POPULATION AND WATER USE

The first part of this sheet presents information on water use and the population in the study area. Population statistics and population growth are discussed. Water-use data are compiled and estimates are made of the quantity of water withdrawn from the Kirkwood-Cohansey aquifer system and consumed by the population. The second part of this sheet presents two water budgets of the area compiled from the water-use and discharge information as well as precipitation and evapotranspiration data in order to estimate ground-water recharge.

Population

The estimated total population of the study area for each decennial census since 1930 and from provisional estimates made for 1988 is shown in figure 5-1. Population was estimated by taking a percentage of the reported population of each municipality equal to the percentage of land in the study area occupied by that municipality. The population is assumed to be evenly distributed. Table 5-1 lists the population and area of each municipality in the study area and the total estimated population of the study area.

The high rate of population growth in the study area since 1950 is a result of several factors. The growth rate of Ocean County increased in the 1950's and 1960's with the opening of the Garden State Parkway in 1955, increased automobile ownership, and the availability of inexpensive real estate. A statewide trend of population shift from industrialized, urban areas to rural and exurban areas, such as Ocean County, caused the high rate of population growth to continue into the 1970's and 1980's. This trend is expected to continue in the 1990's. (See New Jersey Department of Labor, 1984, p. iii-iv.)

Water Use

Water-use statistics for the study area are presented below. Reported values for 1988 are used to estimate annual withdrawals of water for public- and self-supplied domestic use, irrigation, industrial use, and mining. From these estimates, the consumptive use of water (that part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment (Solley and others, 1988, p.v)) in each category can be calculated and totaled for use in a water budget for the study area.

Public Supply

Although public-supply systems commonly provide water for both domestic and industrial users, public supply in this report is considered to be only water used for domestic purposes. In New Jersey more than 75 percent of public-supply water is allotted for domestic supply (Carr and others, 1990, p. 372). Reported annual public-supply withdrawals from the Kirkwood-Cohansey aquifer system in the study area from 1975 through 1988 are listed in table 5-2. The small amount of surface water used for public supply also is listed. Municipalities that do not withdraw any public-supply water from the Kirkwood-Cohansey aquifer system are not shown. A total of 5,389 Mgal of ground water from the Kirkwood-Cohansey aquifer system and 644 Mgal of surface water reportedly were withdrawn for public supply in 1988 (U.S. Geological Survey Site-Specific Water Use Data System, unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.).

Solley and others (1988, p. 17) estimate that about 18 percent of the domestic water used in New Jersey is consumed. Domestic wastewater in the study area, however, is treated and released into the ocean, resulting in 100 percent consumptive use. Consumptive use of the ground-water withdrawals from the Kirkwood-Cohansey aquifer system in the study area for public-supplied domestic purposes is about 5,400 Mgal, or about 0.92 inch, of water per year over the study area. Consumptive use of surface water for these purposes is about 640 Mgal, or about 0.11 inch, of water per year over the study area.

Domestic Self-Supply

Estimation of self-supplied domestic water use is difficult because withdrawals are not reported to any public agency. One way to estimate the volume of water withdrawn by individual users is to estimate the domestic population of the study area and to subtract the amount of water available from public suppliers. In a large part of the study area, however, the population undergoes a large seasonal change as a result of the influx of vacationers to the beach resorts. Domestic water use in the study area can be approximated without population data by estimating the volume of freshwater consumed from the total amount of wastewater produced in the study area. After accounting for the percentage of the population that is not served by sanitary sewers, the volume of freshwater that is self-supplied can be estimated. Total withdrawals from the Kirkwood-Cohansey aquifer system consumed for self-supplied domestic use in the study area are about 440 Mgal, or about 0.075 inch, of water per year over the study area.

Irrigation

Reported values of water use for irrigation are limited, but estimates have been made from the amount of irrigated land in the study area and are listed in table 5-3. The amount of irrigated land in each municipality was compiled by the New Jersey Agricultural Statistics Service (James Gibson, written commun., 1987) and is assumed to be evenly distributed throughout the study area. Municipalities with no reported irrigated land are omitted from the table. The New Jersey Department of Agriculture estimates that about 8 inches of water per year are required for irrigation (M. Ferdows Ali, New Jersey Department of Agriculture, written commun., 1988). Annual irrigation water use calculated from the available data is listed in the last column on table 5-3.

