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SURFACE WATER

This section describes the surface-water system in the Rancocas Creek study area. Discharge, base-flow, and flow-duration data for long-term streamflow-gaging stations and the results of low-flow correlations for 25 low-flow partial-record sites in the study area were compiled and analyzed.

Discharge at Gaging Stations

The surface-water system in the study area consists of the Rancocas, Crosswicks, Assunpink, Assiscunk, Blacks, and Crafts Creeks and their many tributaries; lakes; and wetlands. The drainage basins of these six streams encompass 347, 144, 91, 46, 23, and 14 mi^2, respectively. The streams are gaining streams that derive most of their flow from ground water that is discharged from the unconfined aquifers. Overall, they flow westward and drain into the Delaware River.

At various times, the USGS has maintained as many as eight continuous-record streamflow-gaging stations in the study area (fig. 3-1). The five stations with the longest periods of record are Assunpink Creek at Trenton, N.J. (01464000), since 1923; Crosswicks Creek at Extonville, N.J. (01464500), during 1940-51 and since 1952; Middle Branch Mount Misery Brook in Lebanon State Forest, N.J. (01466000), during 1952-65; McDonalds Branch in Lebanon State Forest, N.J. (01466500), since 1953; and North Branch Rancocas Creek at Pemberton, N.J. (01467000), since 1921. Two continuous-record streamflow-gaging stations, Assunpink Creek near Clarksville, N.J. (01463620), and South Branch Rancocas Creek at Vincentown, N.J. (01465850), have shorter periods of record and were used as low-flow stations in the low-flow correlation analysis. An eighth continuous-record streamflow-gaging station, Mill Creek near Willingboro, N.J. (01467019), was not included because its period of record (1974-79) is too short to provide meaningful long-term statistical parameters.

The minimum and maximum monthly mean discharges, and the mean monthly discharge, for the four streamflow-gaging stations with the longest records are shown in figures 3-2 through 3-5. The minimum and maximum daily discharges and the mean annual, 30-day, 5-year, and 7-day, 10-year low-flow discharges for the period of record at all five stations are listed in table 3-1.

A base-flow-separation technique described by Rutledge (1993) makes use of a computer program that partitions stream discharge into direct-runoff and base-flow components. Direct runoff consists of overland runoff and precipitation that falls directly on the stream. Base flow is the fair-weather flow of the stream, and is composed of ground-water discharge and other relatively constant discharges, such as discharges from wastewater-treatment plants, into the stream. This method was used to perform base-flow separations for this study; the results are summarized in table 3-1. Mean annual discharges at the four streamflow-gaging stations with the longest periods of record, divided into direct runoff and base flow, are shown by water year[2] in figures 3-6 through 3-9.

The mean annual base flow of Assunpink Creek at Trenton (01464000) ranged from 41.3 ft^3/s in water year 1932 to 169.7 ft^3/s in water year 1984, with a mean of 90.8 ft^3/s, and from 50.8 percent of total flow in water year 1938 to 80.3 percent in water year 1980, with a mean of 68.3 percent. The mean annual base flow of Crosswicks Creek at Extonville (01464500) ranged from 52.3 ft^3/s in water year 1966 to 129.9 ft^3/s in water year 1973, with a mean of 88.9 ft^3/s, and from 54.6 percent of total flow in water year 1971 to 77.5 percent in water year 1988, with a mean of 66.1 percent. At McDonalds Branch in Lebanon State Forest (01466500), mean annual base flow ranged from 1.1 ft^3/s in water year 1995 to 3.6 ft^3/s in water year 1973, with a mean of 2.0 ft^3/s, and from 89.5 percent of total flow in water year 1989 to 98.6 percent in water year 1985, with a mean of 93.9 percent. The mean annual base flow of North Branch Rancocas Creek at Pemberton (01467000) ranged from 81.0 ft^3/s in water year 1966 to 229.3 ft^3/s in water year 1978, with a mean of 140.9 ft^3/s, and from 68.4 percent of total flow in water year 1938 to 90.7 percent in water year 1995, with a mean of 82.5 percent.

A flow-duration curve is a cumulative-frequency curve that shows the percentage of time that any specified discharge is equaled or exceeded (Langbein and Iseri, 1960, p. 11). The shape of the curve is determined by the hydrologic and geologic characteristics of the drainage basin. A curve with a "flat" slope indicates that streamflow is derived largely from a steady supply of water from storage and, therefore, varies little. Water from storage can come from the ground-water system through the steady release of water from permeable deposits in hydraulic connection with the stream (ground-water discharge), from surface water by the steady release of water from lakes and wetlands, or from a combination of the two sources. A steep cumulative-frequency curve indicates that a relatively small proportion of streamflow is from storage (little steady release of water from ground and surface water), and that flow is derived largely from direct runoff and tends to be variable. A streamflow-variability index for flow-duration curves, calculated as the discharge that is equaled or exceeded 20 percent of the time divided by the discharge that is equaled or exceeded 80 percent of the time, was proposed by Miller (1966, p. 24). Miller reported that the streamflow-variability index for New Jersey streams with drainage areas greater than 25 mi^2 ranges from approximately 2 (low variability) to 20 (high variability). The streamflow-variability index for Coastal Plain streams reported by Miller (1966) ranges from 2.2 to 3.6. All the streamflow-gaging stations in the study area are located in the Coastal Plain Physiographic Province.

Flow-duration curves of mean daily flows for the streamflow-gaging stations Assunpink Creek at Trenton, N.J., (01464000), during water years 1924-96; Crosswicks Creek at Extonville, N.J. (01464500), during water years 1941-51 and 1953-96; and North Branch Rancocas Creek at Pemberton, N.J. (01467000), during water years 1922-96 are shown in figure 3-10. The streamflow-variability indexes at these gaging stations are 3.9, 3.1, and 2.9, respectively; these values indicate that these streams have uniform flow characteristics, even with respect to other Coastal Plain streams, and derive most of their flow from ground-water and surface-water storage. The streamflow-variability index for the streamflow-gaging station Assunpink Creek at Trenton (01464000) is higher because part of the basin is in the Piedmont Physiographic Province, where overland runoff is greater and infiltration is smaller than in the Coastal Plain. Curves for the other streamflow-gaging stations are not presented because these streams drain areas less than 25 mi^2 above the gage. The discharges that were equaled or exceeded 5 percent and 95 percent of the time at Assunpink Creek at Trenton are 413.4 ft^3/s and 25.3 ft^3/s, respectively; those for Crosswicks Creek at Extonville are 385.3 ft^3/s and 34.5 ft^3/s, respectively, and those for North Branch Rancocas Creek at Pemberton are 393.2 ft^3/s and 52.4 ft^3/s, respectively. The median-exceedance discharge (discharge that is likely to be exceeded 50 percent of the time) is 94.6 ft^3/s for Assunpink Creek at Trenton, 94.0 ft^3/s for Crosswicks Creek at Extonville, and 141.2 ft^3/s for North Branch Rancocas Creek at Pemberton.

Discharge at Low-Flow Partial-Record Stations

The magnitude and frequency of streamflow at stations for which a continuous record is unavailable commonly are estimated by correlating instantaneous low-flow discharge at a low-flow partial-record station with the concurrent mean daily discharge at a nearby streamflow-gaging station, or index station. Twenty-five low-flow partial-record stations in both the Piedmont and Coastal Plain Physiographic Provinces were used in low-flow-correlation analyses. Measured discharge values at each low-flow partial-record station were correlated with mean daily discharge at index gaging stations in and near the study area. The locations of the index gaging stations and low-flow partial-record stations are shown in figure 3-1.

