ESTIMATED GROUND-WATER AVAILABILITY IN THE DELAWARE RIVER BASIN, 1997-2000

By Ronald A. Sloto and Debra E. Buxton

In cooperation with the Delaware River Basin Commission

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Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
billion gallons (Bgal)	3,785,000	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per day per square mile [$(gal/d)/mi^2$]	0.001461	cubic meter per day per square kilometer [$(m^3/d)/km^2$]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile [$(Mgal/d)/mi^2$]	1,461	cubic meter per day per square kilometer [$(m^3/d)/km^2$]
million gallons per year (Mgal/yr)	15.99	cubic meter per second (m^3/s)
billion gallons per year (Bgal/yr)	15,990	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]

ESTIMATED GROUND-WATER AVAILABILITY IN THE DELAWARE RIVER BASIN, 1997-2000

by Ronald A. Sloto and Debra E. Buxton

Abstract

Ground-water availability using a watershed-based approach was estimated for the 147 watersheds that make up the Delaware River Basin. This study, conducted by the U.S. Geological Survey in cooperation with the Delaware River Basin Commission (DRBC), supports the DRBC's Water Resources Plan for the Delaware River Basin. Different procedures were used to estimate ground-water availability for the region underlain by fractured rocks in the upper part of the basin and for surficial aquifers in the region underlain by unconsolidated sediments in the lower part of the basin. The methodology is similar to that used for the Delaware River Basin Commission's Ground-Water Protected Area in Pennsylvania. For all watersheds, ground-water availability was equated to average annual base flow.

Ground-water availability for the 109 watersheds underlain by fractured rocks in Delaware, New Jersey, New York, and Pennsylvania was based on lithology and physiographic province. Lithology was generalized by grouping 183 geologic units into 14 categories on the basis of rock type and physiographic province. Twenty-three index streamflow-gaging stations were selected to represent the 14 categories. A base-flow-recurrence analysis was used to determine the average annual 2-, 5-, 10-, 25-, and 50-year-recurrence intervals for each index station. A GIS analysis used lithology and base flow at the index stations to determine the average annual base flow for the 109 watersheds. Average annual base flow for these watersheds ranged from 0.313 to 0.915 million gallons per day per square mile for the 2-year-recurrence interval to 0.150 to 0.505 million gallons per day per square mile for the 50-year-recurrence interval.

Ground-water availability for watersheds underlain by unconsolidated surficial aquifers was based on predominant surficial geology and land use, which were determined from statistical tests to be the most significant controlling factors of base flow. Twenty-one index streamflow-gaging stations were selected to represent the 13 categories of predominant surficial geology and land use for the 38 Coastal Plain watersheds. A base-flow-recurrence analysis was used to determine the average annual 2-, 5-, 10-, 25-, and 50-year-recurrence intervals for each group of predominant surficial geology and land use. Average annual base flow for these watersheds ranged from 0.465 to 1.169 million gallons per day per square mile for the 2-year-recurrence interval to 0.178 to 0.670 million gallons per day per square mile for the 50-year-recurrence interval.

Estimated 2-, 5-, 10-, 25-, and 50-year annual base-flow-recurrence interval values for each watershed in the Delaware River Basin are considered to be the quantity of ground water available for each watershed over a range of climatic conditions. The recurrence intervals are considered to be relative indicators of climatic difference; the 2-year-recurrence value represents wetter years, and the 50-year-recurrence value represents drier years. The remaining available ground water in each watershed was determined by subtracting current (1997-2000) ground-water withdrawals and consumptive domestic use and adding water recharged by agricultural irrigation and land application of treated-sewage effluent. Ground-water use ranged from 0 to 60.8 percent of available ground water for the 2-year-recurrence interval; it exceeded 25 percent in four watersheds and 50 percent in two watersheds. Ground-water use ranged from 0 to 75.9 percent of available ground water for the 5-year-recurrence interval; it exceeded 25 percent in five watersheds and 50 percent in three watersheds. Ground-water use ranged from 0 to 84.5 percent of available ground water for the 10-year-recurrence interval; it exceeded 25 percent in seven watersheds and 50 percent in four watersheds. Ground-water use ranged from 0 to 103 percent of available ground water for the 25-year-recurrence interval; it exceeded 25 percent in nine watersheds, 50 percent in three watersheds, and 100 percent in one watershed. Ground-water use ranged from 0 to 127 percent of available ground water for the 50-year-recurrence interval; it exceeded 25 percent in 11 watersheds, 50 percent in 6 watersheds, and 125 percent in 1 watershed. If ground water pumped for quarry dewatering is not considered as a withdrawal, the ground-water use percentage in some watersheds would drop substantially.

Introduction

Water is one of the most important natural resources in the Delaware River Basin. The Delaware River, the largest undammed river east of the Mississippi, drains 12,765 mi^2;

50.3 percent of the basin is in Pennsylvania, 23.3 percent is in New Jersey, 18.5 percent is in New York, and 7.9 percent is in Delaware (fig. 1). The large Philadelphia-Camden metropolitan area is in the Delaware River Basin, as well as the major cities of Dover and Wilmington, Del.; Trenton, N.J.; and Allentown, Pa. Nearly 15 million people (about 5 percent of the Nation's population) rely on the water of the basin for public-water supply and industrial use. New York City, which is outside the basin, uses reservoirs in the upper part of the basin for public-water supply.

In September 1999, the governors of the four Delaware River Basin states adopted a resolution directing the Delaware River Basin Commission (DRBC) to develop a new comprehensive water-resources plan for the basin. The Water Resources Plan for the Delaware River Basin presents a basinwide vision of long-range goals and directions to guide water-resources management. The plan provides a unified framework for addressing new and historic water-resource issues and problems in the basin. The plan uses a goal-based planning process that incorporates key result areas with goals, objectives, and milestones (Delaware River Basin Commission, 2004).

The first key result area in the Water Resources Plan for the Delaware River Basin is "Sustainable Use and Supply." Sustainability is defined as "the use of a resource in a manner that meets current needs without compromising the ability to adequately meet the needs of future generations" (Delaware River Basin Commission, 2004, p. 93). The first goal under this key result is "Equitably balance multiple demands on the limited water resources of the Basin, while preserving and enhancing conditions in watersheds to maintain or achieve ecological integrity." To meet this goal, it is necessary to assess current ground-water availability (Delaware River Basin Commission, 2004, p. 18-20).

A key element of water-resources planning is a systematic approach for comparing existing and future water withdrawals against available water supplies and environmental requirements. Major components of water-resources planning include the development of water-supply and water-use data, sometimes referred to as the water budget, and allocation policy, such as withdrawal limits. Development of water-allocation policy generally entails assessment of the availability of water in a watershed, as well as the comparison of the effects of different policies on water allocation and environmental conditions.

This study was conducted by the U.S. Geological Survey (USGS) during 2003-05, in cooperation with the DRBC, to determine the availability of ground water on a watershed basis in the Delaware River Basin. The results of this study provide water-resource managers and policy makers with a methodology to compare the current (1997-2000) use of ground water with the available ground water in each watershed in the Delaware River Basin.

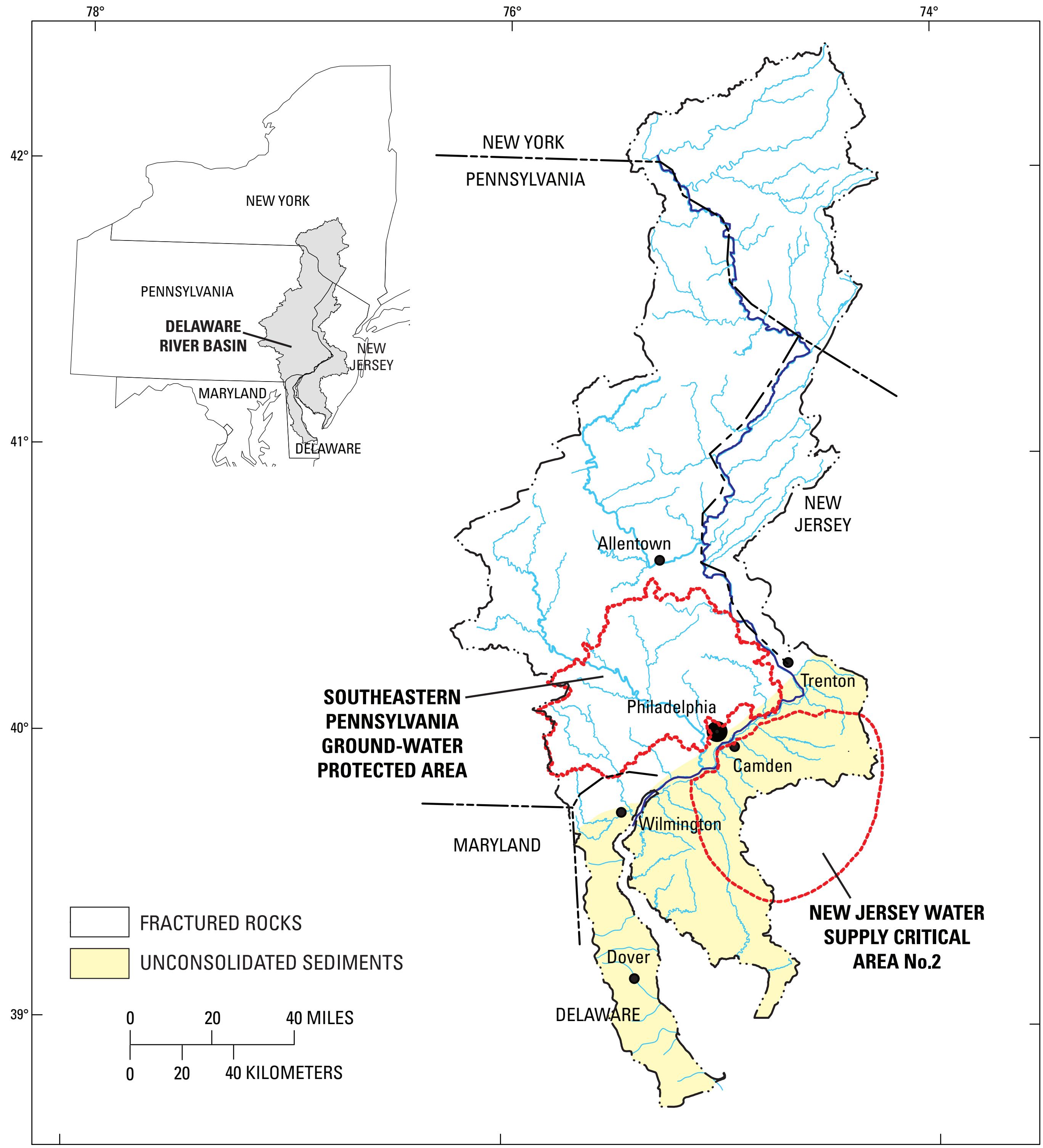
Purpose and Scope

This report describes the methodology for determining ground-water availability in the Delaware River Basin using a watershed-based approach, presents ground-water availability by watershed, and compares availability with current use. Ground-water availability was determined by different methods for watersheds underlain by fractured, consolidated rocks and for surficial aquifers in watersheds underlain by unconsolidated sediments. Ground-water availability was determined for all 147 watersheds in the basin; average watershed size was about 87 mi^2. For all watersheds, ground-water availability was equated to average annual base flow. The 2-, 5-, 10-, 25-, and 50-year annual base-flow-recurrence intervals calculated for each watershed represent a range of climatic conditions from wet (2-year-recurrence interval) to dry (50-year-recurrence interval). Current ground-water use was determined for each watershed and compared to available ground water over this range of climatic conditions. The report identifies watersheds where ground-water use exceeds 25 percent of the 10-, 25-, and 50-year annual base-flow-recurrence values.

Study Area

The study area includes the entire Delaware River Basin (fig. 1). Approximately 77 percent of the basin is underlain by fractured, consolidated rocks, and 23 percent of the basin is underlain by unconsolidated sediments. The fractured-rock lithologies include igneous (diabase), sedimentary (sandstone, shale, conglomerate, limestone, and dolomite), and metamorphic (gneiss, schist, quartzite, and marble) rocks. Surficial unconsolidated sediments are Cretaceous to Holocene gravel, sand, clay, and silt. The physiography and topography of the basin is highly varied and is discussed in following sections. Average annual precipitation in the basin ranges from 40 to 50 in/yr (Jenner and Lins, 1991, p. 58).

The DRBC Southeastern Pennsylvania Ground-Water Protected Area and about half of the New Jersey Water Supply Critical Area No. 2 also are included in the study area (fig. 1). The Southeastern Pennsylvania Ground-Water Protected Area was established in 1980 to protect the ground-water resources in the Triassic Lowland Section of the Piedmont Phyisographic Province and adjacent areas to assure the effective management of water withdrawals to avoid depletion of streamflow and ground water and to protect the quality of that water, assure that ground-water withdrawals are consistent with DRBC policies, to protect the rights of present and future users of water resources, and to provide a mechanism to more accurately plan and manage water resources (Delaware River Basin Commission, 1999). The New Jersey Water Supply Critical Area No. 2 was designated in 1999 where excessive water withdrawals posed a major threat to the long-term integrity of the water supply. Water allocations from the Potomac-Raritan-Magothy aquifer system were reduced an average of 22 percent within this area by the state.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area
Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W.

Figure 1. Location of the Delaware River Basin and areas underlain by fractured rocks and unconsolidated sediments.

Ground-Water Availability

Ground-water availability estimates were made for all watersheds in the Delaware River Basin. The estimates were made using spatial data in a Geographic Information System (GIS). The spatial analyses used available data sets. The approach used for fractured rocks is similar to that used for determining ground-water-withdrawal limits in the DRBC Southeastern Pennsylvania Ground-Water Protected Area (Delaware River Basin Commission, 1999).

Watershed Characterization

Watersheds were delineated jointly by the DRBC and the USGS and were based on a modified hydrologic unit code (HUC) fifth-level watershed designation. Large watersheds were subdivided into smaller areas, and small watersheds were accreted to yield watersheds of approximately 50 to 150 mi^2 (fig. 2). The Delaware River Basin was divided into 147 watersheds ranging from 17.9 to 210 mi^2; the average size was 87.4 mi^2 (table 1). Eighty percent (118) of the watersheds are between 30 and 120 mi^2.

Watershed size was chosen to produce a manageable number of watersheds in the Delaware River Basin. The approach used for fractured rocks in this study is similar to that used for the DRBC Southeastern Pennsylvania Ground Water Protected Area (Town and Bird, 1998; Delaware River Basin Commission, 1999). Watershed size used for the 1,680 mi^2 Protected Area ranged from 6.28 to 55.4 mi^2 and averaged 19.8 mi^2. Using an average watershed size of 19.8 mi^2 for the Delaware River Basin would produce 645 watersheds. When comparing ground-water use to availability, watershed size becomes very important. For example, a withdrawal of 1 Mgal/d is equal to 0.05 (Mgal/d)/mi^2 for a 20-mi^2 watershed but only 0.008 (Mgal/d)/mi^2 for a 120-mi^2 watershed. Selecting an appropriate watershed size is a compromise between missing a potential problem area because the chosen watershed size is too large and having too many potential problem areas because the chosen watershed size is too small. The comparison between water use and available ground water for this study was made using a spatial-data analysis. The advantage of using a spatial-data analysis is that any watershed can be subdivided into smaller watersheds and the analysis rerun to further define a problem area.

Geologic Units

The upper part of the Delaware River Basin is underlain by consolidated, fractured rocks, and the lower part is underlain by unconsolidated sediments (fig. 1). A geologic map of the Delaware River Basin was compiled as a GIS spatial data set using available digital mapping. Geologic units were digitized from the map of Higgins and Conant (1990, plate 1) only for the 8 mi^2 of Maryland in the Delaware River Basin because digital geologic mapping was not available.

Geologic units for Delaware were taken from the digital geologic map of Plank and others (2000, plate 1) for the fractured rocks of the Piedmont Physiographic Province. This map was used where it extends into Chester and Delaware Counties, Pa. Geologic units for the unconsolidated sediments of New Castle County, Del., was taken from Ramsey (2005).

Geologic units for most of Pennsylvania were taken from the digital version of the Pennsylvania state geologic map compiled by Berg and others (1980). Geologic units for Chester County were taken from the digital geologic map of Sloto (1994, plates 1 and 2), and were taken for Delaware County from the digital geologic map of Balmer and Davis (1996, plate 1).

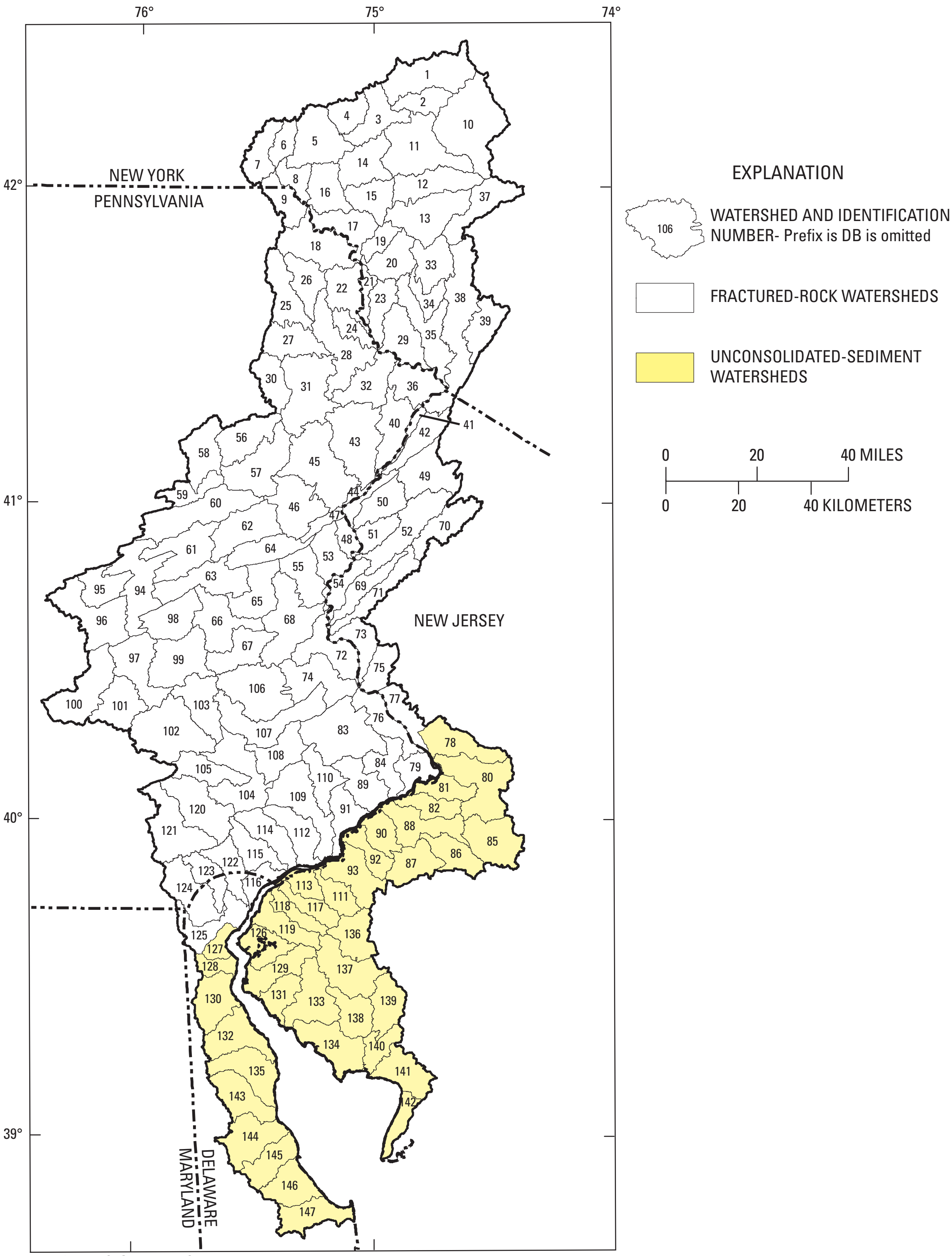
Geologic units for the part of New Jersey underlain by fractured rocks were taken from the digital geologic map of Drake and others (1996). Geologic units for the part of New Jersey underlain by unconsolidated sediments were provided in digital form by the New Jersey Geological Survey. Geologic units for New York were taken from digital maps based on lithology compiled by Fisher and others (1970a, 1970b, 1970c).

For the compiled digital geologic map of fractured rocks, geologic unit names and map symbols were made consistent across state lines, where possible. Some groupings of units were made. All mapped occurrences of diabase and basalt in New Jersey were grouped into one unit called diabase. All subunits of the Passaic Formation in New Jersey were grouped into a single unit equivalent to the Brunswick Group in Pennsylvania. All mapped subunits of the Lockatong, Stockton, Martinsburg, and Jacksonburg Formations, the Beekmantown Group, Triassic-Jurassic conglomerate, and the rocks of the Jutland Klippe were grouped.

Estimates of ground-water availability for watersheds underlain by fractured rocks were based on generalized lithology and physiographic province. The 183 mapped fractured-rock geologic units were generalized into 14 rock types (fig. 3). Physiographic provinces are taken from Sevon (2000) for Pennsylvania, Pristas (2002) for New Jersey, and Fenneman and Johnson (1946) for Delaware and New York.

Ground-Water Withdrawals

Ground-water-withdrawal data were provided in a database by the DRBC (David Sayers, written commun., 2004). The accuracy of locations and quantities were not verified. Withdrawals include water pumped for public supply, irrigation, and commercial, industrial, and institutional use. Withdrawal amounts for Delaware were based on 2000 data and ranged from 0.06 to 426 Mgal/yr; for New Jersey were based on 1999 data and ranged from 0.01 to 3,181 Mgal/yr; for New York were based on 1999 data and ranged from 0.9 to 248 Mgal/yr; and for Pennsylvania were based on 1997 data and ranged from 0.01 to 7.4 Mgal/yr. A point-feature GIS dataset of ground-water withdrawals was created, and a spatial-data analysis was used to determine the quantity of ground-water withdrawal for each watershed by summing withdrawals



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30′N, central meridian 75°00′W.

Figure 2. Watersheds in the Delaware River Basin. Watershed names are listed in table 1.

Table 1. Watersheds in the Delaware River Basin. --Continued

[mi^2, square miles; DB, Delaware River Basin; DE, Delaware; NJ, New Jersey; NY, New York;, PA, Pennsylvania]

Basin identification number	Drainage area (mi^2)	State	Streams
DB-001	144	NY	Upper part of West Branch Delaware River
DB-002	52.3	NY	Little Delaware River
DB-003	82.8	NY	Middle part of West Branch Delaware River
DB-004	53.1	NY	Upper part of West Branch Delaware River and East Branch Delaware River
DB-005	123	NY	Lower part of West Branch Delaware River
DB-006	39.2	NY	Cold Spring Creek, Butler Brook, Bone Creek
DB-007	67.8	NY	Oquaga Creek
DB-008	42.5	NY	Whitaker Brook, Rhoads Creek, Cadosia Creek, City Brook, Read Creek (tributaries to Delaware River)
DB-009	62.1	PA / NY	Faulkner Brook, Balls Creek, Shehawken Creek, Sherman Creek
DB-010	210	NY	Upper part of East Branch Delaware River above Platte Kill
DB-011	161	NY	Upper part of East Branch Delaware River and tributaries to Pepacton Reservoir
DB-012	97.1	NY	Upper part of Beaver Kill
DB-013	133	NY	Willowemoc Creek
DB-014	91.5	NY	Middle part of East Branch Delaware River below Pepacton Reservoir
DB-015	70.0	NY	Lower part of Beaver Kill
DB-016	78.5	NY	Lower part of East Branch Delaware River
DB-017	82.5	NY	Hankins Creek, Basket Creek, Hoolihan Creek, Abe Lord Creek, Humphries Creek, Blue Mill Stream (tributaries to Delaware River)
DB-018	122	PA	Equinunk Creek
DB-019	35.7	NY	East Branch Callicoon Creek
DB-020	76.2	NY	North Branch Callicoon Creek
DB-021	25.8	NY	Unnamed tributaries to Delaware River
DB-022	80.1	PA	Calkins Creek, Cooley Creek, Hollister Creek, Beaverdam Creek, Peggy Run (tributaries to Delaware River)
DB-023	59.2	NY	Ten Mile River
DB-024	39.4	PA	Masthope Creek, Westcolong Creek (tributaries to Delaware River)
DB-025	92.2	PA	West Branch Lackawaxen River
DB-026	70.0	PA	Dyberry Creek
DB-027	82.2	PA	Middle Creek
DB-028	126	PA	Lackawaxen River
DB-029	88.8	NY	Fish Cabin Creek, Mill Brook, Halfway Brook, Beaver Brook, Narrow Falls Brook, Grassy Swamp Brook (tributaries to Delaware River)
DB-030	67.5	PA	West Branch Wallenpaupack Creek
DB-031	160	PA	Wallenpaupack Creek
DB-032	92.6	PA	Shohola Creek, Panther Creek (tributaries to Delaware River)
DB-033	77.9	NY	Mongaup River above Swinging Bridge Reservoir
DB-034	40.3	NY	Mongaup River tributaries to Swinging Bridge Reservoir
DB-035	111	NY	Mongaup River below Swinging Bridge Reservoir, Shingle Kill
DB-036	80.2	PA	Walker Lake Creek, Pond Eddy Creek, Cummins Creek, Sawkill Creek, Craword Branch (tributaries to Delaware River)
DB-037	92.7	NY	Neversink River above Neversink Reservoir

Table 1. Watersheds in the Delaware River Basin. --Continued

[mi², square miles; DB, Delaware River Basin; DE, Delaware; NJ, New Jersey; NY, New York;, PA, Pennsylvania]

Basin identification number	Drainage area (mi²)	State	Streams
DB-038	197	NY / NJ	Neversink River below Neversink Reservoir
DB-039	72.5	NY	Basher Kill
DB-040	88.5	PA	Raymondskill Creek, Dingmans Creek, Conashaugh Creek, Dry Brook, Adams Creek, Hornbecks Creek, Toms Creek (tributaries to Delaware River)
DB-041	17.9	NJ	Unnamed tributaries to Delaware River
DB-042	66.2	NJ	Flat Brook
DB-043	158	PA	Bush Kill
DB-044	30.7	NJ	Vancampens Brook, Dunnfield Creek, and tributaries to Delaware River
DB-045	174	PA	Brodhead Creek
DB-046	114	PA	Pocono Creek
DB-047	34.8	PA	Cherry Creek, Caledonia Creek (tributaries to Delaware River)
DB-048	30.2	PA	Slateford Creek, Jacoby Creek, Allegheny Creek (tributaries to Delaware River)
DB-049	107	NJ	Paulins Kill above Stillwater Village, Trout Brook
DB-050	69.8	NJ	Paulins Kill below Stillwater Village
DB-051	48.8	NJ	Stony Brook, Delawanna Creek, Beaver Brook
DB-052	120	NJ	Pequest River
DB-053	74.9	PA	Martins Creek, Mud Run (tributaries to Delaware River)
DB-054	47.9	NJ	Pophandusing Brook, Buckhorn Creek, Lopatcong Creek, and tributaries to Delaware River
DB-055	79.9	PA	Bush Kill
DB-056	93.2	PA	Upper part of Lehigh River
DB-057	129	PA	Tobyhanna Creek
DB-058	91.1	PA	Bear Creek
DB-059	49.4	PA	Middle part of Lehigh River above Sandy Run
DB-060	149	PA	Middle part of Lehigh River above Black Creek
DB-061	117	PA	Middle part of Lehigh River above Pohopoco Creek
DB-062	111	PA	Pohopoco Creek
DB-063	113	PA	Lower part of Lehigh River
DB-064	78.3	PA	Aquashicola Creek
DB-065	91.8	PA	Lower part of Lehigh River above Little Lehigh Creek
DB-066	106	PA	Jordan Creek
DB-067	83.8	PA	Little Lehigh Creek
DB-068	149	PA	Lower part of Lehigh River below Little Lehigh Creek
DB-069	58.2	NJ	Pohatcong Creek
DB-070	81.7	NJ	Musconetcong River above Trout Brook
DB-071	73.9	NJ	Musconetcong River below and including Trout Brook
DB-072	96.9	PA	Frya Run, Cooks Creek, Tinicum Creek, and tributaries to Delaware River
DB-073	62.5	NJ	Harihokake Creek, Nishisakawick Creek, and tributaries to Delaware River
DB-074	112	PA	Tohickon Creek
DB-075	54.4	NJ	Lockatong Creek, Wickecheoke Creek, and tributaries to Delaware River
DB-076	77.3	PA	Geddes Run, Hickory Creek, Paunnacussing Creek, Aquetong Creek, Hollow Run, Pidcock Creek, Jericho Creek, Houghs Creek, Dyers Creek

Table 1. Watersheds in the Delaware River Basin. --Continued

[mi², square miles; DB, Delaware River Basin; DE, Delaware; NJ, New Jersey; NY, New York;, PA, Pennsylvania]

Basin identification number	Drainage area (mi²)	State	Streams
DB-077	62.5	NJ	Alexauken Creek, Moores Creek, Jacobs Creek, and tributaries to Delaware River
DB-078	95.7	NJ	Assunpink Creek
DB-079	54.0	PA	Martins Creek and tributaries to Delaware River
DB-080	144	NJ	Crosswicks Creek
DB-081	52.3	NJ	Crafts Creek, Black Creek, and tributaries to Delaware River
DB-082	53.1	NJ	Assiscunk Creek and tributaries to Delaware River
DB-083	168	PA	Neshaminy Creek above Little Neshaminy Creek
DB-084	65.1	PA	Neshaminy Creek below Little Neshaminy Creek
DB-085	110	NJ	North Branch Rancocas Creek above New Lisbon Dam, Greenwood Branch
DB-086	68.6	NJ	South Branch Rancocas Creek above Bobbys Run
DB-087	76.0	NJ	South Branch Rancocas Creek above South West Branch
DB-088	95.8	NJ	Rancocas Creek main stem with North Branch below New Lisbon Dam and South Branch below Bobbys Run
DB-089	80.2	PA	Poquessing Creek, Pennypack Creek, and tributaries to Delaware River
DB-090	56.2	NJ	Pennsauken Creek, Pompeston Creek, and tributaries to Delaware River
DB-091	65.7	PA	Frankford Creek and tributaries to Delaware River
DB-092	51.3	NJ	Cooper River
DB-093	98.9	NJ	Woodbury Creek, Big Timber Creek, Newton Creek, and tributaries to Delaware River
DB-094	137	PA	Little Schuylkill River
DB-095	66.9	PA	Upper part of Schuylkill River above Pottsville
DB-096	138	PA	Upper part of Schuylkill River below Pottsville
DB-097	107	PA	Tributaries to middle part of Schuylkill River
DB-098	90.8	PA	Maiden Creek above Sacony Creek
DB-099	125	PA	Maiden Creek below Sacony Creek
DB-100	131	PA	Upper part of Tulpehocken Creek above Blue Marsh Reservoir
DB-101	88.3	PA	Lower part of Tulpehocken Creek below Blue Marsh Reservoir
DB-102	170	PA	Tributaries to middle part of Schuylkill River
DB-103	91.5	PA	Manatawny Creek
DB-104	140	PA	Lower part of Schuylkill River and tributaries above Skippack Creek
DB-105	70.2	PA	French Creek
DB-106	144	PA	West Branch Perkiomen Creek
DB-107	134	PA	Perkiomen Creek above and including East Branch
DB-108	84.0	PA	Perkiomen Creek below East Branch
DB-109	129	PA	Lower part of Schuylkill River and tributaries below Skippack Creek
DB-110	63.7	PA	Wissahickon Creek
DB-111	50.2	NJ	Mantua Creek
DB-112	81.6	PA	Darby Creek
DB-113	41.0	NJ	Cedar Swamp, Repaupo Creek, Clonmell Creek, and tributaries to Delaware River
DB-114	77.2	PA	Crum Creek, Ridley Creek, Marcus Hook Creek
DB-115	66.4	PA	Chester Creek
DB-116	40.9	PA / DE	Naamans Creek, Shellpot Creek, and tributaries to Delaware River

Table 1. Watersheds in the Delaware River Basin. --Continued

[mi^2, square miles; DB, Delaware River Basin; DE, Delaware; NJ, New Jersey; NY, New York;, PA, Pennsylvania]

Basin identification number	Drainage area (mi^2)	State	Streams
DB-117	49.7	NJ	Raccoon Creek, Birch Creek
DB-118	44.0	NJ	Oldmans Creek
DB-119	72.0	NJ	Salem River above dam, Salem Canal, and tributaries to Delaware Bay
DB-120	123	PA	East Branch Brandywine Creek
DB-121	135	PA	West Branch Brandywine Creek
DB-122	65.2	PA / DE	Brandywine Creek (main stem)
DB-123	56.1	PA / DE	Red Clay Creek
DB-124	104	PA / DE	White Clay Creek
DB-125	85.0	DE	Christina River and tributaries to Delaware River
DB-126	68.8	NJ	Salem River below dam and tributaries to Delaware Bay
DB-127	31.5	DE	Army Creek, Red Lion Creek, Dragon Creek, and tributaries to Delaware River
DB-128	32.4	DE	C and D Canal and tributaries to Delaware Bay
DB-129	77.7	NJ	Alloway Creek, Hope Creek, and tributaries to Delaware Bay
DB-130	91.1	DE	Augustine Creek, Appoquinimik River, Blackbird Creek, and tributaries to Delaware Bay
DB-131	55.2	NJ	Stow Creek and tributaries to Delaware Bay
DB-132	99.7	DE	Smyrna River, Duck Creek, Mill Creek, and tributaries to Delaware Bay
DB-133	107	NJ	Cohansey River
DB-134	111	NJ	Back Creek, Cedar Creek, Nantuxent Creek, Dividing Creek, and tributaries to Delaware Bay
DB-135	101	DE	Leipsic River, Simons River, Little River, and tributaries to Delaware Bay
DB-136	75.9	NJ	Scotland Run, Still Run, Little Ease Run
DB-137	115	NJ	Maurice River above Sherman Avenue Bridge and Muddy Run
DB-138	69.7	NJ	Maurice River above Menantico Creek
DB-139	75.4	NJ	Menantico Creek, Manumuskin River
DB-140	48.9	NJ	Maurice River below Menantico Creek
DB-141	86.5	NJ	West Creek, East Creek, Dennis Creek, and tributaries to Delaware Bay
DB-142	45.2	NJ	Tributaries to Delaware Bay
DB-143	88.3	DE	Saint Jones River
DB-144	104	DE	Murderkill River
DB-145	74.8	DE	Misspillion River and tributaries to Delaware Bay
DB-146	83.3	DE	Cedar Creek, Slaughter Creek, Primehook Creek, and tributaries to Delaware Bay
DB-147	83.5	DE	Round Pole Branch and tributaries to Delaware Bay

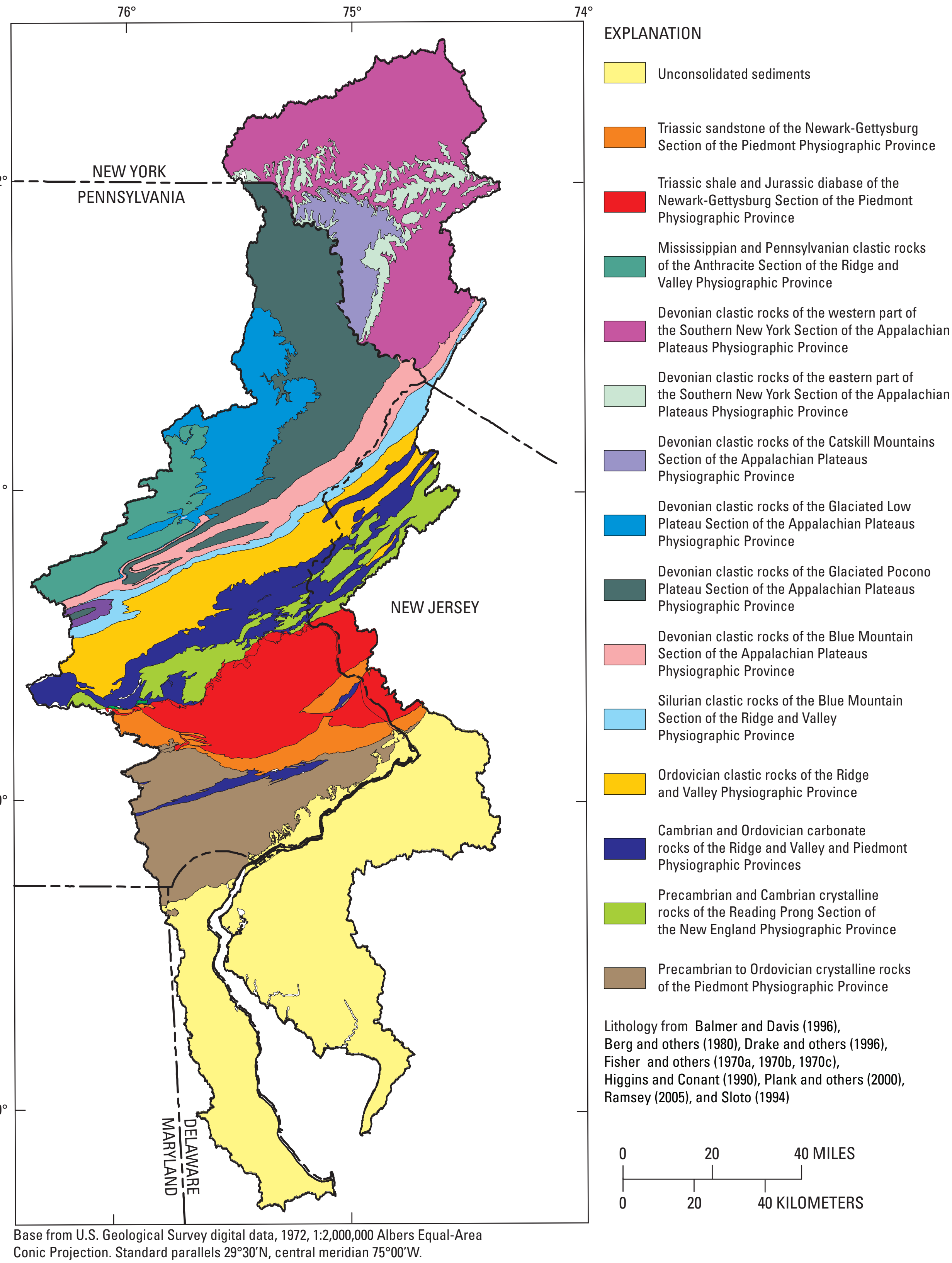


Figure 3. Generalized lithology in the Delaware River Basin.

in each watershed (fig. 4). Watershed ground-water withdrawals ranged from less than 0.001 to 0.364 (Mgal/d)/mi^{2}and were less than 0.01 (Mgal/d)/mi^2 for 74 watersheds (table 2).

