STATE OF NEW JERSEY
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT

DIVISION OF WATER POLICY AND SUPPLY

SPECIAL REPORT NO. 26

GEOLOGY AND GROUND-WATER RESOURCES OF BURLINGTON COUNTY, NEW JERSEY

Prepared in Cooperation With
United States Department of the Interior
Geological Survey

1968

GEOLOGY AND GROUND-WATER RESOURCES OF BURLINGTON COUNTY, NEW JERSEY

By

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U. S. Geological Survey

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State of New Jersey

State of New Jersey

Department of Conservation
and Economic Development

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LETTER OF TRANSMITTAL

Honorable Robert A. Roe, *Commissioner*
Department of Conservation and
Economic Development
John Fitch Plaza
Trenton, New Jersey

Dear Sir:

I am transmitting a report entitled "The Geology and Ground-Water Resources of Burlington County, New Jersey" which presents the results of an investigation that was conducted by the Ground-Water Branch, Water Resources Division, U. S. Geological Survey, in cooperation with the Division of Water Policy and Supply, as part of the state-wide program authorized by the 1958 Water Supply Law.

The report summarizes the geology pertinent to the development of the ground-water resources of Burlington County. It evaluates the relative importance of these aquifers as to their present use and suitability for future development. The probable magnitude of the ground-water supplies which can be developed from each aquifer within the County and the quality of the ground-water in each of the aquifers are discussed.

The information in this report is of great 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

December 29, 1967

ABSTRACT

Burlington County, which lies between Trenton, Atlantic City and Camden, has an area of 827 square miles. The county is in the Atlantic Coastal Plain physiographic province, has moderate temperatures and a dependable rainfall of 44 inches per year. The area is attracting new industries and additional population. Water usage is increasing with this economic growth; 26 mgd (million gallons per day) of ground water were used in 1960.

The Raritan and Magothy Formations are the most prolific producers, but the Cohansey Sand and Kirkwood Formation have a great and, as yet, untapped potential. Small to moderately large supplies have been obtained from other aquifers. The maximum average potential recharge to the ground-water reservoirs is estimated to be about 790 mgd. Presently, most of it is rejected because the aquifers are essentially full. On this basis, it is believed that ground-water supplies in Burlington County are sufficient for the foreseeable future. However, well spacing must be planned to avoid local overdevelopment.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

This investigation of the ground-water resources and geology of Burlington County is part of a program of water-resources studies in New Jersey carried on by the U. S. Geological Survey in cooperation with the Division of Water Policy and Supply of the New Jersey Department of Conservation and Economic Development.

The purposes of this investigation were: to map the extent and thickness of the water-bearing deposits; to determine the occurrence, quantity, and chemical quality of the ground water; and to estimate the amount of ground water available for future development.

Many of the selected well data have been published in an earlier basic-data report (Rush, 1962) and are considered to be representative of both low-capacity and high-capacity wells in the county. The basic-data report contains records of 208 wells, 114 drillers' logs, and 67 chemical analyses.

The present report is based on the data presented in the earlier report and on field work from April 1960 through December 1961. The investigation was made under the general direction of Allen Sinnott, district geologist.

LOCATION AND EXTENT OF THE AREA

Burlington County is in the southcentral part of New Jersey, extending from the Delaware River on the northwest to the Atlantic Ocean on the southeast. The county is adjoined by Camden and Atlantic Counties on the southwest and Mercer, Monmouth, and Ocean Counties on the northeast. (See fig. 1.) Burlington County is the largest county in New Jersey, occupying 827 square miles. It had a population of 224,499 in 1960 according to the Federal Census. Mount Holly is the county seat.

PREVIOUS AND CURRENT INVESTIGATIONS

The geology of the area has been studied intermittently during the past 100 years. Well records and drillers' logs can be found in the Annual Reports of the New Jersey State Geologist. Bascom and others (1909) published a Geologic Folio of Philadelphia, which includes parts of Burlington County. The U. S. Geological Survey began reconnaissance ground-water investigations in New Jersey in 1923 in cooperation with the State. In 1932, a report on the ground-water supplies of the Camden area was published (Thompson, 1932). In 1952, a report on the progress of the 11-county Philadelphia region investigation, which included Burlington County, was published in mimeograph form (Barksdale and Graham,

