HYDROGEOLOGY OF THE REGION OF GREENWICH TOWNSHIP, GLOUCESTER COUNTY, NEW JERSEY

By Cynthia Barton and Jane Kozinski

U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Temperature	
degree Celsius (°C)	°F = 1.8 x °C + 32	degree Fahrenheit (°F)

GLOSSARY

Aquifer. A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Arkosic sand. Sand containing 25 percent or more feldspar usually derived from the disintegration of granitic rocks.

Cone of depression. A low area in the potentiometric surface usually centered in the area of greatest concentration of withdrawals.

Confining unit. A body of relatively impermeable material stratigraphically adjacent to one or more aquifers. The hydraulic conductivity may range from nearly zero to some value several orders of magnitude lower than that of the aquifer.

Dip. The angle at which the formation or bed is inclined from the horizontal, measured at a right angle to the strike (trend of the formation or bed). Downdip indicates a direction that is downward and parallel to the dip inclination, and updip indicates the upward direction.

Equipotential line. A line on a map or section along which total heads are the same.

Flow line. The idealized path followed by particles of water.

Graywacke sand. Sand that is dark in color, contains a predominant clay matrix, and has a large percentage of rock fragments such as chert, quartzite, phyllite, and igneous rocks.

Head, static. The height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the pressure at a given point. Head, when used alone in this report, is understood to mean static head.

Hydraulic conductivity. A measure of the ability of a material to transmit water.

Hydraulic gradient. The change in static head per unit of distance in a given direction. If not specified, the direction is understood to be that of the maximum rate of change in head.

Lunar day. The period of the moon's rotation about the Earth. (The mean lunar day is equal to 24 hours and 50 minutes.)

Potentiometric surface. A surface that represents the static head in an aquifer. The potentiometric surface is defined by the levels to which water will rise in tightly cased wells open to the aquifer. See head, static.

Sea level. Sea level refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929." It is the average sea level based on tidal observations at various stations along the coasts during 1900-29.

Solar day. The period of the Earth's rotation on its axis. (The mean solar day is equal to 24 hours.)

Specific capacity (of a well). The rate of discharge of water from the well divided by the drawdown in the well; used to estimate the aquifer's transmissivity.

Stage. Elevation of a water surface above any chosen datum plane.

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ABSTRACT

The U.S. Geological Survey in cooperation with Greenwich Township and the New Jersey Department of Environmental Protection studied the hydrogeology of, and hydrologic conditions in, a 115-square-mile area in and near Greenwich Township in northern Gloucester County, New Jersey.

In the study area, a veneer of upper Cenozoic alluvium overlies a regional system of aquifers and confining units that consists of a southeastward-dipping (40-60 feet per mile), seaward-thickening wedge of Cretaceous delta-plain deposits. The Merchantville-Woodbury confining unit overlies the Potomac-Raritan-Magothy aquifer system, which consists of three aquifers that together are the source of 99 percent of the region's ground-water withdrawals. The confining unit between the upper and middle aquifers is discontinuous, and a third confining unit that consists of extensive clay beds divides the middle aquifer into upper and lower parts. This aquifer system is underlain by lower Paleozoic and Precambrian bedrock.

Water levels in the shallow and regional ground-water systems have declined since the late 1800's as a result of pumpage. The study area lies within the northwestern part of a large regional cone of depression in the potentiometric surface of the aquifer system. Hydraulic gradients indicate a potential for induced recharge from the Delaware River, downward movement of water in the aquifer system, and east-southeastward flow in the confined aquifer toward pumping centers at a gradient of 3 to 15 feet per mile. Water levels in wells are below sea level where connection to the river is limited by dikes and floodgates. Ground-water levels fluctuate less than 2.5 feet due to tides and 5 feet as a result of seasonal use of ground water.

A steady-state water budget for 1976-86 of 60.4 million gallons per day, includes recharge, induced recharge, subsurface lateral flow across regional boundaries, vertical leakage through the overlying confining unit, pumpage, base flow, and discharge to wetlands. Because water loss through pumping and subsurface flow to the southeast, induced by pumping outside the study area, is replaced primarily by river recharge and subsurface flow across northeastern and southwestern boundaries, the quality of river recharge and the potential for migration of saltwater from the confined system are critical factors in the maintenance of ground-water quality.

INTRODUCTION

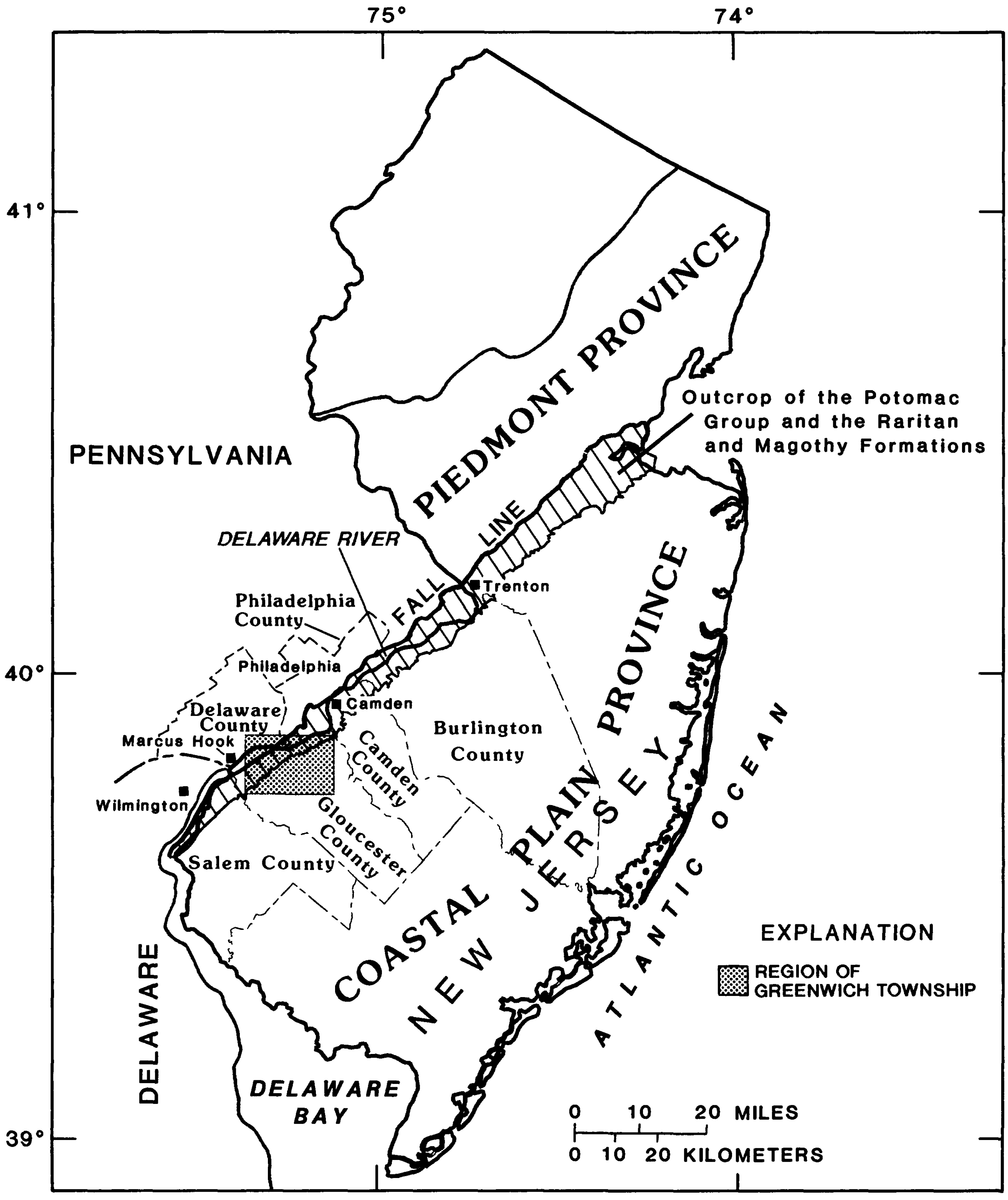
Contamination originating from spills of organic chemicals, such as gasoline and chlorinated solvents, has been identified as a major threat to the ground-water resources of the State of New Jersey (Tucker, 1981). The problem is particularly acute in the Greenwich Township region--a 115-mi^2 (square mile) area adjacent to the Delaware River estuary, principally in northern Gloucester County, New Jersey (fig. 1). The region lies primarily on, or a few miles downdip from, the outcrop of the Potomac-Raritan-Magothy aquifer system. This aquifer system is the major source of water in the New Jersey Coastal Plain (Vowinkel, 1984) and is the principal source of potable ground water in the Greenwich Township region. An industrial complex within the recharge area includes at least five industries that have onsite ground-water contamination possibly resulting from the use, production, storage, and disposal of hazardous organic and inorganic substances (Fusillo and others, 1984, table 6). Offsite, subsurface migration of contaminants could ultimately force the closing of one of the six public-supply wells in Greenwich Township and Paulsboro Borough (well 15-347). Water samples from four more of these wells have contained low concentrations (generally below drinking-water standards) of purgeable organic compounds since 1985.

Parts of the Potomac-Raritan-Magothy aquifer system within the region contain saline water (concentrations greater than 250 milligrams of chloride per liter of water) (Barksdale and others, 1958, p. 124-128, fig. 24; Hardt and Hilton, 1969, p. 12-15, fig. 5; J.C. Lewis, U.S. Geological Survey, written commun., 1986). The presence of saline water in the aquifer system is caused by the intrusion of saltwater from the Delaware River estuary and (or) from deeper confined parts of the aquifer system in the southwestern part of the region (Barksdale and others, 1958, p. 125, fig. 24; Hardt and Hilton, 1969, fig. 4). Hence, the potential for saltwater intrusion into the aquifers that are used to supply potable water is an additional issue of concern for the communities in the Greenwich Township region.

Water managers in Greenwich Township and Paulsboro Borough need quantitative information regarding the quantity and quality of water resources in the region. They also need to know the potential for contamination of existing water supplies and to be aware of alternatives for development of these supplies if one or more of the wells in the region becomes unusable. To address this concern, the U.S. Geological Survey, in cooperation with Greenwich Township and the New Jersey Department of Environmental Protection, conducted a comprehensive assessment of the ground-water resources in the region from 1986-88. The objectives of this study were to (1) characterize the hydrogeology of, and hydrologic conditions in, the Greenwich Township region; (2) assess the ground-water quality; (3) develop a ground-water-flow model; (4) evaluate the potential for contamination of the potable-water supplies; and (5) evaluate alternatives for the development of the ground-water resources. This report addresses the first objective.

Purpose and Scope

This report describes the hydrogeology of, and hydrologic conditions in, the Greenwich Township region. The report contains hydrogeologic sections, maps of the altitude of the top of hydrogeologic units, and



Base from U.S. Geological Survey
1:250,000 quadrangles

Figure 1.--Location of the region of Greenwich Township, Gloucester County, New Jersey.

estimates of the hydraulic properties of the aquifers and confining units. It includes a description of surface water in the region; a determination of the amount and distribution of ground-water withdrawals during 1956-86; a comparison of 1986 ground-water levels and flow directions with those in 1983; an evaluation of long-term and seasonal changes in ground-water levels; an evaluation of the influence of tidal changes on ground-water levels; and a quantitative, steady-state description of the regional water budget. This report does not include an assessment of ground-water quality.

Previous Investigations

Studies in areas adjacent to or including the Greenwich Township region have focused primarily on assessing ground-water resources or simulating regional ground-water flow in the Potomac-Raritan-Magothy aquifer system. These investigations were conducted in the lower Delaware River valley (Barksdale and others, 1958), the Coastal Plain of southeastern Pennsylvania (Greenman and others, 1961), the Delaware River basin (Parker and others, 1964), Gloucester County (Hardt and Hilton, 1969), Salem County (Rosenau and others, 1969), Camden County and vicinity (Farlekas and others, 1976; A.S. Navoy, U.S. Geological Survey, written commun., 1986), Logan Township (Andres, 1984; J.C. Lewis, U.S. Geological Survey, written commun., 1986), Philadelphia, Pennsylvania (Sloto, 1986), Delaware County, Pennsylvania (W.T. Balmer and D.K. Davis, U.S. Geological Survey, written commun., 1988), and the Coastal Plain of New Jersey (Gill and Farlekas, 1976; Luzier, 1980; Harbaugh and others, 1980; Zapecza, 1989; and Martin, 1987).

Geologic studies in southern New Jersey and the northern Delmarva Peninsula include descriptions of the stratigraphy of post-Magothy Formation Upper Cretaceous (Owens and others, 1970) and upper Cenozoic sediments (Owens and Minard, 1979). Evaluations of water levels in the aquifers of the region include maps of the water table in Philadelphia, Pennsylvania (Paulachok and Wood, 1984), and in southern Gloucester County, New Jersey (P.J. Lacombe, U.S. Geological Survey, written commun., 1988), and maps of the potentiometric surfaces of the major aquifers of the New Jersey Coastal Plain in 1983 (Eckel and Walker, 1986).

Well-Numbering System

Two systems are used by the U.S. Geological Survey in New Jersey to identify wells. One is based on a 15-digit station number or U.S. Geological Survey National Water Data Storage and Retrieval System (WATSTORE) identifier. The first six digits represent degrees, minutes, and seconds of latitude, and the next seven digits represent degrees, minutes, and seconds of longitude. The remaining two digits indicate the sequence in which wells with the same latitude and longitude were inventoried. The WATSTORE identifier is used throughout the United States to access water-quality information, and also is used in the National Water Information System data base maintained by the U.S. Geological Survey.

The second numbering system is based on a six-digit number developed by the New Jersey District of the U.S. Geological Survey. The well number consists of a two-digit county code and a four-digit sequence number that indicates the order in which wells within the county were inventoried. The county code used in this report is 15 for Gloucester County.

Acknowledgments

The authors are grateful to personnel of Greenwich Township; Paulsboro Borough; Mobil Oil Corporation; Hercules, Inc.; E.I. Dupont; Air Products and Chemicals, Inc.; EM Diagnostic Systems, Inc.; Sun Oil Company; BP Oil Company; and the New Jersey Department of Environmental Protection for their support of this investigation. We also thank the landowners in the Greenwich Township region who permitted access to their wells for data collection and the representatives of the companies (Air Products and Chemicals, Inc.; BP Oil Company; Chemical Leaman Tank Lines; E.I. Dupont; EM Diagnostic Systems, Inc.; Essex Chemical Company; Exxon; Hercules Incorporated; Mobil Oil Corporation; Rollins Environmental Services, Inc.; and G.P.M. Associates) who provided detailed geologic, water-level, and water-use data. Special thanks go to Mr. William Stefka of Greenwich Township for allowing us to install wells on his property and to Mobil Oil Corporation for allowing us to install a tide gage on its property.

DESCRIPTION OF STUDY AREA

Location and Physiography

The Greenwich Township region comprises approximately 115 mi^2 (square miles) in and near Greenwich Township, Gloucester County, New Jersey (pl. 1a). More than 85 percent of the Greenwich Township region, including all or part of Deptford, East Greenwich, Greenwich, Harrison, Logan, Mantua, West Deptford, and Woolwich Townships, Woodbury City, and Paulsboro Borough, is in northern Gloucester County, New Jersey. The region also includes the City of Chester and Tinicum Township, on the northwestern bank of the Delaware River in southern Delaware and Philadelphia Counties, Pennsylvania; however, little data are available for these areas.

The Greenwich Township region includes parts of two major physiographic provinces (fig. 1). In the extreme northwestern part of the region in Pennsylvania, Precambrian and lower Paleozoic crystalline metamorphic and igneous rocks of the Piedmont physiographic province underlie the surface. The Piedmont is bounded to the southeast by the Fall Line (fig. 1), which generally separates the Piedmont from the Atlantic Coastal Plain physiographic province. The Atlantic Coastal Plain, which extends across the remainder of the study area, is a southeastward-dipping, seaward-thickening wedge of unconsolidated to loosely consolidated sediments.

The New Jersey part of the Coastal Plain consists of three physiographic subprovinces--lowlands, intermediate uplands, and uplands (Owens and Minard, 1979, p. D3, fig. 3). All of the Coastal Plain in the Greenwich Township region lies within the lowland subprovince. In this region, land surface slopes gently northwestward toward the Delaware River. Land-surface altitude ranges from sea level near the Delaware River to 140 ft (feet) above sea level in the southeastern part of the study area. The lowest point in the dredged channel of the Delaware River is about 45 ft below sea level (Luzier, 1980, p. 21). An area of about 2.7 mi^2 in the Repaupo Creek drainage basin in the central part of the region (fig. 2) is below sea level. Areas less than 25 ft above sea level generally are covered by tidal-marsh deposits and vegetation; in Greenwich Township, however, tidal flooding is limited by dikes and floodgates.

Climate

The climate of the Greenwich Township region is predominantly continental, with warm summers and moderately cold winters. Prevailing winds are from the northwest. The region lies in the southwest climatic zone of New Jersey (Ludlum, 1983, p. 35). This zone, located in the lower Delaware River drainage basin, is characterized by low elevation, low relief, and tidal creeks. Frequent nightly fogs occur because of the proximity of the Delaware River. These fogs insulate the surface and reduce radiant heat losses from the earth, resulting in mean temperatures for this zone that are higher than in other climatic zones of New Jersey (Ludlum, 1983, p. 35). At the National Weather Service station at Marcus Hook, Pennsylvania (fig. 1), the mean annual temperature is 56.1 °F (degrees Fahrenheit) for the period from 1941-70. The extreme low mean monthly temperature of 33.9 °F occurred in January and the extreme mean high of 78.0 °F occurred in July.

Annual precipitation tends to be much lower in the southwest climatic zone than in more topographically varied regions of New Jersey (Ludlum, 1983, p. 35). Figure 2, a bar graph of annual precipitation at the Marcus Hook, Pennsylvania, weather station from 1931-86, illustrates long-term precipitation trends in the region. The mean annual precipitation at this station for this period is 42.3 in. (inches). The most severe and prolonged drought in this area, and throughout New Jersey, since precipitation measurement began in the early 1820's, took place from 1961 to 1966 (Anderson and others, 1972, p. 375). Analysis of monthly precipitation trends from 1931 to 1986 indicates that the driest month is October, with a mean precipitation of 2.63 in., and the wettest month is July, with a mean precipitation of 4.18 in.

METHODS OF STUDY

Hydrogeology

The hydrogeology of the Greenwich Township region was investigated to assess the ground-water resources in the region. Except for Cenozoic surficial deposits (table 1), hydrogeologic units overlying the Englishtown aquifer system, such as the Wenonah-Mount Laurel aquifer, are not discussed in this report. A description of these units can be found in a report on the hydrogeologic framework of the New Jersey Coastal Plain by Zapecza (1989).

In general, the outcrop of a hydrogeologic unit is considered to be an approximation of the surface configuration of an aquifer or confining unit if vegetation, structures, and paved surfaces were removed; the subcrop of a unit underlies other deposits. In some parts of the Greenwich Township region, aquifers and confining units are not covered by other deposits, so that use of the term "outcrop" is appropriate. In most of the region, however, aquifers and confining units underlie upper Cenozoic deposits so that use of the term "subcrop" is appropriate.

The location of the Fall Line (fig. 1) was originally mapped at a scale of 1:250,000 (U.S. Geological Survey, 1967). The outcrops of the geologic units within the region were compiled at a scale of 1:63,360 (1 in. = 1 mi)

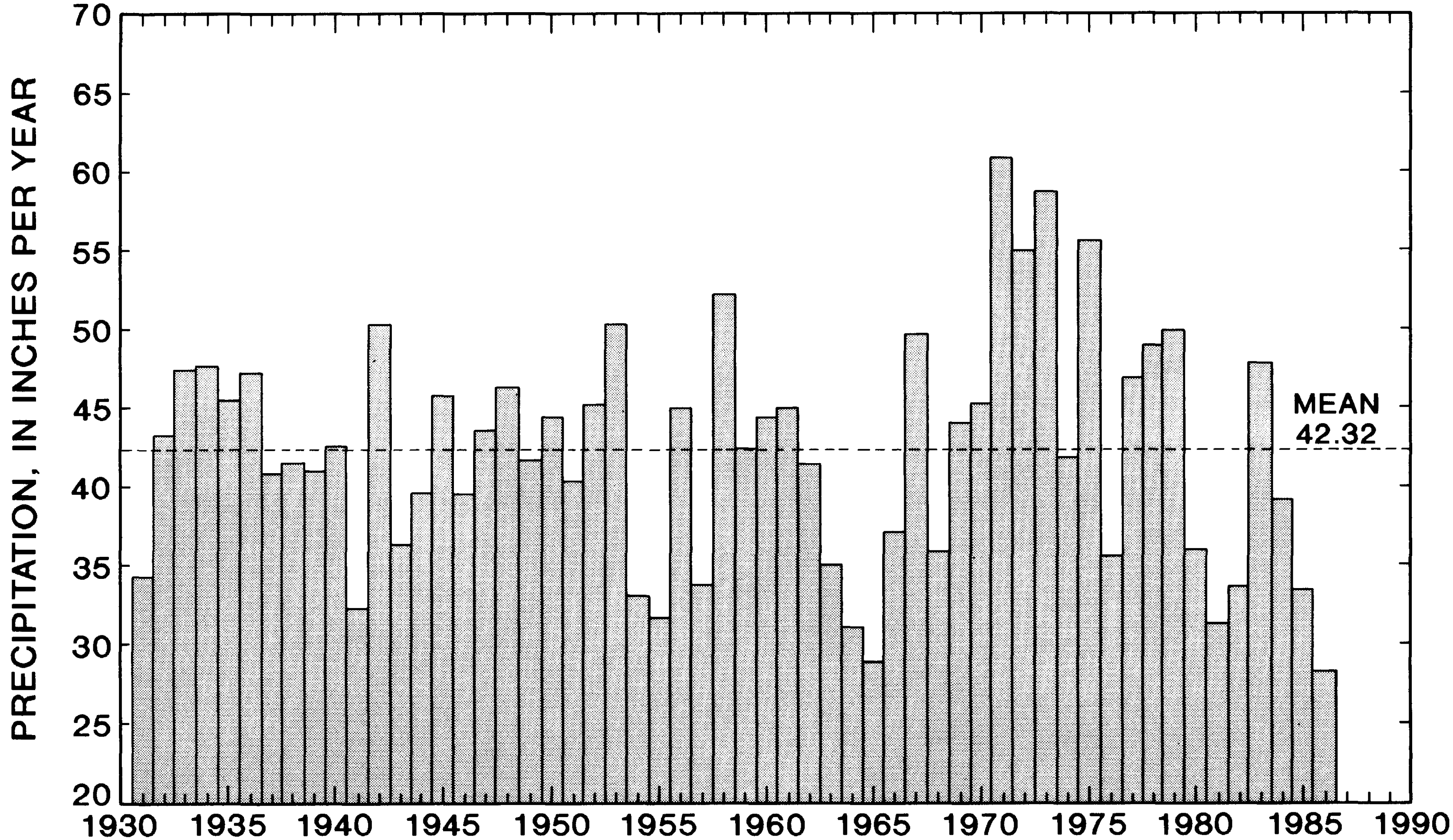


Figure 2.--Annual precipitation at Marcus Hook, Pennsylvania, weather station, 1931-86.

Table 1.--Geologic and hydrogeologic units in the region of Greenwich Township, Gloucester County, New Jersey

[Modified from Zapecza (1989, table 2)]

<table>
<tr><th>Era</th><th>System</th><th>Series</th><th colspan="2">Geologic unit</th><th colspan="2">Hydrogeologic unit</th></tr>
<tr><td rowspan="7">Cenozoic</td><td rowspan="3">Quaternary</td><td>Holocene</td><td rowspan="3">Trenton Gravel</td><td>Alluvial deposits</td><td rowspan="5" colspan="2">Surficial material, commonly hydraulically connected to underlying aquifers. Locally some units may act as confining units. Thick sands are capable of yielding large quantities of water.</td></tr>
<tr><td rowspan="2">Pleistocene</td><td>Van Sciver Lake beds</td></tr>
<tr><td>Spring Lake beds</td></tr>
<tr><td rowspan="4">Tertiary</td><td rowspan="2">Miocene</td><td colspan="2">Pensauken Formation</td></tr>
<tr><td colspan="2">Bridgeton Formation</td></tr>
<tr><td>Eocene</td><td rowspan="2" colspan="2">Other geologic units are found in the southeastern corner of the region but are not discussed in this report. See Zapecza (1989) for detailed discussion of these units.</td><td rowspan="2" colspan="2">Hydrogeologic units not discussed in this report.</td></tr>
<tr><td>Paleocene</td></tr>
<tr><td rowspan="8">Mesozoic</td><td rowspan="8">Cretaceous</td><td rowspan="7">Upper Cretaceous</td><td colspan="2">Englishtown Formation</td><td colspan="2">Englishtown aquifer system</td></tr>
<tr><td colspan="2">Woodbury Clay</td><td rowspan="2" colspan="2">Merchantville-Woodbury confining unit</td></tr>
<tr><td colspan="2">Merchantville Formation</td></tr>
<tr><td colspan="2">Magothy Formation</td><td rowspan="5">Potomac-Raritan-Magothy aquifer system</td><td>Upper aquifer</td></tr>
<tr><td rowspan="2" colspan="2">Raritan Formation*</td><td>Confining unit</td></tr>
<tr><td>Middle aquifer</td></tr>
<tr><td rowspan="2" colspan="2">Potomac Group</td><td>Confining unit</td></tr>
<tr><td>Lower Cretaceous</td><td>Lower aquifer</td></tr>
<tr><td>Paleozoic and Precambrian</td><td colspan="2">Pre-Cretaceous</td><td colspan="2">Wissahickon Formation</td><td colspan="2">Bedrock confining unit</td></tr>
</table>

* Raritan Formation may be absent in southern New Jersey (Owens and others, 1970, fig. 5, p. 9)

by the New Jersey Geological Survey in the 1970's (New Jersey Geological Survey, undated). Outcrops or subcrops of the hydrogeologic units in the Potomac-Raritan-Magothy aquifer system were defined at a map scale of 1:24,000 and are presented in this report at a smaller scale of 1:48,000. Refinement of the outcrops or subcrops of hydrogeologic units of the Potomac-Raritan-Magothy aquifer system was accomplished by projecting updip the top surfaces of units from subsurface interpretations and modifying those projections with geologic logs from wells in the hypothesized subcrop. Marine electromagnetic geophysical surveys (Duran, 1986; A.S. Navoy, U.S. Geological Survey, written commun., 1987) provided additional hydrogeologic information on the subcrops beneath the Delaware River (pl. 1a).

Upper Cenozoic deposits were not differentiated from Cretaceous deposits by rigorous stratigraphic methods. Field observations, lithologic descriptions in geologic or drillers' logs, regional trends of hydrogeologic units in Cretaceous deposits, and present-day geomorphology were used to approximate contacts between upper Cenozoic and Cretaceous deposits. In general, differentiation was difficult where upper Cenozoic deposits are coarse-grained and overlie the subcrop of an aquifer in Cretaceous deposits. In some cases, all sands and gravels between land surface and a regionally defined confining unit were included in the configuration of the aquifer in Cretaceous deposits. Where these deposits overlie the subcrop of a confining unit in Cretaceous deposits, they were more easily differentiated from the confining unit.

Similarly, differentiation also was difficult where upper Cenozoic deposits are fine-grained and overlie the subcrop of a confining unit in Cretaceous deposits. In some cases, all silts and clays between land surface and a regionally defined aquifer were included in the configuration of the Cretaceous confining unit. Where these deposits overlie the subcrop of an aquifer, they were more easily differentiated from the aquifer. Hence, descriptions of the extent and thickness of upper Cenozoic deposits in this region are approximations.

Beneath and adjacent to the Delaware River estuary, aquifers and confining units in Cretaceous deposits have been eroded extensively and replaced by upper Cenozoic deposits. In many places, upper Cenozoic deposits appear to be reworked Cretaceous materials. Hence, differentiation of aquifers and confining units and determination of unit subcrops are particularly difficult in these areas. Hydrogeologic subcrops were identified on the basis of updip projections from hydrogeologic sections and hydrogeologic data from beneath and adjacent to the Delaware River. Without additional detailed mapping of upper Cenozoic deposits, however, interpretations within these areas should be viewed as approximations.

