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WATER-RESOURCES INVESTIGATIONS REPORT 03-4337
Resource evaluation--SHEET 5 OF 5
Gordon, A.D., Hydrology of the unconfined Kirkwood-Cohansey aquifer system, Forked River and Cedar, Oyster, Mill, Westecunk, and Tuckerton Creek Basins and adjacent basins in the southern Ocean County area, New Jersey, 1998-99

RESOURCE EVALUATION

This sheet describes population changes and water use in, and develops a water budget for, the Atlantic Coastal study area. Current (2000) population data for the study area and changes in population during 1930-2000 are presented. All known water withdrawals from the Kirkwood-Cohansey aquifer system, confined aquifers, and surface-water bodies in the study area are tabulated, and consumptive use from each of these sources is estimated. A water budget for the Kirkwood-Cohansey aquifer system in the mainland section of the Atlantic Coastal study area (water-budget area) that incorporates all known withdrawals from all sources is calculated for the period 1986-95.

Population

The census data that are collected at the beginning of each decade (decennial census) were used to describe population trends in the Atlantic Coastal study area. The estimated total population in the study area at each decennial census from 1930 to 2000 is shown in figure 5-1. The population of each municipality in the study area for each decennial census period was estimated by multiplying the reported population of the municipality by the percentage of land in the municipality that is in the study area. This method may cause the population in urban areas to be underestimated and the population in rural areas to be overestimated.

From 1930 to 2000, the population of the study area increased more than 1,300 percent. Growth was most rapid from 1970 to 1990, when the population tripled. The population and land area of each municipality in the study area in 2000 is listed in table 5-1. The total estimated population of the study area is more than 97,000, which is more than 1 percent of the total population of New Jersey in 2000 (U.S. Bureau of the Census, 2001b).

Water Withdrawals from the Kirkwood-Cohansey Aquifer System and from Surface Water, and Consumptive Use

As the population of the study area increased, many municipalities developed or expanded water supplies to meet the demand. Estimates of water use in the water-budget area of the Atlantic Coastal study area are presented for the most recent year for which complete reported water-use data are available (1999). Water use is changing constantly as industries and commercial businesses close down or start up and as the population distribution changes; thus, the most recent complete yearly data (1999) provide the most accurate and current assessment of water usage in the study area. Withdrawals in 1985 and 1999 in the water-budget area by water-use category are shown in table 5-2. Ground-water withdrawals increased nearly 84 percent over this period. Annual withdrawals of water for public- and self-supply domestic, commercial, industrial, mining, irrigation, thermoelectric power, and sewage-treatment facility use as reported by the water user to the NJDEP are estimated. Agricultural water use in the study area is minimal.

From the estimates of ground-water withdrawals, the consumptive use of water in each water-use category was calculated and totaled for the water budget. Consumptive use is that part of the 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, 1998). All withdrawal data were obtained from the USGS's Site-Specific Water Use Data System (SSWUDS) database.

Domestic water use (both public- and self-supply) accounts for most of the water use from ground-water sources in the study area, whereas water for irrigation and mining purposes accounts for most water use from surface-water sources. Withdrawals from the Kirkwood-Cohansey aquifer system and from surface water and consumptive use in 1999 are summarized in table 5-3 by water-use category. (Withdrawals from the barrier islands are not included in table 5-3 because withdrawals from the Kirkwood-Cohansey aquifer system on the barrier islands are small--less than 1 percent of the total withdrawals.) Residential water use totaled 2,444 Mgal, including domestic self-supply withdrawals of approximately 1,077 Mgal and public-supply deliveries of 1,367 Mgal. Consumptive use of ground water is estimated to be approximately 1,653 Mgal (0.404 in. over the water-budget area), or 95 percent of total consumptive use. Consumptive use of surface water is estimated to be approximately 78 Mgal (0.019 in. over the water-budget area), or 5 percent of total consumptive use. Withdrawals and consumptive use for commercial self supply and industrial purposes, sewage-treatment facilities, and thermoelectric-power use are small compared to those for other water-use categories.

Public Supply

Public-supply systems commonly provide water for domestic, industrial, and commercial users, but most water is used for domestic purposes. Most of these users are assumed to be served by public sewer systems. Data on public-water suppliers were analyzed to develop water-distribution and consumptive-use coefficients for domestic and commercial deliveries, as well as public water use and losses.

Public-supply withdrawals from the Kirkwood-Cohansey aquifer system in 1999 totaled about 1,608 Mgal (table 5-3), which is about 59 percent of the total withdrawals from this aquifer system in the study area. About 82 percent (1,319 Mgal) of the total withdrawals for public supply is estimated to be delivered to domestic users. About 3 percent (48 Mgal) of total the withdrawals for public supply is estimated to be commercial deliveries. Industrial users are estimated to receive a negligible amount of publicly supplied water. About 15 percent of the public-supply withdrawals (241 Mgal) is estimated to be used for distribution-system maintenance, distribution-system losses, and public water use (Nawyn, 1997). Distribution-system maintenance is the backwashing of filters and well screens. Distribution losses consist of water lost through damaged water pipes, improperly registering water meters, and unauthorized water connections. Public water use is water supplied from a public-water supply and used for such purposes as firefighting and street cleaning, or in municipal buildings and recreational facilities (Solley and others, 1998).

Public-supply withdrawals from the Kirkwood-Cohansey aquifer system in the study area are considered to be 100-percent consumptive because all the treated wastewater is discharged outside the study area, to the Atlantic Ocean. Therefore, the total consumptive use of public-supply deliveries (domestic and commercial) during 1999 is almost 1,367 Mgal (0.334 in. over the water-budget area) (table 5-3). Consumptive use of public-supply withdrawals used for maintenance, losses, and public water use is considered to be 20 percent, or a coefficient of 0.2 (Nawyn, 1997); therefore, the total consumptive use during 1999 is about 48 Mgal (0.012 in. over the water-budget area) (table 5-3).

Domestic Self-Supply

All self-supplied water withdrawn for domestic purposes in the study area was assumed to come from the unconfined Kirkwood-Cohansey aquifer system. This assumption is based on information from the USGS GWSI database, and the understanding that confined aquifers are much deeper, and, therefore, less economical for a homeowner to tap for domestic supply, than the unconfined aquifer system. Estimation of domestic self-supply water use is difficult because withdrawals are not reported to any public agency. To estimate domestic self-supply withdrawals, information on the number of housing units, population, and source of water for the housing units within each municipality in the study area was determined from 1990 census data (U.S. Bureau of the Census, 2000). The number of persons per housing unit in a municipality in 1990 was determined by dividing the municipal population by the number of housing units in the municipality. The number of publicly supplied persons in 1990 was determined by multiplying the number of persons per housing unit by the number of housing units served by public suppliers. The number of self-supplied persons in 1990 was estimated by subtracting the number of publicly supplied persons from the total population. To estimate the number of domestic self-supply and public-supply users in 2000, the percentage population increase from 1990 to 2000 was determined for each municipality (U.S. Bureau of the Census, 2001a). The percentage increase in population was multiplied by the population served by domestic self-supply in 1990 to obtain the 2000 population served by domestic self-supply. The 2000 population estimate is assumed to equal the 1999 population. Because the study area includes parts of some municipalities, the number of domestic self-supply users was apportioned on the basis of the area of the municipality within the study area. The estimated population served by domestic self-supply and by public supply in 1999 is shown for townships with domestic self-supply withdrawals in figure 5-2. In most of the townships in Ocean County that are in the study area, a larger percentage of the population was served by public supply than by domestic self-supply in 1999. Exceptions were Ocean, Eagleswood, and Lacey Townships. Lacey Township had the largest number of domestic self-supply users, more than 19,000, in the study area in 1999.