Ground-Water Recharge

Ground-water recharge as used for this study is water recharged by golf course and agricultural irrigation and land-application sewage-treatment systems. Ground-water recharge was determined from the data provided by the DRBC. A point-feature GIS dataset of recharged water was created, and a spatial-data analysis was used to determine the quantity of recharge for each watershed by summing the recharge in each watershed. Recharge was less than 0.001 (Mgal/d)/mi^2 for 94 watersheds (table 2). Recharge ranged from 0.001 to 0.149 (Mgal/d)/mi^2 for the other 53 watersheds. Only six watersheds had recharge rates greater than 0.01 (Mgal/d)/mi^2.

Domestic Water Use

Domestic water use in this study is considered to be consumptive water use by self-supplied households with individual wells and septic systems. The percentage of households on domestic wells was determined from 1990 census data because that information was not included in the 2000 census. The percentage of households on domestic wells in 1990 was multiplied by the 2000 population to determine the number of people using domestic wells for each census block. Where a census block was wholly in a watershed, that population was applied to the watershed. Where part of a census block was in a watershed, the population was weighted by area of the census block in the watershed. Populations were then summed for each watershed. A per-capita use of 65 gal/d per person was used for Pennsylvania (William Gast, Pennsylvania Department of Environmental Protection, written commun., 2003), and 75 gal/d per person was used for Delaware, New Jersey, and New York. A consumptive rate of 10 percent of per-capita use was assumed. Domestic use ranged from less than 0.001 to 0.003 (Mgal/d)/mi^2 (table 2).

Assumptions and Limitations

Because of differences in lithology, different methods were used to estimate ground-water availability for fractured rocks and unconsolidated sediments. For fractured rocks, ground-water divides were assumed to coincide with surface-water divides. Each watershed was considered as a closed system with all ground water in the watershed discharged to the stream; flow across watershed boundaries was considered negligible. This assumption is valid for most of the basin underlain by fractured rocks; however, it may not be valid for some areas underlain by carbonate rock or where ground-water pumping is concentrated at or near a watershed divide.

The USGS HYSEP hydrograph-separation computer program (Sloto and Crouse, 1996) was used to separate streamflow hydrographs into base-flow (ground-water discharge) and overland-runoff components. It was assumed that the HYSEP program divides surface runoff from ground-water discharge for all watersheds. For most years in the lower part of the basin, this assumption is valid. In the upper part of the basin where elevations are higher and the climate is colder, precipitation in the form of snow may be stored on the land surface and released to streams by melting. The HYSEP program is not able to distinguish between slow snowmelt added to streamflow and ground-water discharge. Some of the water determined by HYSEP to be ground-water discharge (base flow) may be snowmelt, and the annual base flows may be overestimated.

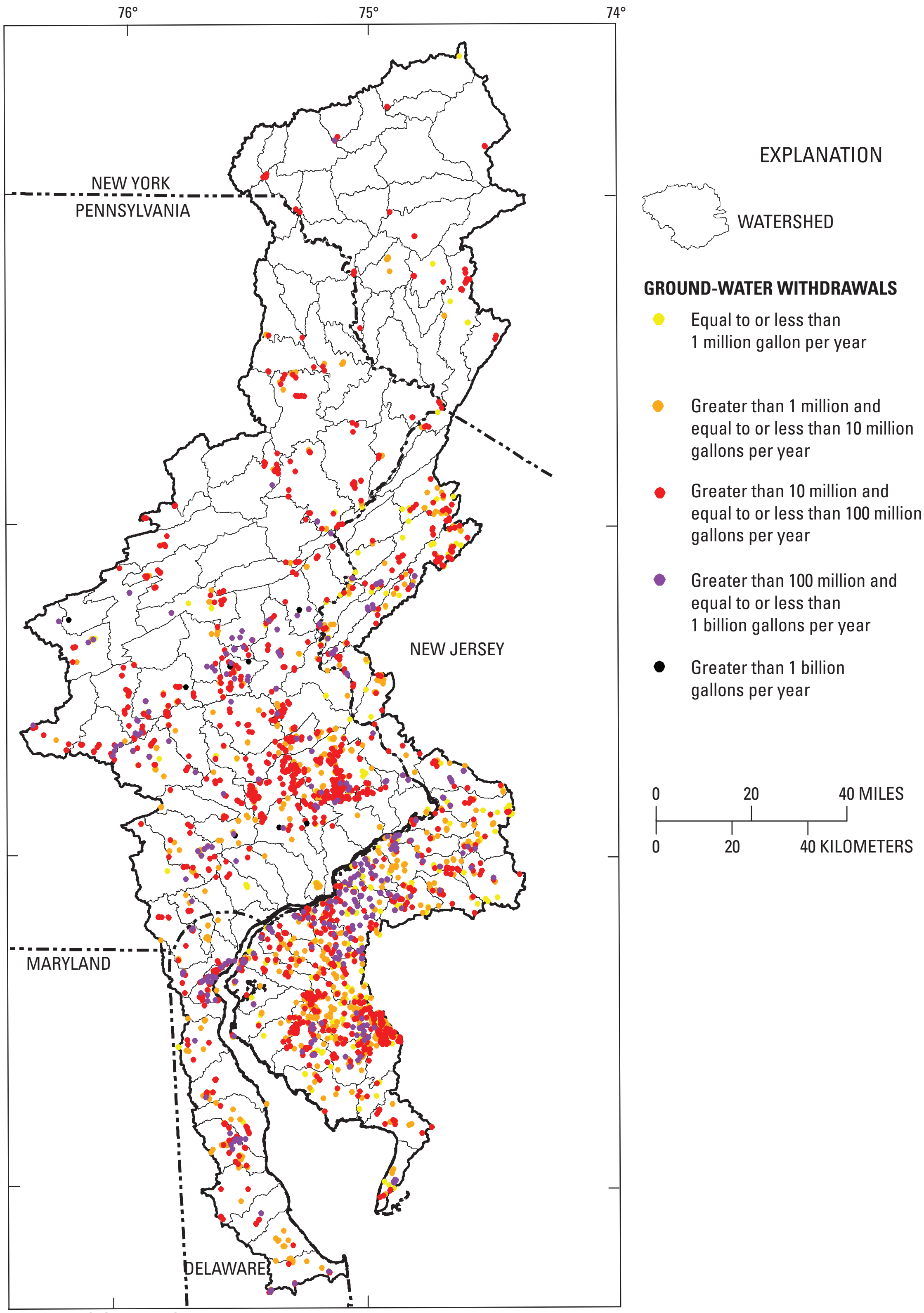
Watersheds in the unconsolidated sediments of the Coastal Plain are underlain by surficial aquifers that discharge to local streams and to a complex, multi-layered confined aquifer system that extends across many counties. The effects of pumping confined aquifers can extend well beyond watershed boundaries and even beyond the Delaware River Basin. The availability of ground water from confined Coastal Plain aquifers was not determined for this study. The watershed approach and equating availability to stream base flow is not suited for estimating confined-aquifer ground-water availability; therefore, ground-water availability was estimated only for unconfined aquifers of Coastal Plain watersheds. In the Coastal Plain, the controlling factors of base flow needed to be determined before ground-water availability could be estimated.

For all watersheds, ground-water availability was equated to average annual base flows. Streamflow-gaging stations used in the base-flow analyses were carefully chosen to select those that were not affected by dams, surface-water withdrawals, or discharges by sewerage-treatment plants, industries, or mines. However, most stations have some anthropogenic effects. The limitations, potential sources of error, and physical factors that affect base-flow estimates, are discussed by Sloto and Crouse (1996) and White and Sloto (1990).

A common period of record was not used to calculate base-flow-recurrence values because of the widely varying dates of the period of record for the stations and the need for enough data to produce a 50-year-recurrence interval. Because a common period of record was not used, the base-flow-recurrence intervals may be influenced by climate.

Estimation of Ground-Water Availability for Fractured Rock

Ground-water availability for watersheds underlain by fractured rocks was estimated from base flow from the 14 generalized rock types in figure 3. A base-flow-recurrence analysis using the HYSEP hydrograph-separation computer program was made for selected long-term index streamflow-gaging stations that were representative of each generalized rock type. Streamflow hydrographs were separated into surface-runoff and base-flow components to estimate annual



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30′N, central meridian 75°00′W.

Figure 4. Annual ground-water withdrawals in the Delaware River Basin, 1997-2000.

Table 2. Ground-water withdrawal, recharged water, and domestic water use for watersheds in the Delaware River Basin. --Continued

[Basin locations are shown on figure 2, and watershed names are given in table 1; (Mgal/d)/mi^2, million gallons per day per square mile; DB, Delaware River Basin; <, less than]

Basin identification number	Ground-water withdrawal [(Mgal/d)/mi^2]	Recharged water [(Mgal/d)/mi^2]	Domestic water use [(Mgal/d)/mi^2]
DB-001	0.002	<0.001	<0.001
DB-002	<.001	<.001	<.001
DB-003	<.001	<.001	<.001
DB-004	.025	<.001	<.001
DB-005	<.001	<.001	<.001
DB-006	.002	<.001	<.001
DB-007	.002	<.001	<.001
DB-008	.005	<.001	<.001
DB-009	<.001	<.001	<.001
DB-010	.001	<.001	<.001
DB-011	<.001	<.001	<.001
DB-012	.001	<.001	<.001
DB-013	.004	<.001	<.001
DB-014	<.001	<.001	<.001
DB-015	<.001	<.001	<.001
DB-016	.004	<.001	<.001
DB-017	<.001	<.001	<.001
DB-018	<.001	<.001	<.001
DB-019	<.001	<.001	.001
DB-020	.002	<.001	.001
DB-021	.003	<.001	.001
DB-022	<.001	<.001	.001
DB-023	<.001	<.001	.001
DB-024	<.001	<.001	.001
DB-025	.002	<.001	.001
DB-026	<.001	<.001	<.001
DB-027	.002	<.001	.001
DB-028	.001	<.001	.001
DB-029	<.001	<.001	<.001
DB-030	<.001	<.001	.001
DB-031	.005	<.001	.001
DB-032	<.001	<.001	.001
DB-033	.005	<.001	.001
DB-034	<.001	<.001	.001
DB-035	<.001	<.001	.001
DB-036	.007	<.001	.001
DB-037	<.001	<.001	<.001
DB-038	.013	<.001	.001
DB-039	.002	<.001	.001
DB-040	.003	<.001	.001
DB-041	<.001	<.001	.001
DB-042	<.001	<.001	.001
DB-043	.008	.002	<.001
DB-044	<.001	<.001	.001
DB-045	.012	.001	.001
DB-046	.002	.002	.001
DB-047	.031	.002	.001
DB-048	.003	<.001	<.001
DB-049	.006	<.001	.002
DB-050	.001	<.001	.001
DB-051	.014	<.001	.002
DB-052	.060	.068	.002
DB-053	.009	<.001	.001
DB-054	.123	<.001	.002
DB-055	.364	.008	.001
DB-056	<.001	<.001	<.001
DB-057	.009	<.001	<.001
DB-058	.001	<.001	<.001
DB-059	.005	<.001	<.001
DB-060	.004	<.001	<.001
DB-061	.009	<.001	<.001
DB-062	<.001	<.001	<.001
DB-063	.013	<.001	.001
DB-064	.010	.002	<.001
DB-065	.043	<.001	.001
DB-066	.078	<.001	.001
DB-067	.168	.002	.001
DB-068	.057	.005	.001
DB-069	.031	<.001	.002
DB-070	.035	<.001	.001
DB-071	.052	<.001	.002
DB-072	.001	.001	.001
DB-073	.033	<.001	.001
DB-074	.019	<.001	.001

Table 2. Ground-water withdrawal, recharged water, and domestic water use for watersheds in the Delaware River Basin. --Continued

[Basin locations are shown on figure 2, and watershed names are given in table 1; (Mgal/d)/mi², million gallons per day per square mile; DB, Delaware River Basin; <, less than]

Basin identification number	Ground-water withdrawal [(Mgal/d)/mi²]	Recharged water [(Mgal/d)/mi²]	Domestic water use [(Mgal/d)/mi²]
DB-075	.007	.001	.001
DB-076	.047	<.001	.001
DB-077	.006	<.001	.001
DB-078	.047	<.001	.001
DB-079	<.001	.001	<.001
DB-080	.038	.006	.001
DB-081	.038	.001	<.001
DB-082	.142	.001	.001
DB-083	.066	.001	.001
DB-084	.024	.001	.002
DB-085	.027	.030	.001
DB-086	.014	.149	.001
DB-087	.064	.005	.001
DB-088	.082	.012	<.001
DB-089	.039	.001	.001
DB-090	.290	<.001	<.001
DB-091	.002	<.001	<.001
DB-092	.318	.001	<.001
DB-093	.221	.002	<.001
DB-094	.100	.002	.001
DB-095	.071	<.001	<.001
DB-096	.029	.018	.001
DB-097	.058	.003	.001
DB-098	.001	<.001	.001
DB-099	.050	.003	.001
DB-100	.005	.001	.001
DB-101	.031	.001	.002
DB-102	.028	.001	.001
DB-103	.002	<.001	.001
DB-104	.071	.014	.001
DB-105	.006	<.001	.001
DB-106	.013	<.001	.001
DB-107	.027	<.001	.002
DB-108	.050	.001	.002
DB-109	.074	.002	<.001
DB-110	.130	.001	<.001
DB-111	.154	.002	.001
DB-112	<.001	<.001	<.001
DB-113	.099	.004	.001
DB-114	.005	.004	.001
DB-115	.006	<.001	.001
DB-116	<.001	<.001	<.001
DB-117	.045	.002	.001
DB-118	.034	.008	.002
DB-119	.089	.001	.001
DB-120	.044	.001	.001
DB-121	.006	<.001	.002
DB-122	.001	.001	.001
DB-123	.013	<.001	.002
DB-124	.021	<.001	.001
DB-125	.054	<.001	.001
DB-126	.020	.001	.001
DB-127	.340	<.001	.001
DB-128	.013	<.001	<.001
DB-129	.011	.001	.001
DB-130	.015	<.001	<.001
DB-131	.007	.001	.001
DB-132	.013	<.001	<.001
DB-133	.093	.003	.001
DB-134	.006	<.001	<.001
DB-135	.011	<.001	.001
DB-136	.076	.002	.003
DB-137	.138	.005	.001
DB-138	.070	.001	.001
DB-139	.076	.005	.001
DB-140	.003	<.001	.001
DB-141	.018	.001	.001
DB-142	.108	<.001	.002
DB-143	.067	<.001	.001
DB-144	.006	<.001	.001
DB-145	.027	<.001	.001
DB-146	.002	<.001	<.001
DB-147	.047	<.001	<.001

calendar-year base flows using the local-minimum technique of the HYSEP hydrograph-separation computer program (Sloto and Crouse, 1996).

Index Stations

To identify all possible index stations, a list was complied of all current and discontinued USGS streamflow-gaging stations with more than 20 years of record draining fractured rocks in the Delaware River Basin. Drainage areas for the initial 218 stations ranged from 0.61 to 6,780 mi^2. Stations with drainage areas less than 10 mi^2 and larger than 350 mi^2 were eliminated; the choice of these drainage-area sizes was arbitrary. Stations downstream of dams or affected by significant regulation or diversions were eliminated unless the period of record prior to regulation or diversion was greater than 20 years. In those cases, only the period of record prior to regulation was used. Stations draining highly urbanized areas of Philadelphia and the immediate vicinity were eliminated. The final list of potential index stations consisted of 57 streamflow-gaging stations (table 3). Streamflow hydrographs for the period of record from the 57 streamflow-gaging stations in table 3 were separated into surface runoff and base flow using the local-minimum technique of the HYSEP program to estimate annual calendar-year base flows. Only complete calendar years of nonprovisional record were used for the analysis. A frequency distribution was calculated and plotted for each station.

The 57 streamflow-gaging stations were grouped by generalized rock type within each physiographic province (fig. 5). A spatial-data analysis was used to determine the percentage of each generalized rock type in each drainage basin. If a basin drained predominantly one generalized rock type, it was selected as an index station. Average annual base flow was selected for the 2-, 5-, 10-, 25-, and 50-year (where available) recurrence interval from the base-flow-frequency analysis. Base-flow-recurrence curves were compared, and index stations representative of each generalized rock type were chosen. In some cases, the base-flow-frequency distributions were similar for several stations draining one predominant generalized rock type, and an average distribution was selected as representative. Twenty-three streamflow-gaging stations (fig. 6) were chosen to represent the 14 generalized rock types (table 4).

Using the base-flow-recurrence values of the generalized rock types, a spatial-data analysis was used to determine the average annual base flow for the 2-, 5-, 10-, 25-, and 50-year-recurrence intervals for each watershed by weighting the base flow for the percentage of each generalized rock type in the watershed. This is equivalent to the available quantity of ground water in each watershed for a range of climatic conditions from wet (2-year-recurrence value) to dry (50-year-recurrence value).

Precambrian to Ordovician Crystalline Rocks of the Piedmont Physiographic Province

The Piedmont Upland Section of the Piedmont Physiographic Province is underlain predominantly by Precambrian to Ordovician age metamorphic crystalline rocks (gneiss, schist, and quartzite) that form gently rolling hills and valleys. Several streamflow-gaging stations were available for this section including West Branch Brandywine Creek near Honey Brook, Pa. (USGS station number 01480300), Red Clay Creek at Wooddale, Del. (01480300), and White Clay Creek near Newark, Del. (01479000) (fig. 6). Drainage area and period of record for each station is given in table 3.

West Branch Brandywine Creek near Honey Brook was used as the index station for Piedmont crystalline rocks by Schreffler (1996, p. 8) and Town and Bird (1998). However, because of the short period of record available at that time (33 years, 1961-93), the 50-year-recurrence interval was estimated by curve extension. Station Red Clay Creek at Wooddale has a higher base flow than West Branch Brandywine Creek near Honey Brook, and station White Clay Creek near Newark has a lower base flow than West Branch Brandywine Creek near Honey Brook. An average annual base-flow-recurrence-interval curve for the crystalline rocks of the Piedmont Upland Section was created by taking the average base flow for the three stations for the 2-, 5-, 10-, and 25-year-recurrence intervals and the average of the Red Clay and White Clay Creek stations for the 50-year-recurrence interval (fig. 7). For watersheds underlain mostly by Piedmont crystalline rocks, but partially overlain by a thin veneer of Coastal Plain sediments, the Coastal Plain sediments were assigned the value of the underlying crystalline rocks.

The Piedmont Lowland Section of the Piedmont Physiographic Province is a long valley (Chester Valley) underlain predominantly by Cambrian and Ordovician carbonate rocks (limestone, dolomite, and marble) of the Chester Valley Sequence. A streamflow-gaging station on a stream draining these rocks is not available; therefore, the station Little Lehigh Creek near Allentown, Pa., was used. This is the index station used for carbonate rocks by Schreffler (1996, p. 8) and Town and Bird (1998).

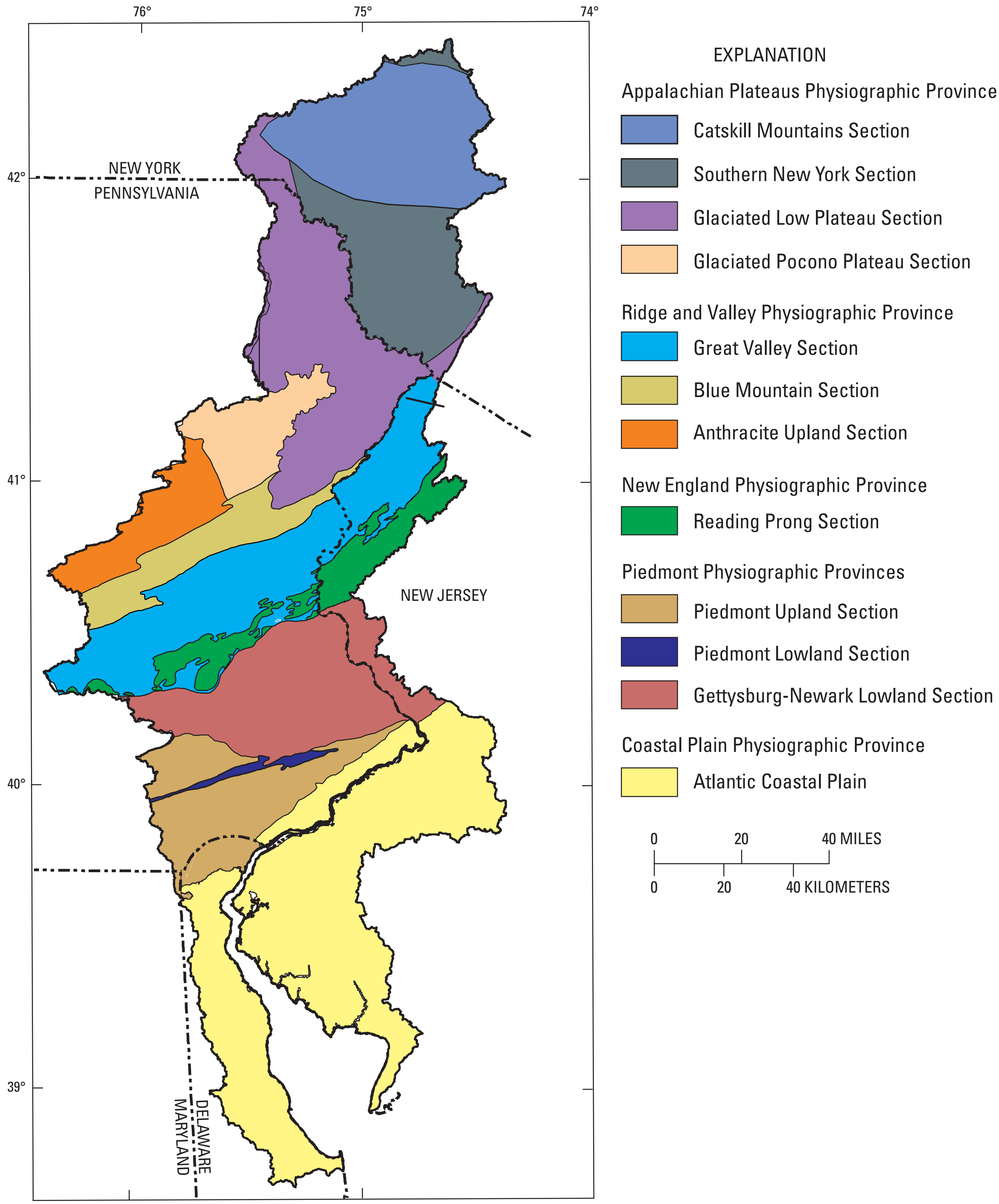
Triassic Clastic Rocks and Jurassic Diabase

The Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province is underlain predominantly by Triassic clastic rocks (primarily sandstone and shale) and intrusive Jurassic diabase. The sedimentary rocks of the Gettysburg-Newark Lowland Section form rolling low hills and valleys. Isolated higher hills are underlain by resistant diabase. Skippack Creek near Collegeville, Pa. (01473120), was selected as the index station for Triassic shales (fig. 8). The drainage area above this station is 75 percent Brunswick Group and 21 percent Lockatong Formation. It was the index

Table 3. Potential index streamflow-gaging stations draining fractured rocks in the Delaware River Basin.

[USGS, U.S. Geological Survey]

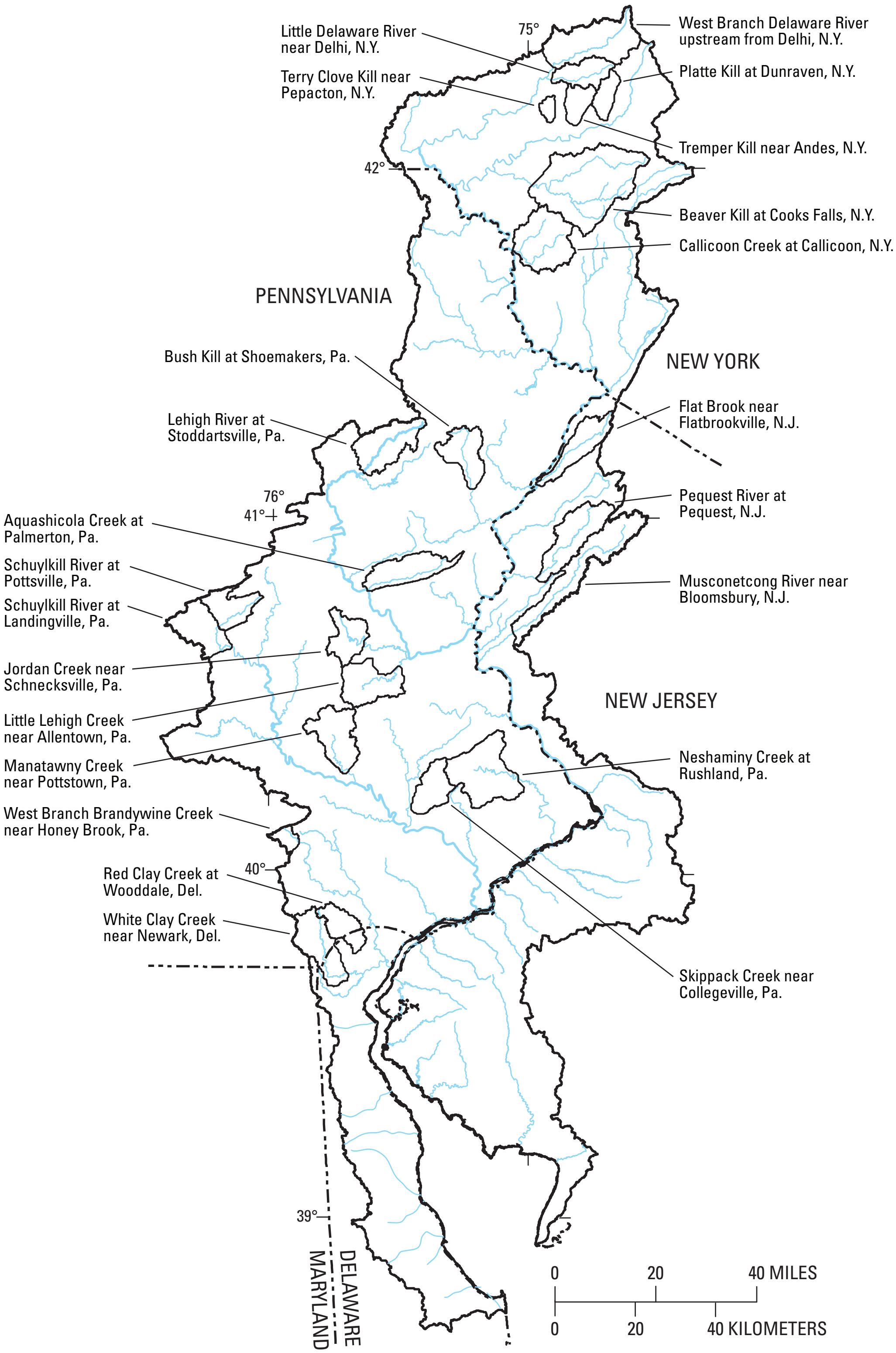
USGS station number	Station name	Drainage area (square miles)	Period of record
01413500	East Branch Delaware River at Margaretville, N.Y.	163	1938-2001
01414000	Platte Kill at Dunraven, N.Y.	34.9	1942-61, 1997-2001
01414500	Mill Brook near Dunraven, N.Y.	25.2	1938-2001
01415000	Tremper Kill near Andes, N.Y.	33.2	1938-2001
01415500	Terry Clove Kill near Pepacton, N.Y.	13.6	1938-61
01418500	Beaver Kill at Craigie Clair, N.Y.	81.9	1938-69
01419500	Willowemoc Creek near Livingston Manor, N.Y.	62.6	1938-69
01420000	Little Beaver Kill near Livingston Manor, N.Y.	20.1	1925-80
01420500	Beaver Kill at Cooks Falls, N.Y.	241	1915-2001
01421900	West Branch Delaware River upstream from Delhi, N.Y.	134	1938-64, 1997-2001
01422000	West Branch Delaware River at Delhi, N.Y.	142	1938-69
01422500	Little Delaware River near Delhi, N.Y.	49.8	1938-64, 1998-2001
0142400103	Trout Creek near Trout Creek, N.Y.	20.2	1953-66, 1997-2001
01424500	Trout Creek at Cannonsville, N.Y.	49.5	1941-62
01426000	Oquaga Creek at Deposit, N.Y.	67.6	1941-72
01427500	Callicoon Creek at Callicoon, N.Y.	110	1941-81
01428000	Tenmile River at Tusten, N.Y.	45.6	1947-72
01437500	Neversink River at Godeffroy, N.Y.	307	1938-2001
01439500	Bush Kill at Shoemakers, Pa.	117	1909-11, 1913-2001
01440000	Flat Brook near Flatbrookville, N.J.	64.0	1924-2001
01440400	Brodhead Creek near Analomink, Pa.	65.9	1958-2001
01441000	McMichaels Creek at Stroudsburg, Pa.	65.3	1912-37
01442500	Brodhead Creek at Minisink Hills, Pa.	259	1951-2001
01445500	Pequest River at Pequest, N.J.	106	1922-2001
01446000	Beaver Brook near Belvidere, N.J.	36.7	1923-61
01447500	Lehigh River at Stoddartsville, Pa.	91.7	1944-2001
01447720	Tobyhanna Creek near Blakeslee, Pa.	118	1962-2001
01448000	Lehigh River at Tannery, Pa.	322	1917, 1919-58
01449360	Pohopoco Creek at Kresgeville, Pa.	49.9	1967-2001
01450000	Pohopoco Creek near Parryville, Pa.	109	1941-69
01450500	Aquashicola Creek at Palmerton, Pa.	76.7	1940-2001
01451500	Little Lehigh Creek near Allentown, Pa.	80.8	1946-2001
01451800	Jordan Creek near Schnecksville, Pa.	53.0	1967-2001
01452500	Monocacy Creek at Bethlehem, Pa.	44.5	1949-2001
01456000	Musconetcong River near Hackettstown, N.J.	68.9	1922-72
01457000	Musconetcong River near Bloomsbury, N.J.	141	1904-06, 1922-2001
01459500	Tohickon Creek near Pipersville, Pa.	97.4	1936-72
01460000	Tohickon Creek at Point Pleasant, Pa.	107	1884-99, 1901-13
01465000	Neshaminy Creek at Rushland, Pa.	134	1885-1913, 1932-33
01467500	Schuylkill River at Pottsville, Pa.	53.4	1944-68
01468500	Schuylkill River at Landingville, Pa.	133	1948-52, 1964, 1974-2001
01470756	Maiden Creek at Virginville, Pa.	159	1974-94
01470779	Tulpehocken Creek near Bernville, Pa.	66.5	1975-2001
01471000	Tulpehocken Creek near Reading, Pa.	211	1951-78
01471980	Manatawny Creek near Pottstown, Pa.	85.5	1975-2001
01472157	French Creek near Phoenixville, Pa.	59.1	1969-2001
01472198	Perkiomen Creek at East Greenville, Pa.	38.0	1982-2001
01472199	West Branch Perkiomen Creek at Hillegass, Pa.	23.0	1982-2001
01472500	Perkiomen Creek near Frederick, Pa.	152	1885-1913
01473000	Perkiomen Creek at Graterford, Pa.	279	1915-1956
01473120	Skippack Creek near Collegeville, Pa.	53.7	1966-93
01475850	Crum Creek near Newtown Square, Pa.	15.8	1982-2001
01479000	White Clay Creek near Newark, Del.	89.1	1932-35, 1944-56, 1960-2001
01480000	Red Clay Creek at Wooddale, Del.	47.0	1944-2001
01480300	West Branch Brandywine Creek near Honey Brook, Pa.	18.7	1961-2001
01481000	Brandywine Creek at Chadds Ford, Pa.	287	1912-52, 1963-71
01481500	Brandywine Creek at Wilmington, Del.	314	1947-71



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000
Albers Equal-Area Conic Projection. Standard parallels 29°30′N,
central meridian 75°00′W.

Physiographic provinces from
Sevon (2000), Pristas (2002), and
Fenneman and Johnson (1946)

Figure 5. Physiographic provinces in the Delaware River Basin.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30′N, central meridian 75°00′W.

Figure 6. Index stations used for fractured rock watersheds in the Delware River Basin.

