STATE OF NEW JERSEY
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT

DIVISION OF WATER POLICY AND SUPPLY

SPECIAL REPORT NO. 23

GROUND-WATER RESOURCES OF MONMOUTH COUNTY, NEW JERSEY

Prepared in cooperation with
United States Department of the Interior
Geological Survey

1968

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By

LEO A. JABLONSKI

U. S. Geological Survey

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AND ECONOMIC DEVELOPMENT

ROBERT A. ROE, *Commissioner*

DIVISION OF WATER POLICY AND SUPPLY
GEORGE R. SHANKLIN, *Director and Chief Engineer*

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HONORABLE ROBERT A. ROE, *Commissioner*
Department of Conservation and
Economic Development
John Fitch Plaza
Trenton, New Jersey 08625

Dear Sir:

I am transmitting a report entitled "Ground-Water Resources of Monmouth County, New Jersey," which was completed under the cooperative agreement with the Ground-Water Branch, Water Resources Division, U. S. Geological Survey, as part of the statewide program authorized by the 1958 Water Supply Law.

The report evaluates the relative importance of the aquifers of Monmouth County and suitability for future development. The probable magnitude of the ground-water supplies which can be developed within the County and the quality of the ground-water in each of the aquifers are discussed.

The information in this report is of vital interest and importance to the growth of the County and provides a basis for the protection and safe development of the ground-water resources essential for such growth. I therefore recommend that this report be published as a Special Report of the Division of Water Policy and Supply.

Respectfully submitted,
George R. Shanklin
Director and Chief Engineer

July 1, 1968

GROUND-WATER RESOURCES OF MONMOUTH COUNTY, NEW JERSEY

By Leo A. Jablonski

ABSTRACT

Monmouth County includes an area of 538 square miles in east-central New Jersey. The climate is characterized by moderate temperature, moderate humidity, and moderate precipitation.

The exposed rocks in the area are chiefly sands and clays, which range in age from Late Cretaceous through Recent. The formations strike northeast-southwest and dip gently to the southeast. These rocks range in total thickness from about 500 to 1,200 feet or more and are underlain by basement rocks of late Precambrian(?) age.

The principal aquifers underlying Monmouth County occur in the Raritan and Magothy Formations, the Englishtown Formation, the Wenonah Formation and Mount Laurel Sand, the Vincentown Formation, and the Kirkwood Formation.

Ground water constituted about 50 percent of the total water use in 1958. The daily withdrawal of ground water was at an average rate of 21.6 mgd (million gallons per day) in 1958 and about 32 mgd in 1965 (N. J. Division of Water Policy and Supply). The water demand is expected to increase to about 133 mgd by the year 2000. An analysis of streamflow records for the period 1932 to 1950 suggests that, excluding the Raritan and Magothy Formations, the major aquifers that occur under water-table conditions in the county discharge an average of about 178 mgd to streams.

The aquifers in the Raritan and Magothy Formations contribute little or no water directly to streams in Monmouth County. These aquifers have been the most productive in the county. However, because salt water has been found in the lower parts of these formations in Ocean County, further development should proceed watchfully to assure that salt water does not threaten existing supplies.

Aquifers in the Raritan and Magothy Formations and the Englishtown Formation supplied 76 percent of the ground water used in 1958. These aquifers, in conjunction with the Wenonah Formation and Mount Laurel Sand of Late Cretaceous age, are capable of providing relatively large yields to wells. The average yield of 63 large-diameter wells tapping these aquifers is 580 gpm, at depths ranging from 100 to 1,140 feet. In

general, the concentrations of chemical constituents in water from the aquifers would not restrict the use of the water for most purposes. High concentrations of iron do occur and require treatment. The concentrations of dissolved solids in 39 of 41 samples were 160 ppm (parts per million) or less.

INTRODUCTION

PURPOSE AND SCOPE

This investigation was made by the U. S. Geological Survey as part of a continuing program for the collection and interpretation of basic data relative to the ground-water supply of the State of New Jersey. It was made in cooperation with the Division of Water Policy and Supply of the New Jersey State Department of Conservation and Economic Development, to aid in the administration and development of the water resources of the State.

The extensive use of ground water and the anticipated demand for additional future supplies have resulted in the need for an appraisal of the ground-water resources of Monmouth County. Accordingly, the purpose of this investigation has been to evaluate and interpret the geologic and hydrologic factors relating to the occurrence, movement, and chemical quality of ground water in Monmouth County.

Many of the data on which this report is based have been published in two earlier basic-data reports (Jablonski 1959 and 1960). This report contains discussions of the water-bearing properties of the formations occurring in the county and of the water resources as presently developed. Well records and well logs supplementing those previously published are also included.

The field work was begun in the spring of 1957 and continued intermittently until completion in the fall of 1959. Both the field work and the preparation of the report were supervised by Allen Sinnott, District Geologist in charge of cooperative ground-water studies in New Jersey.

LOCATION AND EXTENT

Monmouth County is in east-central New Jersey (fig. 1), 20 miles south of New York City and 75 miles northeast of Philadelphia, Pa. It is between longitudes 73°58′ and 74°37′ W, and latitudes 40°05′ and 40°29′ N. The county is bounded on the west by Mercer and Middlesex counties, on the southwest by Burlington County, on the south by Ocean County, on the east by the Atlantic Ocean, and on the north by Raritan Bay and Sandy Hook Bay. (See fig. 2).

The county occupies a total area of 538 square miles or 344,390 acres. Of this area, 479 square miles is land surface and 59 square miles is water area.

PREVIOUS INVESTIGATIONS

Previous investigations have been made of the geology and ground-water resources of the area, and the information contained in these earlier studies has been utilized in this report.

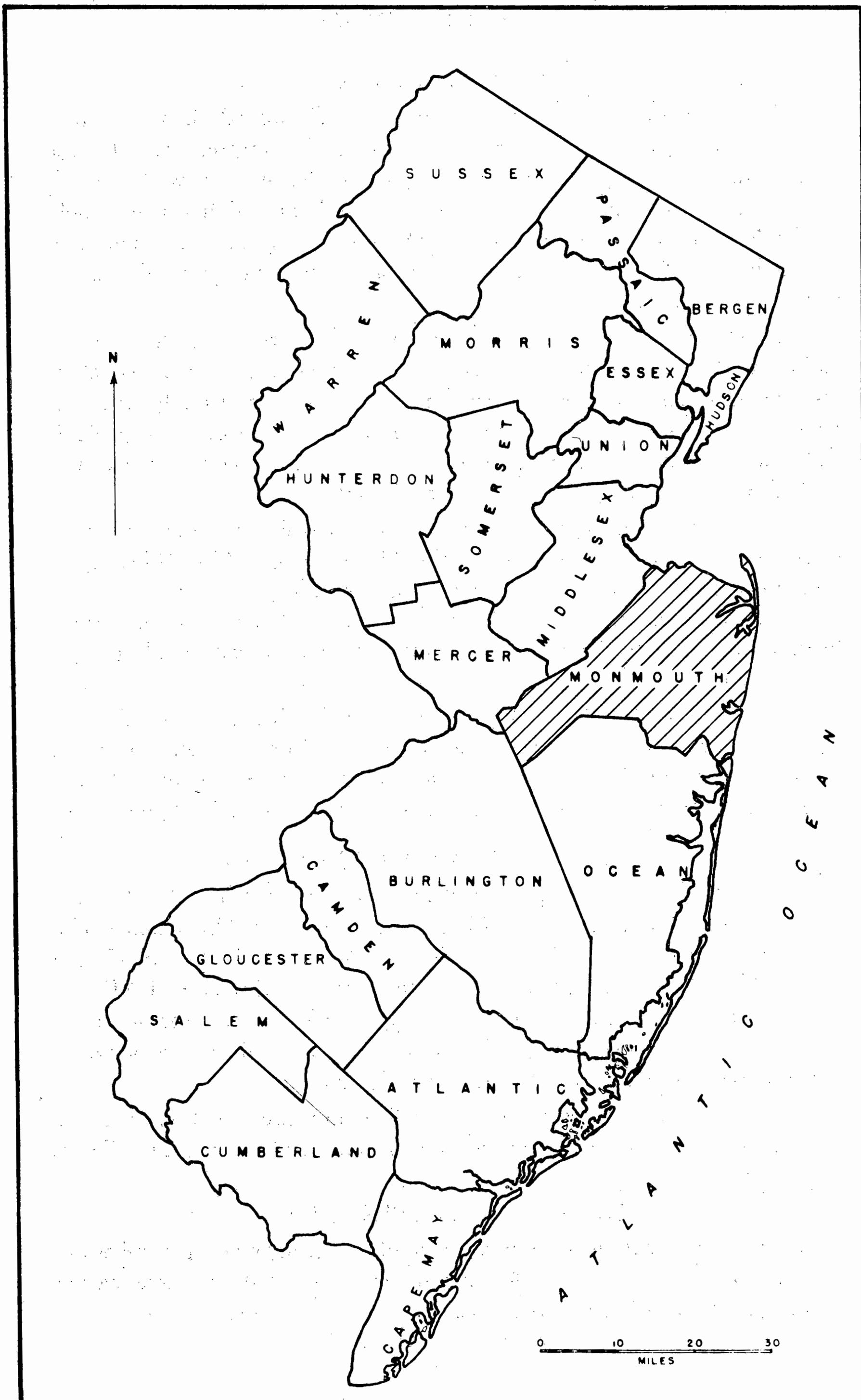


Figure 1.—Map of New Jersey showing the location of the area described in this report.

The geology of the area was studied and mapped by the staff of the State Geologist between 1854 and 1912. Annual reports of the State Geologist from 1864 to 1910 contain logs and records of wells drilled during this period. Mansfield (1923) studied the potash content in sands from Monmouth County. Thompson (1930) made a comprehensive study of the ground-water supplies in the Asbury Park area. The Monmouth County Planning Board (1957) outlined broadly the water requirements in the county. Owens and Minard (1960) intensively studied and mapped the geology of the New Egypt quadrangle, which includes a small portion of Monmouth County. Basic geologic and hydrologic data are collected at present by the Division of Water Policy and Supply and the office of the State Geologist.

WELL-NUMBERING AND LOCATION SYSTEM

Wells appearing on figure 2 are numbered areally from 1 through 41, P 1 through P 76, I 1 through I 5, and D 1 through D 145. The numbered series having no letter prefixes indicate wells for which data are included in this report; the P and I series appear in New Jersey Division of Water Policy and Supply Water Resources Circular 4 (Jablonski, 1960); and the D series appears in Circular 2 (Jablonski, 1959).

The wells are identified by a system of numbers based upon the New Jersey topographic atlas sheets. There are 17 state atlas sheets numbered consecutively from 21 to 37. Monmouth County is included in parts of atlas sheets 28 and 29 (fig. 3). The atlas sheets are at a scale of 1 inch to a mile and contain 26 minutes of longitude and 28 minutes of latitude. The numbering system was described by Kümmel (1913, p. 13 and 14) as follows:

> "Each atlas sheet is divided into rectangles measuring 6-minutes of latitude and 6-minutes of longitude. Beginning in the upper left-hand corner, these are numbered across the sheet from 1 to 5, inclusive, number 5 being an incomplete rectangle comprising 2-minutes of longitude at the right. Those on the second row are numbered 11 to 15, those on the third 21 to 25, those on the fourth 31 to 35 and on the fifth 41 to 45. The rectangles numbered 41 to 44, inclusive, differ from the others in comprising 6-minutes of longitude and 4-minutes of latitude. Number 45 embraces 2-minutes of longitude and 4-minutes of latitude. Each of these rectangles is divided into smaller rectangles measuring 2-minutes of latitude and 2-minutes of longitude by lines already engraved upon the sheet. The 2-minute rectangles in each of the 6-minute rectangles are numbered from 1 to 9 beginning in the upper left-hand corner and numbering to the right, number 4 being on the left under number 1. The subdivisions of the incomplete

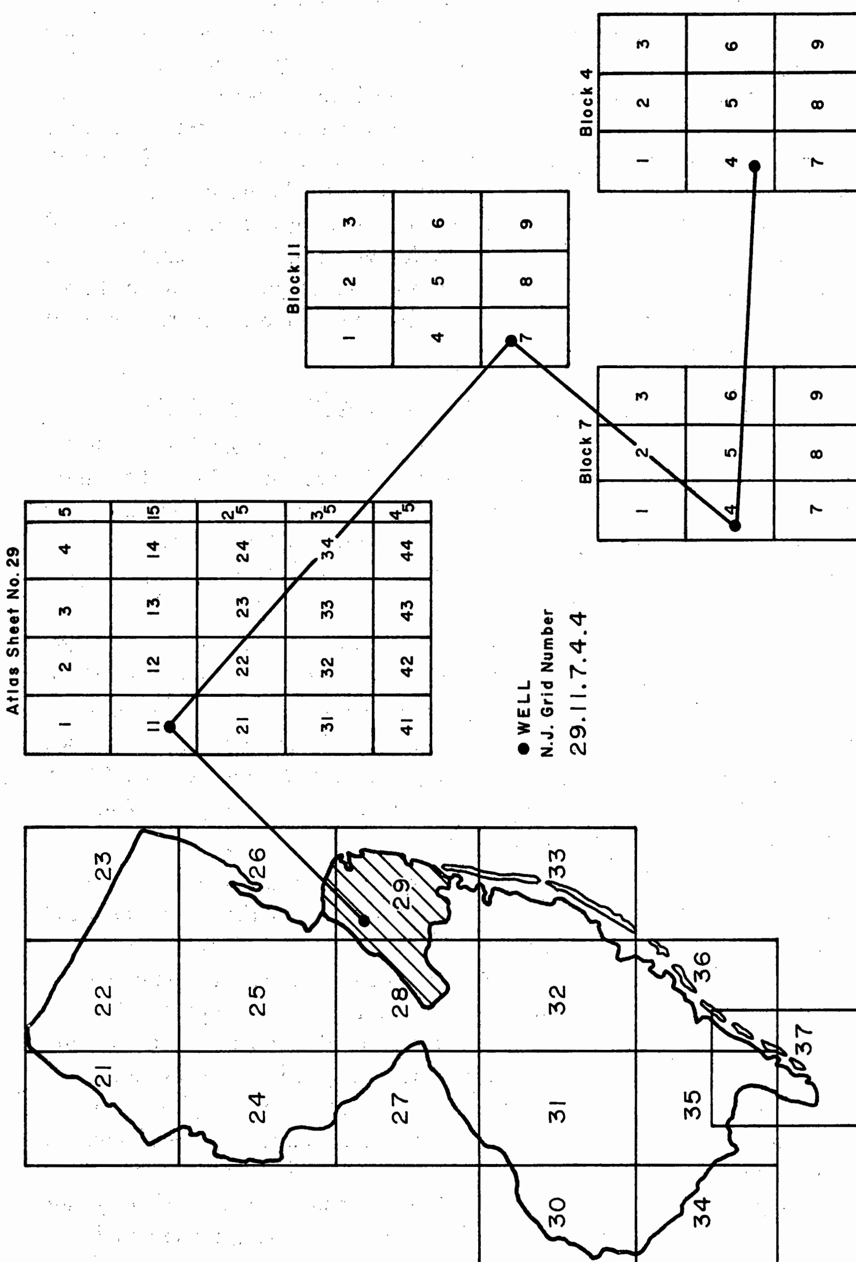


Figure 3.—New Jersey well numbering system.

6-minute rectangles on the right of the sheet, i.e., those numbered 5, 15, 25, 35, are numbered 1, 4, 7, of those at the bottom, i.e., numbers 41, 42, 43, 44, the subdivisions are numbered 1, 2, 3, 4, 5, 6. The subdivisions of the incomplete rectangle in the lower right-hand corner, number 45, are numbered 1, 4. It is evident that by writing first the number of the atlas sheet; second, the number of the 6-minute rectangle; and third, the number of any 2-minute rectangle, we can form a combination of numbers peculiar to any 2-minute rectangle within the State. In order to locate points more accurately each of the 2-minute rectangles is divided into nine equal parts, numbered from 1 to 9, beginning in the upper left-hand corner, and each of these is again divided into nine, numbered similarly. The smallest rectangles represent areas about 330 yards from east to west and 440 yards from north to south. By adding the appropriate numbers of these two smaller divisions to the three already written, it is possible to get a combination which represents the exact location of any area 330 x 440 yards."

ACKNOWLEDGMENTS

Appreciation is extended to many well owners who permitted use of their wells for the measurement of water levels, for the collection of water samples, and for pumping tests. The cooperation of the Monmouth County Planning Board, whose staff supplied maps and statistical information, is gratefully acknowledged. Special thanks are extended to Mr. Charles Pike, Planning Director, and Mr. Cornelius Schipper, Planning Assistant, of the Board for their invaluable assistance during the course of the investigation.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

Monmouth County lies entirely within the Atlantic Coastal Plain physiographic province. The county is characterized by broad stretches of lowlands ranging in altitude from sea level to 150 feet. In contrast to the lowlands, a prominent ridge stretches southwest from Raritan Bay to Clarksburg and then southward. This ridge forms the divide between the streams draining into the Atlantic Ocean on the east, and the streams draining into the Raritan and Delaware Rivers on the north and west. The highest altitude in the Coastal Plain of New Jersey (391 feet) is on this ridge at Crawford's Hill, south of Keyport. The northeastern extension of the ridge attains an altitude of 269 feet in the Highlands of Navesink. It extends westward as a well-defined ridge for 15 miles to Morganville, then broadens between Morganville and Freehold, maintaining a general altitude of 200 feet. From Freehold, it continues to a group of hills in the vicinity of Clarksburg. The hills are more than 300 feet in altitude, the highest being Pine Hill (372 feet). The range extends through Clarksburg and southward into Ocean County.

Numerous branches extend outward from the main divide. One of the more noticeable of the smaller divides on the ocean side extends from Freehold to Asbury Park, and has an altitude of 184 feet less than a mile from the ocean. On the west side of the main divide, there are fewer prominences. The most important extends northwest from Clarksburg and forms a divide between the drainage systems of the Raritan and Delaware Rivers.

Sandy Hook, a recurved spit, is an interesting topographic feature in Monmouth County. It was formed by the deposition of material previously eroded from beaches as far south as Bay Head in Ocean County. According to Haupt (1906), the Shrewsbury and Navesink Rivers were open to the sea in 1769 and Sandy Hook was not then separated from the mainland by the Navesink River.

Major streams flowing to the Delaware River are Crosswicks Creek, Doctors Creek, and Assunpink Creek; to the Raritan River are Deep Run Brook, Matchaponix Brook, Manalapan Brook, and Millstone River. Matawan Creek, Shrewsbury River, and Navesink River flow into Raritan Bay. Major streams discharging to the Atlantic Ocean are Manasquan River, Shark River and the north branch of the Metedeconk River. The county has good drainage with the exception of a few sluggish streams in the southern part.

LAND USE AND CULTURE

The land use in 1950 was 47.9 percent for farms, 21.9 percent for forests, 10.9 percent publicly owned, 0.8 percent for industry, and 18.5 percent for residential and other purposes. (Monmouth County Planning Board, 1958). Although Monmouth County is principally an agricultural county, many light industries and some larger industries are located in Freehold, Red Bank, and Matawan.

The population of the county in 1950 was 225,327 and in 1960 was 334,401, according to the U. S. Census Bureau. The population increase of about 48 percent between 1950 and 1960 has been concentrated in the urban areas; in 1960 these areas contained about 78 percent of the population. The urban population increased 85 percent whereas the rural population decreased about 12 percent from 1950 to 1960. The greater part of the population is concentrated in the eastern third of the county. This concentration, coupled with an influx of 2 million tourists during the summer months, has made the coastal area the chief area of water use.

CLIMATE

The climate of Monmouth County is generally moderate, with warm summers, mild winters, and an evenly distributed average monthly rainfall.

Table 1 gives the climatic summary for 23 years of record at the Long Branch weather station.

High humidity occurs frequently along the coast and less frequently inland. Freezing temperatures occur intermittently from October through April. The average first frost occurs on October 17, and the average last frost occurs on April 24, allowing an average growing season of 198 days.

The average annual precipitation is 44.67 inches and the mean annual temperature is 52.6°F, based on the composite record from the weather stations at Freehold, Sandy Hook, and Long Branch. The graph on figure 4 shows the average annual precipitation at the Long Branch weather station in Monmouth County.

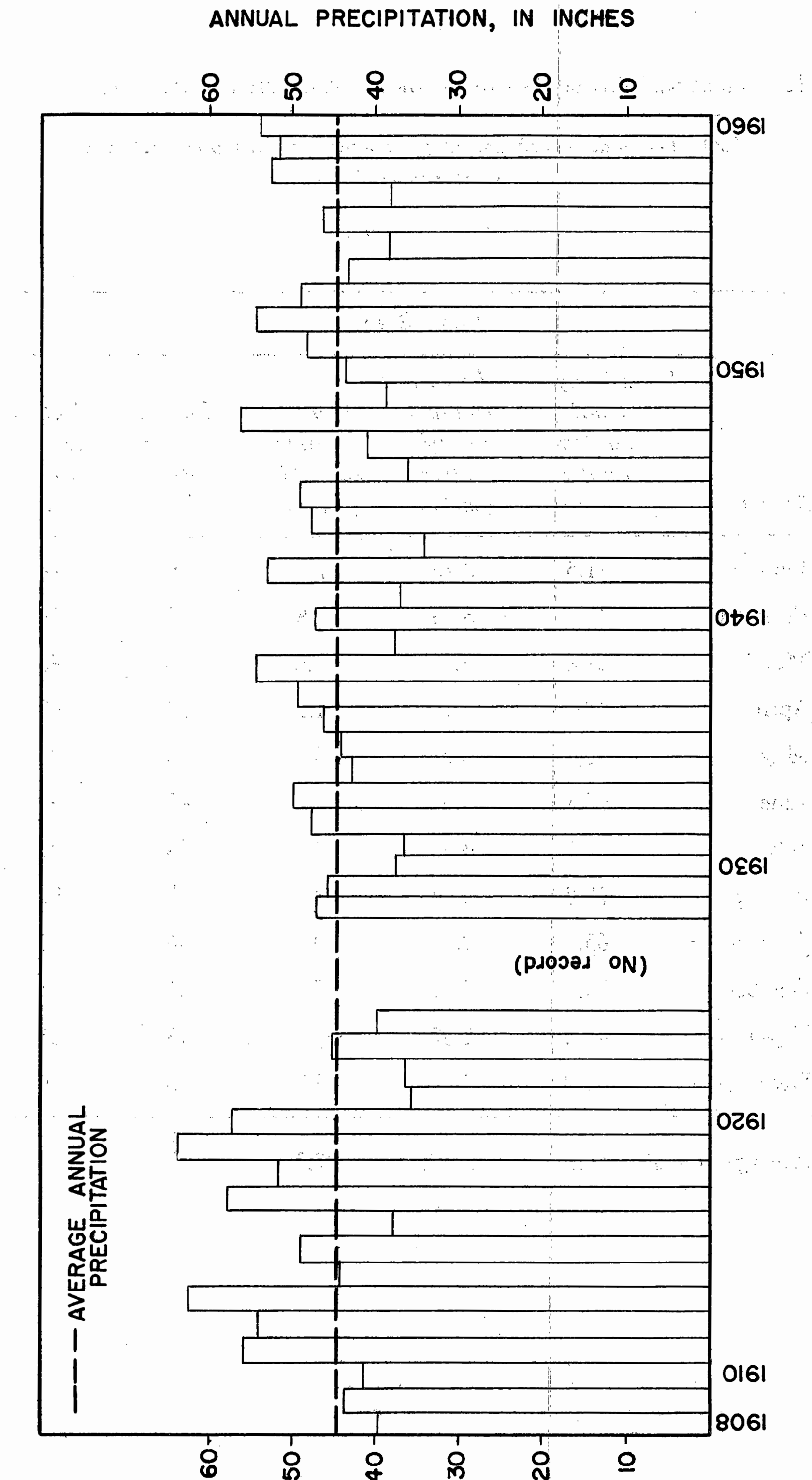


Figure 4.—Annual precipitation at Long Branch, 1908-60 (from records of the U. S. Weather Bureau).

Table 1.—Monthly and annual air temperature and precipitation at Long Branch, N. J.

(1908-1930)

Long Branch					
Month	*Average monthly air temperature (°F)*	*Average monthly precipitation (inches)*	*Average monthly snowfall (inches)*	*Lowest temperature (°F)*	*Highest temperature (°F)*
January	31.5	3.73	7.0	-6	74
February	31.2	3.44	7.8	-9	76
March	39.4	3.58	5.6	6	83
April	48.2	4.18	1.2	12	92
May	58.0	3.21	0	30	97
June	67.1	3.56	0	42	99
July	72.1	4.39	0	48	102
August	70.8	4.44	0	47	98
September	65.9	2.62	0	36	96
October	55.4	2.82	T	27	91
November	44.2	2.82	.2	13	81
December	34.2	3.53	5.2	-8	69
Average annual	51.5	42.32	27.0	—	—

SUMMARY OF GEOLOGY

STRATIGRAPHY AND STRUCTURE

Monmouth County is in the New Jersey section of the Atlantic Coastal Plain physiographic province of the eastern United States. The Atlantic Coastal Plain province is underlain by unconsolidated rocks of Mesozoic and Cenozoic age. These strata occupy a belt extending from Raritan Bay, in Monmouth County, southwestward along the Atlantic and Gulf Coasts into Mexico. Northeast of Raritan Bay, similar strata underlie parts of Staten Island, Long Island, New England, and the Cape Cod peninsula.

The formations present in Monmouth County are listed in table 2, which gives their age, water-bearing properties, strike, dip, and thickness. The descriptions of the formations are adapted in part from Weller (1907) and Owens and Minard (1960).

The Coastal Plain formations in Monmouth County are marine and continental sedimentary rocks, chiefly of Late Cretaceous and Tertiary age. These rocks are composed of sand, silt, and clay with minor amounts of gravel. Locally, beds of iron-cemented sandstone and calcarenite are present. Thin deposits of clay, sand, and gravel of Quaternary age cover the older formations in places. The Coastal Plain sediments were deposited on an erosional bedrock surface of late Precambrian(?) and Triassic age.

The eroded edges of the formations are exposed at the surface in bands trending northeast-southwest, as indicated on the geologic map, figure 5. The dip of the formations ranges from 10 to 62 feet per mile to the southeast. The total thickness increases to the southeast as shown on geologic cross sections A-A′, B-B′, and C-C′. See figures 5 and 6. The combined thickness of the Coastal Plain formations increases from about 500 feet in the northwestern part of the county to 1,200 feet or more in the southeastern part.

GEOLOGIC HISTORY

The following discussion has been modified from a report by Lewis and Kümmel (1915).

More than 600 million years ago, during the late Precambrian Period, the oldest known rocks underlying Monmouth County were deposited as sands and muds in a geosyncline. The accumulation of a great thickness of overlying sediments created sufficient heat and pressure to form sandstones, shales, and arkoses. These consolidated rocks were later intruded by igneous rocks and altered to form the gneisses and schists of the Wissahickon Formation. However, in past years, the age of the Wissahickon Formation has been questionable. The age assignment of late Precambrian(?) for this unit is preferred.

A long interval of erosion or nondeposition followed and the late Precambrian(?) rocks were worn to a nearly flat surface. Then, about 120 million years ago, during the Early Cretaceous Epoch, the Appalachian Mountains to the west were uplifted, and eastward-flowing streams deposited sand, clay, and gravel in the bays and estuaries along the coast. After partial erosion of the Upper Cretaceous deposits, the sea began to fluctuate across Monmouth County, and sand or clay was deposited during the respective retreats and advances of the sea. Cretaceous deposition was brought to a close in Monmouth County by a complete withdrawal of the sea.

An interval of erosion ensued, and the landward edges of the Cretaceous deposits were removed. The next advance of the sea occurred over 60 million years ago during the Tertiary Period. Alternating erosion and deposition continued throughout the period, and sands, clays, and gravels were deposited on the older Cretaceous materials.

The deposits formed during the past million years and those now forming belong to the Quaternary System. The beginning of this period is known as the Pleistocene Epoch and has been called the "Ice Age." Sand and gravel were deposited in Monmouth County during the Ice Age by melt waters from the glaciers to the north. The Quaternary deposits since that time belong to the Recent Series.

nty, N. J.

Era	System	Series		Dip (feet per mile, outheast)[1]	Thickness penetrated (feet)	Average strike of beds (northeast)[1]
CENOZOIC	Quaternary	Recent	Alluvium a	—	0-30	—
		Pleistocene	Cape May, Formatior	—	0-60	—
	Tertiary	Miocene(?) and Pliocene(?)	Cohansey S	10	0-30	70°
		Miocene	Kirkwood F	20	60-100	70°
		Eocene	Manasquan Shark Ri	25	25-100	55°
		Paleocene	Vincentown	27	10-130	55°
			Hornerstow	50	30-100	55°
MESOZOIC	Cretaceous	Upper Cretaceous	Red Bank Formatior	33	30-135	50°
			Navesink F	35	10-45	50°
			Mount Lau Wenonah F	35	15-85	50°
			Marshalltov	37	30-50	45°
			Englishtowr	39	36-150	45°
			Woodbury Merchantvi	41 42	50 50-60+	45° 45°
			Magothy F	40-45	25-175	40°
			Raritan Fo	45-52	150-400+	—
PRE-CAMBRIAN	Late Pre-cambrian(?)		Wissahicko	62	—	—

[1]Minard and Owens, 1960, p. 9.

WATER RESOURCES

SUPPLY

The water supply of Monmouth County is derived from surface streams and from ground-water reservoirs beneath the surface. The Coastal Plain strata that immediately underlie the land surface form water-table aquifers —aquifers in which the water is not confined under artesian pressure between strata of low permeability. The water table aquifers receive recharge from precipitation. Precipitation directly on streams, overland runoff of precipitation, and discharge of water from the water-table aquifers to streams account for streamflow. Hence, precipitation is the source, direct or indirect, of streamflow. The long-term average annual precipitation is a measure of the total water supply of an area. The average annual precipitation of 44.67 inches in the county is equivalent to 775 million gallons of water per square mile. A significant part of the precipitation cannot be recovered for development, however, because it is returned to the atmosphere by evaporation and by the transpiration of plants. Only the precipitation that enters streams or becomes ground water is potentially available for use.