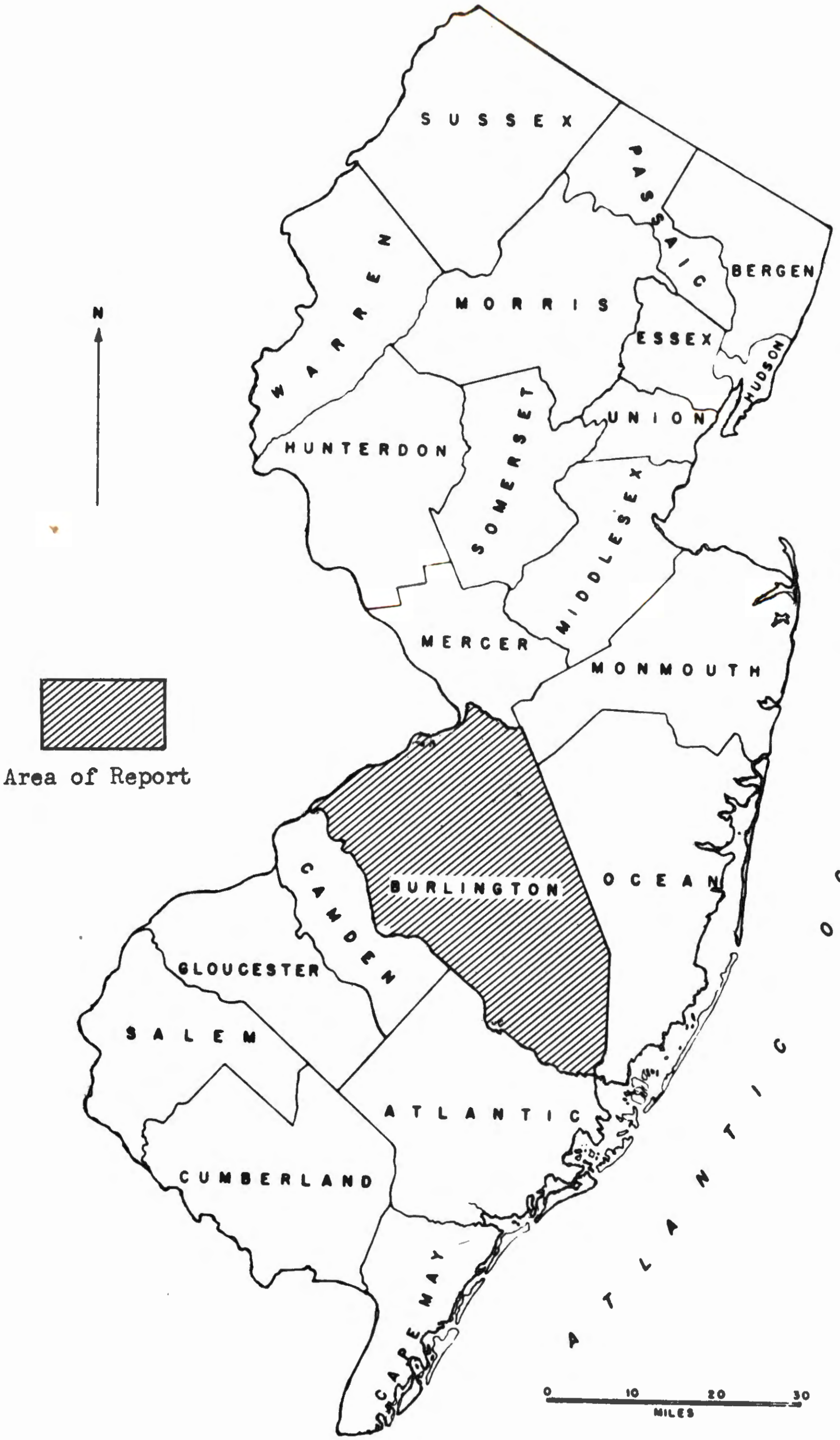


Figure 1.—Map of New Jersey showing location of Burlington County.

1952). In 1958, a comprehensive report on the ground-water resources of the tri-state region adjacent to the lower Delaware River (Barksdale and others, 1958), including Burlington County, was published.

Detailed studies are being made of four 7½-minute quadrangles in Burlington County. These quadrangles are Columbus, New Egypt, Pemberton, and Browns Mills. This work is being done by J. P. Owens and J. P. Minard of the Geologic Division, U. S. Geological Survey. Reports based on their field mapping are now in preparation for Pemberton and Browns Mills quadrangles. Their reports on the Columbus (Owens and Minard, 1962) and the New Egypt (Minard and Owens, 1962) quadrangles are now available.

The Pennsylvania Department of Commerce and the U. S. Geological Survey began in 1944 a cooperative investigation of the quality of the surface water of Pennsylvania. Three reports on this work (White, 1947 and 1951, Beamer, 1953) provide much information about the chemical quality of the water entering the tidal reaches of the Delaware River which includes that part of the river along the northwest boundary of Burlington County.

Several brief articles in technical journals relating to ground-water conditions in Burlington County have been published (Barksdale, 1952; Barksdale and Jones, 1953; Barksdale and Lang, 1955).

Similar investigations of the geology and ground-water resources of neighboring counties are in progress or are completed. A report on Mercer County (Vecchioli and Palmer, 1962) has been completed. Investigations of the ground-water resources of Ocean County, Camden County, and Monmouth County are essentially completed.

ACKNOWLEDGMENTS

The cooperation of many people of Burlington County materially aided the investigation. Industrial officials, farmers, and other residents of the area furnished information on their wells and allowed access to their properties for collecting geologic and hydrologic data. Special thanks are due the staffs of the Bureau of Geology and Topography and Division of Water Policy and Supply (both of the State of New Jersey) for furnishing data from their files. The local well drillers were helpful in the evaluation of logs and other data. The writer acknowledges the advice of his colleagues of the Geological Survey.

GEOGRAPHY

PHYSIOGRAPHY

Burlington County is in the Atlantic Coastal Plain physiographic province, which extends from Massachusetts to Florida. The topography of the county is that of a low-lying, gently-rolling plain. The general altitude of the area ranges from sea level to 150 feet; the maximum altitude is about 200 feet.