Table 4. Generalized lithology, index stations, and average annual base-flow-recurrence values for fractured rocks in the Delaware River Basin. --Continued

[Physiographic province designations from Sevon (2000), Pristas (2002), and Fenneman and Johnson (1946)]

Generalized lithology and physiographic province	Index station	Average annual base flow (million gallons per day per square mile)				
		2-year	5-year	10-year	25-year	50-year
Precambrian to Ordovician crystalline rocks (Upland Section of the Piedmont Physiographic Province in Delaware, Maryland, New Jersey, and Pennsylvania)	Average of White Clay Creek near Newark, Del., Red Clay Creek at Wooddale, Del., and West Branch Brandywine Creek near Honey Brook, Pa.	0.524	0.391	0.331	0.289	0.274
Triassic sandstone (Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province in New Jersey and Pennsylvania)	Derived from Neshaminy Creek at Rushland, Pa.	.590	.438	.404	.350	.288
Triassic shale and Jurassic diabase (Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province in New Jersey and Pennsylvania)	Skippack Creek near Collegeville, Pa.	.313	.249	.211	.175	.150
Precambrian and Cambrian crystalline rocks (Reading Prong Section of the New England Physiographic Province in Pennsylvania and the Highlands Physiographic Province in New Jersey	Average of Musconetcong River near Bloomsbury, N.J., Pequest River at Pequest, N.J., and Manatawny Creek near Pottstown, Pa.	.682	.563	.490	.422	.351
Ordovician clastic rocks (Great Valley Section of the Ridge and Valley Physiographic Province in Pennsylvania and the Valley and Ridge Physiographic Province in New Jersey)	Jordan Creek near Schnecksville, Pa.	.514	.435	.412	.361	.276
Cambrian to Ordovician carbonate rocks (Upland and Lowland Sections of the Piedmont Physiographic Province, the Great Valley Section of the Ridge and Valley Physiographic Province in Pennsylvania and the Valley and Ridge Physiographic Province in New Jersey)	Little Lehigh Creek near Allentown, Pa.	.692	.518	.434	.314	.281
Silurian clastic rocks (Blue Mountain Section of the Ridge and Valley Physiographic Province in Pennsylvania and the Valley and Ridge Physiographic Province in New Jersey)	Flat Brook near Flatbrookville, N.J.	.702	.576	.520	.451	.398
Mississippian and Pennsylvanian clastic rocks (Anthracite Valley Section of the Ridge and Valley Physiographic Province in Pennsylvania)	Average of Schuylkill River at Pottsville, Pa. and Shamokin Creek at Shamokin, Pa.	.915	.707	.650	.584	.505
Devonian clastic rocks of the Blue Mountain Section of the Ridge and Valley Physiographic Province in Pennsylvania and the Valley and Ridge Physiographic Province in New Jersey	Aquashicola Creek at Palmerton, Pa.	.810	.640	.610	.522	.480
Devonian clastic rocks of the Glaciated Pocono Plateau Section of the Appalachian Plateaus Physiographic Province in Pennsylvania	Bush Kill at Shoemakers, Pa.	.874	.686	.639	.554	.473

Table 4. Generalized lithology, index stations, and average annual base-flow-recurrence values for fractured rocks in the Delaware River Basin. --Continued

[Physiographic province designations from Sevon (2000), Pristas (2002), and Fenneman and Johnson (1946)]

Generalized lithology and physiographic province	Index station	Average annual base flow (million gallons per day per square mile)				
		2-year	5-year	10-year	25-year	50-year
Devonian clastic rocks of the Glaciated Low Plateau Section of the Appalachian Plateaus Physiographic Province in Pennsylvania	Lehigh River at Stoddartsville, Pa.	.860	.730	.651	.555	.488
Devonian clastic rocks of the Catskill Mountains Section of the Appalachian Plateaus Physiographic Province in New York	Average of Little Delaware River near Delhi, N.Y., Platte Kill at Dunraven, N.Y., Terry Clove Kill near Pepacton, N.Y., Tremper Kill near Andes, N.Y., and West Branch Delaware River upstream from Delhi, N.Y.	.687	.546	.492	.403	.373
Devonian clastic rocks of the western part of the Southern New York Section of the Appalachian Plateaus Physiographic Province in New York	Beaver Kill at Cooks Falls, N.Y.	.905	.728	.634	.553	.549
Devonian clastic rocks of the eastern part of the Southern New York Section of the Appalachian Plateaus Physiographic Province in New York	Callicoon Creek at Callicoon, N.Y.	.573	.401	.336	.309	.302

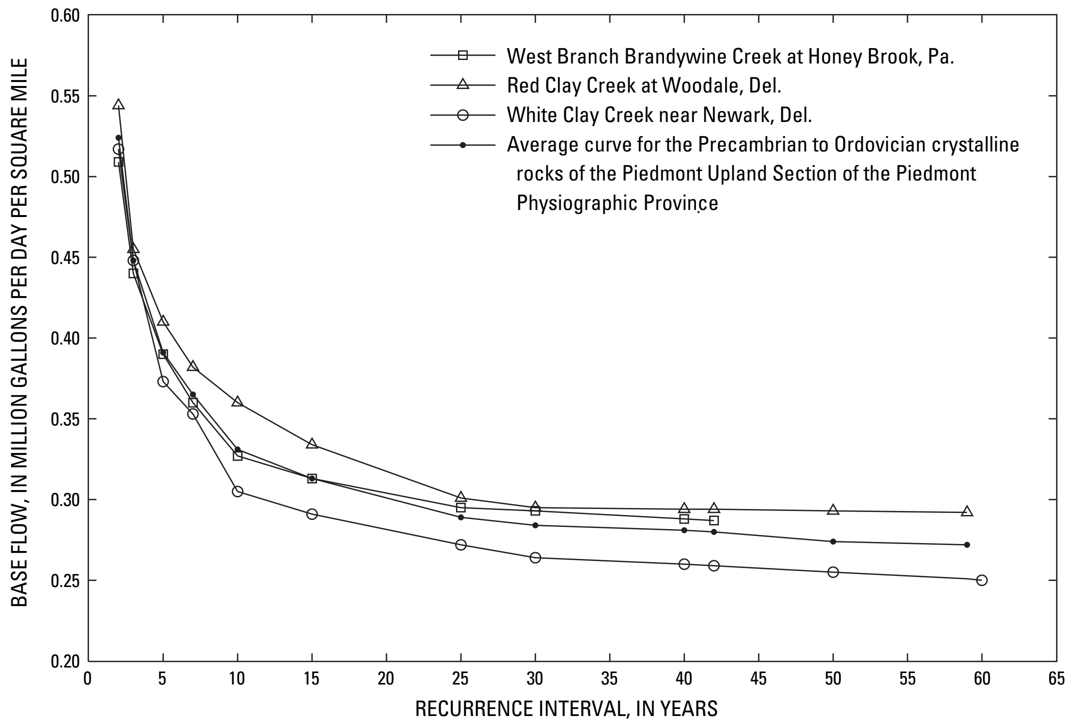


Figure 7. Base-flow-frequency curves for streamflow-gaging stations in the Precambrian to Ordivician crystalline rocks of the Piedmont Upland Section of the Piedmont Physiographic Province.

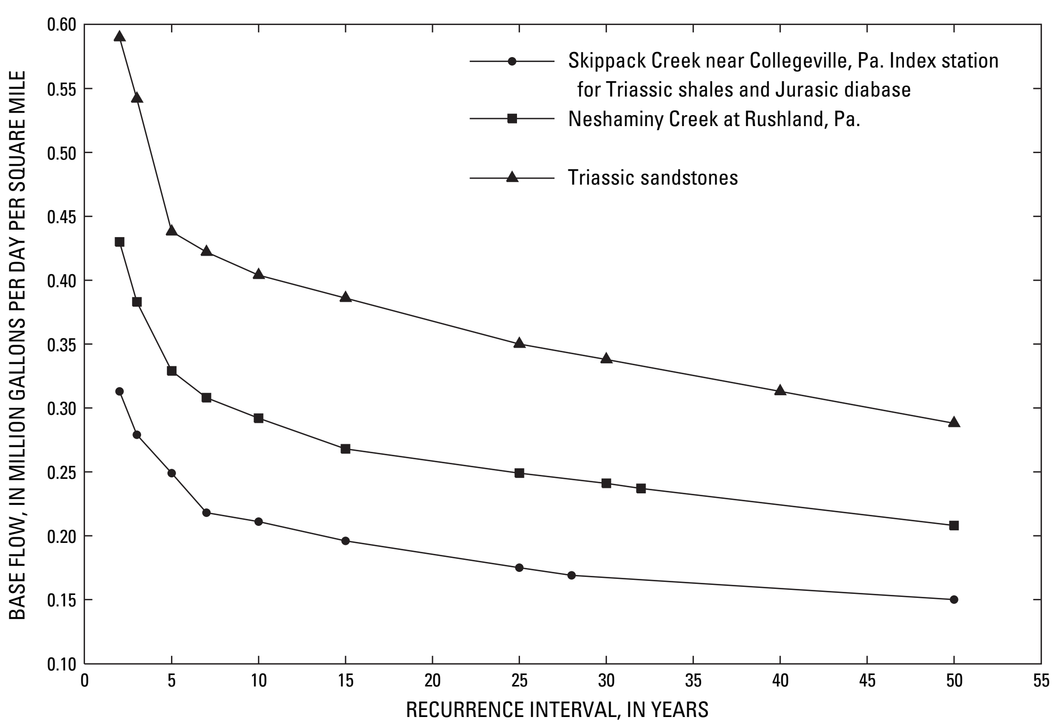


Figure 8. Base-flow-frequency curves for streamflow-gaging stations in the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province.

station for Triassic shales used by Schreffler (1996, p. 8) and Town and Bird (1998).

A suitable index station for Triassic sandstone in the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province is not available. The drainage area above station Neshaminy Creek at Rushland (01465000) is 42.0 percent Stockton Formation, 44.2 percent Brunswick Group, and 13.5 percent Lockatong Formation. The period of record for this station predates urbanization of the area. The contribution from the Stockton Formation, considered representative of Triassic sandstones, was calculated by:

$$Q_{Stockton} = \frac{Q_{Neshaminy} - (Q_{Skippack})(PctArea_{Bruns+Lock})}{PctArea_{Stockton}}, \qquad (1)$$

where

$Q_{Stockton}$ is the base-flow contribution from the Stockton Formation, in million gallons per day per square mile,

$Q_{Neshaminy}$ is the base flow measured at station Neshaminy Creek at Rushland, in million gallons per day per square mile,

$Q_{Skippack}$ is the base flow measured at station Skippack Creek near Collegeville, in million gallons per day per square mile,

$PctArea_{Bruns+Lock}$ is the area, in percent as a decimal, of the Neshaminy Creek Basin above the streamflow-gaging station at Rushland underlain by the Brunswick Group and Lockatong Formation, and

$PctArea_{Stockton}$ is the area, in percent as a decimal, of the Neshaminy Creek Basin above the streamflow-gaging station at Rushland underlain by the Stockton Formation.

A streamflow-gaging station on a stream draining Jurassic diabase is not available. Diabase has the lowest specific capacity [0.08 (gal/min)/ft], and the Lockatong Formation has the second lowest specific capacity [0.12 (gal/min)/ft] of the Mesozoic rocks in northern Bucks County (Sloto and Schreffler, 1994, p. 39). The Lockatong Formation has the lowest median nondomestic well yield (6.8 gal/min), and diabase has the second lowest median nondomestic well yield (7.5 gal/min) of the Mesozoic rocks in northern Bucks County (Sloto and Schreffler, 1994, p. 39). Because the hydraulic characteristics of these rocks are similar, Skippack Creek near Collegeville, Pa., was used as the index station for diabase.

Precambrian and Cambrian Crystalline Rocks of the Reading Prong

The Reading Prong Section of the New England Physiographic Province (Highlands Physiographic Province in New Jersey) is underlain predominantly by Precambrian to early Cambrian crystalline rocks. These rocks form circular to linear, rounded low hills or ridges that project upward in contrast to the surrounding lowlands. Streamflow-gaging stations draining mostly crystalline rocks include Musconetcong River near Bloomsbury, N.J. (01457000), Pequest River at Pequest, N.J. (01445500), and Manatawny Creek near Pottstown, Pa. (01471980) (fig. 6). An average base-flow-recurrence-interval curve was created by taking the average base flow for the three stations for the 2-, 5-, 10-, and 25-year-recurrence intervals and the average of the Musconetcong and Pequest River stations for the 50-year-recurrence interval (fig. 9).

Ordovician Clastic Rocks of the Ridge and Valley Physiographic Province

The Great Valley Section of the Ridge and Valley Physiographic Province (called the Valley and Ridge Physiographic Province in New Jersey) is underlain predominantly by Ordovician shale and sandstone of the Martinsburg Formation to the northwest and Cambrian and Ordovician limestones and dolomites to the southeast. The Great Valley Section consists of a very broad lowland with gently undulating hills eroded into the shale and sandstone to the northwest and a lower and flatter landscape developed on the carbonate rocks to the southeast. The drainage area above Jordan Creek near Schnecksville, Pa. (01451800), is underlain mostly by the Martinsburg Formation, and that station was selected as the index station for rocks of the Martinsburg Formation and Hamburg Klippe (fig. 6). Because of the 35-year period of record, the 50-year recurrence interval was estimated by curve extension (fig. 10).

Cambrian and Ordovician Carbonate Rocks of the Ridge and Valley Physiographic Province

For carbonate rocks (limestone and dolomite) of the Great Valley Section of the Ridge and Valley Physiographic Province and the Piedmont Upland and Lowland Sections, Little Lehigh Creek near Allentown, Pa. (01451500) (fig. 6), was selected as the index station (fig. 10). This is the index station used for carbonate rocks by Schreffler (1996, p. 8) and Town and Bird (1998). For the HYSEP base-flow-frequency analysis, the drainage area of Little Lehigh Creek above the streamflow-gaging station was reduced by 7.8 mi^2. Wood and others (1972, p. 17) state that the ground-water basin contributing most of the streamflow passing the streamflow-gaging station is smaller than the surface-water basin. A combination of ground-water flow beneath the surface-water divide and direct diversions accounted for the differing ground- and surface-water divides. Wood and others (1972, p. 20) stated that 7.8 mi^2 of the ground-water basin drains to Shantz Spring and Cedar Creek. Sloto and others (1991, p. 24) showed that the drainage divide between the Little Lehigh Creek and Shantz Spring was nearly at the same location in 1984 as the divide

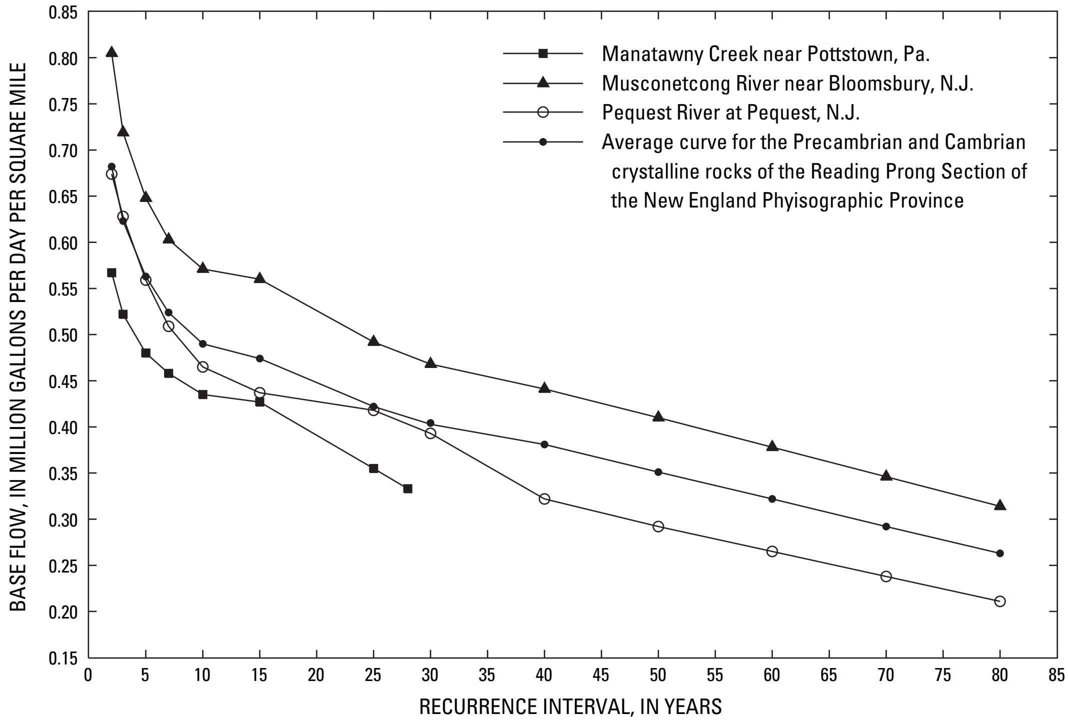


Figure 9. Base-flow-frequency curves for streamflow-gaging stations in the Precambrian and Cambrian crystalline rocks of the Reading Prong Section of the New England Physiographic Province.

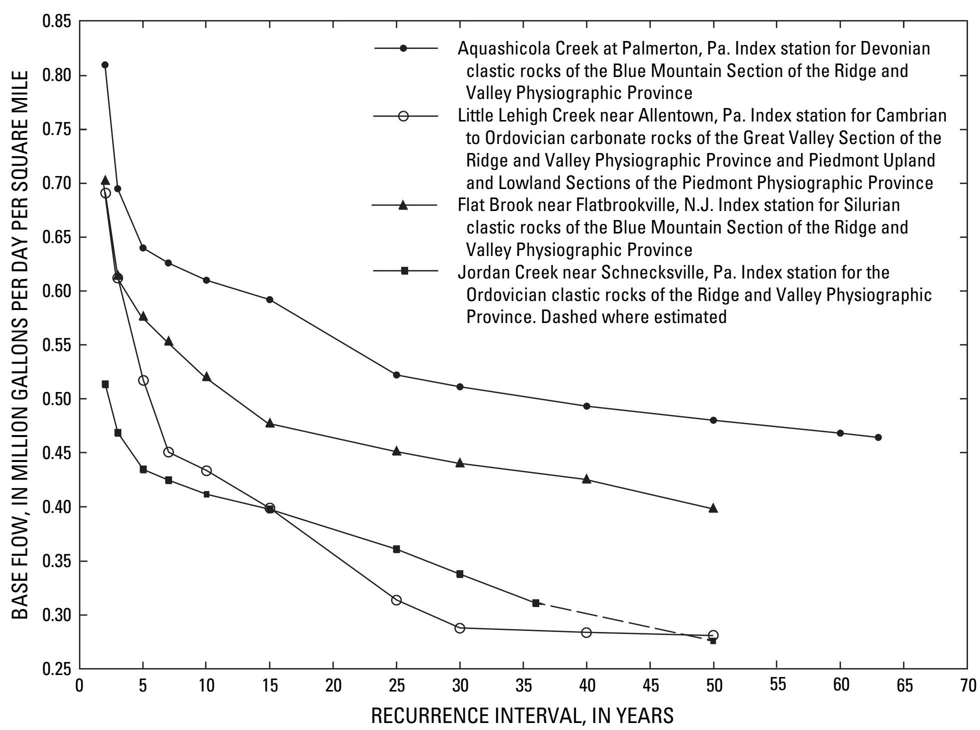


Figure 10. Base-flow-frequency curves for streamflow-gaging stations in the Ridge and Valley Physiographic Province in Pennsylvania and New Jersey.

on the 1968 water-table map of Wood and others (1972, pls. 1 and 4A).

Silurian Clastic Rocks

The Blue Mountain Section of the Ridge and Valley Physiographic Province is underlain predominantly by Silurian and Devonian clastic rocks that form low linear ridges and shallow valleys. For the Silurian-age rocks, Flat Brook near Flatbrookville, N.J. (01440000) (fig. 6), was selected as the index station (fig. 10). The drainage basin above the Flat Brook station is underlain predominantly by rocks mapped as Silurian clastic rocks.

Mississippian and Pennsylvanian Clastic Rocks

The Anthracite Upland Section of the Ridge and Valley Physiographic Province in Pennsylvania is underlain predominantly by Mississippian and Pennsylvanian clastic rocks. It is an upland that has low, linear to rounded hills and is characterized by strip mines, underground mines, and coal-mining waste piles. Streamflow-gaging stations on streams draining this area include Schuylkill River at Landingville, Pa. (01468500), and Shamokin Creek at Shamokin, Pa. (01554500), which is in the adjacent Susquehanna River Basin (fig. 11). Streamflow measured at the Schuylkill River at the Landingville and Shamokin Creek stations for some time periods reflects regulation by mine pumps at low flow (White and Sloto, 1990). Biesecker and others (1968, p. 113) noted

> "that portion of the Appalachian Mountain Section underlain by mined coal beds has the highest low-flow discharge per unit area of any part of the [Schuylkill] basin."

That probably accounts for the higher base flow at Schuylkill River at Landingville relative to other stations draining clastic rocks in the Delaware River Basin. In unmined regions of the Anthracite Upland Section, low-flow discharge per unit area is about half that of the mined areas (Biesecker and others, 1968, p. 113-114). For the Mississippian and Pennsylvanian clastic rocks of the Anthracite Upland Section, an average base-flow-recurrence interval curve was created by taking the average base flow for the Landingville and Shamokin stations (fig. 6). The 50-year-recurrence interval for the Landingville station was estimated by curve extension.

Devonian Clastic Rocks

Devonian clastic rocks underlie a large area in northeastern Pennsylvania, northern New Jersey, and southeastern New York. Devonian clastic rocks have been divided by physiographic province in the following sections.

Blue Mountain Section of the Ridge and Valley Physiographic Province

For streams draining the Devonian clastic rocks of the Blue Mountain Section of the Ridge and Valley Physiographic Province, streamflow-gaging stations include Aquashicola Creek at Palmerton, Pa. (01450500), Pohopoco Creek at Kresgeville, Pa. (01449360), and McMichaels Creek at Stroudsburg, Pa. (01441000). Aquashicola Creek at Palmerton (fig. 6) was selected as the index station because it had the longest period of record of the three stations (fig. 10).

Glaciated Pocono Plateau Section of the Appalachian Plateaus Physiographic Province

The Appalachian Plateaus Physiographic Province in Pennsylvania is divided into the Glaciated Low Plateau Section and the Glaciated Pocono Plateau Section (fig. 4). The Glaciated Pocono Plateau Section is underlain predominantly by flat lying, erosion resistant Devonian clastic rocks that form a broad upland. Two streamflow-gaging stations are available for the Glaciated Pocono Plateau Section: Bush Kill at Shoemakers, Pa. (0143950), and Brodhead Creek near Analomink, Pa. (01440400). Both drain mainly rocks mapped as the Long Run and Walcksville Members of the Catskill Formation (Berg and others, 1980). The base-flow-recurrence curves are similar; however, Bush Kill at Shoemakers, Pa. (fig. 6), was selected as the index station because of its longer period of record (fig. 12).

Glaciated Low Plateau Section of the Appalachian Plateaus Physiographic Province

The Glaciated Low Plateau Section of the Appalachian Plateaus Physiographic Province in Pennsylvania is underlain predominantly by Devonian clastic rocks. It is an area of diverse topography consisting of rounded hills and broad to narrow valleys, all of which have been modified by glaciation. Lehigh River at Stoddartsville, Pa. (01447500) (fig. 6), was selected as the index station (fig. 12). The drainage area above Lehigh River at Stoddartsville is underlain predominantly by rocks mapped as the Duncannon Member of the Catskill Formation (Berg and others, 1980).

Catskill Mountains Section of the Appalachian Plateaus Physiographic Province

The Appalachian Plateaus Physiographic Province in New York is divided into the Catskill Mountains Section and the Southern New York Section (fig. 4). Both of these sections are underlain predominantly by Devonian clastic rocks. For the northern part of the Catskill Mountains Section underlain by clastic rocks of the Walton, Oneonta, and Gardeau Formations (Fischer and others, 1970c), five streamflow-gaging stations were available: Little Delaware River near Delhi, N.Y. (01422500), Terry Clove Kill near Pepacton, N.Y. (01415500), Platte Kill at Dunraven, N.Y. (01414000), West Branch

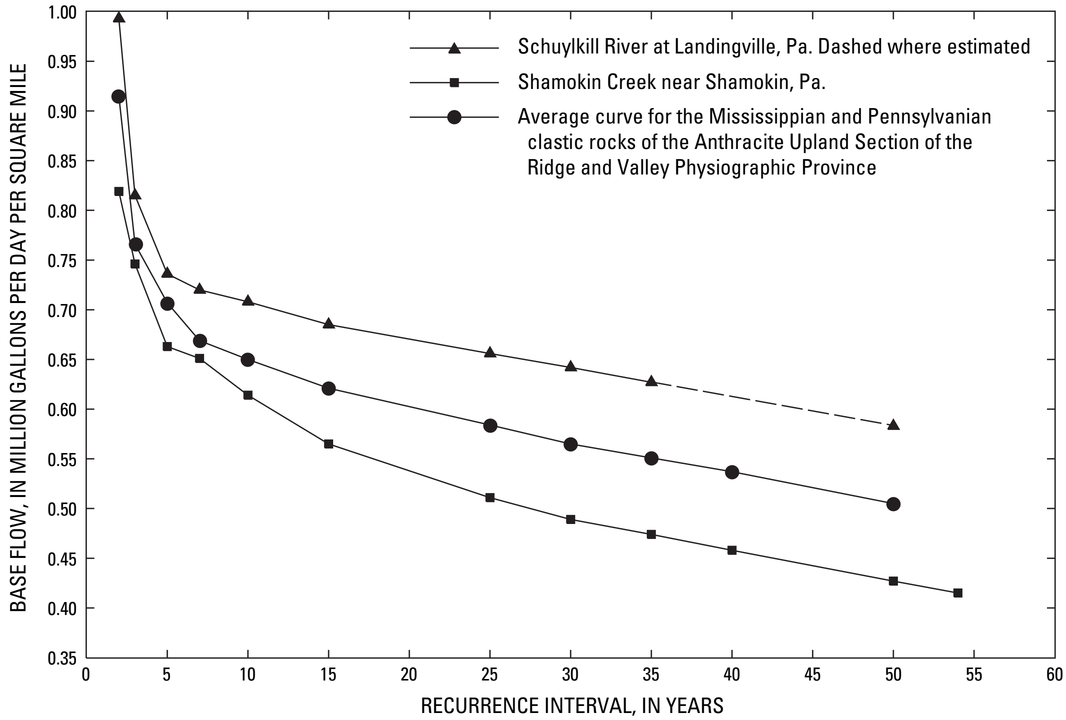


Figure 11. Base-flow-frequency curves for streamflow-gaging stations in the Mississippian and Pennsylvanian clastic rocks of the Anthracite Upland Section of the Ridge and Valley Physiographic Province.

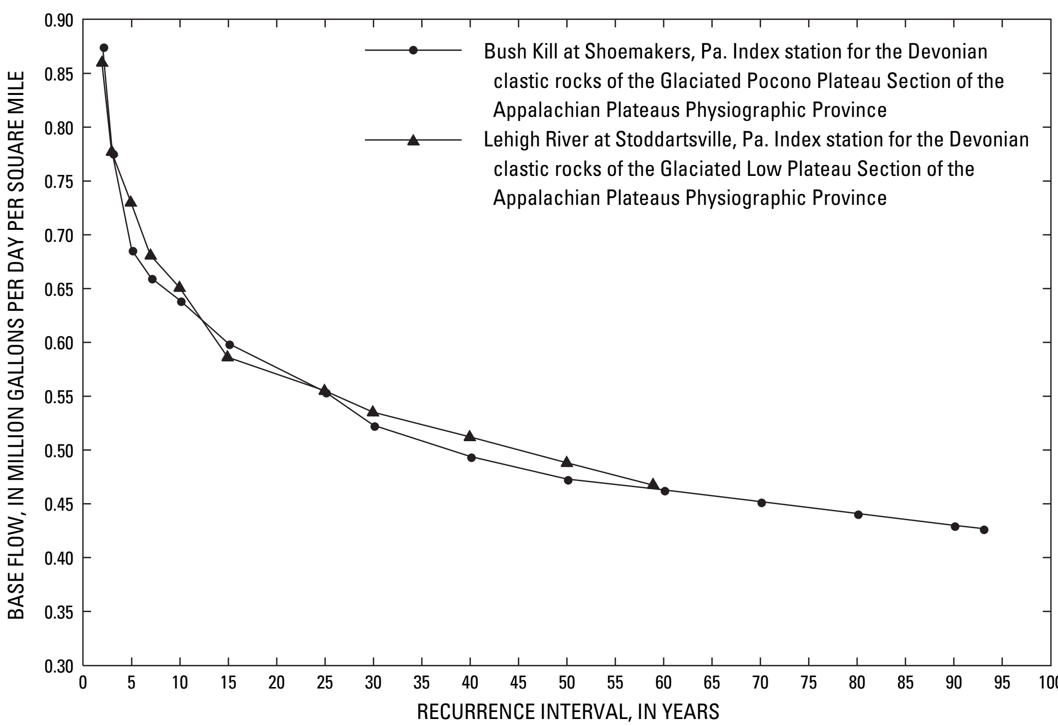


Figure 12. Base-flow-frequency curves for streamflow-gaging stations in the Devonian clastic rocks of the Appalachian Plateaus Physiographic Province in Pennsylvania.

Delaware River upstream from Delhi, N.Y. (01421900), and Tremper Kill near Andes, N.Y. (01415000) (fig. 6). An average base-flow-recurrence-interval curve representative of those rocks was created by taking the average base flow for the five stations for the 2-, 5-, 10-, and 25-year-recurrence intervals and using the 50-year-recurrence interval for the Tremper Kill station (fig. 13).

For the southern part of the Catskill Mountains Section underlain by clastic rocks of the Slide Mountain Formation and the upper part of the Walton Formation (Fischer and others, 1970c), Beaver Kill at Cooks Falls, N.Y. (01420500) (fig. 6), was selected as the index station (fig. 14).

Southern New York Section of the Appalachian Plateaus Physiographic Province

For the Southern New York Section of the Appalachian Plateaus Physiographic Province in New York underlain predominantly by the Honesdale Formation (Fischer and others, 1970c), two suitable streamflow-gaging stations were available: Callicoon Creek at Callicoon, N.Y. (01427500), and Tenmile River at Tusten, N.Y. (01428000). The drainage area above the Tenmile River station is underlain entirely by the Honesdale Formation, and most of the drainage basin above the Callicoon Creek station is underlain by the Honesdale Formation. The base-flow-frequency curves are similar. Callicoon Creek at Callicoon (fig. 6) was selected as the index station because the station has a longer period of record, which includes the entire period of record of the Tenmile River station (fig. 14).

Comparison between Base Flow Estimated by Hydrograph Separation and Spatial-Data Analysis

To determine how well base flow estimated by hydrograph separation compared with base flow estimated by spatial-data analysis, base flow for the 57 gaged watersheds in table 3 was estimated using a spatial-data analysis. The percentage of each generalized rock type in each gaged watershed was determined. Using the base-flow values for each generalized rock type from the index stations and the percentage of each generalized rock type in the gaged watersheds, base-flow-recurrence intervals were estimated. Base flow estimated by each method was compared (table 5).

For the 2-year-recurrence interval, the difference between annual base flow estimated by hydrograph separation and by spatial-data analysis for the 57 streamflow-gaging stations ranged from -24.4 to 30.8 percent (table 5). Ninety percent of the differences ranged between -19 and 18.9 percent. The average difference was 0.1 percent.

For the 5-year-recurrence interval, the difference between annual base flow estimated by hydrograph separation and by spatial-data analysis for the 57 streamflow-gaging stations ranged from -25.4 to 31.6 percent (table 5). Ninety percent of the differences ranged between -20.1 and 21.1 percent. The average difference was 0.6 percent.

For the 10-year-recurrence interval, the difference between annual base flow estimated by hydrograph separation and by spatial-data analysis for the 57 streamflow-gaging stations ranged from -30 to 30.6 percent (table 5). Ninety percent of the differences ranged between -24.2 and 22.9 percent. The average difference was 0.4 percent.

For the 25-year-recurrence interval, 51 streamflow-gaging stations were available for analysis. The difference between annual base flow estimated by hydrograph separation and by spatial-data analysis ranged from -30.6 to 41.6 percent (table 5). Ninety percent of the differences ranged between -22.8 and 26.6 percent. The average difference was 0.4 percent.

For the 50-year-recurrence interval, 19 streamflow-gaging stations were available for analysis. The difference between annual base flow estimated by hydrograph separation and by spatial-data analysis ranged from -31.3 to 38.3 percent (table 5). Ninety percent of the differences ranged between -25.2 and 20.5 percent. The average difference was 0 percent.

Estimation of Ground-Water Availability for Unconsolidated Sediments

To estimate ground-water availability for unconsolidated sediments, natural base flow must be defined and quantified. The estimation of natural base flow in unconsolidated sediments of Coastal Plain watersheds requires an understanding of the factors controlling ground-water discharge to streams. The possible controlling factors can be natural or anthropogenic and include leakage to underlying confined aquifers, precipitation rates, soil characteristics, surficial geology, land cover, stream length, drainage-basin area, population, point discharges, and well pumpage. The relations between mean annual unit-area base flow in streams of the New Jersey Coastal Plain and the controlling factors were systematically investigated by conducting a statistical analysis.

The availability of ground water from confined Coastal Plain aquifers was not determined for this study. The watershed approach and equating availability to stream base flow is not suited for estimating confined aquifer ground-water availability. Determining the source of ground-water withdrawals in a confined system is a complex regional issue. The effects of pumping can extend well beyond watershed boundaries and even beyond the Delaware River Basin. Generally, ground water withdrawn from confined aquifers primarily is from decreased streamflow over large areas, and a much smaller part is from confined-aquifer storage and changes in flows to and from other parts of the confined-aquifer system. The source of water to wells in the New Jersey Coastal Plain was investigated in a Regional Aquifer-System Analysis (RASA) by Martin (1998) and more recently in a smaller scale study of the updip areas of the Wenonah-Mount Laurel aquifer by Watt and Voronin (2005). The RASA study transient-model simulation results showed that approximately 90 percent of

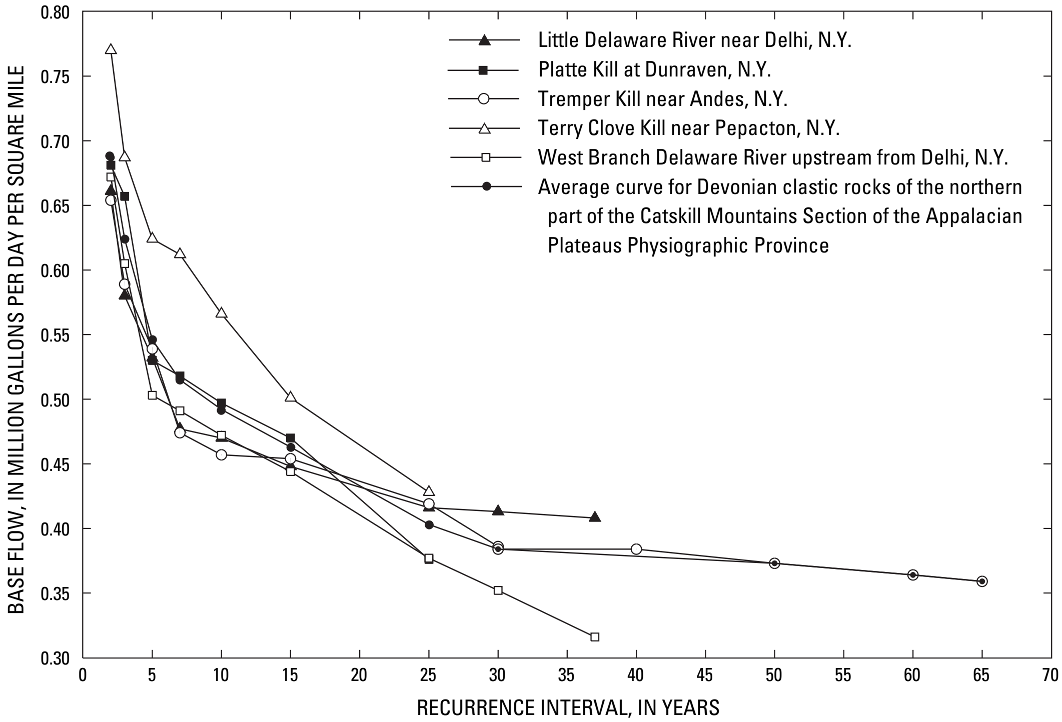


Figure 13. Base-flow-frequency curves for streamflow-gaging stations in the Devonian clastic rocks in the northern part of the Catskill Mountains Section of the Appalachian Plateaus Physiographic Province in New York.