If the weighted average discharge data for the drainage areas given in table 3 is typical of the weighted average natural discharge of all the drainage areas in the county, then about 540 mgd (million gallons per day) is the average natural stream discharge out of the county. Adjusting for surface-water diversions, the actual stream discharge out of the county in 1958 probably was about 515 mgd. State law requires that certain minimum flows be sustained downstream from any point of surface-water diversions. The total minimum streamflow out of Monmouth County required by law is roughly 70 mgd.

To determine the surface-reservoir storage capacity that would be required at any particular site in the county to provide a certain sustained yield requires consideration of the hydraulic continuity between the water-table aquifers and some of the surface-water bodies. As discussed later in this section, a significant part of the streamflow is obtained as discharge from water-table aquifers. A change in the ground-water withdrawals from the water-table aquifers would affect the amount of discharge from these aquifers to the streams which, in turn, would influence the rate of streamflow. However, if the withdrawals were for nonconsumptive use within the basin there would be little change in the annual discharge.

Table 3.—Average discharge of selected streams in Monmouth County

Drainage system[1]	*Area (square miles)*	*Average discharge (cfs per square mile)*	*Period of record*
Manasquan River	43.4	1.66	1932-60
Crosswicks Creek	83.6	1.50	1941-50 and 1953-60
Swimming River	48.5	1.57	1923-60
Matawan Creek	6.1	1.66	1933-54
		weighted average 1.56 cfs per square mile	

[1]See figure 2 for location of gaging stations.

UTILIZATION

The total withdrawal of fresh water in Monmouth County during 1958 was at an average rate of approximately 44 mgd. Ground water was used at a total rate of about 21.6 mgd and surface water at a rate of 22.4 mgd. It is estimated that total consumption during 1965 was 63 mgd; about 32 mgd ground water and 31 mgd surface water (N. J. Division of Water Policy and Supply).

Surface Water

Surface water in 1958 was used by public water supplies at a rate of 12.4 mgd and by farmers for irrigation at an estimated rate of 10.0 mgd. Public water supplies derived surface water from Jumping Brook, Shark River, Swimming River, and Whale Pond Brook, the diversion from Swimming River constituting about 84 percent of the total pumpage from the four streams. The surface water used for irrigation was supplied chiefly by streams in the western part of the county.

Ground Water

The ground-water usage in 1958 represents an increase of 18.1 mgd since 1900. The chief source of ground water in Monmouth County is wells tapping the Raritan and Magothy Formations and the Englishtown Formation. Aquifers in these formations supplied 76 percent of the ground water in 1958.

Public water-supply installations were the largest users of ground water, and they supplied chiefly homes and industries. Other consumers having privately owned wells include industries, household supplies, and farmers for stock or irrigation. In 1958 public supplies accounted for about 61 percent of the present ground-water use in the county, industries 20 percent, and irrigation and household supplies 19 percent.

For this report, all known irrigation and public-supply wells and many industrial wells were visited, and all available data concerning them were obtained. Two hundred and fifty household wells also were visited to obtain representative data on wells of this type.

Public Water Supplies

Water for the 52 municipalities in Monmouth County is obtained from wells and streams. There are 26 public supplies of which 22 are dependent upon ground water, 1 upon surface water, and 3 upon a combination of both. The 26 public supplies furnish water for about 87 percent of the population, the rest depending upon privately owned wells.

The average daily consumption by public supplies totaled about 13.2 million gallons from ground water and 12.4 million gallons from surface water in 1958; the combined consumption represents 58 percent of the total water used in the county. As of 1958, public supplies in the county were authorized to withdraw as much as 46 mgd from surface water supplies developed on Jumping Brook, Swimming River, and Shark River.

Domestic and Stock Supplies

Homes and farms not served by public water systems rely on privately owned wells. On the basis of a 1958 estimate, about 43,000 people in the county live in areas not served by public water systems. If it is assumed that the average per capita use is 50 gpd (gallons per day), domestic use of ground water is at a rate of about 2 mgd. The quantities of ground water used by livestock and poultry probably do not exceed a total rate of 150,000 gpd.

Industrial Supplies

The Monmouth County Planning Board made an inventory in 1958 of all industries not supplied by public water systems. Industrial use of ground water was at a rate of 4.2 mgd in 1958.

Irrigation Supplies

The demand for water to irrigate farm lands has increased rapidly in recent years. The Federal Census listed 109 acres of land under irrigation in Monmouth County in 1944. The Soil Conservation District listed 15,378 acres as being irrigated in 1959. Based on daily plant requirements of 0.27 inch per acre during dry periods, water would be needed at the rate of 7,150 gpd to cover an acre of land, or about 110 mgd to cover the acreage irrigated in the county. Actual inventory of representative farms in the county indicates that water was withdrawn for irrigation at an average rate of about 12 mgd in 1957, or about 29 mgd during the irrigation season. Of this amount, about 2 mgd was ground water. For the purposes of this water utilization inventory, it was assumed that the amount of water used for irrigation in 1958 was the same as in 1957.

FUTURE DEMANDS

The water demand of Monmouth County is expected to increase from 44 mgd in 1958 to 92 mgd in 1975, and to 133 mgd by the year 2000 (Monmouth County Planning Board, 1958, p. 7).

GROUND WATER

GEOHYDROLOGY

The following is a brief discussion of the factors governing the occurrence and movement of ground water. For a more complete discussion of the subject the reader is referred to Meinzer (1923), Ferris (1949, p. 198-226), and Todd (1959, p. 14-77).

Precipitation that enters the ground becomes "subsurface water." Subsurface water includes all the water beneath the earth's surface; ground water refers only to that which is at or below the level in the zone of saturation where all openings in the rock are filled with water under atmospheric, or, greater, pressure.

In Monmouth County, ground water occurs in the pore spaces among the individual grains of the unconsolidated sediments that underlie the entire county. Ground water occurs in all the rock formations, but not all the formations are important as sources of water supply. According to their relative water-bearing capacities, the formations are called aquifers (water-bearing) or aquicludes (essentially non-water-bearing).

The aquifers serve as storage reservoirs and as transmission conduits. They hold ground water in storage, and they transmit it toward points of discharge in response to hydraulic gradients. When a new withdrawal is imposed on an aquifer that is in equilibrium, the aquifer can obtain a new equilibrium if the quantity of water withdrawn can be balanced by an increase in recharge or decrease in natural discharge. Until such a balance is established, water is withdrawn from storage.

Ground water occurs under water-table (unconfined) or artesian (confined) conditions. It is important to know the condition of occurrence because the response of water-table aquifers to pumping is different from that of artesian aquifers, and the effects of development are therefore different.

Water-table aquifers contain ground water which is under atmospheric pressure at the top of the saturated portion. These aquifers yield water from storage and transmit the effects of pumping to other parts of the aquifer slowly, because a lowering of the head of water in a water-table aquifer (a decline of the water table) represents actual draining of water from pores.

Artesian conditions exist where relatively impermeable confining beds overlie and underlie an aquifer completely filled with water under hydrostatic pressure. The effects of a change in the head of water caused by pumping a well in an artesian aquifer is transmitted quickly to considerable distances in such aquifers. A lowering in the head of an arteisan aquifer results not in draining of water from pores but in the squeezing of a small amount of water from fine-grained materials, and also in slight expansion of the water itself. The total quantity of the water released from storage per unit volume of the aquifer is much smaller than the amount that can be drained from pores under water-table conditions; hence, a larger area of the aquifer is affected in pumping at a given rate. An artesian aquifer yields water yet remains saturated so long as the head is above the upper limit of the aquifer. Conditions change from artesian to water-table at a place when the head of water declines below the upper limit of the aquifer at that place.

Where the head of water in an artesian aquifer is above the land surface, a well tapping the aquifer will be a flowing well.

In Monmouth County, most of the ground water withdrawn has been taken from the artesian aquifers. Many domestic well owners withdraw water from water-table aquifers, but their total withdrawals are quite small compared to the total ground-water withdrawals. It should be noted that an aquifer may exist under water-table conditions at one place and under artesian conditions at another. As far as is known, the aquifers in Monmouth County occur under water-table conditions only in their outcrop areas.

Available data do not permit a determination of the average annual recharge to each of the aquifer outcrop areas in Monmouth County. Stream-gaging stations are not located at aquifer boundaries, so the observed flows cannot show the baseflow discharge from each of the aquifers. An analysis of the streamflow in the Manasquan River at Squankum for the period 1932 through 1950 indicates that the average baseflow discharge from the water-table aquifers in that basin probably is in excess of about 0.55 mgd per square mile. The aquifers that contribute directly to the streams in this basin are primarily the Kirkwood Formation and the Vincentown Formation. The estimated average baseflow discharge for the period May through October of each year from 1932 through 1950 was used to compute the minimum average daily baseflow discharge for that year. Certainly, this method is not valid for determining the average baseflow conditions, but the value obtained is a conservative estimate of average daily baseflow discharge that may be useful in making estimates of the amount of ground water available from aquifers that occur under water-table conditions in the county. This is because the long-term recharge to the water-table aquifer must be at least as great as the long-term baseflow discharge if precipitation is the only source of recharge. Thus, the long-term baseflow discharge is a conservative estimate of the recharge to these aquifers.

Assuming that the average baseflow characteristics of all aquifers that occur under water-table conditions somewhere in the county are typified by the conditions in the Manasquan River drainage area, an average of in excess of 0.55 mgd per square mile of aquifer outcrop area is discharged from aquifers to streams in Monmouth County. This represents ground water that the aquifers could not transmit away from the outcrop areas under the gradients that prevailed from 1932 through 1950. Widespread development of these aquifers in and near their outcrop areas could recover much of the water now discharged by these aquifers. Such development would decrease the baseflow to the streams. The water use very likely will not be entirely consumptive; hence, a certain percentage of the ground water withdrawn will be returned to aquifers or streams in the county. Development downdip from the outcrop areas also could recover some of the water now discharged as baseflow by creating steeper gradients from the parts of the aquifer that receive recharge from precipitation.

The aquifer in the Raritan and Magothy Formations probably contributes little or no water directly to streamflow in the county because practically all the outcrop area of this aquifer is outside Monmouth County, and the confining beds overlying it within the county are of low permeability and could not leak much water upward into the streams. It has been the most productive aquifer underlying Monmouth County. More water was pumped from this aquifer in 1958 than was pumped from all the other aquifers underlying the county. The optimum yield of this aquifer in the county is dependent on the distribution and intensity of development in other parts of the Coastal Plain. Also it depends on the extent of salt water in the aquifer landward from where it occurs in the aquifer underlying the Atlantic Ocean. Until more is known about the extent of this salt water, development of the aquifer should proceed with caution to assure greatest permanency of existing supplies. Frequent sampling of outpost wells is one method of detecting intrusion of salt water.

Records of fluctuations of the water table throughout the Coastal Plain show that little recharge from precipitation takes place to the aquifers during the growing season. Hence, during the growing season, much of the precipitation is transpired by vegetation, evaporated from the land surface, and used to restore the soil moisture in the zone above the water table. Figure 7 shows the average seasonal trend of water levels in the Morrell well and figure 8 shows the seasonal trend since 1943 in the Hulsart and Morrell wells. The water levels in these wells are not ap-

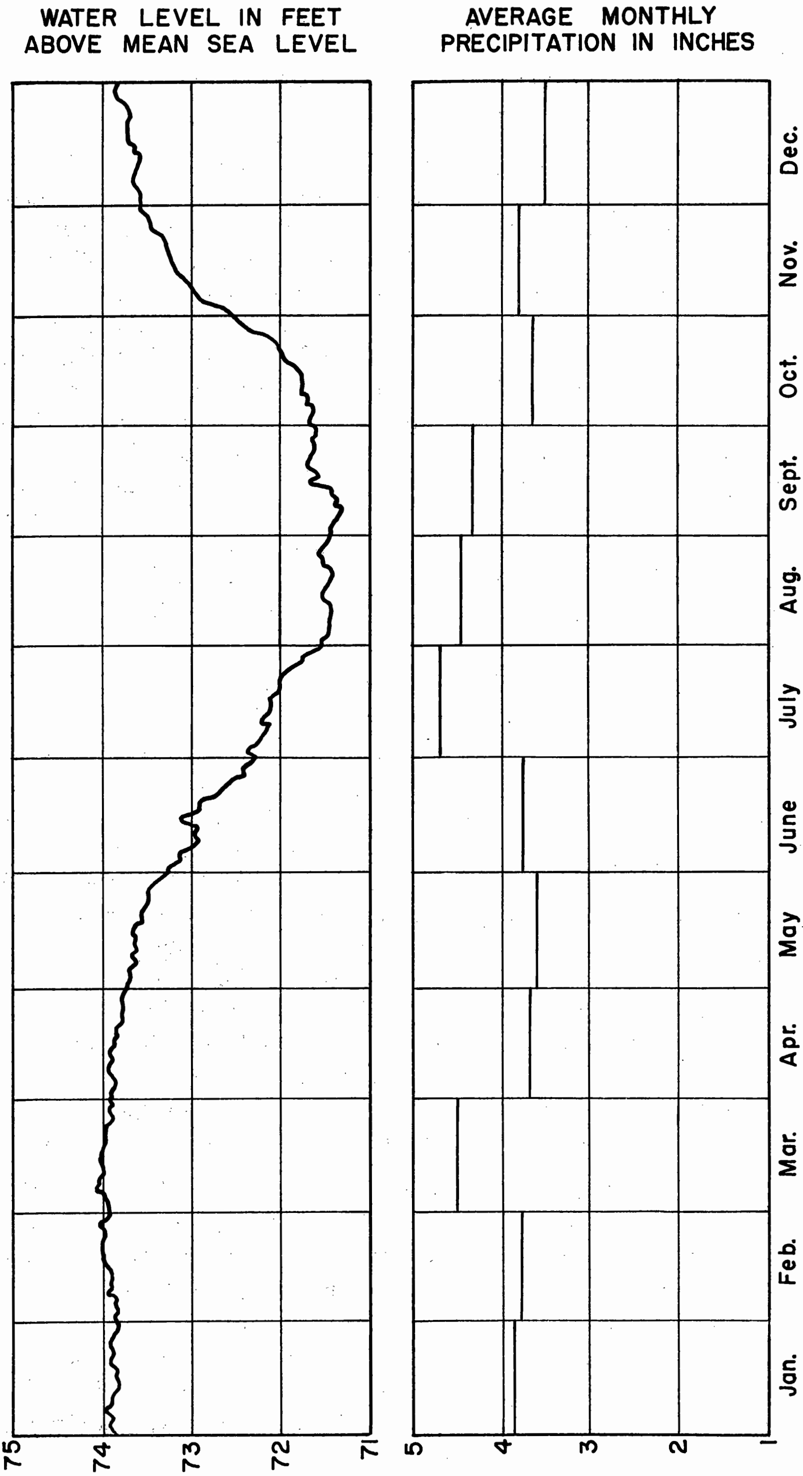


Figure 7.—Average daily water level in the Morrell well 1923-54 and average monthly precipitation at Freehold 1905-54.

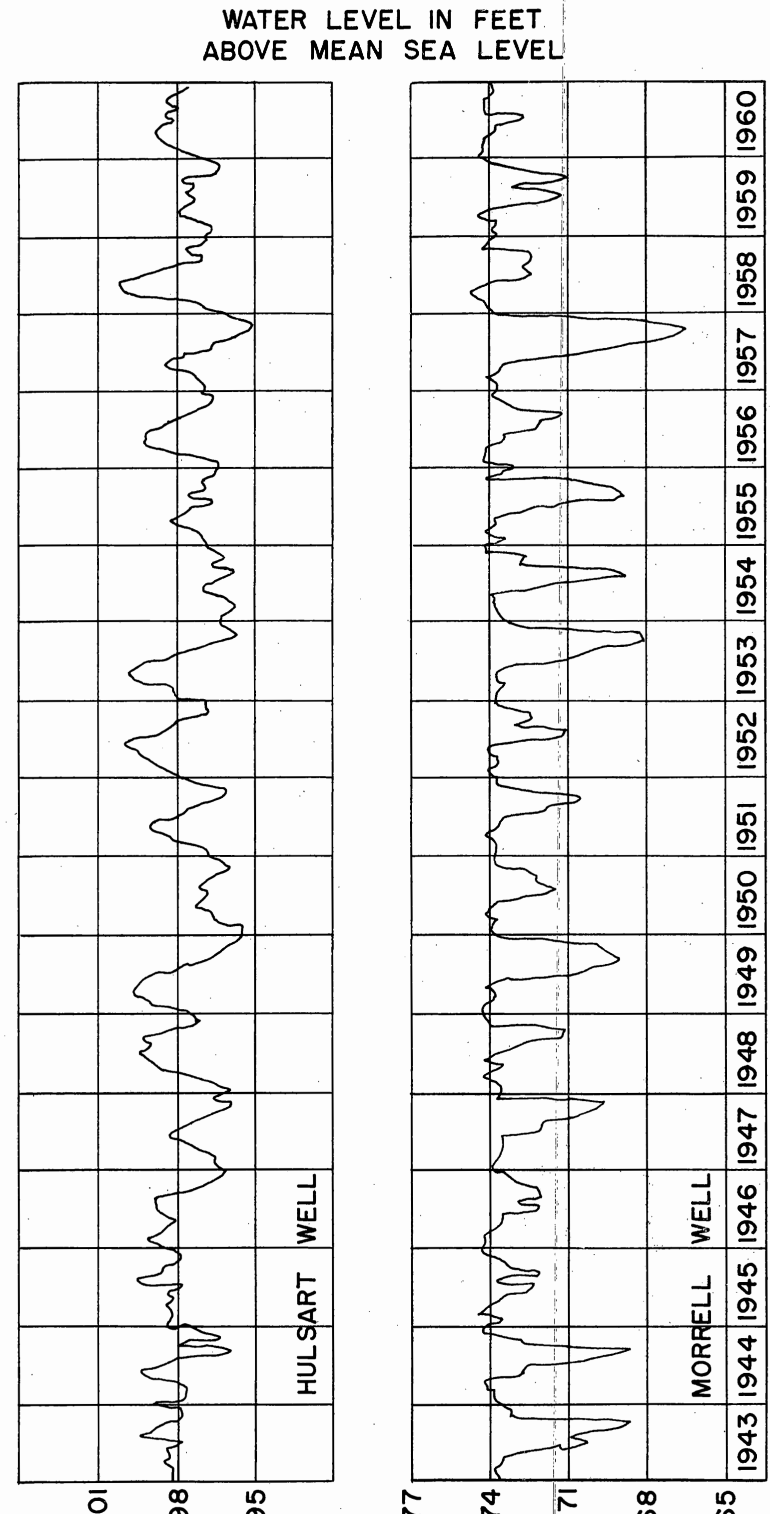


Figure 8.—Hydrograph of the Hulsart well and Morrell well (1943-60).

preciably affected by pumping. The location of the Hulsart and Morrell wells is shown on figure 2. Barksdale and others (1943, p. 37) and Remson and Randolph (1958, p. 80-83) discuss in detail the significance of the water-level fluctuations and trends in these two wells. As shown by figure 7, although the average monthly precipitation during July, August, and September is higher than that for the winter months (with the exception of March), the average daily water level is lower during the summer months than in the winter months. Most of the recharge to the aquifers takes place during the nongrowing season when the evaporation and transpiration losses are at a minimum. Thus, the total annual precipitation is not as significant an indicator of annual aquifer recharge as is the precipitation that takes place during the nongrowing season. In general, late October to late April constitutes the nongrowing season or principal aquifer recharge period. The precipitation during the November through April period at Freehold is about 22 inches. This value probably is a reasonable approximation of the average precipitation in the county during the nongrowing season.

The water-level fluctuations shown in figure 8 reflect, at least qualitatively, the relationship of aquifer recharge and discharge in the area immediately encompassing these particular observation wells. A rising water-level trend indicates a period when aquifer recharge exceeds aquifer discharge. A declining water-level trend indicates a period when aquifer recharge is less than aquifer discharge. A constant water-level trend indicates a period during which aquifer recharge and discharge are equal.

These ground-water levels also indicate, at least qualitatively, the ground-water discharge from the water-table aquifers to streams. Ground-water discharge to streams is related to the position of the water table. In general, the higher the mean water-table level, the higher will be the ground-water discharge to streams. Thus, if the water-level changes in the Hulsart and Morrell wells can be considered indicative of changes in the mean water-table level in the county, their water-level fluctuations reflect the relative seasonal variations in ground-water discharge to streams.

The quantitative significance of ground-water discharge to streams is reflected by the shape of the flow-duration curves shown on figure 9. A flow-duration curve is a cumulative frequency curve that shows the percentage of time during which specified discharges were equaled or exceeded in a given period, irrespective of chronological sequence. The curves for the two streams represent conditions as they occur in eastern and western Monmouth County. According to Searcy (1959, p. 22) a curve with a flattening slope at low discharge indicates a large amount of perennial storage. In the Coastal Plain, this perennial storage probably is mostly

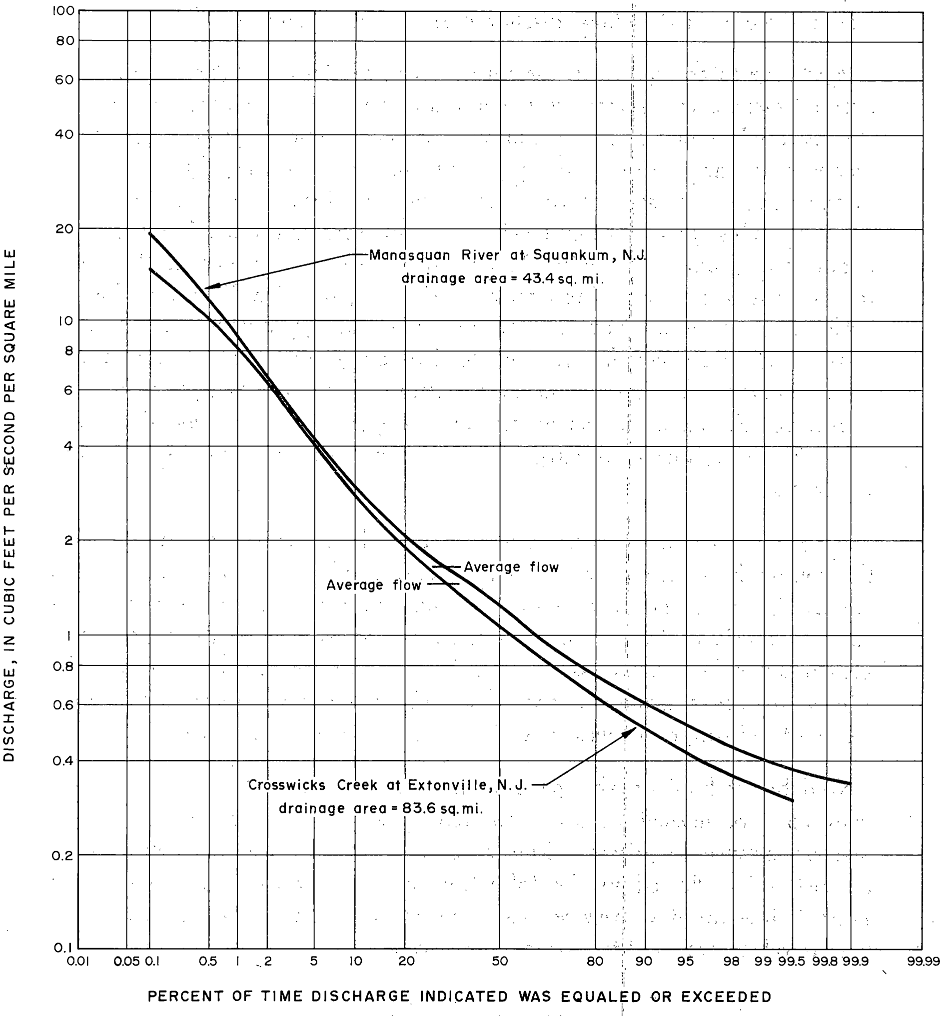


Figure 9.—Duration curves for daily flows, Crosswicks Creek at Extonville (1941-51, 1952-57 W.Y.) and the Manasquan River at Squankum (1932-58 W.Y.)

ground-water storage. On this basis, the streams in the county receive a large amount of discharge from the ground-water reservoirs. This conclusion complements a baseflow analysis of the streamflow in the Manasquan River that indicated that at least 55 percent of the streamflow was derived from baseflow discharge from water-table aquifers.

Recharge to an aquifer in the form of vertical leakage takes place whenever its piezometric surface is lower than that of an adjacent aquifer and the materials separating the aquifers are permeable. Generalized piezometric maps are given in later sections for most of the major aquifers in the county representing the approximate conditions for a short period in 1959. Most of the water levels shown on these piezometric maps were obtained in production wells. Arrangements were made with well owners to discontinue pumping from most of the large-yield wells for as long a period as practicable prior to a selected period of a few days during which water-level measurements were made throughout the county. The water levels observed represent conditions a short time after pumping had discontinued. As such, the piezometric maps suggest in a very general manner the areas of apparent recharge and discharge and direction of ground-water flow.

As far as is known, each zone of materials above bedrock underlying the county is permeable to a certain degree. However, only a few data are available on the permeability of the zones that consist primarily of clayey materials. Much more information on the permeability of these aquicludes is needed to assist in predicting with reasonable accuracy the effects of future ground-water development and the practical sustained yields of existing or proposed wells in any particular aquifer.

Reliable values of the permeability characteristics of the aquiclude materials are needed in order to determine the significance of vertical leakage between aquifers. The need for detailed data on these characteristics is reflected in the following formula, which is a variation of Darcy's law for flow between two aquifers through a series of essentially horizontal layers of different permeabilities:

$$Q = \frac{h \quad A}{\frac{b_1}{P_1} + \frac{b_2}{P_2} + \cdots\cdots + \frac{b^n}{P}}$$

where

h = difference in total head between top and bottom of the zone of materials separating two aquifers, in ft

A = area over which leakage occurs, in sq ft

$b_1 + b_2 + \dots\dots + b^n$ = total thickness of zone separating two aquifers

b_1 = thickness of 1st layer, in ft

P_1 = permeability of 1st layer, in gpd per sq ft

Q = vertical leakage between two aquifers, in gpd

It should be noted from this equation that if the permeability of the layer of lowest permeability is sufficiently smaller than the others, then the permeability and thickness of that layer will effectively control the rate of vertical leakage through the entire series of layers. To illustrate, this point, consider the following hypothetical situation.

Two aquifers are separated by a zone 100 feet thick consisting of 96 feet of silt and several thin clay layers with a cumulative thickness of 4 feet. The permeabilities of the silts and clays are 0.6 and 0.001 gpd per sq ft, respectively. The vertical leakage formula indicates

$$Q_{\text{actual}} = \frac{h\ A}{\frac{96}{0.6} + \frac{4}{0.001}} = \frac{h\ A}{4160}$$

Suppose that the samples collected and analyzed for permeability were only from the silt part of this zone and that it was assumed that, because most of the zone consists of silts, the effective permeability of the 100-foot zone probably is equal to the permeability of the silts. Using this information the vertical leakage formula indicates

$$Q_{\text{estimated}} = \frac{h\ A}{\frac{100}{0.6}} = \frac{h\ A}{166.6}$$

Then note that the estimated vertical leakage would be about 25 times the actual vertical leakage between the aquifers. Obviously, errors of this magnitude could result in misleading conclusions regarding the significance of vertical leakage.

Thus, if an aquiclude is not homogenous, but consists of layers of materials that would be expected to have radically different values of permeability, a reasonably reliable estimate of leakage through the aquiclude requires (among other things) a knowledge of the permeability and thickness of the least permeable layer. Permeability analyses of samples from some of the aquicludes suggest that their permeability may vary significantly from place to place. Because of this apparent variability, the relatively small number of samples that have been analyzed for permeability cannot be depended on to represent the aquicludes adequately.

Pumping-test methods of analyzing the permeability characteristics of aquicludes are preferable because the volume of materials sampled is large and the value of effective permeability determined represents the aquiclude over a large area. Because some of these methods have been developed only very recently, there has been little opportunity to apply them to test data in this area.

An aquifer also can be recharged by inducing seepage of water from a stream with which it is in hydraulic connection. As far as known, the natural ground-water gradients in the outcrop areas in the county are toward streams. Pumping could reverse these gradients in some places and water from the streams would be induced into the aquifers. A practical advantage for locating a well near a stream with which it has hydraulic connection is that the drawdown required for the well to have any particular yield is less than the drawdown that otherwise would have been needed.

HYDRAULICS

Coefficients have been formulated to describe the ability of ground-water reservoirs to store and transmit water. The most important of these are the coefficients of permeability, transmissibility, and storage. The most practical applications of the coefficients are: (1) predicting water-level trends; (2) locating and spacing wells; and (3) estimating the yield of aquifers. Lang (1961) discusses the spacing of wells.

Permeability reflects the ability of a material to transmit water, and the coefficient is a measure of the permeability for a given material. Transmissibility, or the coefficient of transmissibility, is a measure of the ability of a ground-water reservoir to transmit water. Transmissibility is a product of the permeability and the saturated thickness of a ground-water reservoir. The coefficient of storage cannot be given a simple physical interpretation but an understanding of its significance can be gained from the definition.

These terms may be defined as follows:

Coefficient of permeability.—The rate of flow, in gallons per day at a temperature of 60°F, through a cross-sectional area of 1 square foot under a unit hydraulic gradient. If this coefficient is determined in the field at a temperature other than 60°F, it is called the field coefficient of permeability.

Coefficient of transmissibility.—The rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide, extending the full saturated height of the aquifer under a unit hydraulic gradient.

Coefficient of storage.—The volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

In field practice, the coefficients of transmissibility and storage are usually determined by an aquifer test, and the average coefficient of permeability is computed by dividing the transmissibility by the saturated aquifer thickness. The values of the coefficients determined for one test, even under ideal conditions, do not permit a quantitative evaluation of the entire aquifer. Rather, a series of tests throughout the aquifer is necessary for more complete evaluation. The ideal conditions required to determine accurately the coefficients by aquifer tests usually cannot be fully met in the field. The values determined under these nonideal conditions serve as comparative indices and permit only a semiquantitative evaluation of the aquifer. When aquifer tests have not been made in an area, it may be useful to obtain a rough estimate of the coefficient of transmissibility from the specific capacities of production wells. Theis and others, (1963, p. 331-338) indicates how the coefficient of transmissibility can be estimated from the specific capacity of a well.

For more complete discussion of general ground-water hydraulics, the reader is referred to Ferris (1949, p. 226-272), Todd (1959, p. 77-114), or Bruin and Hudson (1955). Hantush (1960, p. 3713-3725) presents an analysis of the response of an aquifer being supplied by lateral replenishment and leakage from overlying and underlying aquifers.

