Surface-water discharge in the study area is described in the first part of this sheet. Discharge values, divided into base-flow and direct-runoff components, from two continuous-record streamflow-gaging stations and a flow-duration curve are presented. Values for base flow; average discharge; and 7-day, 10-year and 30-day, 5-year low-flow discharges are calculated by using low-flow correlations for seven low-flow partial-record stations. The second part of this sheet shows the relation of precipitation to discharge and evapotranspiration.

SURFACE WATER

The surface-water system in the study area consists of the Metedeconk River, the Toms River, Kettle Creek, numerous tributaries, manmade lakes, and wetland areas. Nearly all the surface-water bodies are interpreted to be ground-water discharge areas; the only exceptions are some of the manmade lakes, in which water levels are artificially elevated, making them ground-water recharge areas.

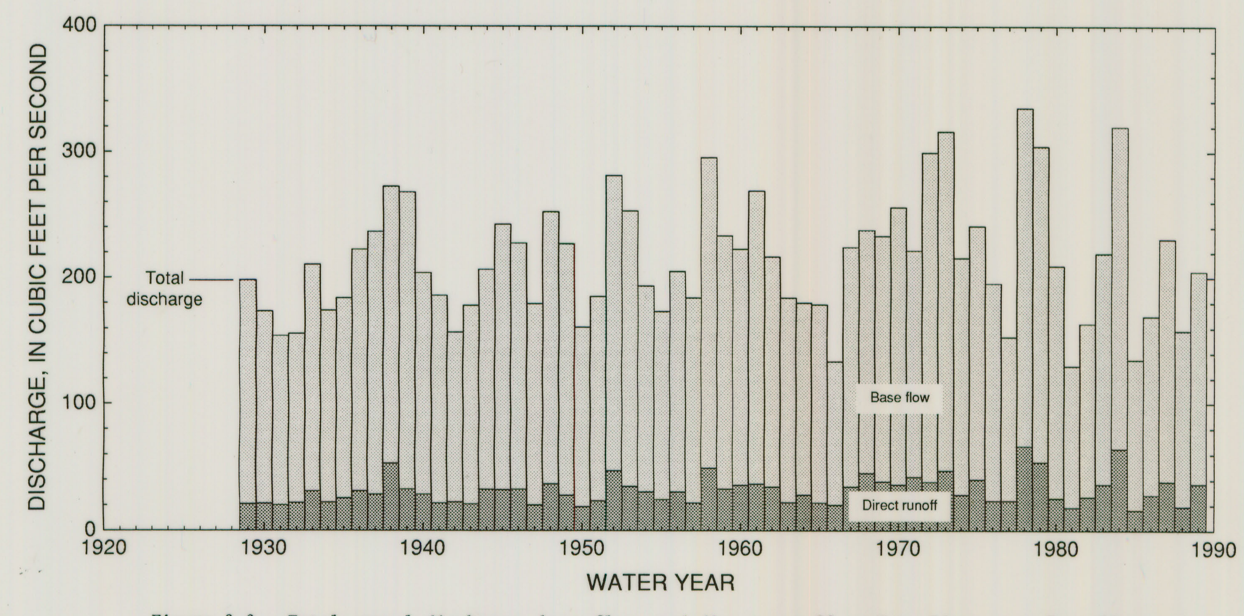


Figure 3-2.--Total annual discharge, base flow, and direct runoff at Toms River near Toms River, N.J. (01408500), 1929-89.

Discharge at Streamflow-Gaging Stations

The USGS has maintained a streamflow-gaging station at Toms River near Toms River, N.J. (01408500), since 1929, and another at North Branch Metedeconk River near Lakewood, N.J. (01408120), since 1973 (fig. 3-1). Annual discharge at these gaging stations is shown in figures 3-2 and 3-3, respectively. The annual discharge is separated into two components, base flow and direct runoff. Base flow, the larger component of annual discharge, consists of ground water that is discharged into the stream. The smaller component of discharge, direct runoff, consists of overland runoff and precipitation that falls directly on the stream. Base flow and direct runoff were determined by means of a computerized base-flow-separation technique described by Pettyjohn and Henning (1979) and adapted for use by the USGS by Sloto (1988). The computer program can be used to generate estimates of base flow and direct runoff by three different methods. The method used in this study area is the sliding-interval analysis.

The annual base flow of the Toms River near Toms River ranged from a low of 112 ft^3/s in 1981 to a high of 269 ft^3/s in 1973, with a mean of 182 ft^3/s (fig. 3-2). In percentages, the base-flow component ranged from 80 to 89 percent of total annual flow, with a mean of 85 percent. The annual base flow of the North Branch Metedeconk River near Lakewood, N.J., ranged from a low of 26 ft^3/s in 1981 to a high of 63 ft^3/s in 1978, with a mean of 44 ft^3/s (fig. 3-3). Base flow as a percentage of total annual flow ranged from 63 to 79 percent, with a mean of 71 percent. The base-flow component of streamflow in both streams consists of ground water from the Kirkwood-Cohansey aquifer system.

The minimum mean, mean, and maximum mean monthly discharges at the two streamflow-gaging stations are shown in figures 3-4 and 3-5. Minimum and maximum discharges are caused primarily by severe droughts and extremely high precipitation, respectively. Table 3-1 lists the minimum, mean, and maximum daily discharge for the period of record at four streamflow-gaging stations: Toms River near Toms River (01408500); Manasquan River at Squankum (01408000), north of the study area; Crosswicks Creek at Extonville (01464500); and North Branch Rancocas Creek at Pemberton (01467000). The latter two stations are west of the study area. Because of the short period of record at North Branch Metedeconk River near Lakewood (01408120), discharge values for this streamflow-gaging station are based on low-flow calculations (see below) and are not included in table 3-1. Stations outside the boundary of the study area are included in this table because they were used as index stations in the low-flow correlation analyses.