Roughly half of the water used for irrigation in the State of New Jersey originates from surface-water sources and the other half is derived from ground-water sources (Carr and others, 1990, p. 372). Most of the ground water used for irrigation in the study area is pumped from shallow wells in the Kirkwood-Cohansey aquifer system. A total of about 140 Mgal is withdrawn annually--70 Mgal from surface water and 70 Mgal from ground water (table 5-3). In New Jersey, about 90 percent of the water used for irrigation is consumed (Solley and others, 1988, p. 25); therefore, consumptive use of water from the Kirkwood-Cohansey aquifer system in the study area for irrigation purposes is about 63 Mgal, or about 0.011 inch, of water per year, and consumptive use of surface water for irrigation is about the same.

Industry

Table 5-4 shows the use of self-supplied water from the Kirkwood-Cohansey aquifer system and from surface-water sources in the study area by industry from 1975 through 1988. A total of 474.0 Mgal of ground water and 2,929.7 Mgal of surface water reportedly was withdrawn in 1988 for self-supplied industrial use (U.S. Geological Survey Site-Specific Water Use Data System, unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.). Because in this study area public-supply water is considered to be for domestic use only, self-supplied industrial water use is equal to total industrial water use. Solley and others (1988, p. 33) estimate that about 7 percent of industrial water use in New Jersey is consumptive. The amount of ground water from the Kirkwood-Cohansey aquifer system that is consumed for industrial purposes is estimated to be about 33 Mgal, or about 0.0056 inch, of water per year, and the amount of surface water that is consumed is estimated to be about 200 Mgal, or about 0.034 inch, of water per year.

Mining

Water used for mining in the study area is withdrawn primarily from surface-water sources for use by sand and gravel companies. Table 5-5 lists withdrawals reported by two companies in the study area from 1984 through 1988. In 1988 the two companies used 2,036 Mgal of surface water (U.S. Geological Survey Site-Specific Water Use Data System, unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.). Solley and others (1988, p. 37) estimate that about 10 percent of mining water use in New Jersey is consumptive. Withdrawals from the surface-water system for mining use are estimated to be about 200 Mgal, or about 0.034 inch, of water per year in the study area.

Total Water Use

Water for domestic use (both public- and self-supplied), irrigation, industry, and mining accounts for all significant water use in the study area. Figure 5-2 summarizes the estimates of consumptive use of both ground and surface water in these categories.

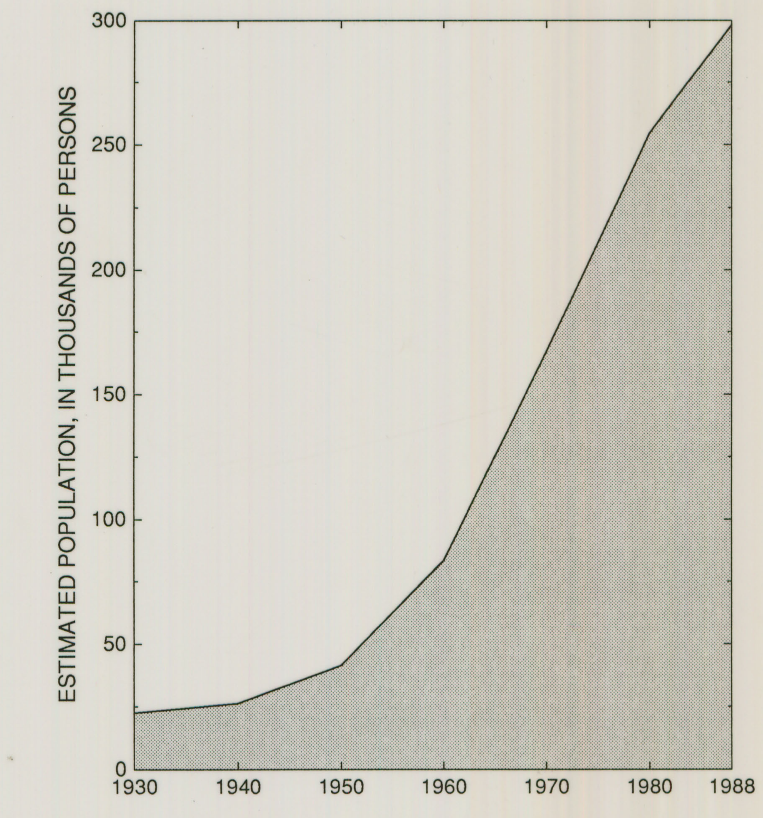


Figure 5-1.--Estimated population of the study area, 1930-88. (Data from New Jersey Department of Labor, 1984, and New Jersey Department of Labor, 1989; data for 1988 are provisional)