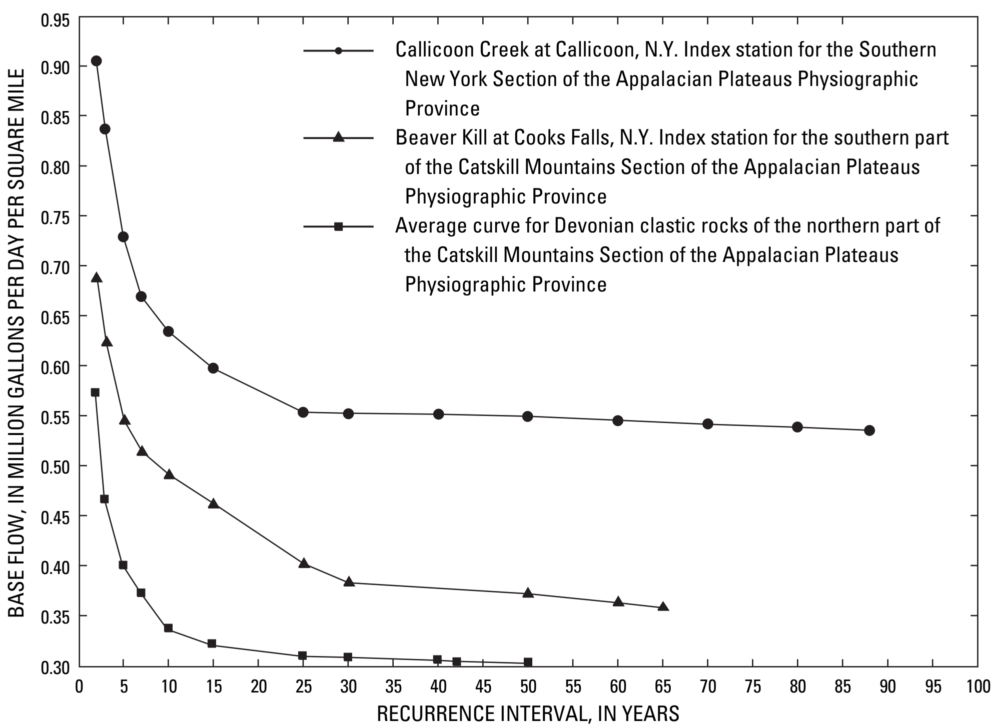


Figure 14. Base-flow-frequency curves for streamflow-gaging stations in the Devonian clastic rocks of the Appalachian Plateaus Physiographic Province in New York.

Table 5. Comparison between baseflow estimated by hydrograph separation and spatial-data analysis for selected gaged fractured-rock watersheds in the Delaware River Basin.—Continued

[--, no data]

U.S. Geological Survey station number	Station name	2-year recurrence average annual base flow (million gallons per day per square mile)			5-year recurrence average annual base flow (million gallons per day per square mile)			10-year recurrence average annual base flow (million gallons per day per square mile)			25-year recurrence average annual base flow (million gallons per day per square mile)			50-year recurrence average annual base flow (million gallons per day per square mile)		
		Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)
01413500	East Branch Delaware River at Margaretville, N.Y.	0.746	0.694	-7.2	0.589	0.551	-6.7	0.507	0.496	-2.2	0.475	0.408	-15.2	0.457	0.379	-18.7
01414000	Platte Kill at Dunraven, N.Y.	.681	.689	1.2	.530	.547	3.2	.497	.493	-0.8	.376	.404	7.2	--	.375	--
01414500	Mill Brook near Dunraven, N.Y.	.896	.724	-21.2	.741	.574	-25.4	.691	.511	-30.0	.579	.427	-30.2	.554	.404	-31.3
01415000	Tremper Kill near Andes, N.Y.	.654	.688	5.1	.539	.547	1.5	.457	.493	7.6	.419	.404	-3.6	.373	.374	0.3
01415500	Terry Clove Kill near Pepacton, N.Y.	.770	.687	-11.4	.624	.546	-13.3	.566	.492	-14.0	.428	.403	-6.0	--	.373	--
01418500	Beaver Kill at Craigie Clair, N.Y.	.962	.753	-24.4	.716	.594	-18.6	.677	.523	-25.7	.607	.446	-30.6	--	.429	--
01419500	Willowemoc Creek near Livingston Manor, N.Y.	.929	.760	-20.0	.704	.603	-15.5	.660	.533	-21.3	.499	.452	-9.9	--	.433	--
01420000	Little Beaver Kill near Livingston Manor, N.Y.	.838	.802	-4.4	.674	.639	-5.3	.531	.562	5.7	.482	.481	-0.2	.469	.467	-0.4
01420500	Beaver Kill at Cooks Falls, N.Y.	.905	.748	-19.0	.729	.588	-21.4	.634	.517	-20.3	.553	.442	-22.3	.549	.426	-25.2
01421900	West Branch Delaware River upstream From Delhi, N.Y.	.672	.687	2.2	.503	.545	8.0	.472	.492	4.1	.377	.403	6.7	--	.373	--
01422000	West Branch Delaware River at Delhi, N.Y.	.555	.687	21.3	.413	.545	27.6	.391	.492	22.9	.350	.403	14.1	--	.373	--
01422500	Little Delaware River near Delhi, N.Y.	.660	.687	4.0	.532	.546	2.6	.470	.492	4.6	.416	.403	-3.2	--	.373	--
0142400103	Trout Creek near Trout Creek, N.Y.	.588	.687	15.5	.442	.546	21.1	.414	.492	17.2	--	.403	--	--	.373	--
01424500	Trout Creek at Cannonsville, N.Y.	.632	.687	8.3	.524	.545	3.9	.416	.492	16.7	--	.403	--	--	.373	--
01426000	Oquaga Creek at Deposit, N.Y.	.517	.705	30.8	.426	.560	27.2	.378	.503	28.4	.272	.415	41.6	--	.388	--

Table 5. Comparison between baseflow estimated by hydrograph separation and spatial-data analysis for selected gaged fractured-rock watersheds in the Delaware River Basin.—Continued

[--, no data]

U.S. Geological Survey station number	Station name	2-year recurrence average annual base flow (million gallons per day per square mile)			5-year recurrence average annual base flow (million gallons per day per square mile)			10-year recurrence average annual base flow (million gallons per day per square mile)			25-year recurrence average annual base flow (million gallons per day per square mile)			50-year recurrence average annual base flow (million gallons per day per square mile)		
		Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)
01427500	Callicoon Creek at Callicoon, N.Y.	0.573	0.659	14.0	0.401	0.487	19.4	0.336	0.414	20.8	0.309	0.372	18.5	--	0.366	--
01428000	Tenmile River at Tusten, N.Y.	.539	.577	6.8	.409	.405	-1.0	.361	.339	-6.3	.291	.312	7.0	--	.305	--
01437500	Neversink River at Godeffroy, N.Y.	.583	.708	19.4	.472	.563	17.6	.421	.509	18.9	.384	.422	9.4	.319	.392	20.5
01439500	Bush Kill at Shoemakers, Pa.	.875	.869	-0.7	.686	.684	-0.3	.639	.637	-0.3	.554	.552	-0.4	.473	.474	0.2
01440000	Flat Brook near Flatbrookville, N.J.	.702	.715	1.8	.576	.584	1.4	.520	.530	1.9	.451	.459	1.8	.398	.408	2.5
01440400	Brodhead Creek near Analomink, Pa.	.790	.872	9.9	.677	.694	2.5	.654	.641	-2.0	.508	.554	8.7	--	.476	--
01441000	McMichaels Creek at Stroudsburg, Pa.	.805	.832	3.3	.611	.660	7.7	.553	.621	11.6	.469	.534	13.0	--	.479	--
01442500	Brodhead Creek at Minisink Hills, Pa.	.829	.853	2.9	.648	.677	4.4	.576	.632	9.3	.556	.544	-2.2	.486	.477	-1.9
01445500	Pequest River at Pequest, N.J.	.674	.667	-1.0	.559	.524	-6.5	.465	.451	-3.1	.418	.358	-15.5	.292	.305	4.4
01446000	Beaver Brook near Belvidere, N.J.	.625	.602	-3.7	.479	.481	0.4	.406	.429	5.5	.393	.349	-11.9	--	.286	
01447500	Lehigh River at Stoddartsville, Pa.	.861	.864	0.3	.730	.729	-0.1	.651	.651	0.0	.555	.557	0.4	.488	.489	0.2
01447720	Tobyhanna Creek near Blakeslee, Pa.	.876	.860	-1.8	.720	.729	1.2	.688	.650	-5.7	.591	.555	-6.3	--	.487	--
01448000	Lehigh River at Tannery, Pa.	.847	.873	3.0	.708	.725	2.4	.613	.651	6.0	.541	.562	3.8	--	.492	--
01449360	Pohopoco Creek at Kresgeville, Pa.	.896	.848	-5.5	.761	.673	-12.3	.688	.629	-9.0	.663	.541	-20.3	--	.477	--
01450000	Pohopoco Creek near Parryville, Pa.	.722	.846	15.8	.565	.675	17.7	.488	.629	25.2	.432	.541	22.4	--	.479	--

Table 5. Comparison between baseflow estimated by hydrograph separation and spatial-data analysis for selected gaged fractured-rock watersheds in the Delaware River Basin.—Continued

[--, no data]

U.S. Geological Survey station number	Station name	2-year recurrence average annual base flow (million gallons per day per square mile)			5-year recurrence average annual base flow (million gallons per day per square mile)			10-year recurrence average annual base flow (million gallons per day per square mile)			25-year recurrence average annual base flow (million gallons per day per square mile)			50-year recurrence average annual base flow (million gallons per day per square mile)		
		Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)
01450500	Aquashicola Creek at Palmerton, Pa.	0.810	0.794	-2.0	0.640	0.633	-1.1	0.610	0.590	-3.3	0.522	0.509	-2.5	0.480	0.454	-5.6
01451500	Little Lehigh Creek near Allentown, Pa.	.625	.673	7.4	.468	.523	11.1	.392	.447	13.1	.284	.347	20.0	.253	.299	16.7
01451800	Jordan Creek near Schnecksville, Pa.	.514	.515	0.2	.435	.435	0.0	.412	.412	0.0	.361	.361	0.0	--	.276	
01452500	Monocacy Creek at Bethlehem, Pa.	.582	.628	7.6	.435	.490	11.9	.374	.427	13.2	.227	.332	37.6	.190	.280	38.3
01456000	Musconetcong River near Hackettstown, N.J.	.813	.683	-17.4	.625	.561	-10.8	.486	.488	0.4	.439	.418	-4.9	.313	.348	10.6
01457000	Musconetcong River near Bloomsbury, N.J.	.810	.674	-18.3	.651	.546	-17.5	.574	.474	-19.1	.498	.396	-22.8	.415	.332	-22.2
01459500	Tohickon Creek near Pipersville, Pa.	.259	.313	18.9	.211	.249	16.5	.189	.211	11.0	.161	.175	8.3	--	.150	--
01460000	Tohickon Creek at Point Pleasant, Pa.	.335	.313	-6.8	.246	.249	1.2	.230	.211	-8.6	.190	.175	-8.2	--	.150	--
01465000	Neshaminy Creek at Rushland, Pa.	.430	.430	0.0	.329	.328	-0.3	.292	.292	0.0	.249	.249	0.0	--	.208	--
01467500	Schuylkill River at Pottsville, Pa.	.837	.915	8.9	.677	.707	4.3	.592	.650	9.3	.447	.584	26.6	--	.505	--
01468500	Schuylkill River at Landingville, Pa.	.993	.901	-9.7	.736	.698	-5.3	.708	.645	-9.3	.656	.576	-13.0	--	.502	--
01470756	Maiden Creek at Virginville, Pa.	.606	.548	-10.1	.457	.456	-0.2	.420	.422	0.5	--	.363	--	--	.285	--
01470779	Tulpehocken Creek near Bernville, Pa.	.786	.665	-16.7	.622	.508	-20.2	.554	.432	-24.7	.439	.324	-30.1	--	.282	--
01471000	Tulpehocken Creek near Reading, Pa.	.682	.596	-13.5	.494	.478	-3.3	.422	.427	1.2	.309	.349	12.2	--	.286	--
01471980	Manatawny Creek near Pottstown, Pa.	.567	.637	11.6	.480	.510	6.1	.435	.441	1.4	.355	.363	2.2	--	.307	--

Table 5. Comparison between baseflow estimated by hydrograph separation and spatial-data analysis for selected gaged fractured-rock watersheds in the Delaware River Basin.—Continued

[--, no data]

U.S. Geological Survey station number	Station name	2-year recurrence average annual base flow (million gallons per day per square mile)			5-year recurrence average annual base flow (million gallons per day per square mile)			10-year recurrence average annual base flow (million gallons per day per square mile)			25-year recurrence average annual base flow (million gallons per day per square mile)			50-year recurrence average annual base flow (million gallons per day per square mile)		
		Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)	Hydrograph separation	Spatial-data analysis	Difference (percent)
01472157	French Creek near Phoenixville, Pa.	0.566	0.523	-7.9	0.463	0.391	-16.9	0.397	0.341	-15.2	0.281	0.297	5.5	--	0.265	--
01472198	Perkiomen Creek at East Greenville, Pa.	.576	.584	1.4	.486	.473	-2.7	.462	.412	-11.4	--	.351	--	--	.294	--
01472199	West Branch Perkiomen Creek at Hillegass, Pa.	.620	.552	-11.6	.519	.447	-14.9	.473	.388	-19.7	--	.329	--	--	.276	--
01472500	Perkiomen Creek near Frederick, Pa.	.434	.429	-1.2	.322	.343	6.3	.303	.296	-2.3	.278	.250	-10.6	--	.211	--
01473000	Perkiomen Creek at Graterford, Pa.	.334	.388	15.0	.280	.310	10.2	.224	.266	17.1	.210	.224	6.5	--	.190	--
01473120	Skippack Creek near Collegeville, Pa.	.313	.313	0.0	.249	.249	0.0	.211	.211	0.0	.175	.175	0.0	--	.150	--
01475850	Crum Creek near Newtown Square, Pa.	.567	.523	-8.1	.477	.390	-20.1	.421	.330	-24.2	--	.289	--	--	.274	--
01479000	White Clay Creek near Newark, Del.	.517	.534	3.2	.373	.398	6.5	.305	.337	10.0	.272	.291	6.7	.255	.275	7.5
01480000	Red Clay Creek at Wooddale, Del.	.544	.535	-1.7	.410	.399	-2.7	.360	.337	-6.6	.301	.291	-3.4	.293	.275	-6.3
01480300	West Branch Brandywine Creek near Honey Brook, Pa.	.509	.529	3.9	.390	.395	1.3	.327	.334	2.1	.295	.290	-1.7	.274	--	--
01481000	Brandywine Creek at Chadds Ford, Pa.	.565	.682	18.8	.407	.560	31.6	.357	.486	30.6	.319	.415	26.2	.310	.346	11.0
01481500	Brandywine Creek at Wilmington, Del.	.606	.538	-11.9	.393	.403	2.5	.362	.341	-6.0	.325	.294	-10.0	--	.276	--
	Average difference	**--**	**--**	**.1**	**--**	**--**	**0.6**	**--**	**--**	**0.4**	**--**	**--**	**0.4**	**--**	**--**	**0.0**

the Coastal Plain withdrawals came from decreased streamflow, approximately 3 percent came from aquifer storage, and 6 percent from changes in confined flows and flows to the ocean and bays. The Wenonah-Mount Laurel aquifer study estimated possible future pumpage in a steady-state simulation where changes in storage were not considered. The simulation showed that 81 percent of the confined-aquifer withdrawals near the aquifer outcrop area is from streamflow in the outcrop of the Wenonah-Mount Laurel aquifer and the overlying Vincetown aquifer. These studies support the concept that withdrawals from confined-aquifer wells can affect stream base flow beyond local watersheds. An analysis using a regional-flow model could examine the source of water to confined-aquifer wells and estimate the changes in base flow within affected watersheds. Results of such an analysis would provide a basis for determining which existing and future withdrawals should be considered in evaluating the status of allocated water in a particular watershed as it relates to base flow.

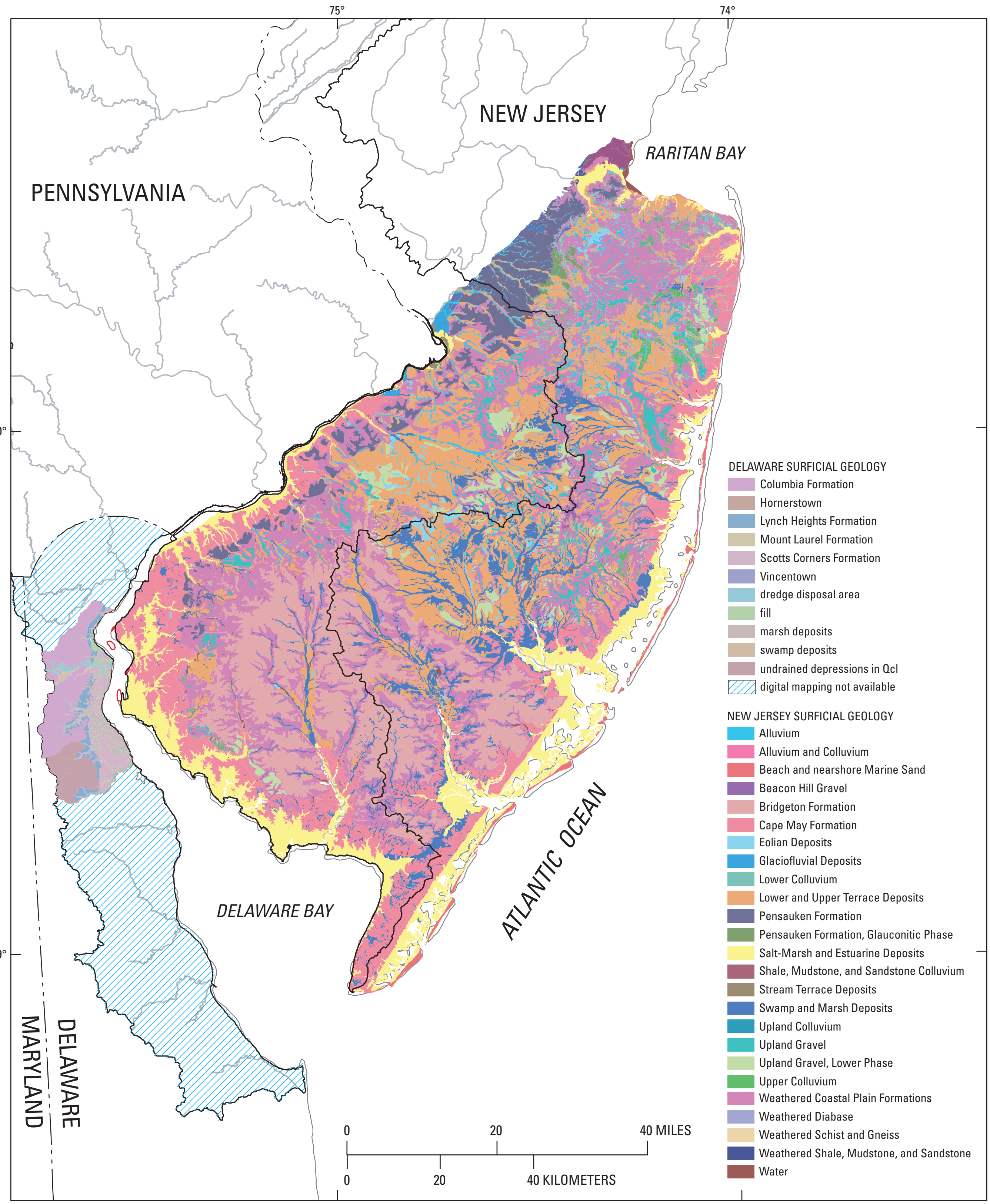
To estimate ground-water availability in the unconfined aquifers, mean annual base flows were compiled for the available period of record for 119 USGS streamflow-gaging stations in the New Jersey Coastal Plain. These data came from reports that were part of the New Jersey Surficial Aquifer Program conducted during 1987-2002 in cooperation with the NJDEP (Watt and Johnson, 1992; Watt and others, 1994; Lacombe and Rosman, 1995; Johnson and Watt, 1996; Johnson and Charles, 1997; Charles and others, 2001; Watt and others, 2003; Gordon, 2004) and a report on the sources of water to wells in the Wenonah-Mount Laurel Aquifer of New Jersey (Watt and Voronin, 2005). The variables representing the possible controlling factors were gathered and stored in digital form from various sources including the USGS, NJDEP, Natural Resources Conservation Service, and U.S. Census Bureau. A spatial-data analysis was applied by a "cookie cutter" method to determine the variables for the drainage-basin area associated with each of the 119 stations. Base-flow and variable data for each drainage basin were stored and managed in a relational database. Some variables were divided by basin drainage area, so relations could be compared per unit area.

Initially, the data were evaluated using exploratory data analysis (EDA). Scatterplots and basic summary statistic results (minimum, maximum, median, mean, and quartiles) of the EDA showed that the data were non-normally distributed. This provided insight for determining that nonparametric statistical tests were to be used for data analysis. Relations between mean annual unit-area base flow and the variables associated with a drainage basin were explored using the Kruskal-Wallis test, Spearman's Rho rank correlation, linear regression, multiple-linear regression, and the Dunn test. The Kruskal-Wallis test is a nonparametric test used to compare independent groups of data. The Spearman's Rho rank correlation measures the strength of the linear relation between two variables, whereas regression analysis defines the mathematical relation between two variables. The Dunn test is a nonparametric multiple comparison test that determines which variable in a group is different.

Results of the Kruskal-Wallis test at the alpha less than 0.05 level gave Kruskal-Wallis chi-square values ranging from 3.86 to 21.24. Relations were significant between mean annual unit-area base flow and variables including predominant outcrop area of Coastal Plain geology, predominant land-use types, developed and undeveloped land, predominant surficial geology, soil characteristics, recharge, and discharge to ground water. Spearman's Rho rank correlation showed a range of normal-z values from 2.01 to 5.32 at the alpha less than 0.05 level with correlations between mean annual unit-area base flow and predominant outcrop area of Coastal Plain geology, developed and undeveloped land, predominant surficial geology, predominant land use, recharge, soil characteristics, and stream length. Regression techniques verified the results of the Kruskal-Wallis and Spearman's Rho tests indicating the same group of variables and some groupings of the variables were significantly related to mean annual unit-area base flow.

Certain variables, such as developed and undeveloped land, are representative or surrogates of other variables, such as land-use type. It had to be determined which variable or variables were the best fit for the analysis of estimating base flow. This decision relied on the statistic results, but also included exploring and understanding the concepts of base flow and ground-water hydrology principles. Predominant surficial geology (fig. 15) and predominant land use (fig. 16) were chosen as the best representative variables that show a relation to mean annual unit-area base flow. The Dunn test and boxplots showed that mean annual unit-area base flows were different between the groups of predominant surficial geology and predominant land use, and identified which groups were different (fig. 17). For predominant surficial geology, stream terrace deposits had the highest median base flow per unit area of 1.16 ft^3/s (fig. 17A). Weathered Coastal Plain formations had a median base flow per unit area of 1.04 ft^3/s, and the Bridgeton Formation had the lowest median base flow per unit area of 0.95 ft^3/s (fig. 17A). In general, surficial geology types that contained clay had a lower median base flow per unit area of 0.99 ft^3/s compared to a median base flow per unit area of 1.16 ft^3/s for those without clay (fig. 17B). For land use, undeveloped land use had the highest median base flow per unit area of 1.18 ft^3/s, agricultural land use had a median base flow per unit area of 1.01 ft^3/s, and urban land use had the lowest median base flow per unit area of 0.95 ft^3/s (fig. 17C).

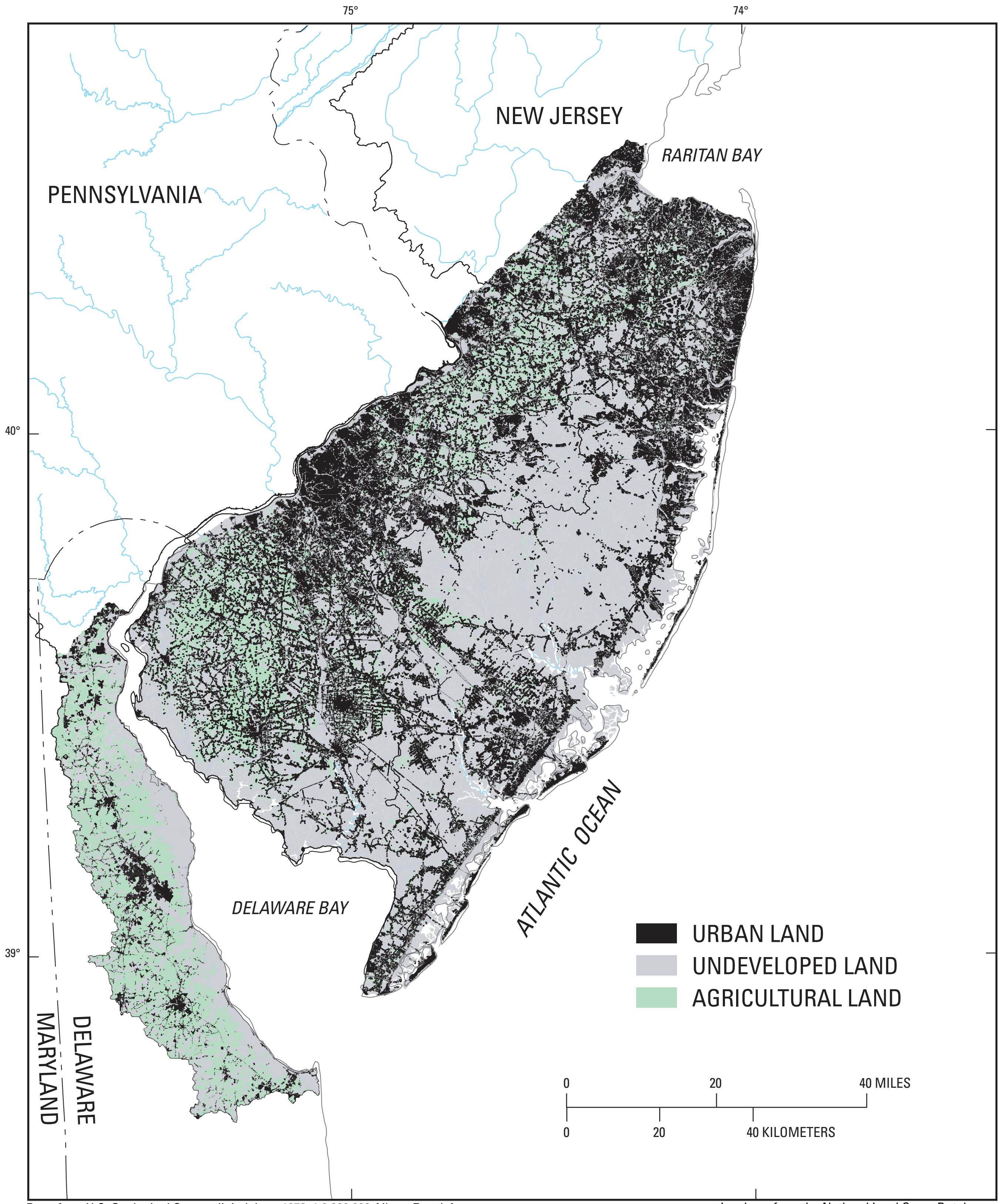
The digital surficial geologic map of New Jersey completed in 2003 was obtained from the New Jersey Geological Survey on CD (New Jersey Geological Survey, 2005). Predominant surficial geology for the New Jersey Coastal Plain part of the Delaware River Basin was represented by five main categories that make up 81 percent of the areas surficial geology (fig. 15). Twenty-five percent of the area is covered by weathered Coastal Plain formations, 16 percent by lower and upper stream-terrace deposits, 16 percent by the Cape May Formation, 14 percent by the Bridgeton Formation, and 10 percent by salt marsh and estuarine deposits. Surficial geol-



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30′N, central meridian 75°00′W.

Geology from New Jersey Geological Survey (2005) and the Delaware Geological Survey

Figure 15. Surficial geology in the Coastal Plain of the Delaware River Basin.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30′N, central meridian 75°00′W.

Land use from the National Land Cover Database

Figure 16. Land use in the Coastal Plain of New Jersey and Delaware.

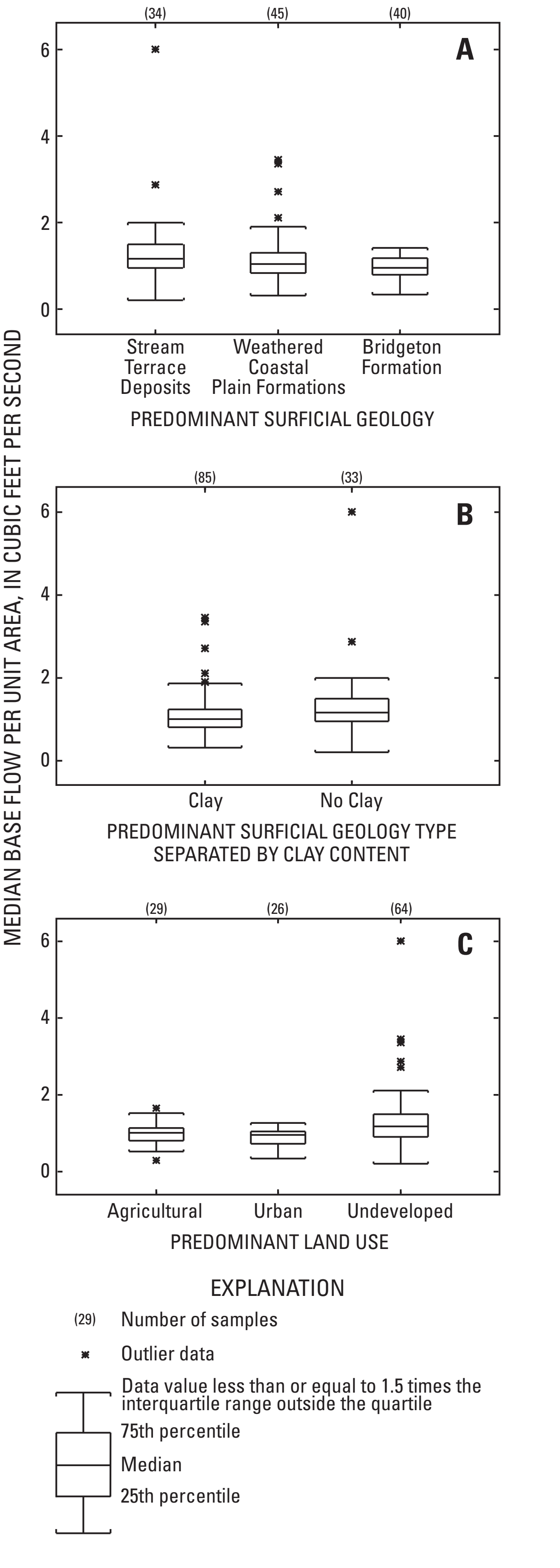


Figure 17. Distribution of median base flow per unit area for 119 watersheds by: (A) predominant surficial geology, (B) predominant surficial geology separated by clay content, and (C) predominant land use.

ogy for Delaware was available only for one of three counties, New Castle County, and was obtained electronically from the Delaware Geological Survey (Lillian Wang, Delaware Geological Survey, written commun., 2005). The predominant surficial geology of the only index station in this area is the Columbia Formation overlain by undrained depressions and is not representative of the predominant surficial geology of the watersheds in Delaware (table 6).

Digital land-use maps of New Jersey and Delaware for 1975-97 were obtained from NJDEP (Edward Apalinski, New Jersey Department of Environmental Protection, written commun., 2005) and the USGS Delaware River National Water Quality Assessment Program (Susan Colarullo, U.S. Geological Survey, written commun., 2005), respectively, and originate from National Land Cover Data (NLCD). Predominant land use was separated into three categories: urban, undeveloped, and agricultural (fig. 16). The New Jersey Coastal Plain part of the Delaware River Basin is 55 percent undeveloped, 23 percent urban, and 22 percent agricultural on the basis of 1995-97 land use. The Delaware part of the Delaware River Basin is approximately 43 percent undeveloped, 13 percent urban, and 44 percent agricultural on the basis of 1995-97 land use. Urban land use encompasses residential, commercial, industrial, transportation, utilities, urban, institutional, and governmental classifications. Undeveloped land use includes brushland, rangeland, forest, water, wetlands, and barren land. Agricultural land use includes cropland, pastures, idle fields, orchards, nurseries, confined feeding operations, and all other lands listed as agricultural.

Ground-water availability for unconfined aquifers in watersheds underlain by unconsolidated sediments of the Coastal Plain is based on predominant surficial geology and predominant land use in each watershed (fig. 18) and was estimated by the following method. A spatial-data analysis was used to determine the predominant surficial geology and land use in each of the 38 watersheds in the Coastal Plain of the Delaware River Basin. Watersheds with the same predominant surficial geology and land use needed index stations with corresponding predominant surficial geology and land use to establish base-flow estimates for the watersheds. A list of suitable long-term streamflow-gaging stations, termed index stations, was compiled for the New Jersey and Delaware Coastal Plain. A spatial-data analysis was used to determine the predominant surficial geology and land use of each index station's watershed, and index stations were grouped by predominant surficial geology and/or land use. A base-flow-recurrence analysis using the HYSEP hydrograph-separation computer program (Sloto and Crouse, 1996) and, in a few instances, the PART streamflow-partitioning computer program (Rutledge, 1998) was conducted for the index stations. Recurrence intervals were calculated for each index station, and, if a group contained more than one index station, an average base-flow-frequency curve was estimated. A single or average annual 2-, 5-, 10-, 25-, and 50-year base-flow-recurrence interval was used as the representative recurrence

Table 6. Index streamflow-gaging stations draining unconsolidated Coastal Plain sediments in the Delaware River Basin.