The subsurface location and configuration of selected hydrogeologic units within the Greenwich Township region are represented on maps of the altitudes of the tops of hydrogeologic units and in four hydrogeologic sections. Maps of the thickness of aquifers and confining units can be derived from these maps. Maximum and average thicknesses of hydrogeologic units used in this report were estimated from discretized (23 x 35 grid with cell dimensions of 2,000 ft x 2,000 ft) top-surface maps generated with a Geographic Information System.

Maps, sections, and well-log interpretations from previous regional investigations of the hydrogeologic units throughout New Jersey (Zapecza, 1989) and in the Camden, New Jersey, region (A.S. Navoy, U.S. Geological Survey, written commun., 1985) were used to determine a preliminary framework that was refined during this study. A total of 105 geophysical logs and 191 drillers' logs from 207 wells were interpreted (table 2, at end of report). The logs were selected on the basis of their location, and quality and the pertinence of the hydrogeologic data. Selected information about the wells from which these logs were derived is given in table 3. Seismic and electromagnetic geophysical surveys in the Delaware River (P.B. Duran, 1986; A.S. Navoy, U.S. Geological Survey, written commun., 1987) and in northwestern Greenwich Township (P.B. Duran, U.S. Geological Survey, written commun., 1986) provided additional subsurface hydrogeologic information. (Locations of surveys are shown in pl. 1a).

Estimates of the hydraulic properties of the hydrogeologic units were determined from aquifer tests (with observation wells), from laboratory permeability tests on cores from clay-rich zones of confining units, and from the results of regional ground-water-flow modeling simulations. Data collected and estimates of hydraulic properties reported by sources other than the U.S. Geological Survey are identified herein and were not verified.

Laboratory permeability tests and hydrometer analysis of particle size were performed on cores from clay-rich zones of confining units at three sites (150615, 150622, and 150712, pl. 1a). All permeability tests were performed by a private laboratory using a constant-volume close-loop variable-head triaxial system (E.N. Manuel, Woodward Clyde Consultants, written commun., 1985, 1986). For samples from wells 15-615 and 15-622, permeability was measured three times at an effective pressure equivalent to the depth of burial; an average permeability for these tests is reported. For samples from well 15-712, incremental effective pressure was applied until the limit of the compressor was reached. Permeability tests were conducted at each interval, and the permeability measured at the final degree of saturation is reported.

Data from specific-capacity or well-acceptance tests (with no observation wells) conducted at the time of well installation provided specific-capacity values that also were used to estimate the hydraulic properties of aquifers. Horizontal hydraulic conductivity was estimated by the method of Bennett (1976, p. 8), based on the equation,

$$K = 212\frac{Q}{sd},$$

where K is horizontal hydraulic conductivity,
Q is discharge in gallons per minute,
s is drawdown in the well in feet, and
d is the length of the screen in feet.

Only data for specific-capacity tests that were conducted for 6 hours or longer and in wells with a screen diameter of 6 in. or greater were included in the analysis. These estimates are lower than the actual horizontal hydraulic conductivity because Bennett's approximation method does not take into account well losses or the fact that well screens only partially penetrate the aquifer.

Hydrologic Conditions

The occurrence and flow of ground water in the Greenwich Township region was evaluated by using maps of the potentiometric surface of the upper, middle, and lower aquifers of the Potomac-Raritan-Magothy aquifer system in 1986. These potentiometric-surface maps were generated from static water-level measurements at 60 wells during August 25-September 3, 1986; regional water-level trends in Philadelphia, Pennsylvania (Paulachok and Wood, 1984), and southern Gloucester County, New Jersey (P.J. Lacombe, U.S. Geological Survey, written commun., 1988); and regional water-level trends in the confined part of the Potomac-Raritan-Magothy aquifer system in the Camden region (A.S. Navoy, U.S. Geological Survey, written commun., 1988) and the New Jersey Coastal Plain (Eckel and Walker, 1986). The wells chosen for the measurement of water levels include 20 screened in the upper aquifer, 23 screened in the middle aquifer, and 17 screened in the lower aquifer.

Water levels were measured by the wetted-steel-tape, electric-tape, or air-line method. The wetted-steel-tape method was preferred because it is the most direct and accurate method. Where a steel-tape could not be used, water levels were measured with the electric-tape or air-line method. Withdrawal wells were shut down for at least 1 hour prior to measurement. Where possible, withdrawal wells located within a 0.25-mi (mile) radius of a measured well also were shut down at least 1 hour prior to measurement. Although water in some parts of the aquifer system is slightly saline, measured water levels are not corrected for water density. All corrections are on the order of a hundredth of a foot and are smaller than measurement error.

During the measurement period, precipitation was at or near the seasonal low (fig. 2), and the effects of heavy summer pumping on ground-water levels were at a maximum. Most of the measured wells screened in the confined part of the aquifer system experienced some fluctuations in water levels caused by tides. No attempt was made to account for tidal fluctuations when static water levels were measured. Water levels in 19 of these wells with continuous water-level recorders fluctuate as much as 2.5 ft daily; however, the median fluctuation in ground-water levels is on the order of a tenth of a foot. Thus, equipotential lines are associated with a zone of error that is not shown on the potentiometric-surface maps. The width of the zone of error depends on the amplitude of the tidal fluctuation in the ground-water level, which decreases with distance from the Delaware River. Horizontal and vertical hydraulic gradients among the 19 wells were determined at hourly intervals during a tide cycle. Although horizontal and vertical hydraulic gradients among these wells change during a tide cycle, no reversals in gradient were detected. Thus, the hydraulic gradients on the potentiometric-surface maps approximate the net gradients in the region.

Water-level measurements were taken in only two wells screened in the Englishtown aquifer system (wells 15-188 and 15-676). Ground-water levels in the Englishtown aquifer system were estimated from topography and from water levels mapped in 1983 (Eckel and Walker, 1986) and 1988 (R. Rosman, U.S. Geological Survey, written commun., 1989).

HYDROGEOLOGY

The hydrogeology of the Greenwich Township region is depicted in plates 1b and 2. Plate 1b shows the approximate locations of the outcrops or subcrops of the various hydrogeologic units in the region; plate 2 (a-d) shows four hydrogeologic sections through these units.

Upper Cenozoic Deposits

A detailed study of upper Cenozoic deposits in the Greenwich Township region would be needed in order to accurately define their extent, lithology, and relation to underlying Cretaceous deposits. The general description of these deposits within the region that follows was obtained primarily from Owens and Minard (1979). Upper Cenozoic deposits in the Greenwich Township region range in age from Quaternary to Tertiary (table 1, pl. 3a) and consist of four geologic units: Holocene and upper Pleistocene Delaware River alluvial deposits and fill, the Pleistocene "Trenton Gravel," the upper Miocene Pensauken Formation, and the upper Miocene Bridgeton Formation.

Throughout most of the Greenwich Township region, upper Cenozoic deposits occur in an essentially flat-lying veneer (generally less than 30 ft thick) which lies unconformably on southeastward-dipping, unconsolidated Cretaceous deposits that constitute the regional system of aquifers and confining units. Previous investigators, including Bascom and others (1909), Parker and others (1964, pl. 7), Hardt and Hilton (1969, pl. 1a), and Owens and Minard (1979, p. D11), have indicated that geologic units that comprise the upper Cenozoic deposits are discontinuous across the region; however, an examination of well logs during this study indicated that the upper Cenozoic deposits may be more extensive than previously mapped. Plate 3a, a map of upper Cenozoic deposits in the region, is a modified compilation of the previous work. The major modifications to these previously published maps include addition of Holocene alluvial deposits in and adjacent to stream channels to heads of tide, and addition of Quaternary deposits in Paulsboro Borough, northeastern Greenwich Township, and northern West Deptford Township.

Geophysical and drillers' logs of wells in northern Paulsboro Borough, northeastern Greenwich Township, and northwestern West Deptford Township indicate that some confining units in the Potomac-Raritan-Magothy aquifer system (the confining unit between the upper and middle aquifers and the confining unit dividing the middle aquifer) cannot be traced laterally throughout this area; instead, up to 100 ft of sand and gravel have been logged in 20 wells in this area. Regional trends in the location of subcrops suggest that these confining units subcrop in parts of this area, but in fact they are absent. The absence of confining-unit subcrops and the proximity of the area to the Delaware River suggest that Cretaceous deposits may have been eroded. Erosion of Cretaceous deposits in this area and deposition of sand and gravel during the Pleistocene Epoch has been suggested by previous investigators of the region (Owens and others, 1974; Andres, 1984, p. 14). Based on Owens and Minard's (1979) map and discussion of geologic units that comprise the upper Cenozoic deposits in the lower

Delaware River Valley and the northern Delmarva Peninsula, upper Cenozoic sand and gravel deposits located in this area are probably the Van Sciver Lake beds of Pleistocene age (table 1).

In addition to this area of possible extensive Pleistocene erosion, detailed hydrogeologic investigations by the U.S. Geological Survey in Logan Township (J.C. Lewis, U.S. Geological Survey, written commun., 1989) indicate that erosion and replacement by thick (as much as 60 ft) upper Cenozoic deposits also may have occurred in areas adjacent to Raccoon Creek, especially where the creek empties into the Delaware River. In these areas, however, upper Cenozoic deposits are fine-grained.

Holocene and upper Pleistocene alluvial deposits and fill are limited primarily to the Delaware River channel and tidal wetlands within the region (pl. 3a). Marine geophysical surveys (Duran, 1986; A.S. Navoy, U.S. Geological Survey, written commun., 1987) indicate that in most of the region Delaware River channel deposits are predominantly silt and sand; however, near National Park Borough and Logan Township, deposits are mostly clay and fine silt. Channel deposits may retard the movement of water from the Delaware River into the Potomac-Raritan-Magothy aquifer system; however, dredging to a depth of at least 40 ft to maintain a shipping channel may allow river water to flow unimpeded into the aquifer system.

Tidal wetlands comprise more than 5 percent of the region. Significant wetlands regions include Cedar Swamp in northern Logan Township, and areas near the mouths of the Repaupo Creek and Clonmell Creek drainage basins in Greenwich Township (pl. 1a). These wetland regions contain marsh and swamp deposits of dark silt and clay mixed with organic matter that may be sufficiently permeable to allow appreciable amounts of recharge and discharge to pass through them (Parker and others, 1964, p. 65). Some tidal wetlands adjacent to the Delaware River have been diked and filled with dredge spoils from the river (Evans and others, 1974, p. 41-42). Potential effects of this filling include a reduction in the capacity of the land to store flood waters, reduction in the capacity of naturally occurring upper Cenozoic deposits to transmit recharge to underlying aquifers in Cretaceous deposits, and degradation of the quality of water by contaminated dredge spoils.

The Pleistocene "Trenton Gravel" is a predominantly gray to pale-reddish-brown, gravelly graywacke sand, which was deposited in a broad valley that can be traced from near Trenton southward along the present-day Delaware River channel. Owens and Minard (1979, p. D29) divided this deposit into two units--Spring Lake beds at altitudes of about 40 to 60 ft above sea level and the Van Sciver Lake beds at about 20 ft above sea level. In the Greenwich Township region, these deposits are of estuarine origin and are found primarily in the northwestern part of the region adjacent to the Delaware River in New Jersey (Owens and Minard, 1979) and Pennsylvania (Berg and others, 1980). Van Sciver Lake beds crosscut Spring Lake beds and underlie much of the low-lying parts of the river valley. Little is known about the lithology of the "Trenton Gravel" in the region; however, regional trends (Owens and Minard, 1979, p. D38) indicate that these deposits may be finer grained and have a lower feldspar content than those mapped in Trenton.

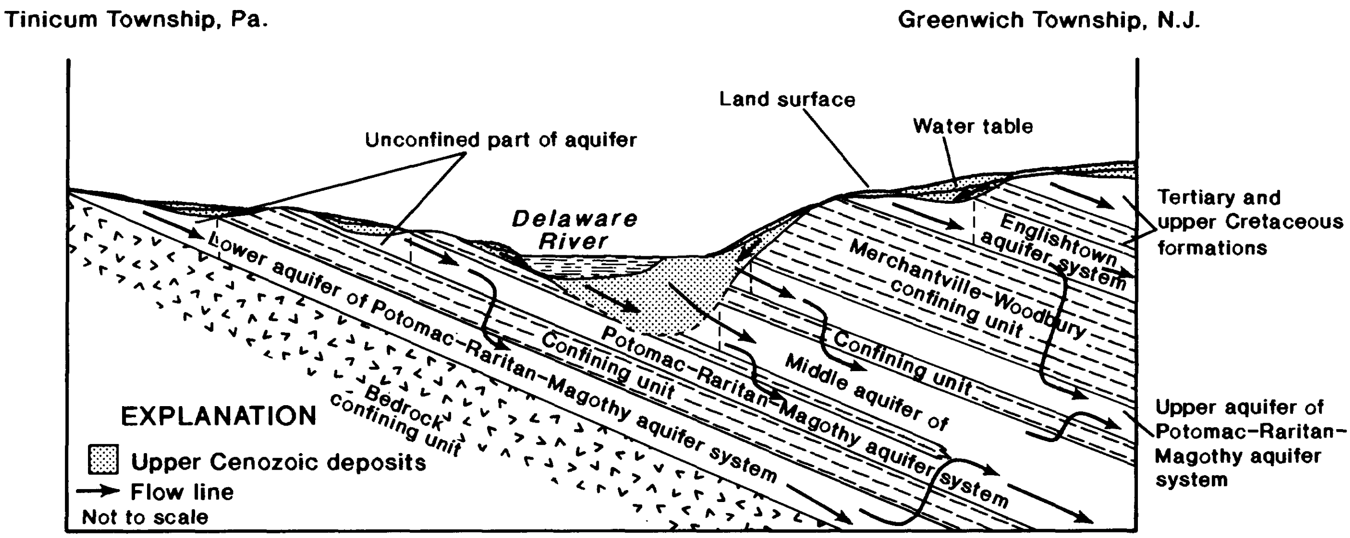
The Pensauken Formation is present in the central part of the Greenwich Township region (pl. 3a) in a band that trends southwest-northeast (Owens and Minard, 1979, p. D44, fig. 40). Pensauken Formation deposits are approximately 40 ft thick (Owens and Minard, 1979, p. D25-26, figs. 21 and 22), lie at altitudes of between about 25 to 70 ft above sea level (Owens and Minard, 1979, p. D20), and disconformably overlie the Bridgeton Formation (Owens and Minard, 1979, p. D18). The Pensauken Formation generally is divided into two units (Owens and Minard, 1979, p. D20-21). The upper unit consists of thin horizontal beds of glauconitic sand with a low feldspar content. These deposits may be primarily reworked Coastal Plain deposits. The lower unit consists of yellow or dark-reddish-brown, iron-oxide-stained and partially cemented, arkosic sands which may be derived primarily from non-Coastal Plain deposits. Both units are present near Swedesboro Borough.

The Bridgeton Formation, found in the southeastern and northwestern parts of the Greenwich Township region (pl. 3a), consists predominantly of massive, yellow or dark-reddish-brown, feldspathic clayey sands overlying lighter colored, coarsely stratified sands (Owens and Minard, 1979, p. D9). These deposits are discontinuous and typically are found on scattered hills at altitudes of 90 to 150 ft (Owens and Minard, 1979, p. D10).

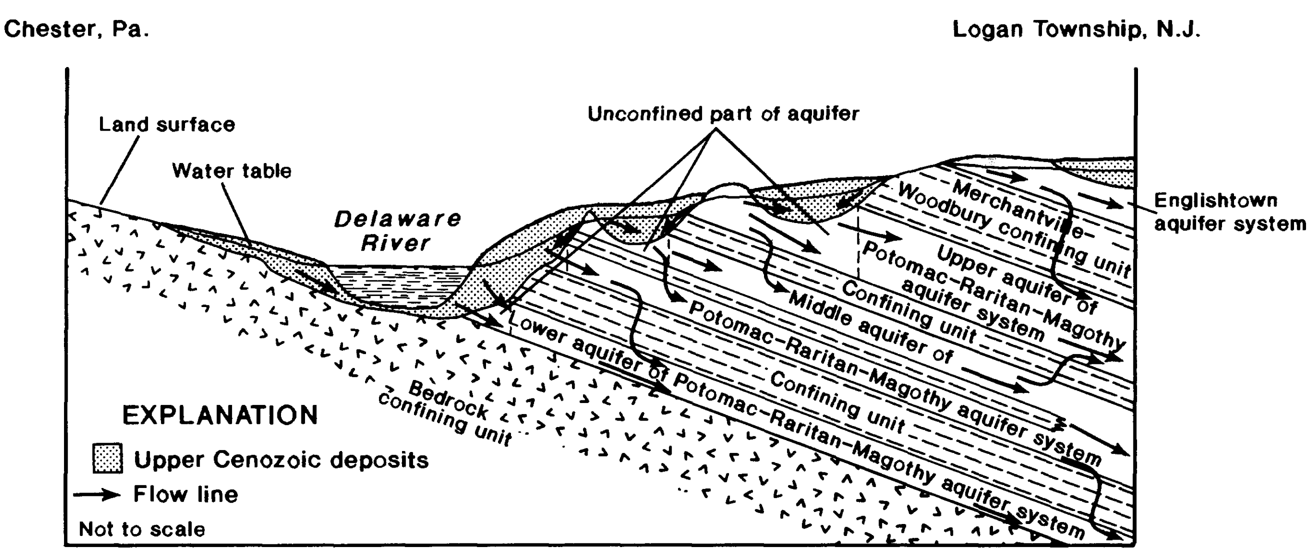
The hydraulic characteristics of upper Cenozoic deposits are not well known, and the hydrologic connection between these deposits and the underlying aquifer systems in Cretaceous deposits is complex (fig. 3). Where upper Cenozoic deposits are coarse-grained and overlie the subcrop of a confining unit in Cretaceous deposits, the upper Cenozoic deposits generally are not sufficiently thick to provide large supplies of ground water. Nevertheless, in some areas wells in these deposits yield from 10 to 50 gal/min (gallons per minute)--sufficient for domestic or small-farm uses (Hardt and Hilton, 1969, p. 31; Parker and others, 1964, p. 64). Where coarse-grained upper Cenozoic deposits overlie the subcrop of an aquifer, they probably transmit recharge to the underlying aquifer. Well yields in these areas may be higher than 50 gal/min. Where upper Cenozoic deposits are fine-grained and overlie the subcrop of a confining unit, they probably retard the transmission of ground water as does the confining unit. Where fine-grained upper Cenozoic deposits overlie the subcrop of an aquifer, water in the underlying aquifer is most likely confined and recharge to the aquifer is probably reduced.

Englishtown Aquifer System

The Englishtown aquifer system consists of the Englishtown Formation of Late Cretaceous age (table 1). Coarse-grained upper Cenozoic deposits overlying the subcrop of the Englishtown Formation may transmit recharge to the aquifer system (Barksdale and others, 1958, p. 137, 138). As mapped by Owens (U.S. Geological Survey, 1967), the Englishtown Formation subcrops in the southeastern part of the study area (pl. 1b) and generally is composed of less than 40 ft (Zapecza, 1989, p. B13; Owens and others, 1970, p. 6) of intercalated, thin-bedded sand-clay sequences (Owens and others, 1970, p. 6, 10). Southwest of the study area, the formation changes first to thick-bedded, and then massive, silt and fine sand. Major sand constituents in the formation include quartz, feldspar, glauconite, and mica; clay beds and massive dark-colored beds contain large concentrations of micas and lignite.



a. Hydrogeologic section from Tinicum Township, Pennsylvania, to Greenwich Township, New Jersey.



b. Hydrogeologic section from Chester, Pennsylvania, to Logan Township, New Jersey.

Figure 3.--Idealized hydrogeologic sections illustrating ground-water flow in the region of Greenwich Township, Gloucester County, New Jersey.

Fossiliferous pale-gray sideritic concentrations are present in the base of the intercalated sequences. Throughout most of the region, the Englishtown Formation dips to the southeast at about 40 ft/mi (feet per mile) (Barksdale and others, 1958, p. 137) and grades downward into the Woodbury Clay (table 1). In the southwest, where the Woodbury Clay is absent (Minard, 1965), the Englishtown Formation overlies and grades downward into the Merchantville Formation (Owens and others, 1970, p. 10).

Within the study area, the Englishtown aquifer system is not a major source of water supply because the aquifer is thin and has a large proportion of fine-grained sediments, which results in lower yields, and because more productive aquifers are available (Zapecza, 1989, p. 13). The aquifer system has been developed primarily for domestic or small-farm irrigation use. Well yields in southern New Jersey range from about 50 to 500 gal/min (Parker and others, 1964, p. 54; Barksdale and others, 1958, p. 137). Aquifer tests in the Englishtown aquifer system (Martin, 1987, table 3) indicate that transmissivity of the aquifer system generally is less than 2,000 ft^2/d (feet squared per day) throughout southern New Jersey. Based on Martin's (1987, fig. 58) calibration of a regional ground-water-flow model, transmissivity of the aquifer system in the Greenwich Township region probably is less than 500 ft^2/d.

Merchantville-Woodbury Confining Unit

In the southeastern part of the Greenwich Township region, the Potomac-Raritan-Magothy aquifer system is confined from above by the Merchantville-Woodbury confining unit. This confining unit consists of the Woodbury Clay and thick interbedded clay, silt, and sand of the Merchantville Formation, both of Late Cretaceous age (table 1). The subcrop of the confining unit covers approximately 27.5 mi^2 of the Greenwich Township region (pl. 1b).

The Woodbury Clay subcrops in a narrow belt (0.1 to 1 mile in width) that parallels the subcrop of the Merchantville Formation but pinches out southwest of Repaupo (U.S. Geological Survey, 1967). In the Greenwich Township region, the Woodbury Clay is a dark-blue to black, very micaeous, fossiliferous silty clay (Hardt and Hilton, 1969, p. 18). The Woodbury Clay dips to the southeast at 38 to 44 ft/mi and has an average thickness of about 50 ft (Hardt and Hilton, 1969, p. 18). The Woodbury Clay is the least permeable confining unit in the New Jersey Coastal Plain (Barksdale and others, 1958, p. 136). No wells in Gloucester County are known to obtain water from this unit (Hardt and Hilton, 1969, p. 18).

The Woodbury Clay is conformably underlain by the Merchantville Formation (table 1). In the Greenwich Township region, the Merchantville Formation consists of green to black, glauconitic and micaceous silt and clay, or quartzose or glauconitic sandy clay (Hardt and Hilton, 1969, p. 15). Near Swedesboro Borough and Mantua and Wenonah Townships (pl. 1a) the upper part of the Merchantville Formation is composed of fine- to coarse-grained glauconitic sand (Hardt and Hilton, 1969, p. 15). The formation dips to the southeast at about 43 ft/mi and ranges in thickness from 45 to 70 ft (Hardt and Hilton, 1969, p. 17). The Merchantville Formation functions chiefly as a confining unit, but the upper, sandy part of the formation is a minor aquifer in the Greenwich Township region. Wells tapping this aquifer are generally domestic-supply wells that range in depth from 100 to 155 ft, yield from 15 to 90 gal/min, and are distributed in a narrow belt from Swedesboro Borough to Wenonah Township (Hardt and Hilton, 1969, p. 17).

Together, the Woodbury Clay and Merchantville Formation comprise the Merchantville-Woodbury confining unit (table 1), the most extensive confining unit in the New Jersey Coastal Plain (Zapecza, 1989, p. B12). The top surface of the Merchantville-Woodbury confining unit ranges in altitude from greater than 40 ft above sea level to greater than 100 ft below sea level (pl. 3b). The surface slopes uniformly to the southeast at about 55 ft/mi. The combined thickness of the two formations averages about 100 ft and reaches a maximum of about 160 ft in the Greenwich Township region. In general, the confining unit thickens toward the southeast. In northwestern West Deptford Township along Little Mantua Creek, the subcrop of the confining unit probably has been eroded and partially replaced by late Cenozoic-age sand and gravel.

In general, the Merchantville-Woodbury confining unit is an effective confining layer between overlying aquifers and the upper aquifer of the Potomac-Raritan-Magothy aquifer system (Zapecza, 1989, p. B12; Barksdale and others, 1958, p. 136). Hydrometer analysis of the particle size of core materials taken from a clay-rich zone in the lower part of the unit at two sites within the region (wells 15-615 and 15-712, pl. 1a) indicates a clay content of only 15 percent by weight. Results of permeability tests on materials from the same cores indicate that vertical hydraulic conductivity values range from 6.8×10^{-4} to 7.1×10^{-3} ft/d (feet per day) (table 4). Vertical leakance of the confining unit within the study area was estimated to be 5×10^{-7} per day on the basis of results of a calibrated regional ground-water-flow model (Martin, 1987, fig. 67). Multiplying this value by the maximum thickness of the confining unit determined for this region (160 ft) yields a vertical hydraulic conductivity of 8×10^{-5} ft/d, somewhat lower than the range indicated by the permeability tests. Higher conductivities may be indicated by permeability tests because the unit generally is sandier in this region than throughout the rest of the New Jersey Coastal Plain (Hardt and Hilton, 1969, p. 15).

Potomac-Raritan-Magothy Aquifer System

The oldest Coastal Plain deposits in New Jersey, the Magothy and Raritan Formations and the Potomac Group (table 1), lie unconformably beneath the Merchantville-Woodbury confining unit. Together, these deposits form the Potomac-Raritan-Magothy aquifer system (Gill and Farlekas, 1976; Luzier, 1980). The aquifer system subcrops in a 3- to 5-mi-wide band (fig. 1 and pl. 1b) and covers about 44 mi^2 in the Greenwich Township region. In the northeast, the aquifer system underlies the Delaware River and subcrops in Pennsylvania (pl. 1b). The aquifer system is wedge-shaped, strikes northeast-southwest, and dips to the southeast at about 40 to 60 ft/mi. It is predominantly composed of nonmarine, delta-plain deposits of interbedded gravel, sand, silt, and clay (Owens and Sohl, 1969, p. 235-242).

Table 4.--Summary of data on the vertical hydraulic conductivities of selected confining units in or near the region of Greenwich Township, Gloucester County, New Jersey

['P' indicates data obtained from a permeability test; 'M' indicates data obtained from a ground-water-flow model; * indicates hydraulic conductivity calculated by multiplying the maximum thickness of the confining unit in the Greenwich Township region by the minimum leakance estimated for the region by using the referenced model; data not referenced are from current study. Location of wells shown in plate 1a]

Well number	Vertical hydraulic conductivity (feet per day)	Type of data	Location	Reference
		Merchantville-Woodbury confining unit		
15-712	7.1×10^{-3}	P	Greenwich Township, New Jersey	
15-615	6.8×10^{-4}	P	Logan Township, New Jersey	J.C. Lewis, U.S. Geological Survey, written commun., 1986
--	5.2×10^{-4} to 1.7×10^{-3}	M	New Jersey Coastal Plain	Luzier (1980, p. 29, fig. 9)
--	*8.0×10^{-5}	M	New Jersey Coastal Plain	Martin (1987, fig. 67) maximum thickness = 160 feet
		Confining unit between the upper and middle aquifers of the Potomac-Raritan-Magothy aquifer system		
15-712	1.8×10^{-5}	P	Greenwich Township, New Jersey	
15-615	9.4×10^{-5}	P	Logan Township, New Jersey	J.C. Lewis, U.S. Geological Survey, written commun., 1986
15-622	3.3×10^{-5}	P	Logan Township, New Jersey	J.C. Lewis, U.S. Geological Survey, written commun., 1986
--	*4.0×10^{-4}	M	New Jersey Coastal Plain	Martin (1987, fig. 66) maximum thickness = 90 feet
		Confining unit dividing the middle aquifer of the Potomac-Raritan-Magothy aquifer system		
15-712	3.9×10^{-5}	P	Greenwich Township, New Jersey	
15-615	3.2×10^{-5}	P	Logan Township, New Jersey	J.C. Lewis, U.S. Geological Survey, written commun., 1986
15-622	1.5×10^{-4}	P	Logan Township, New Jersey	J.C. Lewis, U.S. Geological Survey, written commun., 1986
		Confining unit between the middle and lower aquifers of the Potomac-Raritan-Magothy aquifer system		
15-712	1.5×10^{-5}	P	Greenwich Township, New Jersey	
15-615	2.5×10^{-5} to 1.1×10^{-4}	P	Logan Township, New Jersey	J.C. Lewis, U.S. Geological Survey, written commun., 1986
15-622	8.8×10^{-5} to 1.3×10^{-4}	P	Logan Township, New Jersey	J.C. Lewis, U.S. Geological Survey, written commun., 1986
--	*1.0×10^{-3}	M	New Jersey Coastal Plain	Martin (1987, fig. 65) maximum thickness = 101 feet
--	3.5×10^{-3}	M	Philadelphia, Pennsylvania	Sloto (1986, p. 23, table 2)

In most of southern New Jersey, the Potomac-Raritan-Magothy aquifer system generally is considered to consist of three major aquifers and two confining units--the upper aquifer, the confining unit between the upper and middle aquifers, the middle aquifer, the confining unit between the middle and lower aquifers, and the lower aquifer (Zapecza, 1989, p. B8). Where the aquifer system subcrops in the Greenwich Township region, differentiation of these hydrogeologic units is difficult. In general, confining units are less continuous or lens-like in this region than in areas downdip. The most significant departures from the regional description of the aquifer system are the presence of (1) a sandier, thinner, and hence, in some areas, less impermeable, confining unit between the upper and middle aquifers; and (2) laterally extensive clay-rich beds which locally divide the middle aquifer into two parts and comprise a third confining unit. In addition, as mentioned above, differentiation of hydrogeologic units in the aquifer system is particularly difficult beneath and adjacent to the Delaware River. Erosion and superposition of upper Cenozoic deposits disrupts the lateral continuity of the Cretaceous units, and because upper Cenozoic and Cretaceous deposits have similar lithologies, areas of upper Cenozoic deposition generally are not apparent without detailed study.

