Pa.	Oct. 1959–July 1974; Oct. 2004–Sep. 2010	West Branch Perkiomen Creek at Hillegass, Pa. (01472199)	0.958	Jordan Creek at Allentown, Pa. (01452000)	0.863		
01472000	Schuylkill River at Pottstown, Pa.	Apr. 1979–Sep. 2010	Schuylkill River at Berne, Pa. (01470500)	0.964				
01472157	French Creek near Phoenixville, Pa.	Oct. 1959–Sep. 1968	Brandywine Creek at Chadds Ford, Pa. (01481000)	0.948	Tohickon Creek near Pipersville, Pa. (01459500)	0.846		
01472174	Pickering Creek near Chester Springs, Pa.	Oct. 1959–Dec. 1966; Oct. 1983–Sep. 2010	Little Lehigh Creek near Allentown, Pa. (01451500)	0.910	French Creek near Phoenixville, Pa. (01472157)	0.909	Brandywine Creek at Chadds Ford, Pa. (01481000)	0.771
01472198	Perkiomen Creek at East Greenville, Pa.	Oct. 1959–Aug. 1981	Jordan Creek at Allentown, Pa. (01452000)	0.917	French Creek near Phoenixville, Pa. (01472157)	0.794		
01472199	West Branch Perkiomen Creek at Hillegass, Pa.	Oct. 1959–Sep. 1981	Manatawny Creek near Pottstown, Pa. (01471980)	0.958	Jordan Creek at Allentown, Pa. (01452000)	0.874		
01473120	Skippack Creek near Collegeville, Pa.	Oct. 1959–Apr. 1966; Oct. 1994–Sep. 2010	French Creek near Phoenixville, Pa. (01472157)	0.855	Jordan Creek at Allentown, Pa. (01452000)	0.794		
01475510	Darby Creek near Darby, Pa.	Oct. 1959–Jan. 1964; Oct. 1990–Sep. 2010	Crum Creek near Newtown Square, Pa. (01475850)	0.906	Tohickon Creek near Pipersville, Pa. (01459500)	0.749		
01475530	Cobbs Creek at U.S. Hghwy No. 1 at Philadelphia, Pa.	Oct. 1959–Sep. 1964	Shellpot Creek at Wilmington, Del. (01477800)	0.841				
01475850	Crum Creek near Newtown Square, Pa.	Oct. 1959–Sep. 1981	Darby Creek near Darby, Pa. (01475510)	0.906	West Branch Brandywine Creek near Honey Brook, Pa. (01480300)	0.875	Little Lehigh Creek near Allentown, Pa. (01451500)	0.905
01477120	Raccoon Creek near Swedesboro, N.J.	Oct. 1959–Mar. 1966	Red Clay Creek at Wooddale, Del. (01480000)	0.858				
01479820	Red Clay Creek near Kennett Square, Pa.	Oct. 1959–Dec. 1987	Red Clay Creek at Wooddale, Del. (01480000)	0.951				
01480015	Red Clay Creek near Stanton, Del.	Oct. 1959–Sep.1988	Red Clay Creek at Wooddale, Del. (01480000)	0.980				
01480100	Little Mill Creek at Elsmere, Del.	Oct. 1959–Sep.1963; Oct. 1980–Sep. 2010	Shellpot Creek at Wilmington, Del. (01477800)	0.893				
01480300	West Branch Brandywine Creek near Honey Brook, Pa.	Oct. 1959–May 1960	Tohickon Creek near Pipersville, Pa. (01459500)	0.818				
01480675	Marsh Creek near Glenmoore, Pa.	Oct. 1959–July 1966	Brandywine Creek at Chadds Ford, Pa. (01481000)	0.934	Tohickon Creek near Pipersville, Pa. (01459500)	0.855		

Appendix 1. Reference streamgages with record extension techniques applied.—Continued

[USGS, U.S. Geological Survey]

USGS streamgage number	Name	Portion of record extended	Index station 1 (station number)	Corre-lation coef-ficient	Index station 2 (station number)	Corre-lation coef-ficient	Index station 3 (station number)	Corre-lation coef-ficient
01481000	Brandywine Creek at Chadds Ford, Pa.	Oct. 1959–Sep. 1962; Oct. 1974–Sep. 2010	Schuylkill River at Pottstown, Pa. (01472000)	0.945	French Creek near Phoenixville, Pa. (01472157)	0.851		
01482500	Salem River at Woodstown, N.J.	Feb. 1985–June 1989; Oct. 1990–Sep. 2002	White Clay Creek near Newark, Del. (01479000)	0.808				
01483000	Alloway Creek at Alloway, N.J.	Oct. 1972–Sep. 2010	Crosswicks Creek at Extonville, N.J. (01464500)	0.816				
01483500	Leipsic River near Cheswold, Del.	Oct. 1957–Sep. 2010	Codorus Creek at Spring Grove, Pa. (01574500)	0.765				
01484000	Murderkill River near Felton, Del.	Jan. 2009–Sep. 2010	Nanticoke River near Bridgeville, Del. (01487000)	0.884				
01484270	Beaverdam Creek near Milton, Del.	Oct. 1959–Apr.1971; Oct. 2005–Sep. 2010	Nanticoke River near Bridgeville, Del. (01487000)	0.846				
01484300	Sowbridge Branch near Milton, Del.	Oct. 1978–Sep. 2010	Nanticoke River near Bridgeville, Del. (01487000)	0.862				
01484500	Stockley Branch at Stockley, Del.	Oct. 2004–Sep. 2010	Nanticoke River near Bridgeville, Del. (01487000)	0.861				
01488500	Marshyhope Creek near Adamsville, Del.	Jan. 2003–Sep. 2004	Nanticoke River near Bridgeville, Del. (01487000)	0.897				
01498500	Charlotte Creek at West Davenport, N.Y.	Oct. 1975–Sep. 2010	West Branch Delaware River at Walton, N.Y. (01423000)	0.958				
01499000	Otego Creek near Oneonta, N.Y.	Oct. 1968–Sep. 2010	Susquehanna River at Conklin, N.Y. (01503000)	0.965				
01533950	South Branch Tunkhannock Creek near Montdale, Pa.	Oct. 1959–Aug. 1960; Oct. 1978–Sep. 2010	Tunkhannock Creek near Tunkhannock, Pa. (01534000)	0.941				
01576754	Conestoga River at Conestoga, Pa.	Oct. 1959–Sep. 1984	French Creek near Phoenixville, Pa. (01472157)	0.901	Schuylkill River at Berne, Pa. (01470500)	0.859		
01578400	Bowery Run near Quarryville, Pa.	Oct. 1959–Sep. 1962; Apr. 1981–Sep. 2010	West Branch Brandywine Creek near Honey Brook, Pa. (01480300)	0.834	Codorus Creek at Spring Grove, Pa. (01574500)	0.742		

Appendix 2. Basin characteristics used in the development of flow-duration exceedance probability regression equations for the Delaware River Basin.