Figure 3-6 is a flow-duration curve of discharge at the Toms River near Toms River streamflow-gaging station for 1929-89. A flow-duration curve is a cumulative-frequency curve showing the percentage of time that any specified discharge is equaled or exceeded (Langbein and Iseri, 1960, p. 11). The shape of this curve can be used to determine certain flow characteristics of the stream. For example, a curve with a flat slope reveals the presence of substantial ground-water and surface-water storage, which tends to equalize the flow, whereas a steep curve indicates a stream whose flow is derived largely from direct runoff, and therefore is more variable. The median discharge at the Toms River near Toms River streamflow-gaging station is about 187 ft^3/s, the 1-percent-exceedance discharge is 640 ft^3/s, and the 99-percent-exceedance discharge is 67 ft^3/s (fig. 3-6).

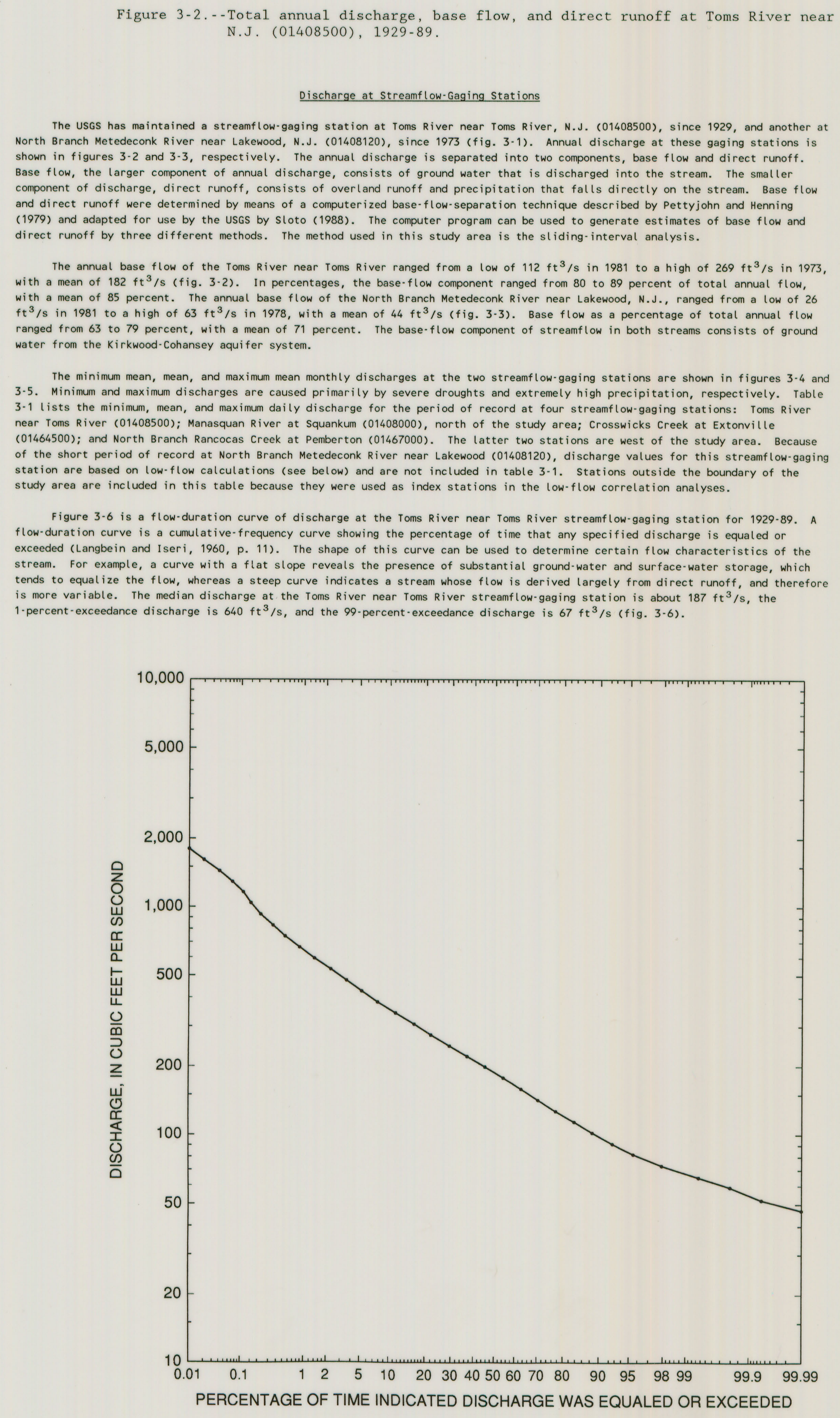
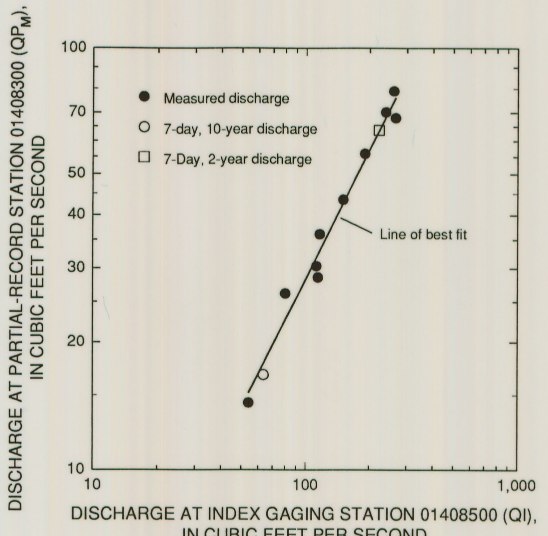


Figure 3-6.--Duration curve of daily flow, Toms River near Toms River, N.J. (01408500), 1929-89.