Upper Aquifer

The approximate subcrop area of the upper aquifer is shown in plate 4a. The upper aquifer consists predominantly of the Magothy Formation (Zapecza, 1989, p. 11), which consists of white, coarse-grained, quartzo-feldspathic, micaceous, and pyritic sand and gravel interbedded with white, gray, and black lignitic, silty clay. Coarse-grained upper Cenozoic deposits overlying the subcrop of the upper aquifer may transmit recharge to this aquifer. Individual clay beds within the upper aquifer commonly are a few feet thick, but can be as thick as 30 ft. The upper aquifer has an average thickness of 72 ft and generally thickens to the southeast; it is thickest (164 ft) near Clarksboro. In Paulsboro Borough, Greenwich Township, and northwestern West Deptford Township, the upper aquifer probably has been eroded and replaced by thick upper Cenozoic sand and gravel deposits (pls. 2 and 4a). The top surface of the aquifer ranges in altitude from greater than 20 ft above sea level in the subcrop to greater than 260 ft below sea level in the southeastern part of the study area. In general, the top surface slopes uniformly to the southeast at 50 ft/mi.

Estimates of the hydraulic properties of the upper aquifer within the Greenwich Township region are listed in tables 5 and 6. Table 5 lists estimates of transmissivity determined from calibration results of regional ground-water-flow models (Martin, 1987, fig. 57; Luzier, 1980, p. 23-24, fig. 7), which range from 4,000 to 30,000 ft^2/d (table 5), increasing with aquifer thickness in a downdip direction. Table 6 lists the results of 22 specific-capacity tests conducted in the Greenwich Township region and the resultant hydraulic conductivity values. Results of the specific-capacity tests indicate that wells tapping the upper aquifer can sustain pumping rates greater than 1,000 gal/min. The specific capacities of the 22 wells range from 4 to 46 gal/min per foot of drawdown; the median is 20 gal/min per foot of drawdown. The median hydraulic conductivity of the upper aquifer is estimated to be 122 ft/d (table 6). In general, hydraulic conductivity values are highest in the southeast and adjacent to Mantua Creek. Multiplying the median hydraulic conductivity by the average thickness of the aquifer in this region (72 ft) yields a transmissivity of about 9,000 ft^2/d for the upper aquifer, a value within the range suggested by Martin (1987).

Confining Unit between the Upper and Middle Aquifers

The confining unit between the upper and middle aquifers (table 1) is composed of gray and white silty clay with interbedded silt and sand, and is part of the deposits mapped as the undivided Raritan Formation and Potomac Group (Owens and others, 1970, p. 9, fig. 5; U.S. Geological Survey, 1967). Beneath and along the bank of the Delaware River near National Park Borough and West Deptford Township, fine-grained deposits included in the subcrop of the confining unit may be predominantly late Cenozoic in age. Hydrometer analysis of the particle size of core materials taken from clay-rich zones in this unit at three sites indicate a clay content ranging from 27 to 57 percent by weight. (See methods section for a more detailed discussion.) Throughout most of southern Greenwich and eastern Logan Townships, the confining unit is sandy. The top surface of the confining unit between the upper and middle aquifers, shown in plate 4b, generally slopes toward the southeast at about 40 ft/mi. Altitudes range from as high as 10 ft above sea level in the subcrop to approximately 320 ft below sea level in the southeastern part of the region. The unit generally thickens towards the south to a maximum of about 90 ft. In many areas, however, the confining unit is thinner than 20 ft and locally may be discontinuous. In Paulsboro Borough and Greenwich and northwestern West Deptford Townships, the confining unit is absent and probably was eroded and replaced by upper Cenozoic sand and gravel. Adjacent to and west of Raccoon Creek in Logan Township, confining materials probably are predominantly late Cenozoic in age (pls. 2 and 4b).

Available data on the hydraulic properties of the confining unit between the upper and middle aquifers include results of laboratory permeability tests conducted on core materials taken from clay-rich parts of the unit at three sites. Minimum vertical hydraulic conductivity estimated from these tests ranges from 1.8×10^{-5} to 9.4×10^{-5} ft/d (table 4). Minimum vertical leakance of the confining unit in the Greenwich Township region, estimated from calibration results of the regional ground-water-flow model developed by Martin (1987, fig. 66), is 5×10^{-6} per day. An estimate of the minimum vertical hydraulic conductivity of the confining unit, determined by multiplying vertical leakance by the maximum thickness of the confining unit in this region (90 ft), is 4×10^{-4} ft/d, higher than the range estimated from results of permeability tests, which may yield lower values because they reflect only the properties of a clay-rich zone of this unit.

Middle Aquifer

The approximate subcrop area of the middle aquifer is shown in plate 1b. Most of the subcrop lies within New Jersey, adjacent to the Delaware River. In the north, the aquifer subcrops beneath the Delaware River and in Pennsylvania. The middle aquifer consists predominantly of medium- to coarse-grained white and brown sand and gravel interbedded with gray silt and clay, and is part of the deposits mapped as undifferentiated Raritan Formation and Potomac Group (Owens and others, 1970, p. 9, fig. 5; U.S.

Table 5.--Summary of data on transmissivity, horizontal hydraulic conductivity, and storage coefficients for selected aquifers in or near the region of Greenwich Township, Gloucester County, New Jersey

['A' indicates data obtained from an aquifer test; 'M' indicates data obtained from a ground-water-flow model; dashes indicate no data available]

Transmissivity (feet squared per day)	Horizontal hydraulic conductivity (feet per day)	Storage coefficient (dimensionless)	Type of data	Location	Reference
		Upper aquifer of the Potomac-Raritan-Magothy aquifer system			
15,000 to 30,000	--	8.0×10^{-5} to 2.0×10^{-4}	M	New Jersey Coastal Plain	Luzier (1980, p. 23-24, fig. 7)
4,000 to 10,000	--	--	M	New Jersey Coastal Plain	Martin (1987, fig. 57)
		Middle aquifer of the Potomac-Raritan-Magothy aquifer system			
6,280	198	1.5×10^{-4}	A	E.I. Dupont, Gibbstown, New Jersey	Barksdale and others (1958, p. 97)
6,950	--	--	A	Borough of National Park, New Jersey	Hardt and Hilton (1969, p. 11)
2,000 to 9,000	--	--	M	New Jersey Coastal Plain	Martin (1987, fig. 56)
		Lower aquifer of the Potomac-Raritan-Magothy aquifer system			
6,800 to 9,100	140 to 190	9.0×10^{-5} to 1.7×10^{-4}	A	Eagle Point, Westville, New Jersey	Barksdale and others (1958, p. 97)
5,600	50 to 60	--	A	Borough of National Park, New Jersey	Hardt and Hilton (1969, p. 11)
6,000 to 10,000	--	--	M	New Jersey Coastal Plain	Martin (1987, fig. 55)
--	138	3.0×10^{-4}	M	Philadelphia, Pennsylvania	Sloto (1986, p. 23, table 2)

Table 6.--Summary of specific-capacity-test data and estimated hydraulic conductivity for the Potomac-Raritan-Magothy aquifer system in the region of Greenwich Township, Gloucester County, New Jersey

[Hydraulic conductivity (K) was calculated by use of the approximation method of Bennett (1976, p. 8), based on the equation

$$K = 212 \frac{Q}{sd},$$

where Q is discharge in gallons per minute (gal/min); s is drawdown in the well, in feet, calculated by subtracting static water level from production level (level measured during the test); and d is the length of the screen, in feet. Location of wells is shown in plate 1a. Information about wells is listed in table 3. "--" indicates missing data]

Well number	Date of test	Duration (hours)	Discharge (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Screen length (feet)	Estimated hydraulic conductivity (feet per day)
			Upper aquifer				
15-006	11/07/1967	8	1,150	25	46	19	218
15-008	03/28/1973	8	1,023	33	31	63	105
15-011	01/14/1958	8	1,018	59	17	26	141
15-015	11/30/1948	8	100	10	10	19	112
15-016	12/27/1955	8	503	12	42	21	425
15-028	02/17/1956	12	536	20	27	25	228
15-065	05/15/1950	8	700	50	14	29	103
15-189	07/16/1951	24	600	50	12	25	102
15-192	02/22/1957	8	533	13	41	22	397
15-194	03/10/1969	6	513	20	26	32	171
15-206	09/12/1950	8	500	59	8	21	86
15-240	05/01/1963	8	650	40	16	41	84
15-274	05/20/1944	24	500	30	17	37	96
15-275	02/05/1951	8	1,200	40	30	42	152
15-276	03/14/1963	8	608	24	25	46	117
15-284	01/11/1962	8	1,000	27	37	30	263
15-290	11/01/1960	8	525	26	20	31	139
15-295	01/29/1973	8	250	19	13	20	140
15-330	10/01/1973	24	1,001	53	19	45	89
15-332	04/--/1946	10	1,100	54	20	40	108
15-333	01/26/1953	8	1,056	47	22	38	126
15-392	08/13/1964	8	37	10	4	10	79
Median		8	604	28.5	20	29.5	121.5
			Middle aquifer				
15-022	06/09/1949	8	300	20	15	19	167
15-023	07/31/1967	8	100	14	7	21	72
15-069	07/08/1959	8	1,007	29	35	60	123
15-070	02/03/1944	8	524	22	24	20	252
15-071	10/03/1949	24	180	13	14	10	293
15-072	04/15/1950	24	700	45	16	10	330
15-073	09/10/1951	16	800	60	13	20	141
15-077	10/27/1949	24	183	15	12	9	287
15-079	10/24/1967	24	754	41	18	25	156
15-080	06/--/1946	24	650	54	12	16	159
15-087	10/14/1949	24	205	12	17	10	362
15-093	12/15/1950	8	602	53	11	25	96
15-140	05/26/1970	24	402	22	18	52	74
15-165	06/02/1930	36	150	15	10	10	212
15-170	05/16/1970	7	125	7	18	20	189
15-171	04/19/1972	24	175	34	5	20	55
15-178	02/09/1972	36	69	32	2	20	23
15-211	08/01/1973	12	205	50	4	20	43
15-212	03/10/1951	24	1,000	120	8	30	63
15-213	09/12/1957	8	900	38	24	40	125
15-216	05/--/1950	8	800	33	24	25	205
15-348	05/24/1978	12	800	40	20	30	143
15-368	03/14/1963	8	608	24	25	47	114
15-391	12/15/1950	8	126	59	2	25	18
15-413	03/22/1979	24	105	59	2	20	19
15-431	05/--/1980	34	1,007	28	36	94	80
15-435	07/24/1981	72	1,130	55	21	60	73
15-569	12/09/1981	72	1,002	63	16	40	85
Median		24	568	33.5	15.5	20.5	124

Table 6.--Summary of specific-capacity-test data and estimated hydraulic conductivity for the Potomac-Raritan-Magothy aquifer system in the region of Greenwich Township, Gloucester County, New Jersey--Continued

Well number	Date of test	Duration (hours)	Discharge (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Screen length (feet)	Estimated hydraulic conductivity (feet per day)
			Lower aquifer				
15-091	06/05/1949	24	140	65	2	19	24
15-103	12/28/1945	24	860	13	66	20	700
15-104	06/30/1940	24	1,000	18	56	30	406
15-107	12/10/1945	24	840	9	93	30	659
15-139	05/20/1970	10	412	15	27	44	132
15-173	03/14/1972	25	406	19	21	47	96
15-174	03/16/1972	24	175	29	6	30	43
15-175	02/01/1972	21	300	54	6	20	59
15-176	01/17/1972	24	205	12	17	40	90
15-177	01/25/1977	36	250	18	14	40	74
15-181	03/01/1972	72	510	46	11	20	117
15-217	10/29/1976	56	100	3	33	10	815
15-220	05/26/1954	8	500	16	31	22	301
15-221	03/20/1970	8	602	14	43	28	325
15-283	12/05/1961	8	1,000	105	10	25	81
15-285	10/04/1961	8	1,000	36	28	30	196
15-304	04/04/1970	8	1,500	31	48	52	197
15-306	03/02/1970	8	1,515	65	23	42	118
15-308	04/21/1969	24	457	27	17	40	90
15-313	02/15/1961	8	752	37	20	46	94
15-314	01/03/1949	48	1,200	76	16	38	88
15-317	03/16/1973	8	1,001	25	40	40	212
15-318	01/12/1948	24	1,100	59	19	30	132
15-319	03/10/1948	90	1,100	52	21	30	149
15-320	10/23/1947	8	1,110	34	33	40	173
15-321	10/29/1948	8	1,029	44	23	40	124
15-322	12/17/1947	24	1,012	43	24	30	166
15-327	12/05/1957	8	1,205	95	13	27	99
15-331	04/27/1960	10	1,016	24	42	52	172
15-373	12/08/1980	72	1,280	81	16	40	84
15-401	01/12/1972	24	151	11	14	20	140
15-410	08/19/1978	8	1,000	41	24	40	129
15-414	02/06/1979	24	201	17	12	19	130
15-439	04/24/1970	8	542	16	34	20	359
15-533	12/07/1981	24	750	37	20	32	134
Median		24	840	31	21	30	132

Geological Survey, 1967). Beneath the Delaware River and adjacent to the river in northeastern Greenwich Township and Paulsboro Borough, parts of the middle aquifer probably were eroded and replaced by upper Cenozoic sand and gravel (pl. 4b). These coarse-grained upper Cenozoic deposits probably transmit recharge to the underlying aquifer. Adjacent to Raccoon Creek in Logan Township and adjacent to Repaupo Creek in Greenwich Township, the middle aquifer probably was eroded and replaced by fine-grained upper Cenozoic deposits that may retard the transmission of recharge to the underlying aquifer. Locally the middle aquifer is divided into two parts by a clay confining unit (pls. 1b and 2).

Plate 5a shows the subsurface configuration of the top of the upper, water-bearing part of the middle aquifer, which ranges in altitude from above sea level to greater than 360 ft below sea level in the southeastern part of the region. In general, the top surface of the aquifer slopes uniformly to the southeast at approximately 50 ft/mi. The surface has a southeast-trending valley in the area of Mantua Creek. The total thickness of the middle aquifer averages 87 ft, reaching a maximum of more than 160 ft near both southern Greenwich Township and Woodbury Heights. The aquifer has a lobate shape, with two lobes trending south and east where the thickness is greater than 80 ft.

The subcrop of the confining unit dividing the middle aquifer is shown in plate 5b. Geologic logs indicate that this unit consists primarily of gray or red and white mottled clay. This confining unit consists predominantly of deposits mapped as undivided Raritan Formation and Potomac Group (Owens and others, 1970, p. 9, fig. 5; U.S. Geological Survey, 1967). Hydrometer analysis of the particle size of core materials taken from clay-rich zones of this unit at three sites indicate that the clay content ranges from 45 to 70 percent by weight. As shown in plate 5b, the confining unit is discontinuous and is mappable as two south-trending lobes. Altitudes of the top surface of the confining unit range from above sea level in the subcrop to greater than 415 ft below sea level in the southeastern part of the study area. In general, the surface slopes uniformly at approximately 60 ft/mi. Zones in which the confining unit could not be differentiated are shown in plate 5b. Where present, the unit's average thickness is 20 ft; in northwestern West Deptford Township, it is thicker than 60 ft. Beneath the Delaware River and adjacent to the river in Paulsboro Borough and in Greenwich and West Deptford Townships, upper Cenozoic sand and gravel deposits may replace the confining unit. Near Raccoon Island in Logan Township and in Tinicum Township in Pennsylvania, confining materials may be predominantly late Cenozoic in age. Regional mapping of the aquifer system by Zapecza (1989) suggests that the confining unit dividing the middle aquifer pinches out downdip (pl. 2).

Plate 6a shows the extent and subsurface configuration of the top of the lower, water-bearing part of the middle aquifer. This surface is the same as the base of the confining unit dividing the middle aquifer. Areas in which the middle aquifer cannot be differentiated into two parts by a confining unit are indicated in plate 6a. Where the unit is present, the thickness of the lower part of the middle aquifer in the Greenwich Township region averages 36 ft and reaches a maximum of about 100 ft.

Estimates of the hydraulic properties of the middle aquifer are listed in tables 5 and 6. Table 5 lists the results of two aquifer tests conducted in the Greenwich Township region; transmissivities range from 6,280 to 6,950 ft^2/d, and a storage coefficient of 1.5×10^{-4} was reported for one test. Table 6 lists the results of specific-capacity tests and the resultant estimated hydraulic conductivities for 29 wells tapping the middle aquifer. The results of the specific-capacity tests indicate that pumping rates in excess of 1,000 gal/min can be sustained locally. For example, well 15-569 was pumped at a rate of 1,002 gal/min for 72 hours, resulting in 63 ft of drawdown and a specific capacity of 16 gal/min per foot of drawdown (table 6), which is the median specific capacity of the 28 wells tested. The specific capacities of these wells range from 2 to 36 gal/min per foot of drawdown. The median hydraulic conductivity, estimated from the specific-capacity-test data (Bennett, 1976, p.8), is 124 ft/d (table 6). Estimated hydraulic conductivities increase toward the Delaware River. From the median hydraulic conductivity and average thickness of the middle aquifer (87 ft), transmissivity is estimated to be 10,788 ft^2/d.

Another estimate of the transmissivity of the middle aquifer, determined from calibration results of a regional ground-water-flow model (Martin, 1987, fig. 56), ranged from 2,000 to 9,000 ft^2/d (table 5), increasing with aquifer thickness in the downdip direction within the Greenwich Township region. This range spans the values reported for aquifer tests but is lower than the estimate based on specific-capacity-test data. Aquifer tests conducted in the middle aquifer by ground-water consultants working in the region (Legette, Brashears and Graham, Inc., 1984; Environmental Resources Management, 1986; D.E. Choate, Mobil Oil Corporation, written commun., 1986) suggest an even wider range of hydraulic properties, with estimates of horizontal hydraulic conductivity ranging from 90 to 423 ft/d, transmissivity ranging from 990 to 25,537 ft^2/d, and storage coefficients ranging from 5.0×10^{-5} to 1.0×10^{-3}.

Hydraulic properties of the confining unit dividing the middle aquifer were estimated from results of laboratory permeability tests conducted on undisturbed cores of clay-rich parts of this unit collected from two sites in Logan Township and one in Greenwich Township (table 4). Estimates of minimum vertical hydraulic conductivity based on the results of these tests range from 3.9×10^{-5} to 1.5×10^{-4} ft/d. Aquifer-test results and differences in water quality and ground-water levels between aquifers above and below this confining unit measured during this study suggest that locally the unit may be effective in limiting ground-water flow.

Confining Unit between the Middle and Lower Aquifers

Plate 6b shows the approximate subcrop or outcrop area of the confining unit between the middle and lower aquifers. Geologic logs indicate that this confining unit consists primarily of very fine-grained, red and white mottled clay and silt. This confining unit comprises deposits mapped as undivided Raritan Formation and Potomac Group (Owens and others, 1970, p. 9, fig. 5; U.S. Geological Survey, 1967). Fine-grained upper Cenozoic deposits overlying the subcrop are thickest in areas adjacent to the Delaware River channel, particularly adjacent to Raccoon Creek in Logan Township.

Particle-size analyses by hydrometer of materials from seven cores taken from clay-rich zones of this unit at three sites in the Greenwich Township region indicate that clay content ranges from 25 to 55 percent by weight. The top surface of the confining unit dips toward the southeast at 50 to 100 ft/mi (pl. 6b). Steeper slopes generally are found in areas adjacent to the subcrop and in northern West Deptford Township. A broad valley in the top surface of the confining unit is found in the area near Mantua Creek. The northeastern part of the region has an additional surface depression. The thickness of the confining unit ranges up to a maximum of 101 ft (well 15-312) and averages 45 ft (pl. 6a). The unit generally thickens toward the south, but has a lobate configuration similar to that of the middle aquifer. Near Raccoon Island in Logan Township, Cretaceous clay-rich material in combination with overlying upper Cenozoic silt and clay is more than 60 ft thick.

The hydraulic properties of the confining unit between the middle and lower aquifers were estimated from laboratory permeability tests on seven cores from clay-rich zones of the unit at three sites in the Greenwich Township region (table 4). Estimates of vertical hydraulic conductivity based on the results of these tests range from 1.5×10^{-5} to 1.3×10^{-4} ft/d (table 4). Estimates made by consultants working in the region (D.E. Choate, Mobil Oil Corporation, written commun., 1986) indicate that vertical hydraulic conductivity values may be higher (2.8×10^{-4} to 1.2×10^{-3} ft/d) in some areas adjacent to the Delaware River in Paulsboro Borough and Greenwich Township. Minimum vertical hydraulic conductivity in the region (1×10^{-3} ft/d, table 4) was estimated by multiplying the maximum thickness of the unit (101 ft) by minimum vertical leakance of the unit (1×10^{-5} per day), which was estimated from calibration results of a regional ground-water-flow model (Martin, 1987, fig. 65). This estimate is an order of magnitude higher than the range estimated on the basis of permeability-test results. A higher regional estimate is expected because permeability tests were conducted only on clay-rich zones of the unit. On the basis of aquifer-test results and differences between water levels and water quality in the middle and lower aquifers measured during this study, this confining unit is considered to be locally effective at limiting vertical flow.

Lower Aquifer

The lower aquifer overlies weathered bedrock throughout the Greenwich Township region. Geologic logs indicate that, in the Greenwich Township region, the lower aquifer consists predominantly of white, yellow, or brown quartzo-feldspathic, micaceous, coarse sand interbedded with gravel and red and gray lignitic silt and clay. Individual clay beds within the lower aquifer generally are less than 25 ft thick. This aquifer consists primarily of deposits mapped as undivided Raritan Formation and Potomac Group. Coarse-grained upper Cenozoic deposits overlying the subcrop are particularly thick on and near Monds Island in Greenwich Township. According to Zapecza's regional study (1989, p. 10 and pl. 6), the lower aquifer does not crop out in southern New Jersey, but pinches out against bedrock. Updip projections of the lower aquifer on the hydrogeologic sections shown in plate 2, however, suggest that the lower aquifer may subcrop in New Jersey adjacent to and beneath the Delaware River, as well as on the northwestern side of the river in Pennsylvania. In these areas, the lower aquifer is truncated by thick upper Cenozoic deposits. Hence, if upper Cenozoic deposits are permeable and ground-water gradients are appropriate, water movement from the river to the lower aquifer is possible.

Plate 7a shows the subsurface configuration of the top of the lower aquifer. Altitudes range from about sea level in the subcrop area to greater than 660 ft below sea level in the southeastern part of the study area. The top surface slopes to the southeast at 40 to 110 ft/mi. A small southeast-trending valley is found in the area near the mouth of Mantua Creek. The thickness of the lower aquifer averages about 100 ft and reaches a maximum of more than 340 ft. Although the aquifer generally thickens toward the southeast, two deviations from this trend are noted. The lower aquifer thins in the area near Nehonsey Brook and, in combination with overlying upper Cenozoic sands, thickens in the subcrop area adjacent to the Delaware River.

Estimates of the hydraulic properties of the lower aquifer in the Greenwich Township region are listed in tables 5 and 6. Table 5 lists the results of two aquifer tests conducted in the Greenwich Township region; hydraulic conductivities range from 50 to 190 ft/d, transmissivities range from 5,600 to 9,100 ft^2/d, and storage coefficients range from 9.0×10^{-5} to 1.7×10^{-4}. Aquifer tests conducted by consultants working in the region (D.E. Choate, Mobil Oil Corporation, written commun., 1986) show similar ranges in hydraulic properties. Table 6 lists the results of specific-capacity tests and corresponding hydraulic-conductivity values estimated from these tests (Bennett, 1976, p. 8) for 35 wells tapping the lower aquifer. The specific-capacity tests indicate that pumping rates in excess of 1,500 gal/min can be sustained locally. For example, well 15-306 was pumped at a rate of 1,515 gal/min for 8 hours, resulting in a drawdown of 65 ft and a specific capacity of 23 gal/min per foot of drawdown (table 5). The specific capacities of the 35 wells range from 2 to 48 gal/min per foot of drawdown; the median specific capacity is 21 gal/min per foot of drawdown. Hydraulic-conductivity values in the lower aquifer increase both toward the Delaware River and toward Deptford Township. A median hydraulic conductivity of 132 ft/d was determined for these wells. By multiplying the median hydraulic conductivity by the average thickness of the lower aquifer (98 ft), the average transmissivity for the Greenwich Township region is estimated to be 12,940 ft^2/d.

Another estimate of the transmissivity of the lower aquifer in the Greenwich Township region was determined from calibration results of a regional ground-water-flow model (Martin, 1987, fig. 55). This estimate ranges from 6,000 to 10,000 ft^2/d (table 5)--slightly lower than the estimate based on specific-capacity-test data but similar to estimates based on aquifer-test results.

Bedrock

In southern New Jersey, the lower confining unit beneath the Potomac-Raritan-Magothy aquifer system (table 1) consists of lower Paleozoic and Precambrian metamorphic and igneous bedrock (Zapecza, 1989). In the Greenwich Township region, the bedrock is composed of micaceous and feldspathic schist and gneiss of the Wissahickon Formation (Barksdale and others, 1958, p. 69; Hardt and Hilton, 1969, p. 9). Fractures, joints, foliation, and folds are characteristic structural features of this formation. Although the thickness of the Wissahickon Formation is unknown, it is probably several thousand feet (Hardt and Hilton, 1969, p. 9). Overlying solid bedrock, there is a gradational zone of weathered bedrock which may range up to 100 ft in thickness. The weathered-bedrock material grades from chemically unaltered but highly fractured bedrock to a saprolite--a light to dark gray, micaceous clay containing gravel-sized fragments of underlying bedrock.

Plate 7b shows the subcrop area of the bedrock beneath the upper Cenozoic deposits and the subsurface configuration of the bedrock surface. Because the contact between solid bedrock and unconsolidated material is gradational, the altitude of the top surface is subject to error on the order of tens of feet. Altitude of the bedrock surface ranges from more than 50 ft above sea level in the subcrop area in the northwestern part of the Greenwich Township region (in Pennsylvania) to more than 900 ft below sea level in the southeastern part. In general, the bedrock surface dips at a rate of approximately 60 to 100 ft/mi. Near Nehonsey Brook, a broad, northwest-trending valley is present in the bedrock surface.

In the Greenwich Township region, the Wissahickon Formation is the lower confining unit of the Potomac-Raritan-Magothy aquifer system. In its unweathered state, the Wissahickon Formation is relatively impervious to water (Barksdale and others, 1958, p. 73). Open joints and fractures can provide for storage, however; where interconnected, the unit can transmit ground water. Recharge from the overlying sand-and-gravel aquifers provides essentially all of the ground water in the bedrock that flows through the unfilled and interconnected joints and fractures within the weathered zone (Hardt and Hilton, 1969, p. 9). According to Barksdale and others (1958, p. 74), storage coefficients for the weathered-bedrock zone range from 5×10^{-3} to 2×10^{-2}. These values are comparable to those for the Potomac-Raritan-Magothy aquifer system; however, 7 wells tapping the weathered bedrock have an average specific capacity of 1.70 gal/min per foot of drawdown and 12 wells have an average yield of 45 gal/min (Barksdale and others, 1958, p. 74-75). These values are low compared to those for the overlying unconsolidated deposits.