RECOVERY BY WELLS

Construction

Wells are the chief means of recovering ground water and obtaining data for determining the ground-water resources of an area. An understanding of the basic principles of well construction and development is essential, therefore, to all prospective users of ground water. The basic principles of construction and development apply to all wells, but methods vary depending on the local geology and topography.

Methods.—A water well is a hole or shaft sunk into the earth to obtain ground water. Wells are classified according to the method of construction as dug, bored, jetted, driven, and drilled. Most ground-water supplies in Monmouth County are obtained from dug, drilled, or driven wells. Brief descriptions of dug, drilled, and driven wells follow; more complete discussions of the various types of wells can be found in Tolman (1937, p. 392-408), and Todd (1959, p. 116-139).

Dug wells.—These are large-diameter wells constructed by hand tools. They are commonly less than 40 feet deep in Monmouth County.

The demands for water in recent years have exceeded the yield of most dug wells; moreover, the danger of pollution has caused the use of dug wells as a source of supply to decline gradually in past years.

The two main advantages of dug wells are: (1) they utilize water from all water-bearing formations penetrated, and (2) they permit storage of considerable quantities of water, available for immediate use. The disadvantages are: (1) they are susceptible to pollution, (2) construction depends on a relatively shallow water table and formations that yield water easily, and (3) they can be extended generally only a few feet below the water table and may go dry during droughts.

Driven wells.—A driven well is constructed by driving a pointed screen, called a drivepoint, into a water-bearing formation. The screen is on the end of a string of 1¼ to 2½ inch pipe and is driven by a maul or a heavy weight alternately raised and dropped. In general, this type of well utilizes shallow water-bearing sand or gravel, but can be driven to depths of more than 100 feet depending on the materials to be penetrated.

Although there are numerous limitations in the construction of a driven well, it offers substantial yields at low cost.

Drilled wells.—There are many modified types of drilled wells, but the two most common are cable-tool (percussion) and hydraulic rotary wells.

A rotary well is drilled by the rotation of a cutting bit on the bottom of a string of drill pipes. The hole is kept open by circulation of liquid mud which also removes the drill cuttings. The well pipe, or casing, and screen are positioned after the drilling is completed. Hydraulic rotary wells in the county range from 4 to 36 inches in diameter and have been drilled to depths of more than 1,300 feet.

The cable-tool method uses a bit which is alternately raised and dropped to excavate the hole. The cuttings are removed from the hole by a bailer or long pipe-like bucket. In sand and similar materials, the well casing must be driven down as drilling proceeds to prevent caving of the sides of the hole. The screen is installed after the aquifer is reached. Cable-tool wells in the county range from 3 to 12 inches in diameter and have been drilled to depths of more than 1,300 feet.

Compared to other methods of well construction, cable-tool and rotary-drilling methods are faster, can go to greater depths, and can produce wells that yield much larger and more reliable supplies of ground water. Both methods require a water supply during construction.

Rotary and cable-tool drilled wells are by far the most important types in Monmouth County; rotary wells are most numerous among industries, public supplies, and irrigation water systems.

Well Screens.—Development of most water-bearing formations in Monmouth County require installation of a well screen. The screen allows an envelope of sand or gravel to form as the well is pumped and surged, and maintains the envelope after development. The sand envelope grades from coarsest to finest grain size away from the screen. The envelope is developed by removing the fine material surrounding the screen to produce an arrangement of coarse particles that best fits the well screen. Surging is the chief method used for developing screen wells. The screen size opening is determined by the grain size and distribution of the water-bearing material. Well screen information can be obtained from screen manufacturers.

Specific Capacity.—The specific capacity of a well is the rate of yield per unit of drawdown; generally expressed in gpm for each foot of water-level drawdown in the well. The specific capacities of wells that are not located close to geohydrologic boundaries of an aquifer suggest a relation to the aquifer's coefficient of transmissibility in the area of the well; high specific capacities suggest a high coefficient of transmissibility and low specific capacities suggest a low coefficient of transmissibility. The specific capacity of a well near a geohydrologic boundary of an aquifer may be affected significantly by this boundary. The specific capacity of a well not located near an aquifer boundary may not necessarily reflect the coefficient of transmissibility of the aquifer near the well because specific capacity is also affected by, among other things, the well construction and development, the aquifer coefficient of storage, and the part of the aquifer the well is screened in.

CHEMICAL CHARACTER OF THE GROUND WATER

The geology and climate of an area largely determine the chemical and physical characteristics of the ground water and therefore its usefulness as a water supply. The mineral matter contained in ground water is dissolved principally from the rock and soil with which the water comes in contact. Therefore, changes in geology and in the direction and rate of movement of ground water can cause variations in the quality of water.

This section presents a discussion of the results of chemical analyses of water samples from 76 wells in Monmouth County (Jablonski, 1959, 1960). Raw water samples were taken because treatment usually removes or reduces some chemical constituents. Concentrations given are rounded according to the practice of the U. S. Geological Survey.

Ground water in New Jersey generally contains less than 400 ppm (parts per million) of dissolved mineral matter and is satisfactory for domestic, irrigation, and most industrial uses. The mineral constituents that may affect the suitability of ground water for most purposes are silica, iron, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, nitrate, and hydrogen sulfide. Also, in the discussion that follows, dissolved solids, specific electrical conductance, pH, and bacterial pollution are considered.

Individual Constituents

Silica (SiO_2).—Silica in water appears to have little effect on human beings, livestock, fish, or plant life. It is of chief concern to industrial users, especially when the water is to be used for boilers, because it contributes to the formation of a hard scale that prevents the rapid transfer of heat. Silica concentrations above 5 ppm can cause scaling, even at operating pressures as low as 150 pounds per square inch. Silica in water can be removed by treatment.

Analyses of Monmouth County ground waters indicate that silica ranges from a trace to 45 ppm; 30 of the 76 samples contained between 10 and 24 ppm.

Iron (Fe).—Concentrations of iron, or of iron and manganese together, greater than 0.3 ppm are objectionable because the water stains fixtures, utensils, and fabrics. Iron and Manganese also give the water an unpleasant taste. Many industrial uses cannot tolerate more than 0.35 ppm, although some can tolerate almost none at all and others can tolerate as much as 1 ppm. The U. S. Public Health Service Drinking Water Standards (1962) recommend a limit of 0.3 ppm of iron for drinking water.

Iron is commonly treated by chemicals or aeration to cause precipitation. The iron precipitate is then removed either by filtering or settling in tanks. Domestic treatment units on the market will remove as much as 10 ppm of iron at a rate of 3 gpm (gallons per minute). Greater rates of flow can be successfully treated by using more than one unit.

Iron in samples of ground water from Monmouth County ranges from 0 to 33 ppm. Only 9 of 76 samples contained 0.3 ppm or less.

Calcium (Ca) and magnesium (Mg).—Although calcium and magnesium are only slightly soluble in pure water, water containing carbon dioxide dissolves these elements from rocks and soils. Most of the hardness of water is caused by calcium and magnesium salts. These constituents also tend to form boiler scale.

Calcium ranges from 1.4 to 40 ppm and magnesium from 0.2 to 15 ppm in 41 ground-water samples from Monmouth County.

Sodium (Na) and potassium (K).—The compounds of these two metals are present in all natural waters and are not harmful to animal life in the concentrations generally found. However, concentrations greater than 50 to 100 ppm may cause foaming in steam boilers when associated with bicarbonate. Irrigation waters that contain high concentrations of sodium salts may cause the soil to become less permeable.

According to 28 samples in which sodium and potassium were determined, sodium ranges from 0.9 to 18 ppm and potassium from 1.0 to 9.0 ppm.

Bicarbonate (HCO_3).—Bicarbonate in moderate concentrations has little effect on the usefulness of water for most purposes. Bicarbonate along with carbonate (CO_3) is sometimes reported as alkalinity and expressed as calcium carbonate $CaCO_3$).

The concentration of bicarbonate in ground water tested in Monmouth County ranges from 0 to 140 ppm; this is not considered excessive.

Sulfate (SO_4).—Water containing more than 250 ppm of sulfate may have a laxative effect when used for drinking. Sulfate in water that contains calcium and magnesium tends to form a hard scale when used in boilers, and may increase the cost of softening the water.

The sulfate concentration in ground water tested in Monmouth County is low—less than 38 ppm—and thus is of no particular consequence.

Chloride (CL).—Chloride is noticeable to the taste at concentrations of about 250 or 300 ppm when present as sodium chloride, although concentrations of 1,000 ppm may be safe for drinking. Chloride tends to accelerate corrosion in pipes, boilers, and other fixtures, and is injurious to crops when present in excessive quantities.

The concentration of chloride in ground water tested in Monmouth County is generally low. The maximum concentration was 164 ppm, and only 8 among 82 samples contained more than 9 ppm.

Fluoride (F).—Fluoride is of interest because of the dental effects it produces (Dean, 1936; Dean and others, 1942). Concentrations in excess of 1.5 ppm may cause permanent mottling of tooth enamel when present in water used for drinking by growing children. When present in concentrations up to about 1 ppm, fluoride has been shown to lessen the incidence of tooth decay in children.

The concentration of fluoride found in ground water tested in Monmouth County is 0.6 ppm or less.

Nitrate (NO_3).—More than several parts per million of nitrate indicates the possibility of organic pollution. Water containing more than about 44 ppm of nitrate may cause infant cyanosis ("blue-baby disease") if used in infant-feeding formulas; the cyanosis is caused by methemoglobinemia (Maxcy, 1950). Many industries cannot tolerate more than a few parts per million of nitrate in process water.

One sample (well D 78) showed 82 ppm of nitrate, but analyses from other wells tested indicate concentrations of less than 1 ppm.

Hydrogen sulfide (H_2S).—Hydrogen sulfide imparts a "rotten egg" odor to water. Because it is a gas, special sampling methods are necessary for analysis, and no tests were made for H_2S; however, it is common in ground water from the Kirkwood Formation in Monmouth County.

Dissolved solids.—The concentration of dissolved solids is an index of the total mineralization of the water. Concentrations up to about 500 ppm are usually considered satisfactory for drinking. Livestock tolerances are higher but extremely variable, ranging from about 3,000 to 15,000 ppm. Few industrial processes will permit more than 1,000 ppm of dissolved solids. In New Jersey, ground waters are low to moderate in dissolved solids. Dissolved solids range from 21 to 437 ppm in the ground waters sampled in Monmouth County; of 41 samples from Monmouth County, 39 contained 160 ppm or less.

Other Determinations

Specific conductance.—Specific conductance is a measure of the ability of water to carry an electric current and thus is a general indication of the content of ionized constituents. The specific conductance multiplied by about 0.6 to 0.7 gives an approximation of the dissolved-solids content in parts per million. Thus, relatively rapid field determinations of specific conductance can be made and converted to a fairly reliable estimate of the dissolved-solids content.

Specific conductance is expressed as reciprocal ohms x 10^6 (micromhos) at 25°C, and ranges from 36 to 360 micromhos in 62 samples of ground water in Monmouth County. This would indicate a range of approximately 25 to 252 ppm of dissolved solids.

Hardness.—The hardness of water is commonly indicated by the amount of soap required to make a lather. Hardness is most commonly expressed in an analysis as calcium carbonate ($CaCO_3$). Calcium and magnesium salts are the principal constituents causing hardness. The tolerance for hardness in most industrial uses ranges from about 50 to 250 ppm, but some allow only a few parts per million. Water can be treated to reduce the hardness, and several effective domestic softening units are on the market.

Water is generally considered soft to 60 ppm, moderately hard between 61 and 120 ppm, and hard above 120 ppm. Of 88 samples tested from Monmouth County, 46 had a hardness of 60 ppm or less and 9 a hardness of between 61 and 120 ppm; the total range was from 4 to 260 ppm.

pH.—The pH of a solution is a measure of the effective hydrogen-ion concentration. Water having a pH of 7.0 is neutral; less than 7.0, acidic; and more than 7.0, alkaline. Water having a low pH may corrode pipes, and that having a pH below 4.0 usually has a sour taste. The minimum pH for boiler-feed waters is 8.0, but a lower pH is suitable for many other industrial uses. The optimum pH for irrigation water depends on the crops to be grown and the physical and chemical properties of the soil.

In Monmouth County, the pH of the ground waters tested ranged from 3.9 to 8.9, with the majority of the values falling between 6 and 8.

Bacterial pollution.—This is not a problem in most ground-water supplies because the water is filtered naturally in its movement through the interstices of the rock. However, filtration may be incomplete in some instances, as in the case of a dug well located very close to a cesspool. The decomposition products of organic matter may also cause serious pollution in any type of aquifer, because these materials are in solution and not removable by filtration. The State Department of Health makes tests for bacterial pollution in all public supplies and has established allowable limits on bacteria content.

Temperature.—Ground water maintains a nearly constant temperature throughout the year and in the first 200 feet below land surface is about equal to the mean annual air temperature. Water that occurs at greater depths usually shows an increase in temperature that corresponds to the increase in earth temperature with depth. The range of ground-water temperatures in the county was 57°-72°F at depths ranging from 150 to 1,100 feet, respectively.

WATER-BEARING PROPERTIES OF THE GEOLOGIC FORMATIONS

The formations underlying Monmouth County contain several water-bearing zones, or aquifers. The aquifers in the Raritan and Magothy Formations and the Englishtown Formation supplied 76 percent of the total 1958 ground-water diversion. Aquifers providing the remaining 24 percent occur in the Wenonah Formation and Mount Laurel Sand, the Red Bank Sand, the Vincentown Formation, and the Kirkwood Formation.

The aquifers are recharged by precipitation on their outcrop areas and in some cases by vertical leakage from adjacent aquifers. Under natural conditions, ground-water discharge occurs along streams that cross the outcrop areas. However, pumping could reverse the natural ground-water gradient to streams and induce water from the streams into the aquifers. At these places, the streams would be sources of recharge to the aquifer.

For the purposes of this report, the outcrop area of each aquifer has been assumed to be the maximum area over which that aquifer could receive recharge from precipitation. Part of the water falling on adjacent formations considered to be aquicludes migrates overland to ultimately recharge the aquifers. Thus, the effective intake areas of the aquifers probably are greater than the aquifer outcrop areas.

In this report, aquifer thickness of any particular formation is represented by the cumulative thickness of what are believed to be the water-bearing zones in that formation. It has been assumed that regionally these different zones are hydraulically connected and act as a single aquifer. Also it has been assumed that the water in the outcrop of each aquifer occurs under water-table conditions.

CRETACEOUS SYSTEM—UPPER CRETACEOUS SERIES

Raritan and Magothy Formations

Geology

The Raritan Formation and Magothy Formation are composed of sand interbedded with clay. The Raritan Formation lies unconformably on an eroded bedrock surface of gneiss and schist of late Precambrian(?) age and is unconformably overlain by the Magothy Formation. The water-bearing sands that constitute the aquifers in these formations range considerably in thickness and areal extent, and individual water-bearing zones cannot be correlated readily. These formations are discussed as a unit in this report because the water-bearing sands in the formations are believed to be regionally interconnected and function as a single aquifer.

The Magothy Formation has an outcrop area of approximately 1.6 square miles in Monmouth County; the Raritan Formation does not crop out in Monmouth County. The formations have an outcrop area of about 154 square miles in Middlesex County to the northwest. The dip is to the southeast at 40 feet per mile for the Magothy Formation, and more than 52 feet per mile for the Raritan Formation. The combined thickness of the Raritan and Magothy Formations increases from 175 feet at their outcrop area to more than 580 feet downdip in the southeastern part of Monmouth County.

The formations have been differentiated in adjacent Middlesex County on faunal and lithologic grounds. The Raritan Formation alone has been subdivided locally into seven members (Barksdale and others, 1943, p. 18) and they are from top to bottom:

Amboy stoneware clay
Old Bridge Sand Member (no. 3 sand of older reports)
South Amboy fire clay
Sayreville Sand Member (no. 2 sand of older reports)
Woodbridge fire clay
Farrington Sand Member (no. 1 sand of older reports)
Raritan fire clay

The members of the Raritan Formation are composed of medium- to coarse-grained quartzose sand or clay, containing varying amounts of lignite and pyrite. The clay is white or variegated; the sand is white to light gray. The Raritan Formation is chiefly nonmarine in origin but marine fossils have been reported in samples from wells downdip.

The Magothy Formation consists in outcrop of alternating beds of dark-gray or black clay and white micaceous fine-grained sand. It lies unconformably on the Raritan Formation. A conspicuous bed of white sand 40 feet thick occurs locally near the top of this formation. An ironstone bed commonly marks the upper limit of the Magothy Formation (Weller, S. J., 1907, p. 31). The presence of marine fossils attests to a marine origin for parts of the Magothy Formation.

Figure 10 shows the outcrop area of the Magothy Formation in Monmouth County, the thickness of the aquifer in the Raritan and Magothy Formations in selected areas, and the configuration of the top of the aquifer.

The average thickness of the aquifer is about 50 feet. In most places, the aquifer is at least 40 feet thick.

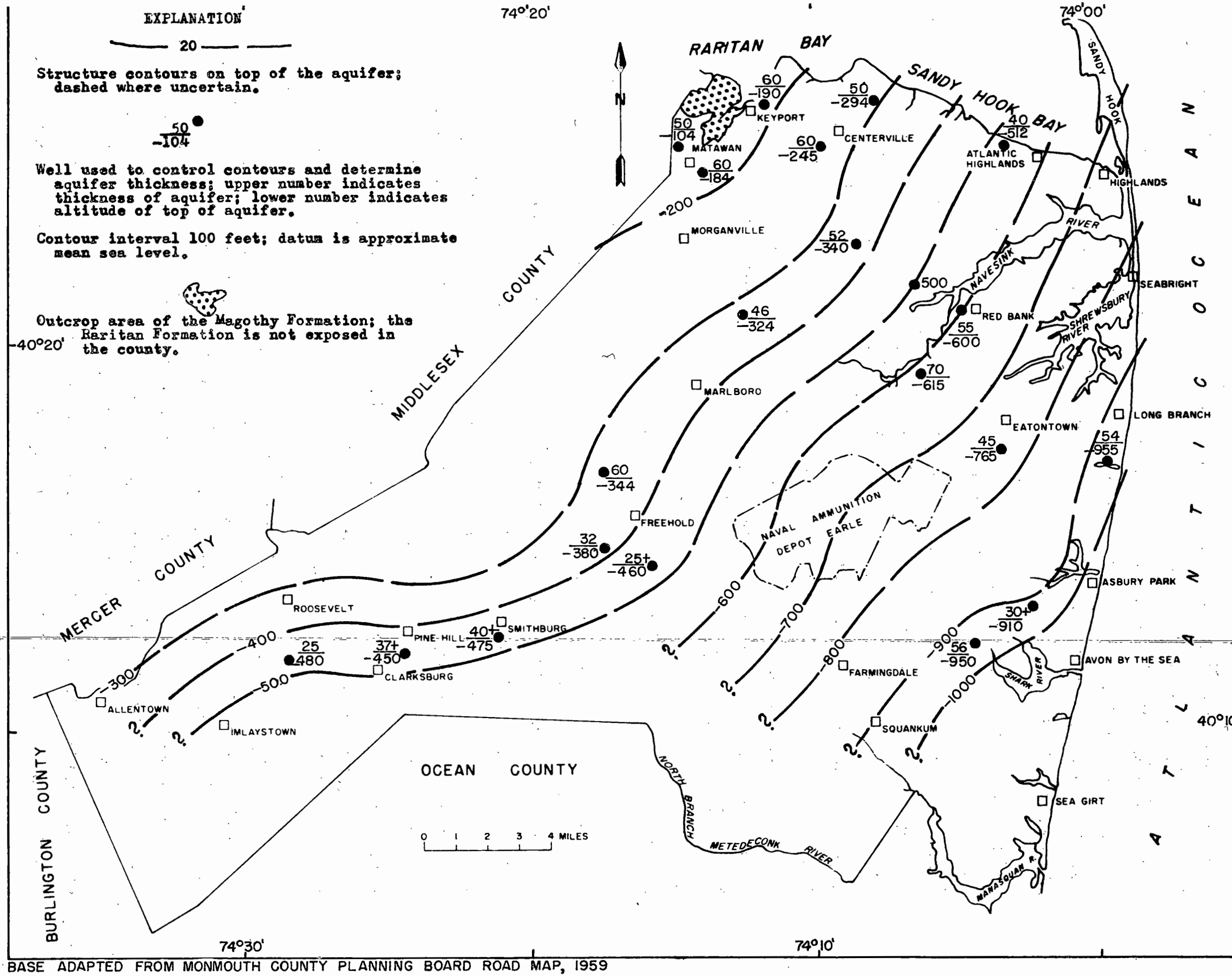


Figure 10.—Structure contours on top of the aquifer in the Raritan and Magothy Formations and thickness of the aquifer.

Hydrology

More water has been pumped from the aquifer in the Raritan and Magothy Formations than from any other aquifer in Monmouth County and in Middlesex County. The total pumpage from the aquifer in the two counties was approximately 90 million gallons per day in 1958. In Monmouth County, the aquifer supplied approximately 12.3 million gallons per day, or 57 percent of all the ground water used in 1958.

Precipitation recharges the sands in the Raritan and Magothy Formations through outcrop areas in Middlesex County and in Monmouth County. The intake area of the principal sand members of the Raritan Formation in Middlesex County (Old Bridge Sand and Farrington Sand Members) as far as were defined by Barksdale and others (1943) is about 42 square miles. In that report, the extent of these sands was not defined in the southwestern part of Middlesex County. The author has estimated that these sands have an additional intake area of about 8 square miles in the southwestern part of Middlesex County. The Magothy Formation has an intake area of about 41 square miles in Middlesex and Monmouth Counties. If the Magothy Formation can be considered to be effectively a sand in the outcrop area, then the sands of the Raritan and Magothy Formations in Middlesex and Monmouth Counties have an intake area of as much as 91 square miles.

Barksdale and others (1958) estimate that the average annual precipitation available for recharge to aquifers of the Raritan and Magothy Formations is about 20 or 21 inches. This is equivalent to about 1 mgd per square mile of intake area. On the basis of this rate of recharge and an intake area of about 91 square miles in Middlesex and Monmouth Counties, it is estimated that 91 mgd is the average available recharge to the intake areas of the aquifer in the Raritan and Magothy Formations in Middlesex and Monmouth Counties.

Figure 11 shows generalized piezometric contours for the aquifer of the Raritan and Magothy Formations for a selected period in 1959 when most of the pumping had been discontinued for a short time. Although very generalized, this illustration does suggest the direction of flow of water in the aquifer. Water moves generally from the northwestern part of the county toward discharge areas in the eastern and northern parts of the county. In the southwestern part of the county water moves generally outward from the area encompassed by the 60-foot contour.

A comparison of figures 11 and 14, which show Piezometric contours for the aquifer of the Raritan and Magothy Formations, and the aquifer of the Englishtown Formation, respectively, for a selected period in 1959,

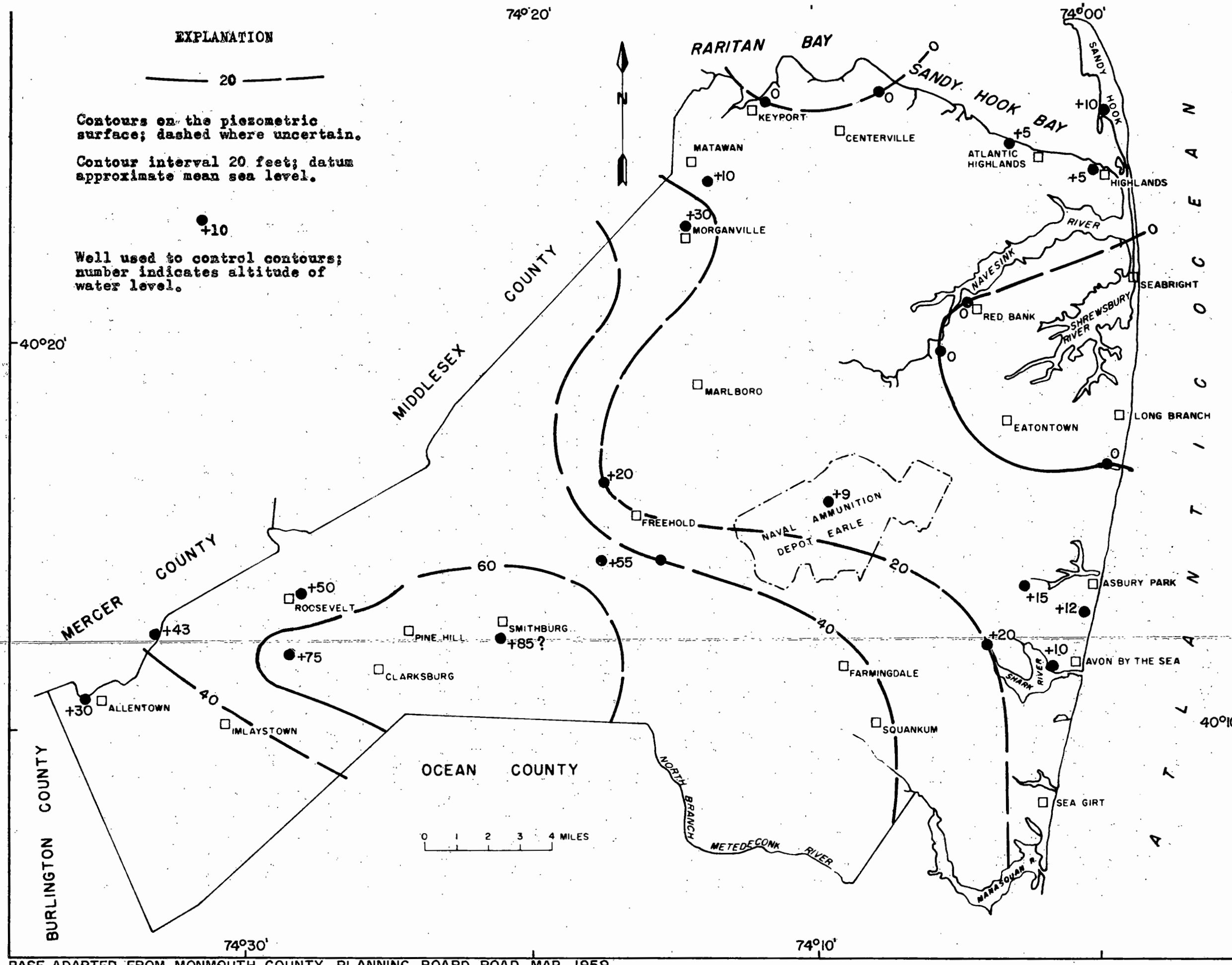


Figure 11.—Contours on the piezometric surface of the Raritan and Magothy Formations for a selected period in 1959.

shows the head differences between these aquifers at that time. The water levels in the Englishtown Formation were higher than those in the Raritan and Magothy Formations everywhere except in the southeastern part of the county. This indicates that water was flowing from the Englishtown Formation downward to the Raritan and Magothy Formations in a large part of the county.

The expected yield of wells tapping the Raritan and Magothy aquifer is higher and more reliable than that from any other aquifer. The yield of wells ranges from a few gallons per minute to 1,400 gpm, and the average yield of 36 large-diameter wells is 700 gpm.

Hydraulic Properties of the Aquifer

Water levels in the Raritan and Magothy Formations indicate that artesian conditions exist throughout Monmouth County. Results of aquifer tests for sands in the Raritan Formation in Middlesex County indicate an average coefficient of transmissibility for the aquifer or about 47,000 gpd per ft, an average coefficient of permeability of 900 gpd per sq ft, and a range of from 2.4×10^{-3} to 3.7×10^{-5} for the coefficient of storage.

Estimates of the coefficient of transmissibility from the specific capacities of 27 wells in Monmouth County indicate an average transmissibility of 46,500 gpd per ft, with a range of from 30,000 to 100,000 gpd per ft; and an average coefficient of permeability of 935 gpd per sq ft, with a range of from 600 to 1,600 gpd per sq ft. The specific capacities of 11 of these wells indicated transmissibilities greater than 50,000 gpd per ft and coefficients of permeability greater than 1,000 gpd per sq ft.

Laboratory tests of samples from the Raritan and Magothy Formations in adjacent Middlesex County were made during an earlier investigation (Barksdale and others, 1943, p. 42). The coefficient of permeability, in the Raritan sands ranged from 210 to 3,500 gpd per sq ft for 18 samples tested. Of the samples tested, 7 showed permeabilities greater than 1,000 gpd per sq ft. The tests also showed porosities to range from 25 to 46 percent of the volume of the sediments and averaged 40 percent. The permeabilities for 5 samples of the Magothy sands were 925, 900, 100, 100, and 60 gpd per sq ft; the average porosity and average specific yield of these samples were 45 percent and 40 percent, respectively.

Chemical Character of the Water

The water from the Raritan and Magothy Formations is generally of excellent chemical quality, except for low pH and high concentrations of iron. The dissolved-solids content is generally less than 110 ppm, ranging from 34 to 117. The hardness is less than 20 ppm in 15 of 21 samples tested, and ranges from 13 to 103. High concentrations of iron are common, and 17 of 21 samples tested contained 6 ppm or more of iron. The range of pH values is from 4.6 to 7.4 and 21 of 28 samples tested showed a pH ranging from 5.6 to 6.6. Chloride concentrations were less than 3 ppm in 24 of 27 samples tested. The concentrations of the remaining chemical constituents would not limit the use of the water for most purposes.

The low concentrations of chloride in the water samples tested indicate no salt-water contamination in the aquifer of the Raritan and Magothy Formations in Monmouth County.

The aquifer contains salt water or high-chloride water in two areas near Monmouth County. One area is updip in Middlesex County and the other is east of Monmouth County where the aquifer underlies the Atlantic Ocean.

As of 1958, high-chloride water had advanced more than two miles into that part of the aquifer in Middlesex County adjacent to the Raritan River and South River, about 6 miles northwest of the Monmouth County boundary (Appel, 1962). The high-chloride water was induced into the aquifer from estuaries that have hydraulic connection with the aquifer.

Future Development

The development of the aquifer in Monmouth County cannot be planned independently of development of the aquifer in other parts of the Coastal Plain. This is because significant geologic and hydrologic boundaries of the aquifer occur outside of Monmouth County. In addition, the aquifer occurs under artesian conditions in more than 90 percent of the Coastal Plain of New Jersey, and practically all of Monmouth County. Hence, the effects of pumpage in one part of the aquifer may extend to distant parts of the aquifer. Optimum utilization of the aquifer cannot be accomplished until an analysis has been made of the overall geologic and hydrologic characteristics of the Raritan and Magothy Formations in New Jersey. However, the available information should be useful as a guide to future development of the aquifer in this county.