Withdrawals for domestic self-supply were estimated by multiplying the number of self-supplied users in the study area by the domestic water-use coefficient of 85 gal/d per person (Solley and others, 1998). Estimated domestic self-supply withdrawals in 1990 and 1999 by township are shown in table 5-4. Lacey Township accounts for about 53 percent of the total domestic self-supply withdrawals in the study area. Total withdrawals from the Kirkwood-Cohansey aquifer system in the study area for domestic self-supply use during 1999 are estimated to be about 1,077 Mgal, an increase of 21 percent from 1990. Withdrawals for domestic self-supply represent about 39 percent of all withdrawals from the Kirkwood-Cohansey aquifer system in the study area (table 5-3).

Residents who use self-supplied water for domestic purposes either treat their wastewater with on-site septic systems or discharge it to sewers. The population served by septic systems or by sewer systems in the study area in 1990 was determined from data from the U.S. Bureau of the Census (U.S. Bureau of the Census, 2000); however, the Bureau of the Census did not distinguish between the population using public-supply water with on-site septic systems and the population using domestic self-supply water with on-site septic systems. The percentage population increase from 1990 to 2000 for each municipality was used to estimate the number of self-supplied and public-supply users with septic systems in 2000. The percentage increase in population was multiplied by the reported 1990 estimates for the population served by sewers and the population served by on-site septic systems to obtain the 2000 estimate. The 2000 population estimate is assumed to equal the 1999 population. Because the study area includes parts of some municipalities, the number of domestic self-supply users was apportioned on the basis of the area of the municipality within the study area. Approximately 14 percent of the population in the study area during 1999 used on-site septic systems. The estimated population served by on-site septic systems in 1999 was multiplied by the per capita water-use value for New Jersey of 85 gal/d (Solley and others, 1998) to obtain the total withdrawals for this population. This value subsequently was used to calculate artificial recharge to the unconfined aquifer system from septic systems in the water budget.

A consumptive-use coefficient of 0.2 was used for domestic self-supply water use. This coefficient is higher than that used for public-supply water use (0.18) because self-supplied users typically use more water outdoors, for purposes such as lawn watering and gardening, than many publicly supplied residents whose outdoor water use may be more limited (Nawyn, 1997). Consumptive use of domestic self-supply withdrawals is estimated to be about 215 Mgal (0.053 in. over the water-budget area) (table 5-3).

Commercial Self-Supply

Commercial self-supply withdrawals include water used by motels, hotels, restaurants, office buildings, and other commercial facilities (Solley and others, 1998). Commercial self-supply withdrawals in the study area totaled almost 26 Mgal during 1999 (table 5-3). According to Nawyn (1997), about 4 percent of the water withdrawn for commercial purposes in New Jersey is consumed. Therefore, the total consumptive use of commercial self-supply withdrawals is estimated to be 1 Mgal (less than 0.001 in. over the water-budget area) (table 5-3).

Industrial Self-Supply

Annual withdrawals of ground water reported by self-supplied industries in the study area in 1999 were from dewatering wells and totaled almost 4 Mgal (table 5-3). The withdrawals discharge to sewers and leave the study area; therefore, the consumptive use of this water is 100 percent (4 Mgal, or 0.001 in. over the water-budget area) (John Nawyn, U.S. Geological Survey, written commun., 2001).

Mining

Annual withdrawals for mining use reported by sand-and-gravel companies in the study area totaled about 469 Mgal from surface water and about 1 Mgal from ground water during 1999. According to Nawyn (1997), about 8 percent of the water withdrawn for mining purposes in New Jersey, or approximately 38 Mgal (0.009 in. over the water-budget area), is consumed.

Irrigation

Withdrawals for irrigation in the study area during 1999 are shown in table 5-3. Most of the water used for irrigation is from surface-water sources. Withdrawals of surface water for irrigation totaled more than 48 Mgal in 1999, including about 3 Mgal for cranberry production. Withdrawals of ground water for irrigation totaled more than 6 Mgal. Therefore, total annual reported irrigation withdrawals in the study area during 1999 were nearly 55 Mgal.

Surface-water irrigation withdrawals for cranberry production chiefly are nonconsumptive (Clawges and Titus, 1993). Irrigation withdrawals for agricultural non-cranberry production, however, are consumptive because little water is returned to the system as a result of evaporation and uptake by plants (Nawyn, 1997); therefore, the consumptive-use coefficient is 0.9 (90 percent). Consumptive use for non-cranberry irrigation from surface-water sources is estimated to be about 41 Mgal (0.01 in. over the water-budget area) and consumptive use for non-cranberry irrigation from ground-water sources is almost 6 Mgal (0.001 in. over the water-budget area) (table 5-3). Therefore, total consumptive use for irrigation is approximately 47 Mgal (0.011 in. over the water-budget area).

Other Water Use

Annual withdrawals from the Kirkwood-Cohansey aquifer system for thermoelectric power totaled more than 8 Mgal, and withdrawals for use in sewage-treatment facilities totaled almost 4 Mgal, during 1999 (table 5-3). Consumptive use of water used for both these purposes is 100 percent because the water is discharged outside the study area (John Nawyn, U.S. Geological Survey, written commun., 2001). Therefore, the total consumptive use for thermoelectric power and sewage treatment is about 12 Mgal (0.003 in. over the water-budget area) (table 5-3).

Total Water Use, 1990-99

Water use by type (unconfined ground water, confined ground water, and surface water) in the study area during 1990-99 is summarized in table 5-5 and figure 5-3. In the table, withdrawals are separated into two parts: withdrawals from the barrier islands and withdrawals from the mainland. Withdrawals from the confined aquifers in the study area are from the Rio Grande water-bearing zone, the Atlantic City 800-foot sand, and the Piney Point aquifer. Withdrawals from confined aquifers account for about 40 percent of the total withdrawals from all known sources in the study area during 1999 (table 5-5). Like withdrawals from the Kirkwood-Cohansey aquifer system, nearly all the withdrawals from confined aquifers are used for public supply and ultimately are discharged outside the study area.

Water withdrawals on the barrier islands, which comprise Long Beach Township; Barnegat Light, Harvey Cedars, Surf City, Ship Bottom, and Beach Haven Boroughs; and small parts of Berkeley, Lacey, and Ocean Townships, are almost exclusively from the confined aquifers. More than 73 percent of the withdrawals on the barrier islands during 1990-99 were from the Atlantic City 800-foot sand. The populations of these islands shown in table 5-1 reflect the number of year-round residents and do not account for the seasonal increase in population in oceanfront communities during the summer months.

The most widely used source of public-supply water in the study area is the Kirkwood-Cohansey aquifer system (fig. 5-3). Withdrawals from this aquifer system in 1999 totaled about 2,735 Mgal, which represents about 51 percent of total ground-water withdrawals from the mainland area and barrier islands combined (table 5-5). Domestic self-supply water use accounts for about 40 percent of the ground-water withdrawals from the Kirkwood-Cohansey aquifer system (table 5-2) and almost 20 percent of withdrawals in the entire study area in 1999. Withdrawals from the aquifer system have remained steady since 1994, with the exception of 1998, when withdrawals exceeded those for the other years by about 100 Mgal (table 5-5).

Water Budget

The following water budget provides estimated values for the components of the hydrologic cycle in the Atlantic Coastal study area for 1986-95. Although the flow and storage of water in different parts of the hydrologic system can change yearly, seasonally, or daily (as a result of a storm), it is assumed for the purposes of the long-term average water budget used here that no substantial long-term change occurs in the flow and storage of water. The water-budget area does not include the barrier islands; these areas do not have surface-water gaging sites, and water use on the barrier islands is almost entirely from the confined aquifers. Ground-water inflow from adjacent surface-water drainage basins outside the study area is considered in the budget analysis because of its effect on ground-water recharge in the study area. The ground-water and surface-water drainage divides do not coincide always, and ground-water inflow from an adjacent surface-water basin may result.