HYDROLOGIC CONDITIONS

Surface water and ground water are not separate resources but different components of the same resource. Where they are hydraulically connected, changes in surface-water levels, such as those induced by tides, may change ground-water levels. Recharge of surface water to the aquifer system may affect the quality of ground water. Therefore, an assessment of the ground-water resources in Greenwich Township requires a basic understanding of the surface-water system, especially with regard to tidal influences and saltwater intrusion from the Delaware River and its tributaries.

Surface Water

Surface water, which comprises 10 to 15 percent of the area of the Greenwich Township region, drains northwestward from New Jersey and southeastward from Pennsylvania into the Delaware River. The major streams in the New Jersey part of the region are Raccoon Creek in the southwest and

Mantua Creek in the northeast; the main stream in the Pennsylvania part of the region is Darby Creek (pl. 1a). Little Timber Creek, Repaupo Creek, Nehonsey Brook, Clonmell Creek, and Woodbury Creek in New Jersey, and Crum Creek, Ridley Creek, and Chester Creek in Pennsylvania also flow into the Delaware River. Many small tributaries to these streams complete the drainage pattern. Because most of the streams are perennial, many streams probably receive ground-water discharge from the water-table aquifer. During a drought, however, the water table may fall to a level that causes streams, particularly Clonmell Creek, Nehonsey Brook, and some of the tributaries of Repaupo Creek in Greenwich Township (Hardt and Hilton, 1969, p. 44-47, table 5), to cease or to have discontinuous flow. In addition, vertical hydraulic gradients between unconfined and confined aquifers in the region indicate that surface water in many stream reaches recharges the shallow ground-water system where streambeds are permeable; however, ground-water contributions to streamflow and streamflow losses to the ground-water system were not estimated because of regional water-level fluctuations caused by tides.

The Delaware River is an estuary from Trenton, New Jersey, to the Delaware Bay at the Atlantic Ocean. The Delaware River and the lower reaches of its tributaries in the Greenwich Township region are affected daily by tides. Stage in the Delaware River, recorded at a U.S. Geological Survey tide gage at Bramell Point in Paulsboro Borough, fluctuates daily with an amplitude of 5.8 ft from an average of 2.4 ft below sea level to 3.4 ft above sea level (A.J. Velnich, U.S. Geological Survey, written commun., 1987). Tidal reaches of the tributaries experience similar but smaller stage fluctuations. Head of tide in each tributary is indicated in plate 1a. Because these streams have extremely low gradients and wide floodplains, their channels are bounded by extensive tidal wetlands throughout the region.

Lowlands adjacent to the Delaware River in much of the region are subject to tidal flooding (Federal Emergency Management Agency, 1982). High tides flood these lowlands to approximately the same elevation as that of the Delaware River. Flooding is most likely to occur in late summer and fall when storm surges from hurricanes are most frequent and increase tides.

Flood hazards and flood-protection measures in the region are discussed in detail by the Federal Emergency Management Agency (1982). The most extensive flood-protection structures were constructed in Greenwich Township to reclaim tidal wetlands for agricultural use. Currently (1990), more than 5 mi of continuous dike is maintained to protect Gibbstown and about 1.6 mi^2 of industrial land from the tides. A system of channels and floodgate structures on Repaupo Creek, White Sluice Race, Sand Ditch, and Clonmell Creek (pl. 1a) controls drainage in the area behind the floodgates and mitigates tidal flooding. The wooden flapgates of the floodgates open when water levels in the tributaries are higher than that in the Delaware River and close when the hydraulic gradient reverses (M. Peterson, U.S. Dept. of Agriculture, Soil Conservation Service, written commun., 1986). Average stage in tributaries at the floodgates is 1.5 to 2.5 ft below sea level (M. Peterson, U.S. Dept. of Agriculture, Soil Conservation Service, written commun., 1986; J. Redmond, Greenwich Township, written commun., 1986).

Dikes along the Delaware River in Logan Township protect additional lowland areas from tidal flooding. In West Deptford Township, most of the industries in the tidal lowlands between Mantua Creek and Woodbury Creek have been built on fill higher than the 100-year-flood elevation.

Saltwater moves upstream and downstream in the Delaware River twice daily with the ebb and flood of the tide and mixes with freshwater that flows into the estuary. Freshwater flowing into the estuary both dilutes the saltwater and tends to flush it downstream. The long-term mean annual invasion point of saline water in the Delaware River is within the Greenwich Township region at Chester, Pennsylvania (Anderson and others, 1972, p. 381, fig. 7); however, when freshwater flow is very low, as it was during the 1961-66 drought, saltwater may advance into the estuary as far north as Philadelphia. Chloride concentrations greater than 2,000 mg/L (milligrams per liter) have been measured in the river at Chester (Hardt and Hilton, 1969, p. 13; Anderson and others, 1972, p. 381, fig. 7). A chloride concentration of 2,000 mg/L indicates a mixture of about nine parts fresh river water (8.25 mg/L chloride) to one part ocean water (20,000 mg/L chloride) (Drever, 1982, p. 237).

Because the subcrop of the Potomac-Raritan-Magothy aquifer system is incised by the Delaware River and its tributaries, tidal fluctuations and the quality of the river water may affect the ground-water system (Barksdale and others, 1958, p. 124; Hardt and Hilton, 1969, p. 12). Extensive ground-water withdrawals in northern Camden, western Burlington, and eastern Gloucester Counties, New Jersey, have reversed hydraulic gradients, creating a potential for recharge to the aquifer system from the Delaware River. This phenomenon is called induced recharge. Where the Delaware River is hydraulically connected to an aquifer, either because the upper Cenozoic deposits overlying the subcrop are permeable or because the aquifer is directly exposed to the river as a result of channel dredging, water moves downward through the riverbed to the aquifer. Evidence for induced recharge of the aquifer system from the Delaware River has been documented by Barksdale and others (1958, p. 106-108, 115-123) and by Greenman and others (1961, p. 76-81).

Little information on surface-water diversions is available. Surface water in the region is used to supplement industrial and small-farm water supplies. Surface-water diversions by some local industries have increased throughout the 1980's.

Ground Water

Withdrawals

The Potomac-Raritan-Magothy aquifer system is the principal source of potable water in the Greenwich Township region. Table 7 lists the major ground-water usage and users (those with pump capacities of 100,000 gal/d (gallons per day) or greater), the primary wells and aquifers supplying the water, and the annual withdrawal rates in 1973, 1978, and 1983-86 as reported in the U.S. Geological Survey New Jersey State Water Use Data System (SWUDS). Table 7 does not include withdrawals from wells with pump capacities of less than 100,000 gal/d; hence, withdrawals through most irrigation wells and all domestic wells are not included. Withdrawals reported in 1973 and 1978 may not include withdrawals made through wells with pump capacities of 100,000 gal/d or greater that were drilled prior to the enactment of a 1947 "grandfather rights" statute. Withdrawals since 1983, based on written communications with ground-water users in 1986, are recorded in table 7 by individual well rather than by N.J. Department of Environmental Protection allocation permit (which may include withdrawals from more than one well) and include withdrawals by purge wells pumped for on-site containment of ground-water contamination.

The relative amounts and distribution of ground-water withdrawals in the Greenwich Township region during 1986 are shown in figure 4 and plates 8-9a. Withdrawals from all aquifers are concentrated in the eastern part of the region and along the Delaware River in West Deptford and Greenwich Townships and Paulsboro Borough. Ground-water withdrawals in the Pennsylvania part of the study area generally are not significant.

Total reported ground-water withdrawals within the Greenwich Township region from 1956-86 and a breakdown of the withdrawals by type of use are shown in figure 5a. Total ground-water withdrawals in the region increased from 13.6 Mgal/d (million gallons per day) in 1956 to almost 25.9 Mgal/d in 1969, decreased to less than 16.2 Mgal/d in 1981, and increased to almost 20 Mgal/d in 1986. Ninty-nine percent of the total reported withdrawals in the Greenwich Township region are for public-supply or self-supplied industrial usage. Since about 1977, ground-water withdrawals have been approximately evenly divided between the two categories. Withdrawals by public-supply purveyors generally have increased throughout the period of record. Analysis of water-use data by owner indicates that the increase in self-supplied industrial withdrawals during the late 1960's was primarily the result of increased withdrawals by petroleum industries. Withdrawals for agricultural usage are not shown in figure 5a; although agricultural withdrawals are poorly documented, they are small in comparison to public-supply and industrial pumpage (Vowinkel, 1984, p. 14).

Total ground-water withdrawals in Greenwich Township, Paulsboro Borough, and throughout the entire region have increased since 1981. Increased ground-water withdrawals in the 1980's probably are, in part, the result of the below-normal precipitation in this region during the same period (fig. 2). A small percentage of the increase is the result of the recent installation (beginning in 1976) of ground-water purge wells that recover or contain on-site industrial chemicals and contaminated ground water (table 7). Data reported before 1983, shown in figure 5a and c, do not include withdrawals for contaminant remediation; however, these withdrawals beginning in 1983 are included in the totals reported in figure 5 and table 7.

Figure 5b illustrates the seasonal fluctuations in water withdrawals during 1983. Mean monthly ground-water withdrawals in the Greenwich Township region from 1973-86 were greatest during summer months.

The hydrogeologic units tapped by wells in the Greenwich Township region include water-bearing upper Cenozoic deposits; the Englishtown aquifer system; the upper, sandy unit of the Merchantville Formation, and the Potomac-Raritan-Magothy aquifer system. In 1986, withdrawals from the Potomac-Raritan-Magothy aquifer system (and the overlying, hydraulically

Table 7.--Ground-water-withdrawal rates in the region of Greenwich Township, Gloucester County, New Jersey, in 1973, 1978, and 1983-1986

[Data from U.S. Geological Survey New Jersey State Water Use Data System (SWUDS). No information or zero pumpage is denoted by a "-". A pumpage of "0.00" indicates that withdrawals are not equal to zero but are less than 0.01 million gallons per day. A "#" indicates reporting period is prior to well construction. Pumpage estimated from a reported total using data from user is noted with a '*'. WD, Water Department; WC, Water Company; WSC, Water Supply Company; MUA, Municipal Utilities Authority. Undifferentiated Upper Cenozoic deposits overlie and are hydraulically connected to the Potomac-Raritan-Magothy aquifer system. Information about wells is listed in table 3. Location of wells shown in plate 1a]

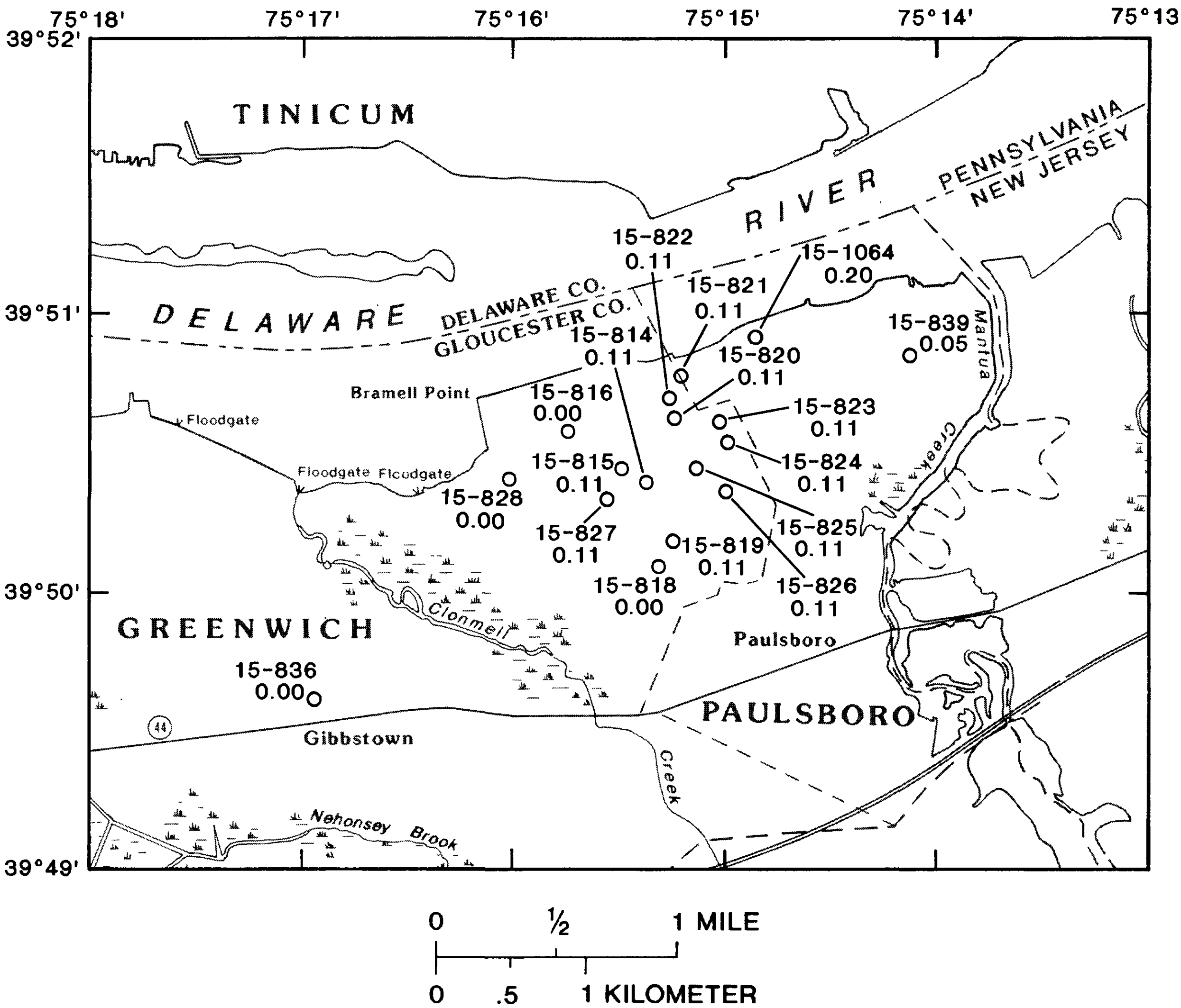
Type of usage Owner	Well number	Annual pumpage (million gallons per day) 1973	1978	1983	1984	1985	1986
		Englishtown aquifer system					
Commercial							
N.J. Turnpike Authority	15-344	-	-	0.00	-	-	-
N.J. Turnpike Authority	15-378	-	-	.00	-	-	-
Withdrawals for commercial use		-	-	.00	-	-	-
Total withdrawals		-	-	.00	-	-	-
		Undifferentiated Quaternary deposits					
Self-supplied industrial and mining							
BP Oil Company	15-839	-	-	-	-	-	0.05*
Exxon	15-1064	-	-	-	-	-	.20*
Hercules Chemical	15-836	#	#	#	#	-	.00
Mobil Oil Corporation	15-814	#	#	0.15*	0.13*	0.11*	.11*
Mobil Oil Corporation	15-815	#	#	.15*	.13*	.11*	.11*
Mobil Oil Corporation	15-816	#	#	.00*	.00*	.00*	.00*
Mobil Oil Corporation	15-818	#	#	.00*	.00*	.00*	.00*
Mobil Oil Corporation	15-819	#	#	#	.13*	.11*	.11*
Mobil Oil Corporation	15-820	-	-	.15*	.13*	.11*	.11*
Mobil Oil Corporation	15-821	-	-	.15*	.13*	.11*	.11*
Mobil Oil Corporation	15-822	-	-	.15*	.13*	.11*	.11*
Mobil Oil Corporation	15-823	-	-	.15*	.13*	.11*	.11*
Mobil Oil Corporation	15-824	-	-	.15*	.13*	.11*	.11*
Mobil Oil Corporation	15-825	-	-	.15*	.13*	.11*	.11*
Mobil Oil Corporation	15-826	-	-	.15*	.13*	.11*	.11*
Mobil Oil Corporation	15-827	-	-	.15*	.13*	.11*	.11*
Mobil Oil Corporation	15-828	#	#	.00*	.00*	.00*	.00*
Withdrawals for industrial and mining use		-	-	1.50	1.43	1.21	1.46
Total withdrawals		-	-	1.50	1.43	1.21	1.46
		Upper aquifer of the Potomac-Raritan-Magothy aquifer system					
Self-supplied industrial and mining							
Chemical Leaman	15-548	#	#	-	-	-	0.01*
Del Monte Corporation	15-240	0.08	0.10	-	-	-	-
Mobil Oil Corporation	15-817	#	#	0.00*	0.00*	0.00*	.00*
Mobil Oil Corporation	15-832	-	-	.15*	.13*	.11*	.11*
P.M.C. Canning Co., Inc.	15-394	-	.01	.02	.01	.01	.01
Polyrez Company, Inc.	15-299	.32	.31	.31	.00	.00	.00
Polyrez Company, Inc.	15-300	-	-	-	.20	.13	.24
Polyrez Company, Inc.	15-437	-	-	-	.28	.28	.21
Shell Chemical Company	15-284	1.09	.69	.43	.19	.03	.22
Inversand Company	15-187	.53	.25	.14	.09	.12	.16
Withdrawals for industrial and mining use		2.02	1.36	1.05	.90	.68	.96

Table 7.--Ground-water-withdrawal rates in the region of Greenwich Township, Gloucester County, New Jersey, in 1973, 1978, and 1983-1986--Continued

Type of usage Owner	Well number	Annual pumpage (million gallons per day) 1973	1978	1983	1984	1985	1986
Upper aquifer of the Potomac-Raritan-Magothy aquifer system							
Public supply							
Deptford Township MUA	15-011	-	-	0.24	0.25	0.23	0.21
Deptford Township MUA	15-016	0.78	0.61	.26	.26	.20	.27
East Greenwich Township MUA	15-028	.52	.39	.39	.20	.20	.28
East Greenwich Township WD	15-355	-	-	-	.17	.20	.20
Greenwich Township WD	15-065	.15	.00	-	-	-	-
Mantua Township MUA	15-189	.19	.20	-	-	-	-
Mantua Township MUA	15-192	.19	.18	-	-	-	-
Mantua Township MUA	15-193	.08	-	-	-	-	-
Mantua Township MUA	15-194	.01	.11	.51	.49	.50	.56
Wenonah Borough WD	15-275	.16	.21	.25	.19	.18	.28
West Deptford WD	15-276	.13	.19	.40	.33	.65	.00
West Deptford WD	15-281	1.04	.46	.45	.61	.82	.21
Woodbury Heights Borough WD	15-330	.02	.31	.35	.20	.30	.31
Woodbury WD	15-006	.76	.24	.33	.90	1.02	.95
Woodbury WD	15-008	.36	.86	-	-	-	.00
Woodbury WD	15-332	.00	.00	.00	.01	.00	.00
Woodbury WD	15-333	.05	.00	-	-	-	-
Withdrawals for public supply		4.44	3.76	3.18	3.69	4.30	3.27
Commercial							
Clearview Regional H.S.	15-131	.03	.03	.00	.05	.06	-
Woodbury Association	15-369	.00	.00	-	-	-	-
Withdrawals for commercial use		.03	.03	.00	.05	.06	-
Irrigation							
Monfardini, Fel	15-366	.00	.01	.02	-	-	-
Nolte, Carl	15-421	.00	.00	.00	-	-	-
Westwood Golf Club	15-295	-	.01	.01	.01	.01	.02
Withdrawals for irrigation		.00	.02	.03	.01	.01	.02
Total withdrawals		6.49	5.17	4.26	4.65	5.05	4.25
Middle aquifer of the Potomac-Raritan-Magothy aquifer system							
Self-supplied industrial and mining							
E. I. Dupont	15-072	0.44	0.14	0.00	0.00	0.39	0.98*
E. I. Dupont	15-079	.25	.16	.32	.29	-	-
E. I. Dupont	15-080	.00	.30	-	-	-	-
E. I. Dupont	15-081	.03	.01	.00	.00	-	-
E. I. Dupont	15-102	.01	-	-	-	-	-
E. I. Dupont	15-692	#	#	#	#	-	.45*
Hercules Chemical	15-076	.18	.15	.07	.13	.10	.10
Hercules Chemical	15-084	.03	-	-	-	-	-
Hercules Chemical	15-092	-	-	-	-	.01	.01
Hercules Chemical	15-833	#	#	#	#	#	.01
Hercules Chemical	15-834	#	#	#	#	#	.00
Hercules Chemical	15-835	#	#	#	#	.01	.02
Hercules Chemical	15-837	#	#	#	#	.01	.03
Hercules Chemical	15-838	#	#	#	-	.01	.01
Mobil Oil Corporation	15-094	-	-	.36*	.36*	.20*	.31*
Mobil Oil Corporation	15-098	2.19	.62	.36*	.36*	.02*	.31*
Rollins Environmental	15-154	.05	.02	-	-	-	-
Shell Chemical Company	15-286	.11	.04	.04	.03	.02	.03
Withdrawals for industrial and mining use		3.29	1.44	1.15	1.17	.76	2.26
Public supply							
Greenwich Township WD	15-069	.10	.21	.19	.61	.22	.28
Greenwich Township WD	15-070	.31	-	-	-	-	-
Greenwich Township WD	15-347	-	.29	.31	.05	.12	.10
Greenwich Township WD	15-348	-	.24	.24	.07	.40	.44
Paulsboro WD	15-210	.00	.76	.73	.47	.54	.57
Paulsboro WD	15-212	.51	.15	.14	.12	.12	.19
Paulsboro WD	15-213	.49	.20	.13	.33	.21	.23
Paulsboro WD	15-215	.21	-	-	-	-	-
Paulsboro WD	15-216	.03	-	-	-	-	-
Penns Grove WSC	15-166	.03	.05	.04	.04	.04	.03
Pureland WC	15-137	.00	.13	.56	.38	.32	.40
Pureland WC	15-144	.00	.10	.07	.21	.05	.06
West Deptford WD	15-435	#	#	.39	.40	.23	1.48
Woodbury WD	15-431	#	#	.71	.39	.25	.51
Withdrawals for public supply		1.68	2.13	3.51	3.07	2.50	4.29
Total withdrawals		4.97	3.57	4.66	4.24	3.26	6.55

Table 7.--Ground-water-withdrawal rates in the region of Greenwich Township, Gloucester County, New Jersey, in 1973, 1978, and 1983-1986--Continued

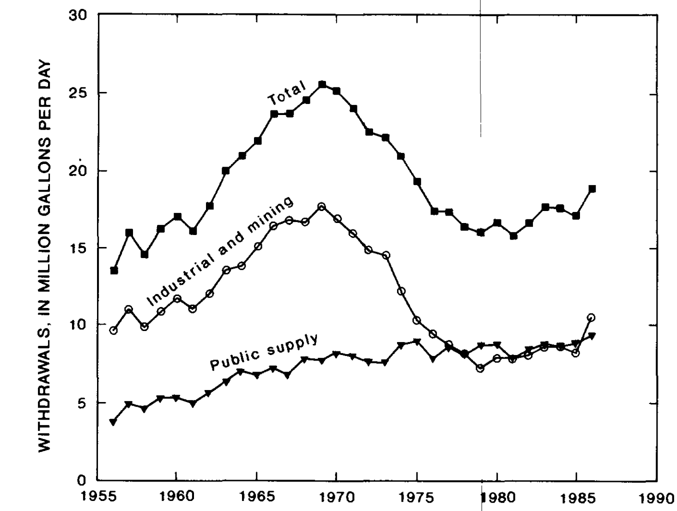
Type of usage Owner	Well number	Annual pumpage (million gallons per day) 1973	1978	1983	1984	1985	1986
Lower aquifer of the Potomac-Raritan-Magothy aquifer system							
Self-supplied industrial and mining							
Air Products & Chemicals	15-411	#	-	0.22	0.18	0.14	0.04*
Air Products & Chemicals	15-672	#	-	-	-	-	.06*
Coastal Eagle Point Oil	15-314	0.58	0.47	.79	.98	.57	.39
Coastal Eagle Point Oil	15-317	.00	.51	1.09	.69	.40	.42
Coastal Eagle Point Oil	15-318	1.15	.52	.62	.37	1.02	.43
Coastal Eagle Point Oil	15-319	.86	.50	.28	.09	.35	.78
Coastal Eagle Point Oil	15-320	.87	.81	.06	.52	.37	.63
Coastal Eagle Point Oil	15-321	.58	.76	.26	.52	.43	.40
Coastal Eagle Point Oil	15-322	1.09	.54	.18	.06	.24	.19
Essex Chemical Company	15-220	.24	.00	.71	.23	.31	.54
Essex Chemical Company	15-221	.17	.00	-	-	-	-
Essex Chemical Company	15-439	-	-	-	.45	.25	.01*
Mobil Oil Corporation	15-109	2.60	.62	.32	.31	.26	.44*
Mobil Oil Corporation	15-118	-	-	.21	.28	.27	.45*
Pennwalt Corporation	15-304	.13	-	-	-	.11	.39
Shell Chemical Company	15-283	.81	.63	.31	.38	.32	.05
Shell Chemical Company	15-285	.18	.10	.11	.28	.48	.54
Withdrawals for industrial and mining use		9.26	5.46	5.16	5.34	5.52	5.76
Public supply							
National Park Borough WD	15-207	0.30	0.32	0.34	0.32	0.32	0.32
West Deptford WD	15-282	.00	.72	.23	.27	.22	.29
West Deptford WD	15-312	.00	.44	.03	.14	.00	.17
West Deptford WD	15-313	.14	-	-	-	-	.00
West Deptford WD	15-373	#	#	.73	.39	.57	.23
Westville Borough WD	15-326	-	-	-	-	-	.11
Westville Borough WD	15-327	.68	.67	.71	.69	.73	.29
Westville Borough WD	15-434	#	#	-	-	-	.24
Woodbury WD	15-331	.36	.17	.18	.19	.28	.19
Withdrawals for public supply		1.48	2.32	2.22	2.00	2.12	1.84
Total withdrawals		10.74	7.78	7.38	7.34	7.64	7.60
Total withdrawals for industrial and mining use		14.57	8.26	8.85	8.84	8.17	10.46
Total withdrawals for public supply		7.60	8.21	8.91	8.76	8.92	9.40
Total withdrawals from Quaternary deposits and Potomac-Raritan-Magothy aquifer system		22.20	16.52	17.76	17.60	17.09	19.86



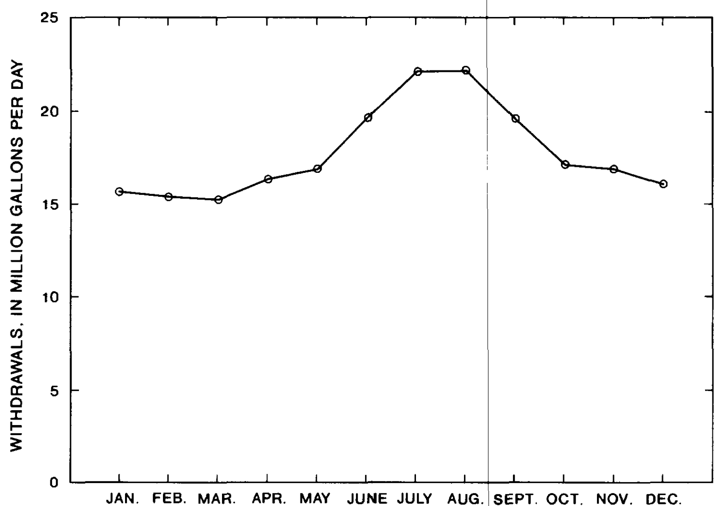
EXPLANATION

15-828
0.00 WELL LOCATION--Upper number is U.S. Geological Survey well number (see table 3). Lower number is well discharge, in million gallons per day (see table 7)

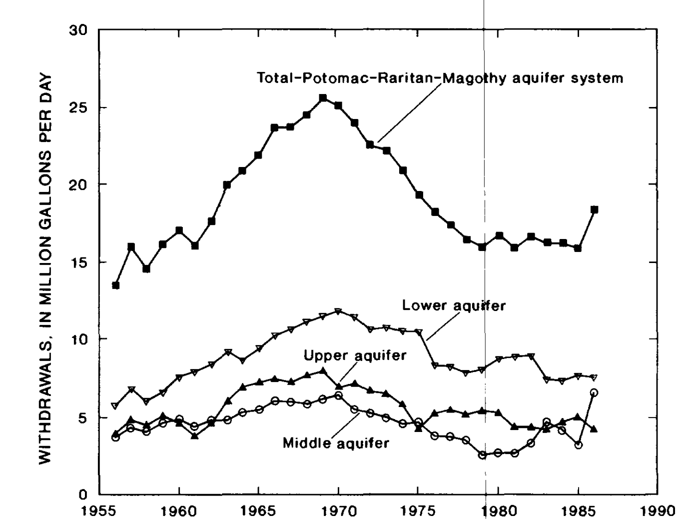
Figure 4.--Distribution of ground-water withdrawals from upper Cenozoic deposits in the region of Greenwich Township, Gloucester County, New Jersey, 1986.



a. Total ground-water use and ground-water use by type, 1956-86.



b. Seasonal fluctuations in ground-water use, 1983.



c. Total ground-water use and ground-water use by aquifer, Potomac-Raritan-Magothy aquifer system, 1956-86.