The low-flow correlations reported here were developed by using the MOVE.1 (Maintenance of Variance Extension, Type 1) method, which makes use of geometric means to eliminate the bias of ordinary-least-squares regression (Hirsch and others, 1982). An example of a low-flow correlation is shown in figure 3-11. The "best-fit" line, $QP_R = (0.01723)\ QI^{(1.1694)}$, is drawn through the data points that represent the measured discharge at the low-flow partial-record station, QP_M, plotted against the mean daily discharge at the index gaging station, QI. The equation of the best-fit line then is used to estimate, or predict, specific discharge statistics at the low-flow partial-record station, QP_R, on the basis of the values of the same discharge statistics measured at the index gaging station, QI. The 25 low-flow partial-record stations and their associated correlation equations are listed in table 3-2.

Two statistical indicators of the accuracy of the predicted discharge, the correlation coefficient and the standard error of estimation, are included in table 3-2. The correlation coefficient is a number from -1.0 to 1.0 that measures the strength of the linear relation between the logarithm (base 10) of the discharge at the low-flow partial-record station and that of the discharge at the index gaging station. For low-flow correlations in this report, the nearer the correlation coefficient is to 1.0, the more reliable the predicted discharge, QP_R. Although the correlation coefficient typically is used to describe the linear strength of ordinary-least-squares regressions, it is computed here for comparison purposes. The standard error of estimation listed in table 3-2 was calculated for the 7-day, 10-year low-flow discharge (lowest mean discharge for a 7-day period that occurs, on average, once every 10 years) by use of an equation developed specifically for MOVE.1 low-flow correlations by W.O. Thomas, Jr. (U.S. Geological Survey) (Telis, 1991). With this equation, the standard error of estimation can be calculated from the standard error of prediction and the time-sampling error for the index gaging station. The nearer the value (which is a percentage) is to zero, the more reliable the predicted discharge, QP_R. This indicator of reliability is calculated only for the 7-day, 10-year low-flow discharge, but also is a useful measure of reliability for other MOVE.1-predicted discharges (R.G. Reiser, U.S. Geological Survey, oral commun., 1994). For each low-flow partial-record site, three index gaging stations were used--the Rancocas and Crosswicks Creeks streamflow-gaging stations (to maximize the comparability of flow regimes) and the one station outside the study area for which the correlation coefficient was highest and the standard error was lowest (table 3-2).

From these correlations, the 30-day, 5-year low-flow discharge; the 7-day, 10-year low-flow discharge; and the mean annual discharge were calculated for the 25 low-flow partial-record stations. For example, to estimate the mean annual discharge at the low-flow partial-record station Miry Run at Holmes Mills, N.J. (01464480), shown in figure 3-11, the mean annual discharge at the index gaging station Crosswicks Creek at Extonville, N.J. (01464500), 134 ft^3/s, is substituted in the correlation equation and solved for the mean annual discharge at the low-flow partial-record station (QP_R),

$$QP_R = (0.01723)\ 134\ ft^3/s^{(1.1694)}\ \text{, and}$$
$$QP_R = 5.3\ ft^3/s\ .$$

The same approach could be used to estimate the mean annual base flow at a low-flow partial-record station for a drought year. For example, figure 3-7 shows that the mean base flow at Crosswicks Creek at Extonville, N.J. (01464500), in water year 1995 was the lowest on record. The 1995 mean base flow at the low-flow partial-record station Blacks Creek at Mansfield Square, N.J. (01464530), can be estimated by use of the appropriate prediction equation from table 3-2, $QP_R = 0.06359\ QI^{(1.2182)}$. First, the 1995 mean base flow for the index gaging station is estimated from the bar graph (50 ft^3/s, fig. 3-7). This value is substituted for QI in the prediction equation to yield a drought-year base-flow estimate of 7.5 ft^3/s for Blacks Creek at Mansfield Square.

The low-flow-correlation prediction equations were used to estimate discharge statistics for all low-flow partial-record stations listed in table 3-2. Estimates of mean annual base flow as a percentage of total flow for the low-flow partial-record stations in the Coastal Plain made by using Crosswicks Creek at Extonville as the index station were consistently lower than those made by using North Branch Rancocas Creek at Pemberton as the index station, possibly because of differences in geology or land use between the two basins. The primary difference between these two drainage basins is their geology. The drainage area above the streamflow-gaging station North Branch Rancocas Creek at Pemberton consists of sediments of the Kirkwood Formation and Cohansey Sand, which are medium- to coarse-grained sands that allow overland runoff to infiltrate. The infiltrated water is stored in the aquifer and later is released as ground-water discharge to the stream. The drainage area above the Crosswicks Creek at Extonville streamflow-gaging station contains sediments of the Kirkwood Formation and Cohansey Sand only in its headwaters. Most of the basin contains sediments from northeast-southwest-trending outcrops of both aquifers and confining units. These aquifers, and especially the confining units, typically consist of finer grained sediments than those of the Kirkwood Formation and Cohansey Sand. These sediments impede infiltration, thereby increasing overland flow. Because less ground water is stored and released to the stream, estimates of base flow are lower.

Estimates of mean base flow in the Assunpink Creek Basin generally are lower than estimates of mean base flow in the Rancocas Creek or Crosswicks Creek Basins because the basin lies partly in the Piedmont Physiographic Province and consists predominantly of urban land. The bedrock and impervious surfaces reduce the amount of water available to recharge the ground-water system. Estimates of mean base flow are highest in the eastern part of the Crosswicks Creek and Rancocas Creek Basins. These areas coincide with the medium- to coarse-grained sands of the outcrops of the Kirkwood Formation and Cohansey Sand, and land use is predominantly agricultural or forested and wetlands; therefore, a large percentage of precipitation is able to infiltrate the surface and percolate to the ground-water system.

Estimates of mean base flow in inches per year over the basin generally are lower for stations with smaller drainage areas and those that traverse outcrop areas with poorly permeable sediments than for those with larger drainage areas and those that traverse outcrop areas with highly permeable sediments. Smaller basins have less area in which to collect water that can infiltrate and provide base flow to streams. In basins that include the outcrop areas of confining units, infiltration is limited and overland flow is maximized, resulting in lower values of base flow. The drainage areas of four of the seven stations for which base-flow estimates are 8 inches or less per year over the basin cross the outcrops of the Woodbury Clay and Merchantville Formation--two formations that make up a major confining unit in the Coastal Plain. The drainage areas of the other three stations encompass the outcrops of the Marshalltown-Wenonah Formation, the composite confining unit, and clayey areas within the Potomac Formation. Of these seven basins, six have drainage areas smaller than 11 mi^2.

Discharge statistics developed from correlation equations provide valuable information from sites for which these statistics otherwise would be unavailable, even though they most likely are less accurate than statistics based on direct measurements from a continuous-record streamflow-gaging station.

PRECIPITATION, DISCHARGE, AND EVAPOTRANSPIRATION

This section describes the effect of climate on the hydrology of the unconfined-aquifer and surface-water system in the Rancocas Creek study area. Precipitation is compared to discharge, and potential evapotranspiration is estimated. These estimates of precipitation, discharge, and evapotranspiration are used in the water-budget analysis that is presented on sheet 5.

Precipitation data from two National Oceanic and Atmospheric Administration weather stations--Moorestown, N.J. (1932-95), and Pemberton, N.J. (1932-93)--for water years 1932-95 were used to obtain a complete record. For each month, the precipitation data from both stations were averaged; if a value from one of the stations was missing, the value from the other station was used alone. Locations of the weather stations are shown in figure 3-1.