[NA, not available; Qwcp, weathered Coastal Plain formations; Qtu, upper stream-terrace deposits; Qcm, Cape May Formation; Tb, Bridgeton Formation; ud, undrained depressions; Qtl, lower stream-terrace deposits]

Station number	Station name	Drainage area (square miles)	Period of record	Predominant land use	Percent land use	Predominant surficial geology	Percent surficial geology
01405400	Manalapan Brook at Spotswood, N.J.	40.7	1957-2004	Undeveloped	54.0	Qwcp	43.0
01408000	Manasquan River at Squankum, N.J.	44.0	1932-2004	Undeveloped	51.8	Qtu	37.4
01408120	North Branch Metedeconk River near Lakewood, N.J.	34.9	1973-2004	Undeveloped	59.1	Qtu	50.8
01408500	Toms River near Toms River, N.J.	123	1929-2004	Undeveloped	79.3	Qtu	38.5
01409000	Cedar Creek at Lanoka Harbor, N.J.	55.3	1933-57, 2004	Undeveloped	94.3	Qtu	36.3
01409500	Batsto River at Batsto, N.J.	67.8	1928-38, 1940-2003	Undeveloped	84.6	Qtu	49.1
01409810	West Branch Wading River near Jenkins, N.J.	84.1	1975-95	Undeveloped	97.3	Qtu	41.5
01410000	Oswego River at Harrisville, N.J	72.5	1931-2003	Undeveloped	98.3	Qtu	32.8
01410150	East Branch Bass River near New Gretna, N.J.	8.11	1978-2004	Undeveloped	98.0	Qcm	33.7
01411000	Great Egg Harbor River at Folsom, N.J.	57.1	1926-2004	Undeveloped	69.4	Tb	36.6
01411300	Tuckahoe River at Head of River, N.J.	30.8	1970-2004	Undeveloped	89.0	Tb	49.9
01411500	Maurice River at Norma, N.J.	112	1933-2004	Undeveloped	54.7	Tb	59.9
01412000	Menantico Creek near Millville, N.J.	23.2	1932-56, 1978-84	Agricultural	38.2	Tb	59.8
01464500	Crosswicks Creek at Extonville, N.J.	81.5	1941-50, 1953-2003	Undeveloped	57.3	Qtu	39.8
01466500	McDonalds Branch in Byrne State Forest, N.J.	2.35	1954-2004	Undeveloped	100	Qwcp	67.1
01467000	North Branch Rancocas Creek at Pemberton, N.J.	118	1922-2004	Undeveloped	86.4	Qtu	38.6
01467081	South Branch Pennsauken Creek at Cherry Hill, N.J.	8.98	1978-2004	Urban	79.3	Qwcp	38.4
01475000	Mantua Creek at Pitman, N.J.	6.05	1942-75, 2004	Urban	60.0	Tb	47.0
01477120	Raccoon Creek near Swedesboro, N.J.	26.9	1967-2004	Agricultural	47.6	Qwcp	60.1
01482500	Salem River at Woodstown, N.J.	14.6	1942-84, 2003	Agricultural	67.2	Qwcp	60.2
01483000	Alloway Creek at Alloway, N.J.	20.3	1953-71	Agricultural	48.7	Qwcp	25.9
01483200	Blackbird Creek at Blackbird, Del.	3.85	1957-2002	Undeveloped	47.9	ud/Qtl	92.1
01483500	Leipsic River near Cheswold, Del.	9.35	1944-56	Agricultural	69.3	NA	NA
01483700	St. Jones River at Dover, Del.	31.9	1958-86	Agricultural	41.3	NA	NA
01487500	Trap Pond Outlet near Laurel, Del.	16.7	1952-70	Undeveloped	61.4	NA	NA

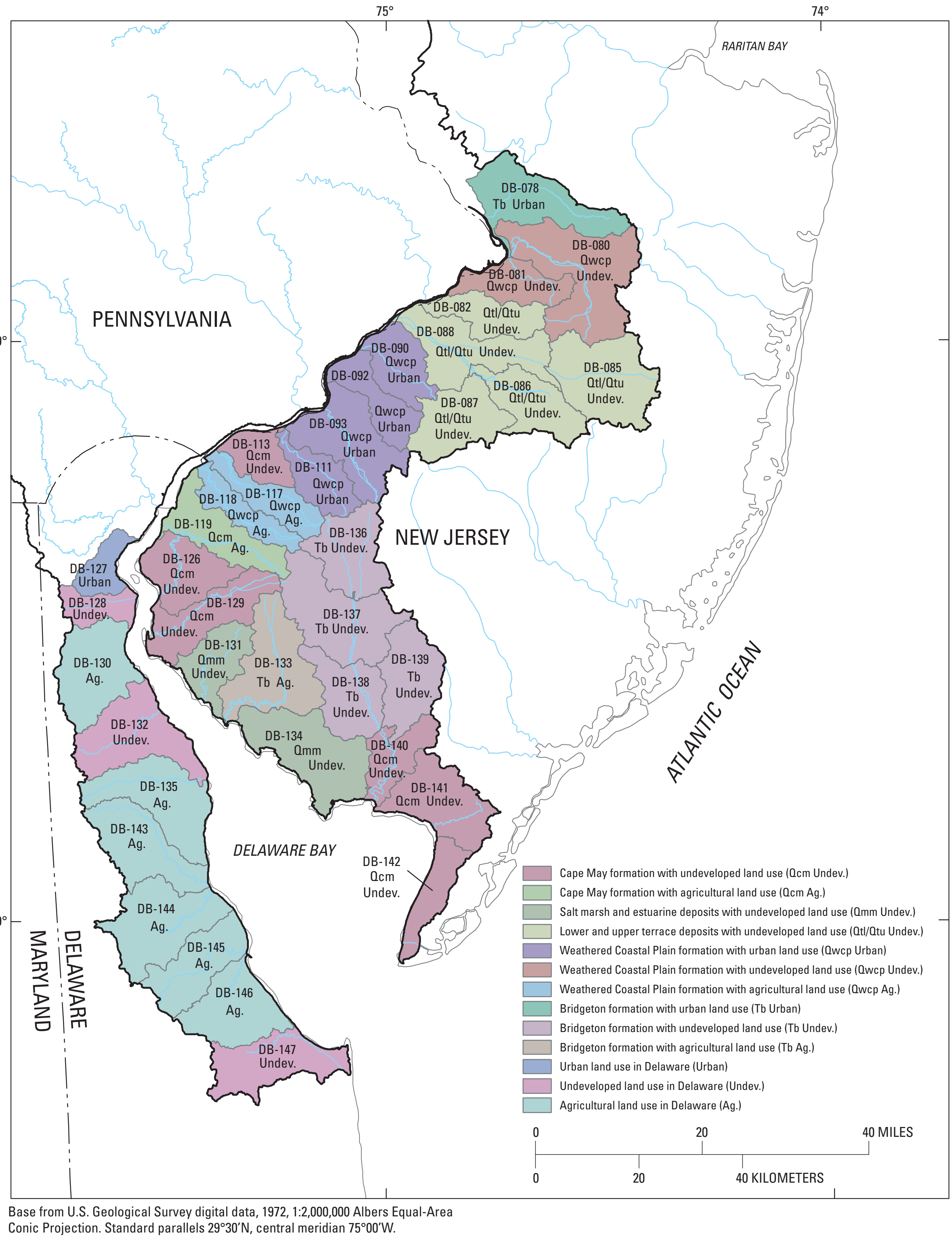


Figure 18. Coastal Plain watersheds with predominant surficial geology and land use in the Delaware River Basin.

interval for watersheds with the same predominant surficial geology and/or land-use group.

Some assumptions were made in this analysis. As with fractured rock, it was assumed the base-flow separation using the HYSEP program divides surface runoff from ground-water discharge. The PART program assumes nearly all ground water discharges to the stream except for some riparian evapotranspiration and where regulation or diversion of flow is considered to be negligible (Rutledge, 1998). A common period of record was not used to calculate base-flow-recurrence values because of the widely varying dates of the period of record for the stations and the need for enough data to produce a 50-year-recurrence interval. The base-flow-recurrence intervals may be influenced by climate because a common period of record was not used. Where a 50-year or longer period of record was not available, estimation techniques were used to extend the data where needed, and linear interpolation was used to calculate some recurrence intervals. In four instances, only one index station was available to estimate base-flow-recurrence intervals for a group of watersheds. An index station was not available that represented both predominant surficial geology and predominant land use for two groups of watersheds. In both of these cases, all other index stations with similar predominant surficial geology and/or predominant land use were used to compute the average annual base-flow-recurrence intervals minimizing the possibility of using one or two stations that may have a relative low or high bias. This unconfined-aquifer analysis is a basic tool to be used to estimate ground-water availability in a complex, multi-layer aquifer system where additional techniques, such as ground-water modeling, could be used to enhance and verify the results.

Index Stations

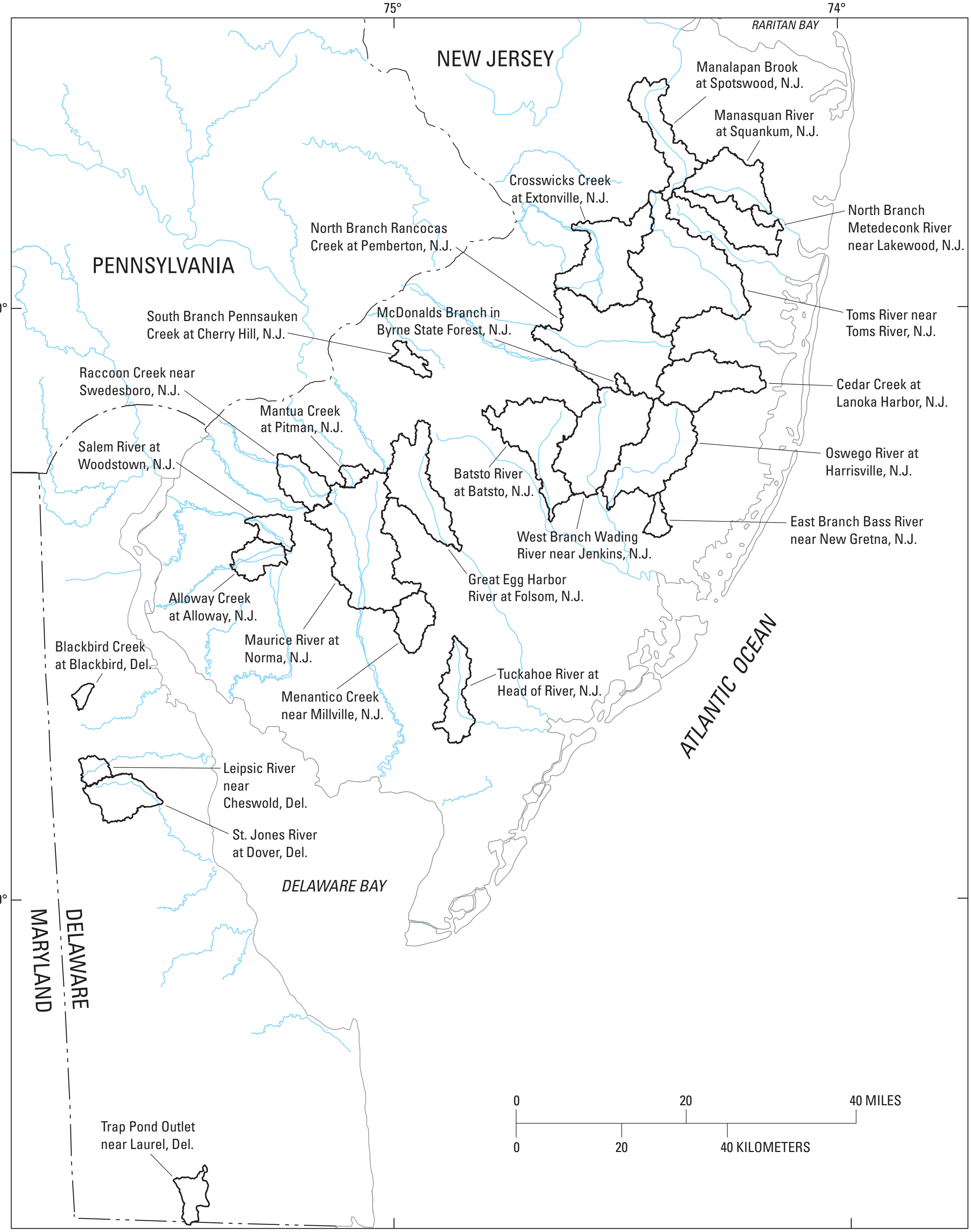
To identify index stations, a list was compiled of all current and discontinued USGS streamflow-gaging stations in the unconsolidated sediments of the New Jersey Coastal Plain with 20 or more years of record. Drainage areas ranged from 2.35 to 123 mi^2 for the initial 30 stations. Stations downstream of dams or mills and stations affected by regulation or diversion were eliminated unless the period of record prior to or after regulation or diversion was greater than 20 years. In those cases, only the unaffected period of record was used. Stations with tidal effects were eliminated. The final set consisted of 21 streamflow-gaging stations for New Jersey (table 6).

A comparison was conducted using both the HYSEP and PART computer programs on streamflow data from index station basins with drainage-basin areas less than and greater than 10 mi^2 to investigate if basin size has an effect on base-flow-separation techniques for Coastal Plain basins. Basins less than 10 mi^2 were eliminated in fractured rock, but using that same elimination criteria in the Coastal Plain would have removed six useful index station basins. As expected, results showed base flows estimated by the HYSEP program with the local-minimum method were lower than base flows estimated by the PART program for each basin tested. The percent difference was similar whether the basin was less than or greater than 10 mi^2 and ranged from 3 to 13 percent. Drainage-basin size in the unconsolidated sediments of the Coastal Plain does not effect base-flow-separation estimates, and, therefore, index station basins smaller than 10 mi^2 can be used to estimate base flow.

A similar list of USGS streamflow-gaging stations was compiled to identify index stations for the unconsolidated sediments of the Delaware Coastal Plain. Drainage-basin areas for the initial 10 stations ranged from 2.83 to 75.4 mi^2. Stations were eliminated using the same criteria as that used for the New Jersey Coastal Plain. Digital basin delineations were in the process of being created by the USGS Delaware Water Science Center at the time of this study. The available basins were obtained from the USGS Delaware Water Science Center (Mark Nardi, U.S. Geological Survey, written commun., 2005). Only four of the available basin delineations met the index-station selection criteria (table 6). The delineation was needed to conduct the spatial-data analysis to determine predominant surficial geology and land use. Two of the four stations (01483500 and 01483700) had less than 20 years of streamflow data. Those two stations were used because they provided the best available data for Delaware.

Streamflow hydrographs from all 21 streamflow-gaging stations in New Jersey and 1 of the 4 stations in Delaware were separated into surface-runoff and base-flow components using the local-minimum technique of the HYSEP program to estimate annual calendar-year base flows. The streamflow data for these stations were retrieved from the USGS Automated Data Processing System (ADAPS). The methodology, as well as limitations, potential sources of error, and physical factors that affect base-flow estimates, is discussed by Sloto and Crouse (1996) and White and Sloto (1990). The streamflow data for the other three streamflow-gaging stations in Delaware were partitioned using the PART program. PART was used when streamflow data were only available from the USGS National Water Information System (NWIS). The resulting base flows were used to estimate annual calendar-year base flows for each station. Only complete calendar years of non-provisional record were used for the analysis. A frequency distribution was calculated and plotted for each station. Average annual base flow was selected for the 2-, 5-, 10-, 25-, and 50-year (where available) recurrence interval from the base-flow-frequency analysis.

Therefore, 25 streamflow-gaging stations (21 in New Jersey and 4 in Delaware) were chosen as index stations for the 13 groups of predominant surficial geology and land use that are represented by the 38 watersheds underlain by unconsolidated Coastal Plain sediments (fig. 19). For stations classified in the same group with similar base-flow-frequency distributions, an average distribution was calculated to represent the group. In some cases, only one station was available to represent the group or only one controlling factor could be used to develop an average base-flow-frequency distribution.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30′N, central meridian 75°00′W.

Figure 19. Index stations used for Coastal Plain watersheds in the Delaware River Basin.

Predominant Surficial Geology and Land-Use Categories in New Jersey Coastal Plain Watersheds

The 28 New Jersey Coastal Plain watersheds contained all 3 predominant land-use types and 5 predominant surficial-geology types. Twenty-one index stations were used to represent the various combinations of land use and surficial geology.

Salt Marsh and Estuarine Deposits and Undeveloped Land Use

The salt marsh and estuarine deposits (Qmm) of the New Jersey Coastal Plain were deposited in salt marshes, estuaries, and tidal channels during the Holocene age sea-level rise and are comprised of silt, sand, peat, clay, and minor pebble gravel. The deposits are brown, dark-brown, gray, and black and contain abundant organic matter. The deposits can be as much as 100 ft thick.

Two watersheds (DB-131 and DB-134) have salt marsh and estuarine deposits and undeveloped land use as predominant controlling factors of base flow (fig. 18). For these 2 watersheds, 15 index stations with similar predominant land use were available. No index stations were available with similar predominant surficial geology. The 15 index stations are Manalapan Brook at Spotswood, N.J. (01405400), Manasquan River at Squankum, N.J. (01408000), North Branch Metedeconk River near Lakewood, N.J. (01408120), Toms River near Toms River, N.J. (01408500), Cedar Creek at Lanoka Harbor, N.J. (01409000), Batsto River near Batsto, N.J. (01409500), West Branch Wading River near Jenkins, N.J. (01409810), Oswego River at Harrisville, N.J. (01410000), East Branch Bass River near New Gretna, N.J. (01410150), Great Egg Harbor River at Folsom, N.J. (01411000), Tuckahoe River at Head of River, N.J. (01411300), Maurice River at Norma, N.J. (01411500), Crosswicks Creek at Exton, N.J. (01464500), McDonalds Branch in Byrne State Forest, N.J. (01466500), and North Branch Rancocas Creek at Pemberton, N.J. (01467000). Additional station information is given in table 6. An average annual base-flow-recurrence-interval curve for predominant salt marsh and estuarine deposits and undeveloped land use was developed by taking the average base flow for all 15 stations for the 2-, 5-, and 10-year-recurrence intervals, 14 stations for the 25-year-recurrence interval, and 9 stations for the 50-year-recurrence interval (table 7 and fig. 20).

Lower and Upper Stream-Terrace Deposits and Undeveloped Land Use

The lower (Qtl) and upper (Qtu) stream-terrace deposits of the New Jersey Coastal Plain were deposited in the late Pleistocene-late Wisconsinan and middle to late Pleistocene, respectively. Generally, they are sand, pebble gravel, minor silt, and cobble gravel and are varying shades of yellow, red, and brown. The deposits form non-glacial terraces as much as 20 to 30 ft thick.

Five watersheds (DB-082, DB-085, DB-086, DB-087, and DB-088) have lower and upper stream-terrace deposits and undeveloped land use as predominant controlling factors of base flow (fig. 18). Nine index stations in the New Jersey Coastal Plain represent this group and were used to calculate an average annual base flow for the five watersheds. These stations are Manasquan River at Squankum, N.J. (01408000), North Branch Metedeconk River near Lakewood, N.J. (01408120), Toms River near Toms River, N.J. (01408500), Cedar Creek at Lanoka Harbor, N.J. (01409000), Batsto River near Batsto, N.J. (01409500), West Branch Wading River near Jenkins, N.J. (01409810), Oswego River at Harrisville, N.J. (01410000), Crosswicks Creek at Exton, N.J. (01464500), and North Branch Rancocas Creek at Pemberton, N.J. (01467000) (table 6). An average annual base-flow-recurrence-interval curve for predominant lower and upper stream-terrace deposits and undeveloped land use was developed by taking the average base flow for all nine stations for the 2-, 5-, and 10-year-recurrence intervals, eight stations for the 25-year-recurrence interval, and six stations for the 50-year-recurrence interval (table 7 and fig. 21).

Cape May Formation

The Cape May Formation (Qcm) of the New Jersey Coastal Plain was deposited during two or more sea-level highstands in the Pleistocene as estuarine, beach, and near-shore deposits. The formation is divided into three units based on marine-terrace elevation and ranges in thickness from 20 to 200 ft (Salisbury and Knapp, 1917). The deposits are sand, pebble gravel, minor silt, clay, peat, and cobble gravel and are shades of pale brown, yellow, gray, and white.

Undeveloped Land Use

Six watersheds (DB-113, DB-126, DB-129, DB-140, DB-141, and DB-142) have the Cape May Formation and undeveloped land use as predominant controlling factors of base flow (fig. 17). One index station in the New Jersey Coastal Plain represents this group and was used for all six watersheds. The station is East Branch Bass River near New Gretna, N.J. (01410150) (table 6). The annual base-flow-recurrence-interval curve for predominant Cape May Formation and undeveloped land use is shown in figure 22. The 50-year-recurrence interval was estimated by curve extension because only 27 years of streamflow data were available (table 7 and fig. 22).

Agricultural Land Use

One watershed (DB-119) has Cape May Formation and agricultural land use as predominant controlling factors of base flow (fig. 18). An index station was not available to represent the Cape May Formation with agricultural land use; therefore, all index stations with similar predominant surfi-

Table 7. Predominant surficial geology, predominant land use, index stations, and average annual base-flow recurrence values for unconsolidated Coastal Plain sediments in the Delaware River Basin.

Predominant surficial geology	Predominant land use	Index station	Average annual base flow (million gallons per day per square mile)				
			Recurrence interval				
			2-year	5-year	10-year	25-year	50-year
Salt marsh and estuarine deposits - Qmm (New Jersey)	Undeveloped	Average of Manalapan Brook at Spotswood, N.J., Manasquan River at Squankum, N.J., North Branch Metedeconk River near Lakewood, N.J., Toms River near Toms River, N.J., Cedar Creek at Lanoka Harbor, N.J., Batsto River near Batsto, N.J., West Branch Wading River near Jenkins, N.J., Oswego River at Harrisville, N.J., East Branch Bass River near New Gretna, N.J., Great Egg Harbor River at Folsom, N.J., Tuckahoe River at Head of River, N.J., Maurice River at Norma, N.J., Crosswicks Creek at Exton, N.J., McDonalds Branch in Byrne State Forest, N.J., and North Branch Rancocas Creek at Pemberton, N.J.	0.765	0.598	0.540	0.482	0.443
Lower and upper stream-terrace deposits - Qtl/Qtu (New Jersey)	Undeveloped	Average of Toms River near Toms River, N.J., Batsto River near Batsto, N.J., Manasquan River at Squankum, N.J., Oswego River at Harrisville, N.J., North Branch Rancocas Creek at Pemberton, N.J., Crosswicks Creek at Exton, N.J., North Branch Metedeconk River near Lakewood, N.J., Cedar Creek at Lanoka Harbor, N.J., and West Branch Wading River near Jenkins, N.J.	.774	.619	.558	.504	.467
Cape May Formation - Qcm (New Jersey)	Undeveloped	East Branch Bass River near New Gretna, N.J.	1.169	.855	.780	.688	.670
	Agricultural	Average of East Branch Bass River near New Gretna, N.J., Menantico Creek near Millville, N.J., Salem River at Woodstown, N.J., Raccoon Creek near Swedesboro, N.J., and Alloway Creek at Alloway, N.J.	.720	.534	.479	.425	.418
Weathered Coastal Plain Formations - Qwcp (New Jersey)	Urban	South Branch Pennsauken Creek at Cherry Hill, N.J.	.619	.478	.443	.393	.390
	Undeveloped	Average of McDonalds Branch in Byrne State Forest, N.J. and Manalapan Brook at Spotswood, N.J.	.563	.431	.3794	.327	.306
	Agricultural	Average of Salem River at Woodstown, N.J., Raccoon Creek near Swedesboro, N.J., and Alloway Creek at Alloway, N.J.	.524	.409	.353	.344	.265
Bridgeton Formation - Tb (New Jersey)	Urban	Mantua Creek at Pitman, N.J.	1.028	.915	.822	.671	.640
	Undeveloped	Average of Great Egg Harbor River at Folsom, N.J., Maurice River at Norma, N.J., and Tuckahoe River at Head of River, N.J.	.739	.568	.511	.458	.431
	Agricultural	Menantico Creek near Millville, N.J.	.862	.607	.560	.509	.470
Delaware Coastal Plain	Urban	Average of Mantua Creek at Pitman, N.J. and South Branch Pennsauken Creek at Cherry Hill, N.J.	.823	.697	.633	.532	.515
	Undeveloped	Average of Blackbird Creek at Blackbird, Del. and Trap Pond Outlet near Laurel, Del.	.548	.399	.340	.278	.267
	Agricultural	Average of Leipsic River near Cheswold, Del. and St. Jones River at Dover, Del.	.465	.340	.309	.234	.178

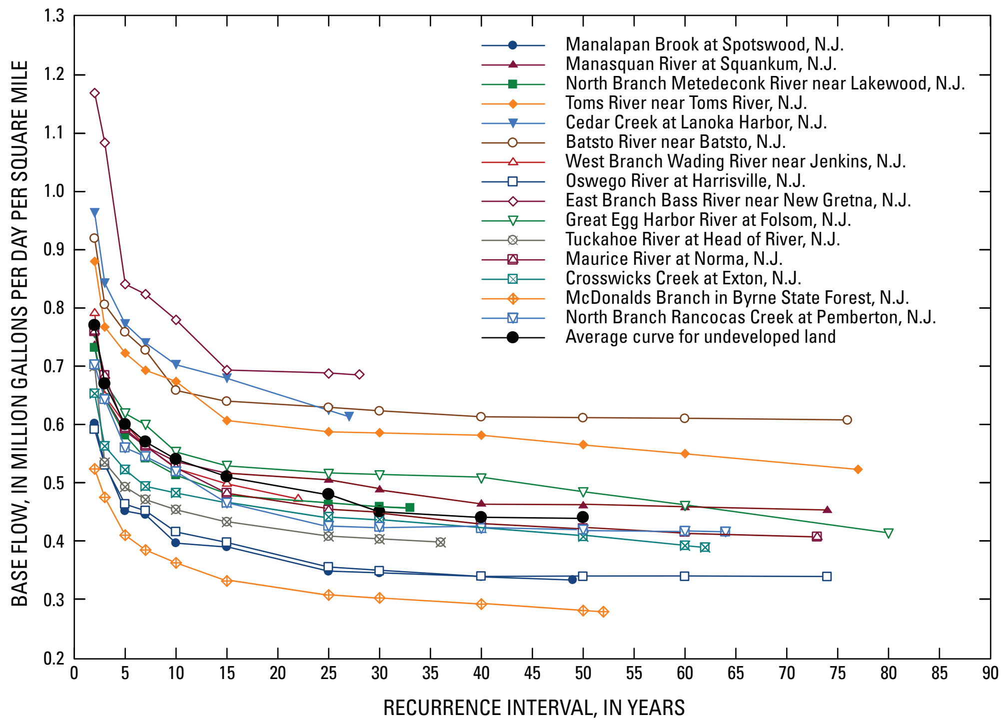


Figure 20. Base-flow-frequency curves for streamflow-gaging stations in the salt marsh and estuarine deposits with undeveloped land use in New Jersey.

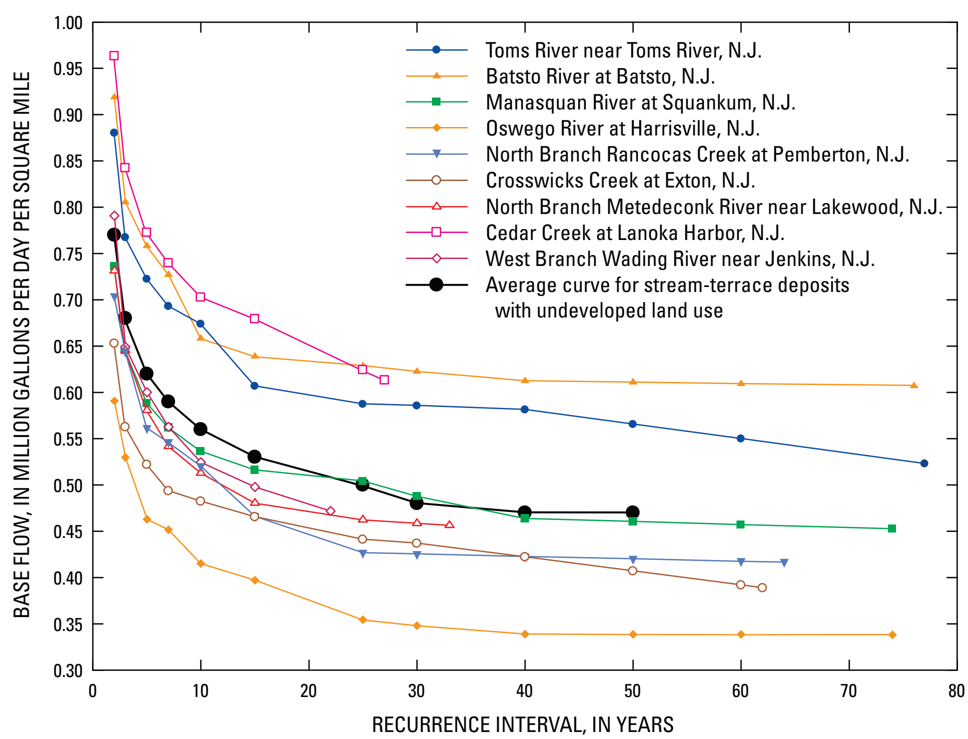


Figure 21. Base-flow-frequency curves for streamflow-gaging stations in lower and upper stream-terrace deposits with undeveloped land use in New Jersey.

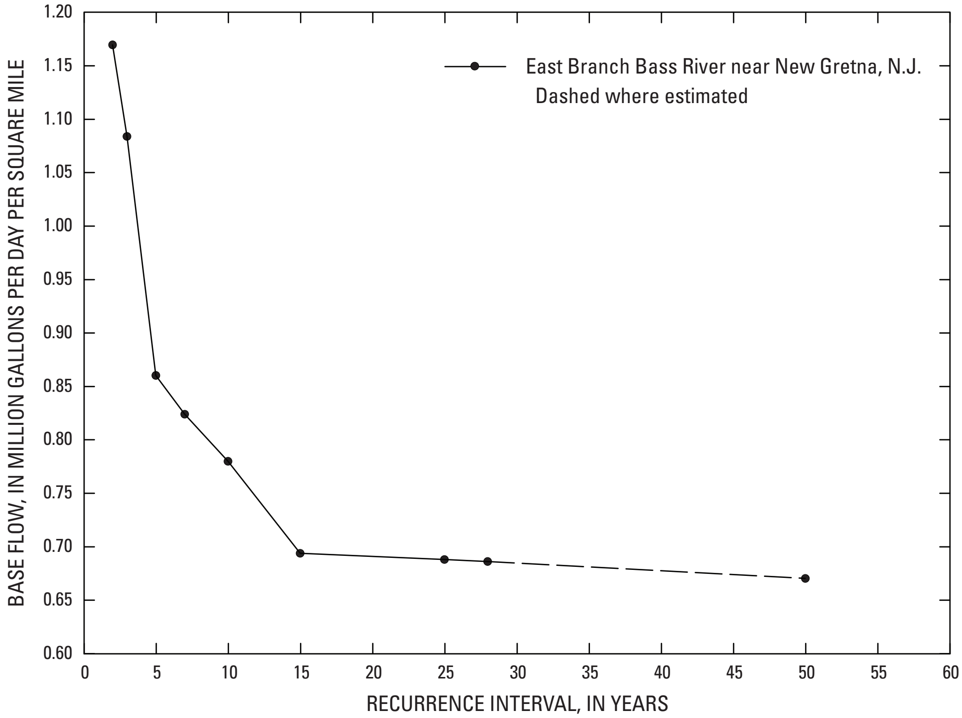


Figure 22. Base-flow-frequency curve for streamflow-gaging station in the Cape May Formation with undeveloped land use in New Jersey.

cial geology and land use were used to calculate the average annual base-flow-recurrence intervals. These stations are East Branch Bass River near New Gretna, N.J. (01410150), Menantico Creek near Millville, N.J. (01412000), Raccoon Creek near Swedesboro, N.J. (01477120), Salem River at Woodstown, N.J. (01482500), and Alloway Creek at Alloway, N.J. (01483000)(table 6). An average annual base-flow-recurrence-interval curve for the Cape May Formation and agricultural land use was developed by using the average base flow for all five stations for the 2-, 5-, 10-, and 15-year-recurrence intervals and four stations for the 25- and 50-year-recurrence intervals (table 7 and fig. 23).

Weathered Coastal Plain Formations

Weathered Coastal Plain formations (Qwcp) are the exposed sand and clay of weathered Coastal Plain bedrock formations. Erosion of these surficial deposits leaves thin, patchy alluvium and colluvium and pebbles.

Urban Land Use

Four watersheds (DB-090, DB-092, DB-093, and DB-111) have weathered Coastal Plain formations and urban land use as predominant controlling factors of base flow (fig.17). One index station in the New Jersey Coastal Plain represents this group and was used for the four watersheds. The station is South Branch Pennsuaken Creek at Cherry Hill, N.J. (01467081) (table 6). The annual base-flow-recurrence-interval curve for predominant weathered Coastal Plain formations and urban land use is shown in figure 23. The 50-year-recurrence interval was estimated by curve extension because only 27 years of streamflow data were available (table 7 and fig. 24).

Undeveloped Land Use

Two watersheds (DB-080 and DB-081) have weathered Coastal Plain formations and undeveloped land use as predominant controlling factors of base flow (fig. 18). Two index stations in the New Jersey Coastal Plain represent this group and were used to calculate the average for the two watersheds. The stations are Manalapan Brook at Spotswood, N.J. (01405400), and McDonalds Branch in Byrne State Forest, N.J. (01466500) (table 6). The 50-year-recurrence interval for Manalapan Brook at Spotswood, N.J., was estimated using curve extension (fig. 25). An average annual base-flow-recurrence-interval curve for predominant weathered Coastal Plain formations and undeveloped land use was developed by taking the average base flow for the two stations for the 2-, 5-, 10-, and 25-year-recurrence interval. The average of the 50-year-recurrence value at McDonalds Branch in Byrne State Forest, N.J., and the estimated 50-year-recurrence value at Manalapan Brook at Spotswood, N.J., was used to calculate the 50-year-recurrence interval (table 7 and fig. 25).

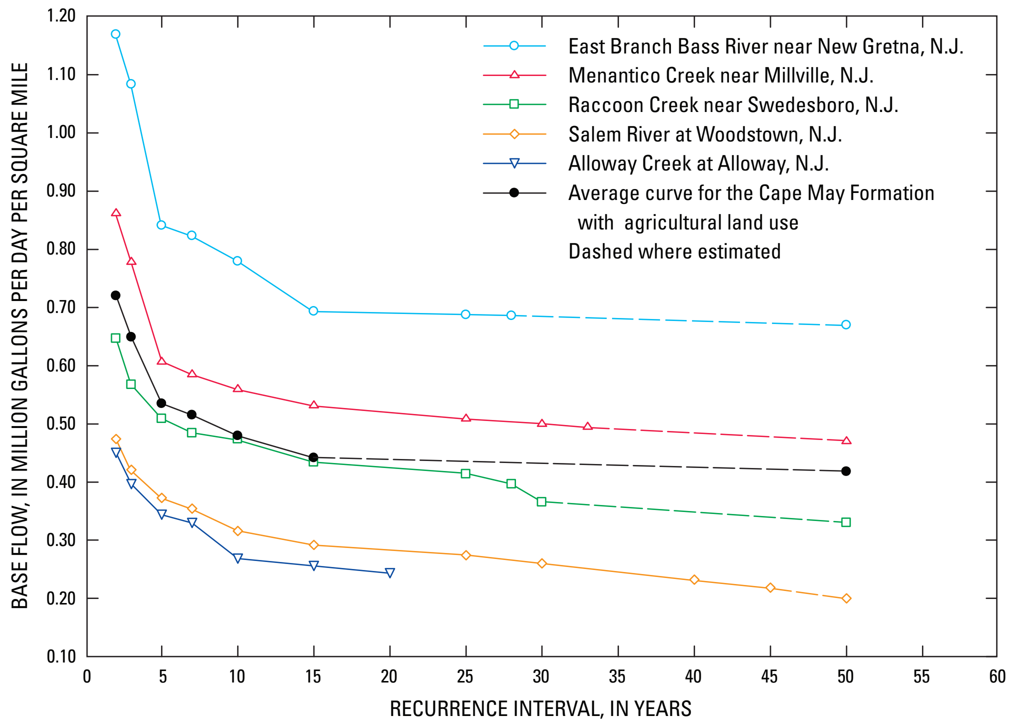


Figure 23. Base-flow-frequency curves for streamflow-gaging stations in the Cape May Formation with agricultural land use in New Jersey.