QI - Discharge, measured in cubic feet per second, at index gaging station Toms River near Toms River, N.J. (01408500)

QP_M - Discharge, measured in cubic feet per second, at partial-record station Toms River at Whitesville, N.J. (01408300)

DATE	QI	QP_M
05/06/1959	190	56.0
09/11/1959	114	28.6
04/19/1960	238	70.3
09/07/1960	112	30.4
05/25/1961	265	68.1
09/08/1961	116	36.1
03/29/1962	260	79.0
10/24/1962	150	43.6
08/30/1963	80	26.2
08/11/1966	54	14.4



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

CORRELATION COEFFICIENT: 0.9869

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

$$QP_R = 0.26249\ QI^{(1.0173)}$$

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 = 2.68%
Standard error of prediction for low-flow partial-record station = 1.22%
Standard error of estimation for low-flow partial-record station = 1.93%

Figure 3-7.--Low-flow correlation of the Toms River near Toms River, N.J., streamflow gaging station (01408500) with the Toms River at Whitesville, N.J., low-flow partial-record station (01408300).

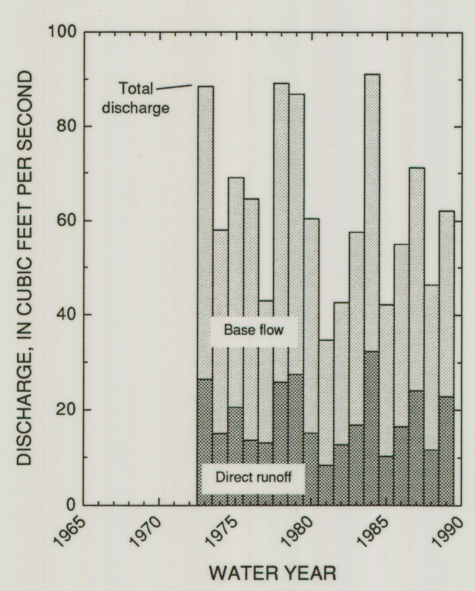


Figure 3-3.--Total annual discharge, base flow, and direct runoff at North Branch Metedeconk River near Lakewood, N.J. (01408120), 1973-89.

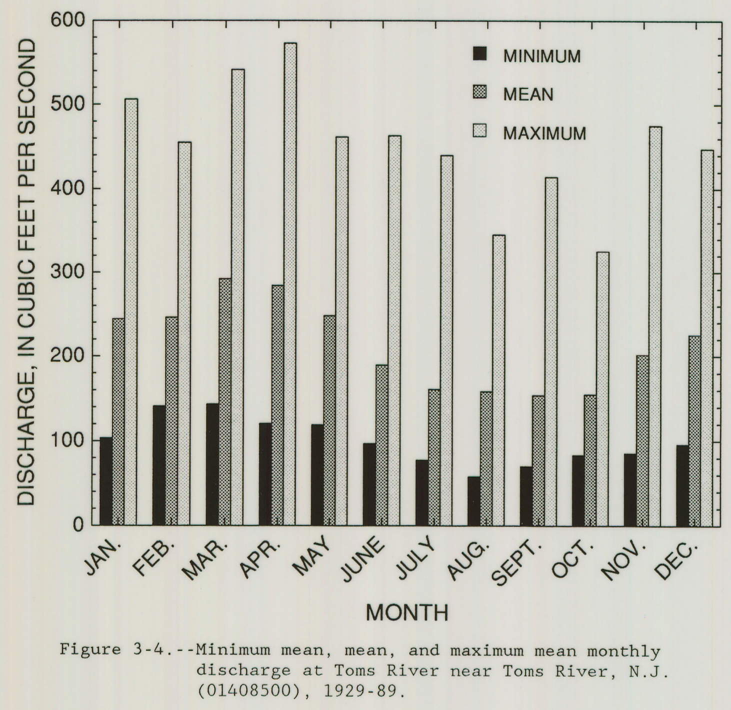


Figure 3-4.--Minimum mean, mean, and maximum mean monthly discharge at Toms River near Toms River, N.J. (01408500), 1929-89.