An analysis by Barksdale and others (1958, p. 110) suggests that salt water was in the aquifer about 4 to 5 miles to the east of the county prior to large-scale development. The accuracy of this estimate is not known. Salt water may, at present, be a few miles closer to or further from the coastal part of the county. Offshore test drilling would be needed to locate the extent of salt water in the aquifer east of the county. Until the actual extent of salt water in the aquifer is known, future development should proceed with caution. Salt water probably is advancing toward parts of the coast in response to existing development. Increased pumping from the aquifer along the coast would accelerate the advance of salt water more so than would the same magnitude of development further inland. Development in the west-central and southwestern parts of the county would not lower the fresh-water head in the aquifer east of the county as much as would development of the same magnitude in other parts of the county.

Much more information is needed on the permeability of the materials separating this aquifer from the aquifer in the Englishtown Formation before the significance of vertical leakage can be properly evaluated. Available information, although very limited, suggests that leakage between these aquifers over large areas may be significant.

Merchantville Formation and Woodbury Clay

The Merchantville Formation and Woodbury Clay function together as a confining layer, separating the aquifer in the Raritan and Magothy Formations from the overlying aquifers. In Monmouth County, their combined thickness is about 100 feet, with an outcrop area of about 9 square miles.

The Merchantville Formation unconformably overlies the Magothy Formation. It consists of dark-grayish-black micaceous clay and clayey silt and includes beds and lenses of glauconite sand. The formation dips to the southeast at a rate of 42 feet per mile and maintains a uniform thickness of about 50 feet. It grades upward into the Woodbury Clay.

The Woodbury Clay consists of dark grayish-black micaceous clay and is also about 50 feet thick. The basal part of the formation contains small amounts of glauconite; the upper part is usually laminated and may contain glauconite. The Woodbury Clay dips to the southeast at a rate of 41 feet per mile.

Laboratory permeability tests have been made on whole samples of these materials from a U. S. Geological Survey test well near New Brooklyn Park, Camden County. The vertical permeabilities of the samples of the Merchantville Formation are 0.002, 0.003, 0.001, 0.0009 gpd per sq ft. The vertical permeabilities of the samples of the Woodbury Clay are 0.03, 0.02, 0.03, 0.01, 0.002 gpd per sq ft.

Englishtown Formation

Geology

The Englishtown Formation rests conformably on the Woodbury Clay and is in turn conformably overlain by the Marshalltown Formation. It occupies an outcrop area of about 45 square miles in Monmouth and Middlesex Counties.

Northeast to southwest along the outcrop, the formation changes from a sand 150 feet thick to a series of silt or clay and sand layers 50 feet thick. The sand is generally quartzose, white or yellow, fine- to medium-grained, and well sorted. It contains various concentrations of mica, lignite, and glauconite. The clay is black to gray, and slightly sandy or silty. The sands, commonly crossbedded, contain some layers of ironstone.

The Englishtown Formation dips southeastward at an average rate of 39 feet per mile. Downdip, the formation consists of layers of clay, sand, and silt in some places 120 feet thick; the sand is finer grained and commonly fossiliferous, but otherwise similar to the sand in outcrop.

Seaber (1962) estimates the southern limit of the aquifer in the Englishtown Formation to be an imaginary line between a point about 5 miles north of Barnegat Bay Inlet, Ocean County and a point at Salem, Salem County. On this basis, the areal extent of the aquifer would be about 1,900 square miles. South of this imaginary line segment the formation is predominantly silty and clayey.

The Englishtown Formation is partly continental and partly marine in origin, and the variation in thickness and lithology of this formation is due chiefly to the environments in which it was deposited. The presence of three such environments of deposition for the formation in Monmouth County has been suggested (Gill, written communication, 1956): shallow brackish conditions in the area of the present outcrop; shallow back-bay conditions downdip; and bay conditions southeast of the county. Figure 12 shows the outcrop of the Englishtown Formation and, by contours, the subsurface extent or the altitude to which a well must be deepened in order to penetrate the formation in the county. Although the aquifer underlies the entire county, it is so thin in some areas that the opportunity for development is restricted. (See fig. 13.)

Hydrology

The Englishtown Formation has a lower ability to transmit water than the aquifer in the Raritan and Magothy Formations, but it yields sufficient water to be considered an important aquifer. The Englishtown is a relatively poor aquifer in a large part of the adjacent counties. Hence, large withdrawals probably will not be made from it in adjacent counties. In 1958, it supplied 4 million gallons per day, or 20 percent of all the ground water used in Monmouth County.

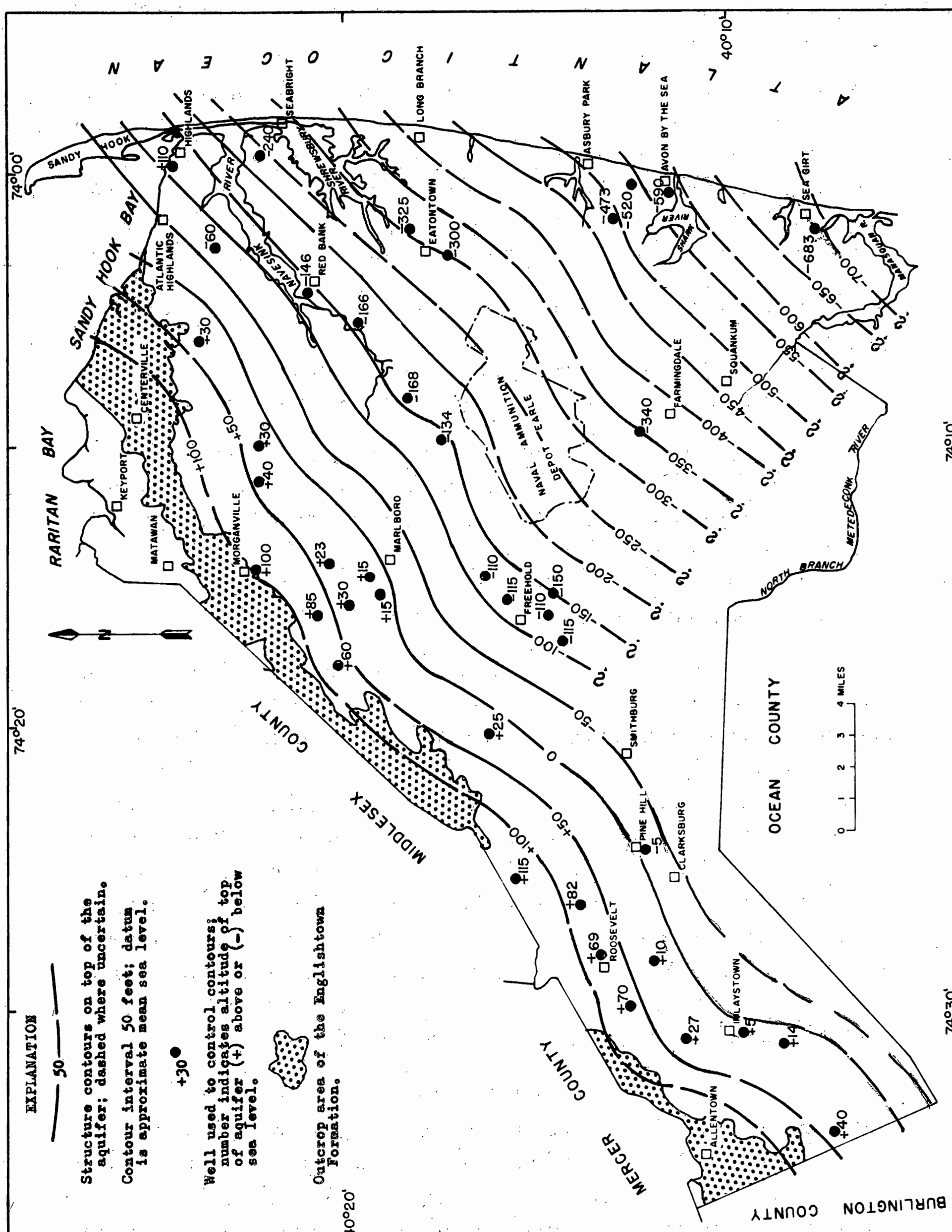
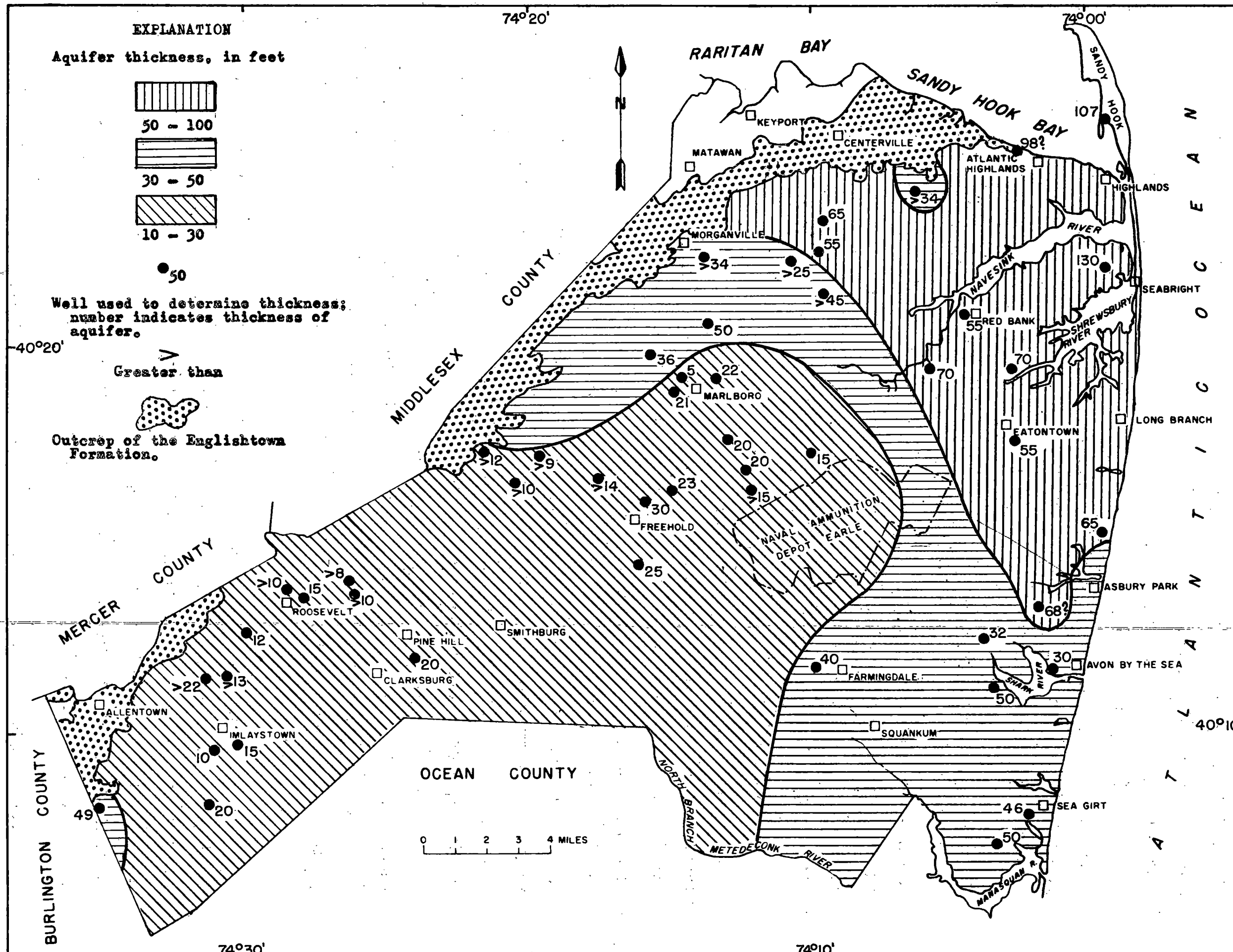


Figure 12.—Structure contours on top of the aquifer in the Englishtown Formation.



BASE ADAPTED FROM MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 13.—Thickness of the aquifer in the Englishtown Formation downdip of the outcrop.

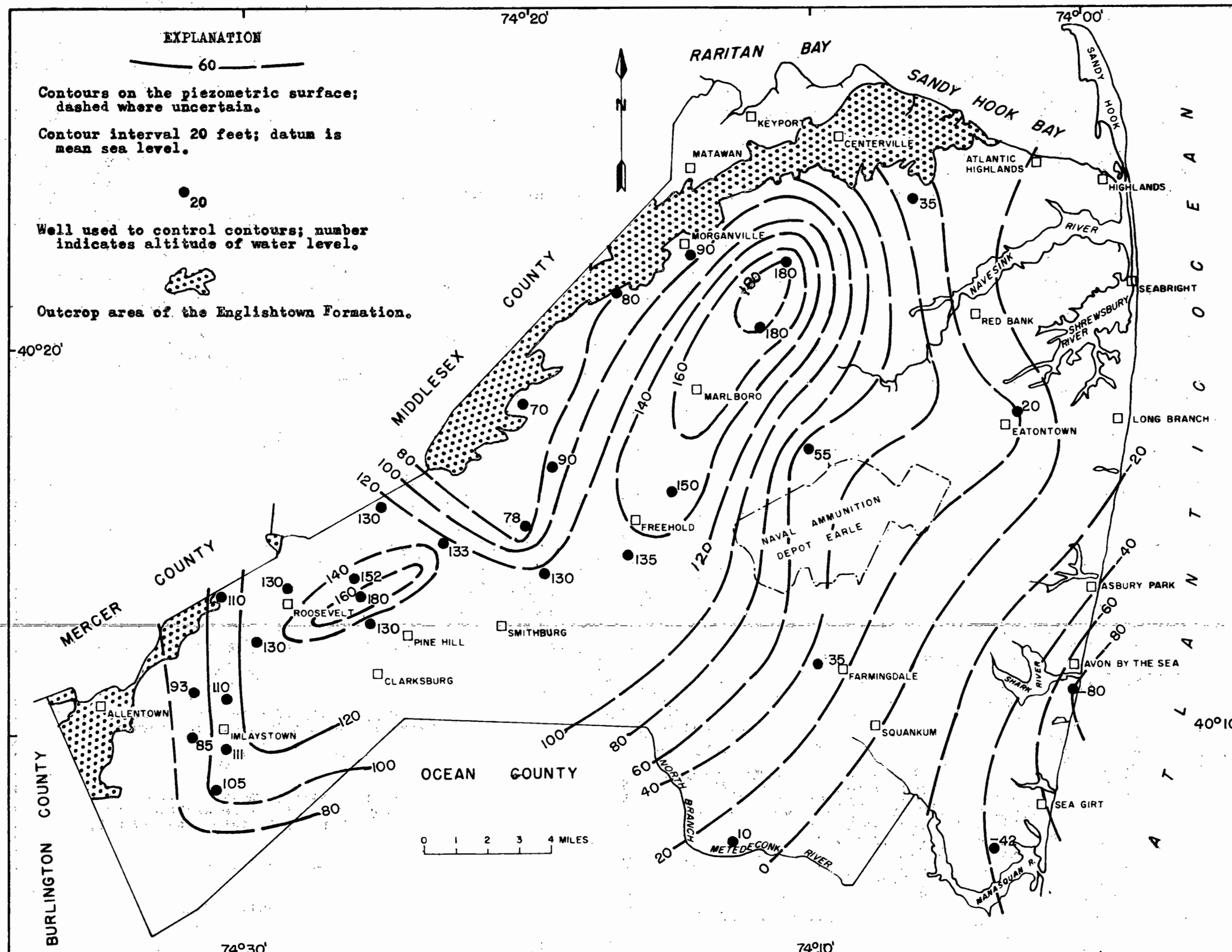
The aquifer is recharged by precipitation in the outcrop area and by vertical leakage from adjacent aquifers. The amount of recharge to the outcrop is not known. Water-level data indicate that in most of the outcrop area the recharge from precipitation is discharged to nearby streams. Ground-water discharge to streams is more than 25 mgd if the part of the recharge that is discharged by the aquifer to nearby streams is equal to the estimated average baseflow discharge from the water table in the Manasquan River Basin.

Figure 14 shows generalized piezometric contours for this aquifer for a selected period in 1959 when most of the pumping had been discontinued for a short time. Although generalized, the piezometric contours suggest the direction of ground-water movement in the aquifer. Water moves from the area encompassed by the 100-foot contour toward the outcrop area and downdip toward the coastal part of the county.

The highest water levels observed in the county were more than 2 miles downdip from the outcrop area. This suggests that the aquifer receives recharge from vertical leakage in the downdip areas where the maximum water levels were observed. For leakage to occur in this area requires the head in at least one of the adjacent formations be higher in that area than the head in the Englishtown Formation. The water levels observed in adjacent aquifers in 1959 did not satisfy this requirement by as much as 40 feet. This apparent contradiction may result from one or more of the following: (1) the water-level measurements in the aquifers were not made simultaneously, but over a period of about one week; (2) the levels in many wells were estimated from airline measurements; and (3) varying degrees of residual effects of pumping. In spite of these limitations, the general features of the nonpumping flow patterns in each of these aquifers is believed to be suggested by the observed water levels.

Because a significant part of the pumpage from the aquifer is from wells along the coast, the general configuration of the piezometric surface suggests that the flow pattern during periods of average pumpage probably is similar to that shown on figure 14. Hence, the source of water to most of the pumping wells downdip in this aquifer must be considered to be from vertical leakage.

A comparison of figures 11, 14, and 21 suggests that during a selected period in 1959: (1) water was flowing from the Englishtown Formation to the Raritan and Magothy Formations except in the eastern part of the county in which the flow was from the Raritan and Magothy Forma-



BASE ADAPTED FROM MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 14.—Contours on the piezometric surface of the Englishtown Formation, January 1959.

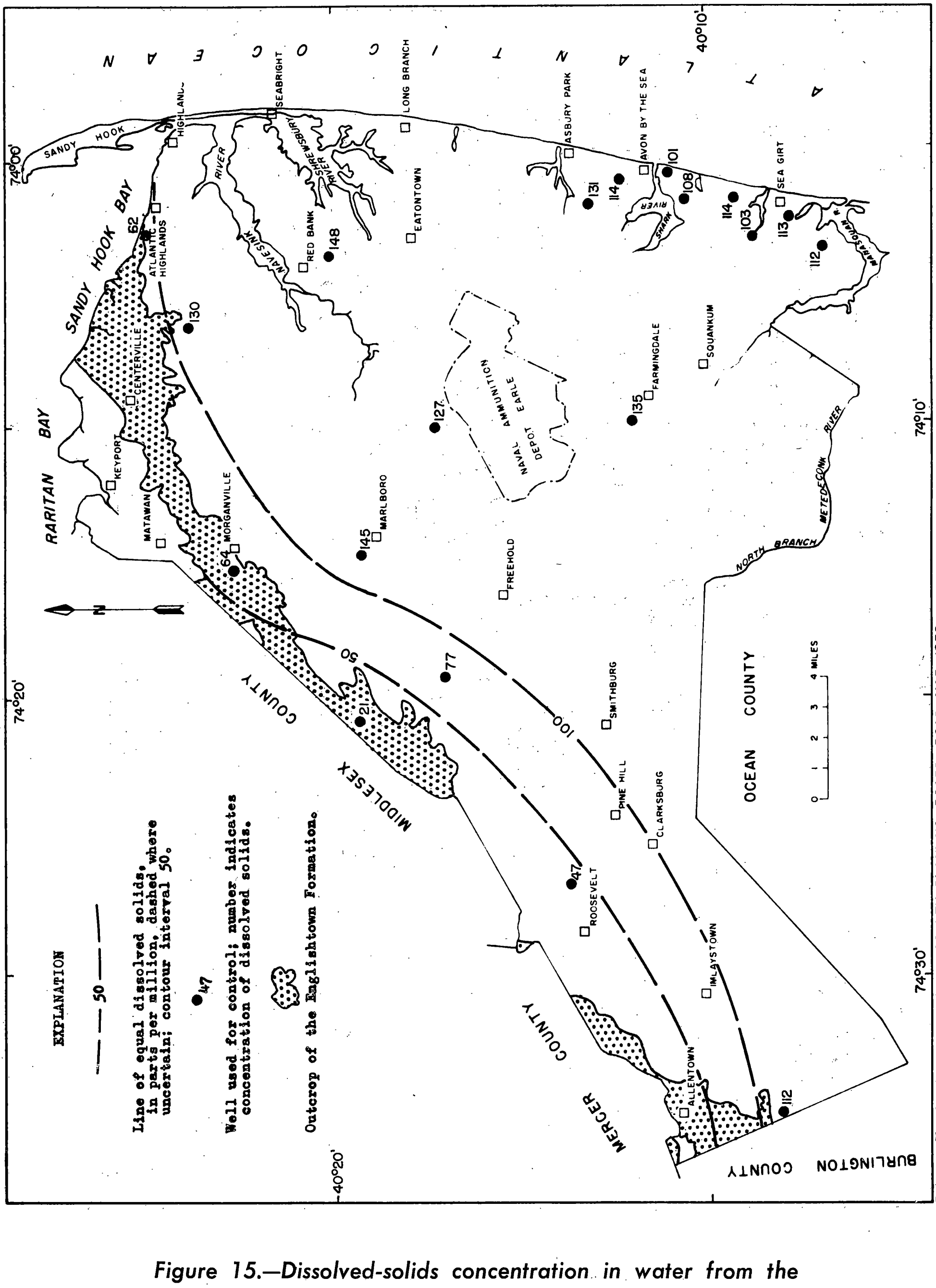


Figure 15.—Dissolved-solids concentration in water from the Englishtown Formation.

tions to the Englishtown Formation, and (2) water was flowing from the Wenonah Formation and Mount Laurel Sand to the Englishtown Formation in the eastern part of the county.

The yield of wells tapping the aquifer ranges from a few gallons per minute to 540 gpm and averages 410 gpm for 20 large-diameter, properly constructed wells.

Hydraulic Properties of the Aquifer

Water levels in the Englishtown Formation indicate that artesian conditions exist, except locally in outcrop.

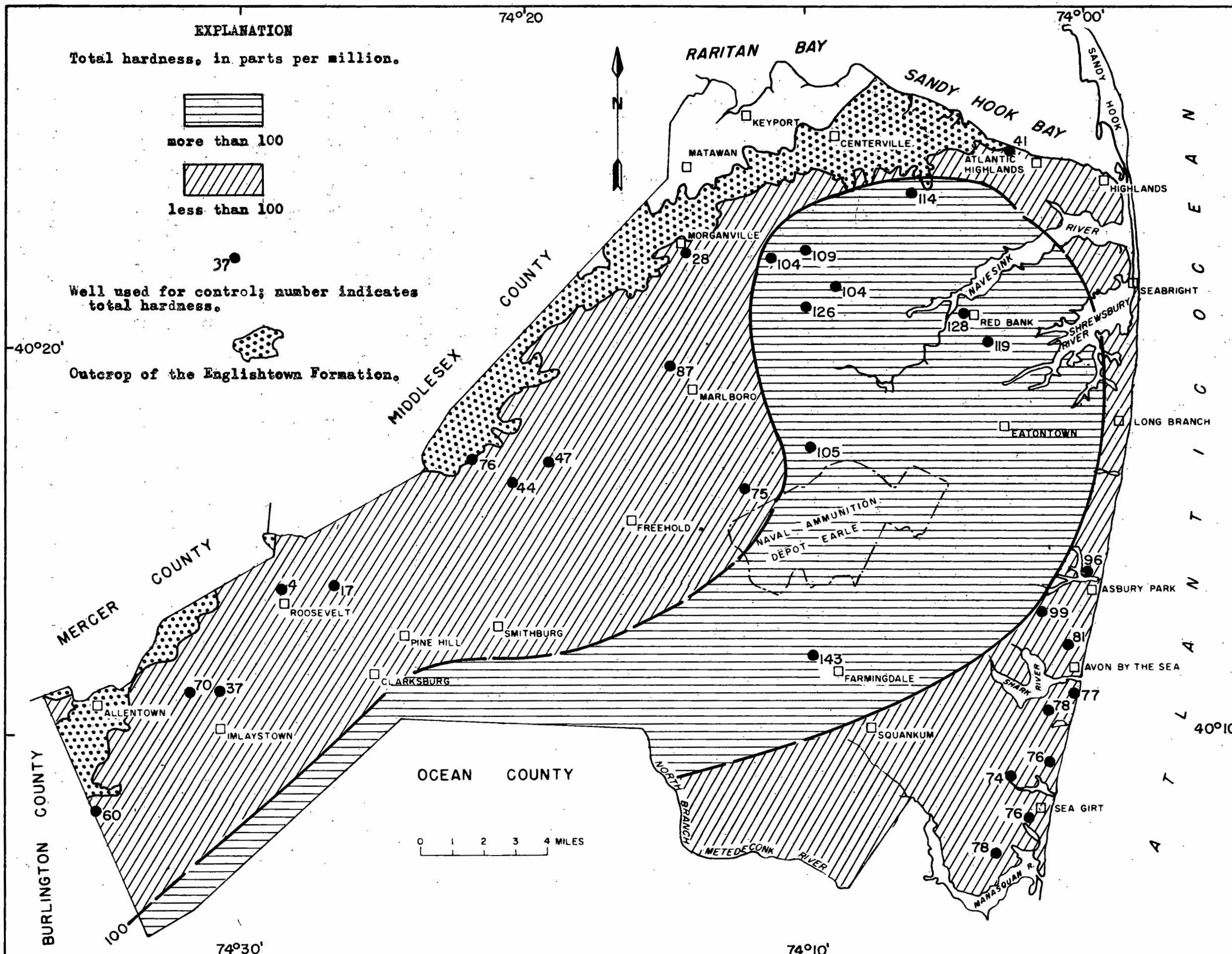
The results of two aquifer tests for the Englishtown Formation indicate a transmissibility of about 10,000 gpd per ft, a coefficient of storage of 1×10^{-4}, and an average coefficient of permeability of 200 gpd per sq ft. These data were obtained in an area where the aquifer consists of fine sand about 50 feet thick. Estimates of the coefficient of transmissibility from the specific capacities of wells show a wide range from 1,000 to 25,000 gpd per ft, and corresponding values for the coefficient of permeability range from 50 to 300 gpd per sq ft. Results of laboratory tests of four samples from the Englishtown Formation in Monmouth County show permeabilities ranging from 340 to 500 gpd per sq ft, averaging 380 gpd per sq ft.

Chemical Character of the Water

The water from the aquifer in Monmouth County is of excellent chemical quality, except for generally excessive iron content. It usually contains less than 160 ppm of dissolved solids, and results of 27 samples analyzed showed a range of from 56 to 160 ppm. Figure 15 shows the concentrations of total dissolved solids in the county. The water is soft, having a total hardness of less than 90 ppm in 31 of 49 samples tested, and a total hardness greater than 120 ppm in only 4 samples. (See fig. 16.)

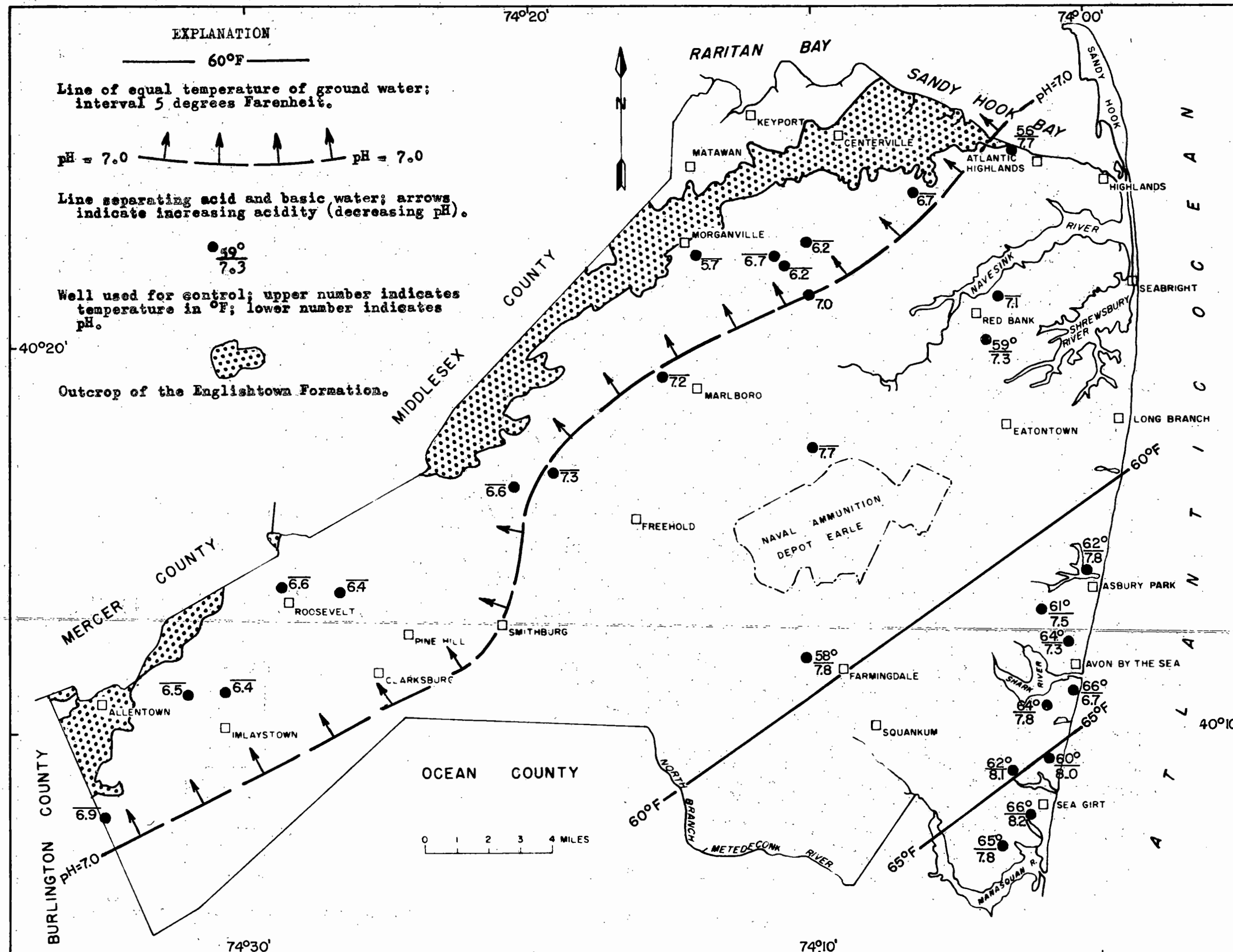
The pH ranges from 7.0 to 8.4 in 39 of 49 samples tested, and 6.2 to 7.0 in 10 samples. The temperature of the water ranges from 57 to 72°F in the county, depending on the depth from which the water is taken. (See fig. 17.)