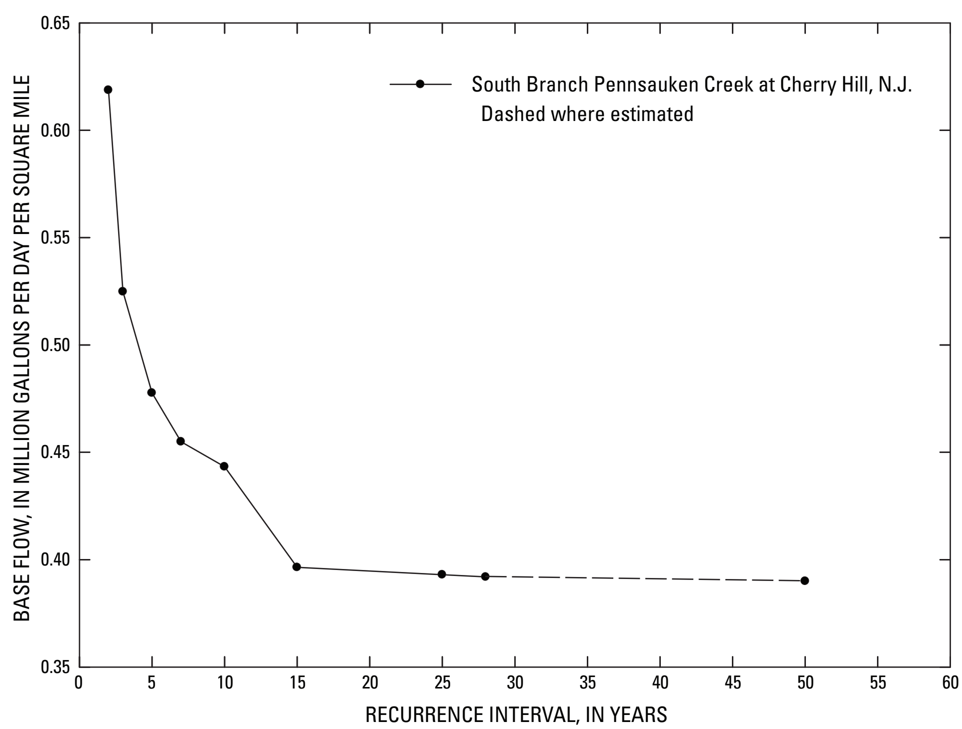


Figure 24. Base-flow-frequency curve for streamflow-gaging station in the weathered Coastal Plain formations with urban land use in New Jersey.

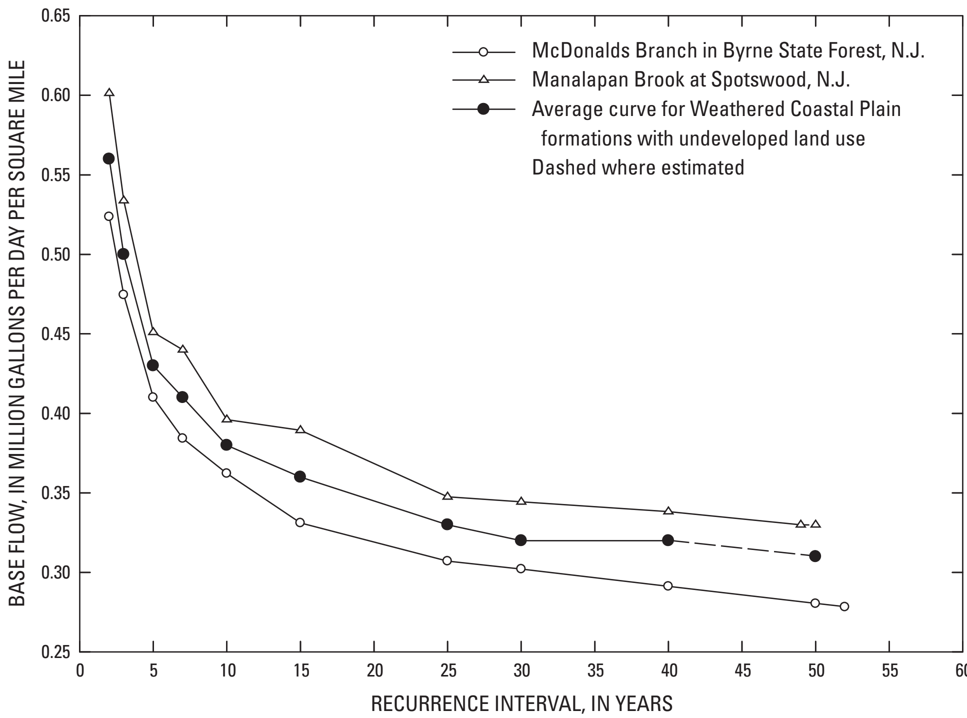


Figure 25. Base-flow-frequency curves for streamflow-gaging stations in the weathered Coastal Plain formations with undeveloped land use in New Jersey.

Agricultural Land Use

Two watersheds (DB-117 and DB-118) have weathered Coastal Plain formations and agricultural land use as predominant controlling factors of base flow (fig. 18). Three index stations in the New Jersey Coastal Plain represent this group and were used to calculate the average for the two watersheds. The stations are Raccoon Creek near Swedesboro, N.J. (01477120), Salem River at Woodstown, N.J. (01482500), and Alloway Creek at Alloway, N.J. (01483000) (table 6). The 50-year-recurrence interval for Raccoon Creek near Swedesboro, N.J., and Salem River at Woodstown, N.J., was estimated using curve extension (fig. 26). An average annual base-flow-recurrence-interval curve for predominant weathered Coastal Plain formations and agricultural land use was developed by taking the average base flow for the three stations for the 2-, 5-, and 10-year-recurrence interval, two stations (Raccoon Creek near Swedesboro, N.J., and Salem River at Woodstown, N.J.) for the 25-year-recurrence interval, and the average of the estimated values at the two stations for the 50-year-recurrence interval (table 7 and fig. 26).

Bridgeton Formation

The Bridgeton Formation (Tb) was deposited during the late Miocene. It is made up of sand, clayey sand, pebble gravel, and minor cobble gravel (Salisbury and Knapp, 1917). The deposits vary in color from red, yellow, white, and pale brown and can be as much as 40 ft thick.

Urban Land Use

One watershed (DB-078) has the Bridgeton Formation and urban land use as predominant controlling factors of base flow (fig. 18). Only one index station in the New Jersey Coastal Plain represents this group. The station is Mantua Creek at Pitman, N.J. (01475000) (table 6). The annual base-flow-recurrence-interval curve for predominant Bridgeton Formation and urban land use is shown in figure 27. The 50-year-recurrence interval was estimated by curve extension because only 35 years of streamflow data were available (table 7 and fig. 27).

Undeveloped Land Use

Four watersheds (DB-136, DB-137, DB-138, and DB-139) have the Bridgeton Formation and undeveloped land use as predominant controlling factors of base flow (fig. 18). Three index stations in the New Jersey Coastal Plain represent this group and were used to calculate the average for the four watersheds. The stations are Great Egg Harbor River at Folsom, N.J. (01411000), Tuckahoe River at Head of River, N.J. (01411300), and Maurice River at Norma, N.J. (01411500) (table 6). The 50-year recurrence interval for Tuckahoe River at Head of River, N.J., was estimated using curve extension

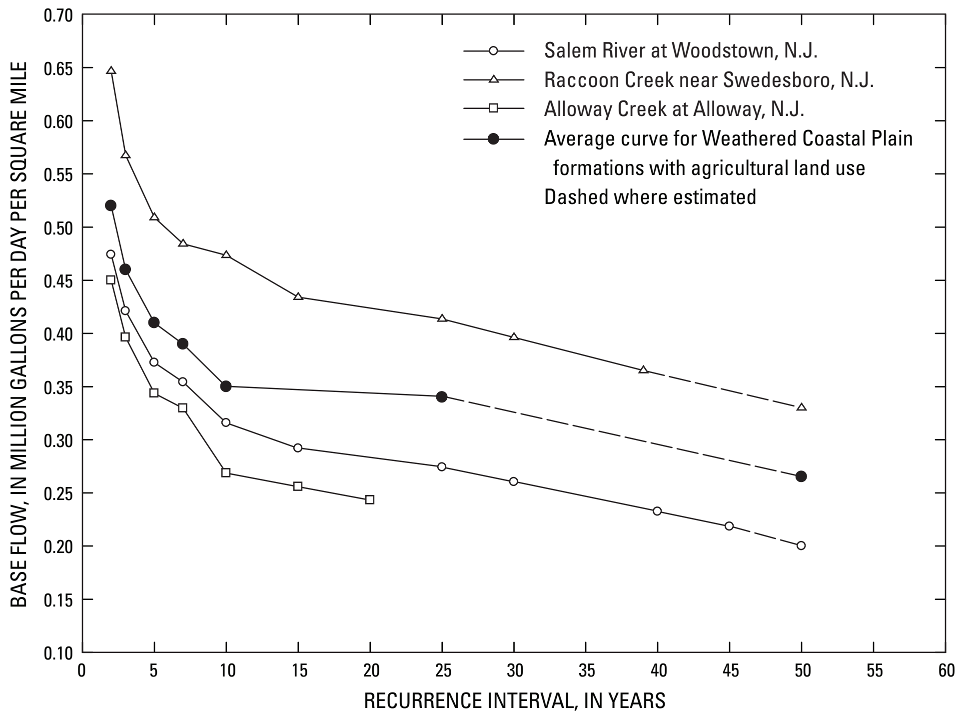


Figure 26. Base-flow-frequency curves for streamflow-gaging stations in the weathered Coastal Plain formations with agricultural land use in New Jersey.

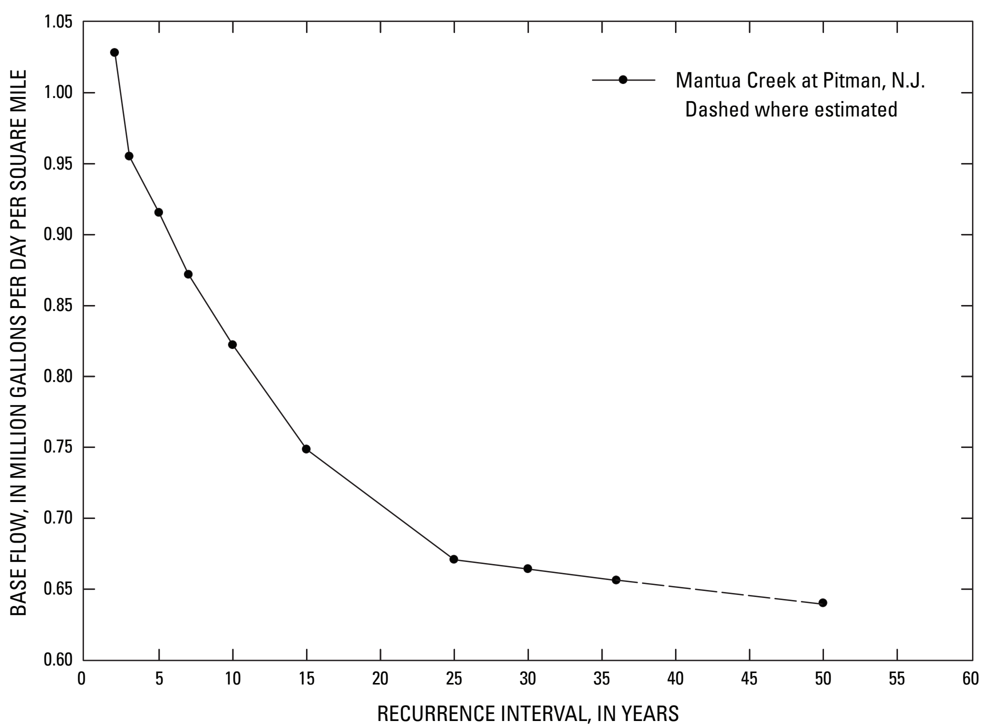


Figure 27. Base-flow-frequency curve for streamflow-gaging station in the Bridgeton Formation with urban land use in New Jersey.

(fig. 28). An average annual base-flow-recurrence-interval curve for predominant Bridgeton Formation and undeveloped land use was developed by taking the average base flow for all three stations for the 2-, 5-, 10-, and 25-year-recurrence intervals and the average of the actual values at two stations and the estimated value at Tuckahoe River at Head of River, N.J., for the 50-year-recurrence interval (table 7 and fig. 28).

Agricultural Land Use

One watershed (DB-133) has the Bridgeton Formation and agricultural land use as predominant controlling factors of base flow (fig. 18). Only one index station in the New Jersey Coastal Plain represents this group, Menantico Creek near Millville, N.J. (01412000) (table 6).The annual base-flow-recurrence-interval curve for predominant Bridgeton Formation and agricultural land use is shown in figure 29. The 50-year-recurrence interval was estimated by curve extension because only 35 years of streamflow data were available (table 7 and fig. 29).

Predominant Land-Use Categories in Delaware Coastal Plain Watersheds

Digital surficial geology was only available for the northernmost county of Delaware. Surficial geology for the other two counties will be available at a future date. Only predominant land use could be used to group sites. The number of stations that could be used as index stations was limited. The 10 watersheds in Delaware contain all 3 general types of land use.

Urban Land Use

One watershed (DB-127) has urban land use as the predominant controlling factor of base flow (fig. 18). An index station represented by urban land use in Delaware was not available. Only about 13 percent of the state in the Delaware River Basin is urban; therefore, the two urban index stations in New Jersey were used to represent urban land use for Delaware. The stations are South Branch Pennsuaken Creek at Cherry Hill, N.J. (01467081), and Mantua Creek at Pitman, N.J. (01475000) (table 6). The 50-year-recurrence interval was estimated by curve extension for both stations (fig. 30). An average annual base-flow-recurrence-interval curve for urban land use was developed by taking the average base flow for both stations for the 2-, 5-, 10-, and 25-year-recurrence intervals and the estimated values at both stations for the 50-year-recurrence interval (table 7 and fig. 30).

Undeveloped Land Use

Three watersheds (DB-128, DB-132, and DB-147) have undeveloped land use as the predominant controlling factor of base flow (fig. 18). Two index stations in the Delaware Coastal Plain represent this group and were used for the three watersheds. The stations are Blackbird Creek at Blackbird, Del. (01483200), and Trap Pond Outlet near Laurel, Del. (01487500) (table 6). Trap Pond Outlet near Laurel, Del., has only 19 years of record but is one of the few stations available in Delaware for use as an index station. Curve extension was used to estimate the 25-year-recurrence interval for Trap Pond Outlet near Laurel, Del., and the 50-year-recurrence interval for both stations (fig. 31). An average annual base-flow-recurrence-interval curve for undeveloped land use was developed by taking the average base flow for both stations for the 2-, 5-, and 10-year-recurrence intervals; the average of one estimated and one calculated base flow for the 25-year-recurrence interval; and the average of the estimated base flows at both stations for the 50-year-recurrence interval (table 7 and fig. 31).

Agricultural Land Use

Six watersheds (DB-130, DB-135, DB-143, DB-144, DB-145, and DB-146) have agricultural land use as the predominant controlling factor of base flow (fig. 18). Two index stations in the Delaware Coastal Plain represent this group and were used for the six watersheds. The stations are Leipsic River near Cheswold, Del. (01483500), and St. Jones River at Dover, Del. (01483700) (table 6). Leipsic River near Cheswold, Del., has only 14 years of record but is one of the few stations available in Delaware for use as an index station. Curve extension was used to estimate the 25-year-recurrence interval for Leipsic River near Cheswold, Del., and the 50-year-recurrence interval for both stations (fig. 32). An average annual base-flow-recurrence-interval curve for undeveloped land use was developed by taking the average base flow for both stations for the 2-, 5-, and 10-year-recurrence intervals; the average of one estimated base flow and one calculated base flow for the 25-year-recurrence interval; and the average of the estimated base flows at both stations for the 50-year-recurrence interval (table 7 and fig. 32).

Ground-Water Availability and Use by Watershed in the Delaware River Basin

A spatial-data analysis was used to estimate 2-, 5-, 10-, 25-, and 50-year annual base-flow-recurrence-interval values for each watershed in the Delaware River Basin (table 8). These values are considered to be the total quantity of ground water available for each watershed over a range of climatic conditions. The recurrence intervals are considered to be relative indicators of climatic difference; the 2-year-recurrence value represents wetter years, and the 50-year-recurrence value represents drier years. Ground-water withdrawal and domestic water use (table 2) were subtracted from and ground-water recharge (table 2) was added to the total available quantity of ground water, and the remaining available ground water for each base-flow recurrence interval was calculated for each watershed by:

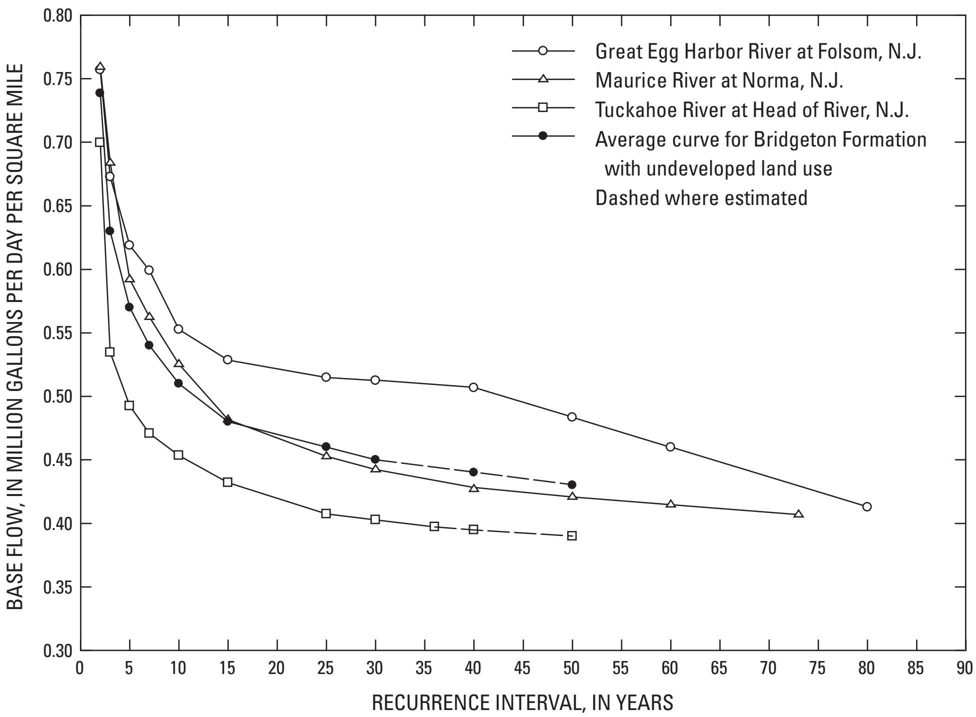


Figure 28. Base-flow-frequency curves for streamflow-gaging stations in the Bridgeton Formation with undeveloped land use in New Jersey.

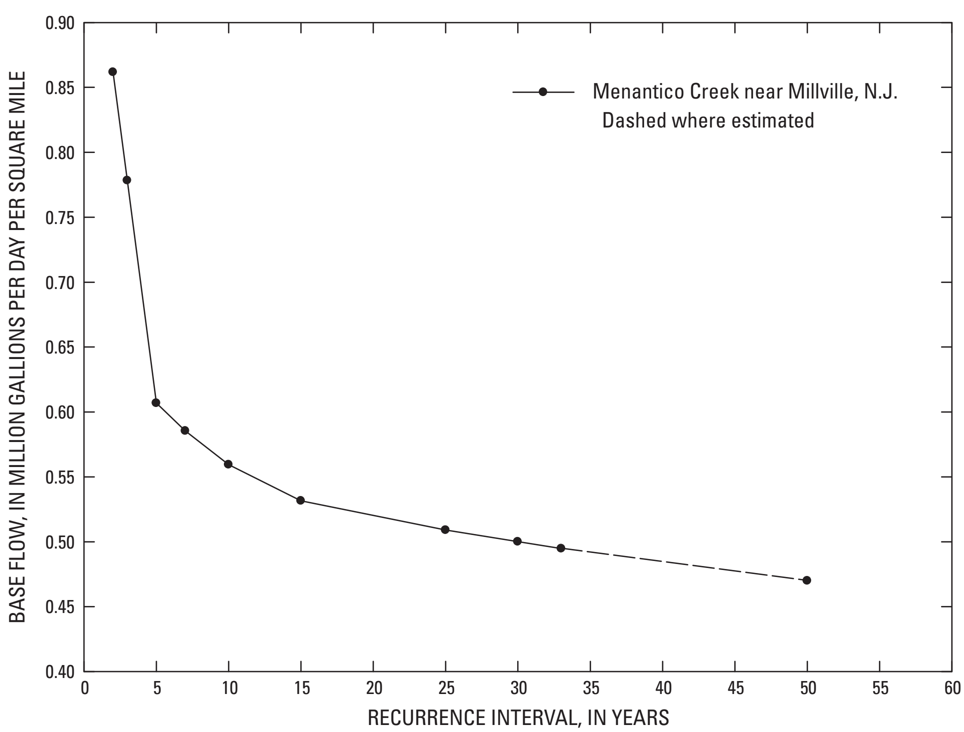


Figure 29. Base-flow-frequency curves for streamflow-gaging stations in the Bridgeton Formation with agricultural land use in New Jersey.

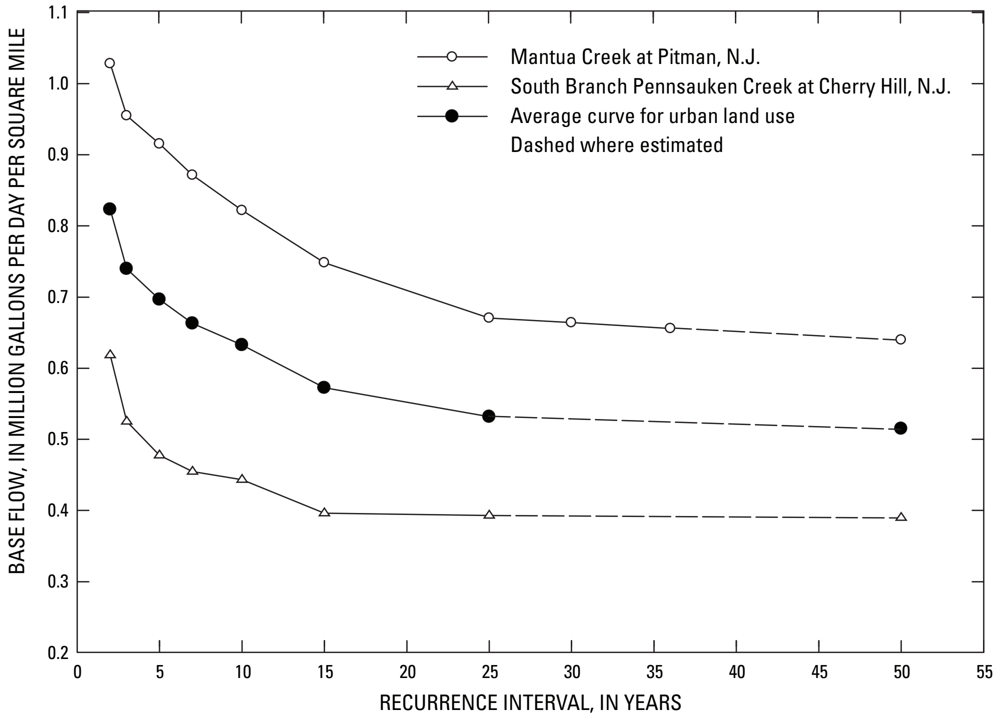


Figure 30. Base-flow-frequency curves for streamflow-gaging stations in the Coastal Plain with urban land use.

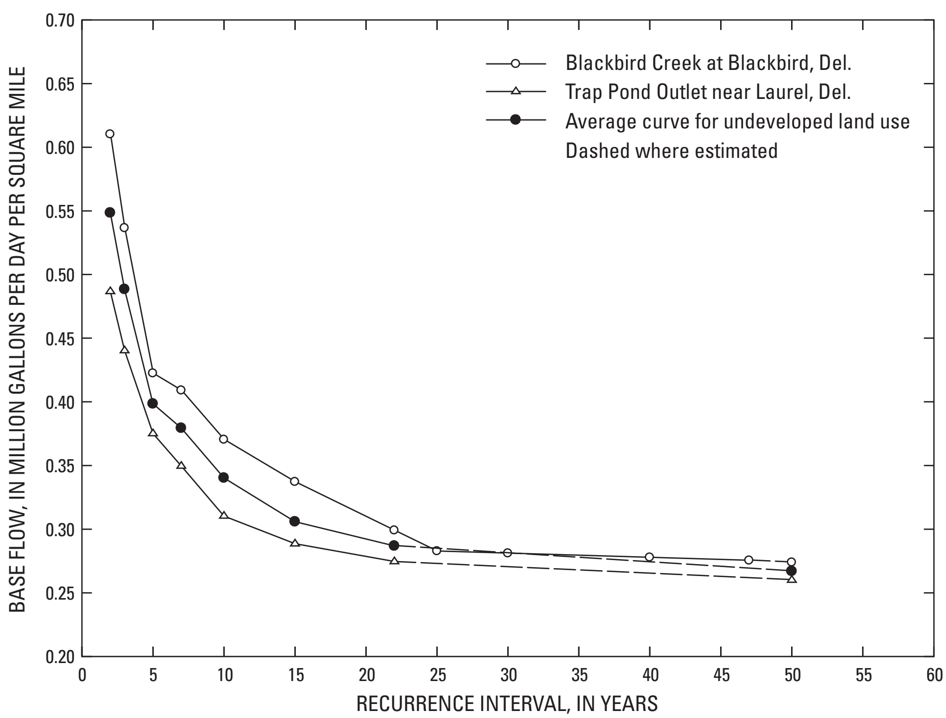


Figure 31. Base-flow-frequency curves for the streamflow-gaging stations in the Delaware Coastal Plain with undeveloped land use.

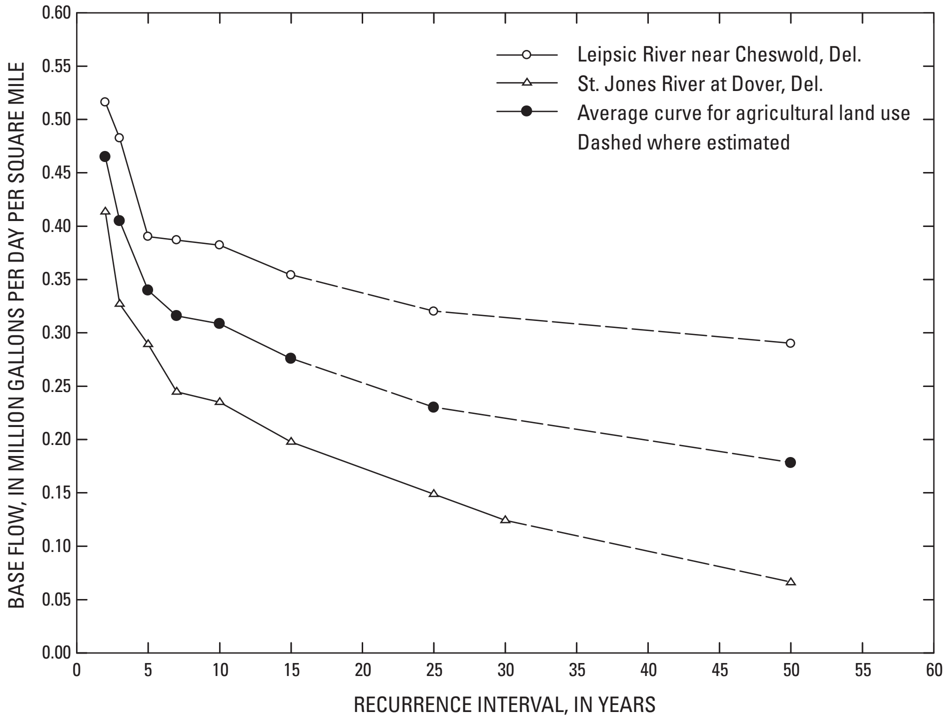


Figure 32. Base-flow-frequency curves for streamflow-gaging stations in the Delaware Coastal Plain with agricultural land use.

$$GW_{remaining} = GW_{total} - GW_{withdrawals} - DU + GW_{recharge}, \quad (2)$$

where

$GW_{remaining}$ is the remaining available ground water,
GW_{total} is the total available ground water,
$GW_{withdrawals}$ is withdrawals from the ground-water system,
DU is consumed domestic well water withdrawals, and
$GW_{recharge}$ is ground-water recharge from golf course and agricultural irrigation and land application of treated-sewage effluent.

Ground-water withdrawal amounts include all pumpage from unconfined and confined wells in the Coastal Plain. The effects of these withdrawals on streamflow for a particular basin may be overestimated because water pumped from confined wells may come from streams outside the watershed.

The remaining available ground water was compared to the total available ground water, and the percentage of available ground water used was calculated (table 8) by:

$$GW_{PercentUsed} = 1- (GW_{remaining} / GW_{total}) \text{ X } 100. \quad (3)$$

The percentage of ground water used is different for each recurrence interval for each watershed and represents different percentages of use under different climatic conditions. It provides a screening tool to indicate which watersheds are approaching critical withdrawals under different climatic conditions. A negative percentage in table 8 indicates that more water is recharged in a watershed than is withdrawn from it.

Ground-water use ranged from 0 to 60.8 percent of available ground water for the 2-year-recurrence interval (table 8). Ground-water use exceeded 25 percent in four watersheds and 50 percent in two watersheds: Woodbury Creek, Big Timber Creek, Newton Creek, and tributaries to the Delaware River (DB-093, 35.4 percent); Army Creek, Red Lion Creek, Dragon Creek, and tributaries to the Delaware River (DB-127, 41.4 percent); Pennsauken Creek, Pompeston Creek, and tributaries to the Delaware River (DB-090, 46.8 percent); Cooper River (DB-092, 51.2 percent); and Bush Kill (DB-055, 60.8 percent) (fig. 33). The major withdrawal of ground water in 1999 in the Woodbury Creek-Big Timber Creek-Newton Creek watershed was by the New Jersey American Water Company; they withdrew 2.5 billion gallons, which was 32 percent of total ground-water withdrawals in the watershed. The major withdrawal of ground water in the Army Creek-Red Lion Creek-Dragon Creek watershed in 2000 was by the Artesian Water Company, Inc.; they withdrew 2.4 billion gallons, which was 61 percent of total ground-water withdrawals in the watershed. The major withdrawal of ground water in 1999 in the Pennsauken Creek-Pompeston Creek watershed was by the New Jersey American Water Company; they withdrew 2.5 billion gallons, which was 42 percent of total ground-water withdrawals in the watershed. The major withdrawal of ground water in 1999 in the Cooper River watershed was by the Camden City Water Department; they withdrew 3.9 billion

Table 8. Ground-water availability, ground-water withdrawals, recharged water, and percent of available ground water used for watersheds in the Delaware River Basin.