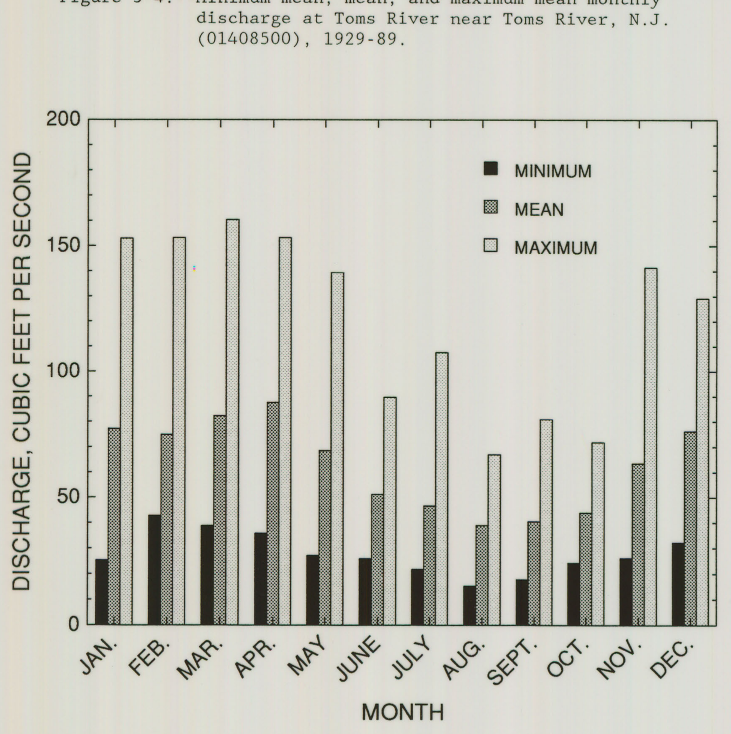


Figure 3-5.--Minimum mean, mean, and maximum mean monthly discharge at North Branch Metedeconk River near Lakewood, N.J. (01408120), 1973-89.

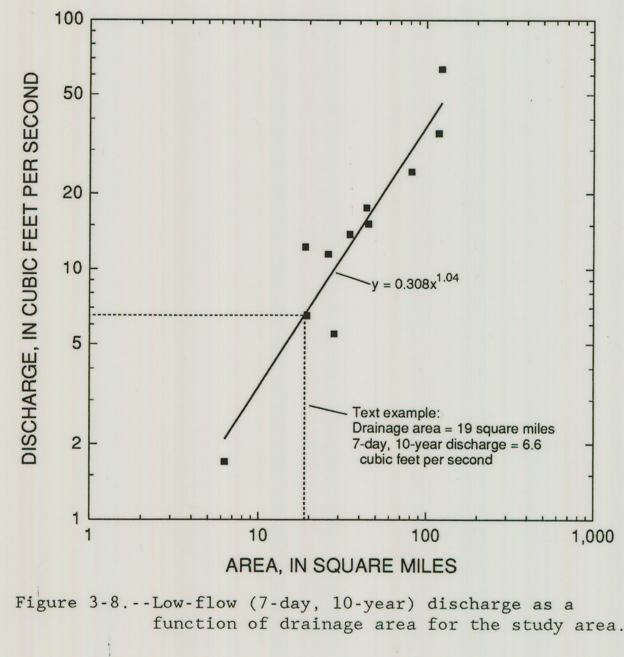


Figure 3-8.--Low-flow (7-day, 10-year) discharge as a function of drainage area for the study area.

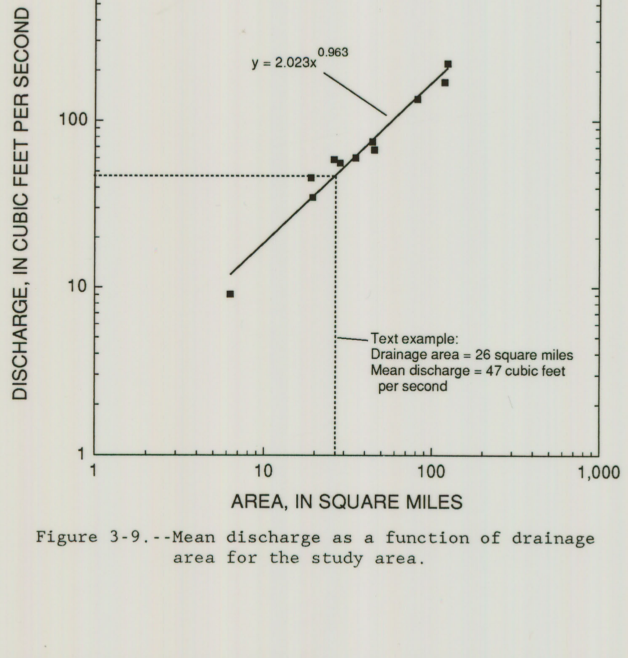


Figure 3-9.--Mean discharge as a function of drainage area for the study area.