[USGS, U.S. Geological Survey; mean annual precipitation, 1981–2010; mean winter precipitation, December–February, 1981–2010]

USGS streamgage number	Latitude at outlet (decimal degrees)	Drainage area (square miles)	Mean annual precipitation (inches)	Mean winter precipitation (inches)	Poorly drained soil (percent)	Sand in soil (percent)	Saturated hydraulic conductivity (micrometers per second)
01350000	42.319502	237	49.8	3.32	1.58	42.5	9.58
01362200	42.117021	63.7	51.1	3.46	1.52	37.9	11.0
01365000	41.866263	38.3	58.1	3.99	0.67	36.7	8.68
01365500	41.845049	21.1	50.8	3.42	2.83	49.1	11.3
01366650	41.714287	52.8	49.2	3.41	4.09	44.7	15.4
01368500	41.343568	58.8	46.5	3.08	4.64	33.8	11.5
01369000	41.275675	98.0	48.0	3.30	3.69	48.0	29.8
01401000	40.333054	44.5	48.7	3.41	9.01	25.2	9.01
01401650	40.468048	5.29	48.0	3.36	8.21	27.3	13.8
01403540	40.636665	5.49	48.9	3.46	6.64	35.8	8.55
01411000	39.595005	57.0	46.6	3.42	14.6	81.3	64.9
01411300	39.306946	30.8	45.1	3.44	1.66	77.8	55.5
01411500	39.495552	111	46.2	3.38	5.12	76.5	53.2
01413500	42.144651	163	46.5	2.94	1.74	39.0	9.77
01414500	42.106310	25.1	48.5	3.14	1.15	37.6	9.14
01415000	42.119723	33.1	45.5	2.90	2.92	38.4	9.16
01418500	41.963074	82.0	51.5	3.48	0.92	40.9	9.54
01419500	41.903374	62.6	53.8	3.72	1.75	48.8	8.69
01420000	41.872815	20.4	52.1	3.57	1.71	48.0	8.52
01420500	41.946577	242	51.6	3.53	1.24	44.6	9.41
01421614	42.349527	0.76	45.9	2.88	0.00	37.0	6.22
01421618	42.361193	14.3	44.7	2.82	1.06	39.7	7.01
01421900	42.280412	134	43.6	2.74	3.17	40.3	11.6
01422389	42.238697	0.76	46.2	2.91	0.00	36.6	6.99
01422500	42.252488	49.8	45.0	2.88	2.44	38.9	7.98
01422738	42.259529	0.61	46.9	3.07	0.00	39.2	4.72
01422747	42.172863	24.7	47.7	3.13	1.77	38.2	8.60
01423000	42.166344	332	45.3	2.91	2.29	39.4	10.6
01423500	42.122030	8.12	48.3	3.20	3.03	35.4	7.53
0142400103	42.173611	20.2	46.2	3.01	1.40	36.5	8.23
01424108	42.187861	1.26	46.1	3.01	0.00	34.9	6.81
01425500	42.161164	1.50	46.1	3.01	0.90	34.9	5.66
01425675	42.174527	4.69	45.7	2.98	2.97	32.1	6.16
01426000	42.058816	67.6	45.3	2.98	3.19	31.7	7.16
01427500	41.760757	110	47.7	3.27	1.96	44.6	8.98
01428000	41.564229	45.7	45.1	3.07	1.97	44.8	8.27
01428750	41.674440	40.6	47.6	3.19	2.28	36.2	7.25
01431000	41.484720	78.8	45.3	3.07	3.26	35.5	7.01
01435000	41.890095	66.7	59.2	4.15	3.08	38.9	9.66
01439500	41.088060	117	48.5	3.35	3.38	53.1	10.8

Appendix 2. Basin characteristics used in the development of flow-duration exceedance probability regression equations for the Delaware River Basin.—Continued

[USGS, U.S. Geological Survey; mean annual precipitation, 1981–2010; mean winter precipitation, December–February, 1981–2010]

USGS streamgage number	Latitude at outlet (decimal degrees)	Drainage area (square miles)	Mean annual precipitation (inches)	Mean winter precipitation (inches)	Poorly drained soil (percent)	Sand in soil (percent)	Saturated hydraulic conductivity (micrometers per second)
01440000	41.106667	65.1	47.4	3.21	0.10	57.0	34.5
01440400	41.084720	67.5	50.5	3.52	4.06	41.6	9.74
01442500	40.998610	261	51.5	3.64	4.42	40.4	13.0
01443500	40.980835	126	46.8	3.21	0.25	43.0	43.3
01445000	40.981113	31.0	46.7	3.22	0.00	42.8	39.0
01445500	40.830556	106	47.6	3.27	0.26	50.1	47.9
01446000	40.844444	36.6	47.7	3.26	2.79	41.0	43.2
01447500	41.130280	91.8	51.2	3.53	5.24	40.3	9.24
01447720	41.084720	119	54.0	3.85	12.8	40.2	9.44
01448500	41.035560	2.40	57.3	4.29	8.72	40.8	30.6
01449360	40.897500	49.8	51.6	3.69	6.46	36.9	24.9
01450500	40.806110	76.6	49.1	3.43	3.25	36.8	33.0
01451500	40.582220	81.9	46.3	3.23	4.70	27.0	16.5
01451800	40.661670	53.0	48.0	3.36	7.70	32.1	23.0
01452000	40.623060	76.2	47.5	3.33	6.25	31.1	22.0
01452500	40.641110	43.3	46.4	3.24	3.06	25.9	15.4
01459500	40.433610	97.8	48.6	3.47	29.9	24.6	7.85
01464500	40.137497	80.7	46.0	3.32	16.1	73.4	50.6
01464907	40.229170	27.0	47.2	3.33	13.9	17.6	19.0
01465798	40.056940	21.4	47.9	3.40	7.47	29.8	8.70
01466500	39.884724	2.34	45.7	3.37	7.97	86.5	78.1
01467048	40.050000	49.8	47.8	3.38	5.03	26.3	16.4
01467086	40.046390	16.2	47.4	3.38	1.70	17.9	3.52
01467150	39.903056	17.1	47.0	3.45	9.73	70.9	42.0
01468500	40.629170	137	49.7	3.39	2.28	38.4	39.9
01470500	40.522500	358	50.1	3.44	2.78	36.9	35.8
01470756	40.514170	158	47.1	3.26	6.69	31.1	22.6
01470779	40.413330	70.4	44.5	3.11	5.39	22.7	11.8
01471000	40.368890	215	44.8	3.13	7.49	27.6	17.8
01471980	40.272780	85.5	46.9	3.23	12.2	30.1	21.7
01472000	40.241670	1,147	46.9	3.25	5.53	31.8	24.0
01472157	40.151390	59.0	46.3	3.29	10.8	35.2	19.8
01472174	40.089440	5.98	47.6	3.42	9.70	35.5	24.4
01472198	40.393890	37.7	47.5	3.28	11.5	30.2	21.6
01472199	40.373890	23.1	48.2	3.30	19.4	30.2	19.2
01473120	40.164440	53.7	46.6	3.30	2.36	18.1	18.8
01475510	39.928890	37.5	46.4	3.34	4.24	28.3	8.41
01475530	39.974720	4.79	46.6	3.36	1.52	27.2	7.37
01475850	39.976390	15.8	46.6	3.35	10.2	34.9	17.2
01477120	39.740556	26.0	45.7	3.33	9.11	71.3	49.5

Appendix 2. Basin characteristics used in the development of flow-duration exceedance probability regression equations for the Delaware River Basin.—Continued

[USGS, U.S. Geological Survey; mean annual precipitation, 1981–2010; mean winter precipitation, December–February, 1981–2010]