Water-Budget Equations

The hydrologic cycle can be represented by a long-term water budget in which inflows are balanced by equivalent outflows and, therefore, there is no long-term net change in storage. The following budget analysis accounts for all known water-system gains and losses in the water-budget area. The water budget can be evaluated by using two internal budgets and their corresponding balance equations: one that describes gains and losses to and from the land surface, and another that describes gains and losses to and from the saturated, unconfined aquifer system. Many of the variables in the two internal budgets are difficult to evaluate. Recharge, a variable that cannot be measured or estimated except from other hydrologic data, was determined separately in each equation, and the two values were compared. The values of precipitation, base flow, direct runoff, evapotranspiration, and withdrawals by pumping were discussed in previous sections of this report.

In order to calculate the amount of water moving through the water-budget area (fig. 5-4), a budget volume must be defined. A budget volume is the "package" of geologic material for which a water budget is calculated. In this study, the budget volume is defined by the extent of the surface-water drainage basins on the mainland of the study area and the thickness of the unconfined aquifer system from the water table to the top of the underlying confining unit. The water-budget area is defined by the area of the surface-water drainage basins on the mainland of the study area and encompasses 235.7 mi^2. The Kirkwood-Cohansey aquifer system in the study area is assumed to be one large, hydraulically connected, unconfined aquifer system. Generalized hydrogeologic sections through the study area that illustrate the budget volume and generalized flow within the system are shown in figures 5-5 and 5-6. Generalized flow is from the unconfined aquifer system to the confined aquifers in the northwest-southeast direction (fig. 5-5). Generalized flow through the Kirkwood-Cohansey aquifer system in a southwest-northeast direction is shown in figure 5-6.

To estimate recharge to the unconfined aquifer in the study area, a land-surface water-budget equation is used. Water is introduced to the land surface through precipitation (P) and artificial recharge of water that was pumped from the unconfined aquifer system, used, treated, and released into surface-water bodies (R_{as}). Water is lost from the land surface through direct runoff (Q_{dr}), evapotranspiration (ET), consumptive use of surface-water withdrawals (W_s), and natural recharge to the aquifer system (R_{ns}). These terms represent the components of the land-surface water-budget equation.

In the same way, as described above, recharge to the ground-water system can be estimated through use of a ground-water budget equation. Water is introduced to the ground-water system through natural recharge (R_{ng}), artificial recharge to the aquifer from septic systems that treat wastewater that initially was pumped from the unconfined aquifer system (R_{ag}), and ground-water inflow from adjacent surface-water basins outside the budget volume (R_i). The R_i term accounts for those parts of the study area where the ground-water and surface-water divides do not coincide, and ground-water inflow across the surface-water drainage divide is not negligible. Water is lost from the ground-water system through base flow (Q_b), consumptive use of unconfined-ground-water withdrawals (W_g), and leakage to the confined aquifers (L). These terms represent the components of the ground-water-system equation of the water budget.

The equation used for the land surface is

$$P + R_{as} = Q_{dr} + ET + W_s + R_{ns}\ ,$$

and the equation used for the ground-water system is

$$R_{ng} + R_{ag} + R_i = Q_b + W_g + L\ .$$

Values of Water-Budget Variables

A single precipitation value (P) was used for the water-budget area and was based on the average value at the Tuckerton, N.J., weather station during 10 years of record, 1986-95. This average value, 44.7 in/yr, was used in the land-surface water-budget equation.

Discharge values are available for three basins in the study area. To obtain the discharge values that were used in the water-budget analysis, total-runoff values were separated into base-flow (Q_b) and direct-runoff (Q_{dr}) components. For the Cedar Creek Basin, discharge measurements made during water years 1933-58 and from December 1970 to September 1971 at the Cedar Creek at Lanoka, N.J. (01409000), continuous-record streamflow-gaging station were used. For the Oyster Creek Basin, discharge measurements made during water years 1966-84 at the Oyster Creek near Brookville, N.J. (01409095), continuous-record streamflow-gaging station were used. For the Westecunk Creek Basin, discharge measurements made during water years 1974-88 at the Westecunk Creek at Stafford Forge, N.J. (01409280), continuous-record streamflow-gaging station were used. Area-weighted values for base flow and direct runoff were calculated for these three stations (fig. 5-4). Discharge values for the part of the basins downstream from the stations were assumed to be equivalent to the long-term area-weighted discharges upstream from the stations. These three basins cover about 33 percent of the water-budget area; therefore, the discharge components for the remaining water-budget area are estimated. Discharge values for the remaining parts of the water-budget area, the tidal areas and tributaries to bays, were assumed to be equivalent to the long-term area-weighted discharges for the three basins. The resulting values of the discharge components used in the land-surface water-budget equation are 25.2 in/yr for base flow (Q_b) and 3.9 in/yr for direct runoff (Q_{dr}).

Evapotranspiration can be calculated by using any of several methods. For this study, potential evapotranspiration was calculated by using the Thornthwaite method (Thornthwaite and Mather, 1957). The latitude of and mean monthly temperature at the site is accounted for in this method, but precipitation, soil moisture, or vegetative cover are not accounted for. Thus, use of this method poses two uncertainties. First, differences in soil and plant types can cause variations in evapotranspiration, even under conditions of adequate soil moisture (Warren and others, 1968, p. C24). Second, the Thornthwaite method is used to estimate a potential evapotranspiration rate rather than an actual rate. Potential evapotranspiration is the amount of moisture that would transpire and evaporate if there was at no time a deficiency of water. The rate of potential evapotranspiration does not account for dry periods when little moisture is available for transpiration or evaporation; therefore, it generally is much higher than the actual evapotranspiration rate. Potential evapotranspiration in the study area was estimated to be 25.4 in/yr (sheet 3).

To estimate actual evapotranspiration in the study area, monthly potential evapotranspiration rates were compared with the average monthly precipitation rate for the Tuckerton weather station. For those months during which the precipitation rate was greater than the potential evapotranspiration rate, the potential evapotranspiration rate was used as the actual rate. For those months during which the precipitation rate was less than the potential evapotranspiration rate, the monthly precipitation rate was used as the actual evapotranspiration rate. These monthly "actual" evapotranspiration rates were totaled for the year and used in the land-surface water-budget equation. The actual evapotranspiration (ET) was estimated to be 23.4 in/yr.

Alternatively from the evapotranspiration calculations described above, evapotranspiration can be calculated by examining the precipitation-runoff relation. In this method, the geology and topography of the area is accounted for and a long period of record is required to make adjustments for changes in storage in the soil. Reported evapotranspiration rates in and near the study area calculated by Vowinkel and Foster (1981, p. 18) and Parker and others (1964, p. 110) using this method range from 16.3 to 22.5 in/yr.

The rate of leakage and flow to the confined aquifers (L) in the ground-water budget is the sum of vertical leakage through the underlying confining units to the aquifer below (the Piney Point aquifer) plus horizontal flow into the downdip confined aquifer (the Atlantic City 800-foot sand) in the southeastern part of the study area. Leakage to the Piney Point aquifer and flow to the Atlantic City 800-foot sand are depicted in the generalized hydrogeologic section shown in figure 5-5. Leakage rates and flow rates were estimated by using a ground-water-flow model of the Coastal Plain of New Jersey (Pope and Gordon, 1999) and average withdrawal data for 1983-88. In the northwestern part of the water-budget area, the leakage rate (0.14 in/yr) represents vertical flow from the Kirkwood-Cohansey aquifer system to the underlying Piney Point aquifer and horizontal flow to downdip confined aquifers. In the southeastern part of the water-budget area, the leakage rate (0.08 in/yr) represents vertical flow through the confining unit overlying the Atlantic City 800-foot sand. The estimated rate of leakage plus horizontal flow to confined aquifers (L) from the Kirkwood-Cohansey aquifer system over the water-budget area is 0.22 in/yr.