The Coastal Plain of New Jersey has been divided into three physiographic subdivisions (fig. 2) by Owens and Minard (1960): an outer lowland where the altitudes rarely exceed 50 feet; an inner upland with altitudes ranging up to nearly 400 feet in Monmouth County, but not greatly exceeding 200 feet in Burlington County; and an inner lowland with altitudes generally below 100 feet.

All three subdivisions of the Coastal Plain are present in Burlington County. The outer lowland is located in the southern part of the county. Here, it is a fairly level plain modified somewhat by recent stream action of the Mullica, Wading, and Bass Rivers. The inner upland, although making up the bulk of the Coastal Plain elsewhere, is not well developed in Burlington County. It is a southward sloping, highly dissected plateau. Erosional outliers, remnants of this plateau, are common in the county. The prominent hills at Arneys Mount, Mount Holly, and Juliustown are of this nature. The inner upland forms the headwaters for all the major streams of the county. The inner lowland occupies the area bordering the Delaware River. Altitudes of this lowland are much less than in the inner upland, ranging from about 10 to 100 feet. This lowland is well developed in Burlington County, occupying nearly half of the county. All the streams of this lowland drain to the Delaware River. The principal stream is Rancocas Creek.

Quackenbush (1955) divides the Coastal Plain into two major divisions, an inner and an outer area. The distinction between them is the degree of sandiness and the extent of the clay strata. The inner Coastal Plain has soils with a greater proportion of fine material and greater fertility than the outer Coastal Plain. Because of the fine material, the inner area has greater moisture retention capacity.

The inner area coincides with the outcrop area of the pre-Miocene formations. (See fig. 3.) The outer area is the outcrop area of the Kirkwood Formation of Miocene age and the Cohansey Sand of Miocene(?) and Pliocene(?) age.

CLIMATE

The climate of Burlington County is characterized by a relatively moderate range of temperatures, by mild winters, and by a generally dependable rainfall. Winter temperatures below 0°F are rare and summer temperatures seldom exceed 100°F.

U. S. Weather Bureau records of precipitation and temperature data are summarized in table 1. At Pemberton, July, the hottest month, has a mean temperature of 75.7°F and February, the coldest month, has a mean temperature of 34.2°F. The average annual temperature is 54.4°F. The growing season (last killing frost in the spring to the first killing frost in the fall) averages about 200 days.

The average annual precipitation at Pemberton is 43.64 inches, ranging from about 30 inches to about 60 inches.

The prevailing wind direction during the summer months is from the southwest, whereas northwest winds prevail during the winter.

Table 1.—Monthly and annual precipitation and air temperature at Pemberton, N. J. (1931 to 1955)

(From publications of the U. S. Weather Bureau)

Month	*Average precipitation (inches)*	*Average mean air temperature (°F)*
January	3.32	34.4
February	2.62	34.2
March	3.73	42.3
April	3.44	52.1
May	3.98	63.0
June	3.89	71.2
July	4.35	75.7
August	4.93	74.0
September	3.69	67.5
October	3.22	57.0
November	3.56	46.1
December	2.91	35.7
Annual	43.6	54.4

ECONOMY

The 1960 population of 224,499 in Burlington County represents an increase of 65 percent over the 1950 population of 135,910. The New Jersey population increased only about 25 percent during the same period.

About 85 percent of the county population lives in the northwest third of the county; about 71 percent is classified as rural.

Farmland comprised about 35 percent of the county area in 1959 (U. S. Bureau of the Census, 1961, p. 110). The principal crops are fruits, vegetables, cranberries, and blueberries. Dairy farms constitute the bulk of livestock farming within Burlington County. Most of the farms are located in the northwest third of the county. Most of the remaining part of the county is timberland consisting chiefly of scrub oak and pine. Some timber is harvested (Quackenbush, 1955, p. 40). A summary of population and agricultural statistics is given in table 2.

Table 2.—Population and agricultural statistics of Burlington County, N. J.

Year	*Population (thousands)*	*Percentage of land in farms*	*Irrigated land (acres)*
1930	94	—	—
1940	97	60	—
1945	—	34	—
1949	—	—	8,387
1950	136	40	—
1954	—	40	13,779
1959	—	35	—
1960	224	—	—

The county is known principally for its agriculture. However, it has a rapidly growing industrial economy along the Delaware River. The principal manufactured items include fabricated and primary metal products, chemicals, textile goods, processed food, and electronic parts and equipment. Other economic products include bulk food, dairy products, and sand and gravel.

The county is divided into 40 municipalities. About 200 communities bear names; however, most are unincorporated. Because of the general use of these names by county residents, some of these places will be referred to by name.

GEOLOGIC HISTORY AND STRUCTURE

GEOLOGIC HISTORY

Paleozoic Era

More than 400 million years ago, in Early Paleozoic time, the oldest known rocks underlying what is now Burlington County were deposited as sands and muds in the Appalachian geosyncline. The geosyncline was a trough roughly paralleling the present Atlantic coast that gradually sank and was inundated by arms of the ocean. Deposition and sinking occurred simultaneously.