USGS streamgage number	Latitude at outlet (decimal degrees)	Drainage area (square miles)	Mean annual precipitation (inches)	Mean winter precipitation (inches)	Poorly drained soil (percent)	Sand in soil (percent)	Saturated hydraulic conductivity (micrometers per second)
01477800	39.760972	7.32	45.7	3.33	5.06	23.6	5.48
01478000	39.637389	20.9	45.5	3.26	15.4	40.7	15.4
01479000	39.699222	89.1	46.2	3.31	7.82	42.6	14.6
01479820	39.816670	27.6	46.7	3.35	7.29	40.9	17.0
01480000	39.762806	47.3	46.5	3.35	6.61	42.8	15.6
01480015	39.715750	52.5	46.4	3.34	6.93	42.9	15.1
01480100	39.734835	6.74	45.6	3.33	6.64	37.5	11.6
01480300	40.072780	18.5	46.4	3.19	19.6	40.4	13.6
01480675	40.097780	8.54	47.2	3.38	21.8	38.6	23.8
01481000	39.869720	288	47.6	3.40	9.49	41.6	17.4
01482500	39.643333	14.6	45.0	3.26	16.2	50.8	30.0
01483000	39.565278	20.3	44.2	3.20	13.2	53.4	34.5
01483500	39.232889	9.50	43.8	3.19	15.1	65.2	83.4
01484000	38.975946	12.5	43.9	3.24	30.8	67.6	87.2
01484100	38.905778	3.51	44.8	3.35	44.0	71.2	116
01484270	38.761501	6.91	45.5	3.44	6.01	75.5	95.4
01484300	38.814279	7.11	45.1	3.39	2.89	73.4	89.1
01484500	38.638861	4.79	45.4	3.38	25.0	70.3	121
01487000	38.728333	72.3	44.3	3.34	30.0	72.8	113
01488500	38.849694	47.5	44.0	3.26	47.8	66.8	121
01498500	42.445075	167	42.6	2.69	6.31	37.0	11.0
01499000	42.450968	108	43.0	2.84	6.97	36.8	14.3
01503000	42.035553	2,234	43.5	2.84	4.81	35.5	11.8
01533950	41.574720	12.7	45.6	3.00	2.43	34.8	8.46
01534000	41.558330	393	44.0	2.87	2.28	35.9	7.53
01538000	41.059167	42.9	46.0	2.96	4.26	34.1	7.62
01539000	41.078056	272	46.8	3.02	2.60	35.6	15.1
01576754	39.946389	468	44.1	2.97	0.86	25.7	10.0
01578400	39.894722	6.04	45.6	3.19	1.39	32.8	10.2

Appendix 3. Observed and predicted flow-duration exceedance probability discharges for streamgages used in regression analysis.

[USGS, U.S. Geological Survey; --, flow-duration exceedance probability discharge could not be computed because of insufficient period of record; O, observed; P, predicted]

USGS streamgage number	Type	Flow-duration exceedance probability discharges (cubic feet per second)																					
		P99.9946	P99.95	P99	P98	P95	P90	P85	P80	P75	P70	P60	P50	P40	P30	P25	P20	P15	P10	P05	P02	P01	P0.0054
01350000	O	4.90	5.80	11.0	14.0	21.0	32.0	45.0	61.0	80.0	103	160	230	320	440	520	634	795	1,060	1,660	2,850	4,120	17,460
	P	14.5	17.6	20.7	24.2	34.2	50.1	69.3	91.8	119	147	207	286	390	543	618	768	936	1,181	1,651	2,454	3,241	16,705
01362200	O	0.00	3.50	5.50	6.90	10.0	15.0	20.0	27.0	35.0	44.0	62.0	83.0	110	150	173	206	253	328	499	809	1,170	--
	P	4.26	5.32	5.63	6.79	9.67	14.2	19.4	25.4	32.4	39.9	56.1	76.4	102	138	159	195	240	311	462	738	1,010	5,560
01365000	O	3.70	4.40	6.60	7.50	10.0	14.0	19.0	24.0	30.0	35.0	47.0	62.0	81.0	104	120	140	170	217	313	505	712	3,450
	P	4.13	4.97	6.91	8.11	11.1	15.4	20.4	25.2	30.9	36.4	47.8	61.8	79.2	102	115	139	171	221	329	534	737	4,578
01365500	O	1.80	2.40	3.20	3.60	4.60	6.20	7.70	9.50	11.0	14.0	18.0	24.0	31.0	41.0	47.0	56.0	68.0	86.0	127	205	290	1,695
	P	1.12	1.45	2.09	2.52	3.56	5.18	7.02	9.01	11.4	14.0	19.3	25.9	34.0	46.2	52.7	63.0	76.4	97.1	140	218	292	1,624
01366650	O	--	--	7.20	8.20	11.0	15.0	18.0	22.0	27.0	32.0	44.0	56.0	72.0	99.0	120	142	177	232	342	520	665	--
	P	3.53	4.50	4.84	5.84	8.23	11.9	16.0	20.6	25.9	31.8	44.1	59.4	78.7	106	121	147	178	228	331	519	702	3,864
01368500	O	--	--	0.60	0.90	1.40	2.40	3.70	5.20	7.40	11.0	19.0	30.0	45.0	70.0	87.0	113	148	210	353	565	772	--
	P	2.07	2.71	4.35	5.42	7.73	11.0	14.6	18.7	23.3	28.3	40.2	54.0	71.4	92.9	106	130	161	212	332	560	794	4,575
01369000	O	--	1.63	4.60	5.60	8.30	13.0	21.0	28.0	37.0	47.0	71.0	98.0	132	182	218	260	313	390	540	762	934	--
	P	9.02	11.6	12.2	14.4	19.4	26.7	34.6	43.1	52.8	63.0	84.5	111	143	189	211	254	303	378	533	806	1,072	6,199
01401000	O	--	--	0.30	0.62	1.20	2.20	3.40	4.80	6.60	8.90	15.0	23.0	34.0	50.0	61.0	76.0	100	145	268	547	852	5,348
	P	1.77	2.26	5.33	6.72	9.27	12.3	15.2	18.2	21.3	24.4	32.7	41.4	51.9	62.0	70.2	85.3	106	144	241	448	676	4,541
01401650	O	--	--	--	--	0.08	0.27	0.47	0.69	0.92	1.20	1.90	2.70	3.80	5.30	6.40	8.00	11.0	16.0	33.0	77.0	125	--
	P	0.19	0.27	0.45	0.59	0.85	1.18	1.50	1.82	2.17	2.56	3.56	4.56	5.75	6.93	7.98	9.55	12.0	16.6	29.1	56.7	86.7	580
01403540	O	--	0.09	0.46	0.63	0.89	1.20	1.50	1.70	2.10	2.50	3.50	4.70	6.20	8.20	9.70	11.0	14.0	20.0	35.0	67.0	104	--
	P	0.19	0.25	0.57	0.73	1.03	1.42	1.80	2.18	2.61	3.08	4.20	5.36	6.72	8.28	9.45	11.2	13.8	18.5	30.5	55.5	81.3	534
01411000	O	12.3	15.0	23.0	25.0	30.0	36.0	41.0	45.0	50.0	54.0	64.0	73.0	84.0	97.0	105	114	128	148	186	242	288	1,270
	P	5.80	7.73	16.0	18.2	22.6	27.7	32.7	36.9	41.6	46.6	55.3	66.6	79.2	102	109	123	138	161	203	277	348	2,166
01411300	O	--	1.79	8.40	10.0	12.0	14.0	16.0	18.0	20.0	22.0	26.0	31.0	38.0	46.0	51.0	58.0	66.0	80.0	106	145	181	--
	P	4.57	6.01	14.8	16.6	19.0	21.7	24.1	25.5	27.4	29.7	34.0	38.5	43.1	52.1	54.5	59.6	65.0	74.4	94.1	127	157	1,194
01411500	O	20.0	23.0	40.0	46.0	56.0	67.0	77.0	86.0	95.0	103	122	143	166	192	207	225	248	280	338	419	493	4,270
	P	15.3	19.6	51.2	56.6	65.3	75.5	85.2	92.2	100	109	125	144	165	204	214	239	262	299	370	489	602	4,251
01413500	O	6.10	7.50	12.0	15.0	21.0	31.0	44.0	59.0	75.0	91.0	130	180	241	325	383	456	556	709	1,030	1,640	2,260	14,770
	P	5.56	7.10	10.3	12.5	18.0	26.7	36.9	49.2	63.8	80.2	116	162	223	308	353	439	539	691	1,007	1,559	2,102	10,854
01414500	O	1.20	1.50	2.50	3.00	4.20	6.20	8.60	11.0	14.0	17.0	24.0	33.0	44.0	58.0	68.0	80.0	96.0	122	176	285	410	2,000
	P	0.88	1.16	1.59	1.98	2.89	4.35	6.04	7.98	10.3	13.0	18.9	26.0	35.2	47.7	55.2	67.6	83.9	110	169	279	386	2,106
01418500	O	--	6.30	11.0	13.0	18.0	24.0	33.0	42.0	51.0	61.0	84.0	110	145	195	228	265	323	409	585	961	1,370	--
	P	5.52	6.80	9.23	10.9	15.2	21.7	29.2	37.4	47.0	57.1	78.3	105	138	185	210	256	312	398	575	893	1,204	6,808
01419500	O	--	7.60	11.0	12.0	16.0	22.0	27.0	33.0	40.0	47.0	63.0	81.0	106	140	165	196	237	308	449	729	1,020	--
	P	5.03	6.11	9.32	10.8	14.7	20.8	27.7	35.0	43.6	52.4	69.6	91.7	119	161	181	217	261	326	453	676	889	5,063
01420000	O	1.10	1.40	2.20	2.60	3.70	5.10	6.50	8.10	10.0	12.0	17.0	22.0	30.0	40.0	48.0	58.0	74.0	100	158	261	270	1,772
	P	1.18	1.49	2.31	2.77	3.87	5.58	7.53	9.59	12.1	14.7	20.1	26.8	34.9	47.0	53.4	63.8	77.4	98.3	142	221	296	1,686