The concentrations of iron in water from some wells would require treatment for removal. However, minor concentrations occur locally several miles downdip from the outcrop area. The results of analyses of 42 samples tested indicate that 24 samples contained less than 3 ppm of iron but only 2 samples contained less than 0.3 ppm. (See fig. 18.)



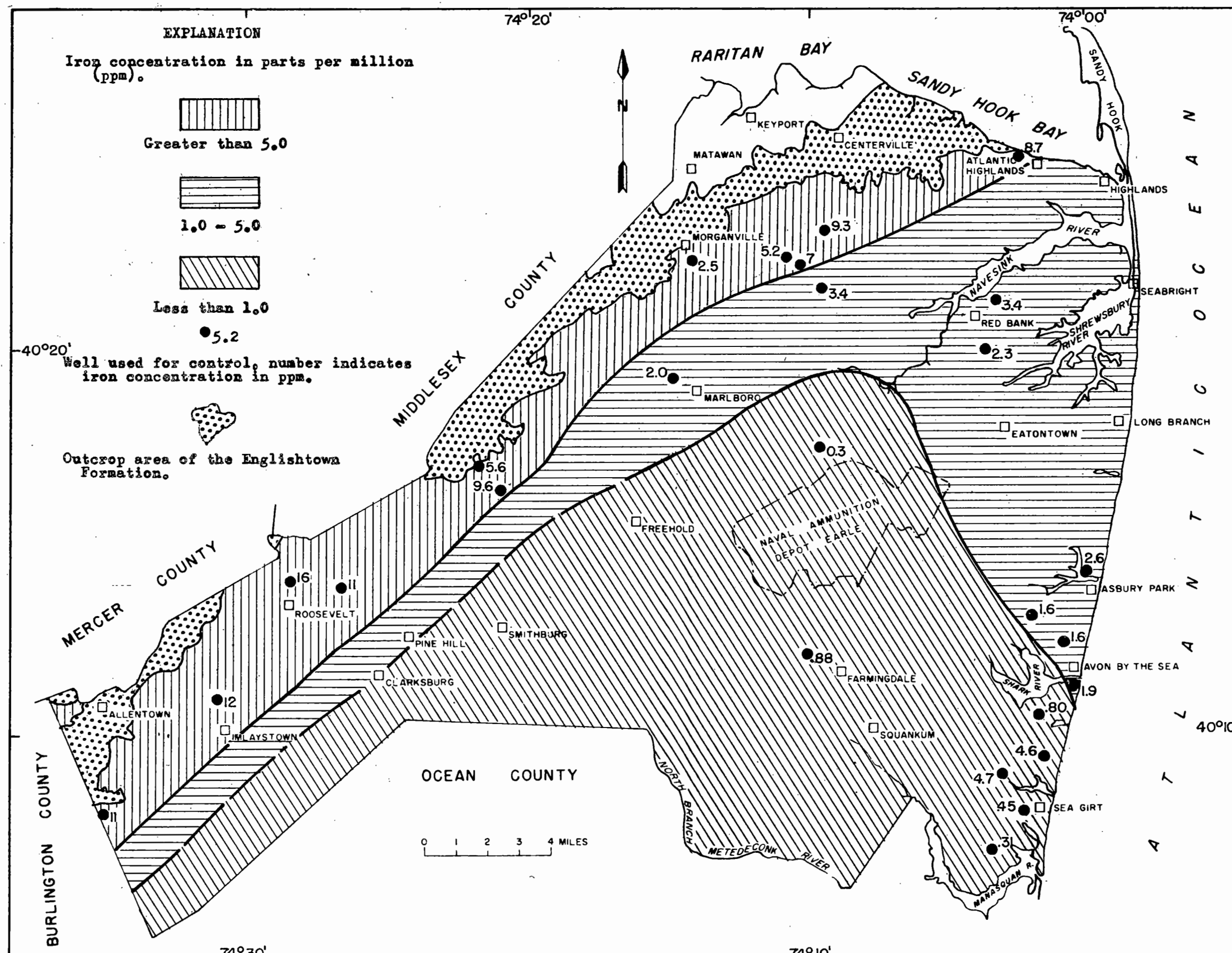
BASE ADAPTED FROM MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 16.—Hardness of water from the Englishtown Formation.



BASE ADAPTED FROM MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 17.—Temperature and pH of water from the Englishtown Formation.



BASE ADAPTED MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 18.—Concentration of iron in water from the Englishtown Formation.

Future Development

The development of the aquifer in the Englishtown Formation in Monmouth County cannot be planned independently of development of the aquifer in other parts of the Coastal Plain—particularly development in neighboring Ocean and Burlington Counties.

As of 1964, there is no indication of salt water or high-chloride water in the aquifer in Monmouth County. However, it is not known if the aquifer is in hydraulic connection with salt water in Sandy Hook Bay or in the Atlantic Ocean. If such connection does exist, salt water may be advancing in the seaward extension of the aquifer toward the coast of Monmouth County.

The available water-level data indicate that, as of 1959, the highest water levels occur several miles downdip from the outcrop area in the county. (See fig. 14.) Development in the area of highest water levels and between this area and the outcrop area would not be threatened with salt-water encroachment problems. This is because the altitude of the bottom of the aquifer is above sea level in most of the county. A large part of the water that is recharged to the aquifer in the outcrop area is discharged to nearby streams. In addition, some of the water that enters the aquifer as vertical leakage in areas downdip from the outcrop flows updip to the outcrop. Thus, development in and near the outcrop could intercept much of the water that presently is being discharged from the aquifer. If the outcrop of the Englishtown Formation can be considered to be effectively the intake area of the aquifer, then it is estimated that the long-term average discharge of the aquifer to nearby streams is at least 25 mgd.

According to Seaber (1962) the thickness of the aquifer decreases to the southeast. Thus, the transmissibility of the aquifer probably is reduced. The effect of this reduction in transmissibility is that the decline in water levels caused by pumping in downdip areas generally will be greater than those resulting from the same intensity of pumping at a place further updip. Water-level data show that water withdrawn by wells along the coast in Monmouth County and in the northeastern part of Ocean County is replenished by vertical leakage from underlying and overlying aquifers. Increased withdrawals from these adjacent aquifers in the areas where leakage occurs would lower the levels in the Englishtown Formation. Much more needs to be known about vertical leakage between these aquifers before the results of withdrawals can be reliably predicted.

Marshalltown Formation

The Marshalltown Formation occupies an outcrop area of 22 square miles in Monmouth County. (See fig. 5.) It conformably overlies the Englishtown Formation and dips southeastward at a rate of 37 feet per mile. It has a relatively uniform thickness of about 30 feet.

Owens and Minard (1960, p. 20) report that no single lithologic description fits the Marshalltown Formation because of its wide textural variation. Generally, it is a dark grayish-black, micaceous, glauconitic, quartzitic sandy clay to very clayey sand.

Being primarily clayey, the Marshalltown Formation acts as an aquiclude or confining layer between the Englishtown Formation and overlying formations. Also, locally, the formation serves in conjunction with part of the overlying Wenonah Formation as an aquiclude. The total thickness of this aquiclude complex ranges from 30 to 80 feet.

Analyses of two outcrop samples of the Marshalltown Formation showed permeabilities of 0.4 and 1.0 gpd per sq ft. Particle-size determinations indicate the samples were silt and fine sand, respectively. Laboratory permeability tests have been made on two disturbed samples of this formation from a U. S. Geological Survey test well near New Brooklyn, Camden County. The permeabilities of these samples are 0.01 and 0.001 gpd per ft.

Wenonah Formation and Mount Laurel Sand

Geology

The Wenonah Formation and Mount Laurel Sand, although distinct formations (Owens and Minard, 1960, p. 21), are considered as one unit in this report because they are hydraulically connected and function as a single aquifer.

The Wenonah Formation consists of dark gray, micaceous, quartz silt and fine-grained sand, locally, interbedded with clay lenses. The overlying Mount Laurel Sand is generally a greenish-gray, glauconitic, clayey quartz sand.

Minard and Owens (1962) described the Wenonah Formation and Mount Laurel Sand in the New Egypt quadrangle as follows:

> Wenonah Formation: "Typically it is a dark gray (when damp), sparingly glauconitic, somewhat clayey, lignitic, very micaceous silt to fine-grained, subangular, quartz sand. The quartz silt and sand are light gray; the mica is mostly colorless muscovite, but an abundance of green chloritized mica, best seen in a washed sample, is a diagnostic feature."

Mount Laurel Sand: "Most of the unweathered Mount Laurel sand is greenish-gray, clayey, glauconitic (5 to 15 percent), medium- to coarse-grained, subangular to subrounded quartz sand, containing some small quartz pebbles and granules and a trace of muscovite. Nearly equal proportions of glauconite sand and quartz sand are present in the upper feet of the formation.

Glauconite is dark green, medium- to coarse-grained, rounded, and somewhat concentrated in pods; quartz is smokey to clear (except where stained by iron oxide), medium- to very coarse-grained, and subangular to subrounded. Some small quartz pebbles (1/8 to 1/4 inch) are also present. Apatite, in the form of round dark brown pellets, is a diagnostic mineral."

Figure 19 shows the distribution of thickness of the aquifer in the Wenonah Formation and Mount Laurel Sand. The average thickness of the aquifer downdip from the outcrop is about 40 feet. In most places, the aquifer is between 30 to 50 feet thick.

Figure 20 shows the configuration of the top of the aquifer of the Wenonah Formation and Mount Laurel Sand. The contacts of these formations are conformable, and they dip to the southeast at 35 feet per mile. Their combined thickness ranges from 15 to 85 feet near the outcrop. The formations maintain a fairly uniform thickness of 75 feet downdip.

Hydrology

The aquifer in the Wenonah Formation and Mount Laurel Sand generally has a relatively low capacity for transmitting water, but the uniform thickness and lithology, and good quality of water make it an important aquifer. Ground water was pumped at an average rate of about 0.65 mgd from this aquifer during 1958. This pumpage represents about 3 percent of the total ground-water withdrawals in Monmouth County for 1958.

Water-level measurements made for a selected period in 1959 when most of the pumping had been discontinued for a short period (fig. 21) suggest that the precipitation that recharged the aquifer in the outcrop south of a point about 5 miles southwest of Morganville in Monmouth County does not flow downdip in the aquifer. In this area, the hydraulic gradient was toward, rather than away from, the outcrop. The precipitation that recharged the aquifer in the outcrop in the remaining northern parts of the county flowed eastward. Because of the relatively low rate of pumpage from this aquifer, water-level contours shown in figure 20 reasonably suggest general conditions in the aquifer for 1959.

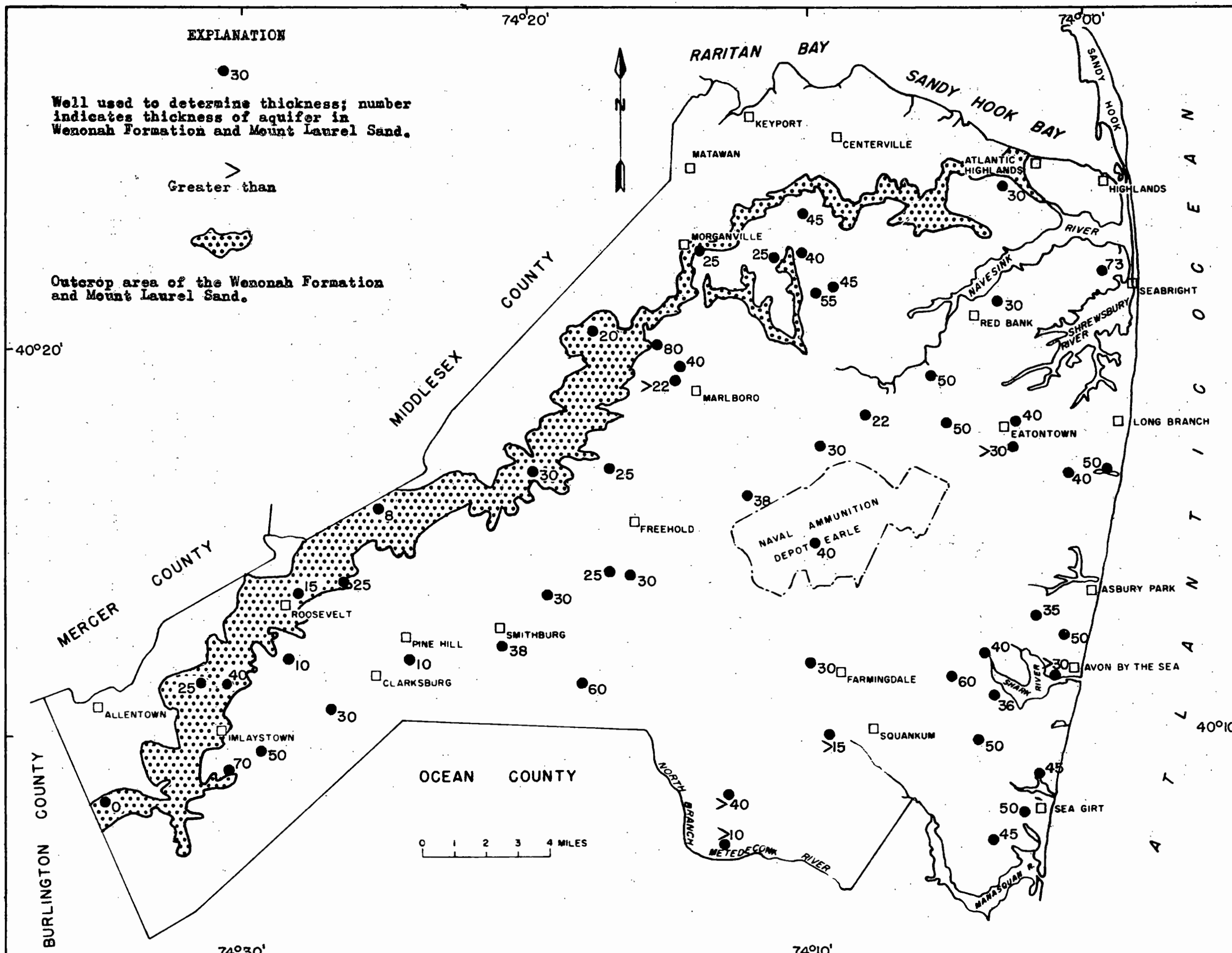
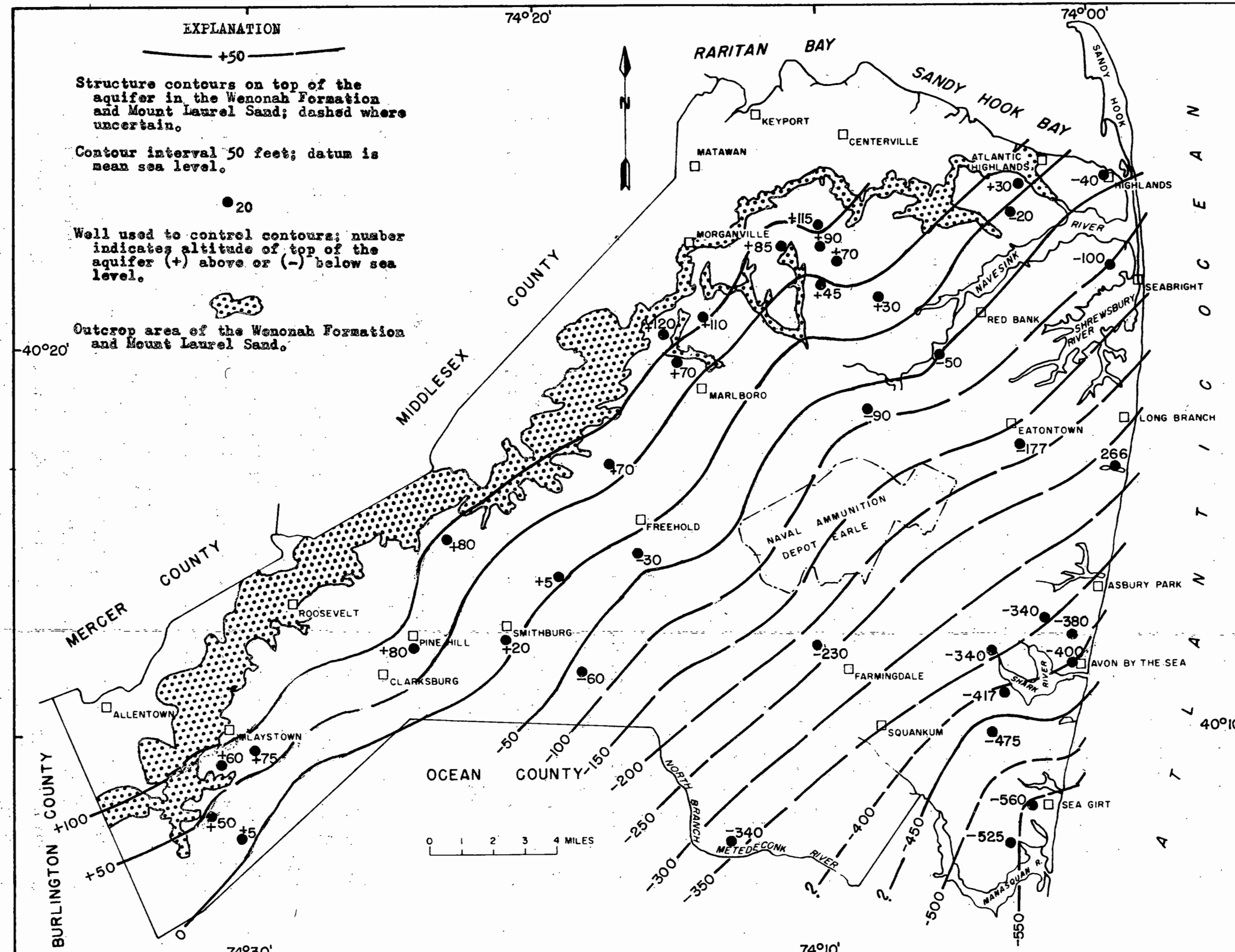


Figure 19.—Thickness of the aquifer in the Wenonah Formation and Mount Laurel Sand.



BASE ADAPTED FROM MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 20.—Structure contours on top of the aquifer in the Wenonah Formation and Mount Laurel Sand.

The highest water levels observed in the county were downdip from the outcrop area between Clarksburg and Roosevelt. This indicates that the aquifer receives recharge from vertical leakage downdip from the outcrop. This high-water-level area coincides with a topographically high area.

The yields of two large-diameter wells tapping this aquifer were 250 and 325 gpm.

Hydraulic Properties of the Aquifer

The aquifer in the Wenonah Formation and Mount Laurel Sand is artesian in Monmouth County, except in the outcrop area.

The results of an aquifer test at Bradley Beach indicate an average coefficient of transmissibility of 5,000 gpd per ft, with a range of from 2,700 to 10,700. The coefficient of storage is about 1.2×10^{-4}, with a range from 7.0×10^{-5} to 2.1×10^{-4}. Because the average thickness of the aquifer in this area is about 40 feet, it is estimated that the average coefficient of permeability is about 130 gpd per sq ft.

Estimates of the coefficient of transmissibility determined from specific capacities of a well near Shrewsbury and a well about 4 miles west of Bradley Beach indicated values of about 5,000 gpd per ft and 3,500 gpd per ft, respectively.

Results of laboratory tests of two samples from a well at Asbury Park (Thompson, 1930, p. 37) showed permeabilities of 566 and 877 gpd per sq ft, and porosities of 34 and 30 percent, respectively.

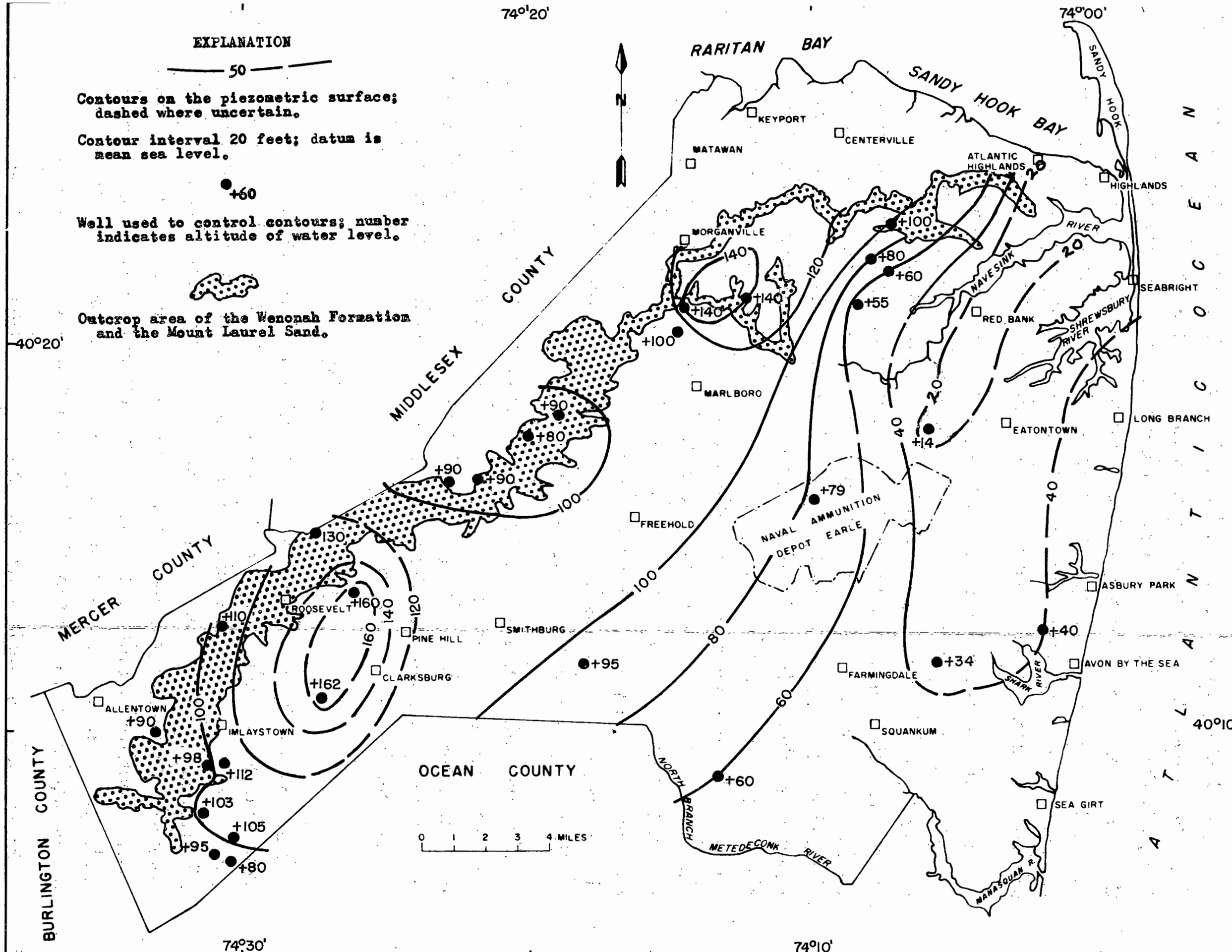
Chemical Character of the Water

The water from the Wenonah Formation and Mount Laurel Sand is moderately hard, has low dissolved mineral content, and is generally of excellent quality. Six analyses of dissolved solids ranged from 112 to 145 ppm. The hardness ranged from 56 to 110 ppm in 8 samples tested and was greater than 100 ppm in 5 of the samples. The pH ranged from 6.5 to 8.1 in seven samples tested. The iron content was less than 0.3 ppm in 8 out of 9 samples tested; one sample showed 10 ppm of iron.

Future Development

The development of the aquifer in the Wenonah Formation and Mount Laurel Sand in Monmouth County cannot be planned independently of development of the aquifer in other parts of the Coastal Plain—particularly development in the neighboring counties of Ocean and Burlington.

As of 1964, there is no indication of high chloride water in the aquifer of the Wenonah Formation and Mount Laurel Sand in Monmouth



BASE ADAPTED FROM MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 21.—Contours on the piezometric surface of the Wenonah Formation and Mount Laurel Sand, January 1959.

County. The aquifer may be in hydraulic connection with salt water in Sandy Hook Bay or in the Atlantic Ocean. Water-level data suggest that the Navesink River may be an area of discharge for the aquifer. If this is the case, there is hydraulic connection between the aquifer and the Navesink River. Hence, if the gradients near the Navesink River should be reversed by pumping, salt water would enter the aquifer. In parts of the county where the base of the aquifer is above sea level, no salt-water encroachment problems occur. (See figs. 19 and 20.)

The available water-level data suggest that in about the southern two-thirds of the county none of the water that is recharged to the aquifer by direct precipitation flows downdip. It is estimated that in more than 30 square miles of the outcrop, the recharge from precipitation to the aquifer does not flow downdip. If the part of this recharge that is discharged by the aquifer to nearby streams is equal to the estimated average baseflow discharge from the water table in the Manasquan River basin, about 16 mgd is discharged by the aquifer in the outcrop to nearby streams. Development in and within about 5 miles of the outcrop in this area could intercept much of this water that presently is being discharged from the aquifer in the outcrop. Development in the northern part of the county probably could intercept as much as 5 mgd of water that presently is being discharged by the aquifer in the outcrop and that is discharged by the aquifer to the Navesink River.

The hydraulic characteristics of this aquifer in and near the outcrop are not known in most of the county. This information is needed to determine the number and optimum distribution of wells needed to intercept any given amount of the water that presently is discharged from the aquifer in the outcrop area.

Navesink Formation

The Navesink Formation is a dark grayish-black clayey glauconitic sand and conformably overlies the Mount Laurel Sand. It occupies an outcrop area of 32 square miles, consists of a fairly uniform thickness of 25 feet, and dips to the southeast at 35 feet per mile. A shell zone commonly occurs at the base of this formation and forms a very good marker horizon. This shell zone is in hydraulic continuity with the underlying Mount Laurel Sand, and locally may be considered as part of the aquifer in the Wenonah Formation and Mount Laurel Sand.

Except for the shell zone, the Navesink Formation, in conjunction with the basal clay member of the overlying Red Bank Sand, forms a confining layer between the Mount Laurel Sand and the overlying formations.

A few domestic wells tap the shell zone and yield up to 15 gpm of water of excellent quality.

Red Bank Sand

Geology

The Red Bank Sand in outcrop contains two distinct members, an upper sand member and a lower clayey sand member (Owens and Minard, 1960, p. 22). The upper sand member functions as an aquifer; however, it thins in the subsurface progressively southeastward and is absent more than 4 to 6 miles from the outcrop.

The formation occupies an outcrop area of 95 square miles, strikes N 45°E, and dips to the southeast at 35 feet per mile. It lies conformably on the Navesink Formation and is unconformably overlain by the Hornerstown Sand. The Red Bank Sand ranges from 30 to 140 feet in thickness. The progressive thinning toward the southwest and southeast is due to erosion of the Red Bank Sand prior to deposition of the Hornerstown Sand. This unconformity is indicated by the difference in strike and dip between the Red Bank and the Hornerstown. (See table 2.) This structural difference also accounts for the complete removal of the sand member or aquifer of the Red Bank Sand downdip. (See fig. 22.)

The upper member of the Red Bank Sand consists of slightly clayey, medium- to coarse-grained quartz sand, and contains minor amounts of mica and glauconite. This member ranges in thickness from 0 to 70 feet, and the color varies from reddish-brown (where weathered) to gray. The lower member is composed of dark gray to black, medium- to fine-grained, very micaceous, clayey, glauconite sand, 20 to 70 feet thick. Fossils from the lower member indicate that the Red Bank Sand was deposited in a marine environment. The Red Bank Sand is considered to include the Tinton Sand, if the latter formation is present. The Tinton Sand consists of clayey, glauconitic, indurated sand, 10 to 20 feet thick.

Hydrology

The aquifer in the Red Bank Sand supplies many domestic wells with water, but the total withdrawal is relatively small. The upper sand member is exposed over a large part of the outcrop area and probably receives considerable recharge from precipitation. Most of this recharge probably is discharged as baseflow to nearby streams and as leakage to underlying formations when head differentials exist.

The yields of wells drilled in the upper sand member of this formation range from 2 to 25 gpm. Because of the indurated and locally clayey nature of the aquifer, many wells are finished as open holes and only short lengths of surface casing are required.

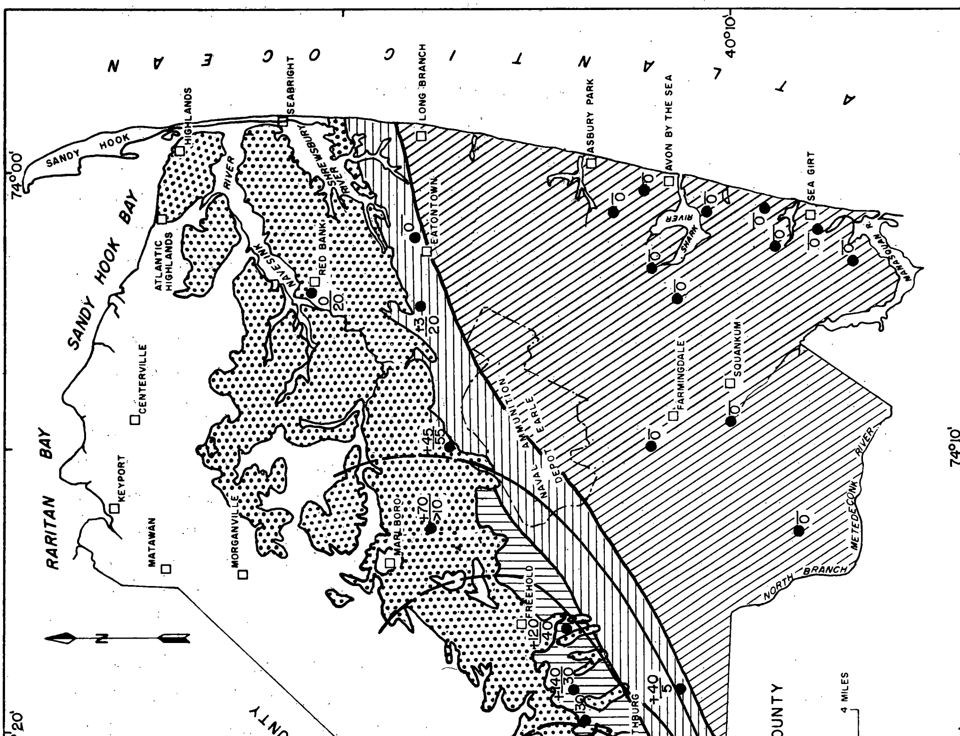


Figure 22.—Structure contours on top of the aquifer of the Red Bank Sand and thickness of the aquifer.