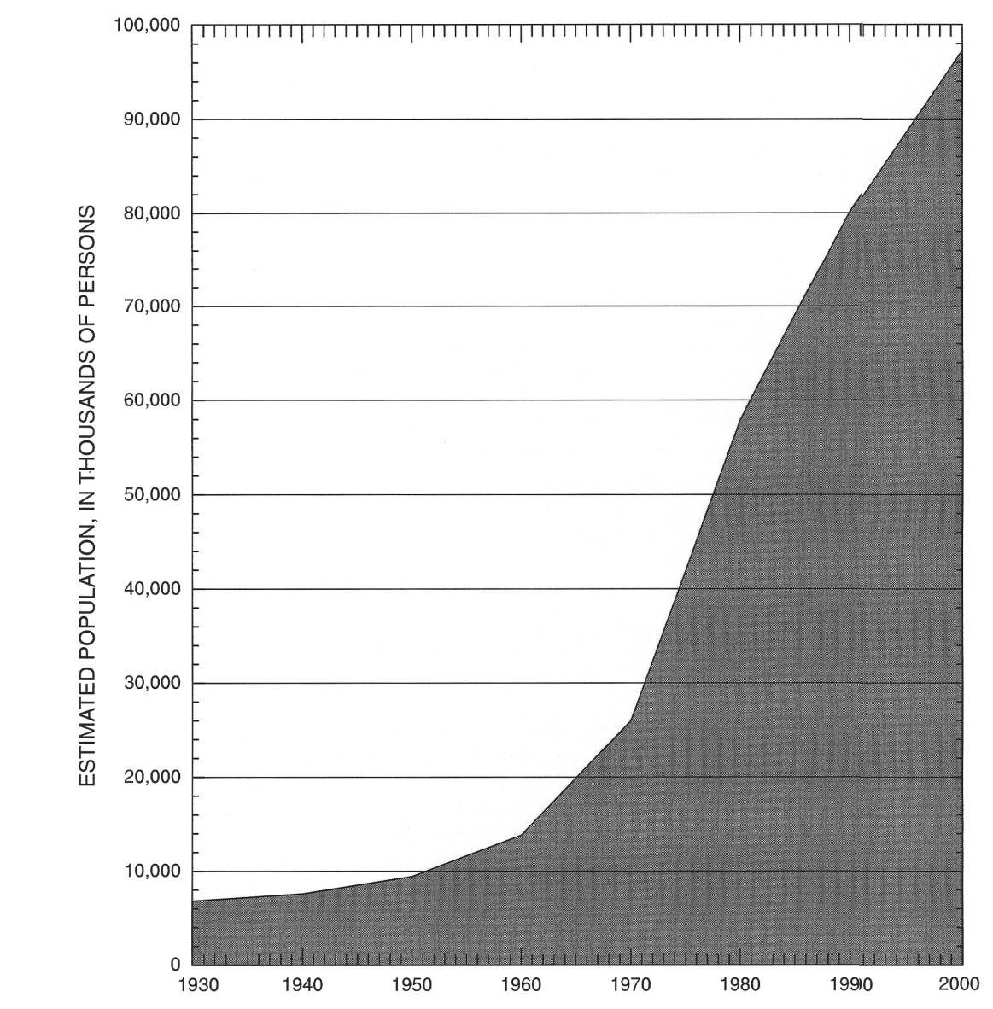


Figure 5-1. Estimated population in the Atlantic Coastal study area, 1930-2000. (Population data for 1930-90 from N.J. Department of Labor (1997); 2000 population from U.S. Bureau of the Census (2001a).)

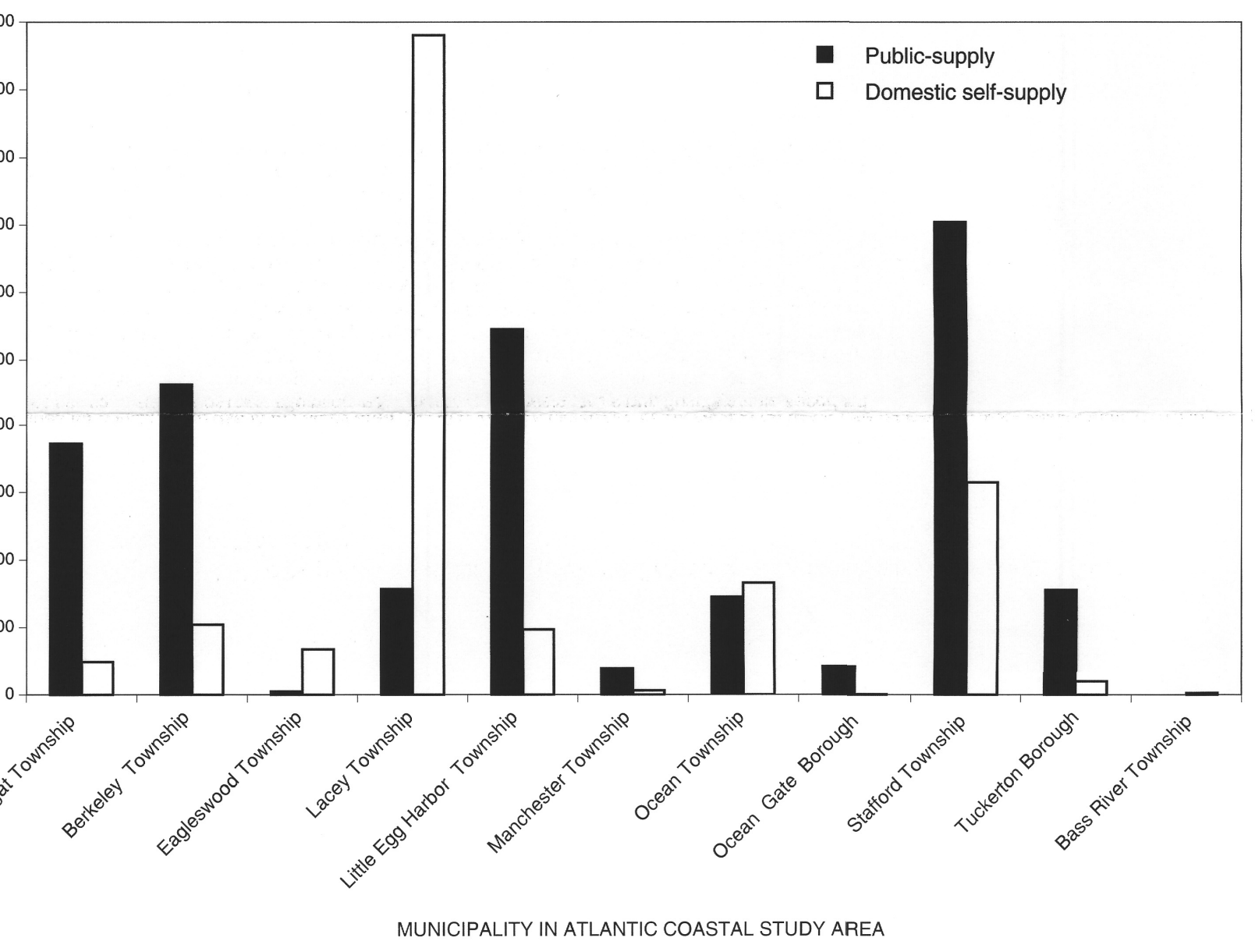


Figure 5-2. Estimated population of public-supply and domestic self-supply users for townships with domestic self-supply withdrawals in the Atlantic Coastal study area, New Jersey, 1999.