Appendix 3. Observed and predicted flow-duration exceedance probability discharges for streamgages used in regression analysis.—Continued

[USGS, U.S. Geological Survey; --, flow-duration exceedance probability discharge could not be computed because of insufficient period of record; O, observed; P, predicted]

USGS stream-gage number	Type	Flow-duration exceedance probability discharges (cubic feet per second)																					
		P99.9946	P99.95	P99	P98	P95	P90	P85	P80	P75	P70	P60	P50	P40	P30	P25	P20	P15	P10	P05	P02	P01	P0.0054
01420500	O	23.0	28.0	41.0	48.0	62.0	86.0	109	133	160	188	248	325	424	561	655	780	960	1,240	1,830	2,850	3,929	21,770
	P	19.6	23.4	33.1	38.1	51.5	72.1	96.2	123	153	184	247	329	434	586	657	805	968	1,206	1,656	2,429	3,189	17,716
01421614	O	--	--	0.05	0.06	0.10	0.18	0.27	0.36	0.44	0.53	0.74	0.98	1.30	1.60	1.90	2.40	3.10	4.10	6.00	10.0	13.0	--
	P	0.01	0.01	0.02	0.03	0.05	0.08	0.11	0.15	0.21	0.28	0.44	0.62	0.86	1.18	1.41	1.70	2.16	2.96	5.05	9.31	13.4	72.1
01421618	O	--	--	0.62	0.77	1.20	2.20	3.50	4.70	6.33	8.10	12.0	16.0	22.0	29.0	34.0	41.0	52.0	68.1	109	180	250	--
	P	0.25	0.34	0.51	0.66	1.00	1.59	2.28	3.13	4.20	5.50	8.47	12.1	16.9	23.7	27.8	34.2	42.7	56.4	87.8	146	201	1,016
01421900	O	--	3.40	8.40	10.0	14.0	21.0	30.0	41.0	52.0	67.0	96.0	135	184	250	296	354	440	566	827	1,300	1,830	--
	P	3.36	4.43	5.41	6.71	9.99	15.4	21.9	30.1	40.1	51.8	78.4	113	159	226	262	328	405	523	770	1,198	1,617	7,779
01422389	O	--	--	0.02	0.03	0.05	0.13	0.22	0.31	0.42	0.52	0.75	0.97	1.30	1.70	1.90	2.30	2.90	4.00	6.04	8.90	12.00	--
	P	0.01	0.02	0.02	0.03	0.05	0.08	0.12	0.16	0.22	0.29	0.45	0.64	0.87	1.18	1.41	1.69	2.15	2.95	5.04	9.31	13.46	73.9
01422500	O	--	0.90	2.40	3.10	4.30	6.60	10.0	14.0	19.0	25.0	36.0	50.0	69.0	94.0	111	134	166	216	321	513	705	--
	P	1.13	1.50	2.12	2.67	3.99	6.17	8.74	11.9	15.8	20.4	30.7	43.7	60.9	85.2	99.3	123	153	200	303	490	671	3,366
01422738	O	--	--	0.02	0.02	0.04	0.07	0.10	0.17	0.25	0.33	0.50	0.68	0.90	1.10	1.30	1.50	1.90	2.50	3.90	6.65	9.05	--
	P	0.01	0.01	0.02	0.03	0.04	0.07	0.10	0.14	0.19	0.24	0.38	0.53	0.72	0.99	1.18	1.40	1.78	2.43	4.10	7.49	10.7	58.9
01422747	O	--	--	1.70	1.90	2.70	4.30	6.00	8.80	12.00	15.0	23.0	29.0	38.0	48.0	55.0	64.0	78.0	101	145	237	320	--
	P	0.80	1.06	1.35	1.70	2.51	3.83	5.36	7.16	9.36	11.9	17.5	24.4	33.3	45.7	53.1	65.1	81.1	106	164	270	374	1,983
01423000	O	13.0	14.0	24.0	29.0	40.0	59.0	83.0	109	137	169	246	340	461	627	741	880	1,070	1,380	2,000	3,070	4,280	21,300
	P	12.0	15.1	19.7	23.6	33.9	50.2	69.7	93.7	122	154	224	315	437	611	699	876	1,073	1,367	1,960	2,968	3,970	19,884
01423500	O	--	--	0.50	0.58	0.60	0.97	1.20	1.60	2.20	2.80	4.50	6.60	9.70	14.0	17.0	20.0	24.0	32.0	47.0	76.0	112	--
	P	0.22	0.30	0.38	0.49	0.75	1.17	1.64	2.20	2.89	3.69	5.53	7.73	10.5	14.3	16.8	20.5	25.9	34.9	56.3	98.4	140	755
0142400103	O	--	0.20	0.40	0.50	0.80	1.50	2.40	3.50	5.40	7.40	12.0	18.0	26.0	36.0	42.0	50.0	62.0	82.5	122	199	270	--
	P	0.54	0.72	0.92	1.17	1.76	2.71	3.81	5.14	6.76	8.66	13.0	18.3	25.1	34.4	40.2	49.5	61.8	81.9	128	215	301	1,586
01424108	O	--	--	0.05	0.05	0.08	0.11	0.17	0.26	0.41	0.61	1.00	1.50	2.10	2.90	3.30	3.90	4.80	6.00	9.20	14.0	18.5	--
	P	0.02	0.03	0.04	0.06	0.09	0.14	0.21	0.28	0.37	0.48	0.75	1.06	1.44	1.95	2.33	2.80	3.56	4.87	8.29	15.3	22.1	122
01425500	O	--	--	0.01	0.02	0.04	0.07	0.10	0.16	0.24	0.36	0.65	1.10	1.70	2.40	3.00	3.60	4.50	6.00	9.60	16.0	24.0	--
	P	0.02	0.03	0.05	0.07	0.11	0.17	0.24	0.33	0.43	0.57	0.88	1.25	1.70	2.30	2.75	3.31	4.21	5.77	9.81	18.0	26.1	143
01425675	O	--	--	0.30	0.35	0.52	0.70	0.90	1.10	1.40	1.80	3.10	4.50	6.20	8.40	10.0	12.0	16.0	21.0	33.0	55.3	70.0	--
	P	0.08	0.11	0.15	0.20	0.31	0.49	0.70	0.96	1.29	1.68	2.63	3.75	5.19	7.08	8.44	10.4	13.2	18.2	30.6	55.9	81.3	428
01426000	O	--	1.10	2.00	2.50	3.70	5.50	8.20	12.0	16.0	21.0	34.0	51.0	73.0	104	127	155	194	254	403	667	905	--
	P	1.70	2.21	2.97	3.76	5.62	8.55	12.0	16.2	21.2	26.9	40.5	57.2	79.3	108	126	158	198	264	415	700	988	5,135
01427500	O	--	4.80	6.84	8.70	12.0	18.0	24.0	30.0	38.0	46.0	64.0	87.0	119	167	200	241	300	403	631	1,040	1,380	--
	P	5.41	6.75	10.3	12.3	17.1	24.4	32.7	42.0	52.9	64.9	90.0	121	161	218	247	301	363	458	652	990	1,318	7,240
01428000	O	--	--	1.80	2.60	3.90	5.60	7.20	9.40	12.0	16.0	24.0	32.0	46.0	66.0	79.0	98.0	119	155	228	356	485	--
	P	1.43	1.86	3.34	4.10	5.78	8.34	11.2	14.4	18.1	22.5	31.9	43.1	57.1	76.9	87.5	106	128	163	240	376	506	2,812
01428750	O	--	--	5.90	6.90	8.20	11.0	14.0	17.0	21.0	24.0	33.0	45.0	58.0	76.0	89.0	107	135	180	291	493	651	--
	P	1.36	1.75	3.02	3.75	5.36	7.78	10.5	13.5	17.0	21.0	29.9	40.4	53.7	70.9	81.4	99.4	123	161	247	410	572	3,251