The resulting deposits, that accumulated to a great thickness, created sufficient pressure and heat to form sandstones, shales, and arkoses. About 250 million years ago, toward the end of the Paleozoic era, the area underwent a great series of structural, mountain-building movements, known as the Appalachian Revolution. Intrusions of molten rock accompanied the folding and thrust faulting that formed the mountain ranges, forming gneisses and schists from the pre-existing sedimentary deposits and igneous rocks. A long period of erosion followed.

Mesozoic Era

The erosion that started in the Paleozoic era continued in the Triassic and Jurassic periods of the Mesozoic era. During this time, the mountains were leveled to a nearly flat surface, or "peneplain." Then about 130 million years ago, starting in the early part of the Cretaceous period, the land was gradually depressed while the Appalachian Mountains to the west were uplifted, and streams deposited layers of sand, clay, and gravel along their channels and in bogs and estuaries. Sea level fluctuated, but subsidence continued as the dominant movement. Deposition of the sediments was intermittent, owing to the fluctuating sea. The downward movement of the area during these depositional intervals was a hinge-type movement, the axis of movement located near and roughly parallel to the present-day Delaware River between Trenton and Philadelphia. As a result, the present-day dip of the beds increases from younger to older deposits in the stratigraphic sequence. Because of this dip increase, wedge-shaped beds were generally produced, increasing in thickness to the southeast.

Cenozoic Era

An interval of erosion ensued, resulting from the uplift of the area and the recession of the sea. The landward edges of the Cretaceous beds were removed. The next advance of the sea occurred about 70 million years ago during the Tertiary period when clays, sands, and gravels were deposited during periods of fluctuating seas.

The Quaternary period began about a million years ago with the advance of the Pleistocene glaciers toward this area. There is no evidence that the glaciers covered Burlington County, but they played a part in its geologic history. Sands, gravels, and clays of this period were deposited in stream valleys; the materials were supplied by the glaciers and transported by melt waters.

The last glacial front began to retreat less than 20 thousand years ago, marking the close of the Pleistocene epoch. Relatively minor deposits, laid down since that time, belong to the Recent epoch.

GEOLOGIC STRUCTURE

Burlington County is underlain by unconsolidated beds of clay, sand, and gravel. These beds have a gentle dip to the southeast; their eroded edges are exposed at the surface in bands trending northeast-southwest, as indicated on the geologic map (fig. 3) and in the cross sections (figs. 4, 5, and 6).

There is no agreement as to the exact strike and the dip of these beds. However, the rate of dip is generally agreed to be between 10 and 100 feet per mile to the southeast. The strike of the beds in most cases appears to be near N55°E.

Spangler and Peterson (1950) prepared a report which, in part, is concerned with the geology of New Jersey. Dip figures of most formations are presented.

Johnson and Richards (1952) attempted to correct and to bring up to date the findings of Spangler and Peterson. They in turn give their interpretation of the dips of the formations.

Minard and Owens (1960) describe a differential subsidence in the southern part of the New Jersey Coastal Plain since early Late Cretaceous Time. They suggest that the differential subsidence resulted in a progressive easterly shift in strike of the successively younger formations. They point out that a small-scale geologic map of New Jersey reveals this. Their detailed mapping in four 7½-minute quadrangles (Columbus, Pemberton, New Egypt, and Browns Mills) strengthens this reportedly overlooked condition. They suggest that this change in strike was caused by a downward movement to the south of the New Jersey Coastal Plain, accompanied by a differential uplift in the northern part of the Coastal Plain. Downwarping, while deposition was going on, caused the thickening of the beds to the south and southeast.

The present writer, in preparing this report, has done detailed subsurface correlating and mapping in Burlington County. Electric, gamma