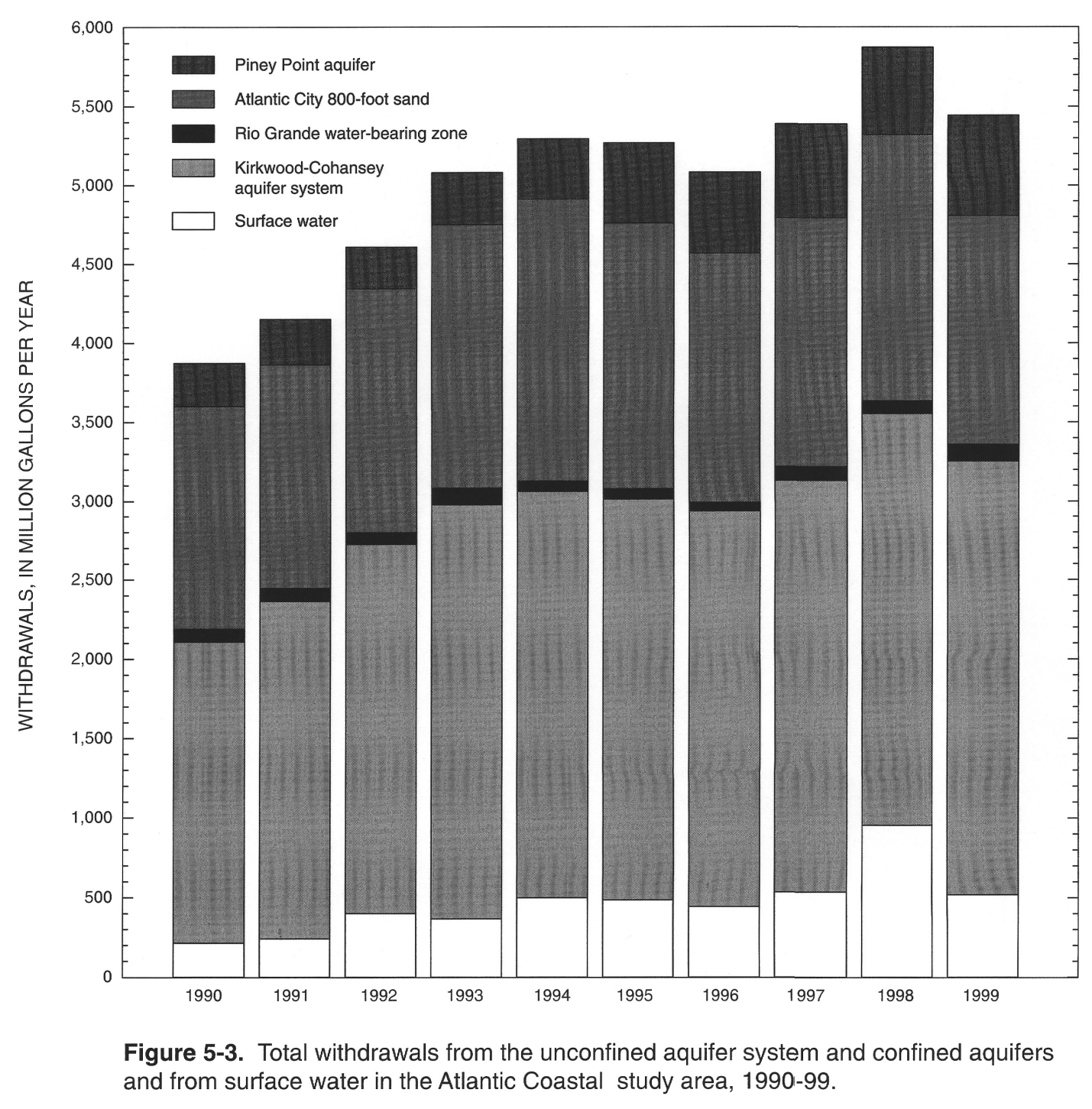
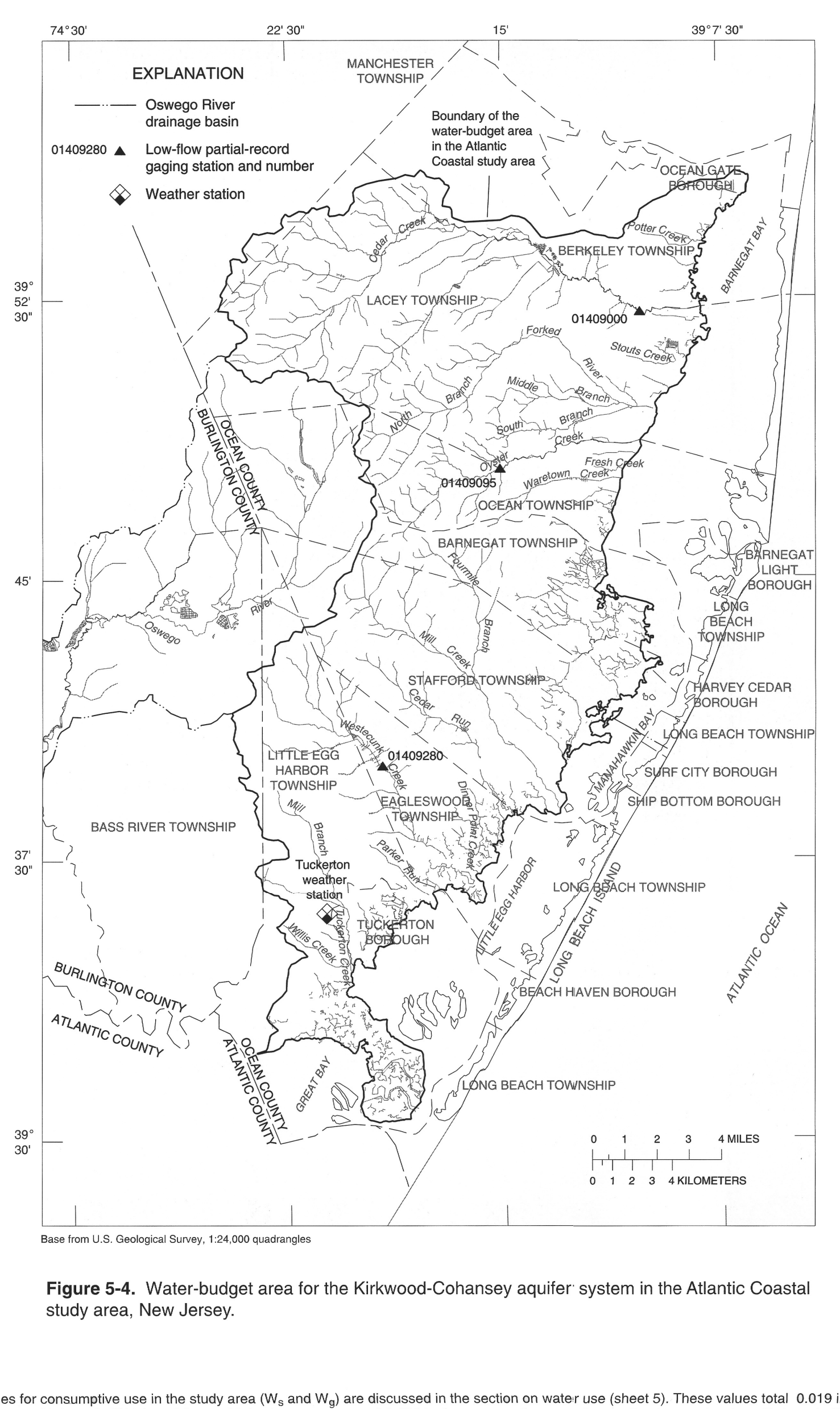


Figure 5-3. Total withdrawals from the unconfined aquifer system and confined aquifers and from surface water in the Atlantic Coastal study area, 1990-99.



Base from U.S. Geological Survey, 1:24,000 quadrangles

Figure 5-4. Water-budget area for the Kirkwood-Cohansey aquifer system in the Atlantic Coastal study area, New Jersey.

The values for consumptive use in the study area (W_s and W_g) are discussed in the section on water use (sheet 5). These values total 0.019 in. for consumptive use of surface-water withdrawals (W_s) for mining and irrigation purposes and 0.404 in. for consumptive use of unconfined-ground-water withdrawals (W_g) (table 5-3).

The values for artificial recharge (R_{as} and R_{ag}) were estimated from available water-use data (table 5-3). Artificial recharge to the surface-water system (R_{as}) was estimated by considering withdrawals from surface water, consumptive water-use rates, and whether discharge points for wastewater-treatment plants were inside or outside the study area. R_{as} derived from commercial, irrigation, and mining sources totaled 0.114 in. over the water-budget area.