Appendix 3. Observed and predicted flow-duration exceedance probability discharges for streamgages used in regression analysis.—Continued

[USGS, U.S. Geological Survey; --, flow-duration exceedance probability discharge could not be computed because of insufficient period of record; O, observed; P, predicted]

USGS streamgage number	Type	Flow-duration exceedance probability discharges (cubic feet per second)																					
		P99.9946	P99.95	P99	P98	P95	P90	P85	P80	P75	P70	P60	P50	P40	P30	P25	P20	P15	P10	P05	P02	P01	P0.0054
01431000	O	--	--	3.70	4.40	7.00	10.0	14.0	19.0	25.0	31.0	45.0	62.0	88.0	125	149	180	224	301	461	747	1,142	--
	P	2.28	2.92	5.36	6.65	9.46	13.6	18.2	23.4	29.5	36.2	51.9	70.3	93.8	124	142	174	214	279	429	705	984	5,533
01435000	O	7.70	9.80	15.0	18.0	25.0	35.0	46.0	56.0	65.0	74.0	95.0	119	148	187	215	250	304	389	575	979	1,470	5,990
	P	8.89	10.5	12.7	14.7	20.0	27.9	37.0	46.1	56.6	66.4	86.4	112	145	189	213	259	317	407	590	936	1,282	7,680
01439500	O	2.60	3.85	8.80	11.0	17.0	27.0	39.0	53.0	69.0	86.0	121	161	210	272	312	362	428	526	704	986	1,270	9,020
	P	6.79	8.44	19.3	22.3	29.2	39.1	49.7	60.6	72.8	85.6	111	143	181	238	263	312	367	449	612	892	1,162	6,906
01440000	O	4.40	5.50	8.60	9.80	13.0	17.0	21.0	26.0	33.0	40.0	55.0	73.0	93.0	120	137	159	190	238	338	515	687	5,340
	P	6.32	8.22	11.0	12.8	16.5	22.0	27.9	33.7	40.4	47.8	62.1	79.1	99.2	130	144	168	196	237	319	458	587	3,577
01440400	O	5.10	5.57	7.76	8.90	12.0	17.0	23.0	31.0	40.0	49.0	67.0	88.0	112	144	165	196	237	301	433	672	913	6,040
	P	4.16	5.17	10.2	12.1	16.2	21.9	28.0	34.1	41.0	47.9	63.1	81.0	103	131	147	176	213	271	398	634	870	5,374
01442500	O	30.1	34.0	50.0	57.0	73.0	95.0	120	147	177	210	277	360	455	590	684	802	963	1,220	1,740	2,650	3,500	29,110
	P	26.0	30.9	51.8	59.7	77.8	102	128	154	182	208	266	338	427	541	598	724	867	1,090	1,549	2,384	3,238	20,183
01443500	O	5.80	11.0	18.0	20.0	27.0	35.0	43.0	52.0	63.0	76.0	103	136	175	224	255	293	346	423	590	889	1,160	5,180
	P	15.2	19.5	19.1	22.5	29.3	38.9	48.7	58.9	70.1	82.2	108	138	174	222	246	294	349	437	625	957	1,283	8,088
01445000	O	--	1.70	2.60	2.95	4.50	6.50	9.30	12.0	16.0	20.0	28.0	37.0	48.0	62.0	70.0	79.0	91.0	106	135	182	224	--
	P	2.97	3.96	3.96	4.81	6.42	8.68	11.0	13.3	16.0	18.9	25.5	32.5	40.9	51.9	58.1	68.7	82.2	105	156	249	340	2,176
01445500	O	12.1	14.0	19.0	22.0	29.0	36.0	44.0	51.0	60.0	70.0	90.0	114	145	183	208	237	276	333	442	601	728	1,930
	P	14.4	18.4	20.8	24.1	30.7	39.8	49.2	58.4	68.5	79.3	102	127	158	201	220	259	303	370	511	754	987	6,342
01446000	O	--	1.30	2.30	2.90	4.30	6.40	9.30	12.0	15.0	19.0	27.0	37.0	48.0	62.0	71.0	82.0	98.0	120	162	229	308	--
	P	3.59	4.77	4.87	5.92	7.95	10.7	13.5	16.3	19.4	22.8	30.4	38.8	48.8	61.4	68.8	81.8	98.4	126	190	310	429	2,741
01447500	O	7.00	8.00	14.0	17.0	23.0	32.0	43.0	54.0	66.0	78.0	103	130	161	203	233	268	318	391	548	810	1,100	16,070
	P	5.50	6.78	13.9	16.4	22.2	30.0	38.4	47.1	56.7	66.3	87.1	112	143	184	206	248	301	384	564	900	1,240	7,556
01447720	O	--	--	30.0	32.0	42.0	54.0	67.0	81.0	96.0	110	141	179	220	275	311	360	436	545	783	1,180	1,580	--
	P	8.19	9.91	17.2	20.4	28.4	38.8	50.5	62.7	76.1	88.6	116	151	196	254	286	350	430	556	822	1,338	1,880	10,792
01448500	O	--	0.27	0.42	0.50	0.66	0.89	1.20	1.40	1.70	1.90	2.50	3.20	4.00	5.10	5.80	6.70	7.80	9.60	14.0	22.0	30.0	--
	P	0.37	0.49	0.35	0.44	0.63	0.88	1.14	1.39	1.68	1.96	2.58	3.29	4.10	5.13	5.88	6.89	8.55	11.4	18.4	33.1	48.1	311
01449360	O	--	11.0	15.0	17.0	22.0	28.0	33.0	38.0	44.0	50.0	62.0	76.0	93.0	113	127	144	168	204	277	392	517	--
	P	5.58	7.06	7.47	9.01	12.2	16.5	20.9	25.4	30.2	35.0	46.1	58.8	74.3	93.1	105	126	154	200	305	512	724	4,582
01450500	O	9.20	11.0	18.0	21.0	27.0	35.0	42.0	50.0	57.0	65.0	81.0	101	125	159	180	209	248	309	444	689	921	4,490
	P	8.75	11.2	11.9	14.3	19.0	25.1	31.4	37.6	44.4	51.4	67.5	85.5	107	133	149	179	216	277	418	685	956	6,212
01451500	O	23.0	25.0	28.0	30.0	35.0	41.0	46.0	51.0	56.0	61.0	71.0	82.0	96.0	113	123	136	152	175	224	321	421	4,550
	P	4.62	5.94	8.98	11.2	15.2	20.3	25.3	30.6	36.2	42.1	57.2	73.2	92.9	113	127	155	191	254	412	729	1,067	7,003
01451800	O	--	0.71	2.80	4.30	7.00	10.0	14.0	18.0	22.0	27.0	37.0	49.0	65.0	89.0	104	127	160	212	325	526	737	--
	P	3.57	4.64	5.86	7.28	10.1	13.6	17.2	21.0	25.0	29.2	39.5	50.9	64.8	80.3	90.8	110	136	180	286	500	726	4,583
01452000	O	0.00	0.00	3.70	4.70	7.84	12.0	17.0	22.0	28.0	33.0	46.0	63.0	83.0	112	131	157	195	253	390	650	927	6,440
	P	5.36	6.90	9.01	11.1	15.2	20.2	25.4	30.7	36.4	42.3	56.9	72.9	92.4	114	128	156	191	251	398	690	997	6,404