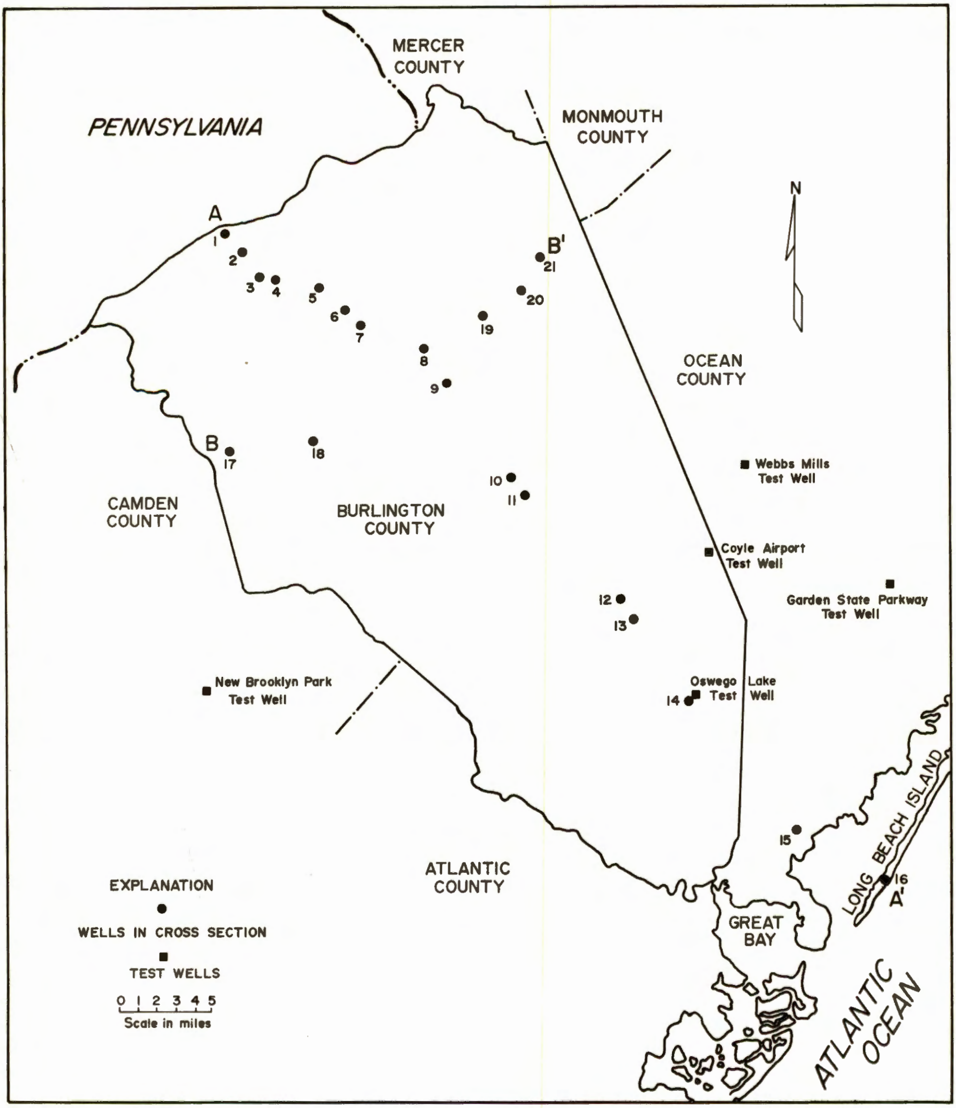


Figure 4.—Map of Burlington County showing location of test wells and geologic cross section.

ray, drillers' logs, and sample logs were used to evaluate the geologic structure within the county.

To aid in geologic and hydrologic interpretations, four test wells were also drilled, by cable-tool method, in Burlington County and in nearby parts of Ocean County (fig. 4). These wells penetrated the Cohansey Sand, the Kirkwood Formation, and part of the Manasquan Formation. With the use of twenty electric logs and driller's logs of test wells drilled in 1951 by Transcontinental Gas Pipe Line Corporation and recently made available to this writer, it is now possible to draw structural contour maps of the entire county. Only the more prominent, easily recognized formation contacts were chosen to be contour mapped, but from these the general structure of the Coastal Plain in Burlington County is easily seen. The horizons mapped were: top of the Wissahickon Formation (fig. 7), top of the first sand of the Raritan and Magothy Formations (fig. 8), top of the Englishtown Formation (fig. 9), the top of the Mount Laurel Sand (fig. 10), and the base of the Kirkwood Formation (fig. 11). From these and additional data the average altitudes of several horizons have been determined. These findings and those of Spangler and Peterson, Johnson and Richards, and Minard and Owens are summarized in table 3.

The conclusions as to the dips of the formations agree closely with those of Johnson and Richards (1952, p. 2152); however, they made no estimate of the strikes. The strikes determined by this writer and those of Minard and Owens (1960 and 1962), are at some variance. The difference may be the result of the size of the area studied in each case. The writer's attitudes apply only to the general conditions in Burlington County, whereas those of Minard and Owens are applied to the New Egypt quadrangle and to the entire Coastal Plain in New Jersey.

This writer's findings are similar to those of Minard and Owens in regard to the differential subsidence and the progressive easterly shift in strike of the younger formations. However, the amount of shift in the strike was found to be much less than the 30 to 40 degrees reported by Minard and Owens.

Table 3.—Attitud

	Formations grees)	
Stratigraphic unit	*Spang Pete*	*Rush*[1]
Pliocene(?) and Miocene(?) Series		
Cohansey Sand	9-1	
Miocene Series		
Kirkwood Formation	12	N 58 E
Eocene Series		
Manasquan Formation	15	N 58 E
Paleocene Series		
Vincentown Formation	20	
Hornerstown Sand	20	
Monmouth Group		
Red Bank Sand	20	
Navesink Formation	20	
Mount Laurel Sand	25	N 57 E
Matawan Group		
Wenonah Formation	25	
Marshalltown Formation	25	
Englishtown Formation	25	N 54 E
Woodbury Clay	25	
Merchantville Formation	25	
Upper Cretaceous Series		N 50 E
Magothy Formation	30	
Raritan Formation	40	
Lower Paleozoic(?) Series		
Wissahickon Formation	40	N 51 E

[1] These attitudes are an average for Burlingt of the Wissahickon Formation. The attitudes for the Wis

GROUND WATER

HYDROLOGIC SETTING

Large quantities of ground water are present within pore and void spaces of the unconsolidated sediments that underlie Burlington County and the Coastal Plain of New Jersey. Precipitation is the principal source of this vast amount of fresh water; however, at great depths and near saline surface-water bodies some salty ground water occurs. The fresh water is generally of good quality with a low mineral content.