Annual precipitation in the study area during 1932-95 ranged from a minimum of 30.4 in. in water year 1995 to a maximum of 63.1 in. in water year 1978, with a mean of 45.1 in/yr. Average minimum, mean, and maximum monthly precipitation values for the Moorestown and Pemberton weather stations during 1986-95 are shown in figure 3-12. Monthly precipitation ranged from a minimum of 0.55 in. in October 1995 to a maximum of 9.38 in. in July 1989, with a mean of 3.94 in. (National Climatic Data Center, U.S. Monthly Precipitation for Cooperative and National Weather Service, accessed April 24, 1995, on the World Wide Web at URL http://www.ncdc.noaa.gov/ol/climate/online/coop-precip.html, data format).

As much as half of the precipitation that falls on the Rancocas Creek study area discharges to streams. Annual discharge at the long-term streamflow-gaging stations in the study area was compared with total annual precipitation. All discharge values are presented in units of inches of water over the area of the drainage basin to facilitate comparison of discharge to precipitation and of discharge among basins. The annual discharge of Assunpink Creek at Trenton, N.J. (01464000), ranged from 10.4 in. in water year 1931 to 34.9 in. in water year 1984 (fig. 3-6). The mean annual discharge was 19.8 in/yr, or 44 percent of the mean annual precipitation for water years 1932-95. The annual discharge of Crosswicks Creek at Extonville, N.J. (01464500), ranged from 11.7 in. in water year 1995 to 37.4 in. in water year 1978 (fig. 3-7). The mean annual discharge was 22.4 in/yr, or 51 percent of the mean annual precipitation for water years 1941-51 and 1953-95. The annual discharge of the McDonalds Branch in Lebanon State Forest, N.J. (01466500), ranged from 6.7 in. in water year 1995 to 22.3 in. in water year 1973 (fig. 3-8). The mean annual discharge was 12.6 in/yr, or 27 percent of the mean annual precipitation for water years 1955-95. The annual discharge of the North Branch Rancocas Creek at Pemberton, N.J. (01467000), ranged from 10.6 in. in water year 1995 to 32.9 in. in water year 1978 (fig. 3-9). The mean annual discharge was 19.7 in/yr, or 44 percent of the mean annual precipitation for water years 1932-95.

The ratio of mean annual streamflow to mean annual precipitation in the study area ranges from 44 to 51 percent, except at McDonalds Branch in Lebanon State Forest, N.J. (01466500), where it is 27 percent. Many factors, such as basin size, land use, geology, regional ground-water flow, greater leakage to deeper aquifers, and water use, could account for McDonalds Branch's lower ratio. The drainage area of McDonalds Branch is small (2.35 mi^2) and topographically high compared to the drainage areas of the other gaged streams. The basin is largely forest and wetlands, and no ground water or surface water is withdrawn within the basin. Flow in this stream is derived almost entirely (94 percent) from ground water. The underlying permeable Cohansey Sand, along with the forest and wetlands, allows most runoff to infiltrate to the ground-water system and to recharge both the stream and the deeper aquifers. Evapotranspiration is greater in this basin than in the others because of the presence of wetlands (see below). Additionally, because the stream is cut less deeply into the aquifer than the larger streams, more of the water available for ground-water discharge flows beneath McDonalds Branch and is captured as base flow by the larger streams, which are topographically lower.

Most of the precipitation that does not become streamflow leaves the Rancocas Creek study area as evapotranspiration. Potential evapotranspiration was estimated by means of the Thornthwaite equation (Thornthwaite and Mather, 1957), in which mean monthly air temperature and latitude are used as an index of the energy available for evapotranspiration. Potential evapotranspiration is the amount of water that is lost through transpiration from plants and evaporation from the soil if water is always unlimited. Mean monthly air temperature at the Moorestown weather station during 1863-1987 is shown in figure 3-13. Estimated mean monthly potential evapotranspiration is shown in figure 3-14. The calculated mean annual potential evapotranspiration for the study area during 1863-1987 is 27.3 in/yr .

[2]Water year, typically used in hydrologic analysis, is the 12-month period from October 1 through September 30. It is designated by the calendar year in which it ends. In this report, all data are reported for the calendar year indicated unless otherwise noted.

Table 3-1. Summary of discharge statistics for continuous-record streamflow-gaging stations in and near the Rancocas Creek study area, New Jersey

[Station locations shown in fig. 3-1; na, data not available]

Streamflow-gaging-station number	Streamflow-gaging-station name	Drainage area (square miles)	Period of record	Years of daily discharge record[1]	Discharge (cubic feet per second): Mean annual[2]	Minimum daily[2]	Maximum daily[2]	30-day, 5-year[3]	7-day, 10-year[3]	Mean annual base flow[4]: Cubic feet per second	Inches over the drainage area	Percentage of total flow[5]
01396500	South Branch Raritan River near High Bridge, N.J.	65.3	October 1918 to September 1996	72	123	13	3,340	29	22.30	92.09	19.16	74.8
01398000	Neshanic River at Reaville, N.J.	25.7	June 1930 to September 1996	60	37.6	0	4,740	0.79	0.26	16.31	8.62	43.4
01401000	Stony Brook at Princeton, N.J.	44.5	October 1953 to September 1996	37	65.8	0	3,410	.91	.20	26.73	8.15	40.6
01408000	Manasquan River at Squankum, N.J.	44.0	July 1931 to September 1996	59	74.3	12	1,720	22.4	17.66	54.5	16.83	73.3
01408500	Toms River near Toms River, N.J.	123	October 1928 to September 1996	62	212	43	1,910	78.8	63.45	184.29	20.35	87.1
01409400	Mullica River near Batsto, N.J.	46.7	September 1957 to September 1996	33	106	5.1	1,630	23.4	15.97	91.69	26.67	86.4
01411000	Great Egg Harbor River at Folsom, N.J.	57.1	September 1925 to September 1996	65	85.7	15	1,300	28.3	22.23	76.2	18.13	88.9
01445500	Pequest River at Pequest, N.J.	106.0	October 1921 to September 1996	69	157	12	2,040	26.5	19.27	131.16	16.81	83.5
01457000	Musconetcong River near Bloomsbury, N.J.	141	July 1903 to March 1907, July 1921 to September 1996	72	238	27	5,850	60	44.73	201.46	19.41	84.6
01464000	Assunpink Creek at Trenton, N.J.	90.6	August 1923 to September 1996	37	132	4.0	4,050	27.6	17.79	90.8	13.6	68.3
01464500	Crosswicks Creek at Extonville, N.J.	81.5	August 1940 to October 1951, October 1952 to September 1996	49	134	11	3,930	34.1	24.56	88.9	14.8	66.1
01466000	Middle Branch Mount Misery Brook in Lebanon State Forest, N.J.	2.82	October 1952 through September 1965	14	[6]1.93	[6]0	[6]25	na	na	1.7	8.1	87.5
01466500	McDonalds Branch in Lebanon State Forest, N.J.	2.35	October 1953 to September 1996	43	2.18	.50	20	na	na	2.04	11.8	93.9
01467000	North Branch Rancocas Creek at Pemberton, N.J.	118	September 1921 to September 1996	69	171	9.0	1,690	49.9	35.11	140.9	16.2	82.5
01467150	Cooper River at Haddonfield, N.J.	17.0	October 1963 to September 1996	27	34.3	1.2	1,510	12.6	8.37	21.05	16.82	61.4