Figure 5.--Ground-water withdrawals in the region of Greenwich Township, Gloucester County, New Jersey.

connected upper Cenozoic deposits) constituted more than 99 percent of the total reported ground-water withdrawals in the Greenwich Township region (table 7). Ground-water pumped from the other units in the study area is used primarily for domestic or small-farm supply and is poorly documented.

During the 1970's, approximately half the total withdrawals from the Potomac-Raritan-Magothy aquifer system were from the lower aquifer, and the remainder was divided between the middle and upper aquifers (fig. 5); by 1986, however, withdrawals were approximately evenly distributed among the three aquifers. Until 1986, withdrawals from the upper aquifer generally were greater than those from the middle aquifer.

Occurrence and Flow

Water table

The water table in the Greenwich Township region is difficult to define because of the paucity of data, the influence of tides on surface water and ground water, and the complex hydrogeology. The shallow ground-water-flow system probably is regionally discontinuous and is most easily defined on a local basis. Figure 3 illustrates some of the possible scenarios for the position of the water table within the region.

In general, the water-table surface is a subdued replica of the land surface, so that water flows from high to low areas. Where upper Cenozoic deposits are coarse-grained and overlie the subcrop of a confining unit in Cretaceous deposits, the water table generally is found within the upper Cenozoic deposits. Shallow ground water flows laterally and recharges more permeable aquifers or discharges to surface water near the top of the underlying confining unit. Where coarse-grained upper Cenozoic deposits overlie the subcrop of an aquifer in Cretaceous deposits, the water table may be found in either unit and, because the units are hydraulically connected, may fluctuate between the two units. In either of these cases, or where aquifers in Cretaceous deposits crop out, ground water in the local (shallow) flow system is transmitted easily to the regional (deep) flow system.

Where upper Cenozoic deposits are fine-grained and overlie the subcrop of an aquifer in Cretaceous deposits, the underlying aquifer may be saturated and confined, or both units may be unsaturated--that is, a perched water table may exist in the soil zone of the upper Cenozoic deposits. Where confining units in Cretaceous deposits crop out or where upper Cenozoic deposits are fine-grained and overlie the subcrop of a confining unit in Cretaceous deposits, runoff probably is high, but the water table may be present in the soil zone of the clay-rich deposits.

Throughout most of the region, the water table is above sea level. Similar findings have been reported by other investigators (Andres, 1984, p. 81-93; Eckel and Walker, 1986; A.S. Navoy, U.S. Geological Survey, written commun., 1988). In the northwestern and southeastern corners of the Greenwich Township region, where the topographic relief is great (more than 100 ft from hilltops to adjacent channels less than 1 mi away), horizontal hydraulic gradients within the shallow ground-water system are nearly as steep as the land surface. In these areas, most of the shallow ground water discharges to nearby surface water, which eventually drains into the Delaware River. Adjacent to the Delaware River, on the subcrop of the Potomac-Raritan-Magothy aquifer system, topographic relief is relatively low and horizontal hydraulic gradients within the shallow ground-water system are low. In this area, the water table is near sea level and tides may have a significant effect on the hydraulic gradients between the surface water and the shallow ground water. In addition, throughout most of this area water has the potential to move downward through leaky confining units to the deep ground-water system, as confirmed by water-level data collected during this study.

In Greenwich Township and Paulsboro Borough, the water table and stream stages are below sea level and below the stage of the Delaware River. This relation exists because the Delaware River is diked and floodgates are positioned at the mouths of five tributaries. Hence, in this area, the base datum for the hydrologic system is below sea level. Because a steep hydraulic gradient exists among the Delaware River (average water level, 1 ft above sea level), the tributaries (average water level at floodgates, 1.5 to 2.5 ft below sea level), and ground water on the landward side of the dike (water levels at least 5 ft below sea level in many areas adjacent to the river), the potential for river water to recharge the aquifer system is great. As the hydraulic gradient steepens (for instance, as a result of increased withdrawals adjacent to the river), the potential for induced aquifer recharge from the Delaware River increases. Recharge of the aquifer system occurs if a hydraulic connection exists between the river and the aquifer system across or beneath the dike. Hydraulic connection depends primarily on the permeability of the upper Cenozoic alluvial deposits that underlie the river and comprise the dikes. Dredging of the Delaware River may enhance the hydraulic connection between the river and the aquifer system.

At some industrial sites in Paulsboro Borough and in Greenwich, Logan, and West Deptford Townships, the water table is below ambient levels and probably was lowered through extensive pumping of the shallow ground-water system. Much of the shallow ground-water pumping is for recovery or containment of on-site ground-water contamination. At many of these sites, vertical hydraulic gradients between the shallow and deep ground-water systems are reversed, creating a potential for upward movement of water from the deep to the shallow system. In general, lowering the water table decreases ground-water discharge to surface water, so that, during drought, streams fed predominantly by ground-water runoff have very low flows or dry up. In addition, gradients between surface water and shallow ground water may reverse, causing surface water to recharge the ground-water system.

Englishtown aquifer system

Ground-water levels in the Englishtown aquifer system ranged from greater than 60 ft above sea level in the subcrop to less than 20 ft above sea level in the east-southeastern part of the region (pl. 9b). Subsurface flow within the confined part of the aquifer is east-southeast toward Camden County at a hydraulic gradient of less than 5 ft/mi. Vertical hydraulic gradients indicate a potential for water to move downward through the Merchantville-Woodbury confining unit to the upper aquifer of the Potomac-Raritan-Magothy aquifer system.

Potomac-Raritan-Magothy aquifer system

Before development, ground-water-flow patterns within the Potomac-Raritan-Magothy aquifer system were controlled by natural hydraulic gradients. These gradients reflected the differences in elevation and distance between recharge and discharge areas, as well as the geology and hydraulic properties of the aquifers and confining units. The main source of recharge to the aquifer system was precipitation on high-altitude areas of the outcrop northeast of the Greenwich Township region (Hardt and Hilton, 1969, p. 12; Barksdale and others, 1958, p. 102). Ground water in these areas moved southeastward in response to natural gradients until it reached the interface between freshwater and saline water in downdip parts of the aquifer system. At the interface, the movement of freshwater was diverted to the northeast and southwest toward Gloucester County. In the Greenwich Township region ground water discharged to the Delaware River (Barksdale and others, 1958, p. 108-112; Hardt and Hilton, 1969, p. 12-13; Gill and Farlekas, 1976).

After development, extensive pumpage of ground water from the Potomac-Raritan-Magothy aquifer system in eastern Gloucester, northern Camden, and western Burlington Counties decreased potentiometric levels in both the unconfined (Paulachok and Wood, 1984) and confined parts of the aquifer system (Eckel and Walker, 1986, p. 11-12). This lowering of water levels resulted in a reversal of ground-water gradients throughout much of the aquifer system. Water from the Delaware River now recharges the aquifer system, and water from the unconfined part of the Potomac-Raritan-Magothy aquifer system is transmitted downdip into the confined parts of the system. In the Greenwich Township region, subsurface flow within the confined aquifers generally is east-southeastward toward a large regional cone of depression centered in the areas of pumping in and near Camden County (Eckel and Walker, 1986). The Greenwich Township region lies within the northwestern part of this cone of depression.

Ground-water levels in each aquifer of the Potomac-Raritan-Magothy aquifer system in August to September 1986 (table 8; pls. 10 and 11a) ranged from near sea level in the subcrop to more than 50 ft below sea level in the eastern part of the Greenwich Township region. The potentiometric surface of each aquifer decreased eastward at a hydraulic gradient ranging from 3 to 15 ft/mi. Decreasing water levels toward the east are the result of the large regional cone of depression. Similarity in the potentiometric surfaces of the three aquifers may be caused by a hydraulic connection among the aquifers through leaky confining units and a similar regional distribution of ground-water withdrawals (Luzier, 1980; Eckel and Walker, 1986).

Ground-water flow from the subcrops of each aquifer to areas downdip is primarily toward the southeast. Flow in the downdip parts of the upper and middle aquifers is eastward toward Camden County. Flow in the downdip parts of the lower aquifer is northeast toward the border between Gloucester and Camden Counties. Differences in the patterns of subsurface flow among and within aquifers are related to differences in the distribution of pumping within the aquifers (pls. 8-9a).

Table 8.--Ground-water levels in selected wells in the region of Greenwich Township, Gloucester County, New Jersey, 1983 and 1986

[Well locations are shown in plates 1a, 9b, 10a, 10b, and 11a; well information is listed in table 3; dashes indicate no measurement taken or value cannot be calculated; HPPM, undifferentiated Holocene-Pleistocene-Pliocene-Miocene-age deposits; QRNR, undifferentiated Quaternary deposits; MLRW, Wenonah-Mount Laurel aquifer; EGLS, Englishtown aquifer system; WBMV, Merchantville-Woodbury confining unit; MRPAU, upper aquifer of the Potomac-Raritan-Magothy aquifer system (MRPA); MRPAM, middle aquifer of the MRPA; MRPAM 1, upper part of the MRPAM; MRPAM 2, lower part of the MRPAM; MRPAL, lower aquifer of the MRPA; datum is sea level]

Aquifer code	Well number	[1]1983 Altitude (feet)	[1]1983 Date (month/day)	1986 Altitude (feet)	1986 Date (month/day)	Change in water level, 1983-86 (feet)
EGLS	15-188	--	--	31	--[2]	
	15-676	--	--	30	--[2]	
HPPM	[3]15-703	--	--	50	8/22	--
	[3]15-704	--	--	47	8/22	--
MLRW	[3]15-686	--	--	51	8/28	--
	[3]15-687	--	--	21	8/28	--
MRPA	15-388	--	--	2	8/26	--
MRPAU	15-006	-56	11/08	-63	9/03	-7
	15-028	-23	11/01	-27	8/21	-5
	[4]15-191	-63	11/08	-67	8/20	-4
	15-192	-35	11/07	-52	8/20	-17
	15-194	-53	11/07	-53	8/20	0
	15-240	-21	11/18	-24	8/29	-3
	15-274	--	--	-68	9/05	--
	15-297	-12	10/31	-13	8/28	-1
	15-330	-50	11/07	-55	9/02	-5
	15-332	-45	10/31	-36	9/03	9

Table 8.--Ground-water levels in selected wells in the region of Greenwich Township, Gloucester County, New Jersey, 1983 and 1986--Continued

Aquifer code		Well number	[1]1983 Altitude (feet)	[1]1983 Date (month/day)	1986 Altitude (feet)	1986 Date (month/day)	Change in water level, 1983-86 (feet)
MRPAU		15-345	-12	11/14	-14	8/29	-2
		15-346	-24	11/08	-34	9/05	-10
		15-355	-30	11/01	-32	8/21	-2
		15-392	--	--	-28	9/15	--
		[3,5]15-546	3	11/16	3	9/02	0
		[3]15-564	--	--	[6] 4	8/20-9/05	--
		[3]15-581	--	--	1	8/26	--
		[3]15-591	--	--	1	8/26	--
		15-617	--	--	[6] -9	8/20-9/05	--
		[3]15-627	--	--	-2	8/25	--
MRPAM	2	15-069	-9	11/15	-12	9/03	-3
	2	15-096	-6	11/15	-7	8/26	-1
		15-140	1	11/16	-2	9/03	-3
	2	15-212	-22	11/02	-24	8/25	-2
	2	15-213	-10	11/02	-11	8/25	-1
		[5]15-242	-21	11/18	-24	8/29	-3
	2	[5]15-279	-24	11/04	-27	8/28	-3
		15-347	-2	11/05	-4	9/03	-2
		[5]15-348	-10	11/16	-12	9/03	-2
	1	15-387	6	11/17	5	8/26	-1
		[5]15-395	-5	11/18	-12	8/25	-7
		[5]15-431	-46	10/31	-51	9/03	-5
		15-435	-43	11/03	-48	8/21	-5
	1	15-540	--	--	[6] 3	8/20-9/05	--
		15-616	--	--	[6]-10	8/20-9/05	--
		15-620	--	--	[6] 5	8/20-9/05	--
	1	[3]15-633	--	--	-2	8/26	--
		15-647	--	--	-5	8/26	--
	1	[3]15-652	--	--	0	8/26	--
	1	[3]15-654	--	--	-1	8/26	--
	2	15-657	--	--	-8	8/28	--
	1	[3]15-660	--	--	0	8/28	--
	2	15-661	--	--	-5	8/28	--
		15-665	--	--	-6	8/26	--
	2	15-679	--	--	-4	8/27	--

Table 8.--Ground-water levels in selected wells in the region of Greenwich Township, Gloucester County, New Jersey, 1983 and 1986--Continued

Aquifer code	Well number	[1]1983 Altitude (feet)	[1]1983 Date (month/day)	1986 Altitude (feet)	1986 Date (month/day)	Change in water level, 1983-86 (feet)
MRPAM 2	15-682	--	--	-5	8/27	--
2	15-683	--	--	-4	8/27	--
2	15-692	--	--	-3	8/28	--
1	[3]15-693	--	--	-2	8/28	--
2	15-696	--	--	-10	8/27	--
MRPAL	15-139	-9	11/16	-10	9/03	-1
	15-282	--	--	-37	8/20	--
	15-285	--	--	-35	8/28	--
	15-296	-16	10/31	-19	8/28	-3
	15-311	-10	11/04	-11	9/02	-1
	15-326	-48	11/03	-50	9/04	-2
	15-373	--	--	-58	8/21	--
	15-438	--	--	-19	9/03	--
	15-533	-33	11/07	-36	8/21	-3
	15-615	--	--	[6]-16	8/20-9/05	--
	15-618	--	--	[6]-5	8/20-9/05	--
	15-634	--	--	-5	8/28	--
	15-678	--	--	-9	8/27	--
	15-680	--	--	-7	8/27	--
	15-694	--	--	-9	8/27	--
	15-695	--	--	-12	8/27	--
	15-711	--	--	-8	8/27	--
QRNR	[3,5]15-303	-8	11/04	-8	9/02	0
	[3]15-644	--	--	-4	8/26	--
	[3]15-667	--	--	-5	8/26	--
	[3]15-677	--	--	-1	8/25	--
	[3]15-689	--	--	1	8/28	--
	[3]15-698	--	--	-1	8/27	--
	[3]15-699	--	--	3	8/27	--
	[3]15-700	--	--	-4	8/27	--
	[3]15-701	--	--	0	8/27	--
	[3]15-709	--	--	-2	8/27	--
	[3]15-710	--	--	0	8/27	--

Table 8.--Ground-water levels in selected wells in the region of Greenwich Township, Gloucester County, New Jersey, 1983 and 1986--Continued

Aquifer code	Well number	[1]1983 Altitude (feet)	[1]1983 Date (month/day)	1986 Altitude (feet)	1986 Date (month/day)	Change in water level, 1983-86 (feet)
WBMV	[3]15-675	--	--	6	8/25	--
	[3]15-690	--	--	7	8/25	--
	[3]15-691	--	--	18	8/22	--
	[3]15-705	--	--	15	8/28	--
	[3]15-706	--	--	20	8/25	--
	[3]15-708	--	--	29	8/25	--

[1]1983 water levels from Eckel and Walker (1986) and Eckel and Walker, 1986, unpublished U.S. Geological Survey water-level data.
[2]1988 water level; from R. Rosman, U.S. Geological Survey, written commun., 1989.
[3]Well screened in unconfined part of the aquifer.
[4]Altitude different from that used by Eckel and Walker (1986).
[5]Aquifer code different from that used by Eckel and Walker (1986).
[6]Average water level calculated from measurements made by continuous water-level recorder, 8/20/86-9/05/86.

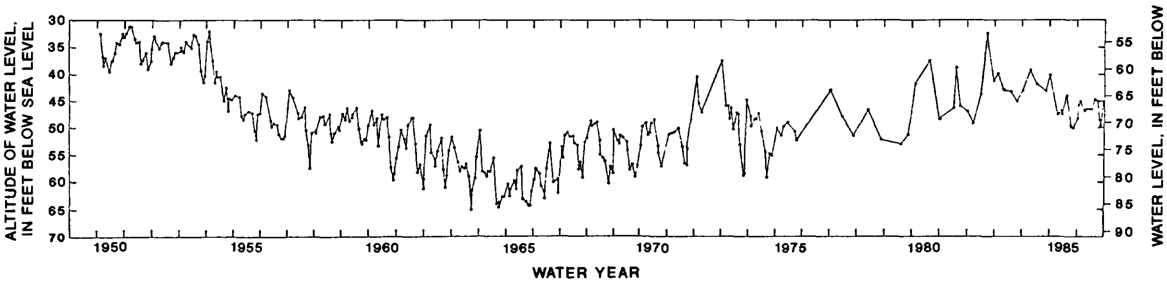
Vertical hydraulic gradients in the subcrops and shallow downdip parts of the aquifers suggest a potential for water to move from the Delaware River into the aquifer system and downward through leaky confining units to underlying aquifers. In deeper, confined parts of the aquifer system in the southeastern part of the region, vertical hydraulic gradients between aquifers are reversed, resulting in a potential for water to move into the upper aquifer. These vertical flow patterns reflect the distribution of pumping among and within the aquifers; that is, toward the southeast, ground water is withdrawn mainly from shallow, stratigraphically high aquifers, which commonly are less costly to develop and contain less saline water (pls. 8-9a).

The direction and horizontal hydraulic gradient of ground-water flow in the Potomac-Raritan-Magothy aquifer system, determined from water levels measured from August 20 through September 5, 1986, are similar to those observed in 1983 (Eckel and Walker, 1986); however, the potentiometric surface is about 5 ft lower than in 1983. Change in water levels from 1983 to 1986 was calculated for 31 wells screened in the aquifer system (table 8). Water levels declined in 27 of the 31 measured wells; the average decline was 4 ft. This decline reflects both annual and seasonal increases in ground-water withdrawals from aquifers in the Greenwich Township region (fig. 5). Water levels in late August 1986 were lower than those in early November 1983 because in August precipitation is at or near the seasonal low (pl. 1a), and the effects of heavy summer pumping are near the maximum (fig. 5). By early November, ground-water levels have recovered substantially from the summer pumping.

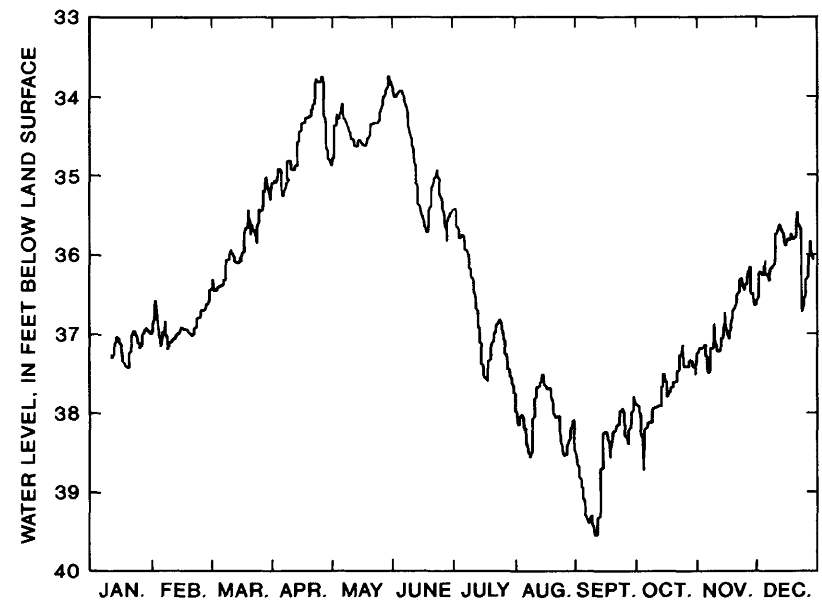
Water-Level Fluctuations

Fluctuations in water levels in wells provide valuable information about the water-bearing characteristics of aquifers. In the Greenwich Township region, fluctuations in ground-water levels result from natural mechanisms, such as climatic and tidal effects, and from human activities such as ground-water pumping. More than one mechanism can operate simultaneously to influence ground-water levels. Long-term, seasonal, and tide-induced fluctuations in ground-water levels in the Greenwich Township region are discussed below; short-term fluctuations in response to short-duration events, such as heavy precipitation or pumping, that occur within time periods of 1 day or less are not discussed. Continuous water-level data were used to analyze water-level fluctuations in the confined part of the aquifer system. No continuous water-level data are available for wells screened in the unconfined part of the aquifer system.

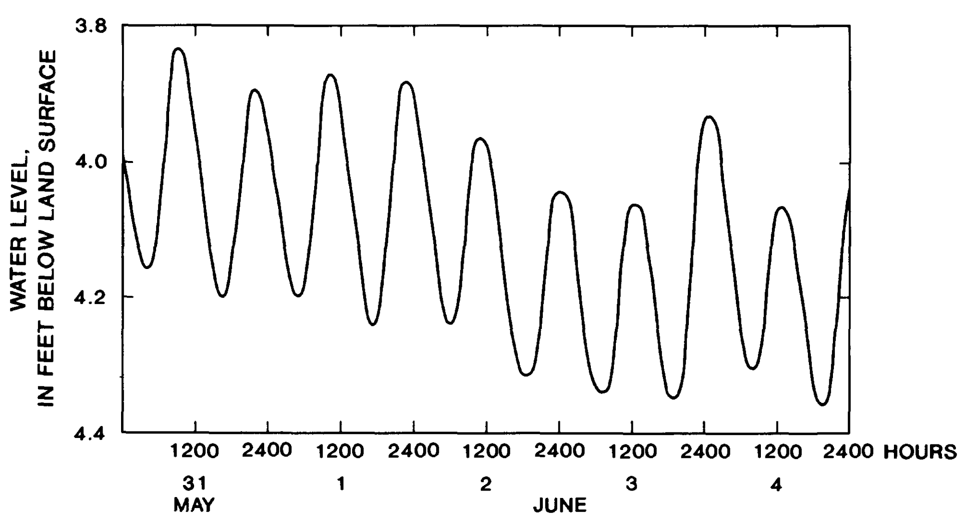
Long-term fluctuations occur over a period of time measured in years. Long-term trends in ground-water levels are primarily caused by long-term changes in precipitation and water use. Figure 6a is a water-level hydrograph of well 15-323 (pl. 1a), which is located at an industrial site directly northeast of the Greenwich Township region and is screened in the confined part of the lower aquifer of the Potomac-Raritan-Magothy aquifer system. This hydrograph illustrates the long-term trends in ground-water levels in industrialized parts of the Greenwich Township region adjacent to the Delaware River from 1949-86. In general, as shown in figure 6a, ground-water levels declined from 1949 to the mid-1960's, rose to 1983, and declined until 1986. Water-level hydrographs of five additional wells



a. Well 15-323, water years 1949-86.



b. Well 15-296, 1983.



c. Well 15-620, May 31 - June 4, 1986.

Figure 6.--Water-level hydrographs of selected wells in the region of Greenwich Township, Gloucester County, New Jersey.

within the industrialized areas in the region (15-097, 15-279, 15-296, 15-297, and 15-316, pl. 1a) show similar long-term trends; these trends correlate closely with those for total ground-water withdrawals and industrial withdrawals during approximately the same period (fig. 5a); however, the lowest water levels were measured in the mid-1960's rather than in 1969, the time of maximum withdrawals. The lower ground-water levels in the mid-1960's probably are related to the 1961-66 drought (fig. 2).

Ground-water levels in the southeastern part of the region are influenced primarily by ground-water withdrawals by public-supply purveyors rather than by withdrawals by industrial facilities. In this part of the region, water levels probably decreased steadily from 1956 to 1986, reflecting the increase in ground-water withdrawals by public-supply purveyors during that period (fig. 5a). Long-term water-level hydrographs of many wells in the Camden region illustrate this regional trend (A.S. Navoy, U.S. Geological Survey, written commun., 1988).

Seasonal fluctuations are regular changes that occur over a period of a year. Seasonal ground-water-level trends are the result of seasonal changes in precipitation and water use. In general, ground-water levels are higher during cool, wet months because of increases in recharge and decreases in ground-water withdrawals; water levels are lower during hot, dry months because of high evapotranspiration rates and increases in withdrawals. Conditions that affect infiltration rates, such as snow cover or frozen ground, also have a significant effect on ground-water levels, however.

Ground-water levels vary as much as 25 ft in some aquifers in the southern New Jersey Coastal Plain during the course of a year (Eckel and Walker, 1986, p. 6). Continuous water-level data for 15 wells (15-139, 15-140, 15-296, 15-323, 15-540, 15-564, 15-615, 15-616, 15-617, 15-618, 15-620, 15-712, 15-713, 15-727, and 15-728, pl. 1a) screened in the confined part of the Potomac-Raritan-Magothy aquifer system in or near the Greenwich Township region during 1983-86 indicate that regional ground-water levels fluctuate as much as 5 ft annually, generally reaching a high in late spring and a low in late summer. Figure 6b, a hydrograph of ground-water levels in well 15-296 (pl. 1a) during 1983, clearly illustrates the seasonal fluctuation of water levels in these confined wells.

Correlation of seasonal fluctuations in precipitation and evapotranspiration with water levels measured in confined aquifers is difficult because precipitation does not infiltrate directly into the confined part of the aquifer system. Even if the time lag between precipitation and recharge to the aquifer is considered, fluctuations in water levels in confined aquifers resulting from seasonal variations in precipitation and evapotranspiration probably are small. Seasonal fluctuations in water levels in confined aquifers are more likely to be caused by seasonal variations in water use. The strong correlation between seasonal trends in ground-water withdrawals and ground-water levels is illustrated by comparing figure 5b with figure 6b. Ground-water levels decline in late summer in response to the increase in ground-water withdrawals.

In the Greenwich Township region, daily fluctuations in ground-water levels occur in response to tides because the subcrop of the Potomac-Raritan-Magothy aquifer system is incised by the Delaware River estuary and its tributaries (pl. 2). Two mechanisms are responsible for tide-induced fluctuations in ground-water levels (fig. 6c)--flux of water into and out of the unconfined aquifer and surface-water loading of the confined aquifer. Changes in surface-water loading during a tidal cycle causes alternating compression and expansion of the confined-aquifer material. When the aquifer material is compressed during high tide, pore volume decreases, increasing heads downdip.

Because different mechanisms cause tide-induced fluctuations in the confined and unconfined aquifer, the magnitude or extent and timing of their effect also vary by aquifer type (Ferris, 1951). For example, in unconfined aquifers, the effect of tide-induced fluctuations varies with the effectiveness of the hydraulic connection between the aquifer and the surface-water body. In both types of aquifers, however, the time lag between tide-induced fluctuations in surface-water levels and those in nearby ground water increases with increasing distance between the well and the tidal surface-water body; the amplitude of change of ground-water levels caused by tides decreases with increasing distance from the tidal surface-water body.

The daily amplitude of change in ground-water levels in 19 wells with continuous water-level recorders in the Greenwich Township region is summarized in table 9. The amplitude of change in each well during a tide cycle was estimated from the difference between the highest and lowest water levels for each solar day. Because a lunar day (24 hours and 50 minutes) does not coincide with a solar day, the calculated difference in water levels may be less than that during a lunar day. For example, the maximum difference in water levels for well 15-620 (pl. 1a) for the solar day June 3, 1986, is 0.40 ft, whereas the maximum difference in water levels for the lunar day starting June 3, 1986, is 0.41 ft.