Artificial recharge to the unconfined aquifer system (R_{ag}) occurs where public-supply or domestic self-supply withdrawals are pumped from the unconfined aquifer system, treated by means of on-site septic systems, and then discharged to the unconfined aquifer system, thus recharging the aquifer system. R_{ag} was estimated from the total withdrawals for the estimated population with on-site septic systems minus the consumptive use of these withdrawals. The total artificial recharge to the unconfined ground-water system (R_{ag}) in the study area is 0.125 in. over the water-budget area (table 5-3).

Ground-water discharge (Q_g), wastewater-treatment-plant discharge (R_{as}), and surface-water withdrawals (W_s) are not differentiated in the application of the base-flow-separation technique (see sheet 3)--that is,

$$Q_b = Q_g + R_{as} - W_s;$$

however, ground-water discharge (Q_g) can be computed from the equation

$$Q_g = Q_b - R_{as} + W_s\ , \text{ or}$$
$$Q_g = 25.2 - 0.114 + 0.019; \text{ therefore,}$$
$$Q_g = 25.1\ .$$

The ground-water discharge (Q_g) for the water-budget area is 25.1 in. The value is substituted for Q_b in the water-budget equation for the ground-water system.

Water-Budget Analysis

The water-budget values discussed previously can be used to determine a water budget for the part of the study area for which continuous-record discharge data are available. These values are (in inches, and, except for the leakage and consumptive-use values, rounded to one decimal place):

$P = 44.7$
$Q_g = 25.1$
$Q_{dr} = 3.9$
$ET = 23.4$
$W_s = 0.019$
$W_g = 0.404$
$R_{ag} = 0.125$
$R_{as} = 0.114$, and
$L = 0.22$.

By inserting these values into the land-surface and ground-water-system budget equations,

$$P + R_{as} = Q_{dr} + ET + W_s + R_{ns}$$
$$44.7 + 0.114 = 3.9 + 23.4 + 0.019 + R_{ns}$$
$$R_{ns} = 17.5 \text{ in. , and}$$
$$R_{ng} + R_{ag} + R_i = Q_g + W_g + L$$
$$R_{ng} + 0.125 + R_i = 25.1 + 0.404 + 0.22$$
$$R_{ng} + R_i = 25.6 \text{ in.}$$

Table 5-1. Estimated population in the Atlantic Coastal study area, New Jersey, by municipality, 1930-2000

[Population data for 1930-1990 from New Jersey Department of Labor (1997); 2000 population data from U.S. Bureau of the Census (2001a)]

Municipality	Estimated population in study area, in percent[1]	Estimated population							
		1930	1940	1950	1960	1970	1980	1990	2000
					Burlington County				
Bass River Township	3.3	22	19	22	23	26	43	50	50
					Ocean County				
Barnegat Township[2]	55.2	572	576	647	701	849	4,803	6,753	8,429
Barnegat Light Borough	100	144	225	227	287	554	619	675	764
Beach Haven Borough	100	715	746	1,050	1,041	1,488	1,714	1,475	1,278
Berkeley Township	28.4	230	320	440	1,213	2,248	6,574	10,598	11,357
Eagleswood Township	100	483	551	623	766	823	1,009	1,476	1,441
Harvey Cedars Borough	100	53	74	106	134	314	363	362	359
Lacey Township	89.8	621	675	867	1,742	4,145	12,716	19,882	22,761
Little Egg Harbor Township	80.5	440	464	518	681	2,392	6,828	10,733	12,836
Long Beach Township	100	355	425	840	1,561	2,910	3,488	3,407	3,329
Manchester Township	2.3	20	18	35	75	151	559	719	895
Ocean Township	96.6	373	412	502	889	2,146	3,604	5,231	6,231
Ocean Gate Borough	40.8	70	98	184	288	441	565	847	847
Ship Bottom Borough	100	277	396	533	717	1,079	1,427	1,352	1,384
Stafford Township	90.4	939	1,132	1,217	1,744	3,330	9,388	12,045	20,369
Surf City Borough	100	76	129	291	419	1,129	1,571	1,375	1,442
Tuckerton Borough	100	1,429	1,320	1,332	1,536	1,926	2,472	3,048	3,517
TOTAL		6,819	7,580	9,434	13,817	25,951	57,743	80,028	97,239

[1] Estimated from land-surface area of municipality within the Atlantic Coastal study area.
[2] Union Township name changed to Barnegat Township, January 1, 1977.

Table 5-2. Withdrawals from the Kirkwood-Cohansey aquifer system in the water-budget area of the Atlantic Coastal study area, New Jersey, by water-use category, 1985 and 1999, in million gallons

[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.)]

Water-use category	Withdrawals (million gallons)		Percent of total withdrawals	
	1985	1999	1985	1999
Public supply	608.636	1,607.963	41.0	58.9
Domestic self-supply[1]	721.54	1,077.4	48.6	39.4
Commercial	34.186	25.7	2.3	.9
Industrial	.028	3.657	<.1	.1
Mining	16.28	1.379	1.1	.1
Irrigation	7.753	6.41	.5	.2
Thermoelectric power	91.411	8.507	6.2	.3
Sewage treatment	4.003	3.72	.3	.1
TOTAL[2]	1,483.837	2,734.736	100	100

[1] Estimated self-supplied withdrawals.
[2] Total does not include withdrawals on barrier islands. (Withdrawals from this aquifer system on the barrier islands are minimal.)

Table 5-3. Withdrawals and consumptive use of surface water and ground water from the Kirkwood-Cohansey aquifer system, and artificial recharge, in the water-budget area of the Atlantic Coastal study area, New Jersey, 1999

Water-use category	Withdrawals		Consumptive use		Artificial recharge[1]	
	Million gallons	Inches over water-budget area	Millon gallons	Inches over water-budget area	Million gallons	Inches over water-budget area
Ground water						
Public supply						
Domestic and commercial deliveries[2]	1,366.769	0.334	[3]1,366.769	0.334	0	0
Maintenance, losses, and public water use[4]	241.194	.059	48.239	.012	192.956	.047
Domestic self-supply[5]	1,077.4	.263	215.48	.053	[6]319.086	.078
Commercial self-supply	25.7	.006	1.028	.000	[7]24.589	.006
Industrial	3.657	.001	[8]3.657	.001	0	0
Mining	1.379	.000	.11	.000	1.269	.000
Irrigation	6.41	.002	5.769	.001	.641	.000
Sewage treatment	3.72	.001	[9]3.72	.001	0	0
Thermoelectric power	8.507	.002	[9]8.507	.002	0	0
Ground-water total[10]	2,734.736	.669	1,653.279	.404	[11]512.683	.125
Surface water						
Irrigation						
Non-cranberry irrigation	45.09	.011	40.581	.010	4.509	.001
Cranberry irrigation[12]	3.422	.001	0	0	3.422	.001
Mining	469.243	.115	37.539	.009	431.704	.106
Surface-water total	517.755	.127	78.12	.019	[13]465.493	.114
TOTAL	3,252.491	.796	1,731.399	.423	978.176	.239

[1] Artificial recharge equals ground-water or surface-water withdrawals minus consumptive use.
[2] Deliveries by public suppliers are estimated to be 0.82 (82 percent) for domestic use, and 0.03 (3 percent) for commercial use, of total public-supply withdrawals.
[3] All wastewater discharged outside the water-budget area.
[4] Maintenance, losses, and public water use are 0.15 (15 percent) of total public-supply withdrawals (Nawyn, 1997).
[5] Domestic self-supply total is based on a per capita use of 85 gallons per person per day.
[6] Artifical recharge includes both public-supply and domestic self-supply users with on-site septic systems. About 14 percent of the population in study area has on-site septic systems.
[7] Except for one self-supplied commercial facility, all have their own wastewater-treatment facility, which discharge to surface water inside the water-budget area.
[8] All water consumed because water from dewatering well discharges to sewage-treatment plant.
[9] All water discharged outside the water-budget area.
[10] This total includes only withdrawals from within water-budget area, which does not include barrier islands. (Ground-water withdrawals from this aquifer system on the barrier islands are minimal; there are no surface-water withdrawals.)
[11] This total does not include recharge from commercial self-supply or mining because the wastewater is discharged to surface water within the water-budget area.
[12] All cranberry irrigation is considered non-consumptive (Clawges and Titus, 1993).
[13] Surface-water total includes surface water and a portion of commercial and mining ground-water withdrawals because wastewater is discharged to surface water within the water-budget area.