[1]Low-flow statistics were calculated from data for each complete climatic year. The climatic year is the 12-month period from April 1 through March 31, and is designated by the calendar year in which it begins. This period allows the entire low-water season to occur in one year. For the low-flow statistics in this study, the periods of record begin with the earliest April 1 and end with the latest March 31, but no later than March 31, 1990. Therefore, the number of years of daily discharge record may not equal the number of years in the period of record.
[2]Values from Reed and others (1996) except where noted
[3]Statistics from MOVE.1 low-flow-correlation program. These values reflect data only through 1990.
[4]Base flow was estimated with the methodology of Rutledge (1993). Base flow was calculated with data for each complete water year. The water year is the 12-month period from October 1 through September 30. It is designated by the calendar year in which it ends. For base flow in this study, the periods of record begin with the earliest October 1 and end with the latest September 30.
[5]Percentages were calculated from unrounded discharge values and, therefore, may not be precisely reproducible from the discharge values shown here.
[6]Values from R.D. Schopp, U.S. Geological Survey, oral commun., 2000

Table 3-2. Correlation equations relating instantaneous low-flow measurements at low-flow partial-record stations to concurrent mean daily flow at continuous-record streamflow-gaging stations (index stations) in and near the Rancocas Creek study area, New Jersey

[Station locations shown in fig. 3-1; QP_R, predicted discharge at partial-record station; QI, measured discharge at index station]