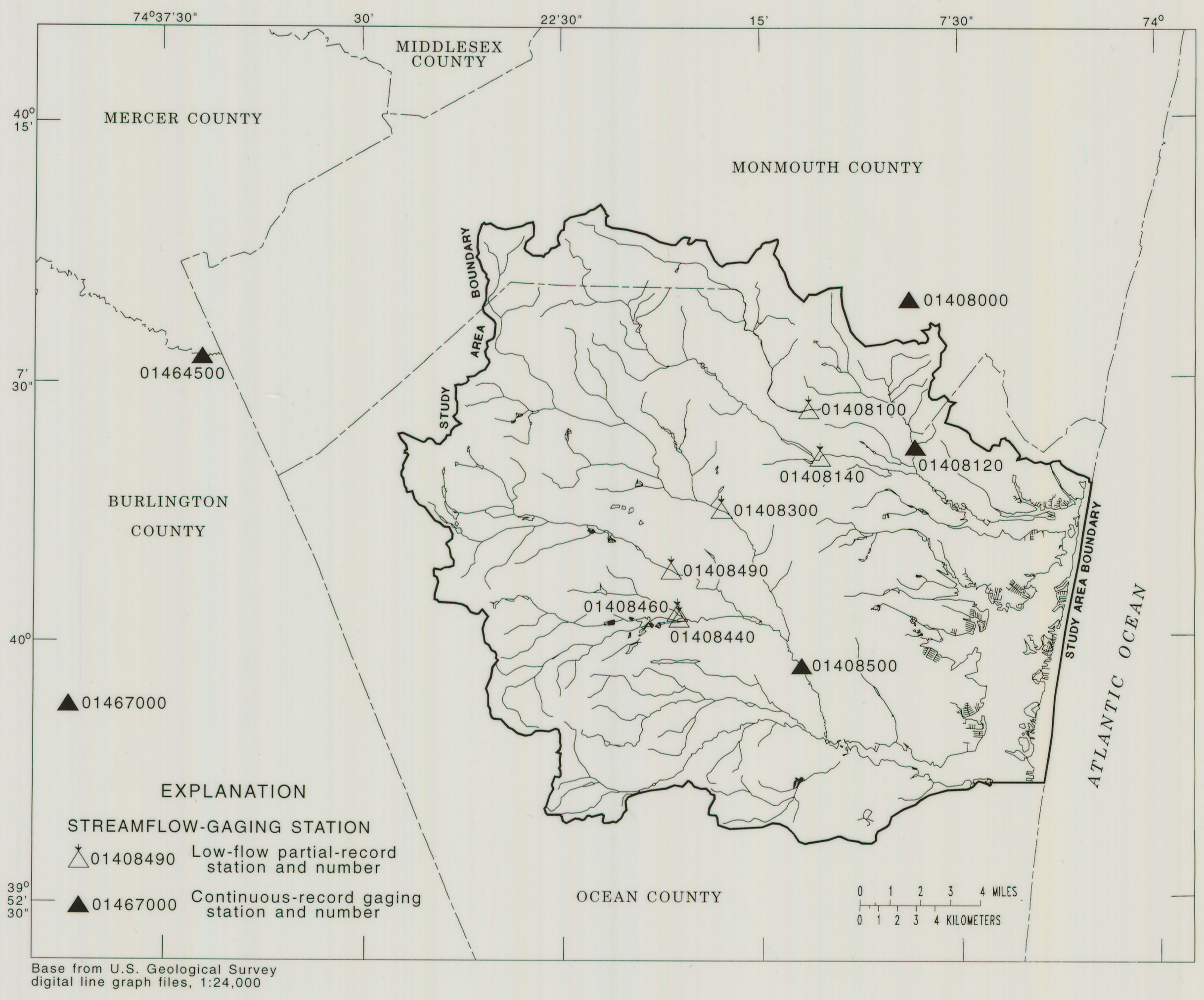


Figure 3-1.--Locations of continuous-record streamflow-gaging stations and low-flow partial-record stations in and near the study area.

Discharge at Low-Flow Partial-Record Stations

Low-flow correlations were performed for seven low-flow partial-record stations in the study area. Each low-flow correlation was made by correlating instantaneous low-flow discharge at the partial-record site with the concurrent mean daily discharge at one streamflow-gaging station, or index station. The low-flow correlations were developed by using the MOVE.1 (Maintenance of Variance Extension, Type 1) method, which is suggested for use in low-flow correlations. MOVE.1 makes use of geometric means to eliminate the bias inherent in ordinary-least-squares regression (Hirsch, 1982). Three low-flow correlations were calculated for each site, each with a different index station, and the results were compared for discrepancies to minimize error. Of the four index stations initially selected, one is within the study area (Toms River near Toms River, N.J., 01408500). Three streamflow-gaging stations outside the study area but in a similar hydrologic setting to that of the study area and for which a long period of record was available also were selected as index stations; one is north (Manasquan River at Squankum, N.J., 01408000) and the other two are west (Crosswicks Creek at Extonville, N.J., 01464500, and North Branch Rancocas Creek at Pemberton, N.J., 01467000) of the study area. For each low-flow partial-record site, the three index stations for which the correlation coefficients were highest were selected for use in the low-flow correlation analysis.

An example of a low-flow correlation is given in figure 3-7. The equation of the "best-fit" line drawn through the plot of discharge data for the Toms River near Toms River (01408500) index gaging station against discharge data for the Toms River at Whitesville (01408300) partial-record station is $QP = (0.26249)\ QI^{(1.0173)}$, where QP is the "predicted" discharge at the partial-record station and QI is the observed discharge at the index station. This equation can be used to estimate the discharge at the Toms River at Whitesville partial-record station from known low or medium discharge at the Toms River near Toms River index station. Low-flow-correlation analyses for each partial-record station were run with the three index gaging stations to calculate mean discharge; 30-day, 5-year and 7-day, 10-year low-flow discharges; and mean base flow. The results are shown in table 3-2. Two statistical indicators, the correlation coefficient and the standard error of estimation, are included in table 3-2 as an indication of the accuracy of the predicted discharge. The correlation coefficient measures the strength of the linear relation between the logarithms (base 10) of the discharge at the low-flow partial-record station and that at the index station. The nearer the correlation coefficient is to 1.0, the more reliable the predicted discharge, QP. Although the correlation coefficient typically is used to describe the linear strength of ordinary-least-square 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 by using an equation developed specifically for MOVE.1 low-flow correlations by Thomas (Telis, 1991). This equation allows the standard error of estimation to be calculated from the standard error of prediction and the time-sampling error for the index station. The nearer the value (which is a percent) is to zero, the more reliable the predicted discharge, QP. This indicator of reliability is calculated only for the 7-day, 10-year low flow but also is a useful measure of reliability for other MOVE.1-predicted discharges (R.G. Reiser, U.S. Geological Survey, oral commun., 1994).