Appendix 3. Observed and predicted flow-duration exceedance probability discharges for streamgages used in regression analysis.—Continued

[USGS, U.S. Geological Survey; --, flow-duration exceedance probability discharge could not be computed because of insufficient period of record; O, observed; P, predicted]

USGS streamgage number	Type	Flow-duration exceedance probability discharges (cubic feet per second)																					
		P99.9946	P99.95	P99	P98	P95	P90	P85	P80	P75	P70	P60	P50	P40	P30	P25	P20	P15	P10	P05	P02	P01	P0.0054
01452500	O	5.30	6.40	11.0	14.0	17.0	21.0	24.0	27.0	29.0	31.0	37.0	43.0	50.0	61.0	68.0	75.0	85.0	99.0	128	180	238	2,093
	P	2.34	3.04	4.54	5.72	7.85	10.5	13.2	15.9	18.9	22.1	30.2	38.6	48.8	59.0	66.9	81.1	100	134	222	401	591	3,963
01459500	O	--	0.39	0.90	1.20	2.10	3.80	5.40	7.40	10.0	14.0	24.0	37.0	56.0	87.0	110	145	204	325	610	1,050	1,790	--
	P	2.02	2.61	4.84	6.34	9.87	14.2	18.9	24.7	30.6	36.5	51.9	71.5	97.3	125	146	185	241	339	589	1,153	1,827	9,539
01464500	O	7.00	9.70	21.0	26.0	32.0	39.0	46.0	52.0	59.0	65.0	78.0	92.0	108	129	144	163	193	248	380	602	817	3,770
	P	6.19	8.23	13.4	15.6	20.4	26.5	33.0	39.3	46.3	53.8	67.5	85.5	107	143	156	180	207	247	322	452	579	3,254
01464907	O	--	--	1.20	1.70	2.40	3.70	5.60	7.70	9.50	11.0	15.0	19.0	25.0	33.0	40.0	49.0	64.0	95.1	194	396	695	--
	P	1.14	1.52	1.96	2.60	3.80	5.21	6.57	8.06	9.58	11.2	15.7	20.4	26.2	31.0	35.9	44.3	56.9	80.5	147	299	478	3,106
01465798	O	--	0.40	1.60	2.20	3.20	4.20	5.10	6.00	6.80	7.70	9.60	12.0	15.0	19.0	23.0	28.0	39.0	61.0	124	259	408	--
	P	0.79	1.03	3.01	3.80	5.13	6.65	8.06	9.40	10.8	12.3	16.1	20.0	24.5	28.8	32.3	38.5	47.3	63.2	105	193	287	2,031
01466500	O	0.50	0.61	0.83	0.86	0.98	1.10	1.20	1.20	1.30	1.40	1.60	1.80	2.00	2.30	2.50	2.80	3.10	3.50	4.30	5.60	6.80	29.5
	P	0.21	0.30	0.48	0.58	0.74	0.96	1.16	1.32	1.52	1.76	2.18	2.64	3.11	4.02	4.38	4.78	5.37	6.34	8.41	12.1	15.2	98.5
01467048	O	--	8.90	13.0	14.0	17.0	21.0	24.0	27.0	30.0	34.0	41.0	50.0	60.0	75.0	85.0	99.2	123	169	282	541	814	--
	P	3.14	4.04	8.22	10.2	13.4	17.1	20.4	23.5	26.7	30.0	39.0	47.8	58.2	67.6	75.4	90.4	111	147	242	440	654	4,764
01467086	O	--	2.10	3.90	4.60	5.90	7.20	8.10	9.00	10.0	11.0	13.0	16.0	19.0	23.0	25.0	29.0	36.0	49.0	81.0	150	204	--
	P	0.43	0.54	2.26	2.92	3.91	5.02	5.98	6.89	7.81	8.81	11.8	14.4	17.4	19.5	22.0	26.4	32.8	45.3	80.7	159	247	1,926
01467150	O	--	3.46	5.60	6.50	8.00	9.90	12.0	13.0	14.0	16.0	18.0	21.0	24.0	28.0	31.0	35.0	43.0	58.0	98.0	175	247	--
	P	1.46	1.97	3.88	4.58	5.82	7.35	8.82	10.1	11.5	13.1	16.1	19.6	23.4	29.7	32.3	36.4	41.6	49.9	67.3	98.5	128	825
01468500	O	--	23.0	47.0	53.0	62.0	76.0	90.0	103	116	130	160	198	242	303	342	389	453	553	750	1,100	1,480	--
	P	18.6	23.5	29.2	34.2	43.8	56.0	68.2	80.0	92.5	105	133	165	203	250	275	328	391	495	724	1,150	1,583	10,676
01470500	O	40.8	61.0	92.0	106	128	160	194	226	258	292	369	461	580	746	856	1,000	1,200	1,500	2,110	3,170	4,256	32,430
	P	54.2	66.2	90.8	104	131	163	196	228	260	291	363	446	547	666	726	874	1,038	1,303	1,874	2,923	4,008	27,264
01470756	O	--	--	17.0	21.0	31.0	42.0	53.0	65.0	76.0	89.0	116	151	192	250	293	349	435	572	862	1,392	2,050	--
	P	11.1	14.1	20.8	25.3	33.9	44.5	55.1	66.3	77.9	89.7	119	152	192	236	263	321	392	512	796	1,351	1,940	12,476
01470779	O	--	16.5	27.0	30.0	35.0	42.0	48.0	52.0	57.0	62.0	74.0	86.0	100	118	130	143	160	188	253	368	508	--
	P	2.63	3.41	6.31	8.05	11.1	14.9	18.5	22.4	26.5	30.9	42.8	55.0	70.0	84.0	95.3	117	145	196	332	612	918	6,089
01471000	O	--	34.0	50.0	55.0	65.0	85.0	98.0	113	127	140	171	212	265	335	380	430	501	607	833	1,240	1,700	--
	P	11.1	14.1	23.2	28.6	38.8	50.9	62.9	76.0	89.3	103	140	179	228	278	312	384	471	621	989	1,716	2,504	16,015
01471980	O	--	12.0	21.0	23.0	28.0	34.0	39.0	44.0	50.0	56.0	69.0	85.0	105	129	145	168	197	245	368	617	887	--
	P	4.19	5.48	9.00	11.3	15.6	20.8	25.9	31.4	37.0	42.8	57.5	73.9	94.0	115	130	159	196	262	424	758	1,122	7,064
01472000	O	175	201	260	298	367	457	545	636	730	820	1,030	1,300	1,630	2,070	2,330	2,690	3,160	3,850	5,200	7,564	9,834	71,200
	P	111	134	240	278	350	432	514	600	681	759	959	1,189	1,477	1,784	1,944	2,383	2,845	3,602	5,270	8,346	11,658	77,707
01472157	O	--	7.57	11.0	13.0	17.0	20.0	24.0	28.0	32.0	36.0	47.0	58.0	72.0	90.0	102	116	137	173	257	438	633	--
	P	3.03	3.96	7.06	8.79	12.0	15.7	19.3	23.1	27.0	31.0	41.2	52.2	65.4	79.9	89.6	108	131	172	273	475	689	4,441
01472174	O	--	--	1.60	1.90	2.40	2.90	3.30	3.60	4.00	4.50	5.40	6.50	7.84	9.40	10.0	11.0	13.0	17.0	26.0	55.3	93.0	--
	P	0.32	0.44	0.68	0.87	1.21	1.62	2.00	2.37	2.76	3.20	4.28	5.36	6.60	7.93	8.99	10.6	13.0	17.4	29.2	54.2	80.7	550