The 25th-, 50th- (median), and 75th-percentile values were used to describe statistically the central tendancy and variability of daily fluctuations in ground-water levels in 15 of the 19 wells in table 9. Percentiles were used rather than mean and standard deviation because data outliers, such as large changes in ground-water levels caused by periodic pumping, are not heavily weighted in the calculation of percentiles. For example, for well 15-323 (pl. 1a), which is influenced by a nearby pumping well, the maximum amplitude of change in water level during a solar day is more than 20 ft (an outlier), whereas the median amplitude of change is only 2.39 ft for the same period. Hence, the median closely approximates the average amplitude of fluctuations in ground-water levels resulting from tides, and most large changes in ground-water levels caused by pumping fall outside the interquartile range (25th to 75th percentile).

Large fluctuations associated with the changing phase of the moon also fall outside the interquartile range. For example, during June 1986, the maximum daily amplitudes of change in the water levels in well 15-620 (pl. 1a) at both full and new moons (0.62 and 0.51 ft, respectively) exceed the calculated 75th-percentile value of 0.45 ft. Because well 15-620 is far from any pumped wells, these data outliers are most likely tide-induced;

Table 9.--Mean altitude of water levels and amplitude of change in water levels caused by daily fluctuations in tides in selected wells in the region of Greenwich Township, Gloucester County, New Jersey

[Unless otherwise noted, data are from continuous water-level recorders operated by the U.S. Geological Survey. Data not collected by the U.S. Geological Survey were not verified. --, data not available; MRPA, Potomac-Raritan-Magothy aquifer system; MRPAU, upper aquifer of the MRPA; MRPAM, middle aquifer of the MRPA; MRPAL, lower aquifer of the MRPA; EPA, U.S. Environmental Protection Agency; BROS, Bridgeport Rental and Oil Services. Well locations shown in plate 1a. Well information listed in table 3]

Well or well-nest name	Well number	Aquifer code	Mean altitude of water level (feet)	Change in water levels: 25th percentile (feet)	Change in water levels: Median (feet)	Change in water levels: 75th percentile (feet)	Period of analysis (month/day/year)
Greenwich Township							
Mobil W-8	15-682	MRPAM	--	--	[1]1.10	--	[2]11/04/1985 - 01/24/1986
	15-711	MRPAL	--	--	[1]2.50	--	[2]08/12/1985 - 11/15/1985
Mobil W-1	15-997	MRPAM	--	--	[1] .30	--	12/01/1985 - 01/15/1986
	15-736	MRPAL	--	--	[1] .40	--	12/01/1985 - 01/15/1986
Stefka	15-728	MRPAU	-5.61	0.04	.05	0.07	05/18/1987 - 11/02/1987
	15-713	MRPAM	-7.10	.04	.06	.08	05/18/1987 - 11/02/1987
	15-712	MRPAL	-11.71	.02	.04	.07	05/18/1987 - 11/02/1987
Logan Township							
Shiveler	15-617	MRPAU	-6.82	0.04	0.06	0.10	06/12/1985 - 11/02/1987
	15-616	MRPAM	-7.67	.04	.07	.11	03/12/1985 - 11/02/1987
	15-615	MRPAL	-13.44	.07	.09	.12	03/12/1985 - 11/02/1987
Gaventa	15-620	MRPAM	2.76	.33	.38	.45	06/12/1985 - 11/02/1987
	15-618	MRPAL	-3.71	.07	.09	.12	05/09/1985 - 11/02/1987
EPA 108, near BROS	15-540	MRPAM	3.82	.26	.30	.35	04/19/1985 - 11/02/1987
Pureland	15-140	MRPAM	.74	.31	.36	.44	06/15/1985 - 06/11/1985
	15-139	MRPAL	-9.03	.26	.30	.35	06/15/1985 - 06/11/1986
National Park Borough							
National Park	15-771	MRPAM	-4.80	1.04	1.09	1.17	07/01/1987 - 12/07/1987
	15-770	MRPAL	-22.86	1.69	2.33	2.70	07/01/1987 - 10/24/1987
West Deptford Township							
Shell Chemical	15-296	MRPAL	-21.13	0.48	0.56	0.66	03/01/1985 - 10/29/1987
Texas Oil	15-323	MRPAL	-42.25	1.99	2.39	2.98	03/01/1985 - 11/01/1987

[1] Data from D. Choate, Mobil Oil Corporation, written commun., 1986
[2] Discontinuous record

yet, they are outside the interquartile range. Nevertheless, the interquartile range of the amplitude of change in ground-water levels includes most of the observations that are attributable to normal tides.

Climatic fluctuations also affect ground-water levels in unconfined aquifers over the course of a solar day; however, the change in water level generally is small. All of the wells listed in table 9 are screened in confined parts of the Potomac-Raritan-Magothy aquifer system.

The data in table 9 illustrate that the amplitude of change in ground-water levels decreases with distance from a tidal surface-water body. For example, well 15-711 (pl. 1a), screened in the confined part of the lower aquifer of the Potomac-Raritan-Magothy aquifer system and located 180 ft south of the Delaware River, experiences water-level fluctuations of 2.50 ft; however, well 15-736 (pl. 1a), screened in the same confined aquifer but located 4,300 ft south of the river, experiences daily fluctuations of 0.40 ft.

Water levels recorded in wells in Paulsboro Borough (D.E. Choate, Mobil Oil Corporation, written commun., 1986) and in National Park Borough (A.S. Navoy, U.S. Geological Survey, written commun., 1987) indicate that the influence of tides on water levels in the unconfined parts of the Potomac-Raritan-Magothy aquifer system is very small (less than 0.1 ft) compared to that in the confined parts of the aquifer system (greater than 2 ft). This difference results partly from the higher storativity of unconfined aquifers than confined aquifers. Fluctuations in the water table are measurable only when the flux of water to and from the aquifer is very large. In addition, the limited hydraulic connection between the river and the unconfined aquifer system resulting from the presence of clay-rich deposits probably reduces tidal effects.

Because tidal fluctuations in water levels are greater in some wells than in others, horizontal and vertical hydraulic gradients change during a tide cycle. Hourly water-level data collected from continuous water-level recorders on nested wells at seven sites and single wells at three sites (table 9) were analyzed to determine whether horizontal- or vertical-gradient reversals occurred among or within the aquifers of the Potomac-Raritan-Magothy aquifer system in the Greenwich Township region. Results of the analysis indicate that, at least for the wells listed in table 9, regular horizontal- and vertical-gradient reversals caused by tidal fluctuations do not occur; however, reversals in hydraulic gradients during a tide cycle may occur on a local scale.

Water Budget

Optimum development and use of water resources depend in large part on an understanding of the complex pattern by which water enters, moves through, and leaves the ground-water system. This pattern, known as the hydrologic cycle, is described in qualitative terms in most earth-science textbooks. A water budget is a simplified quantitative description of the hydrologic cycle.

The movement of water into and out of the Potomac-Raritan-Magothy aquifer system and the overlying and hydraulically connected upper Cenozoic deposits in the Greenwich Township region was quantified in a steady-state water budget for 1976-86 (table 10). This steady-state budget is different from that presented by Hardt and Hilton (1969) in that induced recharge from the Delaware River, inflow to and outflow from boundaries of the budget volume, vertical leakage, discharge to wetlands, and pumpage from the aquifer system are expressed explicitly.

Table 10.--Steady-state water budget for the saturated ground-water system in the region of Greenwich Township, Gloucester County, New Jersey, 1976-86

Input (million gallons per day)		Output (million gallons per day)	
Ground-water recharge	27.8	Base flow	26.6
River recharge	15.6	Pumpage	17.3
Lateral flow	7.2	Lateral flow	12.7
Vertical leakage	9.8	Discharge at wetlands	3.8
Total	60.4	Total	60.4

Change in water storage in the ground-water system during 1976-86 is assumed to be zero, because ground-water withdrawals remained relatively constant during this period (fig. 5) and changes in water storage for the aquifer system throughout the New Jersey Coastal Plain during the last 30 years were less than 5 percent of the total budget (Mary Martin, U.S. Geological Survey, oral commun., 1988). Hence, water inputs and outputs to and from the saturated ground-water system were balanced at 60.4 Mgal/d.

Ground-Water Recharge

Recharge, estimated as precipitation minus losses through evapotranspiration and direct runoff to surface water, is 46 percent of the total water input to the saturated ground-water system in the Greenwich Township region. Recharge occurs over 30.8 mi^2 in the region, where the Potomac-Raritan-Magothy aquifer system subcrops or where thick upper Cenozoic deposits overlie bedrock and truncate against the aquifer system (pl. 2). The northwestern extent of the recharge area coincides with the sharp increase in relief of the bedrock surface and the northwestern extent of "Trenton Gravel" deposits as mapped by Berg and others (1980) and Owens and Minard (1979). The recharge area excludes 15 mi^2 covered by the Delaware River (10.7 mi^2), Cedar Swamp (0.9 mi^2), and wetlands in Greenwich Township (3.4 mi^2).

Mean annual precipitation in the Greenwich Township region, estimated from precipitation data collected at the Marcus Hook, Pennsylvania, weather station from 1931-86 (fig. 2), is 42.3 in/yr (inches per year). Although the mean precipitation during the budget period (1976-86) is less than the long-term mean, the long-term mean is used in this budget because it best represents natural, steady-state conditons.

Because approximately 15 percent of the region is covered by marsh and other surface-water bodies, evapotranspiration of precipitation is high (Andres, 1984, p. 74). Evapotranspiration was estimated to be 50 percent of precipitation, or 21.2 in/yr, for the lower Delaware River valley (Barksdale and others, 1958, p. 28) and Gloucester County (Hardt and Hilton, 1969, p. 54). Because the recharge area defined in this study excludes large surface-water bodies, actual evapotranspiration may be lower than that used in this budget.

About half the precipitation that falls in the recharge area is potentially available for recharge; actual recharge is less because about 11 percent of the potential recharge becomes direct runoff. Runoff includes precipitation that falls directly on surface water and overland flow to surface water. Overland flow in the recharge area probably is small because the surface materials have a high infiltration capacity: permeable upper Cenozoic deposits cover much of the area, slopes are less than 5 percent, and much of the land is undeveloped or used for agriculture (Andres, 1984, p. 80; Vowinkel and Foster, 1981, p. 19). Most of the water falling on clay-rich deposits probably runs off and is absorbed by adjacent, more permeable deposits.

Runoff in the Pinelands of southern New Jersey, an area with a similar geohydrologic setting to that of the Greenwich Township region, was estimated to be 11 percent of total annual streamflow (Rhodehamel, 1970, p. 13); this figure is used in the current water budget. Average annual streamflow in the recharge area was estimated to be 20.4 in/yr on the basis of a streamflow estimate of 1.5 cubic feet per square mi made by Vowinkel and Foster (1981, p. 18; table 4, drainage segment 12) from streamflow measurements at gaging stations on Raccoon and Mantua Creeks during 1941-78. These streamflow data were collected in the subcrop area of other aquifer systems southeast of the study area; therefore, their applicability to this area is questionable. Nevertheless, estimated runoff in the Greenwich Township region based on this annual streamflow is 11 percent of 20.4 in/yr, or 2.2 in/yr.

Hence, recharge to the saturated ground-water system is

$$42.3 \text{ in/yr} - 21.1 \text{ in/yr} - 2.2 \text{ in/yr} = 19.0 \text{ in/yr},$$

or, for the recharge area, 27.8 Mgal/d (table 10). This recharge estimate is similar to that determined for the Camden, New Jersey, region by A.S. Navoy (U.S. Geological Survey, oral commun., 1989); however, results of computer simulations by Luzier (1980, fig. 32, p. 65) suggest that recharge is a much smaller percentage of the total water input in the Camden region. The final values used by Luzier in his model of recharge in the outcrop area southwest of Camden was 4.2 in. (Luzier, 1980, p. 32). This recharge estimate is determined largely by the estimates of evapotranspiration and streamflow. Both estimates are uncertain. An error of only 5 percent in the evapotranspiration estimate is larger than the smallest contribution by a budget-input component. If evapotranspiration is overestimated or underestimated, recharge will be greater or smaller, respectively, than the value used here.

River Recharge

An additional water input to the Potomac-Raritan-Magothy aquifer system is induced recharge from the Delaware River and its tributaries, caused by extensive ground-water withdrawals. Induced recharge to the aquifer system from 14 reaches of the Delaware River in 1973 and 1978 was estimated by Farlekas (Vowinkel and Foster, 1981, p. 32, table 7) by means of a two-dimensional computer simulation of ground-water flow developed by Luzier (1980). According to Luzier (1980, fig. 32, p. 65), recharge from the Delaware River increases in proportion to increases in ground-water withdrawals. Computer simulations and projections by Luzier (1980, p. 66) indicate that river recharge in the Camden region increased from 16 percent of total input in 1956 to 43 percent in 1973 and will continue to increase to 62 percent in the year 2000.

Model-simulated inflow for 1978 from the Delaware River to the Potomac-Raritan-Magothy aquifer system (Vowinkel and Foster, 1981, p. 32, table 7) was used to determine average recharge from the river to the saturated ground-water system in the Greenwich Township region. River recharge was estimated to be 26 percent of the total water input by using the simulation results for river reaches 11, 12, and 13. All of the recharge estimated from river reaches 11 (11.9 ft^3/s (cubic feet per second)) and 12 (11.8 ft^3/s) and about 26 percent (only 1.43 mi of the total 5.41 mi of river reach 13 is within the region) of the recharge from river reach 13 (0.37 of 1.4 ft^3/s) were assumed to enter the Potomac-Raritan-Magothy aquifer system--principally the middle aquifer--through the overlying upper Cenozoic deposits. Induced recharge to the aquifer system totaled 24.07 ft^3/s, or 15.6 Mgal/d (table 10). River recharge is assumed to remain constant during the budget period because pumpage did not vary greatly from 1976-86 (fig. 21).

This estimate of river recharge is subject to the same assumptions as is the flow model and, therefore, should be used with caution. The percentage of total input to the aquifer system that is river recharge (26 percent) is less than the 45 to 52 percent predicted for the Camden region during the same period (Luzier, 1980, fig. 32, p. 65). River recharge may be less in the Greenwich Township region because pumpage is less and accounts for only 29 percent of total losses from the system. In Luzier's (1980) model, pumpage was the only loss from the aquifer system in the Camden region.

Induced recharge to the aquifer system from tributaries to the Delaware River was not estimated but is assumed in this budget to be included in the estimate of induced recharge from the Delaware River. Horizontal hydraulic gradients between surface water and shallow ground water, and vertical gradients between aquifers in the system, suggest a strong potential for movement of water from surface water to the shallow and regional ground-water systems. Therefore, as is the case with the Delaware River, recharge to the aquifer system probably occurs along many reaches of these tributaries where their streambeds are permeable. Because results of computer simulations (Mary Martin, U.S. Geological Survey, oral commun., 1989) indicate that induced recharge from the river is difficult to distinguish from induced recharge from the tributaries and the shallow ground-water system in the subcrop area, the amount of induced recharge estimated by using Luzier's (1980) model was assumed to represent induced recharge from both the river and the tributaries. The relative percentage of recharge from the river compared to that from its tributaries was not determined for this budget but depends largely on the relative permeabilities of their streambeds.

Lateral Flow

Lateral flow into or out of the boundaries of the budget area were estimated by using Darcy's Law: Flow = horizontal hydraulic conductivity x cross-sectional area x hydraulic gradient perpendicular to flow. The boundary of the simulated area was divided into sections (representing volumes of aquifer material), approximately 40 per aquifer (pl. 11b). Geometry was based on the 1986 potentiometric-surface maps for the Potomac-Raritan-Magothy aquifer system in the Greenwich Township region (pls. 10-11a). Volumes adjacent to the boundary required for calculation were chosen such that two sides were equal, parallel, and approximately coincident with equipotential lines (generally with up to a 10-ft difference in head), and two sides were equal, parallel flow lines (pl. 11b). Distance between flow lines, the hydraulic gradient (change in hydraulic head divided by distance along the flow line), and the angle between the flow line and a flow line perpendicular to the boundary were measured for each volume. Average thickness of each aquifer was determined for volumes by using discretized maps of top surfaces of units (pls. 3b-7b). Thickness multiplied by the distance between flow lines yielded the cross-sectional area parallel to flow. Estimates of horizontal hydraulic conductivity used in these calculations are 135 ft/d for the upper aquifer, 155 ft/d for the middle aquifer, and 200 ft/d for the lower aquifer.

Flow along a flow line within each volume was calculated according to Darcy's Law and then multiplied by the cosine of the angle between the flow line and a flow line perpendicular to the boundary to obtain the component of flow through the boundary. Calculated boundary flows for the approximately 40 volumes within each aquifer were then compiled into 21 flow zones for each aquifer (pls. 10-11a, and table 11). The limits of each flow zone are not coincident from aquifer to aquifer; their placement varies with respect to changes in the direction and magnitude of boundary flows within each aquifer.

Table 11 lists the boundary flow for each zone for each aquifer. No-flow boundaries are found where equipotential lines are perpendicular to the boundaries. Volumes with no- or low-flow boundaries are located at the east-central and southeastern boundaries of the region in the upper aquifer, at the southeastern boundary in the middle aquifer, and at the south-central boundary in the lower aquifer. Addition of inflows and outflows for zones comprising each aquifer yields the summary of lateral flows shown in table 11. Subsurface lateral flow into the aquifer system occurs primarily along the northeastern and southwestern boundaries; subsurface lateral flow out of the aquifer system occurs primarily along the southern and eastern boundaries.

Vertical Leakage

In the southeastern part of the Greenwich Township region, the confined parts of the aquifer system can receive recharge by vertical leakage through the Merchantville-Woodbury confining unit from the overlying upper Cenozoic deposits or the Englishtown aquifer system. According to Luzier (1980, fig. 32 and p. 66), vertical leakage through the confining unit to the Potomac-Raritan-Magothy aquifer system in the Camden region increases in proportion to increases in ground-water withdrawals. Results of computer simulations by Luzier (1980), however, indicate that vertical leakage as a percentage of water input in the Camden region decreased from 39 percent of total input in 1956 to 31 percent in 1973 and will continue to decrease to 24 percent in the year 2000.

After estimates of ground-water recharge, river recharge, and lateral flow into the aquifer system have been made, average vertical leakage to the saturated ground-water system in the Greenwich Township region from 1976-86 was estimated to be 9.8 Mgal/d, or 16 percent of total input, by subtracting the total of all other inputs from 60.4 Mgal/d (obtained by totaling water losses) to obtain a balanced budget. This estimate of leakage as a percentage of total input is lower than that predicted by Luzier (1980) for the Camden region during 1976-86 (35 percent). Vertical leakage in the Greenwich Township region, however, probably is proportionately less because vertical hydraulic gradients across the Merchantville-Woodbury confining unit are less steep than those in the Camden County area near the center of the regional cone of depression.

Vertical leakage through confining units within the Potomac-Raritan-Magothy aquifer system may be significant in the Greenwich Township region. Areas with a potential for vertical leakage to underlying aquifers (pls. 10b and 11a) were discussed previously in the section on occurrence and flow of ground water. The magnitude of this leakage was not estimated as part of this water budget because budget components were calculated for the entire aquifer system as one hydrologic system.

Base Flow, Discharge to Wetlands, and Pumpage

Water that infiltrates to become ground water either discharges to surface water or is stored in the saturated ground-water system where it is available to recharge the deeper parts of the system. In the Greenwich Township region, change in storage of surface water behind dikes and floodgates along the Delaware River from 1976-86 is assumed to be zero. Water that enters the shallow ground-water system may discharge to the numerous streams, drainage ditches, and wetlands in the region. With respect to the water budget, the surface-water-discharge estimate was divided into two components--base flow to streams (including small adjacent wetlands) and discharge to large wetlands.

Table 11.--Lateral flows across boundaries of each aquifer of the Potomac-Raritan-Magothy aquifer system in the region of Greenwich Township, Gloucester County, New Jersey

[Flow values are in cubic feet per day unless otherwise noted. Location of flow zones shown in plates 10a, 10b, and 11a. Flow zones are not coincident from aquifer to aquifer; hence, flows are not additive by zone]

Flow zone	Upper aquifer	Middle aquifer	Lower aquifer	All aquifers
1	+ 748.1	- 20,369.6	- 2,181.6	
2	+ 7,127.0	+ 41,472.3	+ 32,020.5	
3	- 76,953.4	- 36,478.7	+ 27,339.8	
4	-118,737.2	- 20,615.0	- 13,136.0	
5	- 19,254.4	- 24,792.6	- 96,257.2	
6	- 11,337.7	- 5,311.5	- 39,685.7	
7	- 4,486.3	- 15,446.5	- 29,201.4	
8	- 19,496.0	- 68,511.0	- 24,111.6	
9	- 18,381.2	- 6,716.4	- 19,677.0	
10	- 1,799.8	- 1,705.4	- 1,009.2	
11	- 5,166.4	- 3,640.7	+ 466.0	
12	- 31,796.6	+ 2,404.0	+ 3,118.0	
13	- 1,272.6	- 77,462.4	+ 44,859.7	
14	0.0	-166,478.1	+ 46,167.7	
15	+ 1,358.5	- 63,416.2	-276,747.7	
16	0.0	- 44,706.2	-201,139.0	
17	- 4,021.0	- 18,950.5	- 24,842.1	
18	- 12,222.5	+234,307.0	- 19,902.8	
19	- 12,464.0	+ 53,789.4	+332,708.8	
20	+ 24,399.2	+ 49,169.4	+ 50,537.2	
21	+ 7,934.4	- 14,518.1	- 30,065.8	
Subtotal input flow	+ 41,567.2	+381,142.1	+537,217.7	+ 959,927.0
Subtotal output flow	-337,389.1	-589,118.9	-777,957.1	-1,704,465.1
Net flow	-295,821.9	-207,976.8	-240,739.4	- 744,538.1
In millions of gallons per day:				
Subtotal input flow	+ 0.3	+ 2.9	+ 4.0	+ 7.2
Subtotal output flow	- 2.5	- 4.4	- 5.8	-12.7
Net flow	- 2.2	- 1.5	- 1.8	- 5.5

Base flow to streams in the recharge area of the Greenwich Township region is 44 percent of total losses from the saturated ground-water system and was estimated to be 18.2 in/yr, or 26.6 Mgal/d, by subtracting runoff from annual streamflow (20.4-2.2 in/yr). Because of tidal contributions, base flow could not be estimated by hydrograph-separation techniques. Discharge to large wetlands in the Greenwich Township region, including Cedar Swamp and wetlands near Repaupo and Clonmell Creeks (pl. 1b), was determined separately by multiplying base flow by area of wetlands (4.3 mi^2) to obtain 3.8 Mgal/d or 6 percent of total losses from the saturated ground-water system.

By use of these estimates, discharge to surface water totals 30.4 Mgal/d and exceeds recharge from precipitation (27.8 Mgal/d or 19.0 in/yr). This suggests that either discharge estimates are too high or water inputs from other system components contribute to surface-water discharge. In addition, estimates of flow from unconfined to confined parts of the Potomac-Raritan-Magothy aquifer system in central New Jersey by both Barksdale and others (1943) and Farlekas (1979) suggest that recharge to the confined system may be as much as 12 to 20 in/yr. Extensive ground-water withdrawals from the aquifer system in this area result in downward movement of water and reduction of base flow to surface water. Hence, estimates of discharges to streams and wetlands may be greatly overestimated.

Discharge of water from the Potomac-Raritan-Magothy aquifer system also occurs through withdrawals of ground water by pumping. Mean annual pumpage from the Potomac-Raritan-Magothy aquifer system in the Greenwich Township region for the budget period 1976-86 remained relatively constant (fig. 5a) at 17.3 Mgal/d. This estimate assumes that pumpage from other aquifers in the region is negligible and that much of the utilized ground water is discharged to the streams through treatment plants (Andres, 1984, p. 81).

SUMMARY AND CONCLUSIONS

The potential for contamination of potable-water supplies resulting from industrial land use and the need for quantitative information on the quality and quantity of the area's water resources prompted a study of hydrogeology and hydrology in the Greenwich Township region. The 115-mi^2 study area is adjacent to the Delaware River estuary in northern Gloucester County, New Jersey, and southern Delaware and Philadephia Counties, Pennsylvania, and is situated at the boundary between the Atlantic Coastal Plain and Piedmont physiographic provinces. Altitudes range to 140 ft above sea level in the southeastern part of the area. The lowest point in the dredged channel of the Delaware River is about 45 ft below sea level. Before the construction of dikes and floodgates in the mid-1700's, areas less than 25 ft above sea level were inundated during high tide in the Delaware River.

The climate is continental, with a mean annual temperature of 56.1 °F and a mean annual precipitation of 42.32 in. The driest month is October and the wettest is July. The most severe drought on record in this area occurred during 1961-66.

A discontinuous mantle of alluvial sand and gravel of late Cenozoic age covers a regional system of aquifers and confining units consisting of a southeastward-dipping (40-60 ft/mi), seaward-thickening wedge of Cretaceous gravel, sand, and clay. Adjacent to the river, upper Cenozoic deposits are as much as 100 ft thick.

In the southeastern part of the study area, upper Cenozoic deposits are underlain by the Englishtown aquifer system, which consists of intercalated thin sand and clay beds that total less than 40 ft in thickness and grade into massive silt and sand deposits southwest of the region. The aquifer system is a minor source of water because yields (50-500 gal/min) and transmissivity values (less than 500 ft^2/d) of the aquifer system are low compared to those of underlying aquifers.

The Englishtown aquifer system is underlain by the Merchantville-Woodbury confining unit--a thick deposit of interbedded glauconitic clay and sand with a minimum vertical hydraulic conductivity of 7.8×10^{-4} ft/d. A zone in the middle of the unit is sandy and locally is a minor aquifer.

The Potomac-Raritan-Magothy aquifer system, which underlies the Merchantville-Woodbury confining unit, is a nonmarine delta-plain deposit that crops out in a 3- to 5-mi-wide band covering 44 mi^2 adjacent to and underlying the Delaware River. The system consists of three aquifers--upper, middle, and lower--and two confining units. Locally, the upper and middle aquifers are connected hydraulically because the confining unit between them is sandy and discontinuous. A third confining unit locally divides the middle aquifer into two parts. Wells that tap the Potomac-Raritan-Magothy aquifer system yield up to 1,500 gal/min. For the aquifers, estimates of transmissivity range from 2,000 to 30,000 ft^2/d; estimates of hydraulic conductivity range from 50 to 198 ft/d; and estimates of storage coefficients range from 8×10^{-5} to 3×10^{-4}. Minimum vertical hydraulic conductivity of the confining units in the system is 1.5×10^{-5} ft/d. The aquifer system is underlain by the Wissahickon Formation, a relatively impermeable metamorphic and igneous bedrock of lower Paleozoic and Precambrian age.

The stage of the Delaware River fluctuates because of tides; average stage ranges from 2.4 ft below sea level to 3.4 ft above sea level. The long-term mean annual invasion point of saline water (greater than 250 milligrams of chloride per liter of water) in the river is within the Greenwich Township region, at Chester, Pennsylvania. The outcrop of the Potomac-Raritan-Magothy aquifer system is incised by the Delaware River. Extensive ground-water withdrawals have reversed hydraulic gradients, causing induced recharge to the aquifer system from the river where the riverbed is permeable. Hence, tidal fluctuations and river water of degraded quality can affect the ground-water system.

The Potomac-Raritan-Magothy aquifer system provides more than 99 percent of the ground-water withdrawals in the region. Pumpage is concentrated in the eastern part of the region and along the river and is greatest during summer. Toward the southeast, stratigraphically higher aquifers in the system are pumped most extensively. Ground-water withdrawals increased from 1956 through 1969, decreased from 1969 through 1981, and increased to more than 19 Mgal/d from 1981 through 1986. Although approximately half of the water pumped in 1986 was for public supplies and half was for industrial use, the long-term trend in withdrawals primarily reflects industrial use. Withdrawals for public supply increased through the period of record.