Some well owners report that the water is acidic and requires treatment for the removal of iron.

Future Development

The occurrence of the aquifer in the Red Bank Sand is essentially limited to Monmouth County.

Very little is known regarding the hydraulic characteristics of the aquifer and the direction of ground-water flow in the aquifer. As of 1964, there is no indication of salt water or high-chloride water in the aquifer. The aquifer may be in hydraulic connection with salt water in the Navesink River, the Shrewsbury River, Sandy Hook Bay, and the Atlantic Ocean. Development in the aquifer near these potential sources of salt water should proceed with caution.

The formation is tapped by wells in more than 80 square miles of its outcrop area. Hence, a considerable volume of water from precipitation probably is recharged to the aquifer in its outcrop. If the part of this recharge that is discharged by the aquifer to nearby streams is equal to the estimated average baseflow from the water table in the Manasquan River Basin, then about 44 mgd is discharged by the aquifer to streams. However, because the aquifer is relatively thin, low values of transmissibility may be assumed. Furthermore, the areal extent of the aquifer is quite limited. Consequently, it is probably not possible or practical to develop large-yield wells in this aquifer. Hence, to intercept a large part of the water that otherwise would be discharged to streamflow or leak downward to underlying aquifers would require a large number of wells. Much more information is needed on the hydraulic characteristics of this sand in order to determine the effectiveness of such development.

TERTIARY SYSTEM—PALEOCENE SERIES

Hornerstown Sand

The total area of outcrop of the Hornerstown Sand in Monmouth County is about 35 square miles. It consists chiefly of a dark-green clayey glauconite sand.

The Hornerstown Sand unconformably overlies the Red Bank Sand and dips to the southeast at 50 to 60 feet per mile (Owens and Minard, 1960, p. 9). It is about 25 feet thick and increases to about 100 feet toward the southeast.

Being mostly clayey, this formation probably serves as an aquiclude either independently or in conjunction with adjacent formations. It serves as an aquiclude independently where the sand member of the Red Bank

Sand is present, separating this aquifer from the overlying Vincentown Formation. Downdip, where the aquifer in the Red Bank Sand has been removed, the Hornerstown Sand serves as a composite aquiclude with the Navesink Formation and the lower member of the Red Bank Sand, separating the Mount Laurel Sand from the Vincentown or Kirkwood aquifers. Although considered an aquiclude in this discussion, the Hornerstown Sand may yield enough water in some parts of the outcrop to satisfy domestic needs.

Vincentown Formation

Geology

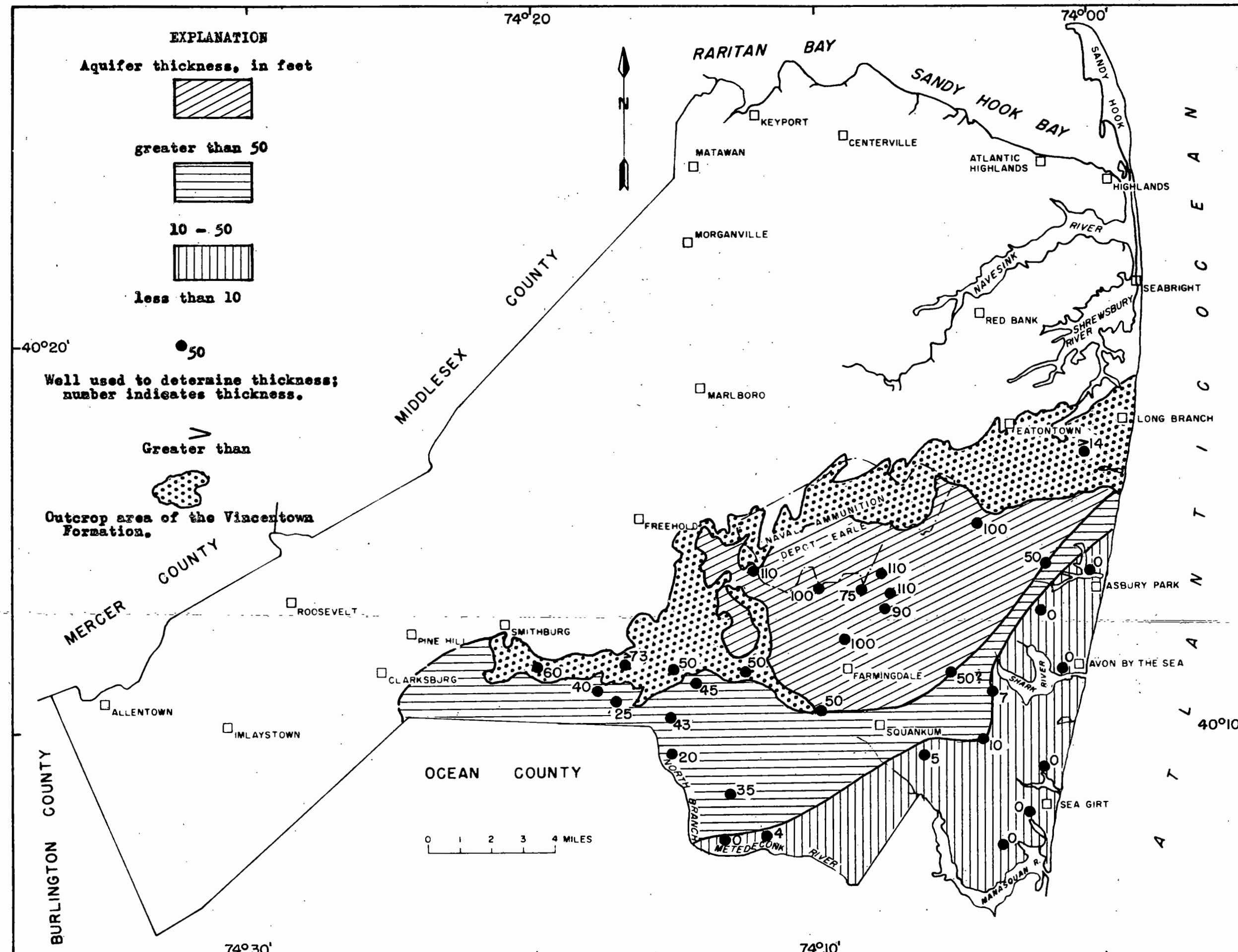
The Vincentown Formation occupies an outcrop area of 30 square miles in Monmouth County. (See fig. 23.) However, the outcrop is not continuous in the county, as it has been overlain in places by the Kirkwood Formation. The Vincentown Formation contains two members (Owens and Minard, 1960, p. 24). The upper member ranges from a fine- to medium-grained quartz sand to a sandy, clayey, limestone approaching a coquina in character. The sand in this member is micaceous, clayey, glauconitic, calcareous, and fossiliferous. The lower member is a greenish-gray, micaceous, clayey, glauconitic, fine- to medium-grained sand. The Vincentown rests unconformably on the Hornerstown Sand, ranges from several feet to 130 feet in thickness, strikes N 55°E, and dips to the southeast at 27 feet per mile.

Hydrology

Less than 1 percent of the ground water used in 1958 in Monmouth County was withdrawn from the aquifer in the Vincentown Formation. Development of the aquifer is limited by its areal extent; moreover, it decreases in thickness toward the southeast—from 100 feet near the outcrop to a few feet 15 miles downdip. (See fig. 23.) The curve delineating the part of the aquifer that is less than 10 feet thick can be considered the downdip usable limit of the aquifer. Southeast of this limit, the aquifer is quite thin, discontinuous, and yields only a few gallons per minute to individual wells.

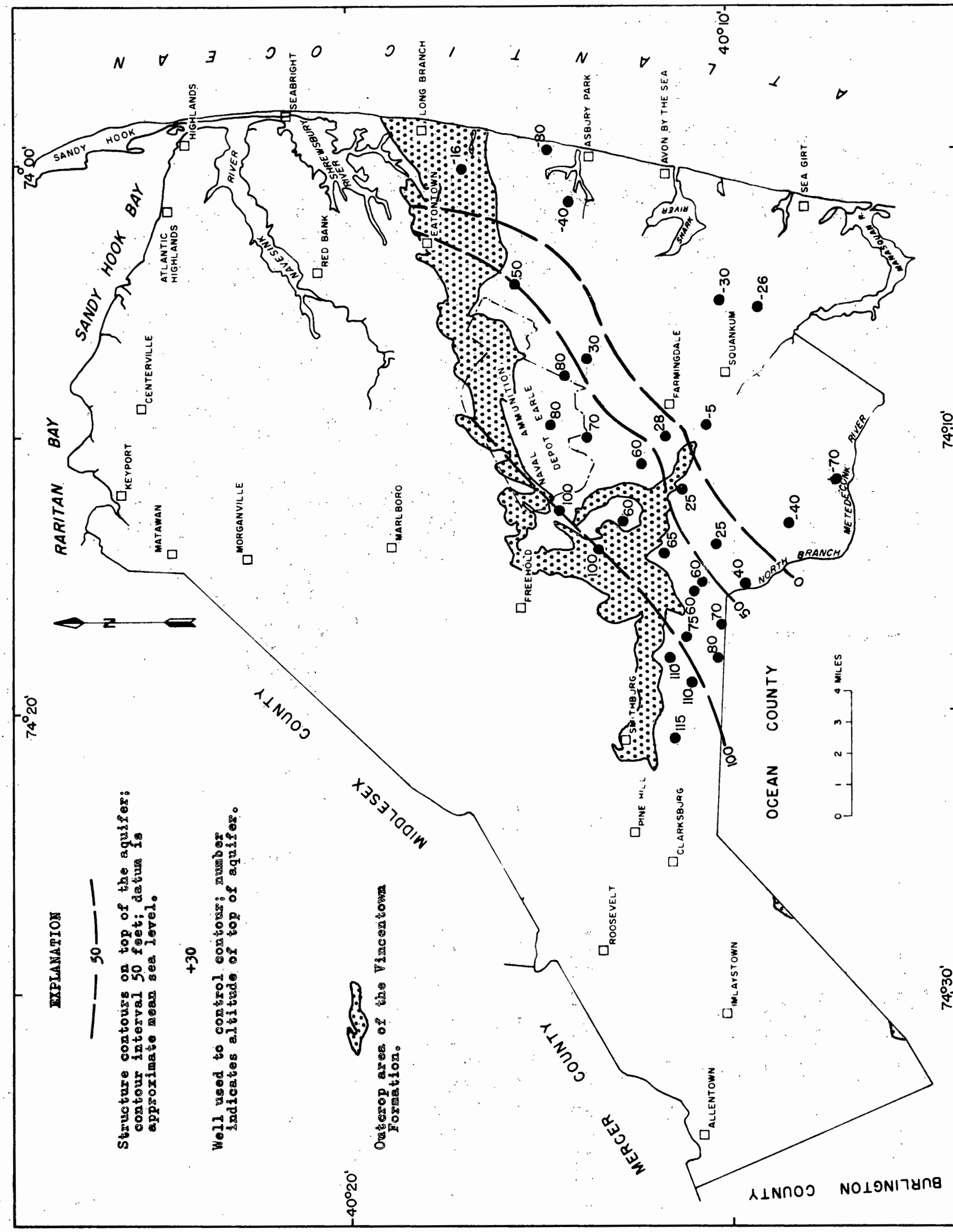
The configuration of the top of the aquifer is shown on figure 24.

The aquifer receives recharge from precipitation in its outcrop and may also receive recharge by vertical leakage from the overlying Kirkwood Formation in which ground water occurs at a higher head than in the Vincentown. Water-level measurements made in 1959 suggest that east of Freehold the general direction of movement of water in this aquifer was from the outcrop toward the coast. (See fig. 25.)



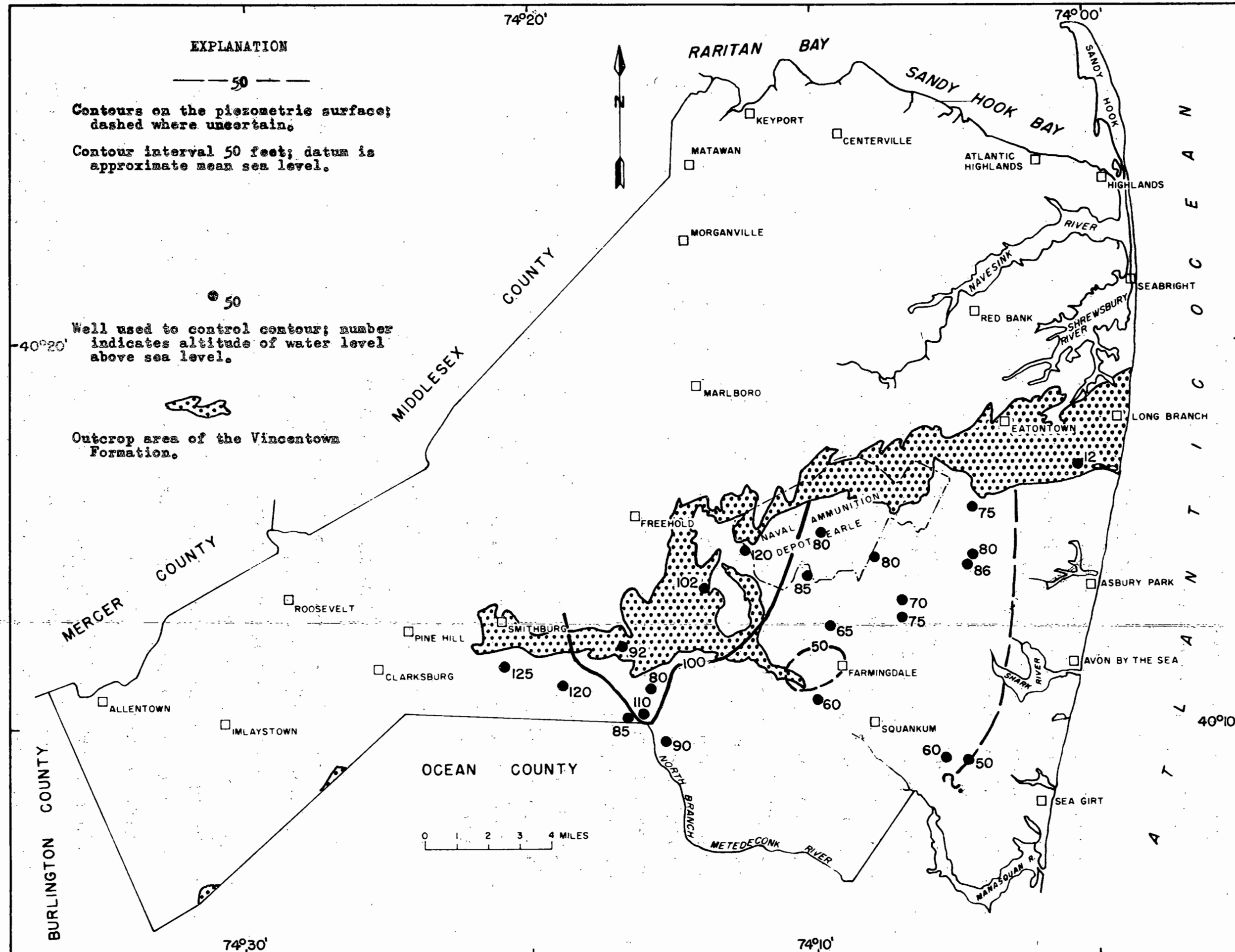
BASE ADAPTED FROM MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 23.—Thickness of the aquifer in the Vincentown Formation.



BASE ADAPTED FROM MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 24.—Structure contours on top of the aquifer in the Vincentown Formation.



BASE ADAPTED FROM MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 25.—Contours on the piezometric surface of the Vincentown Formation for a selected period in 1959.

Drillers and well owners report that the water is generally of excellent quality, although a few wells yield water which contains low pH and undesirable iron concentration.

Future Development

Development of the aquifer in the Vincentown Formation in Monmouth County cannot be planned independently of development of the aquifer in other parts of the Coastal Plain—particularly in the neighboring counties of Burlington and Ocean.

As of 1964, there is no indication of salt water or high-chloride water in the aquifer in Monmouth County. The aquifer may be in hydraulic connection with the Atlantic Ocean. Hence, development of the aquifer near the coast should proceed with caution.

If the part of the recharge the aquifer receives that is discharged by the aquifer to nearby streams is equal to the estimated average baseflow discharge from the water table in the Manasquan River Basin, then about 16 mgd is discharged by the aquifer in the outcrop to nearby streams. Development in and near the outcrop could create the gradients necessary to intercept much of the water that presently is being discharged from the aquifer.

Data are lacking on the permeability of the materials in this aquifer. This information is needed to enable predictions of the effect of development of the aquifer and to indicate if it is practical to develop much of the water available to this aquifer.

TERTIARY SYSTEM—EOCENE SERIES

Manasquan Formation

The Manasquan Formation is composed of two clayey quartz-glauconite sand members. The formation as identified by Owens and Minard (1960, p. 25) is equivalent to the combined Manasquan Formation and Shark River Marl of earlier reports. The Manasquan Formation conformably overlies the Vincentown Formation and occupies an outcrop area of about 8 square miles. The thickness ranges from 25 to 100 feet, and the dip is southeastward at 25 feet per mile.

Being clayey, the Manasquan probably functions as an aquiclude separating the aquifer of the Vincentown Formation and overlying aquifer of the Kirkwood Formation. Where the aquifer of the Vincentown Formation is absent downdip, the Manasquan Formation acts in conjunction with underlying formations to separate the aquifer of the Wenonah and Mount Laurel from the overlying Kirkwood Formation.

TERTIARY SYSTEM—MIOCENE SERIES

Kirkwood Formation

Geology

The Kirkwood Formation has a total areal extent of 140 square miles in Monmouth County. This includes the outcrop area and small areas overlain by younger formations. (See fig. 5.)

This formation unconformably overlies the Shark River Marl, and, locally, the Vincentown Formation and Hornerstown Sand. The next younger formation above the Kirkwood is the Cohansey Sand, but it is not areally extensive in Monmouth County and therefore it is not discussed in detail. The Cohansey-Kirkwood contact is unconformable.

The Kirkwood Formation has a thickness of as much as 100 feet in the county. It strikes N 70°E and dips to the southeast at a rate of 20 feet per mile.

It consists of alternating layers of sand and clay that are chiefly discontinuous. However, there are two rather distinct units. Owens and Minard (1960, p. 31) describe the basal unit as pebbly quartz sand or brown lignitic quartz silt to very fine-grained quartz sand, and the upper unit as light gray to yellowish-brown, very fine-grained quartz sand containing quartz granules and small pebbles.

The lower unit appears to be chiefly brown silt in Monmouth County. The upper unit is fine yellowish-brown or gray quartz sand containing layers or seams of clay.

Hydrology

Development of the aquifer in the Kirkwood Formation apparently has been limited in Monmouth County because the aquifer is generally thin and of limited areal extent. In 1958, the pumpage from the Kirkwood Formation was 1.5 million gallons daily or 7 percent of the total ground-water withdrawals.

The aquifer in the Kirkwood Formation underlies roughly about 25 percent of the county. It ranges in thickness from 0 to 79 feet (fig. 26); however, only 8 percent of the county is underlain by an aquifer thickness of at least 30 feet. The basal configuration of the aquifer is shown on figure 27.

The reported yield of wells tapping this aquifer ranges from 15 to 1,236 gpm. The average yield of seven selected large-diameter properly constructed wells was 460 gpm, and the specific capacity ranged from 7.0 to 20 gpm per foot of drawdown.

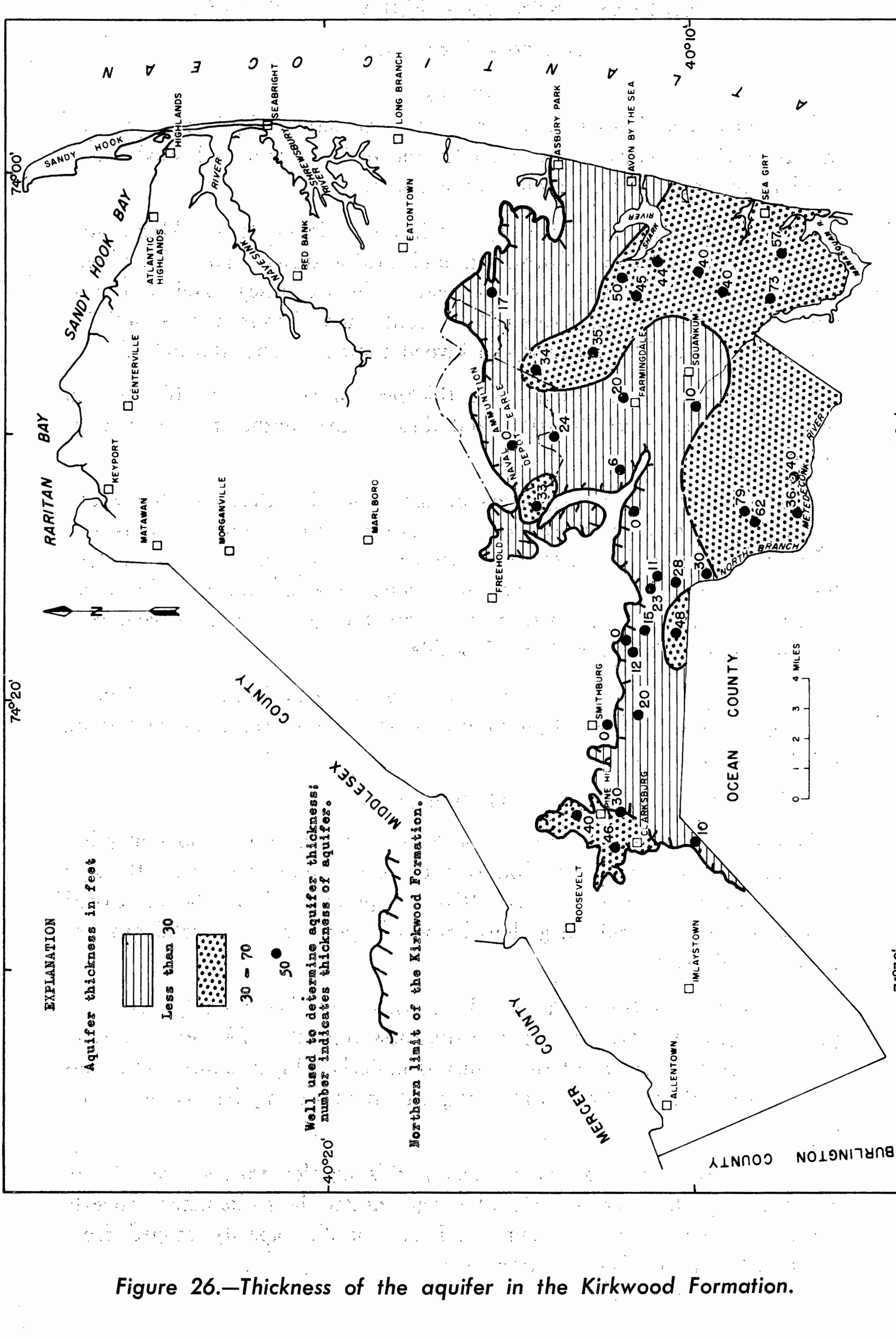


Figure 26.—Thickness of the aquifer in the Kirkwood Formation.

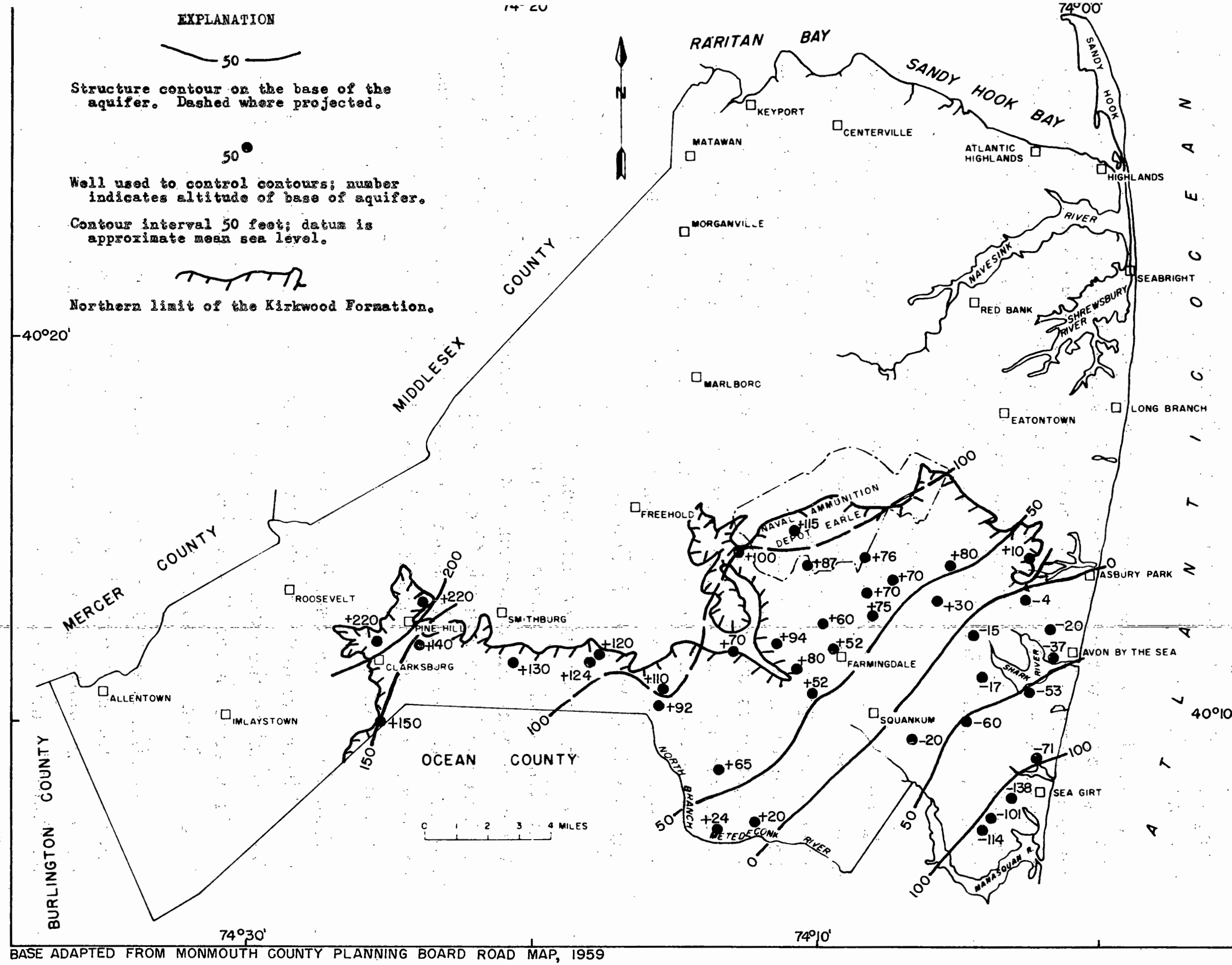


Figure 27.—Structure contours on the base of the aquifer in the Kirkwood Formation.

The general movement of water in the aquifer is chiefly from the topographically high areas toward the Manasquan River, Shark River, and Ocean County.

Results of two partial chemical analyses (Jablonski, 1959, p. 47 and 1960, p. 28) show the water from the Kirkwood Formation is satisfactory for many purposes, although removal of iron may be necessary. The water also contains noticeable amounts of hydrogen sulfide gas, but this is easily removed by aeration. The temperature of the water averages about 57°F and is particularly desirable for cooling purposes.

Future Development

As far as is known, the Kirkwood Formation, or at least its shallowest zone, exists under water-table conditions in most of the outcrop area. Because the aquifer receives recharge from precipitation in the outcrop, the extent of the area of influence of a pumping well is limited by the area required to intercept a quantity of water sufficient to replenish the aquifer for the quantity being withdrawn by the well. Hence, it is unlikely that the pumpage from the Kirkwood Formation in other areas, with the exception of Ocean County, will have an appreciable effect on water levels in Monmouth County.

As of 1964, there is no indication of salt water or high-chloride water in the Kirkwood Formation in Monmouth County. Because the aquifer may be in hydraulic connection with salt water in tidal estuaries along the coast and in the Atlantic Ocean, development near these places should proceed with caution. In about 90 square miles of the county, the base of the aquifer is above sea level; hence, this area is not threatened with salt-water encroachment.

Assuming that the effective intake area of the Kirkwood Formation is about 140 square miles and that the discharge from the aquifer to streamflow is equal to the estimated average baseflow from the water table in the Manasquan River Basin, then about 77 mgd is discharged by the Kirkwood Formation to streams.

The aquifer is at least 30 feet thick in an area of only about 45 square miles. Thus, in about 95 square miles of the area underlain by the aquifer, the aquifer is probably too thin to permit large yields to be developed by individual wells.

Several large-yield wells have been developed in the Manasquan-Sea Girt area. The aquifer transmissibility in that area is estimated roughly to be 40,000 gpd per ft.

The hydraulic characteristics of the Kirkwood Formation are not well known in other parts of the area. On the basis of the limited available information, the areas most favorable for additional development are where the saturated thickness is at least 30 feet and remote from surface-water bodies that contain salt water. Wells located near perennial fresh-water streams or ponds that are in hydraulic connection with the aquifer may permit large sustained yields with relatively small drawdowns.

Post-Kirkwood Formations

The formations deposited after the close of Kirkwood time in what is now Monmouth County consist of the Cohansey Sand of Miocene-Pliocene age, undifferentiated Bridgeton, Pensauken and Cape May Formations of Pleistocene age and Recent alluvium, beach sand and gravel. (See table 2.) They are not of sufficient thickness or areal extent to be important as aquifers. However, locally they do supply water to small-capacity wells.

Where these formations overlie aquifers, the recharge they receive from precipitation is transmitted downward to the underlying aquifers. Where these formations overlie aquicludes, the recharge they receive from precipitation is transmitted laterally to adjacent aquifers or to streams. In areas where these younger formations are less permeable than the underlying older formations, they tend to reduce the rate of recharge.