Low-flow partial-record station number	Low-flow partial-record station name	Drainage area (square miles)	Index gaging-station number	Number of measurements used in analysis	Years of daily discharge record[1]	Correlation coefficient	Standard error of estimation for 7-day, 10-year low-flow discharge (percent)[2, 3]	Correlation equation	Predicted discharge (QP_R) (cubic feet per second): 30-day, 5-year	7-day, 10-year	Mean annual	Predicted mean annual base flow (QP_R): Cubic feet per second	Inches per year over the drainage area	Percentage of total flow
							Piedmont Physiographic Province							
01463650	Shipetaukin Creek at Lawrenceville, N.J.	4.47	01398000	11	60	0.8883	65.23	$QP_R = 0.39075\ QI^{(1.071)}$	0.3	0.09	19.01	7.77	23.58	40.9
			01401000	11	37	.9361	58.56	$QP_R = .18762\ QI^{(1.0597)}$	.17	.03	15.85	6.10	18.51	38.5
			01445500	11	69	.8452	322.94	$QP_R = .0000711\ QI^{(2.3495)}$	.16	.07	10.26	6.72	20.39	65.5
01463670	Shipetaukin Creek at Bakersville, N.J.	8.97	01396500	10	72	.9372	14.26	$QP_R = .00423\ QI^{(1.725)}$	1.41	.9	17.04	10.34	15.64	60.7
			01398000	10	60	.9691	39.58	$QP_R = 2.42517\ QI^{(0.5748)}$	2.12	1.11	19.51	12.07	18.25	61.9
			01401000	10	37	.9781	53.57	$QP_R = 1.53021\ QI^{(0.5653)}$	1.45	.61	16.32	9.80	14.82	60.0
01463690	Little Shabakunk Creek at Bakersville, N.J.	3.98	01398000	18	60	.8373	66.3	$QP_R = .27394\ QI^{(0.9818)}$	.22	.07	9.64	4.25	14.48	44.1
			01401000	18	37	.9343	29.08	$QP_R = .18622\ QI^{(0.9175)}$	.17	.04	8.67	3.80	12.95	43.8
			01445500	10	69	.866	875.51	$QP_R = .00232\ QI^{(1.5216)}$	.34	.21	5.09	3.87	13.19	76.0
01463750	Shabakunk Creek at Ewingville, N.J.	5.00	01398000	10	60	.9417	61.33	$QP_R = .54688\ QI^{(0.8226)}$	.45	.18	10.81	5.44	14.76	50.3
			01401000	10	37	.9526	129.16	$QP_R = .25904\ QI^{(0.8732)}$	.24	.06	10.02	4.56	12.37	45.5
			01457000	10	72	.8734	58.2	$QP_R = .0000143\ QI^{(2.4587)}$	.34	.16	9.97	6.62	17.96	66.4
01463790	West Branch Shabakunk Creek near Ewingville, N.J.	4.56	01396500	18	72	.8346	23.17	$QP_R = .00734\ QI^{(1.3392)}$	.67	.47	4.62	3.13	9.31	67.7
			01398000	18	60	.86	16.25	$QP_R = 1.03415\ QI^{(0.4101)}$	.94	.59	4.58	3.25	9.67	71.0
			01401000	18	37	.8744	19.99	$QP_R = .78867\ QI^{(0.4241)}$	.76	.4	4.66	3.18	9.46	68.2
							Coastal Plain Physiographic Province							
01463620	Assunpink Creek near Clarksville, N.J.[4]	34.3	01408500	8	62	.9519	8.57	$QP_R = .00446\ QI^{(1.6766)}$	6.75	4.69	35.45	28.03	11.08	79.1
			01464500	8	49	.9832	3.12	$QP_R = .03759\ QI^{(1.5323)}$	8.39	5.07	68.30	36.42	14.04	53.3
			01467000	8	69	.9353	12.95	$QP_R = .01276\ QI^{(1.5917)}$	6.44	3.68	45.72	33.90	13.41	74.2
01463830	Miry Run at Robbinsville, N.J.	4.02	01408500	10	62	.9136	23.6	$QP_R = .000004655\ QI^{(2.4292)}$	.19	.11	2.08	1.48	4.99	71.2
			01464500	10	49	.9198	21.43	$QP_R = .0000852\ QI^{(2.2647)}$	.25	.12	5.59	2.21	7.46	39.5
			01467000	10	69	.9147	24.06	$QP_R = .0000591\ QI^{(2.0841)}$	.2	.1	2.66	1.80	6.07	67.7
01463860	Miry Run at Mercerville, N.J.	12.4	01408000	10	59	.9546	15.31	$QP_R = .0001263\ QI^{(2.7343)}$	.62	.32	16.49	7.07	7.73	42.9
			01464500	10	49	.9487	13.34	$QP_R = .0001149\ QI^{(2.5556)}$	.95	.41	31.36	10.99	12.02	35.0
			01467000	10	69	.9001	35.37	$QP_R = .0000486\ QI^{(2.4375)}$	.67	.28	13.48	8.52	9.32	63.2
01463980	Pond Run at Trenton, N.J.	8.94	01408000	15	59	.8107	346.14	$QP_R = .000000000364\ QI^{(5.5372)}$	.01	0	8.34	1.50	2.28	18.0
			01464500	15	49	.7824	477.11	$QP_R = .000000001\ QI^{(4.932)}$	.03	.01	30.97	4.09	6.21	13.2
			01467000	13	69	.6103	26,590.19	$QP_R = .000000048\ QI^{(3.6283)}$	.07	.02	6.07	3.07	4.66	50.6
01464300	Crosswicks Creek near Cookstown, N.J.	24.9	01408500	8	62	.989	.93	$QP_R = .49488\ QI^{(0.7219)}$	11.58	9.9	23.65	21.38	11.65	90.4
			01464500	8	49	.9593	2.68	$QP_R = 1.02645\ QI^{(0.6966)}$	12	9.54	31.12	23.38	12.74	75.1
			01467000	8	69	.946	4.29	$QP_R = .85489\ QI^{(0.6473)}$	10.74	8.56	23.84	21.11	11.50	88.6
01464380	North Run at Cookstown, N.J.	7.28	01408500	9	62	.9636	3.28	$QP_R = .04778\ QI^{(0.9332)}$	2.81	2.3	7.08	6.21	11.57	87.7
			01464500	9	49	.9484	4.91	$QP_R = .13358\ QI^{(0.8728)}$	2.91	2.18	9.60	6.71	12.50	69.9
			01467000	9	69	.9364	7.18	$QP_R = .07064\ QI^{(0.914)}$	2.52	1.83	7.76	6.54	12.19	84.3
01464460	Lahaway Creek near Hornerstown, N.J.	21.4	01408500	9	62	.9918	1.2	$QP_R = .0468\ QI^{(1.1844)}$	8.25	6.38	26.64	22.57	14.31	84.7
			01464500	9	49	.9872	1.93	$QP_R = .17202\ QI^{(1.1086)}$	8.61	5.98	39.24	24.9	15.78	63.5
			01467000	9	69	.9322	10.16	$QP_R = .07536\ QI^{(1.1639)}$	7.14	4.74	29.93	24.05	15.24	80.4
01464480	Miry Run at Holmes Mills, N.J.	3.15	01408500	9	62	.9843	1.98	$QP_R = .00436\ QI^{(1.2494)}$	1.02	.78	3.52	2.95	12.70	83.8
			01464500	9	49	.9849	2	$QP_R = .01723\ QI^{(1.1694)}$	1.07	.73	5.29	3.28	14.12	62.0
			01467000	9	69	.9612	6.06	$QP_R = .00721\ QI^{(1.2277)}$	.88	.57	3.98	3.16	13.61	79.4
01464515	Doctors Creek at Allentown, N.J.	17.4	01408000	18	59	.9292	10.27	$QP_R = .02144\ QI^{(1.6568)}$	3.7	2.5	26.98	16.15	12.59	59.9
			01464500	19	49	.9412	8.17	$QP_R = .02611\ QI^{(1.4445)}$	4.27	2.66	30.86	17.06	13.30	55.3
			01467000	19	69	.8826	21.43	$QP_R = .0031\ QI^{(1.7648)}$	3.07	1.65	27.05	19.41	15.13	71.8
01464530	Blacks Creek at Mansfield Square, N.J.	19.7	01411000	12	65	.9791	3.06	$QP_R = .09408\ QI^{(1.1581)}$	4.52	3.42	16.30	14.22	9.79	87.2
			01464500	12	49	.9776	3.25	$QP_R = .06359\ QI^{(1.2182)}$	4.68	3.14	24.81	15.1	10.36	60.7
			01467000	11	69	.9548	7.62	$QP_R = .0201\ QI^{(1.3578)}$	4.06	2.52	21.64	16.76	11.54	77.5
01464540	Crafts Creek at Hedding, N.J.	10.6	01408000	9	59	.9239	15.5	$QP_R = .00124\ QI^{(1.9684)}$	.56	.35	5.97	3.25	4.16	54.4
			01464500	9	49	.9009	25.21	$QP_R = .0002098\ QI^{(2.1662)}$	.44	.22	8.50	3.5	4.48	41.2
			01467000	9	69	.9203	21.06	$QP_R = .0002925\ QI^{(1.8243)}$	.37	.19	3.47	2.46	3.15	70.9
01464580	Assiscunk Creek at Columbus, N.J.	8.28	01408000	9	59	.9455	9.95	$QP_R = .00346\ QI^{(1.6605)}$	.6	.41	4.42	2.64	4.32	59.7
			01464500	9	49	.9495	11.11	$QP_R = .0008699\ QI^{(1.7996)}$	.5	.28	5.85	2.8	4.59	47.9
			01467000	9	69	.87	34.34	$QP_R = .0002833\ QI^{(1.8276)}$	.36	.19	3.41	2.42	3.96	71.0
01464590	Assiscunk Creek near Burlington, N.J.	37.4	01409400	11	33	.9387	9.4	$QP_R = .16168\ QI^{(1.0116)}$	3.92	2.67	18.09	15.62	5.66	86.3
			01464500	11	49	.9399	7.79	$QP_R = .08245\ QI^{(1.1605)}$	4.95	3.38	24.25	15.1	5.46	62.1
			01467000	11	69	.9219	12.47	$QP_R = .02301\ QI^{(1.3152)}$	3.94	2.48	19.90	15.56	5.64	78.2
01465850	South Branch Rancocas Creek at Vincentown, N.J.[4]	64.5	01411000	73	65	.8906	17.48	$QP_R = .07798\ QI^{(1.5672)}$	14.69	10.07	83.44	69.40	14.59	83.2
			01464500	57	49	.8666	21.26	$QP_R = .05841\ QI^{(1.5891)}$	15.93	9.45	140.17	73	15.35	52.1
			01467000	65	69	.8854	19.46	$QP_R = .07131\ QI^{(1.3807)}$	15.77	9.7	86.35	66.6	14.01	77.1
01465880	Southwest Branch Rancocas Creek at Medford, N.J.	47.2	01464500	16	49	.952	6.59	$QP_R = .29486\ QI^{(1.1397)}$	16.46	11.32	78.32	49.06	14.10	62.6
			01467000	17	69	.9279	13.3	$QP_R = .07095\ QI^{(1.3157)}$	12.17	7.66	61.50	48.03	13.80	78.1
			01467150	10	27	.9789	3.55	$QP_R = .42915\ QI^{(1.5052)}$	19.45	10.5	87.81	42.11	12.10	48.0
01465884	Sharps Run at Route 541 at Medford, N.J.	4.41	01411000	19	65	.7187	55.79	$QP_R = .0000903\ QI^{(2.2932)}$	.19	.11	2.45	1.87	5.75	76.3
			01464500	18	49	.7802	45.94	$QP_R = .0000984\ QI^{(2.1354)}$	.18	.09	3.43	1.43	4.40	41.7
			01467000	18	69	.6492	66.46	$QP_R = .0000725\ QI^{(2.0984)}$	.27	.13	3.52	2.37	7.29	67.3
01465898	Little Creek near Lumberton, N.J.	19.2	01409400	17	33	.7964	39.03	$QP_R = .00893\ QI^{(1.623)}$	1.49	.8	17.30	13.67	9.66	79.0
			01464500	16	49	.6911	78.69	$QP_R = .0003542\ QI^{(2.3176)}$	1.26	.59	30.13	11.64	8.22	38.6
			01467000	17	69	.7807	40.13	$QP_R = .0004968\ QI^{(2.1028)}$	1.85	.88	24.64	16.60	11.73	67.4
01465900	Southwest Branch Rancocas Creek at Eayrestown, N.J.	76.0	01408000	6	59	.8094	25.8	$QP_R = .56684\ QI^{(1.2054)}$	24.04	18.05	102.04	70.23	12.53	68.8
			01464500	6	49	.6707	57.57	$QP_R = .19335\ QI^{(1.3202)}$	20.41	13.23	124.32	72.32	12.91	58.2
			01467000	6	69	.627	76.78	$QP_R = .09269\ QI^{(1.3391)}$	17.42	10.88	90.62	70.46	12.58	77.8
01467020	Mill Creek at Willingboro, N.J.	7.77	01408000	14	59	.9114	23.98	$QP_R = .0003528\ QI^{(2.2144)}$	.34	.2	4.91	2.47	4.31	50.3
			01464500	14	49	.8353	49.92	$QP_R = .0001168\ QI^{(2.2652)}$	.35	.16	7.69	3.03	5.29	39.4
			01467000	14	69	.8813	37.49	$QP_R = .0000654\ QI^{(2.1438)}$	.29	.13	4.01	2.68	4.68	66.8
01467021	Mill Creek at Levitt Parkway at Willingboro, N.J.[5]	9.12	01408000	6	59	.92	12.40	$QP_R = .05\ QI^{(1.18)}$	1.80	1.36	8.07	5.60	8.33	69.4
			01409400	6	33	.78	60.71	$QP_R = .02\ QI^{(1.28)}$	.89	.55	7.82	6.50	9.67	83.1
			01464500	6	49	.86	18.56	$QP_R = .04\ QI^{(1.12)}$	1.88	1.30	9.65	6.09	9.06	63.1