Table 5-1.--Estimated population of the study area based on percentage of land area in the study area

[Provisional data from New Jersey Department of Labor, 1989]

County / Municipality	Total population, 1988	Land area within study area (percent)	Estimated population within study area, 1988
Monmouth County			
Freehold Township	23,401	29	6,786
Howell Township	36,546	34	12,426
Millstone Township	4,962	9	447
Wall Township	20,084	1	201
Ocean County			
Bay Head Borough	1,307	93	1,216
Beachwood Borough	8,551	100	8,551
Berkeley Township	35,323	53	18,721
Brick Township	62,825	86	54,030
Dover Township	74,198	100	74,198
Island Heights Borough	1,604	100	1,604
Jackson Township	31,669	94	29,769
Lacey Township	20,175	2	404
Lakehurst Borough	3,063	100	3,063
Lakewood Township	41,028	100	41,028
Lavallette Borough	2,220	100	2,220
Manchester Township	35,004	58	20,302
Mantoloking Borough	441	100	441
Ocean Gate Borough	1,482	59	874
Pine Beach Borough	1,771	100	1,771
Plumsted Township	5,360	11	590
Point Pleasant Borough	18,272	71	12,973
Seaside Heights Borough	2,188	100	2,188
Seaside Park Borough	1,800	33	594
South Toms River Borough	3,851	100	3,851
Total	437,125		298,248

Table 5-2.--Reported annual withdrawals for public supply from the Kirkwood-Cohansey aquifer system or from surface water in the study area, 1975-88

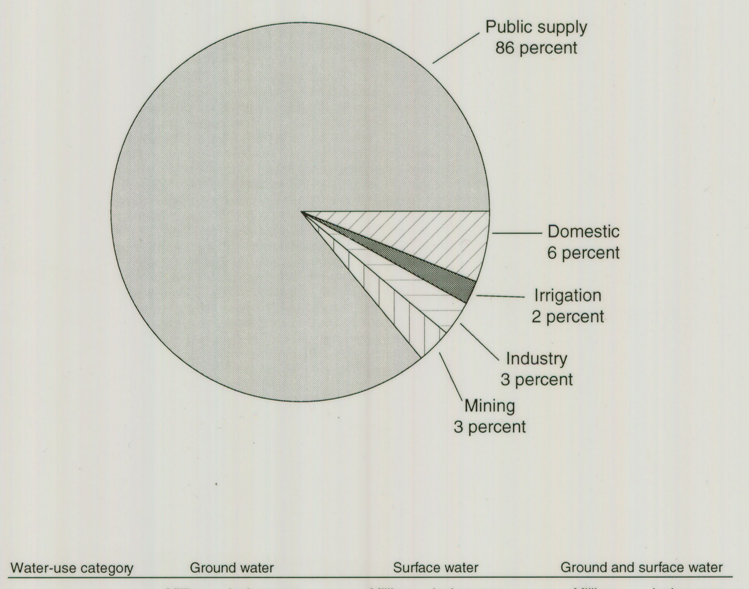
[Withdrawal data from U.S. Geological Survey Site-Specific Water Use Data System--unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.; all values in million gallons; all values rounded to the nearest million gallon; all values represent ground-water withdrawals except Brick Township, which has values for both ground- and surface-water withdrawals in 1987 and 1988; --, no reported withdrawals]