The ground water is moving slowly through the sediments from the areas of recharge from precipitation to areas of natural and artificial discharge. The unconsolidated sediments vary greatly in their ability to transmit and store this water. The transmitting ability is dependent on the interconnection and size of the water-filled spaces within the sediments, whereas the storing capacity is dependent on the total volume of these interconnected spaces. Sand and gravel beds can transmit stored ground water better than clay and silt beds. In Burlington County the aquifers are composed of sand and gravel, the confining beds are of clay and silt. In the outcrop, the aquifer is under water-table conditions, downdip the aquifer is artesian if confining beds are present above and below the aquifer. Water will rise in a well above the top of an artesian aquifer.

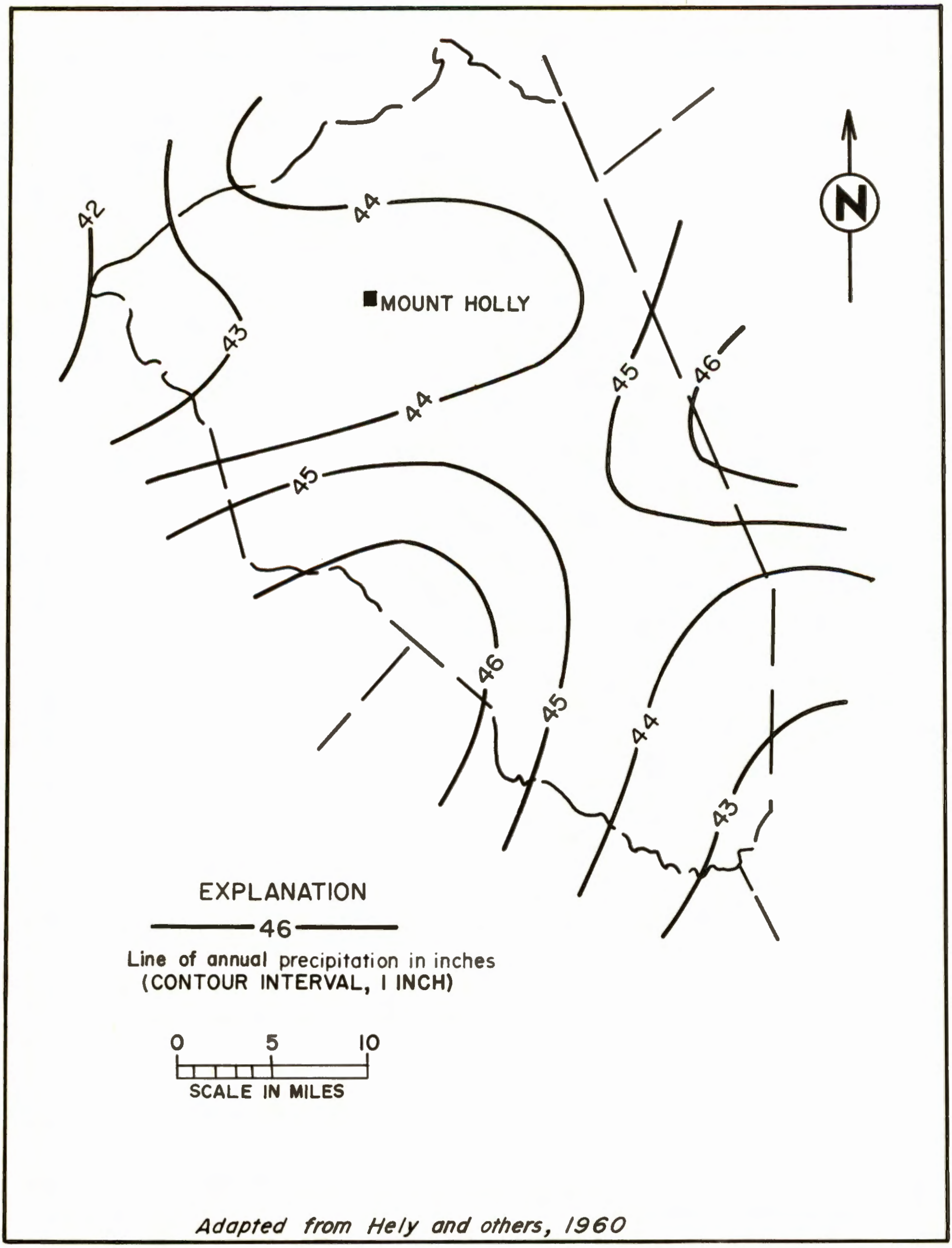
The formations that contain aquifers in Burlington County are: the Raritan and Magothy, the Englishtown, the Wenonah Formation and Mount Laurel Sand, the Vincentown Formation, the Kirkwood Formation, and the Cohansey Sand.

Additional information on the general topics of ground-water occurrence and movement is available in the U. S. Geological Survey Water-Supply Papers 489 (Meinzer, 1923) and 887 (Wenzel, 1942).