SUMMARY AND CONCLUSIONS

Monmouth County is experiencing a rapid increase in population in urban areas. Between 1950 and 1960 the urban population increased 85 percent, whereas the rural population decreased about 12 percent. With increasing urban population, the demand for large yield wells for public water supplies will increase. The greatest part of the permanent population is concentrated in the eastern third of the county. This is also the area which has an influx of an estimated 2 million tourists during the summer. To date, surface-water and ground-water developments in the county have been adequate to meet the water demands in this area. If the recent trend of population continues to increase and greater demands for ground-water withdrawals are made, problems of overdevelopment may occur. Evaluation of the ground-water resources of Monmouth County will provide a basis for their efficient development and management.

The principal aquifers underlying the county occur in the Raritan and Magothy Formations, the Englishtown Formation, the Wenonah Formation and Mount Laurel Sand, the Red Bank Sand, the Vincentown Formation, and the Kirkwood Formation. They crop out in bands trending northeast-southwest and slope downward toward the southeast. Thickness, pumpage, and water-bearing characteristics of these aquifers are summarized in the table on the next page.

The Raritan and Magothy Formations may be in hydraulic connection with the Atlantic Ocean and development could be limited by the threat of salt-water encroachment. Studies made by Barksdale (1958) indicate that salt water is present in the oceanward extensions of the aquifer, perhaps about 4 or 5 miles offshore prior to large-scale development. Information obtained from test wells indicate that Barksdale's estimates of the updip extent of salt-water encroachment are reasonably accurate. Water samples from a test well drilled about 20 miles south of Sea Girt indicated salt-water contamination of the lower part of this aquifer. Until the actual location of the salt water in the aquifer to the east of the county is known, development should proceed with extreme caution. The area most favorable for additional development of the Raritan and Magothy Formations probably is the western part of the county, where pumpage would aggravate the salt-water problem less than would the same intensity of development in the eastern part of the county. Salt water probably is advancing toward coastal parts of the county in response to existing development. Increased development along the coast would accelerate the rate of advancement toward the coast much more than would the same intensity of development in the western part of the county.

Aquifer	*Thickness (feet)*	*1958 Pumpage (mgd)*	*Water-bearing Characteristics*
Raritan and Magothy Formations	25-70	12.3	Most important aquifers. Yields range from 100 to 1,400 gpm to large-diameter wells.
Englishtown Formation	30-50	4.0	Average yield 25 gpm. Maximum reported yield 640 gpm. Average yield to large-capacity wells 410 gpm.
Wenonah Formation and Mount Laurel Sand	30-50	.65	Considered a single aquifer. Average yield 10 gpm. Maximum reported yield 335 gpm.
Red Bank Sand	40	—	Yields range from 3 to 30 gpm to domestic wells.
Vincentown Formation	50-110	—	Numerous domestic wells tap this aquifer—yields range from 10 to 50 gpm.
Kirkwood Formation	0-79	1.5	Yields range from 15 to 1,200 gpm.

The area most favorable for additional development of the Englishtown Formation and Mount Laurel Sand is locally in the vicinity of their outcrop areas southwest of the Sandy Hook Bay where water levels are highest and the threat of salt-water encroachment is less.

Because the aquifer in the Red Bank Sand is generally thin and pinches out within a few miles of the outcrop, it may not be practical to attempt to develop large-yield wells from this aquifer. However, wells located near streams or ponds that are in hydraulic connection with the aquifer may permit large yields. Much more information regarding the hydraulic characteristics of the Red Bank Sand is needed before its significance as an aquifer can be properly evaluated.

Probable favorable additional development in the aquifer of the Vincentown Formation occurs locally in the vicinity of the outcrop area and away from the Atlantic Ocean. However, more information is needed regarding hydraulic characteristics of the water-bearing materials.

The Kirkwood Formation underlies about 25 percent of Monmouth County and makes up the principal water-table aquifer in the southeastern part of the county. Favorable additional development may be available in areas where its saturated thickness is at least 30 feet and remote from saline surface-water bodies.

It is estimated that the water demand in year 2000 will be about 133 mgd, about 89 mgd more than the water use in 1958. The estimated natural baseflow discharge of the major aquifers, that occur under water-table conditions, to streamflow is estimated to be about 178 mgd. Much of this water is physically available for development.

The estimates made of the natural baseflow discharge from each of the many aquifers that occur under water-table conditions somewhere in the county should be considered as first approximations, particularly for the Englishtown Formation, the Wenonah Formation and Mount Laurel Sand, and the Red Bank Sand. Stream-gaging stations located at aquifer boundaries would permit determinations of baseflow discharge from the individual aquifers. Until a better approximation can be made, the estimated baseflow discharges can be used to suggest the amount of water that could be developed from these water-table aquifers. This does not imply that it would be economically feasible to develop each of these aquifers extensively. In some cases, part of the natural discharge out of a poor aquifer that is not hydraulically suitable for large-scale development can be utilized by ground-water development in other aquifers that are in hydraulic connection with streams that drain the poor aquifer. This is accomplished by pumping from the better aquifers near these streams at a rate that establishes a gradient from the streams toward the more productive aquifers. In this way, wells could intercept water that naturally would be discharged from these aquifers to the streams while inducing water from the streams that only recently had been discharged by the poor aquifer to the streams. Development could also be accomplished by on-stream reservoirs in conjunction with nearby ground-water installations.

The available data indicate the depths to and thicknesses of the principal aquifers and aquicludes underlying Monmouth County. Although useful for many purposes, this information does not permit reasonably reliable estimates of the effect of development in any aquifer on the distribution of head in that and adjacent aquifers. Such estimates require, among other things, a knowledge of the hydraulic characteristics of the aquifers and the materials separating them. The hydraulic characteristics of some of the aquifers have been evaluated in a few areas by pumping tests. In other areas, estimates of aquifer transmissibilities were made from specific capacities of individual wells. Much more information is needed on the hydraulic characteristics of these materials. Pumping tests should be made at every opportunity where adequate test control is available. The test data should be analyzed to determine, if possible, both the aquifer and adjacent aquiclude characteristics. This information is needed throughout the Coastal Plain of the State to assist in predicting the effects of development.

The cost of determining the hydraulic characteristics of the principal aquifers in each area before the aquifers are developed in that area probably would be prohibitive. Studies are needed to determine if estimates of the hydraulic characteristics of the aquifers can be made on the basis of water-level changes that occur in response to development. This method is essentially a long-term pumping test. Records of pumping from each of the aquifers in each area, recharge to aquifers from precipitation and streams and aquifer discharge to streams, and water levels in each aquifer in each area would be required. As more and better data became available, estimates of the hydraulic characteristics would be refined. A technique presented by Tyson and Weber (1964) probably can be generalized to estimate the average hydraulic characteristics in each aquifer and aquiclude.

The effect of development of some of the principal aquifers depends, in part, on the hydraulic characteristics of the suboceanic extensions of these aquifers and the degree, if any, of hydraulic connection of these aquifers with salt water. The hydraulic characteristics of these suboceanic extensions have a greater influence on aquifer response to pumping near the coast than to pumping inland from the coast. Because much of the heavy pumping is along the coast, the lack of information of conditions off shore is unfortunate. Studies are needed to determine if economically justifiable methods can be developed to analyze the hydraulic characteristics of suboceanic materials within at least a few miles of the coast.

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LOGS OF WELLS

Representative logs of 23 wells in Monmouth County, N. J., are given in table 4 on the following pages. The logs have been selected on the basis of areal distribution and depth penetrated. Unless otherwise indicated, tentative correlations have been made on drillers' logs by the writer. The logs with correlations by Meredith E. Johnson, Frank J. Markewicz, and others are based chiefly on laboratory examination of drill cuttings. Mr. Johnson is the former State Geologist of New Jersey, and Mr. Markewicz is the Principal Geologist, Bureau of Geology, Division of Resources Development, New Jersey State Department of Conservation and Economic Development.

TABLE 4.—LOGS OF SELECTED WELLS IN MONMOUTH COUNTY, N. J.

Well 1, Mercer County

Altitude, 120 feet

	Thickness (feet)	*Depth (feet)*
Undescribed	10	10
Quaternary:		
Pleistocene and Recent:		
Sand	20	30
Cretaceous:		
Englishtown Formation:		
Sand, yellow	30	60
Merchantville Formation and Woodbury Clay:		
Clay, dark	110	170
Raritan and Magothy Formations:		
Clay, dark	65	235
Sand, fine	2	237
Clay, dark	43	280
Sand, fine, white, not water-bearing	50	330
Clay, dark	1	331
Clay, white	34	365
Clay, red	15	380
Clay, white	2	382
Sand, white	10	392
Clay, dark	8	400
Clay, light	32	432
Sand, fine to medium	32	464

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well 2, Imlaystown

Altitude, 155 feet

	Thickness (feet)	*Depth (feet)*
Cretaceous:		
Red Bank(?) Sand:		
Sand	14	14
Red Bank Sand:		
Sand, clayey	36	50
Navesink Formation:		
Sand, clayey, shells(?) at 50 feet	30	80
Wenonah Formation and Mount Laurel Sand:		
Sand, gray, fine, clayey	25	105
Marshalltown and Wenonah Formations:		
Clay, sandy	35	140
Marshalltown Formation:		
Clay, dark gray	20	160
Englishtown Formation:		
Sand, fine	18	178
Clay, gray	10	188
Sand, fine, lenses of clay	32	220
Clay	6	226
Sand, fine, clayey	14	240
Merchantville Formation and Woodbury Clay:		
Clay	190	430
Raritan and Magothy Formations:		
Sand, fine	30	460
Sand, medium(?)	20	480
Clay, gray	8	488
Sand, medium(?)	16	504
Clay, sandy at 546 and 575 feet	76	580
Clay	38	618
Sand, fine	1	619
Clay, white	3	622
Clay	4	626
No sample	74	700
Clay, varicolored	30	730
Sand, gray, fine to medium	15	745

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well 7, Freehold

(Correlation by Meredith E. Johnson)

Altitude, 140 feet

	Thickness (feet)	Depth (feet)
Tertiary:		
Hornerstown Sand:		
Clay, light brown, sandy, glauconitic	15	15
Cretaceous:		
Red Bank Sand:		
Sand, greenish brown, clayey, glauconitic	25	40
Sand, gray green, fine to coarse, glauconitic	65	105
Navesink Formation:		
Clay, gray, glauconitic, shell fragments	30	135
Wenonah Formation and Mount Laurel Sand:		
Clay, gray, sandy, glauconitic	35	170
Sand, fine, slightly clayey and micaceous	10	180
Sand, gray, very fine, clayey	10	190
Marshalltown Formation:		
Clay, dark gray, micaceous, shell fragments	35	225
Englishtown Formation:		
Clay, gray, sandy, glauconitic	5	230
Clay, dark gray, contains limestone nodules	10	240
Sand, gray, fine, clayey	20	260
Clay, gray, and alternating thin laminae of sand	40	300
Sand, gray, fine, sparsely glauconitic	20	320
Clay, gray, lignitic, sandy, contains limestone nodules	35	355
Woodbury Clay:		
Clay, gray, contains limestone nodules	55	410
Clay, gray, contains shell fragments	15	425
Merchantville Formation:		
Clay, gray, glauconitic and micaceous, contains shell fragments	5	430
Clay, gray, micaceous and glauconitic	40	470
Clay, gray, sandy, slightly micaceous and glauconitic	20	490
Clay, gray, micaceous	10	500
Clay, greenish-gray, contains limestone nodules	10	510
Magothy(?) Formation:		
Clay, gray	10	520
Clay, gray, sandy	10	530

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well 7, Freehold—Continued

	Thickness (feet)	*Depth (feet)*
Cretaceous—Continued:		
Magothy Formation:		
Sand, gray, fine, glauconitic	6	536
Sand, gray, glauconitic	7	543
Clay, dark gray	37	580
Clay, gray, slightly sandy and micaceous, containing pyrite nodules	25	605
Raritan Formation:		
Sand, grayish-brown, very fine	15	620
Sand, yellow, fine to medium	10	630
Sand, gray, fine to medium, slightly clayey	20	650

Well 13, Telegraph Hill

Altitude, 234 feet

Undescribed	19	19
Cretaceous:		
Red Bank Sand:		
Clay, greenish-gray, sandy, glauconitic, micaceous	50	69
Navesink Formation:		
Sand, greenish-gray, fine to medium, clayey; 85 percent glauconite	14	83
Sand, greenish-gray, fine to medium, very micaceous, slightly glauconitic, clayey	21	104
Clay, gray, tough, micaceous and glauconitic	10	114
Wenonah Formation and Mount Laurel Sand:		
Sand, greenish-gray, fine to medium, slightly silty, micaceous, lignitic, glauconitic	32	146
Silt, greenish-gray, sandy, micaceous, slightly glauconitic	5	151
Sand, greenish-gray, fine to medium, silty, micaceous; 80 percent glauconite	10	161
Sand, greenish gray, fine to medium, slightly silty and glauconitic	3	164
Clay and sand in alternating layers, gray, micaceous, lignitic	16	180

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well 13, Telegraph Hill—Continued

	Thickness (feet)	*Depth (feet)*
Cretaceous—Continued:		
Marshalltown Formation:		
Clay, gray, micaceous, lignitic, contains thin seams of silt	42	222
Englishtown Formation:		
Sand, light gray, fine to medium, silty, micaceous, lignitic	15	237
Sand, light gray, medium, slightly silty, lignitic, micaceous	31	268
Clay, light gray, micaceous and lignitic	6	274
Sand, light gray, very fine, silty, lignitic, some glauconite	30	304
Englishtown(?) Formation:		
Clay, light gray, silty, micaceous, slightly lignitic, some glauconite	26	330
Merchantville Formation and Woodbury Clay:		
Clay, gray, glauconitic, slightly micaceous	10	340
Clay, light green, very glauconitic	10	350
Silt, greenish-gray, sandy, micaceous, very lignitic	25	375
Sand, light gray, medium to coarse, poorly sorted, silty, slightly lignitic and glauconitic	10	385
Sand, light gray, medium, silty, some glauconite, lignite, and mica	10	395
Silt, light gray, lignitic, micaceous	30	425
Sand, light gray, fine to medium, silty, slightly micaceous and lignitic	26	451
Raritan and Magothy Formations:		
Sand, yellowish gray, fine to medium, well sorted, micaceous, lignitic	27	478
Clay and sand layers alternating, gray	94	572
Sand, gray, fine; contains lenses of clay	53	625
Clay and sand layers, alternating	217	842
Sand, gray, fine	6	848
Sand, gray, lenses of clay	15	863
Sand, gray, fine, some lignite	31	894
Clay and sand layers, alternating	70	964
Pre-Cretaceous:		
Gneiss(?), weathered	80	1044

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well 17, Sandy Hook

Altitude, 3 feet

	Thickness (feet)	*Depth (feet)*
Quaternary(?):		
Pleistocene(?):		
Cape May(?) Formation:		
Sand	60	60
Clay, blue	8	68
Cretaceous:		
Englishtown Formation:		
Sand, lignitic	53	121
EXTRAPOLATED LOG		
Clay, blue	10	131
Sand, lignitic	54	185
Merchantville Formation and Woodbury Clay:		
Clay, greenish gray, silty	130	315
Raritan and Magothy Formations:		
Sand, dark gray	25	340
Hardpan(?)	9	349
Sand, white	25	374
Clay, hard, silty	9	383
Sand, white, lignitic	17	400
Clay	35	435
Sand	50	485
Clay	15	500
Sand(?), fine, clay	100	600
Clay	100	700

Well 18, One mile west of Seabright

Altitude, 15 feet

Quaternary(?):		
Pleistocene(?):		
Cape May(?) Formation:		
Sand	3	3
Clay	4	7
Cretaceous:		
Red Bank Sand:		
Sand, brown	14	21

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well 18, One mile west of Seabright—Continued

	Thickness (feet)	*Depth (feet)*
Cretaceous—Continued:		
Sand, black	36	57
Sand, greenish-gray, fine to medium, clayey, glauconitic	20	77
Navesink Formation:		
Sand, greenish-gray, fine to medium, clayey and glauconitic	22	99
Shells, indurated	5	104
Gravel, varicolored	4	108
Wenonah Formation and Mount Laurel Sand:		
Sand, greenish-gray	73	181
Clay, white	15	196
Marshalltown Formation:		
Clay, black, silty	47	243
Englishtown Formation:		
Sand, white, lignitic	79	322
Clay, blue	18	340

Well 20, Brookdale

Altitude, 28 feet

Quaternary(?):		
Pleistocene(?):		
Cape May(?) Formation:		
Sand	3	3
Clay	5	8
Cretaceous:		
Red Bank Sand:		
Sand, brown	5	13
Silt, black, clayey	17	30
Sand, contains coarse fragments	9	39
Navesink Formation:		
Sand, fine, very clayey	40	79
Wenonah Formation and Mount Laurel Sand:		
Sand, gray(?)	52	131
Wenonah(?) Formation:		
Silt, black, clayey	23	154

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well 20, Brookdale—Continued

	Thickness (feet)	Depth (feet)
Cretaceous—Continued:		
Marshalltown Formation:		
Silt, black, clayey	26	180
Clay, black, silty, hard	14	194
Englishtown Formation:		
Sand	22	216
Merchantville Formation and Woodbury Clay:		
Clay and sand, glauconitic	73	289
Clay	35	324
Raritan and Magothy Formations:		
Sand, black(?)	64	388
Sand, very fine(?)	14	402
Sand, glauconitic, clayey	64	466
Hardpan(?)	6	472
Shells, indurated	9	481
Sand, glauconitic and clayey	32	513
Sand, brown, lignitic	87	600
Clay, blue	44	644
Sand, white	68	712

Well 21, Eatontown

Altitude, 60 feet

Tertiary(?):		
Paleocene(?):		
Vincentown(?) Formation:		
Sand	26	26
Tertiary:		
Vincentown Formation:		
Sand, fine	10	36
Sand	16	52
Sand and clay, white	10	62
Sand, fossiliferous	10	72
Sand, fossiliferous, lignitic	10	82
Hornerstown(?) Sand:		
Sand, clayey, fossiliferous, lignitic	28	110
Hornerstown Sand:		
Clay, greenish-gray, shell fragments	20	130

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well 21, Eatontown—Continued

	Thickness (feet)	*Depth (feet)*
Cretaceous:		
Red Bank Sand:		
Clay, greenish-gray, shell fragments	80	210
Navesink Formation:		
Clay, greenish-gray, fossiliferous	27	237
Wenonah Formation and Mount Laurel Sand:		
Sand, black(?), very fine to medium	21	258
Wenonah(?) Formation:		
Clay, black, and sand, very fine to fine	47	305
Sand, fine to coarse, and gravel, fine	5	310
Marshalltown Formation:		
Clay, black, and sand, very fine, lignitic	53	363
Englishtown Formation:		
Clay(?), black and sand, very fine	97	460
Merchantville Formation and Woodbury Clay:		
Clay, dark gray	135	595
Raritan and Magothy Formations:		
Clay, and sand, very fine to fine	84	679
Sand, fine to coarse, and gravel, fine	9	688
Clay and sand, fine	167	855
Sand, and gravel, fine	15	870
Clay	5	875
Pre-Cretaceous(?):		
Bedrock(?), weathered	16	891

Well 26, Freehold

Altitude, 110 feet

Cretaceous:		
Red Bank(?) Sand:		
Sand, brown, clayey, glauconitic	10	10
Sand, brown, clayey, indurated, glauconitic	15	25
Red Bank Sand:		
Sand, reddish-brown, fine to coarse, slightly clayey	35	60
Sand, greenish-gray, fine to medium, clayey, slightly glauconitic and micaceous	65	125

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well 26, Freehold—Continued

	Thickness (feet)	*Depth (feet)*
Cretaceous—Continued:		
Navesink Formation:		
Clay(?), gray, sandy, glauconitic, very fossiliferous	35	160
Clay, greenish-gray, very glauconitic	5	165
Wenonah Formation and Mount Laurel Sand:		
Sand, fine, micaceous, clayey	35	200
Sand, and clay, gray, fine	10	210
Sand, gray, fine, clayey, micaceous and glauconitic	30	240
Wenonah(?) Formation:		
Clay, gray, contains thin laminae of fine sand	5	245
Clay, gray, sandy	15	260
Clay, gray, sandy, micaceous	20	280
Marshalltown Formation:		
Clay, gray, contains thin laminae of fine sand	20	300
Clay, sandy, contains shell fragments	10	310
Englishtown(?) Formation:		
Clay and sand. Sand is fine and micaceous	20	330
Englishtown Formation:		
Sand, gray, very fine to medium, slightly clayey	20	350
Englishtown(?) Formation:		
Clay, slightly sandy	50	400
Woodbury Clay:		
Clay, gray, micaceous, contains shell fragments	50	450
Clay, greenish-gray, micaceous	24	474
Merchantville Formation:		
Sand, gray, fine, contains pyrite and limonite	6	480
Clay, greenish-gray, sandy, micaceous, slightly fossiliferous	40	520
Clay, greenish-gray	30	550
Merchantville(?) Formation:		
Clay, greenish-gray, slightly sandy, glauconitic and fossiliferous	20	570
Magothy Formation:		
Clay, gray, sandy	40	610
Sand and clay in alternating layers; sand is fine, gray, and micaceous	20	630
Sand, light gray, very fine	20	650
Sand and clay, interbedded; sand is gray, very fine and micaceous	30	680

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well D64, Marlboro

Altitude, 160 feet

	Thickness (feet)	*Depth (feet)*
Cretaceous:		
Red Bank Sand:		
Clay, gray, silty	20	20
Navesink Formation:		
Clay, gray, sandy, micaceous and lignitic	30	50
Wenonah Formation and Mount Laurel Sand:		
Sand, greenish-gray, fine to medium, silty, contains altered glauconite	30	80
Clay, gray, sandy, lignitic, contains a few fossil fragments	27	107
Marshalltown Formation:		
Clay, greenish-gray, sandy, micaceous and glauconitic	40	147
Englishtown Formation:		
Sand, gray, fine, slightly clayey and micaceous	50	197
Merchantville Formation and Woodbury Clay:		
Hardpan	7	204
Clay, gray, contains layers of hardpan	46	250
Clay, gray, lignitic, contains pyrite	30	280
Clay, green, lignitic	25	305
Clay, gray, fossiliferous	44	349
Raritan and Magothy Formations:		
Clay	53	402
Clay, sandy, contains pyrite, lignite, and lenses of sand	48	450
Clay, sandy	30	480
Clay, tough	24	504
Sand, fine to medium	37	541
Hardpan	8	549
Sand, fine to medium	21	570
Sand, medium, lignitic	26	596
Clay, gray	20	616

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P1, Allentown

(Correlation by Frank J. Markewicz)

Altitude, 70 feet

	Thickness (feet)	*Depth (feet)*
Unnamed:		
No sample	20	20
Cretaceous:		
Woodbury Clay:		
Clay, dark gray, silty, micaceous	30	50
Clay, dark gray, indurated layers, silty, lignitic	20	70
Merchantville Formation:		
Clay, greenish-gray, silty, glauconitic, micaceous, contains rounded quartz pebbles	30	100
Clay, dark gray, silty, glauconitic, micaceous, slightly sandy	30	130
Clay, greenish-gray, silty, micaceous, slightly glauconitic, contains pebbles	30	160
Clay, dark gray, silty, micaceous	22	182
Magothy Formation:		
Sand, dark gray, fine, silty	38	220
Sand and clay interbedded	10	230
Sand, gray, fine to medium, quartzose	10	240
Raritan Formation:		
Clay, gray, silty, lignitic, micaceous	20	260
Sand, light gray, fine to medium, lignitic	16	276
Clay	29	305

Well P3, Roosevelt

Altitude, 198 feet

Cretaceous:		
Red Bank(?) Sand:		
Clay, sandy	8	8
Sand, red and gravel	12	20
Gravel	7	27
Navesink(?) Formation:		
Sand, gravel, and clay streaks	3	30
Clay, gray, sandy	24	54

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P3, Roosevelt—Continued

	Thickness (feet)	*Depth (feet)*
Cretaceous—Continued:		
Wenonah(?) Formation and Mount Laurel(?) Sand:		
Clay, with streaks of gravel	13	67
Clay, gray	22	89
Marshalltown Formation:		
Clay, gray	40	129
Englishtown Formation:		
Sand, fine, with streaks of clay	14	143
Sand, gray, fine	13	156
Sand, gray, and streaks of clay	9	165
Woodbury Clay:		
Clay, gray	41	206
Merchantville Formation:		
Clay, with streaks of shale	9	215
Clay, gray, tough, sand	90	305
Magothy Formation:		
Clay, gray, tough, sandy	59	364
Round tubes of sandy clay, with clay streaks and sand	8	372
Sand, with tough clay streaks	26	398
Sand, gray, fine to medium, with clay streaks	16	414
Raritan Formation:		
Sand, gray, coarse, with clay streaks	22	436
Old Bridge(?) Sand Member:		
Sand, gray, coarse	54	490
South Amboy(?) fire clay:		
Clay, white to gray, with sand streaks	20	510

Well P4, Freehold

Altitude, 100 feet

Unnamed:		
Topsoil	6	6
Cretaceous:		
Navesink Formation:		
Clay, hard	23	29

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P4, Freehold—Continued

	Thickness (feet)	*Depth (feet)*
Cretaceous—Continued:		
Wenonah Formation and Mount Laurel Sand:		
Sand, and soft clay	38	67
Sand, black, fine	21	88
Marshalltown Formation:		
Clay	8	96
Sand	12	108
Clay, tough	28	136
Englishtown Formation:		
Sand	13	149
Clay	23	172
Sand	18	190
Sand, contains pods of white clay	16	206
Clay, and thin seams of sand	13	219
Merchantville Formation and Woodbury Clay:		
Clay, hard	96	315
Raritan and Magothy Formations:		
Limestone	2	317
Clay	96	413
Sand	6	419
Clay	12	431
Lime(?)	1	432
Clay, tough	9	441
Sand, gray, fine	59	500

Well P9, Matawan

Altitude, 80 feet

Unnamed:		
Clay and gravel	10	10
Cretaceous:		
Raritan and Magothy Formations:		
Clay, gray	32	42
Clay and fine muddy sand	38	80
Clay, gray with hard streaks	104	184
Raritan Formation:		
Sand, gray, fine	52	236
Clay, gray	20	256

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P9, Matawan—Continued

	Thickness (feet)	*Depth (feet)*
Cretaceous—Continued:		
Sand, gray	5	261
Clay, gray and white, with sand streaks	113	374
Sand, hard	9	383
Clay, red, with hard streaks	57	440
Sand, coarse	25	465
Clay with hard streaks	4	469
Sand, coarse and fine	17	486
Clay, with hard streaks	12	498

Well P21, Centreville
Altitude, 60 feet

Quaternary:		
Pleistocene (Cape May Formation):		
Gravel and sand	10	10
Cretaceous:		
Englishtown Formation:		
Sand, gray	34	44
Sand, gray, and clay	16	60
Woodbury Clay:		
Sand, gray, and clay	10	70
Clay, fine, sandy	30	100
Merchantville Formation:		
Clay, fine, sandy	40	140
Clay, sandy, with hard streaks	10	150
Raritan and Magothy Formations:		
Sand, fine, rusty	52	202
Sand, fine	103	305
Raritan Formation:		
Old Bridge(?) Sand Member:		
Sand, gray	61	366
Clay, gray	5	371
Sand, coarse	38	409
Sand, hard, and clay	23	432
Clay	21	453
Clay, sand, and pyrite	16	469
Clay, tough	44	513

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P22, Atlantic Highlands

Altitude, 20 feet

	Thickness (feet)	*Depth (feet)*
Fill	8	8
Cretaceous:		
Marshalltown Formation:		
Clay	14	22
Silt, fine	17	39
Clay, blue	5	44
Englishtown Formation:		
Sand, gray, fine	22	66
Sand, gray, fine, and silt	21	87
Sand, gray, loose	33	120
Clay, blue, tough	17	137
Sand, fine and silt	22	159
Woodbury Clay:		
Clay, blue, soft	18	177
Clay, blue, tough	94	271
Merchantville Formation:		
Hardpan	10	281
Clay, sandy	22	303
Clay, blue, tough	44	347
Raritan and Magothy Formations:		
Sand, gray, hard, fine	35	382
Clay, blue, soft	40	422
Clay, blue, tough	38	460
Sand, gray, packed, fine	43	503
Clay, blue, tough	17	520
Sand, gray, coarse	8	528
Clay, blue	4	532
Raritan Formation:		
Old Bridge(?) Sand Member:		
Sand, gray, coarse	29	561
Clay, blue, tough	5	566
Sand, gray, coarse	17	583
Raritan Formation:		
Clay, blue, tough	12	595
Sand, soft and silt	22	617
Clay and boulders	45	662

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P28, Red Bank
Altitude, 40 feet

	Thickness (feet)	*Depth (feet)*
Cretaceous:		
Red Bank Sand:		
Sand	32	32
Clay, soft	47	79
Navesink Formation:		
Clay, black, sandy	12	91
Clay, contains layers of indurated material	24	115
Wenonah Formation and Mount Laurel Sand:		
Clay, sandy	30	145
Sand and clay	30	175
Marshalltown Formation:		
Clay, contains lenses of sand	20	195
Clay	21	216
Englishtown Formation:		
Sand, fine	11	227
Clay	12	239
Sand	22	261
Clay	6	267
Sand	9	276
Englishtown(?) Formation:		
Clay, black	24	300
Clay, with hard layers(?)	50	350
Woodbury Clay:		
Clay, with hard layers(?)	68	418
Sand, compact	2	420
Merchantville Formation:		
Clay, tough	76	496
Raritan and Magothy Formations:		
Clay, sandy	70	566
Sand, gray, fine	19	585
Clay, tough	37	622
Clay	10	632
Sand, gray, medium coarse	55	687
Clay	1	688
Sand	7	695
Clay	7	702

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P30, Long Branch

Altitude, 10 feet

	Thickness (feet)	*Depth (feet)*
Quaternary:		
Pleistocene and Recent:		
Sand, stones, and fill	35	35
Tertiary:		
Hornerstown Sand and Vincentown Formation:		
Clay	12	47
Sand	5	52
Clay and marl	32	84
Sand and marl	25	109
Clay and marl	16	125
Sand	15	140
Clay and marl	20	160
Cretaceous(?):		
Red Bank(?) Sand:		
Sand and marl	46	206
Clay	42	248
Marshalltown Formation and Navesink Formation:		
Marl and clay	28	276
Wenonah Formation and Mount Laurel Sand:		
Sand	6	282
Clay and sand	8	290
Clay	43	333
Wenonah(?) Formation:		
Sand and silt	25	358
Marshalltown Formation:		
Sand and clay	10	368
Clay	31	399
Englishtown Formation:		
Clay, with sand layers	55	454
Sand	5	459
Sand and clay	9	468
Sand	12	480
Sand and clay	21	501
Woodbury Clay:		
Clay	3	504
Clay and sand	21	525