[1]Low-flow statistics were calculated from data for each complete climatic year. A climatic year is the 12-month period from April 1 through March 31, and is designated by the calendar year in which it begins. This period allows the entire low-water season to occur in one year. For the low-flow statistics in this study, the periods of record begin with the earliest April 1 and end with the latest March 31, but no later than March 31, 1990.
[2]Calculated for the 7-day, 10-year low-flow discharge with an equation developed specifically for MOVE.1-low-flow correlations by W.O. Thomas, Jr. (Telis, 1991). This indicator of reliability is calculated only for the 7-day, 10-year low-flow discharge, but also is a useful measure of reliability for other MOVE.1-predicted discharges (R.G. Reiser, U.S. Geological Survey, oral commun., 1994).
[3]Very large standard errors of estimation for the 7-day, 10-year low-flow discharges are associated with sites on small streams with low discharge values.
[4]Continuous-record streamflow-gaging station with a short record. For the purposes of this study, this station is used as a low-flow partial-record station.
[5]Results for this station may be less accurate than results for other stations because of the smaller number of decimal places in the correlation coefficient.

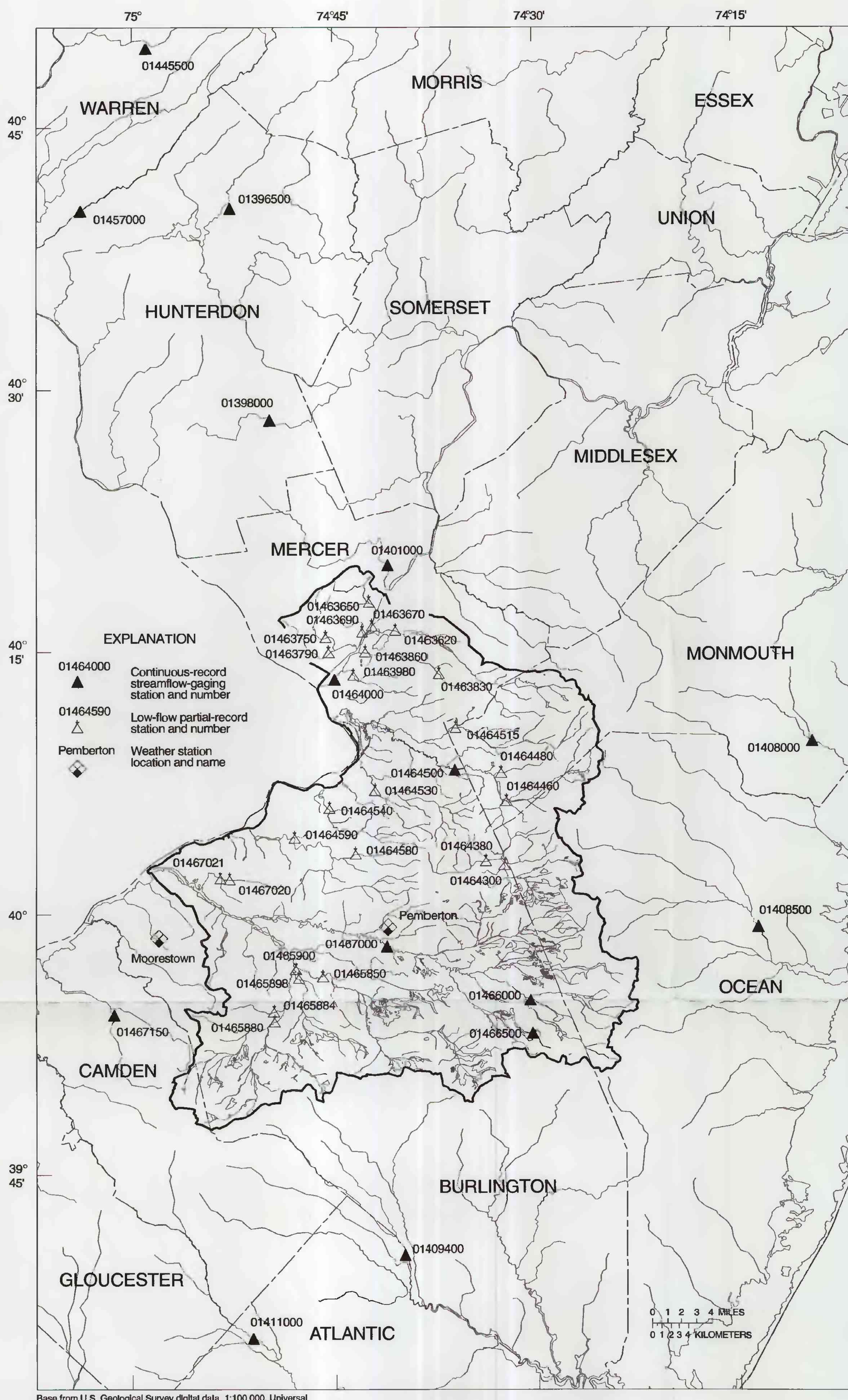


Figure 3-1. Location of continuous-record streamflow-gaging stations, low-flow partial-record stations, and weather stations in and near the Rancocas Creek study area, New Jersey.

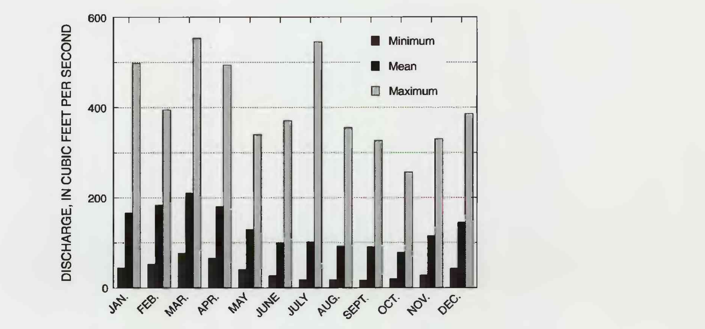


Figure 3-2. Minimum and maximum monthly mean, and mean monthly discharge at Assunpink Creek at Trenton, N.J. (01464000), water years 1924-96.

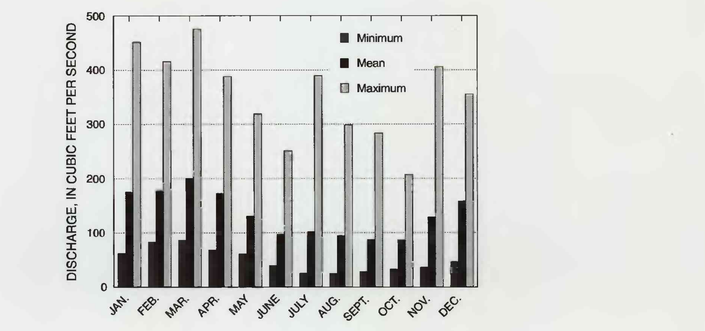


Figure 3-3. Minimum and maximum monthly mean, and mean monthly discharge at Crosswicks Creek at Extonville, N.J. (01464500), water years 1941-51 and 1953-96.