[Watershed locations shown on figure 2. Negative percentage indicates net recharge of water in the watershed, DB, Delaware River basin; <. less than]

Basin identi-fication number	Ground-water availability (million gallons per day per square mile)					Ground-water withdrawal (million gallons per day per square mile)	Recharged water (million gallons per day per square mile)	Domestic water use (million gallons per day per square mile)	Remaining available ground water (million gallons per day per square mile)					Percent of available ground water used				
	Recurrence interval								Recurrence interval					Recurrence interval				
	2-year	5-year	10-year	25-year	50-year				2-year	5-year	10-year	25-year	50-year	2-year	5-year	10-year	25-year	50-year
DB-001	0.687	0.546	0.492	0.403	0.373	0.002	<.001	<.001	0.685	0.544	0.490	0.401	0.371	0.3	0.4	0.4	0.5	0.5
DB-002	.687	.546	.492	.403	.373	<.001	<.001	<.001	.687	.546	.492	.403	.373	0	0	0	0	0
DB-003	.687	.546	.492	.403	.373	<.001	<.001	<.001	.687	.545	.492	.403	.373	0	.1	.1	.1	.1
DB-004	.687	.546	.492	.403	.373	.025	<.001	<.001	.663	.521	.468	.378	.349	3.6	4.5	5.0	6.2	6.6
DB-005	.701	.557	.501	.412	.384	<.001	<.001	<.001	.701	.557	.501	.412	.384	0	0	.1	.1	.1
DB-006	.691	.549	.495	.406	.376	.002	<.001	<.001	.689	.546	.493	.403	.374	.3	.4	.4	.5	.6
DB-007	.704	.559	.503	.415	.387	.002	<.001	<.001	.702	.557	.500	.412	.385	.3	.4	.5	.6	.6
DB-008	.763	.610	.542	.456	.434	.005	<.001	<.001	.758	.604	.537	.450	.429	.7	.9	1.0	1.1	1.2
DB-009	.855	.672	.620	.537	.468	<.001	<.001	<.001	.855	.672	.620	.536	.468	0	.1	.1	.1	.1
DB-010	.695	.552	.497	.408	.380	.001	<.001	<.001	.694	.550	.495	.407	.378	.2	.2	.3	.3	.4
DB-011	.697	.554	.498	.410	.382	<.001	<.001	<.001	.697	.554	.498	.410	.382	0	0	0	0	0
DB-012	.753	.594	.524	.446	.429	.001	<.001	<.001	.752	.593	.523	.445	.428	.1	.2	.2	.2	.3
DB-013	.748	.587	.515	.442	.427	.004	<.001	<.001	.744	.583	.511	.438	.423	.5	.7	.8	.9	.9
DB-014	.721	.574	.514	.426	.401	<.001	<.001	<.001	.721	.574	.514	.426	.401	0	0	.1	.1	.1
DB-015	.711	.547	.477	.414	.400	<.001	<.001	<.001	.711	.547	.476	.413	.400	0	.1	.1	.1	.1
DB-016	.744	.583	.513	.439	.422	.004	<.001	<.001	.740	.579	.509	.435	.419	.5	.7	.7	.9	.9
DB-017	.636	.464	.394	.356	.349	<.001	<.001	<.001	.636	.463	.393	.355	.348	.1	.2	.2	.2	.2
DB-018	.870	.682	.635	.550	.471	<.001	<.001	<.001	.869	.682	.634	.550	.470	.1	.1	.1	.1	.1
DB-019	.586	.413	.347	.318	.311	<.001	<.001	.001	.585	.412	.346	.317	.310	.1	.2	.2	.2	.3
DB-020	.692	.519	.444	.396	.390	.002	<.001	.001	.689	.517	.442	.394	.387	.4	.5	.6	.7	.7
DB-021	.573	.401	.336	.309	.302	.003	<.001	.001	.570	.397	.332	.305	.298	.6	.9	1.0	1.1	1.1
DB-022	.874	.686	.639	.553	.473	<.001	<.001	.001	.874	.685	.638	.553	.473	.1	.1	.1	.1	.1
DB-023	.578	.406	.340	.312	.306	<.001	<.001	.001	.578	.406	.340	.312	.305	.1	.1	.2	.2	.2
DB-024	.875	.686	.639	.554	.473	<.001	<.001	.001	.874	.685	.638	.553	.472	.1	.1	.1	.2	.2
DB-025	.874	.689	.640	.554	.474	.002	<.001	.001	.871	.687	.638	.552	.472	.3	.3	.4	.4	.5

Table 8. Ground-water availability, ground-water withdrawals, recharged water, and percent of available ground water used for watersheds in the Delaware River Basin.—Continued

[Watershed locations shown on figure 2. Negative percentage indicates net recharge of water in the watershed, DB, Delaware River basin; <. less than]

Basin identi-fication number	Ground-water availability (million gallons per day per square mile)					Ground-water withdrawal (million gallons per day per square mile)	Recharged water (million gallons per day per square mile)	Domestic water use (million gallons per day per square mile)	Remaining available ground water (million gallons per day per square mile)					Percent of available ground water used				
	Recurrence interval								Recurrence interval					Recurrence interval				
	2-year	5-year	10-year	25-year	50-year				2-year	5-year	10-year	25-year	50-year	2-year	5-year	10-year	25-year	50-year
DB-026	.875	.686	.639	.554	.473	<.001	<.001	<.001	.874	.686	.639	.554	.473	0	.1	.1	.1	.1
DB-027	.865	.717	.648	.555	.483	.002	<.001	.001	.862	.714	.645	.552	.480	.3	.4	.5	.5	.6
DB-028	.874	.688	.640	.554	.474	.001	<.001	.001	.872	.686	.638	.552	.472	.2	.2	.2	.3	.3
DB-029	.718	.567	.504	.423	.400	<.001	<.001	<.001	.718	.566	.504	.422	.400	.1	.1	.1	.1	.1
DB-030	.861	.730	.651	.555	.488	<.001	<.001	.001	.860	.729	.650	.554	.487	.1	.1	.2	.2	.2
DB-031	.865	.716	.647	.555	.483	.005	<.001	.001	.860	.711	.642	.550	.478	.6	.7	.8	.9	1.1
DB-032	.874	.687	.640	.554	.474	<.001	<.001	.001	.873	.686	.639	.553	.473	.1	.1	.1	.2	.2
DB-033	.705	.560	.502	.415	.388	.005	<.001	.001	.699	.554	.496	.409	.382	.8	1.0	1.2	1.4	1.5
DB-034	.695	.552	.497	.408	.380	<.001	<.001	.001	.694	.551	.496	.407	.378	.2	.3	.3	.4	.4
DB-035	.711	.565	.507	.420	.394	<.001	<.001	.001	.710	.564	.506	.419	.393	.1	.2	.2	.2	.2
DB-036	.840	.662	.624	.537	.477	.007	<.001	.001	.833	.654	.616	.529	.469	.9	1.2	1.3	1.5	1.7
DB-037	.727	.578	.516	.430	.407	<.001	<.001	<.001	.727	.578	.515	.430	.406	0	0	.1	.1	.1
DB-038	.708	.564	.514	.427	.393	.013	<.001	.001	.694	.550	.500	.413	.379	2.0	2.5	2.7	3.3	3.5
DB-039	.725	.578	.531	.445	.408	.002	<.001	.001	.722	.575	.528	.442	.405	.5	.6	.6	.7	.8
DB-040	.826	.652	.617	.530	.479	.003	<.001	.001	.822	.647	.613	.526	.474	.5	.7	.7	.8	.9
DB-041	.810	.640	.610	.522	.480	<.001	<.001	.001	.808	.639	.608	.520	.479	.2	.3	.3	.3	.4
DB-042	.715	.584	.530	.459	.408	<.001	<.001	.001	.715	.583	.530	.459	.407	.1	.1	.1	.1	.1
DB-043	.864	.679	.635	.549	.475	.008	.002	<.001	.857	.673	.628	.542	.468	.8	1.0	1.0	1.2	1.4
DB-044	.671	.551	.499	.431	.374	<.001	<.001	.001	.670	.550	.498	.430	.373	.2	.2	.2	.2	.3
DB-045	.857	.680	.634	.546	.477	.012	.001	.001	.846	.668	.622	.535	.465	1.4	1.7	1.8	2.1	2.5
DB-046	.841	.668	.626	.539	.478	.002	.002	.001	.841	.667	.626	.538	.478	0	.1	.1	.1	.1
DB-047	.734	.595	.547	.472	.423	.031	.002	.001	.705	.566	.517	.443	.393	4.0	5.0	5.4	6.3	7.0
DB-048	.532	.444	.415	.358	.278	.003	<.001	<.001	.529	.441	.412	.354	.275	.7	.8	.9	1.0	1.3
DB-049	.582	.472	.426	.354	.286	.006	<.001	.002	.575	.464	.419	.346	.278	1.3	1.6	1.8	2.2	2.7
DB-050	.579	.468	.424	.351	.284	.001	<.001	.001	.576	.466	.422	.348	.281	.4	.5	.6	.7	.9

Table 8. Ground-water availability, ground-water withdrawals, recharged water, and percent of available ground water used for watersheds in the Delaware River Basin.—Continued

[Watershed locations shown on figure 2. Negative percentage indicates net recharge of water in the watershed, DB, Delaware River basin; <. less than]

Basin identi-fication number	Ground-water availability (million gallons per day per square mile)					Ground-water withdrawal (million gallons per day per square mile)	Recharged water (million gallons per day per square mile)	Domestic water use (million gallons per day per square mile)	Remaining available ground water (million gallons per day per square mile)					Percent of available ground water used				
	Recurrence interval								Recurrence interval					Recurrence interval				
	2-year	5-year	10-year	25-year	50-year				2-year	5-year	10-year	25-year	50-year	2-year	5-year	10-year	25-year	50-year
DB-051	.583	.471	.425	.352	.284	.014	<.001	.002	.567	.456	.410	.336	.268	2.7	3.3	3.7	4.5	5.5
DB-052	.670	.528	.454	.361	.308	.060	.068	.002	.676	.534	.460	.368	.314	-.9	-1.2	-1.4	-1.7	-2.0
DB-053	.559	.459	.421	.356	.283	.009	<.001	.001	.550	.449	.412	.346	.273	1.7	2.1	2.2	2.7	3.3
DB-054	.688	.533	.452	.349	.304	.123	<.001	.002	.563	.408	.327	.225	.179	18.1	23.4	27.6	35.7	41.0
DB-055	.588	.471	.423	.346	.282	.364	.008	.001	.230	.114	.066	-.012	-.076	60.8	75.9	84.5	103	127
DB-055[1]	.588	.471	.423	.346	.282	.027	.008	.001	.568	.451	.403	.326	.261	3.5	4.3	4.8	5.9	7.2
DB-056	.864	.729	.651	.557	.489	<.001	<.001	<.001	.864	.728	.650	.557	.488	0	.1	.1	.1	.1
DB-057	.860	.729	.650	.555	.487	.009	<.001	<.001	.851	.720	.641	.545	.478	1.1	1.3	1.4	1.7	1.9
DB-058	.895	.715	.650	.574	.499	.001	<.001	<.001	.894	.714	.649	.573	.498	.1	.1	.1	.2	.2
DB-059	.913	.707	.650	.583	.505	.005	<.001	<.001	.908	.702	.645	.578	.500	.6	.7	.8	.9	1.0
DB-060	.899	.713	.650	.575	.500	.004	<.001	<.001	.895	.709	.646	.571	.496	.4	.6	.6	.7	.8
DB-061	.866	.687	.636	.555	.492	.009	<.001	<.001	.857	.679	.627	.547	.483	1.0	1.3	1.4	1.6	1.8
DB-062	.846	.674	.629	.541	.479	<.001	<.001	<.001	.846	.674	.629	.541	.478	0	0	0	0	0
DB-063	.677	.551	.516	.447	.381	.013	<.001	.001	.664	.537	.503	.434	.368	2.0	2.4	2.6	3.0	3.5
DB-064	.793	.632	.590	.508	.453	.010	.002	<.001	.786	.625	.582	.501	.446	.9	1.2	1.3	1.5	1.7
DB-065	.579	.467	.421	.347	.280	.043	<.001	.001	.535	.422	.377	.302	.236	7.6	9.5	10.5	12.7	15.8
DB-066	.566	.460	.419	.348	.277	.078	<.001	.001	.487	.381	.339	.268	.198	14.0	17.2	18.9	22.8	28.5
DB-067	.688	.532	.451	.348	.303	.168	.002	.001	.520	.364	.284	.181	.135	24.3	31.5	37.1	48.1	55.3
DB-067[1]	.688	.532	.451	.348	.303	.067	.002	.001	.621	.465	.384	.281	.236	9.7	12.6	14.8	19.2	22.0
DB-068	.658	.509	.436	.339	.292	.057	.005	.001	.605	.456	.383	.286	.239	8.1	10.5	12.2	15.7	18.2
DB-069	.686	.542	.464	.372	.318	.031	<.001	.002	.653	.509	.430	.339	.285	4.8	6.1	7.2	8.9	10.4
DB-070	.682	.558	.485	.413	.345	.035	<.001	.001	.645	.521	.448	.376	.308	5.4	6.6	7.6	8.9	10.7
DB-071	.666	.530	.459	.373	.315	.052	<.001	.002	.612	.476	.405	.319	.261	8.1	10.2	11.8	14.5	17.2
DB-072	.448	.353	.303	.251	.215	.001	.001	.001	.447	.352	.302	.250	.214	.2	.2	.3	.3	.4
DB-073	.372	.298	.254	.213	.181	.033	<.001	.001	.337	.263	.219	.178	.147	9.4	11.7	13.7	16.4	19.3

Table 8. Ground-water availability, ground-water withdrawals, recharged water, and percent of available ground water used for watersheds in the Delaware River Basin.—Continued

[Watershed locations shown on figure 2. Negative percentage indicates net recharge of water in the watershed, DB, Delaware River basin; <. less than]

Basin identi-fication number	Ground-water availability (million gallons per day per square mile)					Ground-water withdrawal (million gallons per day per square mile)	Recharged water (million gallons per day per square mile)	Domestic water use (million gallons per day per square mile)	Remaining available ground water (million gallons per day per square mile)					Percent of available ground water used				
	Recurrence interval								Recurrence interval					Recurrence interval				
	2-year	5-year	10-year	25-year	50-year				2-year	5-year	10-year	25-year	50-year	2-year	5-year	10-year	25-year	50-year
DB-074	.313	.249	.211	.175	.150	.019	<.001	.001	.293	.228	.190	.155	.130	6.5	8.2	9.7	11.6	13.5
DB-075	.364	.284	.246	.207	.176	.007	.001	.001	.357	.276	.239	.200	.168	2.1	2.6	3.0	3.6	4.3
DB-076	.449	.342	.300	.253	.217	.047	<.001	.001	.400	.293	.251	.205	.169	10.8	14.1	16.1	19.1	22.2
DB-077	.356	.278	.240	.202	.172	.006	<.001	.001	.349	.271	.234	.195	.165	1.9	2.5	2.8	3.4	4.0
DB-078	1.028	.915	.822	.671	.640	.047	<.001	.001	.980	.867	.774	.623	.592	4.7	5.2	5.8	7.2	7.5
DB-079	.524	.391	.331	.290	.274	<.001	.001	<.001	.525	.392	.332	.291	.275	-.1	-.2	-.2	-.2	-.2
DB-080	.563	.431	.379	.327	.306	.038	.006	.001	.530	.398	.346	.294	.273	5.9	7.7	8.7	10.1	10.8
DB-081	.563	.431	.379	.327	.306	.038	.001	<.001	.526	.394	.342	.290	.269	6.6	8.6	9.8	11.3	12.1
DB-082	.774	.619	.558	.504	.467	.142	.001	.001	.632	.477	.416	.362	.325	18.3	22.9	25.4	28.2	30.4
DB-083	.439	.335	.298	.252	.212	.066	.001	.001	.374	.269	.232	.187	.146	14.9	19.6	22.0	26.0	31.0
DB-084	.543	.405	.359	.312	.273	.024	.001	.002	.518	.379	.334	.287	.248	4.6	6.2	7.0	8.1	9.2
DB-085	.774	.619	.558	.504	.467	.027	.030	.001	.776	.621	.560	.506	.469	-.3	-.3	-.4	-.4	-.4
DB-086	.774	.619	.558	.504	.467	.014	.149	.001	.908	.753	.692	.638	.601	-17.3	-21.6	-24.0	-26.6	-28.7
DB-087	.774	.619	.558	.504	.467	.064	.005	.001	.714	.559	.498	.444	.407	7.8	9.7	10.8	11.9	12.8
DB-088	.774	.619	.558	.504	.467	.082	.012	<.001	.704	.549	.488	.434	.397	9.0	11.3	12.5	13.9	15.0
DB-089	.540	.402	.348	.303	.277	.039	.001	.001	.501	.363	.309	.264	.238	7.2	9.7	11.2	12.9	14.1
DB-090	.619	.478	.443	.393	.390	.290	<.001	<.001	.329	.188	.153	.103	.100	46.8	60.7	65.5	73.8	74.4
DB-091	.523	.390	.330	.289	.274	.002	<.001	<.001	.521	.388	.328	.287	.272	.4	.5	.6	.7	.7
DB-092	.619	.478	.443	.393	.390	.318	.001	<.001	.302	.161	.126	.076	.073	51.2	66.3	71.6	80.7	81.3
DB-093	.619	.478	.443	.393	.390	.221	.002	<.001	.400	.259	.224	.174	.171	35.4	45.8	49.4	55.7	56.2
DB-094	.849	.668	.615	.543	.475	.100	.002	.001	.751	.569	.516	.444	.377	11.6	14.7	16.0	18.1	20.7
DB-095	.915	.707	.650	.584	.505	.071	<.001	<.001	.844	.636	.579	.513	.435	7.7	10.0	10.9	12.1	14.0
DB-096	.832	.656	.610	.534	.474	.029	.018	.001	.821	.644	.598	.522	.463	1.4	1.8	1.9	2.2	2.5
DB-097	.562	.462	.424	.360	.286	.058	.003	.001	.506	.407	.369	.305	.231	9.8	12.0	13.0	15.4	19.3
DB-098	.526	.444	.419	.367	.284	.001	<.001	.001	.524	.442	.417	.365	.282	.3	.4	.4	.5	.6

Table 8. Ground-water availability, ground-water withdrawals, recharged water, and percent of available ground water used for watersheds in the Delaware River Basin.—Continued

[Watershed locations shown on figure 2. Negative percentage indicates net recharge of water in the watershed, DB, Delaware River basin; <. less than]

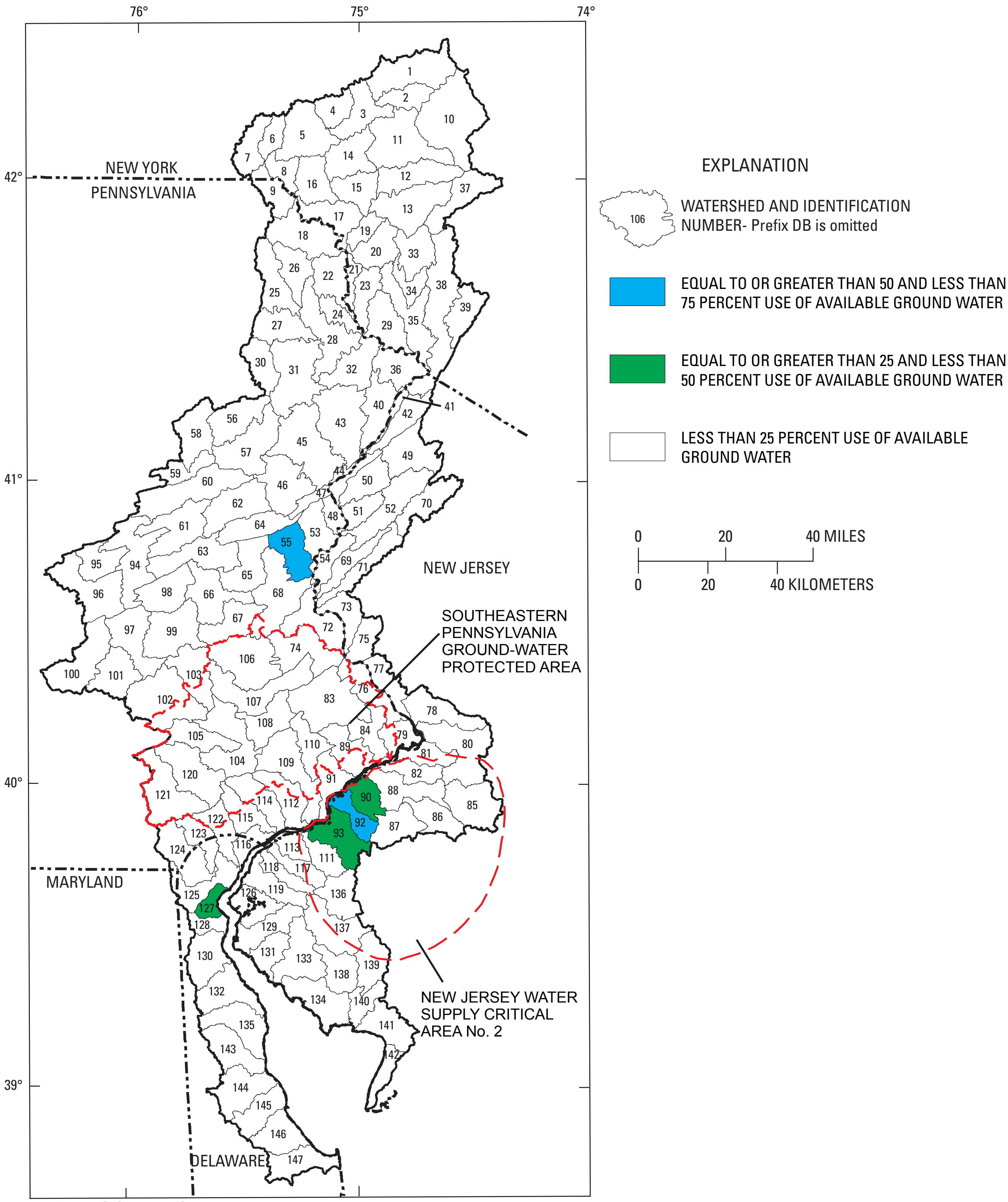
Basin identi-fication number	Ground-water availability (million gallons per day per square mile)					Ground-water withdrawal (million gallons per day per square mile)	Recharged water (million gallons per day per square mile)	Domestic water use (million gallons per day per square mile)	Remaining available ground water (million gallons per day per square mile)					Percent of available ground water used				
	Recurrence interval								Recurrence interval					Recurrence interval				
	2-year	5-year	10-year	25-year	50-year				2-year	5-year	10-year	25-year	50-year	2-year	5-year	10-year	25-year	50-year
DB-099	.607	.485	.431	.349	.288	.050	.003	.001	.558	.436	.382	.301	.239	8.1	10.1	11.4	14.0	17.0
DB-100	.605	.480	.427	.344	.284	.005	.001	.001	.600	.475	.422	.339	.279	.9	1.1	1.2	1.5	1.8
DB-101	.588	.476	.427	.355	.288	.031	.001	.002	.556	.444	.395	.323	.256	5.4	6.7	7.4	9.0	11.0
DB-102	.525	.403	.356	.297	.249	.028	.001	.001	.497	.375	.328	.269	.221	5.3	7.0	7.9	9.4	11.2
DB-103	.616	.493	.425	.351	.297	.002	<.001	.001	.613	.490	.422	.348	.293	.5	.6	.7	.9	1.1
DB-104	.458	.348	.299	.250	.222	.071	.014	.001	.399	.290	.240	.191	.163	12.8	16.8	19.6	23.4	26.4
DB-105	.527	.394	.346	.300	.266	.006	<.001	.001	.520	.387	.339	.294	.259	1.3	1.8	2.0	2.3	2.6
DB-106	.433	.347	.300	.253	.213	.013	<.001	.001	.419	.332	.285	.239	.199	3.3	4.1	4.7	5.6	6.6
DB-107	.341	.272	.231	.193	.165	.027	<.001	.002	.313	.243	.203	.164	.136	8.4	10.6	12.4	14.9	17.4
DB-108	.325	.257	.219	.183	.156	.050	.001	.002	.273	.205	.168	.131	.105	15.9	20.1	23.6	28.3	33.1
DB-109	.552	.412	.357	.302	.272	.074	.002	<.001	.480	.340	.285	.230	.200	13.0	17.4	20.2	23.8	26.5
DB-110	.534	.400	.349	.292	.256	.130	.001	<.001	.404	.271	.220	.163	.127	24.3	32.4	37.1	44.3	50.6
DB-110[1]	.534	.400	.349	.292	.256	.061	.001	<.001	.473	.340	.289	.232	.196	11.3	15.1	17.3	20.7	23.6
DB-111	.619	.478	.443	.393	.390	.154	.002	.001	.466	.325	.290	.240	.237	24.7	32.0	34.5	38.9	39.2
DB-112	.524	.391	.331	.289	.274	<.001	<.001	<.001	.524	.391	.331	.290	.274	-.1	-.1	-.1	-.1	-.1
Db-113	1.169	.855	.780	.688	.670	.099	.004	.001	1.073	.759	.684	.592	.574	8.2	11.2	12.3	14.0	14.3
DB-114	.523	.390	.330	.289	.274	.005	.004	.001	.521	.388	.328	.287	.272	.4	.5	.6	.6	.7
DB-115	.524	.391	.331	.289	.274	.006	<.001	.001	.517	.384	.324	.283	.267	1.3	1.7	2.0	2.3	2.4
DB-116	.514	.384	.325	.284	.269	<.001	<.001	<.001	.514	.383	.325	.284	.269	.1	.1	.1	.1	.1
DB-117	.524	.409	.353	.344	.265	.045	.002	.001	.480	.365	.309	.300	.221	8.4	10.8	12.5	12.8	16.6
DB-118	.524	.409	.353	.344	.265	.034	.008	.002	.496	.381	.325	.316	.237	5.3	6.8	7.9	8.1	10.6
DB-119	.720	.534	.479	.425	.418	.089	.001	.001	.631	.445	.390	.336	.329	12.4	16.7	18.6	20.9	21.3
DB-120	.543	.406	.343	.292	.275	.044	.001	.001	.499	.362	.299	.249	.232	8.0	10.7	12.7	14.9	15.8
DB-121	.532	.397	.336	.290	.275	.006	<.001	.002	.525	.390	.328	.283	.267	1.4	1.8	2.2	2.5	2.7
DB-122	.524	.391	.331	.289	.274	.001	.001	.001	.522	.389	.329	.288	.272	.3	.4	.5	.6	.6

Table 8. Ground-water availability, ground-water withdrawals, recharged water, and percent of available ground water used for watersheds in the Delaware River Basin.—Continued

[Watershed locations shown on figure 2. Negative percentage indicates net recharge of water in the watershed, DB, Delaware River basin; <. less than]

Basin identification number	Ground-water availability (million gallons per day per square mile), Recurrence interval					Ground-water withdrawal (million gallons per day per square mile)	Recharged water (million gallons per day per square mile)	Domestic water use (million gallons per day per square mile)	Remaining available ground water (million gallons per day per square mile), Recurrence interval					Percent of available ground water used, Recurrence interval				
	2-year	5-year	10-year	25-year	50-year				2-year	5-year	10-year	25-year	50-year	2-year	5-year	10-year	25-year	50-year
DB-123	.533	.398	.336	.291	.275	.013	<.001	.002	.518	.383	.322	.276	.260	2.8	3.8	4.4	5.1	5.4
DB-124	.534	.398	.337	.291	.275	.021	<.001	.001	.512	.377	.315	.269	.253	4.1	5.5	6.4	7.5	7.9
DB-125	.519	.387	.328	.287	.272	.054	<.001	.001	.464	.332	.273	.232	.217	10.6	14.2	16.8	19.2	20.2
DB-126	1.169	.855	.780	.688	.670	.020	.001	.001	1.149	.835	.760	.668	.650	1.7	2.3	2.6	2.9	3.0
DB-127	.823	.697	.633	.532	.515	.340	<.001	.001	.482	.356	.292	.191	.174	41.4	48.9	53.9	64.1	66.2
DB-128	.548	.399	.340	.278	.267	.013	<.001	<.001	.535	.386	.327	.265	.254	2.4	3.3	3.8	4.7	4.9
DB-129	1.169	.855	.780	.688	.670	.011	.001	.001	1.158	.844	.769	.677	.659	.9	1.3	1.4	1.6	1.6
DB-130	.465	.340	.309	.234	.178	.015	<.001	<.001	.450	.325	.294	.219	.163	3.2	4.4	4.9	6.4	8.4
DB-131	.765	.598	.540	.482	.443	.007	.001	.001	.758	.591	.533	.475	.436	.9	1.2	1.3	1.5	1.6
DB-132	.548	.399	.340	.278	.267	.013	<.001	<.001	.535	.386	.327	.265	.254	2.4	3.3	3.8	4.7	4.9
DB-133	.862	.607	.560	.509	.470	.093	.003	.001	.771	.516	.469	.418	.379	10.6	15.0	16.3	17.9	19.4
DB-134	.765	.598	.540	.482	.443	.006	<.001	<.001	.759	.592	.534	.476	.437	.8	1.0	1.1	1.2	1.4
DB-135	.465	.340	.309	.234	.178	.011	<.001	.001	.453	.328	.297	.222	.166	2.6	3.5	3.9	5.1	6.7
DB-136	.739	.568	.511	.458	.431	.076	.002	.003	.662	.491	.434	.381	.354	10.4	13.6	15.1	16.8	17.9
DB-137	.739	.568	.511	.458	.431	.138	.005	.001	.605	.434	.377	.324	.297	18.1	23.6	26.2	29.3	31.1
DB-138	.739	.568	.511	.458	.431	.070	.001	.001	.669	.498	.441	.388	.361	9.5	12.3	13.7	15.3	16.2
DB-139	.739	.568	.511	.458	.431	.076	.005	.001	.667	.496	.439	.386	.359	9.7	12.7	14.1	15.7	16.7
DB-140	1.169	.855	.780	.688	.670	.003	<.001	.001	1.165	.851	.776	.684	.666	.3	.5	.5	.6	.6
DB-141	1.169	.855	.780	.688	.670	.018	.001	.001	1.151	.837	.762	.670	.652	1.5	2.1	2.3	2.6	2.7
DB-142	1.169	.855	.780	.688	.670	.108	<.001	.002	1.059	.745	.670	.578	.560	9.4	12.9	14.1	16.0	16.4
DB-143	.465	.340	.309	.234	.178	.067	<.001	.001	.397	.272	.241	.166	.110	14.6	20.0	22.0	29.1	38.2
DB-144	.465	.340	.309	.234	.178	.006	<.001	.001	.458	.333	.302	.227	.171	1.5	2.1	2.3	3.0	3.9
DB-145	.465	.340	.309	.234	.178	.027	<.001	.001	.437	.312	.281	.206	.150	6.0	8.2	9.1	12.0	15.7
DB-146	.465	.340	.309	.234	.178	.002	<.001	<.001	.463	.338	.307	.232	.176	.4	.6	.6	.9	1.1
DB-147	.548	.399	.340	.278	.267	.047	<.001	<.001	.501	.352	.293	.231	.220	8.6	11.8	13.8	16.9	17.6

[1]Does not include ground-water withdrawals by quarries.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30′N, central meridian 75°00′W.

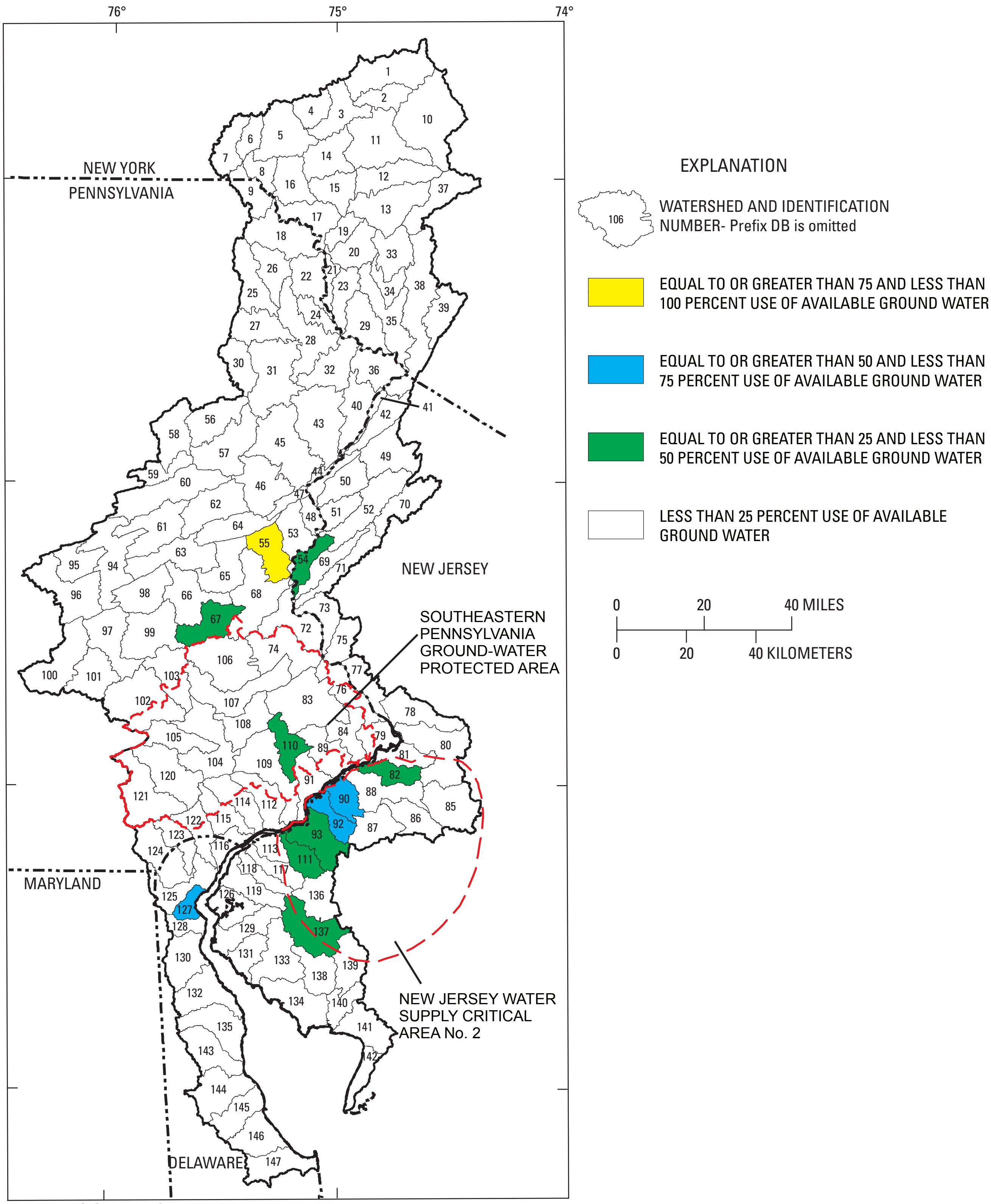
Figure 33. Percent of ground-water use for 2-year annual base-flow recurrence.

gallons, which was 44 percent of total ground-water withdrawals in the watershed. The major withdrawal of ground water in the Bush Kill watershed in 1997 was by the Hercules Cement Company for quarry dewatering; they withdrew 9.8 billion gallons, which was 93 percent of total ground-water withdrawals in the watershed. If quarry dewatering is not considered as a ground-water withdrawal, the ground-water use in the Bush Kill watershed would drop from 60.8 to 3.5 percent of available ground water.

Ground-water use ranged from 0 to 75.9 percent of available ground water for the 5-year-recurrence interval (table 8). Ground-water use exceeded 25 percent in five watersheds and 50 percent in three watersheds: Little Lehigh Creek (DB-067, 31.5 percent); Mantua Creek (DB-111, 32.0 percent); Wissahickon Creek (DB-110, 32.4 percent); Woodbury Creek, Big Timber Creek, Newton Creek, and tributaries to the Delaware River (DB-093, 45.8 percent); Army Creek, Red Lion Creek, Dragon Creek, and tributaries to the Delaware River (DB-127, 48.9 percent); Pennsauken Creek, Pompeston Creek, and tributaries to the Delaware River (DB-090, 60.7 percent); Cooper River (DB-092, 66.3 percent); and Bush Kill (DB-055, 75.9 percent) (fig. 34). The major withdrawal of ground water in 1997 in the Little Lehigh Creek watershed was by the Allentown Municipal Waterworks; they withdrew 3.1 billion gallons from Crystal and Schantz Springs, which was 60 percent of total ground-water withdrawals in the watershed. The major withdrawal of ground water in 1997 in the Wissahickon Creek watershed was by Highway Materials, Inc., for quarry dewatering; they withdrew 1.6 billion gallons, which was 53 percent of total ground-water withdrawals in the watershed. The major withdrawal of ground water in 1999 in the Mantua Creek watershed was by the Mantua Township Municipal Utility Authority; they withdrew 0.36 billion gallons, which was 13 percent of total ground-water withdrawals in the watershed. The Mantua Creek watershed is predominantly urban, and the watershed contains nine other township water departments that each pumped less than 11 percent of the total ground-water withdrawal in 1999. If water pumped for quarry dewatering is not considered as a ground-water withdrawal, ground-water use in the Bush Kill watershed would drop from 75.9 to 4.3 percent of available ground water, and ground-water use in the Wissahickon Creek watershed would drop from 32.4 to 15.1 percent of available ground water.

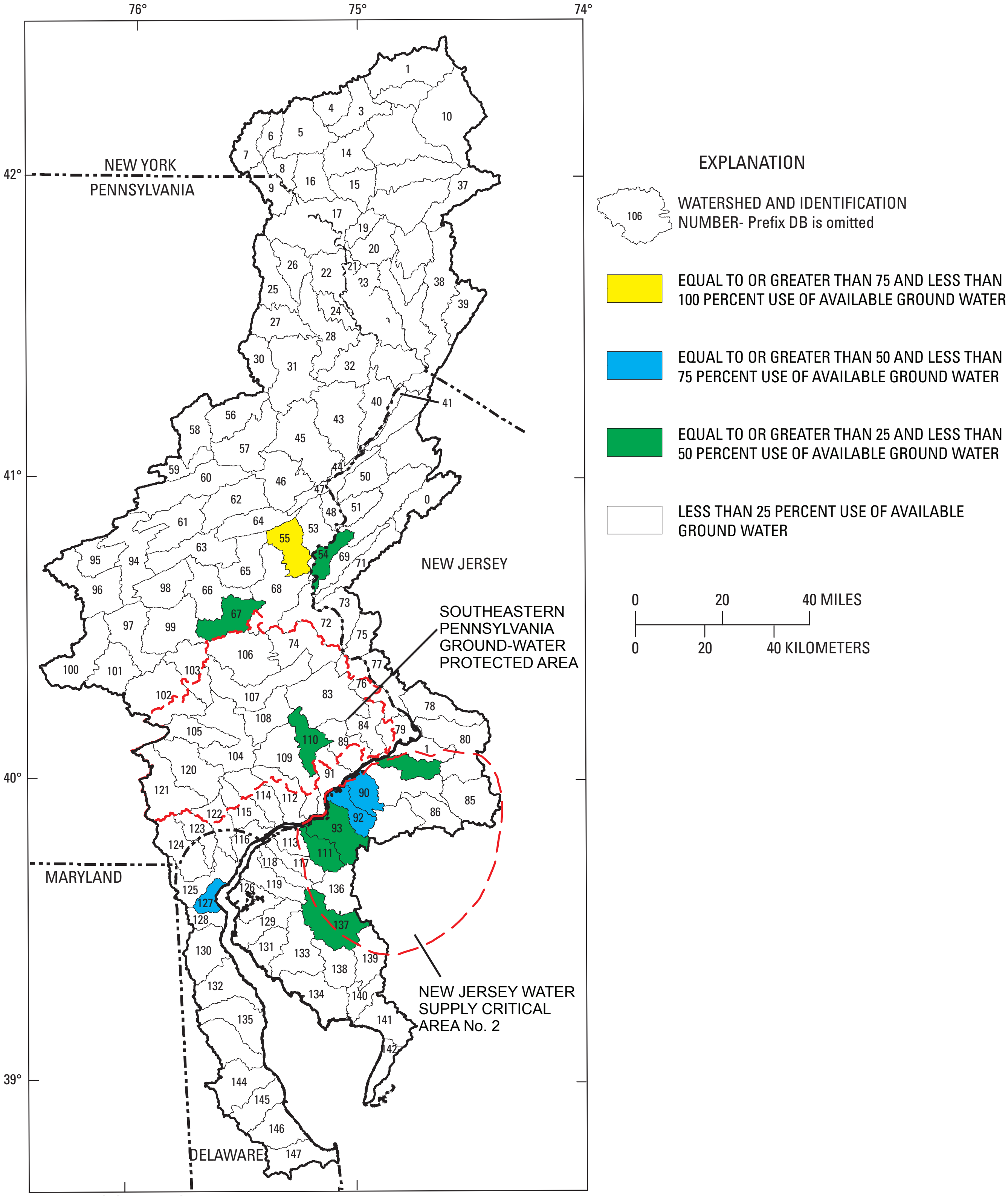
Ground-water use ranged from 0 to 84.5 percent of available ground water for the 10-year-recurrence interval (table 8). Ground-water use exceeded 25 percent in seven watersheds and 50 percent in four watersheds: Assiscunk Creek and tributaries to the Delaware River (DB-082, 25.4 percent); Maurice River above Sherman Avenue Bridge and Muddy Run (DB-137, 26.2. percent); Pophandusing Brook, Buckhorn Creek, Lopatcong Creek, and tributaries to Delaware River (DB-054, 27.6 percent); Mantua Creek (DB-111, 34.5 percent); Little Lehigh Creek (DB-067, 37.1 percent); Wissahickon Creek (DB-110, 37.1 percent); Woodbury Creek, Big Timber Creek, Newton Creek, and tributaries to the Delaware River (DB-093, 49.4 percent); Army Creek, Red Lion Creek, Dragon Creek, and tributaries to the Delaware River (DB-127, 53.9 percent); Pennsauken Creek, Pompeston Creek, and tributaries to the Delaware River (DB-090, 65.5 percent); Cooper River (DB-092, 71.6 percent); and Bush Kill (DB-055, 84.5 percent) (fig. 35). The major withdrawal of ground water in 1999 in the Assiscunk Creek watershed was by Colorite Polymers; they withdrew approximately 1 billion gallons, which was 36 percent of total ground-water withdrawals in the watershed.The major withdrawal of ground water in 1999 in the Pophandusing Brook-Buckhorn Creek-Lopatcong Creek watershed was by the Consumers New Jersey Water Company for public supply; they withdrew 1.2 billion gallons from three wells, which was 56 percent of total ground-water withdrawals in the watershed.The major withdrawal of ground water in 1999 in the Maurice River above Sherman Avenue Bridge and Muddy Run watershed was by the Vineland Water and Sewer Utility; they withdrew approximately 1 billion gallons, which was 52 percent of total ground-water withdrawals in the watershed. If water pumped for quarry dewatering is not considered as a ground-water withdrawal, ground-water use in the Bush Kill watershed would drop from 84.5 to 4.8 percent of available ground water, and ground-water use in the Wissahickon Creek watershed would drop from 37.1 to 17.3 percent of available ground water.