Appendix 3. Observed and predicted flow-duration exceedance probability discharges for streamgages used in regression analysis.—Continued

[USGS, U.S. Geological Survey; --, flow-duration exceedance probability discharge could not be computed because of insufficient period of record; O, observed; P, predicted]

USGS streamgage number	Type	Flow-duration exceedance probability discharges (cubic feet per second)																					
		P99.9946	P99.95	P99	P98	P95	P90	P85	P80	P75	P70	P60	P50	P40	P30	P25	P20	P15	P10	P05	P02	P01	P0.0054
01472198	O	--	4.40	8.70	9.90	13.0	15.0	18.0	20.0	23.0	25.0	33.0	40.0	50.0	61.0	69.0	79.0	93.0	116	171	298	446	--
		1.82	2.42	3.67	4.66	6.55	8.87	11.2	13.6	16.2	18.9	25.6	33.0	42.1	51.6	58.7	71.3	88.6	119	196	358	533	3,367
01472199	O	--	3.20	4.90	5.40	6.70	8.10	9.50	11.0	13.0	15.0	20.0	25.0	31.0	38.0	43.0	49.0	59.0	75.0	111	203	285	--
	P	0.75	1.02	1.63	2.12	3.15	4.41	5.71	7.14	8.66	10.2	14.2	18.8	24.5	30.6	35.3	43.3	54.8	75.4	128	244	374	2,197
01473120	O	--	0.30	1.30	2.40	4.11	6.30	7.90	9.50	11.0	13.0	20.0	28.0	40.0	53.0	64.0	79.0	100	142	288	630	1,042	--
	P	3.72	4.79	7.26	9.18	12.3	15.7	18.9	22.0	25.1	28.4	38.0	47.0	57.7	66.0	74.2	90.0	112	152	263	501	765	5,689
01475510	O	--	--	12.0	14.0	17.0	20.0	23.0	25.0	28.0	31.0	37.0	45.0	52.0	61.0	67.0	75.0	86.0	106	171	301	440	--
	P	1.55	1.99	6.03	7.52	9.86	12.5	14.8	17.0	19.2	21.6	28.1	34.3	41.5	48.0	53.4	63.5	77.2	102	168	304	448	3,305
01475530	O	--	--	1.50	1.60	1.80	2.20	2.50	2.80	3.00	3.30	3.90	4.50	5.20	5.90	6.50	7.50	8.96	12.0	23.0	43.0	68.0	--
	P	0.16	0.22	0.67	0.87	1.16	1.50	1.79	2.05	2.33	2.65	3.53	4.28	5.12	5.84	6.58	7.68	9.42	12.8	22.1	42.5	64.1	498
01475850	O	--	1.10	2.70	3.50	4.60	6.00	7.20	8.50	9.70	11.0	13.0	16.0	19.0	22.0	25.0	28.0	32.0	40.0	64.0	120	186	--
	P	0.69	0.93	1.90	2.42	3.32	4.36	5.32	6.27	7.26	8.33	11.1	13.8	17.0	20.4	23.0	27.2	33.3	44.2	72.7	132	195	1,322
01477120	O	--	3.30	7.60	9.71	12.0	14.0	16.0	17.0	19.0	21.0	24.0	29.0	34.0	39.0	43.0	47.0	54.0	66.0	98.0	170	249	--
	P	2.25	3.04	6.28	7.35	9.19	11.4	13.5	15.3	17.3	19.5	23.8	28.6	34.0	42.9	46.3	52.2	59.1	70.4	94.0	136	174	1,146
01477800	O	0.09	0.10	0.30	0.40	0.57	0.80	1.00	1.20	1.40	1.70	2.20	2.90	3.90	5.20	6.40	8.00	11.0	18.0	41.0	96.4	150	1,444
	P	0.18	0.24	0.89	1.17	1.59	2.05	2.44	2.80	3.18	3.61	4.83	5.90	7.11	8.06	9.11	10.7	13.3	18.3	32.6	64.5	99.7	763
01478000	O	0.20	0.40	1.50	2.10	3.10	4.40	5.40	6.50	7.50	8.50	11.0	13.0	16.0	20.0	22.0	26.0	32.0	47.0	98.2	219	366	2,466
	P	0.65	0.88	2.54	3.21	4.39	5.69	6.88	8.06	9.26	10.6	13.8	17.2	21.2	25.6	28.6	33.8	40.9	53.8	86.3	153	224	1,477
01479000	O	5.10	6.47	16.0	20.0	26.0	32.0	38.0	44.0	49.0	54.0	65.0	78.0	93.0	111	123	139	160	198	300	549	875	7,630
	P	4.67	5.96	19.3	23.1	29.2	35.9	41.9	47.5	53.0	58.9	73.4	88.6	106	126	138	162	191	241	358	583	814	5,731
01479820	O	--	--	5.70	8.40	11.0	13.0	15.0	17.0	19.0	20.0	25.0	29.0	34.0	41.0	44.0	49.0	55.0	65.0	96.0	190	329	--
	P	1.45	1.91	5.01	6.16	8.00	10.1	11.9	13.7	15.4	17.4	22.1	26.9	32.3	38.4	42.4	49.5	59.0	75.9	118	200	284	2,015
01480000	O	4.50	5.65	11.0	13.0	17.0	19.0	22.0	25.0	28.0	31.0	37.0	44.0	53.0	63.0	70.0	79.0	90.0	110	161	293	438	3,890
	P	2.60	3.37	9.97	12.0	15.3	18.9	22.2	25.2	28.2	31.5	39.5	47.6	56.8	67.6	74.0	86.3	102	129	195	321	449	3,205
01480015	O	--	--	13.0	16.0	19.0	22.0	25.0	29.0	32.0	36.0	43.0	52.0	62.0	74.0	82.0	91.0	105	129	192	349	537	--
	P	2.81	3.63	11.3	13.6	17.2	21.2	24.9	28.1	31.4	34.9	43.7	52.5	62.7	74.5	81.4	95.0	112	142	213	351	491	3,507
01480100	O	--	--	0.43	0.68	1.20	1.50	1.80	2.10	2.40	2.80	3.60	4.40	5.20	6.40	7.30	8.90	12.0	17.0	37.0	78.8	118	--
	P	0.24	0.32	0.96	1.23	1.64	2.10	2.50	2.87	3.25	3.70	4.84	5.89	7.06	8.27	9.24	10.7	12.9	17.0	28.0	50.9	74.6	545
01480300	O	1.00	1.40	3.30	4.30	5.70	6.90	7.90	9.00	9.90	11.0	13.0	16.0	18.0	22.0	24.0	27.0	32.0	42.0	78.0	161	259	1,620
	P	0.41	0.57	1.51	1.94	2.80	3.84	4.87	5.97	7.14	8.40	11.4	14.8	19.0	23.9	27.2	32.6	40.3	53.8	87.3	157	233	1,377
01480675	O	--	0.26	0.68	0.91	1.50	2.10	2.60	3.20	3.80	4.40	6.00	7.90	10.0	12.0	14.0	16.0	19.0	25.0	42.0	71.0	97.0	--
	P	0.28	0.39	0.60	0.79	1.17	1.63	2.10	2.60	3.14	3.72	5.12	6.71	8.63	10.9	12.5	15.0	18.8	25.5	42.9	80.8	122	717
01481000	O	42.0	50.0	69.0	80.0	99.7	118	138	158	174	190	230	270	322	391	439	496	571	699	985	1,580	2,230	9,590
	P	20.5	25.3	66.9	78.2	98.7	121	143	163	183	203	251	306	372	449	488	583	688	863	1,251	1,979	2,744	18,502
01482500	O	0.00	0.00	0.80	1.70	2.90	4.40	5.40	6.30	7.30	8.50	10.0	12.0	14.0	18.0	20.0	22.0	27.0	35.0	57.0	107	163	4,325
	P	0.61	0.85	1.78	2.24	3.05	3.98	4.84	5.68	6.57	7.56	9.83	12.3	15.1	18.7	20.8	24.2	28.9	37.1	57.1	96.7	137	874