Table 5-4. Estimated annual ground-water withdrawals from domestic self-supply wells in the Kirkwood-Cohansey aquifer system in the Atlantic Coastal study area, 1990 and 1999

[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.); population data from U.S. Bureau of the Census (2000)]

Municipality	Million gallons		Estimated percentage of population in municipality using domestic self-supplied water in 1990[1]
	1990	1999	
	Burlington County		
Bass River Township	1.5	1.6	98.9
	Ocean County		
Barnegat Township	24.2	30.3	11.6
Berkeley Township	57.4	61.4	18.4
Eagleswood Township	42.8	42.0	93.5
Lacey Township	497.9	567.6	86.2
Little Egg Harbor Township	50.0	59.9	15.1
Manchester Township	3.6	3.8	13.9
Ocean Township	86.7	103.2	53.4
Ocean Gate Borough	.3	.3	1.0
Stafford Township	115.9	194.8	30.9
Tuckerton Borough	10.9	12.6	11.5
TOTAL	891.3	1,077.4	

[1] Estimated from land-surface area of municipality within the Atlantic Coastal study area.

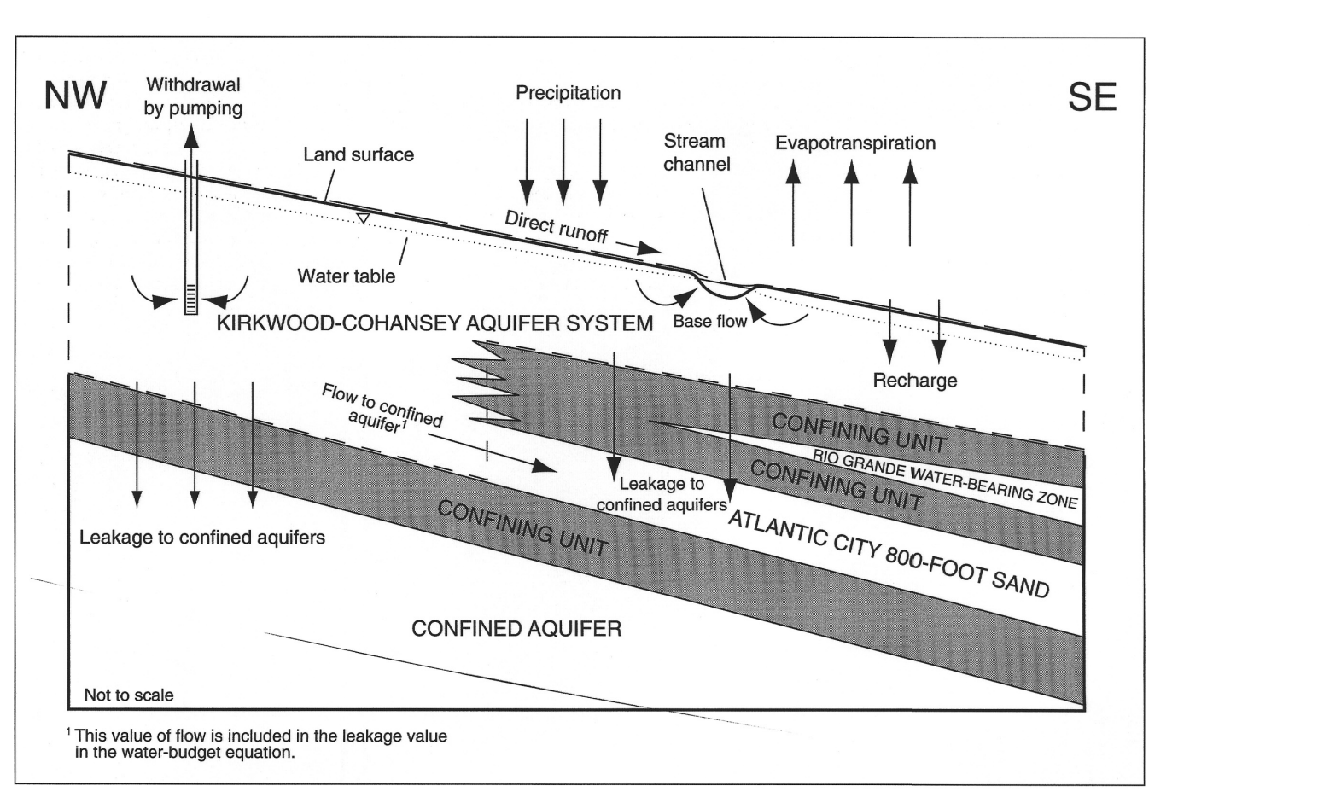

NW
SE
Withdrawal by pumping
Precipitation
Land surface
Stream channel
Evapotranspiration
Direct runoff
Water table
KIRKWOOD-COHANSEY AQUIFER SYSTEM
Base flow
Recharge
Flow to confined aquifer¹
CONFINING UNIT
RIO GRANDE WATER-BEARING ZONE
CONFINING UNIT
Leakage to confined aquifers
ATLANTIC CITY 800-FOOT SAND
CONFINING UNIT
Leakage to confined aquifers
CONFINED AQUIFER
Not to scale
¹ This value of flow is included in the leakage value in the water-budget equation.

Figure 5-5. Generalized northwest-southeast hydrogeologic section through the Atlantic Coastal study area, showing a schematic diagram of the hydrologic cycle. (Modified from Johnson and Watt, 1996; dashed line is budget-volume boundary.)