Ground-water use ranged from 0 to 103 percent of available ground water for the 25-year-recurrence interval (table 8). Ground-water use exceeded 25 percent in nine watersheds, 50 percent in three watersheds, and 100 percent in one watershed: Neshaminy Creek above Little Neshaminy Creek (DB-083, 26 percent); Assiscunk Creek and tributaries to the Delaware River (DB-082, 28.2 percent); Perkiomen Creek below east branch (DB-108, 28.3 percent); St. Jones River (DB-143, 29.1 percent); Maurice River above Sherman Avenue Bridge and Muddy Run (DB-137, 29.3 percent); Pophandusing Brook, Buckhorn Creek, Lopatcong Creek, and tributaries to Delaware River (DB-054, 35.7 percent); Mantua Creek (DB-111, 38.9 percent); Wissahickon Creek (DB-110, 44.3 percent); Little Lehigh Creek (DB-067, 48.1 percent); Woodbury Creek, Big Timber Creek, Newton Creek, and tributaries to the Delaware River (DB-093, 55.7 percent); Army Creek, Red Lion Creek, Dragon Creek, and tributaries to the Delaware River (DB-127, 64.1 percent); Pennsauken Creek, Pompeston Creek, and tributaries to the Delaware River (DB-090, 73.8 percent); Cooper River (DB-092, 80.7 percent); and Bush Kill (DB-055, 103 percent) (fig. 36). The major withdrawal of ground water in 2000 in the St. Jones River watershed was by the Dover Department of Public Works; they withdrew 1.4 billion gallons, which was 67 percent of total ground-water withdrawals in the watershed. The watershed is predominantly agricultural. If water pumped for quarry dewatering is not considered as a ground-water withdrawal, ground-water use in the Bush Kill watershed would drop from 103 to 5.9 percent of available ground water, and ground-water use in the Wissahickon Creek watershed would drop from 44.3 to 19.2 percent of available ground water.



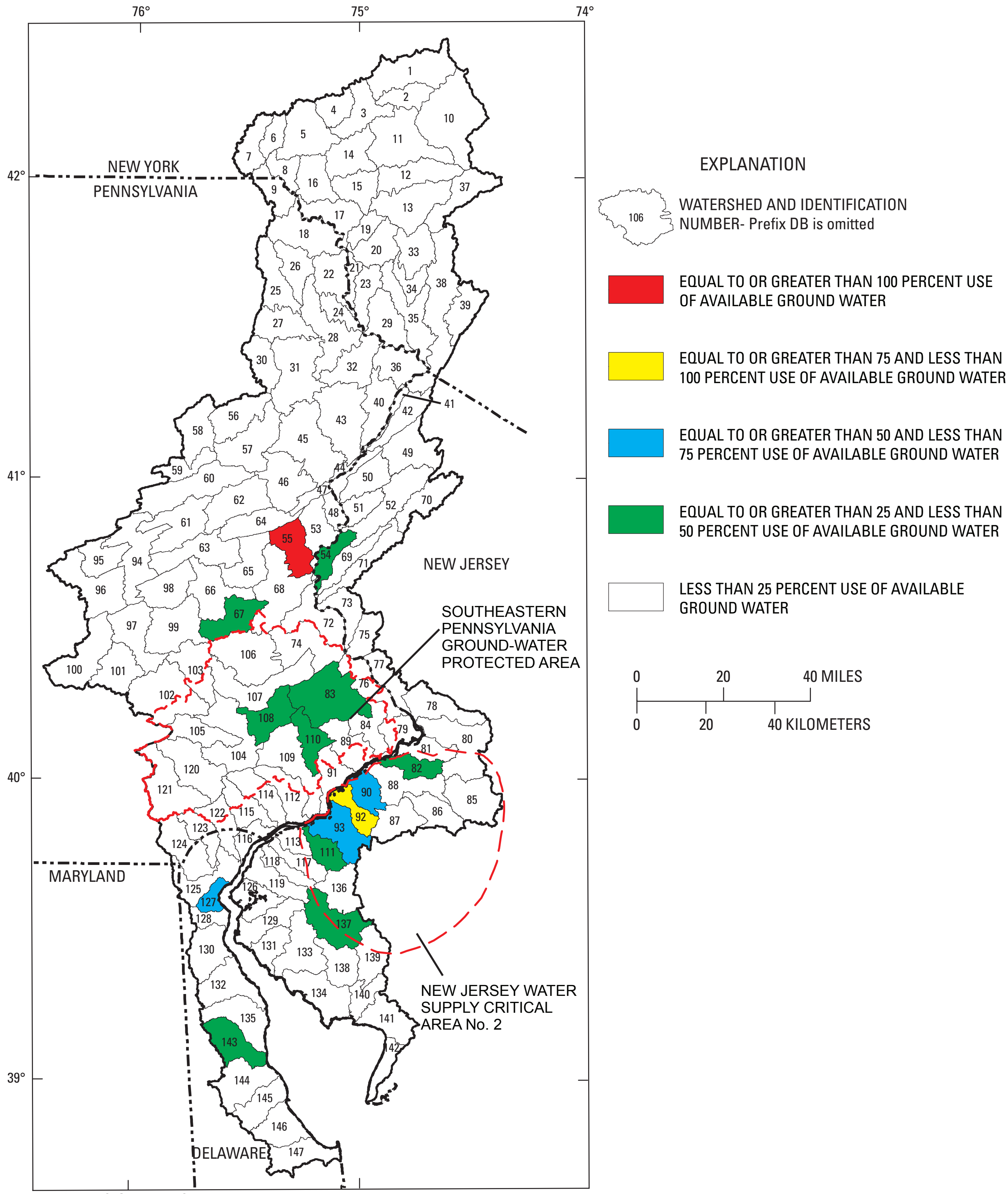
Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30′N, central meridian 75°00′W.

Figure 34. Percent of ground-water use for 5-year annual base-flow recurrence.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30′N, central meridian 75°00′W.

Figure 35. Percent of ground-water use for 10-year annual base-flow recurrence.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30′N, central meridian 75°00′W.

Figure 36. Percent of ground-water use for 25-year annual base-flow recurrence.

Ground-water use ranged from 0 to 127 percent of available ground water for the 50-year-recurrence interval (table 8). Ground-water use exceeded 25 percent in 11 watersheds, 50 percent in 6 watersheds, and 125 percent in 1 watershed: Lower Schuylkill and tributaries above Skippack Creek (DB-104, 26.4 percent); Lower Schuylkill and tributaries below Skippack Creek (DB-109, 26.5 percent); Jordan Creek (DB-066, 28.5 percent); Assiscunk Creek and tributaries to the Delaware River (DB-082, 30.4 percent); Neshaminy Creek above Little Neshaminy Creek (DB-083, 31 percent); Maurice River above Sherman Avenue Bridge and Muddy Run (DB-137, 31.1 percent); Perkiomen Creek below east branch (DB-108, 33.1 percent); St. Jones River (DB-143, 38.2 percent); Pophandusing Brook, Buckhorn Creek, Lopatcong Creek, and tributaries to Delaware River (DB-054, 41 percent); Mantua Creek (DB-111, 39.2 percent); Wissahickon Creek (DB-110, 50.6 percent); Little Lehigh Creek (DB-067, 55.3 percent); Woodbury Creek, Big Timber Creek, Newton Creek, and tributaries to Delaware River (DB-093, 56.2 percent); Army Creek, Red Lion Creek, Dragon Creek, and tributaries to the Delaware River (DB-127, 66.2 percent); Pennsauken Creek, Pompeston Creek, and tributaries to the Delaware River (DB-090, 74.4 percent); Cooper River (DB-092, 81.3 percent); and Bush Kill (DB-055, 127 percent) (fig. 37). The major withdrawal of ground water in 1999 in the Jordan Creek watershed was by GeoSpecialty Chemicals for industrial supply; they withdrew 1.6 billion gallons from eight wells, which was 53 percent of total ground-water withdrawals in the watershed. The major withdrawal of ground water in the Lower Schuylkill and tributaries above Skippack Creek and Perkiomen Creek below east branch watershed was for public supply and industrial use. If water pumped for quarry dewatering is not considered as a ground-water withdrawal, ground-water use in the Bush Kill watershed would drop from 127 to 7.2 percent of available ground water, and ground-water use in the Wissahickon Creek watershed would drop from 50.6 to 23.6 percent of available ground water.

Summary

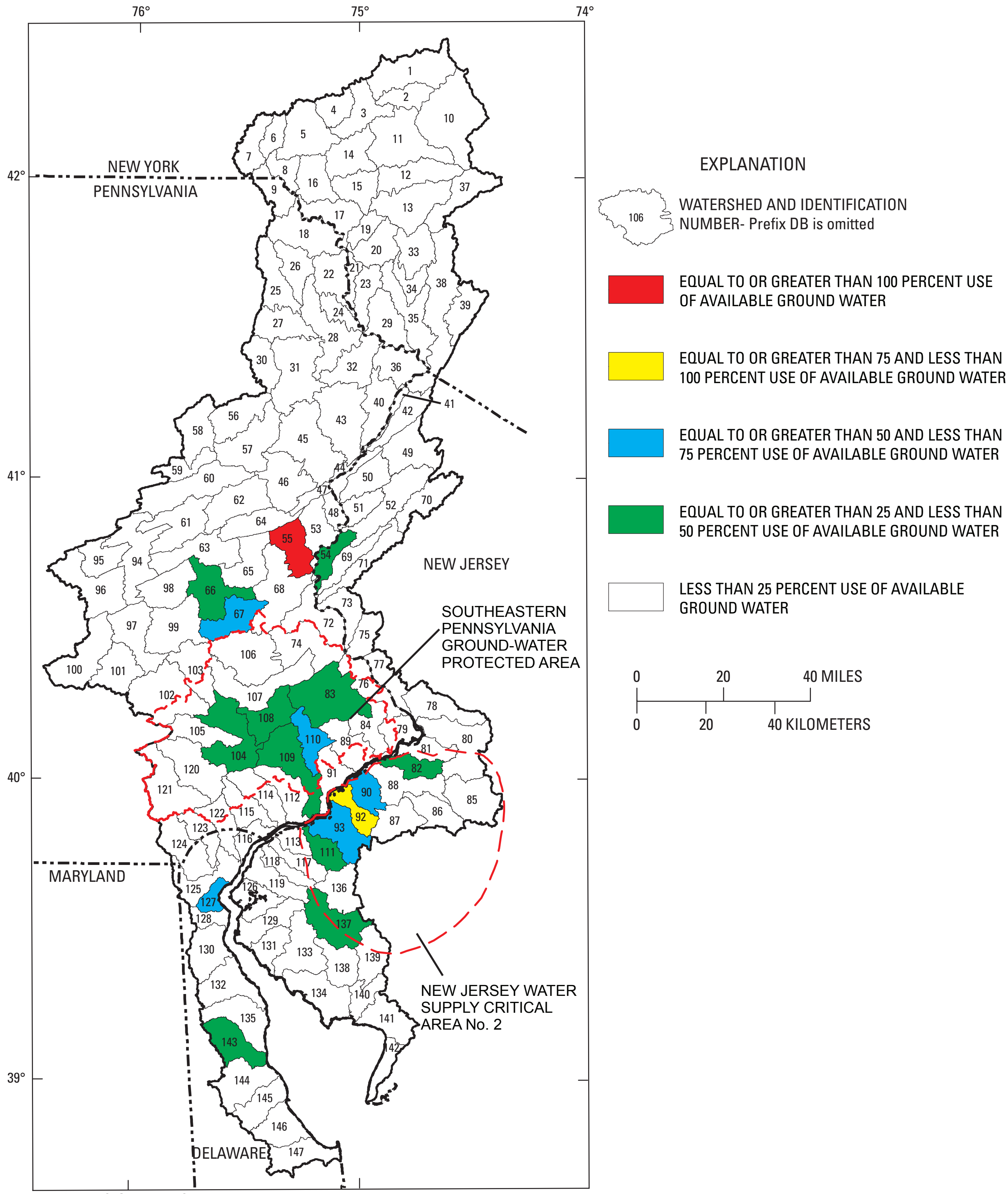
This study was conducted by the U.S. Geological Survey (USGS) during 2003-05, in cooperation with the Delaware River Basin Commission (DRBC), to determine the availability of ground water on a watershed basis in the Delaware River Basin. The results of this study provide water-resource managers and policy makers with a methodology to compare the current (1997-2000) use of ground water with the available ground water in each watershed in the basin. Ground-water availability was estimated for the 147 watersheds that make up the Delaware River Basin. Watersheds were delineated jointly by the DRBC and the USGS and were based on a modified hydrologic unit code (HUC) fifth-level watershed designation. The watersheds ranged in size from 17.9 to 210 mi^2; the average size was 87.4 mi^2. Different procedures were used to estimate ground-water availability for the region underlain by fractured rocks in the upper part of the basin and the region underlain by unconsolidated sediments in the lower part of the basin.

Ground-water availability for 109 watersheds underlain by fractured rocks was based on lithology and phsyiographic province. The 183 geologic units were generalized into 14 rock types. A base-flow-recurrence analysis using the HYSEP hydrograph-separation computer program was made for selected long-term index streamflow-gaging stations that were representative of each generalized rock type. Twenty-three streamflow-gaging stations were chosen to represent the 14 generalized rock types. A spatial data analysis was used to determine average annual base flow for the 2-, 5-, 10-, 25-, and 50-year-recurrence intervals for each station.

For the Piedmont Upland Section of the Piedmont Physiographic Province, the average base-flow recurrence values from three stations were used: West Branch Brandywine Creek near Honey Brook, Pa. (01480300); Red Clay Creek at Wooddale, Del. (01480300); and White Clay Creek near Newark, Del. (01479000). Average annual base flow ranged from 0.524 million gallons per day per square mile [(Mgal/d)/mi^2] for the 2-year-recurrence interval to 0.274 (Mgal/d)/mi^2 for the 50-year-recurrence interval. For the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province, Skippack Creek near Collegeville, Pa. (01473120), was selected as the index station for Triassic shale and Jurassic diabase; average annual base flow ranged from 0.524 to 0.274 (Mgal/d)/mi^2. The drainage basin above this station is 75 percent Brunswick Group and 21 percent Lockatong Formation. Streamflow-gaging station Neshaminy Creek at Rushland, Pa. (01465000), was used to estimate base-flow recurrence for Triassic sandstone. Average annual base flow for Triassic sandstone ranged from 0.590 to 0. 288 (Mgal/d)/mi^2.

For the Reading Prong Section of the New England Physiographic Province (Highlands Physiographic Province in New Jersey), the average of three stations was used: Musconetcong River near Bloomsbury, N.J. (01457000); Pequest River at Pequest, N.J. (01445500); and Manatawny Creek near Pottstown. Pa. (01471980). Average annual base flow ranged from 0.682 to 0.351 (Mgal/d)/mi^2.

For the Great Valley Section of the Ridge and Valley Physiographic Province (Valley and Ridge Physiographic Province in New Jersey), streamflow-gaging station Jordan Creek near Schnecksville, Pa. (01451800), was selected as the index station for rocks of the Martinsburg Formation and Hamburg Klippe. Average annual base flow ranged from 0.514 to 0.276 (Mgal/d)/mi^2. For carbonate rocks (limestone and dolomite) of the Great Valley Section of the Ridge and Valley Physiographic Province and the Piedmont Upland and Lowland Sections, streamflow-gaging station Little Lehigh Creek near Allentown, Pa. (01451500), was selected as the index station. Average annual base flow ranged from 0.690 to 0.281 (Mgal/d)/mi^2. For the Blue Mountain Section of the Ridge and Valley Physiographic Province, streamflow-gaging station Flat Brook near Flatbrookville, N.J. (01440000), was



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30′N, central meridian 75°00′W.

Figure 37. Percent of ground-water use for 50-year annual base-flow recurrence.

selected as the index station for Silurian clastic rocks. Average annual base flow ranged from 0.702 to 0.398 (Mgal/d)/mi^2. Aquashicola Creek at Palmerton, Pa. (01450500), was selected as the index station for Devonian clastic rocks. Average annual base flow ranged from 0.810 to 0.480 (Mgal/d)/mi^2. For the Anthracite Upland Section of the Ridge and Valley Physiographic Province, an average of two stations, Schuylkill River at Pottsville, Pa. (01467500), and Schuylkill River at Landingville, Pa. (01468500), was used for Mississippian and Pennsylvanian clastic rocks. Average annual base flow ranged from 0.915 to 0.505 (Mgal/d)/mi^2.

The Appalachian Plateaus Physiographic Province in Pennsylvania is divided into the Glaciated Low Plateau Section and the Glaciated Pocono Plateau Section. For the Glaciated Pocono Plateau Section, streamflow-gaging station Bush Kill at Shoemakers, Pa. (0143950), was selected as the index station. Average annual base flow ranged from 0.874 to 0.473 (Mgal/d)/mi^2. For the Glaciated Low Plateau Section, streamflow-gaging station Lehigh River at Stoddartsville, Pa. (01447500), was selected as the index station. Average annual base flow ranged from 0.860 to 0.488 (Mgal/d)/mi^2.

For the Appalachian Plateaus Physiographic Province in New York underlain predominantly by Devonian shales of the Upper Walton, Lower Walton, Oneonta, and Gardeau Formations, the average of five streamflow-gaging stations was used. Average annual base flow ranged from 0.687 to 0.373 (Mgal/d)/mi^2. For the area in New York underlain predominantly by the Slide Mountain and Upper Walton Formations, Beaver Kill at Cooks Falls, N.Y. (01420500), was selected as the index station. Average annual base flow ranged from 0.905 to 0.549 (Mgal/d)/mi^2. For the area underlain predominantly by the Honesdale Formation, streamflow-gaging station Callicoon Creek at Callicoon, N.Y. (01427500), was selected as the index station. Average annual base flow ranged from 0.573 to 0.302 (Mgal/d)/mi^2.

Mean annual base flows were compiled for 119 streamflow-gaging stations in unconsolidated deposits of the New Jersey Coastal Plain. A spatial-data analysis and relational database were used to assemble natural and anthropogenic variables representing the possible controlling factors for base flow. Statistical tests conducted on relations between mean annual unit-area base flow and the possible controlling factors showed predominant surficial geology and land use are the significant controlling factors for base flow. A spatial-data analysis was used to determine the predominant surficial geology and land use of the 38 Delaware River Basin Coastal Plain watersheds. A base-flow-recurrence analysis was conducted on 21 index streamflow-gaging stations to determine annual base flow, and the index stations were grouped by the predominant controlling factors. Base-flow-recurrence intervals were averaged to determine the average annual 2-, 5-, 10-, 25-, and 50-year-recurrence intervals for each group of predominant surficial geology and land use, which were used to determine the ground-water availability for each watershed.

For watersheds that have salt marsh and estuarine deposits and undeveloped land use as predominant controlling factors of base flow, the average of 15 index stations in the New Jersey Coastal Plain with undeveloped land use was used to calculate average annual base flow. Average annual base flow ranged from 0.765 to 0.443 (Mgal/d)/mi^2.

For watersheds that have lower and upper stream-terrace deposits and undeveloped land use as predominant controlling factors of base flow, the average of nine index stations in the New Jersey Coastal Plain was used to calculate average annual base flow. Average annual base flow ranged from 0.774 to 0.467 (Mgal/d)/mi^2.

For watersheds that have the Cape May Formation and either undeveloped land use or agricultural land use as predominant controlling factors of base flow, East Branch Bass River near New Gretna, N.J. (01410150), was selected as the index station. Average annual base flow ranged from 1.169 to 0.670 (Mgal/d)/mi^2.

For watersheds that have weathered Coastal Plain formations and urban land use as predominant controlling factors of base flow, South Branch Pennsuaken Creek at Cherry Hill, N.J. (01467081), was selected as the index station. Average annual base flow ranged from 0.619 to 0.390 (Mgal/d)/mi^2. For watersheds that have weathered Coastal Plain formations and undeveloped land use as predominant controlling factors of base flow, an average of two index stations, Manalapan Brook at Spotswood, N.J. (01405400), and McDonalds Branch in Byrne State Forest, N.J. (01466500), was used to calculate average annual base flow. Average annual base flow ranged from 0.563 to 0.306 (Mgal/d)/mi^2. For watersheds that have weathered Coastal Plain formations and agricultural land use as predominant controlling factors of base flow, the average of three index stations, Raccoon Creek near Swedesboro, N.J. (01477120), Salem River at Woodstown, N.J. (01482500), and Alloway Creek at Alloway, N.J. (01483000), was used to calculate average annual base flow. Average annual base flow ranged from 0.524 to 0.265 (Mgal/d)/mi^2.

For watersheds that have the Bridgeton Formation and urban land use as predominant controlling factors of base flow, Mantua Creek at Pitman, N.J. (01475000), was selected as the index station. Average annual base flow ranged from 1.028 to 0.640 (Mgal/d)/mi^2. For watersheds that have the Bridgeton Formation and undeveloped land use as predominant controlling factors of base flow, the average of three index stations, Great Egg Harbor River at Folsom, N.J. (01411000), Tuckahoe River at Head of River, N.J. (01411300), and Maurice River at Norma, N.J. (01411500), was used to calculate average annual base flow. Average annual base flow ranged from 0.739 to 0.431 (Mgal/d)/mi^2. For watersheds that have the Bridgeton Formation and agricultural land use as predominant controlling factors of base flow, Menantico Creek near Millville, N.J. (01412000), was selected as the index station. Average annual base flow ranged from 0.862 to 0.470 (Mgal/d)/mi^2.

Only predominant land use could be used in Delaware to group sites, because digital surficial geology is available only for the northernmost county of the state. The 10 watersheds in Delaware contain all 3 general types of land use; therefore, land use was used as the predominant controlling factor for base flow in Delaware. For watershed that have urban land use as the predominant controlling factor of base flow, the average of two index stations, South Branch Pennsuaken Creek at Cherry Hill, N.J. (01467081), and Mantua Creek at Pitman, N.J. (01475000), was used to calculate average annual base flow. Average annual base flow ranged from 0.823 to 0.515 (Mgal/d)/mi^2. For watersheds that have undeveloped land use as the predominant controlling factor of base flow, the average of two stations, Blackbird Creek at Blackbird, Del. (01483200), and Trap Pond Outlet near Laurel, Del. (01487500), was used to calculate average annual base flow. Average annual base flow ranged from 0.548 to 0.267 (Mgal/d)/mi^2. For watersheds that have agricultural land use as the predominant controlling factor of base flow, the average of two stations, Leipsic River near Cheswold, Del. (01483500), and St. Jones River at Dover, Del. (01483700), was used to calculate average annual base flow. Average annual base flow ranged from 0.465 to 0.178 (Mgal/d)/mi^2.

A spatial-data analysis was used to estimate 2-, 5-, 10-, 25-, and 50-year annual base-flow-recurrence-interval values for each watershed in the Delaware River Basin. These values are considered to be the quantity of ground water available for each watershed over a range of climatic conditions. The recurrence intervals are considered to be relative indicators of climatic difference; the 2-year-recurrence value represents wetter years, and the 50-year-recurrence value represents drier years. Ground-water withdrawal and domestic water use were subtracted from and ground-water recharge was added to the available quantity of ground water, and the percentage of ground-water use for each base-flow recurrence interval was calculated for each watershed.

Ground-water use ranged from 0 to 60.8 percent of available ground water for the 2-year-recurrence interval. Ground-water use exceeded 25 percent in four watersheds and 50 percent in two watersheds. If water pumped for quarry dewatering is not considered as a ground-water withdrawal, ground-water use in the Bush Kill watershed would drop from 60.8 to 3.5 percent of available ground water.

Ground-water use ranged from 0 to 75.9 percent of available ground water for the 5-year-recurrence interval. Ground-water use exceeded 25 percent in five watersheds and 50 percent in three watersheds. If water pumped for quarry dewatering is not considered as a ground-water withdrawal, ground-water use in the Bush Kill watershed would drop from 75.9 to 4.3 percent of available ground water, and ground-water use in the Wissahickon Creek watershed would drop from 32.4 to 15.1 percent of available ground water.

Ground-water use ranged from 0 to 84.5 percent of available ground water for the 10-year-recurrence interval. Ground-water use exceeded 25 percent in seven watersheds and 50 percent in four watersheds. If water pumped for quarry dewatering is not considered as a ground-water withdrawal, ground-water use in the Bush Kill watershed would drop from 84.5 to 4.8 percent of available ground water, and ground-water use in the Wissahickon Creek watershed would drop from 37.1 to 17.3 percent of available ground water.

Ground-water use ranged from 0 to 103 percent of available ground water for the 25-year-recurrence interval. Ground-water use exceeded 25 percent in nine watersheds, 50 percent in three watersheds, and 100 percent in one watershed. If water pumped for quarry dewatering is not considered as a ground-water withdrawal, ground-water use in the Bush Kill watershed would drop from 103 to 5.9 percent of available ground water, and ground-water use in the Wissahickon Creek watershed would drop from 44.3 to 19.2 percent of available ground water.

Ground-water use ranged from 0 to 127 percent of available ground water for the 50-year-recurrence interval. Ground-water use exceeded 25 percent in 11 watersheds, 50 percent in 6 watersheds, and 125 percent in 1 watershed. If water pumped for quarry dewatering is not considered as a ground-water withdrawal, ground-water use in the Bush Kill watershed would drop from 127 to 7.2 percent of available ground water, and ground-water use in the Wissahickon Creek watershed would drop from 50.6 to 23.6 percent of available ground water.

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References Cited

Balmer, W.T., and Davis, D.K., 1996, Groundwater resources of Delaware County, Pennsylvania: Pennsylvania Geologic Survey, 4th ser., Water Resources Report 66, 67 p.

Berg, T.M. and others, 1980, Geologic map of Pennsylvania: Pennsylvania Geologic Survey, 4th ser., Map 1, 2 sheets, scale 1:250,000.

Biesecker, J.E., Lescinsky, J.B., and Wood, C.R., 1968, Water resources of the Schuylkill River Basin: Pennsylvania Department of Forests and Waters Bulletin No. 3, 198 p.

Charles, E.G., Storck, D.A., and Clawges, R.M., 2001, Hydrology of the unconfined aquifer system, Maurice River area: Maurice and Cohansey River Basins, New Jersey, 1994-95: U.S. Geological Survey Water-Resources Investigations Report 01-4229, 5 pl.

Delaware River Basin Commission, 1999, Ground water protected area regulations southeastern Pennsylvania: West Trenton, N.J., 41 p.

Delaware River Basin Commission, 2004, Water resources plan for the Delaware River Basin: West Trenton, N.J., 100 p.

Drake, A.A., Jr., and others, 1996, Bedrock geologic map of northern New Jersey: U.S. Geological Survey Miscellaneous Investigations Series Map I-2540-A, 2 sheets, scale 1:100,000.

Fenneman, N.M., and Johnson, D.W., 1946, Physiographic divisions of the United States: U.S. Geological Survey, 1 sheet, scale 1:7,000,000.

Fisher, D.W., Isachsen, Y.W., and Rickard, L.V., 1970a, Geologic Map of New York State, Finger Lakes sheet: New York State Museum and Science Service, Map and Chart No. 15, 1 sheet, scale 1:250,000.

Fisher, D.W., Isachsen, Y.W., and Rickard, L.V., 1970b, Geologic Map of New York State, Hudson-Mohawk sheet: New York State Museum and Science Service, Map and Chart No. 15, 1 sheet, scale 1:250,000.

Fisher, D.W., Isachsen, Y.W., and Rickard, L.V., 1970c, Geologic Map of New York State, Lower Hudson sheet: New York State Museum and Science Service, Map and Chart No. 15, 1 sheet, scale 1:250,000.

Gordon, A.D., 2004, Hydrology of the unconfined Kirkwood-Cohansey aquifer system, Forked River and Cedar, Oyster, Mill, Westecunk, and Tuckerton Creek Basins and adjacent basins in the southern Ocean County area, New Jersey, 1998-99: U.S. Geological Survey Water-Resources Investigations Report 03-4337, 5 pl.

Higgins, M.W., and Conant, L.B., 1990, The geology of Cecil County, Maryland: Maryland Geological Survey Bulletin 37, 183 p.

Jenner, C.B., and Lins, H.F., 1991, Climatic atlas of the Delaware River Basin: U.S. Geological Survey Professional Paper 1392, 127 p.

Johnson, M.L., and Charles, E.G., 1997, Hydrology of the unconfined aquifer system, Salem River area: Salem River and Raccoon, Oldmans, Alloway, and Stow Creek Basins, New Jersey, 1993-94: U.S. Geological Survey Water-Resources Investigations Report 96-4195, 5 pl.

Johnson, M.L., and Watt, M.K., 1996, Hydrology of the unconfined aquifer system, Mullica River Basin, New Jersey, 1991-92: U.S. Geological Survey Water-Resources Investigations Report 94-4234, 5 pl.

Lacombe, P.J., and Rosman, R., 1995, Hydrology of the unconfined aquifer system in the upper Maurice River Basin and adjacent areas in Gloucester County, New Jersey, 1986-87: U.S. Geological Survey Water-Resources Investigations Report 92-4128, 5 pl.

Martin, Mary, 1998, Ground-water flow in the New Jersey Coastal Plain: U.S. Geological Survey Professional Paper 1404-H, 146 p.

New Jersey Department of Environmental Protection, 2006, Source water assessment program: accessed February 13, 2006, at www.state.nj.us/dep/swap/

New Jersey Geological Survey, 2005, Surficial geology of New Jersey: New Jersey Geological Survey CD Series, CD 06-1, 1:100,000 digital data.

Plank, M.O., Schenck, W.S., Srogi, LeeAnn, 2000, Bedrock Geology of the Piedmont of Delaware and Adjacent Pennsylvania: Delaware Geological Survey Report of Investigations No. 59, 52 p.

Pristas, R.S. (ed.), 2002, Physiographic provinces of New Jersey: New Jersey Geological Survey Digital Geologic Series DGS02-7 (vector digital data).

Ramsey, K.W., 2005, Geologic map of New Castle County, Delaware: Delaware Geological Survey Geologic Map Series No. 13, scale 1:100,000.

Rutledge, A.T., 1998, Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow data - update: U.S. Geological Survey Water-Resources Investigations Report 98-4148, 43 p.

Salisbury, R.D., and Knapp, G.N., 1917, The Quaternary formations of southern New Jersey: New Jersey Geological Survey Final Report, v. 8, 218 p.

Schreffler, C.L., 1996, Water-use analysis program for the Neshaminy Creek Basin, Bucks and Montgomery Counties, Pennsylvania: U.S. Geological Survey Water-Resources Investigations Report 96-4127, 85 p.

Sevon, W.D. (comp.), 2000, Physiographic provinces of Pennsylvania: Pennsylvania Geologic Survey, 4th ser., Map 13, 1 sheet, scale 1:2,000,000.

Sloto, R.A., 1994, Geology, hydrology, and ground-water quality of Chester County, Pennsylvania: Chester County Water Resources Authority Water Resources Report 2, 118 p.

Sloto, R.A. and Crouse, M.Y., 1996, HYSEP: A computer program for streamflow hydrograph separation and analysis: U.S. Geological Survey Water-Resources Investigations Report 96-4040, 46 p.

Sloto, R.A., Cecil, L.D., and Senior, L.A., 1991, Hydrogeology and ground-water flow in the carbonate rocks of the Little Lehigh Creek Basin, Lehigh County, Pennsylvania: U.S. Geological Survey Water-Resources Investigations Report 90-4076, 85 p.

Sloto, R.A. and Schreffler, C.L., 1994, Hydrogeology and ground-water quality of northern Bucks County, Pennsylvania: U.S. Geological Survey Water-Resources Investigations Report 94-4109, 83 p.

Town, D.A., and Bird, P.H., 1998, Geographical information system data sets for the southeastern Pennsylvania ground water protected area: U.S. Geological Survey Open-File Report 98-571, CD.

Watt, M.K., and Johnson, M.L., 1992, Water resources of the unconfined aquifer system of the Great Egg Harbor River Basin, New Jersey, 1989-90: U.S. Geological Survey Water-Resources Investigations Report 91-4126, 5 pl.

Watt, M.K., Johnson, M.L., and Lacombe, P.J., 1994, Hydrology of the unconfined aquifer system, Toms River, Metedeconk River, and Kettle Creek Basins, New Jersey, 1987-90: U.S. Geological Survey Water-Resources Investigations Report 93-4110, 5 pl.

Watt, M.K., Kane, A.C., Charles, E.G., and Storck, D.A., 2003, Hydrology of the unconfined aquifer system, Rancocas Creek area: Rancocas, Crosswicks, Assunpink, Blacks, and Crafts Creek Basins, New Jersey, 1996: U.S. Geological Survey Water-Resources Investigations Report 02-4280, 5 pl.

Watt, M.K., and Voronin, L.M., 2005, Sources of water to wells located in the updip areas of the Wenonah-Mount Laurel Aquifer, Gloucester and Camden Counties, New Jersey, 2005: U.S. Geological Survey Scientific Investigations Report 2005-5250.

White, K.E. and Sloto, R.A., 1990, Base-flow-frequency characteristics of selected Pennsylvania streams: U.S. Geological Survey Water-Resources Investigations Report 90-4160, 66 p.

Wood, C.R., Flippo, H.N., Jr., Lescinsky, J.B., and Barker, J.L., 1972, Water resources of Lehigh County, Pennsylvania Geologic Survey, 4th ser., Water Resources Report 31, 263 p.