An example of the use of a low-flow-correlation equation is given below:

To convert the graph of the annual discharge at Toms River near Toms River, N.J. (01408500) (fig. 3-2), to a graph of the annual discharge at North Branch Metedeconk River at Lakewood, N.J. (01408100), use the low-flow-correlation equation for the stations given in table 3-2. The equation is

$$QP_R = 0.07125\ QI^{(1.1075)} .$$

QP_R, the range of discharges of North Branch Metedeconk River at Lakewood, can be calculated by substituting various discharge values at Toms River near Toms River (25, 50, 75....) from figure 3-2 for QI in the above equation. Therefore, when QI = 25 ft^3/s,

$$QP_R = 0.07125\ (25)^{(1.1075)},\ \text{and}$$

$$QP_R = 2.5\ ft^3/s .$$

In this manner, the discharge data in figure 3-2 can be used to calculate predicted discharges at North Branch Metedeconk River at Lakewood.

In addition to the low-flow-correlation analyses, estimates of mean base flow for each of the partial-record stations are included in table 3-2. These estimates were calculated from mean annual base flow at the Toms River near Toms River streamflow-gaging station by using the low-flow-correlation equation for each station.

Figure 3-8 is a plot of the 7-day, 10-year low-flow values for the 11 surface-water stations listed in tables 3-1 and 3-2 against their respective drainage areas. The line drawn through the data points is a "best-fit" line that is based on the low-flow values from gaging stations and partial-record stations in and near the study area. This plot can be used to estimate the 7-day, 10-year low-flow values for ungaged streams in basins for which the size of the drainage area is known. For example, the 7-day, 10-year low flow of a stream draining a 19-mi^2 basin would be about 6.6 ft^3/s.

The mean discharge of any tributary of the Toms or Metedeconk River can be calculated in a similar manner. The relation between mean discharge and drainage area can be derived from a plot of the mean discharge against drainage area of the same 11 surface-water stations (fig. 3-9). According to figure 3-9, the mean discharge of a stream that drains an area of about 26 mi^2 would be about 47 ft^3/s.

Table 3-1.--Summary statistics for discharge data from continuous-record streamflow-gaging stations in and near the study area

Streamflow gaging-station number	Streamflow gaging-station name	Drainage area (square miles)	Period of record	Period of record used for statistical analysis[2]	Discharge (cubic feet per second): 30-day, 5-year	7-day, 10-year	Minimum daily mean	Mean	Maximum daily mean
01408000	Manasquan River at Squankum, N.J.[1]	44.0	July 1931 - Sept. 1991	April 1932 - March 1990	22.4	17.6	14	75.3	1,720
01408500	Toms River near Toms River, N.J.	123	Oct. 1928 - Sept. 1991	April 1967 - March 1990	78.8	63.4	47	221	1,910
01464500	Crosswicks Creek at Extonville, N.J.[3]	81.5	Aug. 1940 - Oct. 1951, Oct. 1952 - Sept. 1991	April 1941 - March 1951, April 1953 - March 1990	34.1	24.5	16	135	3,930
01467000	North Branch Rancocas Creek at Pemberton, N.J.[3]	118	Sept. 1921 - Sept. 1991	April 1922 - March 1990	49.9	35.1	9.0	171	1,690

[1] North of study area
[2] Low-flow statistics were calculated by using data for the climatic year. The climatic year is the 12-month period from April 1 through March 30, and is designated by the calendar year in which it begins. This period allows the low-water season to occur entirely in 1 year.
3 West of study area

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

[QP_R, predicted discharge; QI, index-station discharge; --, not calculated]

Low-flow partial-record station number	Low-flow partial-record station name	Drainage area, in square miles	Index-gaging station number	Number of measurements used in analysis	Correlation coefficient	Standard error of estimation for 7-day 10-year low-flow discharge (percent)[1]	Correlation equation	Predicted discharge (QP_R) (cubic feet per second): 30-day, 5-year QP_R	7-day, 10-year QP_R	Mean annual QP_R	Mean base flow
01408100	North Branch	19.4	01408000	10	0.9671	4.22	$QP_R = 0.32596\ QI^{(1.0783)}$	9.3	7.2	34.4	--
	Metedeconk River		01408500	10	.9498	5.32	$QP_R = .07125\ QI^{(1.1075)}$	9.0	6.6	28.1	22.7
	at Lakewood, N.J.		01464500	10	.9463	6.65	$QP_R = .12224\ QI^{(1.1922)}$	8.2	5.6	42.4	--
01408120	North Branch	34.9	01408000	85	.9373	7.61	$QP_R = .64536\ QI^{(1.0532)}$	17.1	13.3	61.2	--
	Metedeconk River		01408500	95	.9265	7.69	$QP_R = .23218\ QI^{(1.0141)}$	19.5	14.7	55.4	45.5
	near Lakewood, N.J.		01464500	73	.8768	12.56	$QP_R = .69475\ QI^{(0.9252)}$	18.2	13.4	65.0	--
01408140	South Branch	26.0	01408000	14	.9293	11.50	$QP_R = .19878\ QI^{(1.3207)}$	12.1	8.8	59.8	--
	Metedeconk River		01408500	18	.9551	5.68	$QP_R = .17072\ QI^{(1.06)}$	17.5	13.0	52.2	42.5
	at Lakewood, N.J.		01464500	12	.8737	10.77	$QP_R = .59733\ QI^{(0.9566)}$	17.5	12.8	65.2	--
01408300	Toms River at	45.2	01408000	10	.9559	6.22	$QP_R = .73811\ QI^{(1.0821)}$	21.3	16.5	79.2	--
	Whitesville, N.J.		01408500	10	.9869	1.93	$QP_R = .26249\ QI^{(1.0173)}$	22.3	16.8	63.7	52.3
			01467000	10	.9831	4.15	$QP_R = .34378\ QI^{(1.0038)}$	17.4	12.2	59.9	--
01408440	Union Branch at	19.0	01408000	9	.9577	5.44	$QP_R = .86739\ QI^{(0.9463)}$	16.4	13.1	51.8	--
	Lakehurst, N.J.		01408500	9	.9632	3.78	$QP_R = .24391\ QI^{(0.9633)}$	16.4	12.5	44.2	36.7
			01467000	9	.9326	7.76	$QP_R = .62521\ QI^{(0.8166)}$	15.2	11.4	41.6	--
01408460	Manapaqua Brook at	6.3	01408000	9	.9491	6.45	$QP_R = .05119\ QI^{(1.2358)}$	2.4	1.8	10.7	--
	Lakehurst, N.J.		01408500	9	.9460	7.08	$QP_R = .00977\ QI^{(1.2579)}$	2.4	1.7	8.7	6.8
			01467000	9	.9315	9.82	$QP_R = .03338\ QI^{(1.0664)}$	2.2	1.5	8.0	--
01408490	Ridgeway Branch near	28.2	01408500	9	.9873	2.26	$QP_R = .01608\ QI^{(1.4751)}$	10.1	6.7	46.2	34.7
	Lakehurst, N.J.		01464500	9	.9589	7.75	$QP_R = .02409\ QI^{(1.6556)}$	8.3	4.8	81.1	--
			01467000	9	.9578	8.21	$QP_R = .03945\ QI^{(1.3547)}$	7.9	4.9	41.8	--