County / Municipality	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Monmouth County														
Howell Township	--	--	--	--	--	--	17	92	122	107	86	90	117	140
Ocean County														
Beachwood Borough	102	111	125	124	119	126	128	133	152	209	248	270	273	299
Berkeley Township	140	140	140	140	174	183	175	4	27	25	34	52	107	385
Brick Township														
Ground water	543	459	298	229	0	0	278	266	296	298	308	358	333	274
Surface water	--	--	--	--	--	--	--	--	--	--	--	--	191	644
Dover Township	1,730	1,987	2,052	1,987	2,128	2,340	2,057	1,661	1,933	2,010	1,816	1,895	1,799	1,635
Lakehurst Borough	90	103	112	111	115	113	108	97	104	112	113	116	116	112
Lakewood Township	88	72	55	65	95	60	125	87	79	23	49	71	66	138
Manchester Township	419	578	690	712	666	858	772	740	905	903	938	1,015	933	1,019
Ocean Gate Borough	48	56	63	67	59	59	52	53	58	78	74	73	82	83
Pine Beach Borough	45	45	59	62	57	60	53	50	54	75	73	78	74	85
Point Pleasant Borough	70	64	6	14	0	42	0	39	11	10	94	87	123	140
Seaside Heights Borough	243	244	236	201	203	296	328	313	370	397	369	392	370	358
South Toms River Borough	100	101	97	95	106	112	138	109	23	117	118	257	560	721
Yearly totals														
Ground water	3,618	3,960	3,933	3,807	3,722	4,249	4,231	3,644	4,134	4,364	4,320	4,754	4,953	5,389
Surface water	--	--	--	--	--	--	--	--	--	--	--	--	191	644
Total	3,618	3,960	3,933	3,807	3,722	4,249	4,231	3,644	4,134	4,364	4,320	4,754	5,144	6,033

Table 5-3.--Estimated water use for irrigation from the Kirkwood-Cohansey aquifer system or from surface water in the study area

[Data on irrigated land in each municipality from James Gibson, New Jersey Agricultural Statistics Service, written commun., 1987; differences in totals caused by independent rounding; all values have been rounded to two significant figures]

County / Municipality	Irrigated land in municipality (acres)	Land area within study area (percent)	Estimated irrigated land in study area (million acres)	Estimated annual water use (gallons)
Monmouth County				
Freehold Township	260	29	75	16
Howell Township	570	34	190	41
Millstone Township	1,400	9	130	28
Ocean County				
Berkeley Township	45	53	24	5.2
Dover Township	1.5	100	1.5	.33
Jackson Township	84	94	79	17
Lacey Township	14	2	.28	.061
Lakewood Township	30	100	30	6.5
Manchester Township	59	58	34	7.4
Plumsted Township	620	11	68	15
Total	3,100		630	140



Water-use category	Ground water: Million gallons	Ground water: Inches over the basin	Surface water: Million gallons	Surface water: Inches over the basin	Ground and surface water: Million gallons	Ground and surface water: Inches over the basin
Public supply	5,400	0.92	640	0.11	6,000	1.00
Domestic self-supply	440	.075	0	0	440	.075
Irrigation	63	.011	63	.011	130	.022
Industry	33	.0056	200	.034	230	.040
Mining	0	0	200	.034	200	.034
Total consumptive use	5,900	1.0	1,100	0.19	7,000	1.2

Figure 5-2.--Summary of consumptive water use in the study area.

Table 5-4.--Reported industrial water use from the Kirkwood-Cohansey aquifer system or from surface water in the study area, 1975-88

[Water-use data from U.S. Geological Survey Site-Specific Water Use Data System --unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.; all values in million gallons; yearly totals rounded to the nearest tenth of a million gallon; diffferences in totals caused by independent rounding; --, no reported value]

Year	Municipality: Dover	South Toms River[1]	Jackson[1]	Manchester	Yearly totals: Surface water	Yearly totals: Ground water
1975	860.4	--	--	0.13	--	860.5
1976	1,073.4	--	--	.04	--	1,073.4
1977	936.1	--	--	.13	--	936.2
1978	1,003.3	--	--	.01	--	1,003.3
1979	1,075.8	--	--	.01	--	1,075.8
1980	956.1	--	--	.02	--	956.1
1981	859.1	--	--	.03	--	859.1
1982	797.4	--	--	.01	--	797.4
1983	914.0	--	--	.04	--	914.0
1984	876.8	3,999.9	--	.05	3,999.9	876.9
1985	632.3	2,647.4	--	.00	2,647.4	632.3
1986	603.9	2,493.3	5.5	--	2,498.8	603.9
1987	567.5	2,933.9	20.8	--	2,954.8	567.5
1988	474.0	2,906.3	23.4	.00	2,929.7	474.0