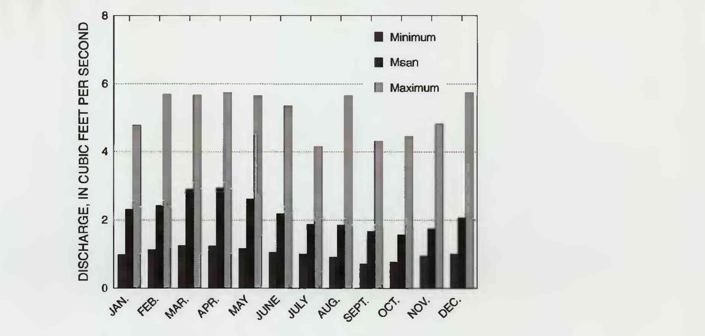


Figure 3-4. Minimum and maximum monthly mean, and mean monthly discharge at McDonalds Branch in Lebanon State Forest, N.J. (01466500), water years 1954-96.

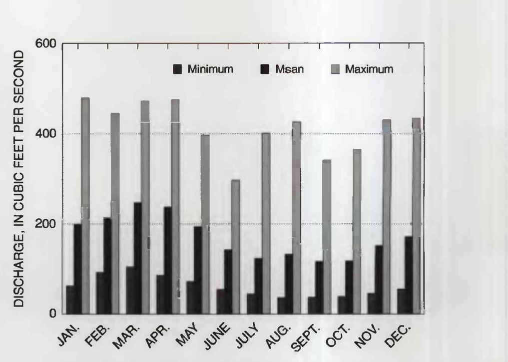


Figure 3-5. Minimum and maximum monthly mean, and mean monthly discharge at North Branch Rancocas Creek at Pemberton, N.J. (01467000), water years 1922-96.

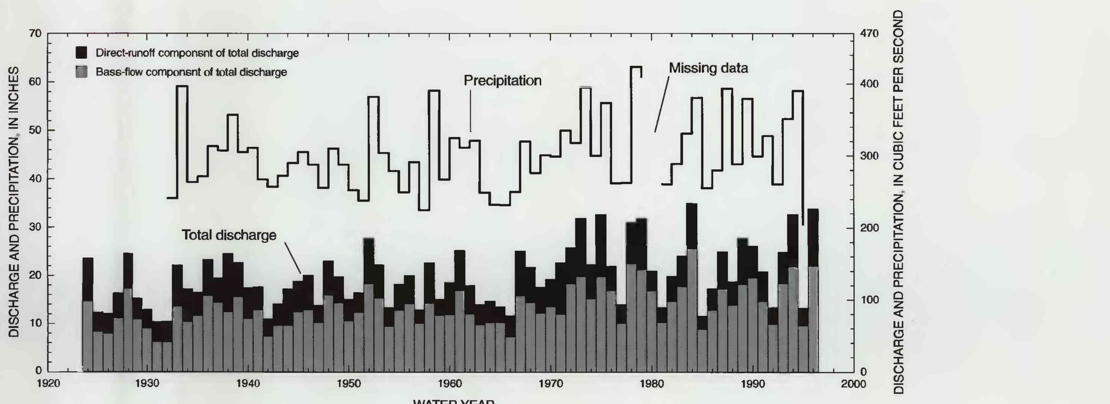


Figure 3-6. Average of total annual precipitation at Pemberton, N.J., and Moorestown, N.J., weather stations, water years 1932-95, and total discharge, base flow, and direct runoff at Assunpink Creek at Trenton, N.J. (01464000), water years 1924-96. (Precipitation data from National Climate Data Center, unpublished data accessed April 24, 1995, on the World Wide Web at URL http://www.ncdc.noaa.gov/ol/climate/online/coop-prec.html)

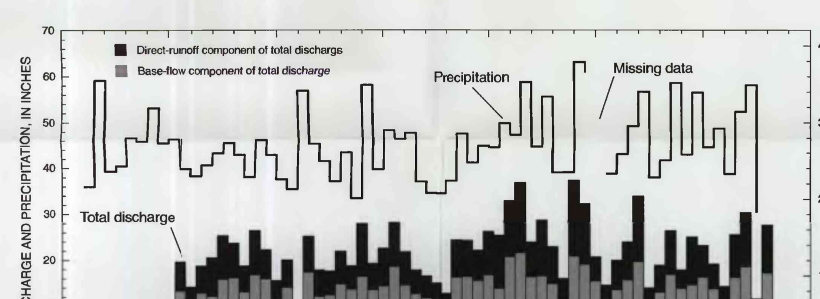


Figure 3-7. Average of total annual precipitation at Pemberton, N.J., and Moorestown, N.J., weather stations, water years 1932-95, and total discharge, base flow, and direct runoff at Crosswicks Creek at Extonville, N.J. (01464500), water years 1941-51 and 1953-96. (Precipitation data from National Climate Data Center, unpublished data accessed April 24, 1995, on the World Wide Web at URL http://www.ncdc.noaa.gov/ol/climate/online/coop-prec.html)

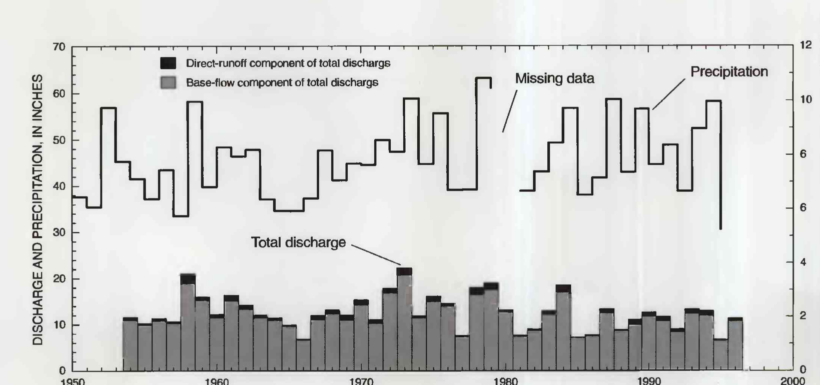


Figure 3-8. Average of total annual precipitation at Pemberton, N.J., and Moorestown, N.J., weather stations, water years 1950-95, and total discharge, base flow, and direct runoff at McDonalds Branch in Lebanon State Forest, N.J. (01466500), water years 1954-96. (Precipitation data from National Climate Data Center, unpublished data accessed April 24, 1995, on the World Wide Web at URL http://www.ncdc.noaa.gov/ol/climate/online/coop-prec.html)

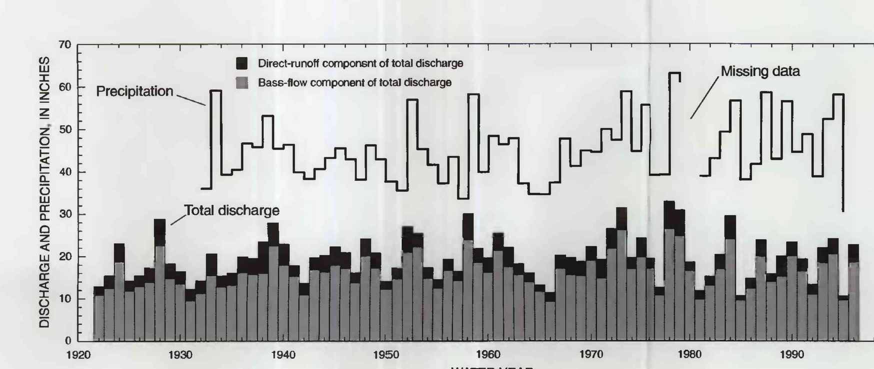


Figure 3-9. Average of total annual precipitation at Pemberton, N.J., and Moorestown, N.J., weather stations, water years 1932-95, and total discharge, base flow, and direct runoff at North Branch Rancocas Creek at Pemberton, N.J. (01467000), water years 1922-96. (Precipitation data from National Climate Data Center, unpublished data accessed April 24, 1995, on the World Wide Web at URL http://www.ncdc.noaa.gov/ol/climate/online/coop-prec.html)