[1] Calculated for the 7-day, 10-year low-flow discharge by using an equation developed specifically for MOVE.1 low-flow correlations by Thomas (Telis, 1991). This indicator of reliability is calculated only for the 7-day, 10-year low flow but also is a useful measure of reliability for other MOVE.1-predicted discharges (R.G. Reiser, U.S. Geological Survey, oral commun., 1994).

RELATION OF PRECIPITATION TO DISCHARGE AND EVAPOTRANSPIRATION

Precipitation is the principal source of water in the study area. Stream discharge and evapotranspiration account for the largest percentage loss of water from the hydrologic system. Figure 3-10 is a plot for water years 1932-89 that shows annual precipitation at the Toms River weather station (National Oceanic and Atmospheric Administration, 1928-89) (fig. 2-2) and the discharge of Toms River near Toms River. The figure illustrates that nearly half the precipitation that falls in the study area becomes stream discharge.

Annual precipitation for the period of record ranged from a minimum of 34.0 inches in water year 1957 to a maximum of 73.6 inches in water year 1958, with a mean of 47.3 inches. Minimum, mean, and maximum monthly precipitation values at Toms River for calendar years 1931 through 1989 are given in figure 3-11. The mean monthly precipitation during this period was 3.9 inches, ranging from a minimum of 0.0 inch in June, August, and September to a maximum of 13.0 inches in July.

A large percentage of the water that enters the study area leaves through stream discharge and evapotranspiration. The annual discharge at Toms River near Toms River during 1929-89 ranged from a minimum of 14.32 inches in 1981 to a maximum of 36.97 inches in 1978. The mean annual discharge was 23.58 inches per year, or about 50 percent of the mean annual precipitation that fell on the basin. Figure 3-12 shows the minimum, mean, and maximum monthly air temperature at the Toms River weather station during 1980-89. The mean monthly air temperature, latitude, and month were used in the Thornthwaite equation to estimate potential evapotranspiration (fig. 3-13) (Dunne and Leopold, 1978, p. 137-138). Calculated annual potential evapotranspiration from the study area for 1980-89 was 27.0 inches. Potential evapotranspiration is the amount of water loss that occurs if there is at no time a deficiency of water in the soil for the vegetation to use. Actual annual evapotranspiration is less than the potential evapotranspiration and, therefore, accounts for a smaller percentage of mean annual precipitation. Actual evapotranspiration is estimated in the "Water Budget" section on Sheet 5.