[1] Water used is surface water

Table 5-5.--Reported surface-water use for mining in the study area, 1984-88

[Water-use data from U.S. Geological Survey Site-Specific Water Use Data System--unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.; all values in million gallons; all values rounded to the nearest million gallon; differences in totals caused by independent rounding; --, no reported value]

Year	Municipalities: Lakewood	South Toms River	Yearly totals
1984	--	25	25
1985	1,951	137	2,089
1986	2,084	130	2,215
1987	1,699	126	1,825
1988	1,955	81	2,036

WATER BUDGET

The hydrologic cycle is a dynamic system consisting of several components whose values can be estimated numerically for use in a water-budget analysis. The variables examined in the water-budget analyses in this report are shown in figure 5-3.

The water budget can be divided into two systems: the land-surface system and the ground-water system. Precipitation is the principal source of water to the land-surface system, and direct runoff, evapotranspiration, water use from surface-water bodies, and recharge to the ground-water system account for the water discharging from the system. Recharge is the principal source of water to the ground-water system, and base flow, water use from the unconfined aquifer, and leakage to deeper aquifers account for water discharging from the system. It is assumed that no water flows across the lateral boundaries of the study area. Two water budgets, one for the Toms River Basin and one for the Metedeconk River Basin, are presented here to examine whether differences in basin size, population, and land use affect the amount of recharge. The variables representing the components of the hydrologic cycle that were estimated for use in the water-budget analysis of the two basins are

P = precipitation,
Q_{dr} = direct runoff,
ET = evapotranspiration,
R = recharge to the aquifer,
Q_b = base flow,
L = leakage to deeper aquifers,
W_s = consumptive water use from surface-water withdrawals, and
W_g = consumptive water use from ground-water withdrawals.

The equation that represents the hydrologic cycle for the land-surface system is

$$P = Q_{dr} + ET + W_s + R .$$

The equation that represents the hydrologic cycle for the ground-water system is

$$R = Q_b + L + W_g .$$

Each variable is described in detail below.