PRECIPITATION, WATER LOSS, AND RUNOFF

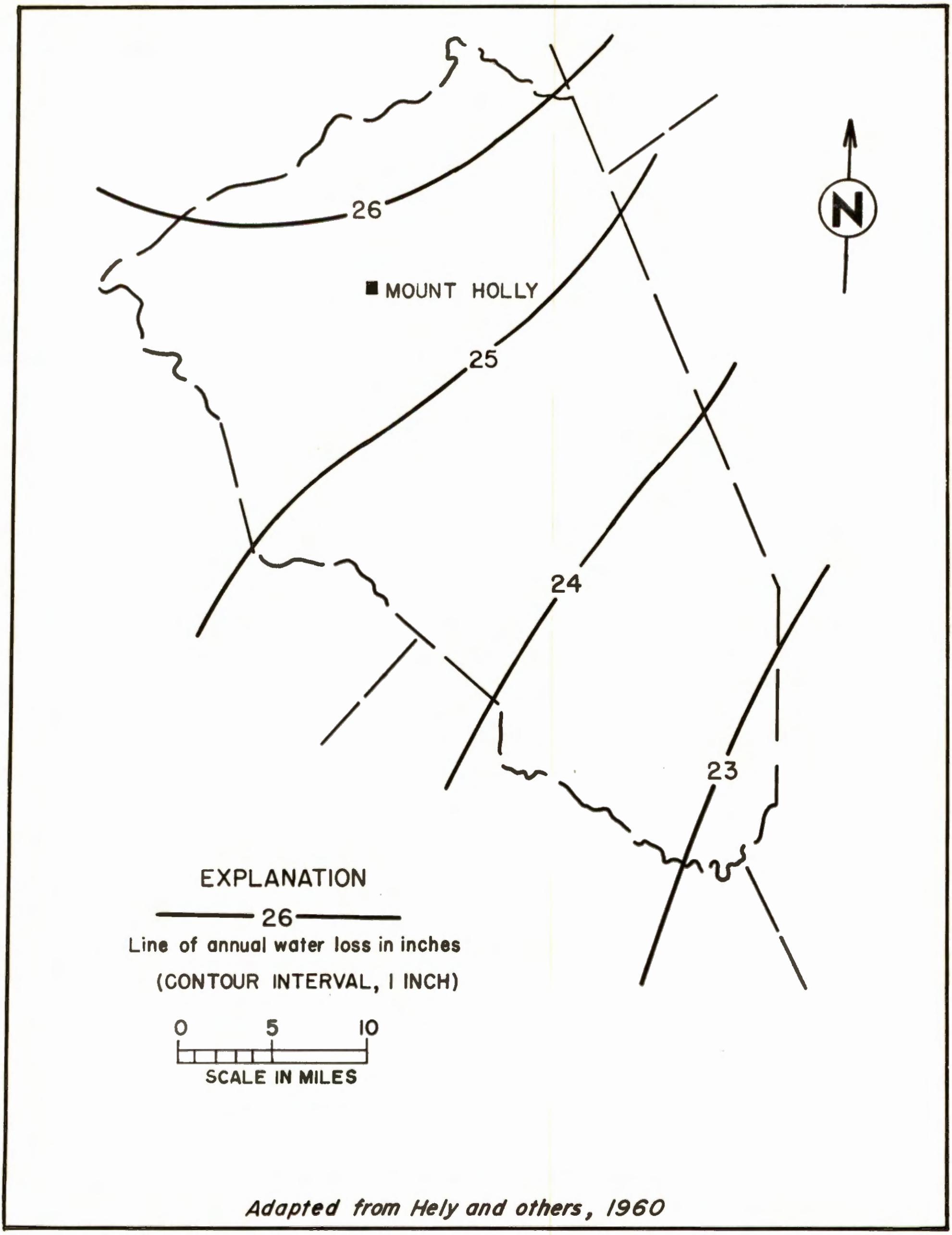
The data and discussion presented by Hely, Nordenson, and others (1961) in a hydrologic atlas of an area including Burlington County, form the basis for the information presented in this part of the report. Three maps showing precipitation, water loss, and runoff in Burlington County are included. The 30-year base period, 1921-50, was selected for all average annual values. The average annual precipitation is shown in figure 12.

Water loss is the portion of precipitation that never becomes runoff. Evaporation from water and land surfaces plus transpiration from plants account for most of it. It is frequently referred to as "Nature's take" as it is a demand that must be satisfied. The average annual water loss