The Greenwich Township region lies within the northwestern part of a large regional cone of depression in the potentiometric surface of the Potomac-Raritan-Magothy aquifer system caused by extensive ground-water withdrawals in northern Camden, western Burlington, and eastern Gloucester Counties. Subsurface flow within the confined aquifers is generally eastward (southeastward for the upper and middle aquifers and northeastward for the lower aquifer), at a hydraulic gradient of 3 to 15 ft/mi, toward the regional cone of depression. Throughout most of the region, hydraulic gradients indicate a potential for downward flow of water from streambeds and the shallow ground-water system to the deeper ground-water system. Reversals in the downward potential are found locally as a result of industrial withdrawals, primarily by purge wells installed for the limitation of ground-water contamination. In the southeastern corner of the region, the potential for ground-water movement is toward areas of pumpage in the upper aquifer.

Fluctuations in ground-water levels caused by climatic and water-use effects include a long-term trend (a decrease from 1949 through the mid-1960's, an increase until 1983, and a decrease to 1986) that primarily reflects industrial withdrawals and a seasonal trend (maximum decrease of 5 ft during summer). From October and November 1983 to August and September 1986, the potentiometric surfaces of the confined aquifers declined 5 ft, mainly as a result of seasonal increases in water use within and southeast of the Greenwich Township region. Tidal fluctuations in ground-water levels have amplitudes of less than 2.5 ft and may cause local reversals in the vertical or horizontal hydraulic gradient.

A steady-state water budget describing inputs and outputs to the saturated ground-water system was developed by analytical methods and is balanced at 60.4 Mgal/d. Water inputs to the system include recharge (27.8 Mgal/d), induced recharge from the Delaware River and its tributaries caused by ground-water withdrawals (15.6 Mgal/d), subsurface lateral flow into the ground-water system across northeastern and southwestern boundaries (7.2 Mgal/d), and vertical leakage through the Merchantville-Woodbury confining unit from overlying aquifers (9.6 Mgal/d). Water losses from the system include pumpage (17.3 Mgal/d), base flow to streams (26.6 Mgal/d) and discharge to wetlands (3.8 Mgal/d), and subsurface lateral flow across the eastern and southern boundaries toward a depression in the potentiometric surface of the aquifer system (12.7 Mgal/d). Because water loss by pumpage and pumpage-induced flow to the southeast beyond the area is replaced primarily by river recharge and flow across northeastern and southwestern boundaries, the quality of induced recharge from the river and migration of saltwater from confined parts of the aquifer system in the southern and southwestern parts of the region are critical factors in the maintenance of ground-water quality.

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Table 2.--Altitudes of the tops of aquifers and confining units in the region of Greenwich Township, Gloucester County, New Jersey

[Altitudes are in feet above or below sea level. Well locations are identified by the last three digits of the well number on plate 1b. Drillers' logs are available for all wells except those marked with a '+'; geophysical logs are available for wells marked with a '*'; ---, contact is not present in the well log; ?, contact probably is present but its altitude cannot be discerned from the log]

			Potomac-Raritan-Magothy aquifer system							
					Middle aquifer					
Well number	Altitude of land surface	Merchantville-Woodbury confining unit	Upper aquifer	Confining unit	Upper part	Confining unit	Lower part	Confining unit	Lower aquifer	Wissahickon Formation
* 15-006	20	-98	?	-290	---	---	---	---	---	---
15-008	21	---	-215	---	---	---	---	---	---	---
* 15-011	58	-31	-137	-226	-262	---	---	---	---	---
15-016	70	---	-105	-203	-215	-261	-276	---	---	---
* 15-023	37	28	-102	-126	-170	---	---	---	---	---
+* 15-027	47	23	-97	---	---	---	---	---	---	---
* 15-028	70	33	-113	---	---	---	---	---	---	---
15-064	10	-3	-35	-113	-119	---	---	-160	-189	-277
15-066	0	-6	-25	-108	-119	---	---	-198	-255	-295
* 15-067	5	---	5	-17	-41	-120	-130	-168	-194	-257
15-069	10	---	6	-10	-50	-90	-120	-159	---	---
15-070	10	---	---	-7	-17	---	---	---	---	---
15-071	1	---	---	---	1	-42	?	-102	---	---
15-072	6	---	---	---	?	-26	-49	-97	---	---
15-073	0	---	---	---	-7	---	---	---	---	---
* 15-075	14	---	13	-14	-38	-93	---	---	---	---
15-076	15	---	---	-5	-11	-66	-72	-106	---	---
15-077	9	---	---	---	8	---	---	-90	---	---
15-079	10	---	---	---	4	-52	-70	-99	---	---
15-081	10	---	---	---	10	-53	-67	-89	---	---
15-083	15	---	---	-2	-7	-87	?	-112	---	---
15-085	12	---	---	?	?	-63	-98	-132	-163	-194
15-086	11	---	---	0	-15	?	?	?	---	---
15-087	5	---	---	---	4	-20	-37	---	---	---
15-088	13	---	---	?	?	-89	-101	-112	---	---

Table 2.--Altitudes of the tops of aquifers and confining units in the region of Greenwich Township, Gloucester County, New Jersey--continued.

Well number	Altitude of land surface	Merchantville-Woodbury confining unit	Potomac-Raritan-Magothy aquifer system: Upper aquifer	Confining unit	Middle aquifer: Upper part	Middle aquifer: Confining unit	Middle aquifer: Lower part	Confining unit	Lower aquifer	Wissahickon Formation
15-089	10	---	---	---	-11	-45	-64	-103	---	---
15-091	10	---	---	---	10	-12	-54	-95	?	---
15-092	4	---	---	---	-4	?	?	-127	---	---
15-093	6	---	---	---	6	-99	-123	-133	---	---
15-094	7	---	---	---	7	-82	-118	-140	---	---
15-095	5	---	---	---	5	-72	-123	-137	---	---
* 15-096	14.2	---	---	---	6	-37	-104	-122	---	---
* 15-097	5	---	---	---	1	-72	-84	-112	---	---
15-098	3	---	---	---	3	-77	-80	-112	---	---
+* 15-100	3	---	---	---	1	-15	-62	-87	---	---
15-101	20	---	---	---	20	-78	-91	?	-160	---
15-109	20	---	---	---	20	-40	-65	-139	-204	-251
+* 15-117	7	---	---	---	---	---	---	---	3	-52
15-118	18	---	---	---	18	-56	-73	-123	-195	---
+* 15-131	130	-108	-230	---	---	---	---	---	---	---
* 15-137	29	13	-15	-89	-131	---	---	---	---	---
15-138	15	11	---	---	---	---	---	---	---	---
15-139	6.1	---	-22	-48	-111	---	---	-186	-260	-338
15-141	0	---	-3	?	-120	---	---	---	---	---
* 15-144	7	---	7	-40	-112	---	---	---	---	---
* 15-154	10	---	-18	-33	-62	---	---	-151	-187	-259
+* 15-157	5	---	---	-7	-30	---	---	-105	-145	-202
* 15-166	5	---	---	-2	-23	-38	-55	-100	---	---
15-170	10.5	---	---	---	7	-65	-83	-112	---	---
* 15-171	5	---	---	---	-4	-24	-36	-77	-130	-159
* 15-173	5	---	---	---	4	-15	-33	-56	-95	---
* 15-175	8	---	---	---	---	---	---	---	-98	---
* 15-176	5	---	---	---	---	2	-14	-67	-99	---
* 15-177	5	---	---	---	---	---	-53	-58	-77	-126
* 15-179	5	---	---	---	5	-10	-38	-58	?	?

Table 2.--Altitudes of the tops of aquifers and confining units in the region of Greenwich Township, Gloucester County, New Jersey--continued.

Well number	Altitude of land surface	Merchantville-Woodbury confining unit	Potomac-Raritan-Magothy aquifer system: Upper aquifer	Confining unit	Middle aquifer: Upper part	Middle aquifer: Confining unit	Middle aquifer: Lower part	Confining unit	Lower aquifer	Wissahickon Formation
* 15-180	5	---	---	---	3	-27	-46	-68	-113	-149
* 15-181	5	---	---	---	?	?	?	?	-102	-121
15-189	80	---	-240	---	---	---	---	---	---	---
* 15-190	80	-96	-226	-323	---	---	---	---	---	---
* 15-191	71	-98	-240	-312	---	---	---	---	---	---
* 15-192	88	-82	-202	-302	-323	-348	-374	---	---	---
* 15-194	10	-59	-166	-285	-309	---	---	---	---	---
* 15-207	30	---	---	-78	---	---	---	---	---	-258
* 15-210	15	3	-17	-101	---	---	---	---	---	---
* 15-211	16	4	-18	?	-104	-136	-174	-211	-231	-333
15-212	15	---	---	-95	-115	-125	-177	-206	---	---
15-213	10	---	-10	-75	-78	-104	-140	---	---	---
15-214	10	---	10	---	---	---	---	---	---	---
* 15-217	20	---	---	---	---	-56	-72	-115	-215	-252
* 15-220	10	---	---	---	---	-70	-121	-136	-178	-269
* 15-221	10	---	---	---	---	-69	-86	-136	-155	---
15-274	80	-25	-185	---	---	---	---	---	---	---
15-275	50	---	-175	---	---	---	---	---	---	---
+* 15-276	60	-32	-144	-230	---	---	---	---	---	---
* 15-279	16	0	-61	-188	-242	---	---	---	---	---
* 15-281	61	23	-94	-187	---	---	---	---	---	---
* 15-282	55	45	-54	-181	-235	---	---	?	-329	---
* 15-283	30	---	-37	-127	-182	-251	-266	---	---	---
* 15-285	12	12	-52	-152	-205	-227	-235	-277	-288	---
* 15-287	30	8	-35	-123	-199	-242	-276	-305	-324	-360
* 15-291	12	-6	-46	-143	-201	---	---	-258	-293	---
* 15-294	5	-13	-63	-160	-240	---	---	-278	-288	-362
+* 15-295	20	20	-51	---	---	---	---	---	---	---
* 15-296	17	2	-23	-117	-183	---	---	-233	-269	---
* 15-298	10	2	-22	-103	-140	-207	-223	-280	-301	-358

Table 2.--Altitudes of the tops of aquifers and confining units in the region of Greenwich Township, Gloucester County, New Jersey--continued.

Well number	Altitude of land surface	Merchantville-Woodbury confining unit	Potomac-Raritan-Magothy aquifer system: Upper aquifer	Confining unit	Middle aquifer: Upper part	Middle aquifer: Confining unit	Middle aquifer: Lower part	Confining unit	Lower aquifer	Wissahickon Formation
+* 15-302	10	---	---	---	---	-116	-168	-201	-237	---
+* 15-307	10	---	---	---	---	---	---	-129	-233	---
+* 15-308	10	---	---	---	---	-91	-156	-186	-226	---
+* 15-309	10	---	---	---	---	-120	?	?	-211	---
* 15-310	10	---	---	-53	-65	-87	-141	-176	-221	---
+* 15-311	10	---	---	---	---	-63	-130	-154	-180	---
* 15-312	20	20	-61	-135	-160	---	---	-190	-291	---
15-313	23	20	-8	?	?	-177	-215	-232	-282	-333
* 15-316	31.8	28	-27	-106	-140	---	---	?	-244	-295
* 15-317	10	6	-32	-82	-114	-150	-184	-200	-215	---
15-326	12	-8	-70	-113	-175	---	---	-235	?	-300
15-327	16	-10	?	?	-173	-189	-203	?	-242	---
* 15-330	40	14	-104	-194	---	---	---	---	---	---
+* 15-331	30	---	-96	-182	-230	---	---	-308	-337	-450
15-332	50	50	-84	---	---	---	---	---	---	---
15-333	20	8	-90	---	---	---	---	---	---	---
15-348	20	---	11	-73	-80	---	---	-138	---	---
15-363	40	25	-95	---	---	---	---	---	---	---
15-366	80	0	-120	---	---	---	---	---	---	---
15-368	50	42	-58	---	---	---	---	---	---	---
* 15-373	28	28	-34	-125	?	-168	-182	-205	---	---
* 15-379	125	-99	-234	---	---	---	---	---	---	---
+* 15-381	25	---	-9	-136	-151	-175	-215	-237	---	---
+* 15-383	51	19	-83	-247	---	---	---	---	---	---
15-390	10	---	---	---	---	-100	---	---	---	---
15-392	90	-21	-142	---	---	---	---	---	---	---
15-394	30	10	-84	---	---	---	---	---	---	---
15-395	20	3	-14	-72	?	---	---	---	---	---
15-398	1	---	---	---	---	---	---	1	-31	---
* 15-399	10	---	---	---	10	-42	-60	-72	---	---

Table 2.--Altitudes of the tops of aquifers and confining units in the region of Greenwich Township, Gloucester County, New Jersey--continued.

Well number	Altitude of land surface	Merchantville-Woodbury confining unit	Potomac-Raritan-Magothy aquifer system: Upper aquifer	Confining unit	Middle aquifer: Upper part	Middle aquifer: Confining unit	Middle aquifer: Lower part	Confining unit	Lower aquifer	Wissahickon Formation
15-401	40	33	-77	-197	-227	-240	-265	-327	-332	-432
15-403	10	---	---	---	?	?	?	-84	-147	---
15-404	5	---	---	---	---	---	---	---	-7	-72
15-408	5	---	-24	-35	-54	-112	-130	-140	---	---
* 15-410	5	---	-39	-103	-129	-149	-192	-202	-227	-289
* 15-411	20	---	---	---	---	-73	-78	-157	-214	---
15-412	5	---	---	---	---	---	---	5	-27	---
15-413	40	28	-110	-156	-191	---	---	-273	-336	-433
* 15-414	30	30	-32	-119	-130	-162	?	-199	-252	-345
15-415	40	---	-115	-204	-243	-282	-302	-371	---	---
15-421	60	34	-72	---	---	---	---	---	---	---
* 15-430	15	10	-13	-127	-137	-165	-196	-207	-240	-315
* 15-431	30	19	-85	-156	-164	---	---	---	---	---
* 15-432	60	-42	-160	---	---	---	---	---	---	---
* 15-434	15	-6	---	---	---	-183	-193	-228	-258	---
* 15-435	40	-10	-117	---	---	---	---	---	---	---
15-438	10	---	---	---	---	-107	-111	-138	---	---
15-439	10	---	---	---	---	-76	?	-145	---	---
15-452	20	20	-12	---	---	---	---	---	---	---
15-453	10	---	9	4	?	---	---	---	---	---
15-454	20	20	-32	---	---	---	---	---	---	---
15-455	20	---	19	---	---	---	---	---	---	---
15-459	10	---	10	-34	-49	---	---	---	---	---
15-462	10	---	8	-19	-35	---	---	---	---	---
15-463	20	20	-15	---	---	---	---	---	---	---
15-466	30	25	-21	---	---	---	---	---	---	---
15-468	10	---	---	1	-22	-70	?	---	---	---
15-471	45	0	-73	---	---	---	---	---	---	---
15-496	45	7	-78	---	---	---	---	---	---	---
15-497	45	35	-61	---	---	---	---	---	---	---

Table 2.--Altitudes of the tops of aquifers and confining units in the region of Greenwich Township, Gloucester County, New Jersey--continued.

Well number	Altitude of land surface	Merchantville-Woodbury confining unit	Potomac-Raritan-Magothy aquifer system: Upper aquifer	Confining unit	Middle aquifer: Upper part	Middle aquifer: Confining unit	Middle aquifer: Lower part	Confining unit	Lower aquifer	Wissahickon Formation
15-498	62	56	-72	---	---	---	---	---	---	---
15-499	60	6	?	---	---	---	---	---	---	---
15-501	50	24	-81	---	---	---	---	---	---	---
15-502	30	25	-29	---	---	---	---	---	---	---
15-503	5	-15	-20	---	---	---	---	---	---	---
15-504	5	---	-24	---	---	---	---	---	---	---
15-507	5	---	---	---	---	---	---	---	---	-76
15-511	10	---	-2	---	---	---	---	---	---	---
15-513	15	5	-6	---	---	---	---	---	---	---
15-514	10	---	---	---	9	-56	-115	-119	-141	---
15-516	40	40	-34	---	---	---	---	---	---	---
15-518	65	35	-37	---	---	---	---	---	---	---
15-519	35	35	-40	---	---	---	---	---	---	---
15-520	62	7	-76	---	---	---	---	---	---	---
15-524	52	6	-53	---	---	---	---	---	---	---
15-527	58	16	-53	---	---	---	---	---	---	---
15-528	15	-10	-101	---	---	---	---	---	---	---
15-530	35	25	-29	---	---	---	---	---	---	---
* 15-533	22	---	7	-85	-101	-131	-165	-185	-216	---
* 15-550	10.2	---	10	-30	-68	-85	?	---	---	---
+* 15-553	10	---	10	-14	-32	-92	-104	-147	---	---
* 15-569	32	20	-18	-96	-133	-175	-200	---	---	---
15-575	1	---	-18	-28	?	---	---	---	---	---
15-582	1	---	-13	---	?	---	---	---	---	---
15-585	7	---	7	-25	-72	---	---	---	---	---
* 15-615	29.3	29	-19	-88	-129	---	---	-235	-261	-399
* 15-618	7	---	7	-54	-78	-103	-117	-159	-216	-243
* 15-621	25	21	-30	-99	-115	-181	-210	-285	-318	-400
* 15-622	10	---	3	-20	-40	-75	-98	-141	-200	-250
15-629	11	---	---	1	-8	---	---	-117	---	---

Table 2.--Altitudes of the tops of aquifers and confining units in the region of Greenwich Township, Gloucester County, New Jersey--continued.

Well number	Altitude of land surface	Merchantville-Woodbury confining unit	Potomac-Raritan-Magothy aquifer system: Upper aquifer	Confining unit	Middle aquifer: Upper part	Middle aquifer: Confining unit	Middle aquifer: Lower part	Confining unit	Lower aquifer	Wissahickon Formation
15-630	12	---	---	-10	?	?	?	-122	---	---
* 15-634	5	---	---	---	4	-22	-47	?	-115	-145
15-647	10	---	---	-12	-23	---	---	---	---	---
15-657	9	---	---	---	---	-41	---	---	---	---
* 15-658	9.35	---	---	---	9	-56	-66	-88	-129	-152
* 15-661	8	---	---	---	7	-16	-53	---	---	---
15-665	14	---	---	-11	-23	---	---	---	---	---
15-668	7	---	---	-10	-17	-58	-64	-113	---	---
* 15-678	9	---	3	-13	-20	-86	-104	-130	-164	---
* 15-680	8	---	---	---	---	---	8	-76	-136	---
* 15-692	5	---	---	---	5	-19	-59	---	---	---
* 15-694	10	---	---	---	10	-71	-81	-117	-201	---
* 15-695	8	---	8	-30	-40	-82	-112	-164	-214	---
* 15-711	11	---	---	---	---	---	11	-109	---	---
* 15-712	6.5	0	-15	-61	-67	-156	-178	-217	-237	-329
* 15-718	20	18	-70	-152	-165	---	---	-196	-295	-360
* 15-719	55	---	---	-182	?	-225	-250	-312	?	-417
* 15-736	16	---	---	---	16	-77	-92	-166	-201	---
* 15-737	12	---	---	---	---	-80	-91	-141	-216	---
* 15-738	4	---	---	---	4	-73	-86	-150	-171	---
* 15-739	5	---	---	---	5	-35	-75	-105	---	---
15-740	20	---	---	---	16	-49	-58	-129	-201	-249
* 15-742	8	-93	-188	-282	-310	-415	-436	-464	-545	-699
* 15-767	9	3	-19	-59	-68	-116	-128	-186	-206	-311
* 15-768	5	5	0	-85	-135	-155	-167	-219	-248	-337
* 15-769	15	10	-10	-60	-80	-100	-120	-175	-219	-328
* 15-770	10	---	2	-50	-82	---	---	-118	-185	---
* 15-772	10	---	---	-54	-70	-102	-107	-116	?	-206
* 15-775	15	---	15	-35	-53	---	---	-99	-153	-200
* 15-778	20	---	20	-32	?	-92	-108	-113	---	---

Table 2.--Altitudes of the tops of aquifers and confining units in the region of Greenwich Township, Gloucester County, New Jersey--continued.

Well number	Altitude of land surface	Merchantville-Woodbury confining unit	Potomac-Raritan-Magothy aquifer system: Upper aquifer	Confining unit	Middle aquifer: Upper part	Middle aquifer: Confining unit	Middle aquifer: Lower part	Confining unit	Lower aquifer	Wissahickon Formation
* 158002	45	---	-41	-166	-207	---	---	---	---	---
* 158006	65	-69	-203	---	---	---	---	---	---	---
* 500001	-12	---	---	---	---	-45	-102	-112	-132	-197
530025	14	---	---	---	---	---	---	---	---	-32
539001	0	---	---	---	---	---	---	---	---	-30

Table 3.--Selected records of wells and borings used to determine the hydrogeologic framework of the region of Greenwich Township, Gloucester County, New Jersey

[Altitude in feet above sea level; dashes indicate no data available; QRNR, undifferentiated Quaternary deposits; HPPM, undifferentiated Holocene, Pleistocene, Pliocene, and Miocene deposits; WBMV, Merchantville-Woodbury confining unit; MRPA, Potomac-Raritan-Magothy aquifer system; MRPAU, upper aquifer of the MRPA; MRPAM, middle aquifer of the MRPA; MRPAM 1, upper part of the MRPAM; MRPAM 2, lower part of the MRPAM; MRPAL, lower aquifer of the MRPA; drillers' logs are available for all wells for which a well depth is listed; H, water-level hydrographs are available; I, hydrogeologic data are available and were used to describe the hydrogeologic framework (see plates 2 through 7); P, pumpage data are available and are listed in table 6 (see plates 8 through 9a); R, ground-water- or contaminant-recovery wells (table 6); S, water-level data from August to September 1986 are available and are shown in plates 9b through 11a and in table 7; T, hourly water-level data are available and were used to determine tidal fluctuations (see table 8); W, data from specific-capacity tests are available and are listed in table 5]

Well number	Latitude (degrees)	Longitude (degrees)	Altitude of land surface (feet)	Top of screened interval[1] (feet)	Bottom of screened interval (feet)	Depth of well (feet)	Diameter of screen[2] (inches)	Aquifer code	Local well number	Available data
				DEPTFORD TOWNSHIP						
15-006	394627	0750813	20	263	308	344	12	MRPAU	SEWELL 1A	I, P, S, W
15-008	394628	0750813	21	244	307	313	12	MRPAU	SEWELL 2A	I, W, P
15-011	394811	0750914	58	255	281	349	12	MRPAU	DTMUA 2	I, P, W
15-015	394833	0750730	80	287	306	316	6	MRPAU	1	W
15-016	394839	0750911	70	252	273	400	12	MRPAU	DTMUA 1	I, P, W
15-022	395026	0750735	40	200	219	--	6	MRPAM	1	W
15-023	395029	0750747	37	215	236	294	6	MRPAM	CHILD CARE 1	I, W
15-369	395000	0750735	50	201	221	--	--	MRPAU	1	P
15-720	394650	0750754	64	323	333	353	4	MRPAU	EXLEY 2	I
				EAST GREENWICH TOWNSHIP						
15-027	394751	0751248	47	212	242	--	6	MRPAU	TEST FOR 3	I
15-028	394755	0751327	70	191	216	223	10	MRPAU	EGWD 2	I, P, S, W
15-355	394822	0751247	42	205	245	--	12	MRPAU	EGWD 3	P, S
15-363	394618	0751542	40	145	151	152	3.75	MRPAU	1	I
15-366	394620	0751507	80	209	219	219	3	MRPAU	1	I,P
15-383	394750	0751249	51	--	--	--	--	MRPA	TEST 3	I
15-421	394811	0751350	60	60	180	200	6	MRPAU	1	I, P
15-471	394636	0751620	45	120	131	131	3	MRPAU	3-105	I
15-496	394651	0751632	45	150	160	160	4	MRPAU	1	I
15-497	394715	0751537	45	109	119	119	4	MRPAU	1	I
15-498	394702	0751554	62	60	70	70	3	MRPAU	1	I
15-499	394651	0751521	60	195	200	208	3	MRPAU	1	I
15-501	394632	0751614	50	162	167	167	4	MRPAU	1	I
15-502	394730	0751630	30	63	70	73	4	MRPAU	2	I
15-520	394625	0751712	62	135	150	150	3	MRPAU	1	I
15-530	394700	0751630	35	66	73	76	4	MRPAU	1	I
15-675	394829	0751615	12.80	3	10	12	4	WBMV	MW-4	S
				GREENWICH TOWNSHIP						
15-064	394857	0751537	10	238	248	287	6	MRPAL	TEST WELL 2-59	I
15-065	394851	0751526	20	69	98	100	15	MRPAU	GTWD 2(NEW 3)	W, P
15-066	394844	0751629	0	200	210	330	6	MRPA	TEST WELL 1-63	I
15-067	394900	0751658	5	157	172	262	6	MRPAM	TEST WELL 1-58	I
15-069	394920	0751619	10	108	168	179	12	MRPAM 2	GTWD 3(NEW 4)	I, P, S, W
15-070	394932	0751722	10	76	96	106	16	MRPAM	5/GTWD 1 (NEW 2)	I, W, P
15-071	394933	0751748	1	89	99	103	6	MRPAM	RR TURNABOUT	I, W
15-072	394936	0751747	6	91	101	103	12	MRPAM 2	REPAUNO 3	I, P, W
15-073	394936	0751747	0	67	87	96	10	MRPAM	REPAUNO NITR 3	I, W
15-075	394940	0751629	14	98	106	125	3	MRPAM 1	GIBBSTOWN OB 4	I
15-076	394939	0751704	15	90.5	120.5	126	10	MRPAM 2	4 1970	I, P
15-077	394944	0751711	9	88	97	101	6	MRPAM	GAGE WELL 3	I, W
15-079	394944	0751734	10	84	109	118	12	MRPAM 2	REPAUNO 6	I, P, W
15-080	394944	0751735	11	89	105	105	13.6	MRPAM 2	REPAUNO 2	W, P
15-081	394945	0751717	10	81	99	104	8	MRPAM 2	REPAUNO 5	I, P
15-083	394948	0751630	15	117	125	159	3	MRPAM 2	GIBBSTOWN OB 3	I
15-084	394948	0751639	12	121	146	--	10	MRPAM	GIBBSTOWN 2	P
15-085	394948	0751639	12	--	--	227	--	MRPAL	GIBBSTOWN TH 2	I
15-086	394948	0751639	11	107	112	126	3	MRPAM	GIBBSTOWN TH 5	I
15-087	394951	0751753	5	92	102	101	6	MRPAM 2	30-32	I, W

Table 3.--Selected records of wells and borings used to determine the hydrogeologic framework of the region of Greenwich Township, Gloucester County, New Jersey--Continued