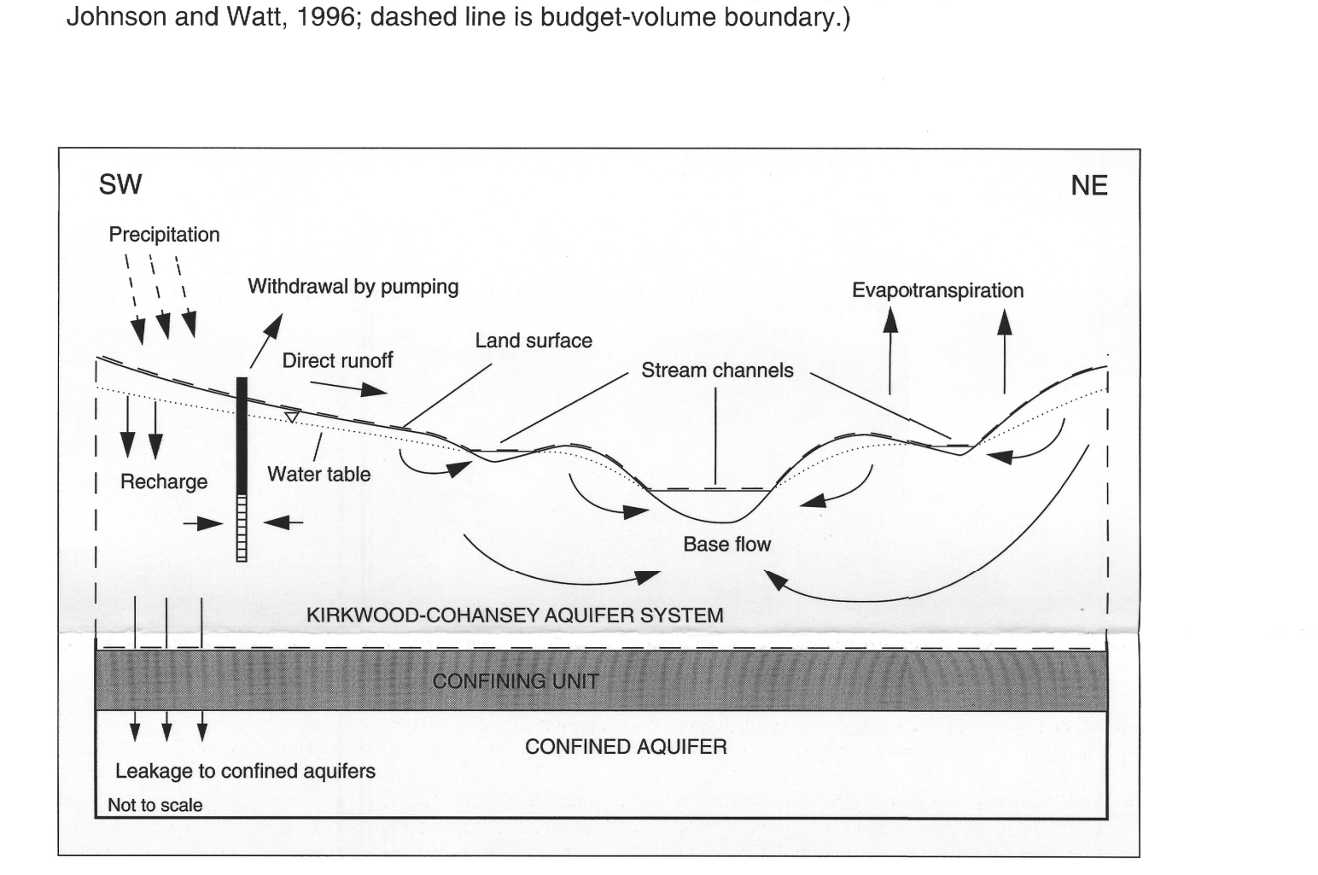


Figure 5-6. Generalized southwest-northeast hydrogeologic section through the Atlantic Coastal study area, showing a schematic diagram of the hydrologic cycle. (Modified from Johnson and Watt, 1996; dashed line is budget-volume boundary.)

The recharge from the land surface to the unconfined aquifer system in the water-budget area (R_{ns}) does not equal the recharge plus ground-water inflow computed for the ground-water budget ($R_{ng} + R_i$). Therefore, it can be assumed that the R_i term is not negligible and ground water from adjacent surface-water basins outside the study area flows into the budget volume. It appears that ground-water discharge in the Oyster Creek Basin is greater than precipitation (fig. 3-6 on sheet 3). Further, the mean annual discharge of the Oswego River at Harrisville (01410000) is 37 percent of the mean annual precipitation (Johnson and Watt, 1996), which is less than in the adjacent basins (for example, 62 percent in Westecunk Creek (01409280)). The headwaters of the Oswego River are adjacent to the surface-water drainage divide of the Oyster Creek drainage basin (fig. 5-4). If the surface-water and ground-water drainage divides in the Oswego River Basin do not coincide, this basin may contribute lateral ground-water flow to the ground-water system of the Oyster Creek drainage basin. It is possible that higher land-surface elevations outside the study area allow for inflow of ground water from the Oswego River drainage basin (Rhodehamel, 1970; Fusillo and other, 1980). Recharge from the Oswego River drainage basin may percolate deep into the Kirkwood-Cohansey aquifer system and discharge at a distance from its recharge point as base flow in the Oyster Creek drainage basin.

The difference between R_{ng} and R_{ns} gives an estimate of the ground-water inflow from adjacent surface-water basins outside the study area. The calculated difference is 8.1 in.--that is,

$$R_i = R_{ng} - R_{ns}\ , \text{ or}$$
$$R_i = 25.6 - 17.5 = 8.1\ .$$

The ground-water-budget equation then becomes

$$R_{ng} + R_{ag} + R_i = Q_g + W_g + L$$
$$R_{ng} = 17.5 \text{ in.}$$

The source of water in the hydrologic cycle is precipitation, and the two major discharge components of the hydrologic cycle are evapotranspiration and base flow (ground-water discharge). Actual evapotranspiration in the water budget is approximately 52 percent of the average annual precipitation during water years 1986-95. Surface-water discharge is composed of base flow and direct runoff. The natural recharge to the aquifer system from precipitation (R_{ns}) calculated in the land-surface equation for the water-budget area is estimated to be 17.5 in., and direct runoff (Q_{dr}) is estimated to be 3.9 in. These two discharge components combined were about 48 percent of the average annual precipitation during water years 1986-95.

Most of the natural ground-water recharge to the aquifer (R_{ng}) and ground-water inflow from adjacent drainage basins (R_i) is removed from the ground-water system as ground-water discharge (Q_g). As a result, a substantial increase in ground-water withdrawals from either the confined or the unconfined aquifer may reduce the amount of ground water available for Q_g, thereby increasing the likelihood that streamflow would be reduced. A substantial increase in withdrawals from the confined aquifers in the study area may induce leakage from the overlying unconfined aquifer, also reducing ground-water discharge, particularly base flow (Q_b).

The water-budget estimates of the flow of water into and out of the unconfined-ground-water and surface-water systems in the study area and of the consumptive use of this water are for current (1999) conditions. This type of water-budget analysis can be updated periodically to assess changes in the aquifer system, such as increased withdrawals.

Table 5-5. Total ground-water withdrawals by aquifer and surface-water withdrawals in the Atlantic Coastal study area, New Jersey, 1990-99

[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 withdrawals in million gallons]

Year	Surface water[1]	Unconfined aquifer	Confined aquifer			Total
		Kirkwood-Cohansey aquifer system[2]	Rio Grande water-bearing zone[3]	Atlantic City 800-foot sand[4]	Piney Point aquifer[3]	
			Withdrawals, excluding barrier islands			
1990	213.896	1,893.446	32.92	676.051	81.912	2,898.225
1991	241.326	2,121.704	19.958	594.427	87.795	3,065.21
1992	400.867	2,322.587	19.318	751.207	81.741	3,575.72
1993	366.655	2,611.892	35.076	852.355	94.858	3,960.836
1994	499.961	2,561.801	17.889	880.884	147.285	4,107.82
1995	486.248	2,527.714	8.438	853.581	230.608	4,106.589
1996	444.721	2,492.769	1.386	810.604	288.164	4,037.644
1997	535.638	2,592.916	35.479	782.885	308.891	4,255.809
1998	954.306	2,597.337	32.068	831.395	308.092	4,723.198
1999	518.932	2,734.736	52.902	565.916	325.442	4,197.928
			Withdrawals from barrier islands			
1990	0	0.256	50.396	814.462	190.252	1,004.97
1991	0	.441	63.282	823.019	199.215	1,022.675
1992	0	.344	56.328	794.226	181.892	976.462
1993	0	0	69.851	815.147	182.586	997.733
1994	0	0	49.604	902.326	235.377	1,137.703
1995	0	0	56.369	828.025	277.843	1,105.868
1996	0	0	53.698	765.582	225.698	991.28
1997	0	2.637	52.412	790.553	287.446	1,080.636
1998	0	.889	49.723	855.511	245.526	1,101.926
1999	0	.877	53.078	882.455	310.25	1,193.582

[1] Withdrawals are for irrigation and mining purposes.
[2] Includes estimated domestic self-supply withdrawals for each year. The total domestic self-supply withdrawals for 1990 and 1999 were estimated from population data obtained from the 1990 and 2000 census data, respectively. For 1990 and 1991, total domestic self-supply withdrawals are estimated to be 891.3 million gallons. For 1999, total domestic self-supply withdrawals are estimated to be 1,077.4 million gallons. For 1992-98, the total estimated domestic self-supply withdrawals are the average of the estimates for 1990 and 1999, or 984.35 millions gallons.
[3] Withdrawals are for public supply.
[4] These withdrawals are mostly for public supply except for some commercial withdrawals in 1990, 1991, and 1992 (3.65, 0.19, and 0.261 million gallons, respectively).

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by

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