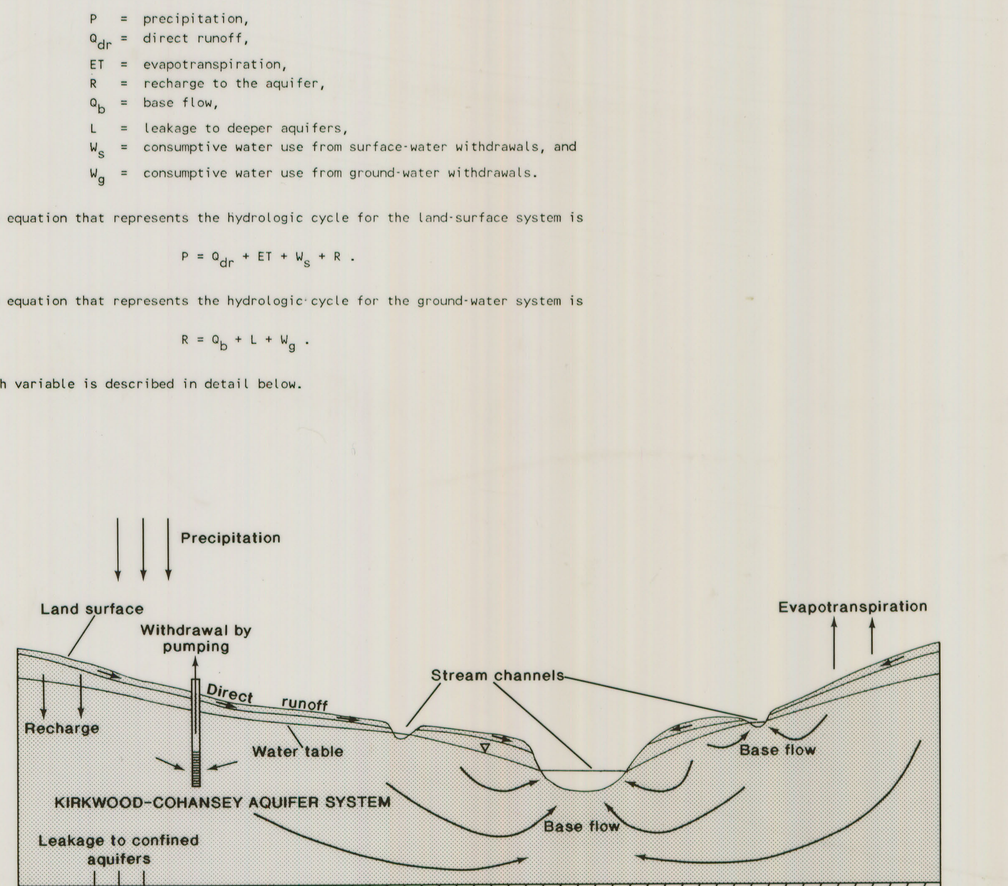


Figure 5-3.--Schematic diagram of the hydrologic cycle.

Different precipitation values were used for the Toms River and the Metedeconk River Basin budgets. Precipitation data for the Toms River Basin were collected at the Toms River weather station, which is located in the southeastern portion of the Toms River Basin, whereas precipitation data for the Metedeconk River Basin were collected at the Hightstown weather station, which is just north and west of the Metedeconk River Basin (fig. 2-2). For both basins, an average of precipitation values for 1980-89 was used to ensure that the data were from the same period of record and to provide estimates representative of recent conditions. Data from nearby weather stations were used to estimate values where data were missing. Mean annual precipitation for the 1980-89 period was 46.4 inches at the Toms River weather station and 45.9 inches at the Hightstown weather station.

Discharge measurements for 1980-89 also were averaged for the streamflow-gaging stations on each river. The results of base-flow separations for each 10-year record were examined to estimate the average base-flow and direct-runoff values for each streamflow-gaging station. (The base-flow-separation technique used is described on sheet 3.) Discharge values used in the Toms River Basin water budget were those measured at the Toms River near Toms River streamflow-gaging station (01408500). Because discharge at this station consists of runoff from more than 60 percent of the total area of the Toms River Basin, the discharge values are assumed to be representative of discharge for the entire basin. Average direct runoff and base flow of the Toms River during the 1980-89 period were estimated to be 3.4 inches and 18.0 inches, respectively.

Discharge values used in the Metedeconk River Basin water budget were those measured at the North Branch Metedeconk River near Lakewood streamflow-gaging station (01408120). Because discharge at this station consists of runoff from less than 40 percent of the total area of the Metedeconk River Basin, the discharge measured there is not likely to represent discharge for the whole basin, and is likely to be affected by local conditions. The percentage of total discharge that is base flow varies more from year to year at the Metedeconk River streamflow-gaging station than at the Toms River streamflow-gaging station. Because the discharge of the North Branch Metedeconk River near Lakewood may not accurately represent discharge in the basin, average values of direct runoff and base flow are rounded to the nearest inch and are 7 inches and 15 inches, respectively.

Potential evapotranspiration was calculated to be 27.0 inches per year by using the Thornthwaite method with the 10-year mean (1980-89) temperature for the Toms River weather station. Actual evapotranspiration in each of the two drainage basins is less than potential evapotranspiration because soil moisture can be inadequate during parts of the year for full potential evaporation or transpiration to take place. The sandy soils in these basins promote rapid infiltration, resulting in low values of runoff and evaporation. Actual evapotranspiration rates, estimated from the potential rate of 27.0 inches per year, differed between the two basins. Williams and others (1940) reported extremes of 21 to 29 inches per year for evapotranspiration in New Jersey, Pennsylvania, Massachusetts, and Connecticut; Rhodehamel (1970, p. 7, 18) reported an evapotranspiration rate of 22.5 inches per year in the central Coastal Plain of New Jersey; and Vowinkel and Foster (1981, p. 18) reported a similar rate (22.5 inches per year) in the Toms River area. However, precipitation was higher and discharge was smaller during 1980-89 than during these previous studies, which resulted in additional available water and a higher rate of evapotranspiration. Therefore, actual evapotranspiration in the Toms River Basin was estimated to be 23.5 inches per year. Actual evapotranspiration in the Metedeconk River Basin was estimated to be slightly lower, primarily on the basis of land-use differences. The Metedeconk River Basin contains a greater percentage of urban land than the Toms River Basin. Paved surfaces reduce both the potential for evaporation and the amount of vegetation available for transpiration. Correspondingly, the percentage of discharge that is direct runoff is much higher in the Metedeconk River Basin (32 percent) than in the Toms River Basin (16 percent). The Toms River Basin also contains more wetlands and areas of open water than the Metedeconk River Basin; these bodies of open water provide a large supply of moisture for evaporation and thus increase evapotranspiration. Therefore, actual evapotranspiration in the Metedeconk River Basin was estimated to be 23.0 inches per year.