Well number	Latitude (degrees)	Longitude (degrees)	Altitude of land surface (feet)	Top of screened interval[1] (feet)	Bottom of screened interval (feet)	Depth of well (feet)	Diameter of screen[2] (inches)	Aquifer code	Local well number	Available data
				GREENWICH TOWNSHIP--Continued						
15-088	394952	0751636	13	96	102	142	3	MRPAM 1	GIBBSTOWN TH 7	I
15-089	394952	0751653	10	77.5	97.5	122	10	MRPAM	GIBBSTOWN 1	I
15-091	394952	0751730	10	84	103	105	8	MRPAL	REPAUNO W	I, W
15-092	394954	0751642	4	107	113	280	3	MRPAM 2	GIBBSTOWN TH 6	I
15-093	394956	0751521	6	111	136	164	12	MRPAM	MOBIL 46	I, W
15-094	394958	0751512	7	116	136	156	16	MRPAM	MOBIL 44	I, P
15-095	394954	0751531	5	129	139	152	16	MRPAM	MOBIL 43	I
15-096	394959	0751650	14.18	129	134	159	3	MRPAM 2	GIBBSTOWN OB 2	I, S
15-097	395000	0751636	5.61	102	107	130	3	MRPAM 2	GIBBSTOWN TH8/TW8 (NEW)	I
15-098	395006	0751532	3	95	115	130	16	MRPAM	MOBIL 45	I, P
15-100	395009	0751706	3	79	84	--	4	MRPAM 2	REPAUNO OB 6	I
15-101	395012	0751520	20	195	225	267	16	MRPAL	MOBIL 40	I
15-102	395016	0751738	3	73	103	--	10	MRPAL	REPAUNO 20	P
15-103	395021	0751730	2	83	103	103	10	MRPAL	REPAUNO H	W
15-104	395021	0751740	2	74	103	103	10	MRPAL	REPAUNO J	W
15-107	395025	0751757	2	75	105	105	10	MRPAL	REPAUNO C	W
15-109	395027	0751503	20	229.5	259.50	280	8	MRPAL	MOBIL 41	I, P
15-117	395033	0751814	7	--	--	--	--	WSCK	CAVERN 9 TEST	I
15-118	395036	0751501	18	220	240	263	12	MRPAL	MOBIL 47	I, P
15-347	394932	0751722	20	82	117	134	12	MRPAM	GTWD 5 (2-A)	P, S
15-348	394910	0751541	20	105	135	164	12	MRPAM	GTWD 6	I, P, S, W
15-391	395020	0751540	20	109	134	164	12	MRPAM	NO-12 1950	W
15-403	395100	0751400	10	190.33	207	211	8	MRPAL	WELL 2-1954	I
15-404	395033	0751753	5	--	--	292	--	MRPAL	TESTHOLE 1	I
15-408	394913	0751620	5	130	140	155	--	MRPAM 2	TEST 1966	I
15-411	395113	0751513	20	238	268	289	8	MRPAL	NO-1-1978	I, P
15-412	395033	0751740	5	--	--	120	--	MRPAL	TEST 4 1965	I
15-503	394819	0751702	5	48	58	58	4	MRPAU	1	I
15-504	394814	0751712	5	51	61	61	4	MRPAU	1	I
15-507	395030	0751730	5	--	--	200	--	WSCK	TW 5	I
15-511	394828	0751656	10	40	47	50	4	MRPAU	2	I
15-513	394843	0751600	15	38	43	44	3.75	MRPAU	1	I
15-514	394925	0751743	10	162.17	173	179	6	MRPAL	TW STATION RD	I
15-629	394939	0751654	11	90	120	133	2	MRPAM	MW 8C	I
15-630	394937	0751645	12	98	118	137	2	MRPAM	MW 19C	I
15-632	394945	0751649	9	14	19	19	6	QRNR	HERCULES PW 6	P
15-633	394955	0751649	12.8	9.5	29.5	30	2	MRPAM 1	MW 2	S
15-634	394944	0751750	5	136.5	141.5	155	6	MRPAL	OBS 40	I, S
15-644	394945	0751644	12.4	8	18	18	2	QRNR	MW 17	S
15-647	394937	0751646	12	48	68	73	2	MRPAM	MW 19B	I, S
15-652	395017	0751639	1.2	17	24	24	2	MRPAM 1	MW 12	S
15-654	395015	0751635	1.53	6.5	21.5	21.5	2	MRPAM 1	MW 14	S
15-657	394941	0751737	9.16	89	94	95	6	MRPAM 2	OBS 38	I, S
15-658	394941	0751737	9.35	144	149	180	6.0	MRPAL	REPAUNO M-37	I
15-660	394953	0751733	8.16	19.6	24.6	24.6	6	MRPAM 1	OBS 33	S
15-661	394953	0751733	8.04	109	119	145	6	MRPAM 2	OBS 31	I, S
15-665	394936	0751711	14.05	101.5	121.5	126.5	2	MRPAM	MW 20C	I, S
15-667	394936	0751711	14.24	14	29	29	2	QRNR	MW 20	S
15-668	394944	0751648	7.83	92	112	125	2	MRPAM 2	MW 10C	I
15-672	395014	0751459	20	244	264	289	8	MRPAL	2-NORTH WELL	P
15-678	394946	0751612	9.40	194	204	209.5	4	MRPAL	W-5C	I, S
15-679	394946	0751612	9.70	118	128	143.5	4	MRPAM 2	W-5D	S
15-680	395038	0751605	8.66	186	196	199.5	4	MRPAL	W-7C	I, S
15-682	395048	0751518	10.79	105	115	120	4	MRPAM 2	W-8D	S, T
15-683	395021	0751533	10.70	92	102	119	4	MRPAM 2	W-9D	S
15-689	395018	0751650	9.5	7	17	21	4	MRPAM	DUPONT 93	S
15-690	394830	0751515	12.8	3	13	15	4	WBMV	MW-1	S
15-692	394952	0751734	5	96	136	142	12	MRPAM 2	INTERCEPTOR 46	I, P, R, S
15-693	394940	0751752	5	18	23	155	6	MRPAM 1	42	S
15-694	395021	0751533	10.7	215	225	226	4	MRPAL	W-9C	I, S
15-695	394952	0751502	8.4	230	240	240	4	MRPAL	W-3C	I, S
15-696	394952	0751502	8.40	162	172	179.5	4	MRPAM 2	W-3D	S
15-698	395014	0751553	4.3	2	12	--	2	QRNR	27	S
15-699	395037	0751605	9.4	0	20	--	2	QRNR	29	S
15-700	394952	0751527	2	2	22	--	2	QRNR	40	S

Table 3.--Selected records of wells and borings used to determine the hydrogeologic framework of the region of Greenwich Township, Gloucester County, New Jersey--Continued

Well number	Latitude (degrees)	Longitude (degrees)	Altitude of land surface (feet)	Top of screened interval[1] (feet)	Bottom of screened interval (feet)	Depth of well (feet)	Diameter of screen[2] (inches)	Aquifer code	Local well number	Available data
					GREENWICH TOWNSHIP--Continued					
15-701	394957	0751539	4.2	.53	12	--	2	QRNR	72	S
15-711	395048	0751518	11.5	152.7	162.7	175	4	MRPAL	W-8C	I, S, T
15-712	394808	0751724	6.5	275	290	383	4	MRPAL	STEFKA-1	I, T
15-713	394808	0751724	5.64	125	155	162	8	MRPAM 1	STEFKA-2	T
15-728	394808	0751724	4.46	46	56	65	4	MRPAU	STEFKA-4	T
15-736	395009	0751505	16.2	222	232	254.5	4	MRPAL	W-1C	I, T
15-737	395024	0751450	12.3	240.0	250.0	250	4.0	MRPAL	W-2C	I
15-738	394948	0751524	4.5	188	198	210	4	MRPAL	W-4C	I
15-739	394936	0751728	5	98	103	115	4	MRPAM 2	33	I
15-740	395033	0751513	20	--	--	281	--	WSCK	HARCO-1	I
15-814	395024	0751521	21.3	15.0	55.0	61.0	24.0	QRNR	RW-12	P, R
15-815	395027	0751528	18.5	12.0	52	58.0	24.0	QRNR	RW-11	P, R
15-816	395035	0751543	23.2	3.0	15.0	25.0	24.0	QRNR	RW-17	P
15-817	395039	0751547	17.4	4.0	16.0	25.0	24.0	QRNR	RW-16	P
15-818	395005	0751517	13.7	2.0	10.0	25.0	24.0	QRNR	RW-15	P
15-819	395011	0751513	17.0	15.0	55.0	64.0	24.0	QRNR	RW-14	P, R
15-820	395038	0751514	21.5	18.3	48.3	--	24	QRNR	RW-2	P, R
15-821	395047	0751512	22.1	19	54	--	24	QRNR	RW-3	P, R
15-822	395042	0751515	20.3	16	51	--	24	QRNR	RW-4	P, R
15-823	395037	0751500	25.4	18	53	--	24	QRNR	RW-5	P, R
15-824	395033	0751457	18.8	13.5	48.5	--	24	QRNR	RW-6	P, R
15-825	395027	0751506	17.3	13.5	48.5	--	24	QRNR	RW-7	P, R
15-826	395022	0751458	19	15	50	--	24	QRNR	RW-8	P, R
15-827	395021	0751533	11.1	5.5	45.5	--	24	QRNR	RW-9	P, R
15-828	395024	0751600	11.7	1	17	25	24	QRNR	RW-18	P, R
15-832	395043	0751527	19.8	13.0	53.0	68	24.0	QRNR	RW-13	P, R
15-833	394942	0751655	11.0	14.5	44.5	49	8.0	MRPAM 1	PW-10	P, R
15-834	394941	0751650	11.1	13.0	43.0	45.0	8.0	MRPAM 1	PW-9	P, R
15-835	394938	0751653	12.2	29.5	69.5	75	8.0	MRPAM 1	PW-8B	P, R
15-836	394937	0751655	14.5	9.9	19.9	21.0	8.0	QRNR	PW-8	P, R
15-837	394938	0751649	15.2	35.0	75.0	95.0	8.0	MRPAM 1	PW-7B	P, R
15-838	394942	0751655	11.6	23.0	43.0	47.0	6.0	MRPAM 1	PW-5B	P, R
15-997	395009	0751505	16.0	116	126	149.5	4.0	MRPAM	W-1D	T
151002	394929	0751749	5	105	125	125	2	MRPAM 1	MATLOCK TRUCKING 21C	I
151025	394945	0751717	5	80.50	86	106	4	MRPAM	DUPONT OBS 1	P
					HARRISON TOWNSHIP					
15-131	394501	0751229	45	--	--	--	--	MRPAU	CLEARVIEW HS 1	I, P
15-346	394529	0751340	80	267	343	--	8	MRPAU	1	S
					LOGAN TOWNSHIP					
15-137	394535	0752054	29	158	208	237	12	MRPAM	PURE 2(3-1973)	I, P
15-138	394553	0752148	15	28	34	--	4	HPPM	1	I
15-139	394608	0752135	7.0	301	345	354	6	MRPAL	TEST WELL 3	I, S, T, W
15-140	394608	0752135	6.1	132	184	204	6	MRPAM	TEST WELL 4	S, T, W
15-141	394606	0752133	0	128	185	226	4	MRPAM	OBS 1 (1970)	I
15-144	394613	0752129	7.60	81	136	140	6	MRPAM	1-1973	I, P
15-154	394716	0752113	10	66	96	290	6	MRPAM	1	I, P
15-157	394728	0752219	5	103	123	207	6	MRPAM	TEST WELL 7	I
15-165	394755	0752108	5	30.5	40.5	43	8	MRPAM	BRIDGEPORT 1	W
15-166	394755	0752108	5	65.4	85.4	127	6	MRPAM 2	BRIDGEPORT 2	I, P
15-170	394854	0751906	10.5	85.4	106	176	8	MRPAM 2	REPAUP 1	I, W
15-171	394817	0752107	5	61	81	171	6	MRPAM 2	RACCOON IS T11	I, W
15-173	394836	0752124	5	113	160	164	6	MRPAL	RACCOON IS T 8	I, W
15-174	394836	0752124	5	42	72	73	6	MRPAM	RACCOON IS T 9	W
15-175	394858	0752225	8	100	120	128	6	MRPAL	RACCOON IS T 1	I, W
15-176	394840	0752145	5	97	137	146	6	MRPAL	RACCOON IS T 2	I, W
15-177	394833	0752207	5	90	130	135	6	MRPAL	RACCOON IS T 4	I, W
15-178	394840	0752145	9	50	70	80	6	MRPAM 2	RACCOON IS T 5	W
15-179	394839	0752135	5	52	72	84	6	MRPAM	RACCOON IS T 7	I
15-180	394822	0752125	5	48	58	191	6	MRPAM 2	RACCOON IS T10	I

Table 3.--Selected records of wells and borings used to determine the hydrogeologic framework of the region of Greenwich Township, Gloucester County, New Jersey--Continued

Well number	Latitude (degrees)	Longitude (degrees)	Altitude of land surface (feet)	Top of screened interval[1] (feet)	Bottom of screened interval (feet)	Depth of well (feet)	Diameter of screen[2] (inches)	Aquifer code	Local well number	Available data
				LOGAN TOWNSHIP--Continued						
15-181	394839	0752135	5	106	126	144	6	MRPAL	RACCOON IS T 6	I, W
15-387	394713	0752121	10.20	80	90	90	4	MRPAM 1	DP 1	S
15-388	394716	0752047	22.30	75	85	90.5	4	MRPA	DP 3	S
15-395	394801	0751759	20	93	113	113	6	MRPAM 1	30-1972	I, S
15-398	394935	0751938	1	50	60	48	4	MRPAL	419	I
15-399	394900	0751913	10	71	91	124	10	MRPAM 2	NO-1 1977	I
15-452	394803	0751802	20	70	80	80	3	MRPAU	8-61B	I
15-453	394832	0751846	10	51	61	61	4	MRPAM	30-1946	I
15-454	394630	0752000	20	65	75	75	4	MRPAU	30-1830	I
15-455	394710	0752034	20	69	79	79	4	MRPAU	30-2021	I
15-459	394800	0752018	10	62	69	72	4	MRPAM	1	I
15-462	394824	0751834	10	59	69	69	4	MRPAM 1	611	I
15-463	394752	0751756	20	56	67	67	3	MRPAU	1	I
15-466	394707	0751828	30	64	74	74	4	MRPAU	1	I
15-468	394838	0751853	10	85	95	95	6	MRPAM 2	1	I
15-540	394800	0751936	7.1	87	97	97	4	MRPAM 1	EPA 108	S, T
15-546	394759	0751948	10.17	20	30	30	2	MRPAU	CL2	S
15-548	394755	0751952	10	30	45	45	6	MRPAU	CLDW	P
15-550	394759	0751949	10.17	99.50	102	102	4	MRPAM 2	DW2	I
15-553	394815	0751927	8.50	0	230	--	4	MRPAM	S-12	I
15-564	394802	0751933	6.8	42	52	--	4	MRPAU	S-9	S
15-569	394529	0752045	32	161	201	236	12	MRPAM	PWC 3	I, W
15-575	394719	0752108	1.31	45	55	55	1.25	MRPAM	MA 11D	I
15-581	394718	0752102	2.48	27	37	37	1.25	MRPAU	MA 5I	S
15-582	394715	0752106	1.64	57	67	71	1.25	MRPA	MA 1D	I
15-585	394704	0752058	7.50	79	89	101	6	MRPAM	DP5	I
15-591	394716	0752115	3.40	9.70	19.70	20	4	MRPAU	25	S
15-615	394637	0751916	29.3	378	388	530	4	MRPAL	SHIVELER LOWER	I, S, T
15-616	394637	0751916	30.6	230	240	348	4	MRPAM	SHIVELER MIDDLE	S, T
15-617	394637	0751916	30.6	60	70	132	4	MRPAU	SHIVELER UPPER	S, T
15-618	394804	0751933	7.0	230	240	290	4	MRPAL	GAVENTA DEEP	I, S, T
15-620	394804	0751933	7.0	131	141	151	4	MRPAM	GAVENTA MIDDLE 1	S, T
15-621	394722	0751731	25	--	--	493	--	WSCK	LOPES TST HOLE	I
15-622	394752	0752002	10	--	--	291	--	WSCK	CLTL TEST HOLE	I
15-627	394644	0752136	7.38	65	75	82	4	MRPAU	MW 103 D	S
15-706	394637	0751916	30.56	10.5	12.0	--	2	WBMV	SHIVELER W TAB	S
15-708	394626	0751931	41.7	10.7	12.2	--	2	WBMV	COONTOWN ROAD-WT-E	S
15-767	394813	0751820	9.0	--	--	396.50	--	WSCK	S & S AUCTION TH	I
15-768	394705	0751943	5.0	--	--	--	--	WSCK	SHOEMAKER TH	I
15-769	394728	0751839	15	--	--	370.0	--	WSCK	GIAMMARINO TH	I
				MANTUA TOWNSHIP						
15-187	394543	0750746	45	325	355	--	10	MRPAU	#2	P
15-188	394605	0751057	80	134	160	--	4	EGLS	YAHRLING 1	
15-189	394602	0750823	80	352	377	377	10	MRPAU	MTMUA 1	I, W, P
15-190	394617	0750833	80	377	397	405	6	MRPAU	NURSERY 1	I
15-191	394629	0750859	72	336	368	374	10	MRPAU	MTMUA 2	I, S
15-192	394635	0751116	80	315	337	480	12	MRPAU	MTMUA 5	I, S, W, P
15-193	394712	0751008	65	295	317	--	8	MRPAU	MTMUA 3	P
15-194	394732	0751037	10	230	265	335	8	MRPAU	MTMUA 4	I, P, S, W
15-379	394601	0751005	145	368	398.5	418	8	MRPAU	MTMUA 6	I
15-432	394707	0751202	60	222	300	345	10	MRPAU	1	I
15-676	394638	0751201	27.50	68	78	82	4	EGLS	KRAMER LANDFILL X-6D	
15-686	394642	0751212	80.30	18	38	65	3	MRPA	KRAMER LF X-12	S
15-687	394638	0751201	27.7	5.5	23.5	26.5	4	MLRW	KRAMER LF X-6S	S
15-742	394652	0751004	84.0	757.2	777.2	871	4	MRPAL	MANTUA DEEP	I
				NATIONAL PARK BOROUGH						
15-206	395146	0751053	10	64	85	87	8	MRPAU	NPWD 1	W
15-207	395156	0751053	30	241	282	307	8	MRPAL	NPWD 2	I, P
15-533	395155	0751051	22	240	272	274	12	MRPAL	NPWD 6	I, S, W
15-770	395202	0751115	10	204	224	243	4	MRPAL	NATIONAL PARK #1-PW-L	I, T
15-771	395202	0751115	10	92.3	123.3	243	8	MRPAM	NATIONAL PARK #2-PW-M	T

Table 3.--Selected records of wells and borings used to determine the hydrogeologic framework of the region of Greenwich Township, Gloucester County, New Jersey--Continued

Well number	Latitude (degrees)	Longitude (degrees)	Altitude of land surface (feet)	Top of screened interval[1] (feet)	Bottom of screened interval (feet)	Depth of well (feet)	Diameter of screen[2] (inches)	Aquifer code	Local well number	Available data
NATIONAL PARK BOROUGH--Continued										
15-772	395206	0751118	10	196	216	230	2	MRPAL	NATIONAL PARK #3-OW-AL	I
15-775	395202	0751127	15	170.5	190.5	242	2	MRPAL	NATIONAL PARK #6-OW-CL	I
15-778	395223	0751117	20	170	190	206	2	MRPAL	NATIONAL PARK #9-OW-BL	I
PAULSBORO BOROUGH										
15-210	394921	0751417	15	185	227	238	12	MRPAM	6-1973	I, P
15-211	394921	0751419	16	207	227	384	6	MRPAM	TEST FOR 6	I, W
15-212	394929	0751447	25	192	220	221	12	MRPAM 2	PWD 4	I, P, S, W
15-213	394947	0751416	10	135	175	196	12	MRPAM 2	PWD 5	I, P, S, W
15-214	394951	0751421	10	88	108	114	6	MRPAU	TEST WELL 1	I
15-215	395023	0751442	16	70	100	114	18	MRPAM	PWD 2	P
15-216	395023	0751442	16	115	140	--	18	MRPAM	PWD 3	W, P
15-217	395037	0751448	20	250	260	285	6	MRPAL	PAULSBORO BORO	I, W
15-220	395051	0751349	10	234	256	289	8	MRPAL	OLIN 1	I, P, W
15-221	395057	0751347	10	258	286	290	12	MRPAL	PAULSBORO 1	I, P, W
15-439	395048	0751401	10	215	235	290	12	MRPAL	ESSEX 2	I, P, W
15-677	395050	0751449	27.60	19	39	39	4	QRNR	MW 8	S
15-709	395053	0751346	9.6	9.1	19.5	26	4	QRNR	OBS 2	S
15-710	395100	0751420	5.2	10	35	97	4	QRNR	BL-1	S
15-839	395052	0751408	11.6	25.0	85.0	86.0	12.0	QRNR	RW-3	P, R
SWEDESBORO BOROUGH										
15-240	394510	0751838	31.5	190	231	--	10	MRPAU	9	S, W, P
15-242	394512	0751830	25	267	298	--	10	MRPAM	6	S
WENONAH BOROUGH										
15-274	394743	0750902	80	273	310	320	12	MRPAU	WWD 1	I, S, W
15-275	394751	0750912	50	268	310	314	12	MRPAU	WWD 2	I, P, W
WEST DEPTFORD TOWNSHIP										
15-276	394821	0751026	60	242	289	336	8	MRPAU	WDTWD 4	I, P, W
15-279	394857	0751250	16.93	315	320	330	6	MRPAM 2	SHELL OBS 7	I, S
15-281	394912	0751026	61	227	243	290	12	MRPAU	WDTWD 3	I, P
15-282	394913	0751105	55	388	450	480	12	MRPAL	5 KINGS HIWAY	I, P, S
15-283	394919	0751256	30	358	383	385	12	MRPAL	SHELL 3	I, P, W
15-284	394919	0751256	30	127	157	159	12	MRPAU	SHELL 4	P, W
15-285	394917	0751307	12	328	358	360	12	MRPAL	SHELL 1	I, P, S, W
15-286	394917	0751307	19	273	288	295	4	MRPAM 2	SHELL 2	P
15-287	394920	0751226	30	--	--	373	--	MRPAL	TEST HOLE 1	I
15-290	394920	0751226	31	109	140	141	8	MRPAU	PUMP TEST 3	W
15-291	394938	0751327	30	334	369	370	3	MRPAL	SHELL OBS 1	I
15-294	394932	0751336	5	--	--	445	--	MRPA	TEST HOLE 3	I
15-295	394939	0751007	20	120	140	140	10	MRPAU	1-1973	I, P, W
15-296	394942	0751317	20.76	321	326	330	6	MRPAL	SHELL OBS 5	I, S, T
15-297	394942	0751317	20.50	113	118	120	6	MRPAU	SHELL OBS 6	S
15-298	394955	0751242	10	--	--	375	--	WSCK	TEST HOLE 2	I
15-299	395002	0751005	35	133	165	--	8	MRPAU	POLYREZ 1	P
15-300	395002	0751005	35	--	--	--	--	MRPAU	POLYREZ 2	P
15-302	395028	0751247	10	--	--	--	--	MRPAL	TEST WELL 2	I
15-303	395030	0751236	10	84	114	--	8	MRPAU	TEST WELL 1	S, 1
15-304	395032	0751241	10	237	289	--	16	MRPAL	418	P, W
15-306	395033	0751233	10	234	276	--	16	MRPAL	417	P, W
15-307	395035	0751249	10	256	296	--	4	MRPAL	TEST WELL 4	I
15-308	395044	0751242	10	231	271	--	8	MRPAL	TEST WELL 8	I, W
15-309	395045	0751255	10	248	288	--	8	MRPAL	TEST WELL 5	I
15-310	395051	0751236	10	243	263	--	4	MRPAL	TEST WELL 6	I
15-311	395104	0751244	10	203	243	--	8	MRPAL	TEST WELL 7	I, S
15-312	395107	0750946	20	322	372	385	12	MRPAL	6 RED BANK AVE	I, P
15-313	395139	0750949	23	307	353	363	12	MRPAL	WDTWD 2	I, W, P
15-314	395153	0750946	15	280	318	--	14.5	MRPAL	EAGLE POINT 6	P, W

Table 3.--Selected records of wells and borings used to determine the hydrogeologic framework of the region of Greenwich Township, Gloucester County, New Jersey--Continued

Well number	Latitude (degrees)	Longitude (degrees)	Altitude of land surface (feet)	Top of screened interval[1] (feet)	Bottom of screened interval (feet)	Depth of well (feet)	Diameter of screen[2] (inches)	Aquifer code	Local well number	Available data
					WEST DEPTFORD TOWNSHIP--Continued					
15-316	395159	0750907	31.75	288	298	327	4	MRPAL	EAGLE PT OBS 1	I
15-317	395200	0750947	10	261	301	329	12	MRPAL	EAGLE POINT 7	I, P, W
15-318	395207	0750930	17	259	289	--	16	MRPAL	EAGLE POINT 2	P, W
15-319	395213	0750936	14	259	289	294	16	MRPAL	EAGLE POINT 4	P, W
15-320	395216	0750915	20	248	288	--	12	MRPAL	EAGLE POINT 1	P, W
15-321	395221	0750856	13	237	277	--	12	MRPAL	EAGLE POINT 5	P, W
15-322	395222	0750918	20	258	288	--	12	MRPAL	EAGLE POINT 3	P, W
15-323	395235	0750950	20.96	255	275	298	6	MRPAL	EAGLE PT OBS 3	H, T
15-368	394908	0751112	50	241.50	288.92	336	8	MRPAM	2	I, W
15-373	395126	0750856	28	323	363	378	12	MRPAL	WDTWD 7	I, P, S, W
15-381	395140	0750952	25	--	--	--	--	MRPA	TEST 1-59	I
15-390	395020	0751340	10	91	106	128	6	MRPAM 1	GCSA 1 71	I
15-401	394900	0751113	40	391	411	505	6	MRPAL	WDTWD 5	I, W
15-410	395213	0750936	5	256	296	319	8	MRPAL	EAGLE POINT 4A	I, W
15-414	395126	0750855	25	326	362	389	6	MRPAL	TEST 7-79	I, W
15-415	394834	0751044	40	287	307	421	6	MRPAM 1	TEST 8-79	I
15-430	395156	0750938	15	256	328	351	12	MRPAL	EAGLE POINT 6A	I
15-435	394836	0751046	40	252	312	330	12	MRPAM	WDTWD 8	I, P, S, W
15-438	395012	0751333	10	202	217	287	6	MRPAL	GCMUA 1	I, S
15-691	394856	0751204	30	18	23	23	2	WBMV	OBS 1	S
15-703	394857	0751204	60	3	23	23	4	HPPM	OBS 1	S
15-704	394857	0751204	60	7.5	17.5	19	4	HPPM	OBS 2	S
15-705	394927	0751300	35	3	13	20	4	WBMV	WO#7	S
15-718	395057	0750933	18.0	346	356	384	6	MRPAL	RED BANK T6	I
15-719	394913	0751105	55	392.2	412	505	6	MRPAL	KINGS HWY T6	I
151045	394950	0751126	47	184	204	308	6	MRPAU	W DEPTFORD 5 GROVE RD	I
					WESTVILLE BOROUGH					
15-326	395216	0750739	12	243	280	327	12	MRPAL	WWD 5	I, P, S
15-327	395221	0750737	16	286	313	323	10	MRPAL	WWD 4	I, P, W
15-434	395224	0750734	15	265	317	317	12	MRPAL	WWD 6	I, P
					WOODBURY CITY					
15-331	394955	0750908	35	405	457	--	12	MRPAL	RAILROAD 5	I, P, W
15-332	395009	0750922	50	148	188	188	12	MRPAU	PARKING LOT 3	I, S, W, P
15-333	395044	0750907	20	129	167	171	12	MRPAU	TATUM 4	I, W, P
15-413	395047	0750833	40	279	299	510	6	MRPAM	TEST 6-79	I, W
15-431	395034	0750842	30	211	305	313	12	MRPAM	RED BANK 6	I, P, S, W
15-437	395008	0751007	50	127	142	203	10	MRPAU	POLYREZ 1R	
					WOODBURY HEIGHTS BOROUGH					
15-330	394858	0750845	40	185.5	230.5	247	12	MRPAU	1 HELEN AVE	I, P, S, W
					WOOLWICH TOWNSHIP					
15-344	394518	0751640	80	69	83	91	6	EGLS	NJTA INT 2	P
15-345	394642	0751823	62	94	100	101	4	MRPAU	1	S
15-378	394523	0751610	100	--	--	--	--	EGLS	MAINT 1	P
15-392	394527	0751607	105	241	251	251	6	MRPAU	1964-S-1	I, S, W
15-394	394513	0751913	30	124	149	170	10	MRPAU	CAN 1-1966	I, P
15-516	394650	0751752	40	112	122	122	4	MRPAU	1	I
15-518	394622	0751836	65	110	115	115	4	MRPAU	1	I
15-519	394649	0751738	35	75	87	87	3	MRPAU	1	I
15-524	394606	0751810	52	125	155	165	4	MRPAU	2	I
15-527	394547	0751841	58	115	125	125	3	MRPAU	1	I
15-528	394512	0751904	15	120	190	195	10	MRPAU	1	I

Table 3.--Selected records of wells and borings used to determine the hydrogeologic framework of the region of Greenwich Township, Gloucester County, New Jersey--Continued

Well number	Latitude (degrees)	Longitude (degrees)	Altitude of land surface (feet)	Top of screened interval[1] (feet)	Bottom of screened interval (feet)	Depth of well (feet)	Diameter of screen[2] (inches)	Aquifer code	Local well number	Available data
PHILADELPHIA, PENNSYLVANIA										
450001	395127	0751447	--	70	90	231	4	MRPAM	MIFFLIN BAR DIKE	I

[1] Some wells have multiple screens; the screened interval listed is the top of the uppermost screen and the bottom of the lowermost screen.

[2] Where more than one screen is present; the screen diameter listed is the smallest.

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