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P30, Long Branch—Continued

	Thickness (feet)	*Depth (feet)*
Cretaceous—Continued:		
Clay	10	535
Clay and sand	10	545
Hardpan	15	560
Merchantville Formation:		
Clay and sand	5	565
Sand	5	570
Clay and sand	10	580
Sand	7	587
Clay	43	630
Raritan and Magothy Formations:		
Clay and sand	10	640
Clay	10	650
Sand and clay	30	680
Clay	50	730
Sand	15	745
Clay	15	760
Sand	70	830
Clay	18	848
Sand, fine	68	916
Clay	20	936
Raritan Formation:		
Old Bridge(?) Sand Member:		
Sand	54	990
Clay	11	1001

Well P38, Asbury Park

(Correlation after State Geologist Report 1895, p. 73)

Altitude, 10 feet

Quaternary:		
Recent:		
Sand	16	16

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P38, Asbury Park—Continued

	Thickness (feet)	Depth (feet)
Tertiary:		
Kirkwood Formation:		
Clay, brown. Diatoms at 40 feet	64	80
Manasquan Formation and Shark River Marl:		
Clay, light-colored	13	93
Greensand	7	100
Clay, whitish, containing foraminifera	40	140
Vincentown Formation:		
Clay, contains greensand	20	160
Greensand	20	180
Clay, contains greensand	20	200
Clay, whitish, with a thin layer of Bryozoan limesand	40	240
Hornerstown Sand:		
Greensand, with Oleneothyris harlini and Gryphea	40	280
Cretaceous:		
Red Bank Sand:		
Sand, black	7	287
Greensand, clayey	53	340
Navesink Formation:		
Greensand, contains Exogyra and Belemnitella	40	380
Mount Laurel Sand:		
Sand, gray, water-bearing	50	430
Tentative Correlation		
Marshalltown and Wenonah Formations:		
Sand, green, clayey	10	440
Sand, dark, micaceous, glauconitic	30	470
Clay, dark, sandy	32	502
Englishtown Formation:		
Sand, lignitic, water-bearing, with clayey layers	58	560
Sand and clay layers, alternating, (coarse sand or gravel at 615 feet)	60	620
Woodbury Clay:		
Clay, glauconitic, (thin seam of sand at 680)	60	680
Merchantville Formation:		
Clay, glauconitic	50	730

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P38, Asbury Park—Continued

	Thickness (feet)	Depth (feet)
Cretaceous—Continued:		
Magothy(?) Formation:		
Sand, fine, clayey	10	740
Clay, glauconitic, some thin layers of sand	214	954
Sand, fine, whitish-gray (lignite at 1,000 feet, rock at 1,026 feet)	72	1026
Raritan Formation:		
Clay, sandy	34	1060
Clay, white	7	1067
Clay, bluish	16	1083
Old Bridge(?) Sand Member:		
Sand, coarse, whitish gray, (conglomerate at 1,100 feet)	52	1135
Raritan Formation:		
Clay, dark bluish, (lignite at 1,160, molluscs at 1,195)	186	1321

Well P49, Avon-by-the-Sea
Altitude, 29 feet

	Thickness (feet)	Depth (feet)
Quaternary:		
Recent:		
Sand	10	10
Tertiary:		
Kirkwood Formation:		
Clay	38	48
Sand and gravel	18	66
Manasquan Formation and Shark River Marl:		
Clay	45	111
Sand, gray, fine, clayey	6	117
Clay	44	161
Vincentown Formation:		
Sand, hard	5	166
Sand, coarse	68	234
Clay, sandy	17	251
Clay	24	275
Sand	10	285
Hornerstown Sand:		
Clay, hard	15	300

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P49, Avon-by-the-Sea—Continued

	Thickness (feet)	Depth (feet)
Tertiary—Continued:		
Hornerstown(?) Sand:		
Clay, soft	33	333
Cretaceous:		
Red Bank Sand:		
Sand, black	30	363
Navesink Formation:		
Clay, black	64	427
Wenonah Formation and Mount Laurel Sand:		
Sand, greenish gray, fine to medium coarse	30	457
Sand, greenish gray, very fine, clayey	48	505
Marshalltown Formation:		
Sand, gray, very fine, clayey	21	526
Clay, gray	24	550
Englishtown Formation:		
Clay, gray, and sand layers	50	600
Sand, gray	30	630
Sand, coarse, and clay layers	48	678
Woodbury Clay:		
Clay, soft	41	719
Sand, hard	6	725
Merchantville Formation:		
Clay	20	745
Clay, sandy	20	765
Clay	21	786
Raritan and Magothy Formations:		
Clay, with coarse fragments	34	820
Sand, brown	25	845
Clay	15	860
Sand, gray	65	925
Clay	5	930
Sand, gray	30	960
Clay, blue	40	1000
Sand, and gravel	35	1035
Clay	22	1057
Sand, brown	5	1062
Clay	14	1076
Sand, brown	17	1093

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P49, Avon-by-the-Sea—Continued

	Thickness (feet)	*Depth (feet)*
Cretaceous—Continued:		
Raritan Formation:		
Old Bridge Sand Member:		
Sand, gray, coarse	45	1138
Clay, white	16	1154

Well P68, Sea Girt

(Modified correlation after State Geologist Report 1895, p. 76)

Altitude, 11 feet

	Thickness (feet)	*Depth (feet)*
Quaternary:		
Recent:		
Beach Sand:		
Sand	10	10
Alluvium:		
Clay, yellow	2	12
Sand, yellow, and gravel	13	25
Alluvium (?):		
Clay, blue, sandy	35	60
Pleistocene (?):		
Cape May (?) Formation:		
Sand, white, fine	6	66
Hardpan	4	70
Tertiary:		
Kirkwood Formation:		
Sand, contains shell fragments	9	79
Sand, white	11	90
Sand, coarse	15	105
Sand, fine	21	126
Clay, brown, and sand laminae, lignitic	109	235
Manasquan Formation:		
Clay, light green, fossiliferous	25	260
Sand, black, glauconitic	15	275
Vincentown (?) Formation:		
Clay (?), light greenish gray, sandy, glauconitic, fossiliferous, contains black pebbles (?) 285 to 306	70	345
Clay (?), black, sandy, glauconitic	15	360

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P68, Sea Girt—Continued

	Thickness (feet)	*Depth (feet)*
Tertiary—Continued:		
Vincentown Formation:		
Clay, light greenish gray	40	400
Clay(?), gray, sandy, glauconitic	25	425
Hornerstown(?) Sand:		
Clay(?), gray, sandy, glauconitic	25	450
Hornerstown Sand:		
Clay(?), black, sandy	69	519
Cretaceous:		
Red Bank Sand:		
Clay(?), black, sandy	40	559
Navesink Formation:		
Clay(?), black, sandy	11	570
Sand, water-bearing	10	580
Wenonah Formation and Mount Laurel Sand:		
Sand, water-bearing	40	620
Wenonah(?) Formation:		
Clay, dark gray, sandy	30	650
Marshalltown Formation:		
Clay, dark gray, sandy	44	694
Englishtown Formation:		
Sand, water-bearing	26	720
Clay, dark gray, thin laminae of ironstone	15	735
Sand, water-bearing	20	755

Well P76, Farmingdale

Altitude, 70 feet

Top soil	4	4
Tertiary:		
Kirkwood Formation:		
Sand, brown, clayey	6	10
Clay, brown, sandy	10	20
Manasquan Formation and Shark River Marl:		
Clay, gray-green	30	50

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well P76, Farmingdale—Continued

	Thickness (feet)	*Depth (feet)*
Tertiary—Continued:		
Vincentown Formation:		
Sand, green with fossils	40	90
Sand, greenish gray, medium, with shell fragments	20	110
Sand, green, fine to medium, clayey, with shell fragments	40	150
Sand, gray and green, clayey, with pebbles	10	160
Sand, gray and green, clayey, with shell fragments	20	180
Hornerstown Sand:		
Sand, gray, clayey, with shell fragments	40	220
Clay, gray, sandy, with shell fragments at 250 ft.	30	250
Cretaceous:		
Navesink Formation and Red Bank Sand:		
Clay, gray, with shell fragments	30	280
Sand, gray, with fossils	20	300
Wenonah Formation and Mount Laurel Sand:		
Sand, gray, with fossils	30	330
Clay, gray, sandy, with lignite	20	350
Sand, gray, clayey, with shells and lignite	10	360
Sand, gray, fine, clayey	10	370
Sand, gray, clayey, glauconitic	30	400
Marshalltown Formation:		
Clay, gray, with a little glauconite	30	430
Englishtown Formation:		
Sand, gray, clayey, with lignite	50	480

Well I-3, Smithburg

(Correlation by Frank J. Markewicz)

Altitude, 160 feet

Unnamed:		
No sample	5	5
Tertiary:		
(?)		
Sand, green, fine to medium, contains a large percentage of glauconite	10	15

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well I-3, Smithburg—Continued

	Thickness (feet)	*Depth (feet)*
Tertiary:		
Vincentown Formation:		
No sample	45	60
Cretaceous:		
Red Bank Sand:		
Sand, green, fine to medium, silty, moderately glauconitic, slightly micaceous	70	130
Navesink Formation:		
Sand, greenish gray, with coarse grains, silty, finely micaceous and glauconitic	50	180
Wenonah Formation and Mount Laurel Sand:		
Sand, gray, very fine, clayey, micaceous, slightly glauconitic and lignitic	50	230
Marshalltown Formation:		
Clay, greenish gray, sandy scattered very coarse sand grains, glauconitic, slightly fossiliferous	35	265
Englishtown Formation:		
Clay, gray, tough, laminated, finely micaceous, slightly lignitic	52	317
Sand, greenish gray, fine to medium, clayey, slightly glauconitic, micaceous	4	321
Woodbury Clay:		
Clay, gray, tough, with scattered coarse grains, slightly micaceous, lignitic	60	381
Merchantville Formation:		
Clay, gray, tough, nodules, scattered siderite, micaceous, slightly fossiliferous	34	415
Merchantville(?) Formation:		
No sample	49	464
Magothy Formation:		
Sand, gray, moderately glauconitic, slightly micaceous and fossiliferous	2	466
No sample	88	554
Sand, yellowish gray, fine, clay lumps, slightly glauconitic and micaceous	10	564
Pyrite nodules, gray	1	565
No sample	35	600

Table 4.—Logs of selected wells in Monmouth County, N. J.—Continued

Well I-3, Smithburg—Continued

	Thickness (feet)	*Depth (feet)*
Cretaceous—Continued:		
Sand, gray, fine to medium, slightly micaceous and lignitic	25	625
No sample	10	635
Raritan Formation:		
Sand, light gray, medium	5	640
No sample	15	655
Sand, light gray, medium	5	660
No sample	2	662
Sand, light gray, medium to coarse, lignitic	5	667
No sample	8	675
Sand, light gray, fine to very coarse	31	706

RECORDS OF SELECTED WELLS

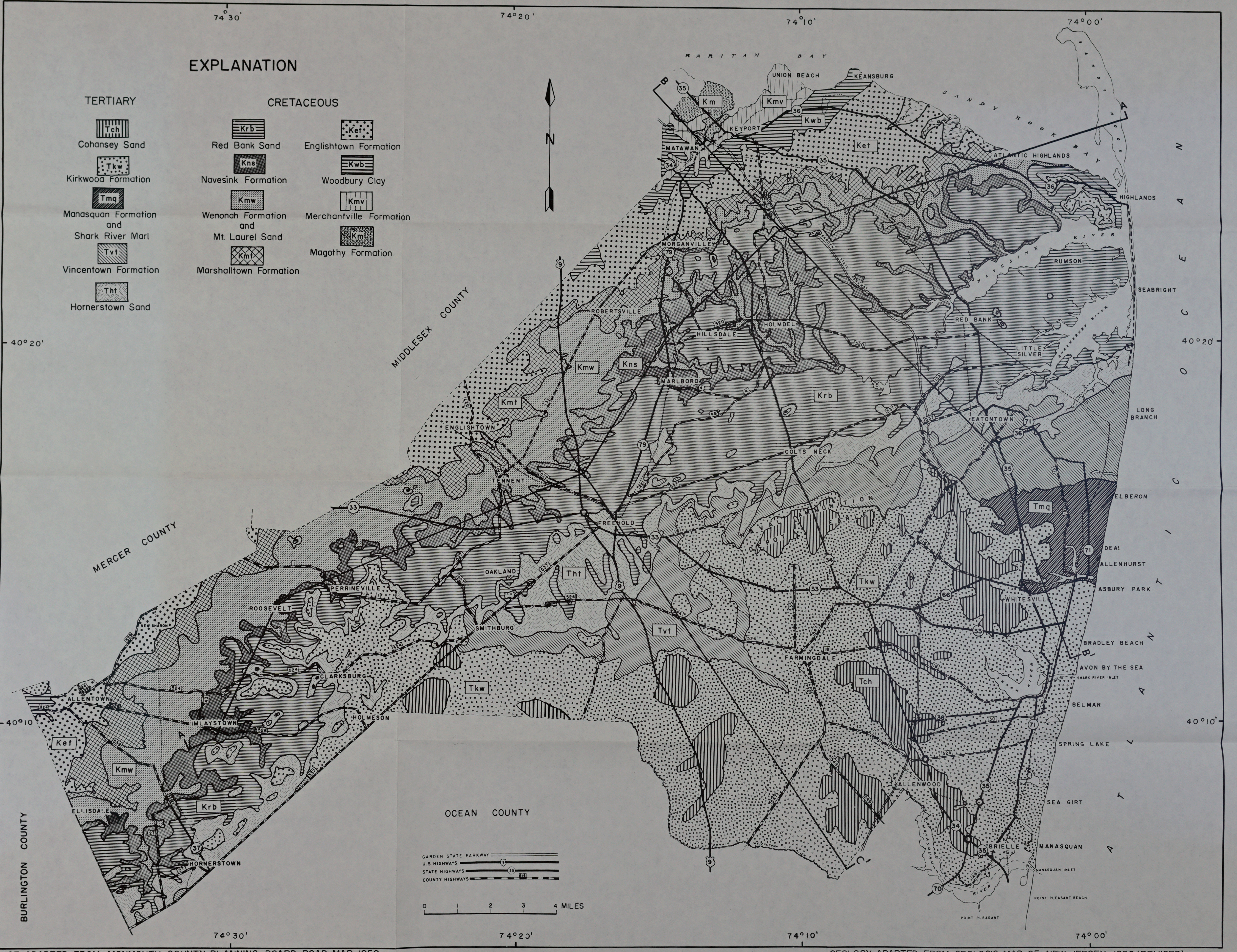
The records of 42 wells are shown in table 5. This table is a supplement to well record tables in two previous reports by Jablonski (1959 and 1960). The location of wells in these reports is shown on figure 2.

Table 5.—Records of selected wells in Monmouth County, N. J.

Well No.	Owner	N. J. Grid number	Driller	Year drilled	Altitude above sea level (ft)	Total depth (ft)	Diameter (in)	Aquifer	Depth to which well is cased (ft)	Screen setting (ft)	Static water level below L.S. (ft)	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm/ft)
22	---------------	29.14.7.8.3	Matthews Brothers	1903	---	---	--	Englishtown Formation	431	-------	12	150	---	----
23	---------------	29.24.1.6.3	George Kisner	1904	30	---	--	Englishtown(?)Formation	---	-------	---	---	---	----
24	Campbell Co.	29.23.2.2.9	A. P. Thompson	1941	120	86	8	Kirkwood Formation	---	-------	35	60	15	4.0
25	S. Burritt Boynton	29.12.8.3.9	Greenhalgh and Kaye	1954	75	220	6	Englishtown Formation	210	210-220	18	15	92	.16
26	Fred Stout	29.12.7.6.7	Stothoff Well Drilling Co.	1944	110	719	6	Raritan and Magothy Formations	625(?)	625(?)-700	133	65	---	----
27	Dept. of the Navy	29.22.2.6.7	H. A. Peters	1958	119	252	6	Wenonah Formation and Mount Laurel Sand	237	237-252	40	103	71	1.4
28	George Van Brunt	29.22.6.2.8	Greenhalgh and Kaye	1956	80	139	4	Vincentown Formation	135	135-138	17	10	6	1.6
29	Richard A. Steffan	29.23.4.4.1	Greenhalgh and Kaye	1955	90	198	4	Vincentown Formation	195	195-198	29	10	34	.29
30	George Nongesser	29.23.4.4.5	Greenhalgh and Kaye	1953	105	202	6	Vincentown Formation	198	198-202	30	30	30	1.0
31	M. Alice Holden	29.23.4.2.7	John Keidel	1950	85	157	4	Vincentown Formation	146	146-151	50	10	13	.76
32	Wardell Dairy	29.23.5.9.6	Stothoff Well Drilling Co.	1941	80	490	6	Wenonah Formation and Mount Laurel Sand	465	465-480	105	60	45	1.3
33	Frank Silverman	29.33.2.2.9	Andy White	1951	80	123	4	Vincentown(?)Formation	113	113-118	45	20	39	.51
34	Irene Horan	29.33.2.5.3	Greenhalgh and Kaye	1954	80	125	4	Vincentown(?)Formation	121	121-125	40	10	13	.76
35	R. W. Lubrich	29.33.2.4.4	Rudolph Kaye	1951	100	132	4	Vincentown(?)Formation	126	126-129	38	11	---	----
36	Leonty Cherozia	29.32.4.4.6	J. Windeler	1948	70	140	3	Vincentown(?)Formation	130	130-134	20	6	10	.6
37	Carl F. Gamer	29.22.8.5.9	Greenhalgh and Kaye	1954	90	98	6	Vincentown Formation	88	88-98	18	30	10	3.0
38	Werner Landmesser	29.21.9.3.9	Greenhalgh and Kaye	1955	225	98	4	Vincentown Formation	95	95-98	63	10	21	.50
39	Michael Gwozdik	29.21.9.3.7	Greenhalgh and Kaye	1954	175	115	4	Vincentown Formation	112	112-115	50	7.5	60	.12
40	Jack Zelenko	29.21.8.9.7	Rudolph Kaye	1949	140	133	4	Vincentown Formation	119	None	30	15	20	.75
41	Louis Glantzman	29.21.8.8.8	Greenhalgh and Kaye	1955	90	70	4	Vincentown Formation	67	67-70	6	10	14	.71
42	William Seeberger	29.21.8.7.4	Greenhalgh and Kaye	1955	160	94	4	Vincentown Formation	91	91-94	36	4	20	.20

Table 5.—Records of selected wells in Monmouth County, N. J.

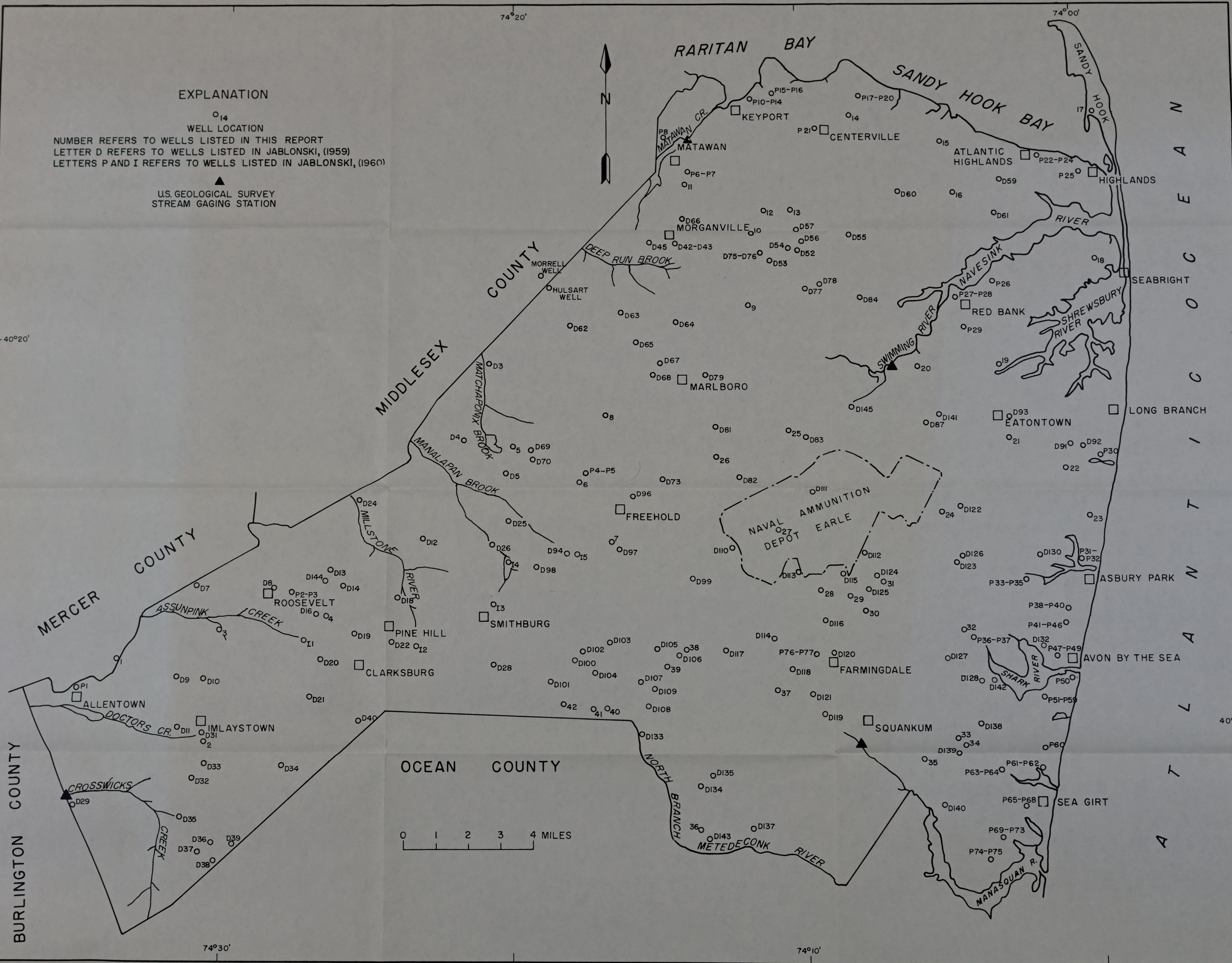
Well No.	Owner	N. J. Grid number	Driller	Year drilled	Altitude above sea level (ft)	Total depth (ft)	Diameter (in)	Aquifer	Depth to which well is cased (ft)	Screen setting (ft)	Static water level below L.S. (ft)	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm/ft)
1	George Wilson	28.23.7.1.5	Stothoff Well Drilling Co.	1958	120	464	10	Raritan and Magothy Formations	437	434-464	77	580	54	10
2	De Pinto	28.33.2.3.8	---------------	----	---	---	--	Raritan and Magothy Formations	---	-------	---	---	--	---
3	Federal Aviation	28.23.6.7.-	Somerville Well Drilling Co.	1959	250	194	6	Englishtown Formation	188	180-188	118	7	38	.18
4	Alvin Merkin	28.24.4.6.8	Greenhalgh and Kaye	1955	210	238	6	Englishtown Formation	232	232-238	80	15	40	.40
5	Mary Sweeden	29.11.7.4.4	Greenhalgh and Kaye	1956	100	68	4	Englishtown Formation	65	65-68	10	7	32	.21
6	Irving Scher	29.11.8.7.8	Greenhalgh and Kaye	1955	192	206	4	Englishtown Formation	200	200-206	40	10	40	.25
7	Cameron Roberson	29.21.2.9.4	Stothoff Well Drilling Co.	1943	140	650	6	Raritan and Magothy Formations	623	623-633	100	50	60	.83
8	Louis Zenga	29.11.8.2.2	Greenhalgh and Kaye	1955	157	146	4	Englishtown Formation	140	140-146	50	10	30	.33
9	F. Tallman	29.12.1.6.9	Greenhalgh and Kaye	1955	225(?)	146	6	Englishtown Formation	136	136-146	40	20	25	.80
10	E. Murray Todd	29.2.8.7.3	Greenhalgh and Kaye	1955	385	256	6	Englishtown Formation	250	250-256	205	10	15	.66
11	Woodbrook, Inc.	29.2.4.7.7	Greenhalgh and Kaye	1955	255	109	4	Raritan and Magothy Formations	106	106-109	55	8.3	35	.23
12	U. S. Army	29.2.8.2.7	William Travis	1957	305	318	10	Englishtown Formation	298	298-318	215	30	58	.51
13	Garden State Parkway	29.2.8.6.1	C. W. Lauman and Co.	----	234	1044	--	--------------------	---	-------	---	---	----	----
14	Cosloy and Thomas	29.3.4.1.1	Greenhalgh and Kaye	1955	20	352	6	Raritan and Magothy Formations	337	337-352	30	100	80	1.2
15	Dept. of the Navy	29.3.5.5.3	C. W. Lauman and Co.	1950	164	212	6	Englishtown Formation	204	204-212	151	11	4.5	2.5
16	---------------	29.3.8.3.1	Matthews Brothers	1900	160	301	6	Englishtown Formation	261	-------	146	40	---	----
17	Newburg Dredging Co.	29.4.5.1.2	Matthews Brothers	1904	3	427	3	Raritan and Magothy Formations	Approx. 387	-------	---	18	---	----
18	---------------	29.14.2.12	Uriah White	1899	15	715	6	Raritan and Magothy Formations	650	-------	5	---	---	----
19	Shrewsbury Dairy	29.13.6.--	Walter Cobb	1943	37	115	8	Wenonah Formation and Mount Laurel Sand	90	90-115	2.5	87	42	2.0
20	---------------	29.13.5.4.1	Matthews Brothers	1897	28	712	4.5	Raritan and Magothy Formations	644(?)	-------	18	174	---	----
21	Bambergers Shopping Center	29.13.9.2.7	---------------	1957	60	891	6	Raritan and Magothy Formations	850	850-865	---	180	---	----



BASE ADAPTED FROM MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 5.—Generalized pre-Quaternary geologic map of Monmouth County, New Jersey.

GEOLOGY ADAPTED FROM GEOLOGIC MAP OF NEW JERSEY, 1950 (REVISED)



BASE ADAPTED FROM MONMOUTH COUNTY PLANNING BOARD ROAD MAP, 1959

Figure 2.—Map of Monmouth County, New Jersey, showing the location of places and selected wells referred to in this report.

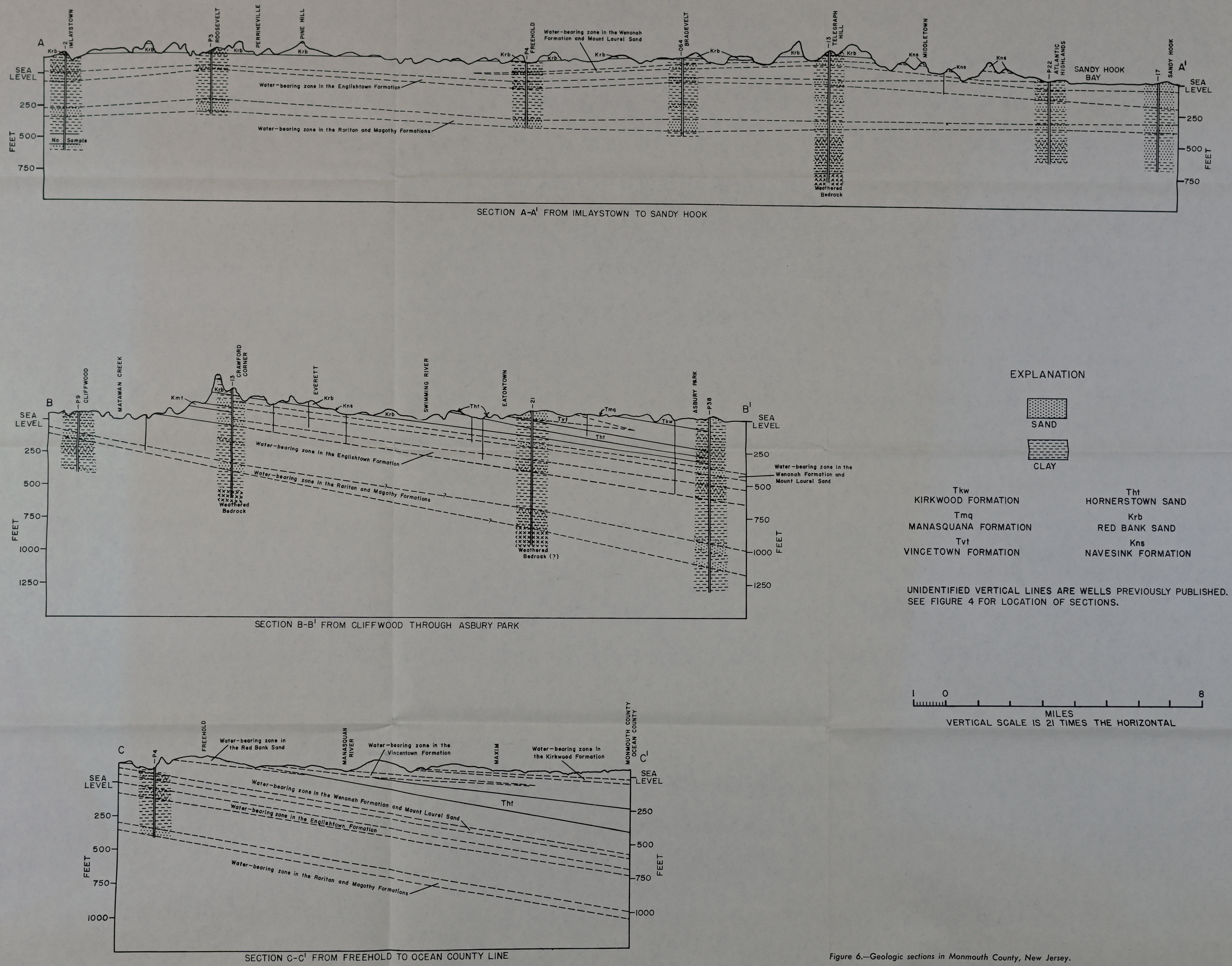


Figure 6.—Geologic sections in Monmouth County, New Jersey.