Water use was calculated for the Toms and Metedeconk River Basins individually by using the same methods used to calculate water use for the whole study area (see "Water Use" section). Total consumptive water use from ground-water withdrawals was 1.4 inches for the Toms River Basin and 0.45 inch for the Metedeconk River Basin. Consumptive water use from surface-water withdrawals totaled 0.13 inch for the Toms River Basin and 0.44 inch for the Metedeconk River Basin.

Leakage rates were calculated for each basin by using an updated version of the New Jersey Regional Aquifer System Analysis ground-water-flow model (Martin, 1990). This model includes pumpage information through 1988 to improve the accuracy of estimates of leakage from the Kirkwood-Cohansey aquifer system to deeper aquifers. Calculated leakage rates are 0.001968 inch per year for the Toms River and 0.000441 inch per year for the Metedeconk River (D.A. Pope, U.S. Geological Survey, written commun., 1991).

The values of the water-budget components discussed above are summarized as follows (in inches):

Toms River Basin	Metedeconk River Basin
$P = 46.4$	$P = 45.9$
$Q_{dr} = 3.4$	$Q_{dr} = 7$
$ET = 23.5$	$ET = 23.0$
$W_s = 0.13$	$W_s = 0.44$
$Q_b = 18.0$	$Q_b = 15$
$L = 0.0020$	$L = 0.00044$
$W_g = 1.4$	$W_g = 0.45$

By inserting these values in the budget equations:

Toms River Basin	Metedeconk River Basin
$P = Q_{dr} + ET + W_s + R$	$P = Q_{dr} + ET + W_s + R$
$46.4 = 3.4 + 23.5 + 0.13 + R$	$45.9 = 7 + 23.0 + 0.44 + R$
$R = 19.37$ or 19.4 inches	$R = 15.46$ or 15 inches

and

Toms River Basin	Metedeconk River Basin
$R = Q_b + L + W_g$	$R = Q_b + L + W_g$
$R = 18.0 + 0.0020 + 1.4$	$R = 15 + 0.00044 + 0.45$
$R = 19.40$ or 19.4 inches	$R = 15.45$ or 15 inches .

In each budget, the calculated recharge values are nearly equal and the difference is well within the range of the estimates made for each individual variable. Recharge in the Toms and Metedeconk River Basins is 42 percent and 33 percent of precipitation, respectively. About 93 percent of the recharge to the Toms River Basin is discharged as base flow, whereas nearly all the recharge to the Metedeconk River Basin becomes base flow. In both basins base flow is the primary means by which available recharge is removed from the ground-water system. As a result, any increase in leakage or ground-water withdrawals will reduce the amount of available base flow, thereby affecting the surface-water system as well.

In both budgets, precipitation is the only component entering the hydrologic system, and discharge and evapotranspiration are the two major components leaving the system. Discharge is 46 percent of precipitation in the Toms River Basin and 48 percent of precipitation in the Metedeconk River Basin. In the Toms River Basin, evapotranspiration is 51 percent of precipitation, whereas evapotranspiration is 50 percent of precipitation in the Metedeconk River Basin. Although water consumption plays a much larger role in the Toms River system than in the Metedeconk River system, it is a small component of both systems. Some of the water withdrawn for public supply in the Toms River Basin is likely transported for use in the Metedeconk River Basin, resulting in a consumptive-use value that is overestimated in one basin and underestimated in the other. Consumptive water use is likely to become a much larger component of the hydrologic system in both basins as the population and the resulting demand for water continue to increase.

In conclusion, these water budgets represent an attempt to quantify the amount of water available in both the ground-water and surface-water systems of these two basins and to indicate the extent of water consumption in each basin under present (1990) conditions. This analysis can be updated periodically as the population increases and as conditions change throughout the study area to provide a valuable means of assessing effects of development on the hydrologic system in the study area.

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