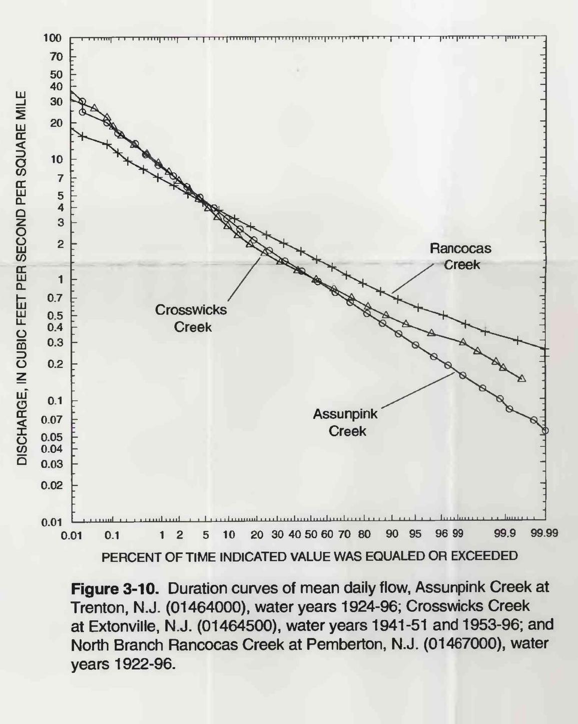


Figure 3-10. Duration curves of mean daily flow, Assunpink Creek at Trenton, N.J. (01464000), water years 1924-96; Crosswicks Creek at Extonville, N.J. (01464500), water years 1941-51 and 1953-96; and North Branch Rancocas Creek at Pemberton, N.J. (01467000), water years 1922-96.

QI - Discharge, measured in cubic feet per second, at index gaging station Crosswicks Creek at Extonville, N.J. (01464500)

QP_M - Discharge, measured in cubic feet per second, at partial-record station Miry Run at Holmes Mills, N.J. (01464480)

DATE	QI	QP_M
07/18/66	25	0.72
09/17/69	65	2.76
04/30/70	132	5.01
09/02/70	55	1.66
04/05/71	98	2.96
04/12/72	113	4.31
09/07/72	47	1.64
05/08/73	133	5.79
10/11/73	37	1.25

A low-flow correlation was made by correlating low-flow discharge at the partial-record station with discharge at the index station.

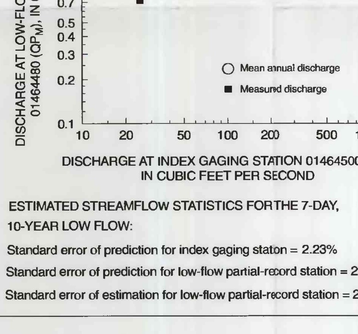
CORRELATION COEFFICIENT: 0.9849

EQUATION OF "BEST-FIT" LINE DRAWN THROUGH DATA:

$QP_R = (0.01723)\ QI^{(1.1694)}$, where

QI = Discharge at index gaging station and

QP_R = Predicted discharge at low-flow partial-record station



ESTIMATED STREAMFLOW STATISTICS FOR THE 7-DAY, 10-YEAR LOW FLOW:

Standard error of prediction for index gaging station = 2.23%

Standard error of prediction for low-flow partial-record station = 2%

Standard error of estimation for low-flow partial-record station = 2%

Figure 3-11. Low-flow correlation of discharge at Miry Run at Holmes Mills, N.J., partial-record station (01464480) with discharge at Crosswicks Creek at Extonville, N.J., index-gaging station (01464500).

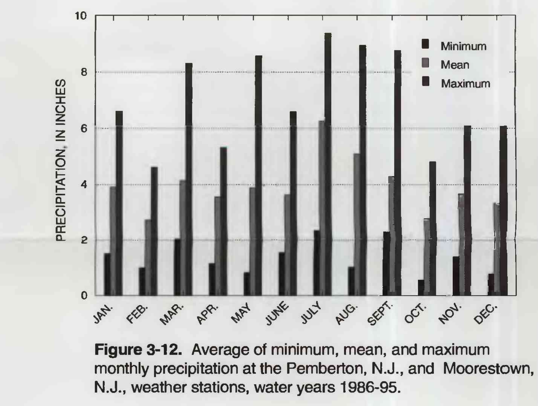


Figure 3-12. Average of minimum, mean, and maximum monthly precipitation at the Pemberton, N.J., and Moorestown, N.J., weather stations, water years 1986-95.

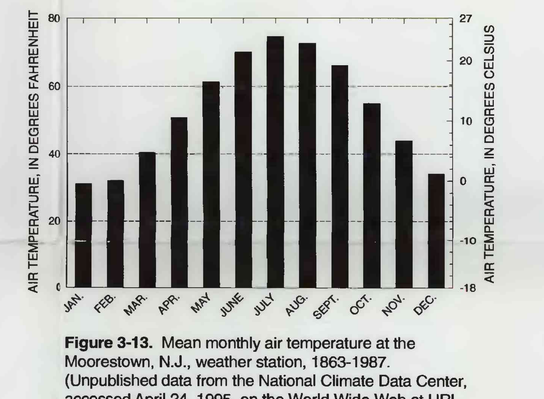


Figure 3-13. Mean monthly air temperature at the Moorestown, N.J., weather station, 1863-1987. (Unpublished data from the National Climate Data Center, accessed April 24, 1995, on the World Wide Web at URL http://www.ncdc.noaa.gov/ol/climate/online/coop-precip.html)

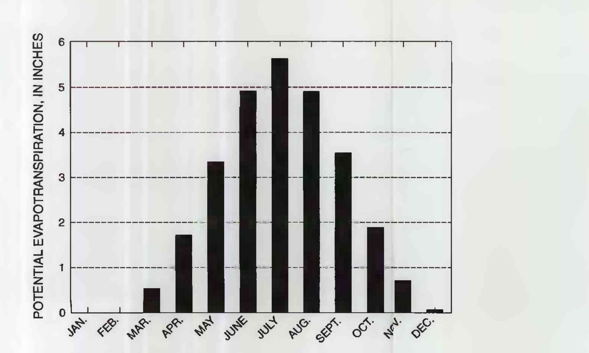


Figure 3-14. Mean monthly potential evapotranspiration for the Moorestown, N.J., weather station, water years 1863-1987.

HYDROLOGY OF THE UNCONFINED AQUIFER SYSTEM, RANCOCAS CREEK AREA: RANCOCAS, CROSSWICKS, ASSUNPINK, ASSISCUNK, BLACKS, AND CRAFTS CREEK BASINS, NEW JERSEY, 1996

by
Martha K. Watt, Allen C. Kane, Emmanuel G. Charles, and Donald A. Storck

2003