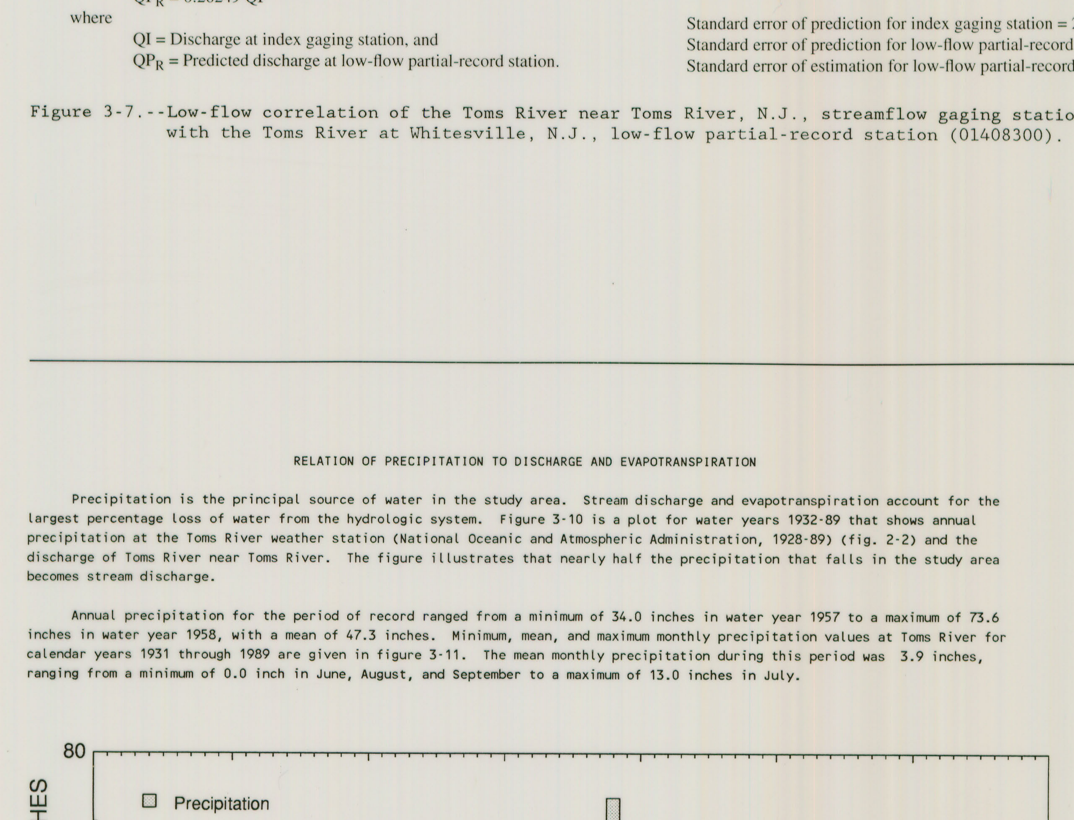


Figure 3-10.--Annual precipitation at the Toms River weather station (National Oceanic and Atmospheric Administration, 1928-89), and total discharge at Toms River near Toms River, N.J. (01408500), in inches, water years 1929-89. (Total discharge is separated into base flow and direct runoff.)

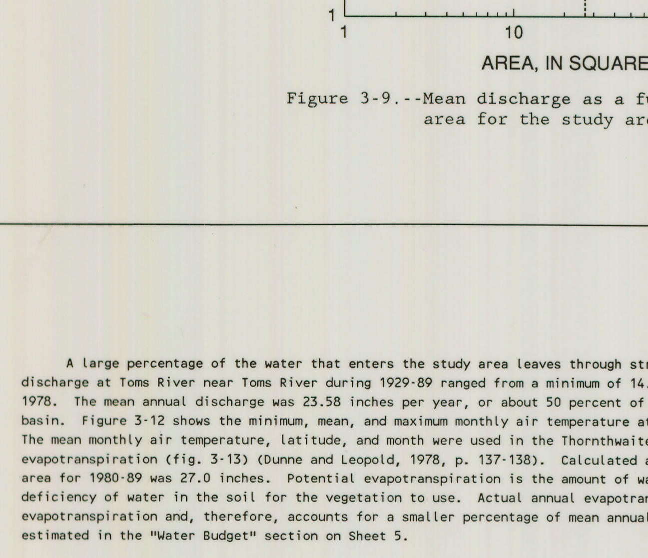


Figure 3-11.--Minimum, mean, and maximum monthly precipitation at the Toms River weather station, N.J., 1931-89 (National Oceanic and Atmospheric Administration, 1928-89).

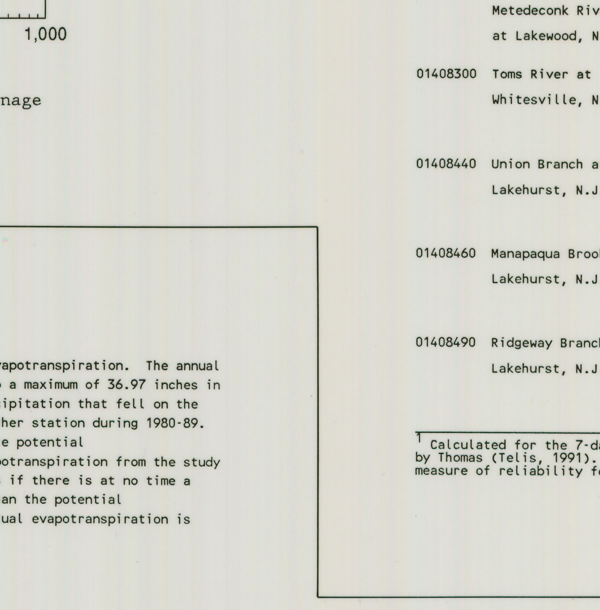


Figure 3-12.--Minimum mean, mean, and maximum mean monthly air temperature at the Toms River weather station, N.J., 1980-89 (National Oceanic and Atmospheric Administration, 1928-89).

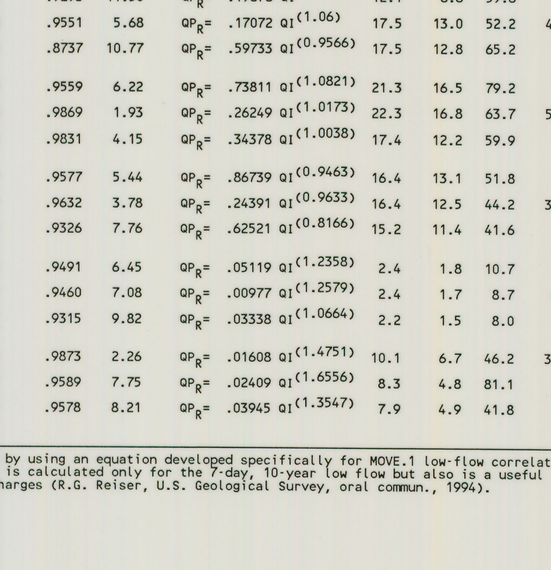


Figure 3-13.--Monthly potential evapotranspiration at Toms River, N.J.

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

HYDROLOGY OF THE UNCONFINED AQUIFER SYSTEM, TOMS RIVER, METEDECONK RIVER, AND KETTLE CREEK BASINS, NEW JERSEY, 1987-90

By
Martha K. Watt, Melissa L. Johnson, and Pierre J. Lacombe

1994