Appendix 3. Observed and predicted flow-duration exceedance probability discharges for streamgages used in regression analysis.—Continued

[USGS, U.S. Geological Survey; --, flow-duration exceedance probability discharge could not be computed because of insufficient period of record; O, observed; P, predicted]

USGS streamgage number	Type	Flow-duration exceedance probability discharges (cubic feet per second)																					
		P99.9946	P99.95	P99	P98	P95	P90	P85	P80	P75	P70	P60	P50	P40	P30	P25	P20	P15	P10	P05	P02	P01	P0.0054
01483000	O	--	--	0.00	0.00	2.50	3.90	5.10	6.50	7.30	8.90	12.0	15.0	19.0	24.0	27.0	31.0	36.0	47.0	70.0	117	167	--
	P	0.99	1.36	2.98	3.69	4.88	6.21	7.42	8.57	9.78	11.2	14.3	17.6	21.3	26.2	28.9	33.3	39.3	49.6	74.1	121	169	1,106
01483500	O	--	--	2.20	2.50	2.90	3.40	3.80	4.20	4.70	5.00	6.00	7.10	8.70	10.0	12.0	13.0	15.0	18.0	28.0	45.0	65.0	--
	P	0.63	0.91	1.65	2.03	2.64	3.30	3.88	4.38	4.93	5.57	6.95	8.39	9.94	12.2	13.4	15.1	17.4	21.5	31.2	49.4	67.2	447
01484000	O	--	1.00	1.50	1.80	2.40	3.00	3.50	4.10	4.70	5.60	7.60	10.0	13.0	17.0	20.0	23.0	27.0	35.0	54.0	96.0	139	--
	P	0.55	0.80	1.45	1.84	2.54	3.27	3.95	4.62	5.30	6.05	7.67	9.59	11.8	14.9	16.5	19.0	22.4	28.2	41.7	68.4	96.1	563
01484100	O	0.01	0.04	0.31	0.40	0.60	0.81	1.10	1.30	1.50	1.80	2.30	2.80	3.40	4.10	4.60	5.10	5.80	6.70	8.90	14.0	21.0	99.9
	P	0.12	0.18	0.26	0.34	0.51	0.69	0.86	1.04	1.23	1.44	1.88	2.42	3.05	3.98	4.51	5.19	6.27	8.12	12.6	21.9	31.9	170
01484270	O	--	--	4.30	4.80	6.00	7.00	7.70	8.30	8.90	9.40	10.0	12.0	13.0	15.0	16.0	17.0	18.0	20.0	24.0	28.0	32.5	--
	P	0.95	1.33	3.25	3.81	4.42	5.01	5.45	5.64	5.93	6.35	7.22	8.01	8.77	10.2	10.8	11.6	12.8	15.0	20.3	29.9	38.5	310
01484300	O	--	--	2.30	2.60	3.20	3.90	4.30	4.90	5.50	6.20	7.70	9.10	10.0	12.0	13.0	14.0	15.0	17.0	21.0	27.0	31.0	--
	P	1.00	1.40	3.54	4.13	4.73	5.33	5.76	5.93	6.21	6.64	7.55	8.32	9.05	10.5	11.0	11.8	13.0	15.3	20.6	30.3	38.9	323
01484500	O	0.08	0.15	0.75	0.91	1.20	1.60	2.00	2.40	2.80	3.30	4.20	5.40	6.70	8.30	9.30	10.0	12.0	15.0	19.0	27.0	35.0	191
	P	0.33	0.48	0.94	1.17	1.54	1.89	2.18	2.41	2.66	2.94	3.56	4.22	4.91	5.96	6.50	7.24	8.38	10.4	15.4	25.2	35.1	236
01487000	O	6.70	8.40	16.0	18.0	22.0	26.0	30.0	35.0	39.0	43.0	54.0	69.0	85.0	105	117	133	153	182	239	345	452	2,700
	P	5.47	7.57	14.1	16.9	21.9	26.6	30.9	34.9	38.8	42.9	51.4	62.4	74.9	94.2	102	117	134	162	222	336	455	2,740
01488500	O	1.20	1.60	3.10	3.60	5.60	7.90	9.80	12.0	14.0	16.0	22.0	30.0	40.0	52.0	60.0	71.0	86.0	114	176	311	447	2,681
	P	1.79	2.60	3.80	4.84	7.06	9.34	11.6	14.1	16.6	19.1	24.5	31.9	40.9	53.8	60.2	71.4	86.0	110	163	273	393	1,987
01498500	O	--	6.31	9.30	11.0	16.0	22.0	29.0	38.0	49.0	61.0	94.0	132	184	260	312	380	463	587	859	1,325	1,798	--
	P	3.35	4.44	4.57	5.77	8.95	14.3	20.8	29.6	40.5	53.5	83.8	124	181	262	308	392	493	648	979	1,564	2,153	9,648
01499000	O	--	4.83	7.46	9.00	12.0	16.0	21.0	28.0	35.0	42.0	62.0	89.0	124	172	205	244	294	366	557	917	1,200	--
	P	2.93	3.90	2.80	3.57	5.60	9.00	13.2	18.8	25.8	34.1	53.7	79.9	116	168	199	252	319	422	646	1,050	1,457	6,527
01533950	O	--	--	0.30	0.50	0.90	1.40	1.90	2.40	2.90	3.50	5.10	7.20	9.60	14.0	17.0	21.0	27.0	37.5	63.0	122	176	--
	P	0.30	0.41	0.70	0.90	1.33	1.97	2.66	3.46	4.41	5.51	8.09	11.0	14.6	19.3	22.4	27.1	33.8	45.1	72.7	127	181	1,035
01534000	O	7.10	9.70	21.0	25.0	36.0	52.0	67.0	85.0	109	135	194	270	373	520	630	765	957	1,260	1,930	3,170	4,330	25,770
	P	11.3	14.1	28.9	34.7	48.3	68.3	90.7	117	147	181	257	349	470	628	711	885	1,078	1,378	2,018	3,136	4,271	23,328
01538000	O	1.60	2.36	4.50	5.10	6.80	9.10	12.0	15.0	18.0	22.0	31.0	41.0	53.0	69.0	80.0	93.0	111	139	198	306	419	2,610
	P	0.98	1.30	3.55	4.45	6.24	8.73	11.3	14.2	17.4	20.9	29.3	38.6	50.2	64.1	73.0	88.6	109	143	226	386	549	3,313
01539000	O	8.40	9.30	19.0	22.0	35.0	54.0	76.0	99.0	125	150	208	278	368	495	580	685	838	1,070	1,560	2,380	3,190	25,760
	P	13.7	17.3	33.5	39.8	53.2	71.4	90.8	112	135	159	214	278	359	458	511	626	756	964	1,420	2,246	3,091	18,752
01576754	O	--	--	95.0	112	143	182	217	251	285	316	390	472	567	694	776	883	1,020	1,240	1,752	2,741	4,140	--
	P	20.1	24.8	90.4	108	135	164	190	217	242	269	345	419	509	590	644	781	934	1,205	1,871	3,143	4,506	33,139
01578400	O	--	--	1.60	1.80	2.10	2.60	3.00	3.30	3.60	3.90	4.60	5.40	6.08	7.20	7.90	8.70	10.00	13.0	19.0	41.8	65.0	--
	P	0.20	0.27	0.91	1.16	1.53	1.96	2.32	2.64	2.99	3.40	4.48	5.41	6.44	7.43	8.30	9.61	11.61	15.4	25.7	47.2	69.4	533.01

Prepared by USGS West Trenton Publishing Service Center.

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USGS

Stuckey, M.H.—**Estimation of Daily Mean Streamflow for Ungaged Stream Locations in the Delaware River Basin, Water Years 1960–2010**—Scientific Investigations Report 2015–5157

ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20155157