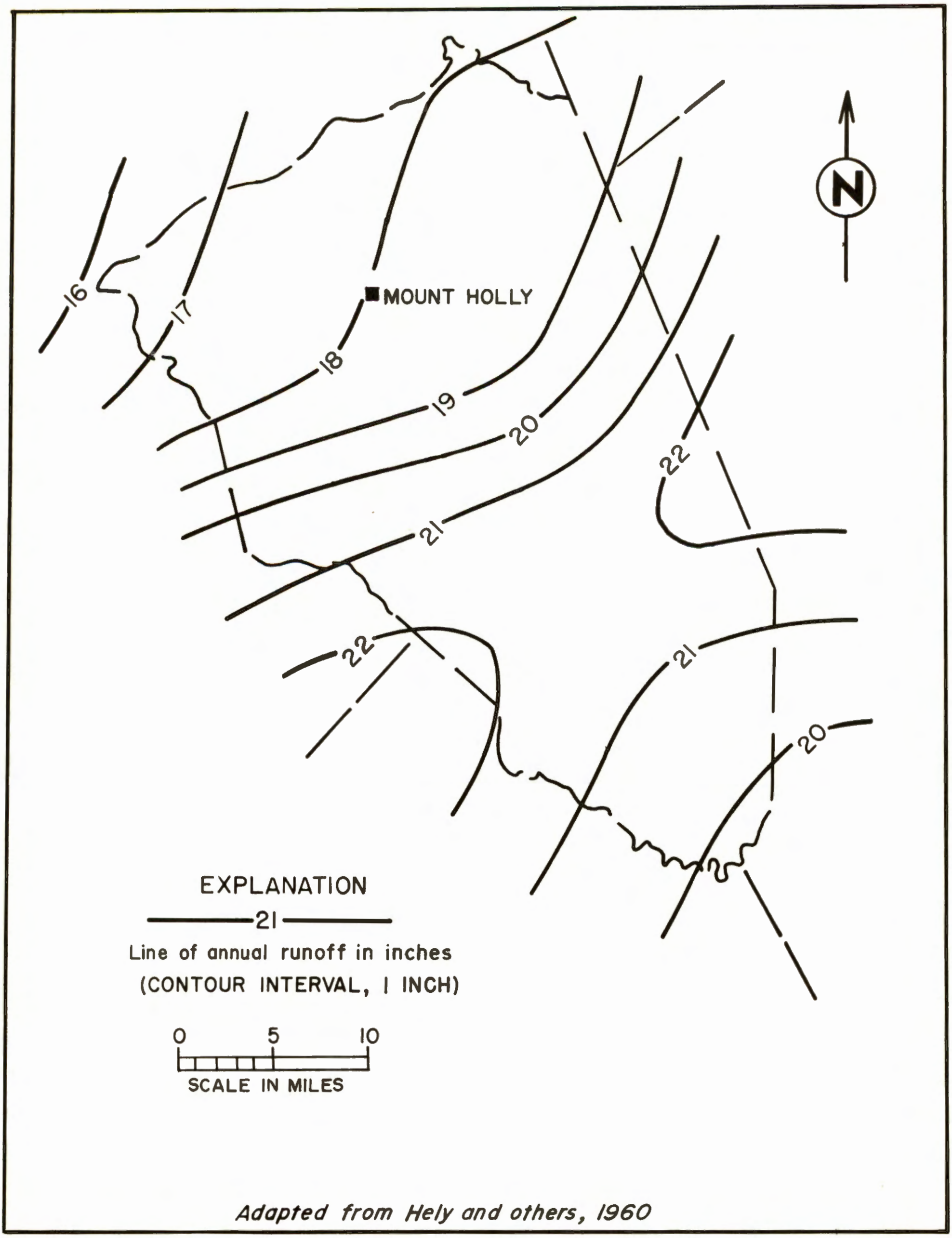
Adapted from Hely and others, 1960

Figure 12.—Map showing mean annual precipitation, 1921-50 for Burlington County, N. J.



Adapted from Hely and others, 1960

Figure 13.—Map showing mean annual water loss, 1921-50 for Burlington County, N. J.



Adapted from Hely and others, 1960

Figure 14.—Map showing mean annual runoff, 1921-50 for Burlington County, N. J.

is shown in figure 13. Temperature is the dominant factor controlling evaporation and water loss.

Runoff is the portion of precipitation that is left over after the demands of water loss have been satisfied. Runoff has two forms, surface and subsurface. Subsurface runoff is the flow of ground water beneath and between stream channels. The average annual runoff is shown in figure 14. This amount of water is potentially available for recharge to the county aquifers, assuming 100 percent infiltration. However, in Burlington County, the aquifers are essentially full of water and most of it is rejected.

WATER LEVELS

Water levels in wells in Burlington County fluctuate mainly in response to recharge to the aquifer, discharge of ground water from it, and loading and unloading of the land surface near the tidal reaches of the major streams.

Water levels are generally highest during the winter and early spring. They begin to decline at the start of the growing season and generally continue to decline until the first killing frost of fall. This decline represents a net loss in storage of ground water. During the growing season, evapotranspiration is high and the resulting water loss reduces the amount of rainfall that enters storage. During this period subsurface runoff continues. Total water consumption by industrial and public supply users is also highest during this same period.

After the growing season, larger amounts of water enter storage, generally exceeding the natural and artificial discharge of ground water within the county. This increase in total ground-water storage is reflected in the general rise of the water levels in the observation wells of the county. Within the areas of locally heavy pumpage, the hydrologic conditions are somewhat different. The pumpage of nearby wells produce sharp fluctuations of several feet. (See figure 15.) The average water levels are reduced, with a cone of depression in the water levels associated with the heavy pumpage and centered about it.

Shown graphically in figure 16 is a typical, long-term record of water levels of an unconfined aquifer under natural conditions in the Penn State Forest observation well, of southeastern Burlington County. The monthly precipitation for the area is also shown. This record shows the seasonal and the long-term trends in water storage. Because the area is not being affected by pumpage, the long-term trend of the water levels shows little change. The typical, seasonal fluctuations are shown by high water levels in the winter and spring and a corresponding decline during the rest of the year. The short-term fluctuations in the water levels are generally related to the rate of precipitation.

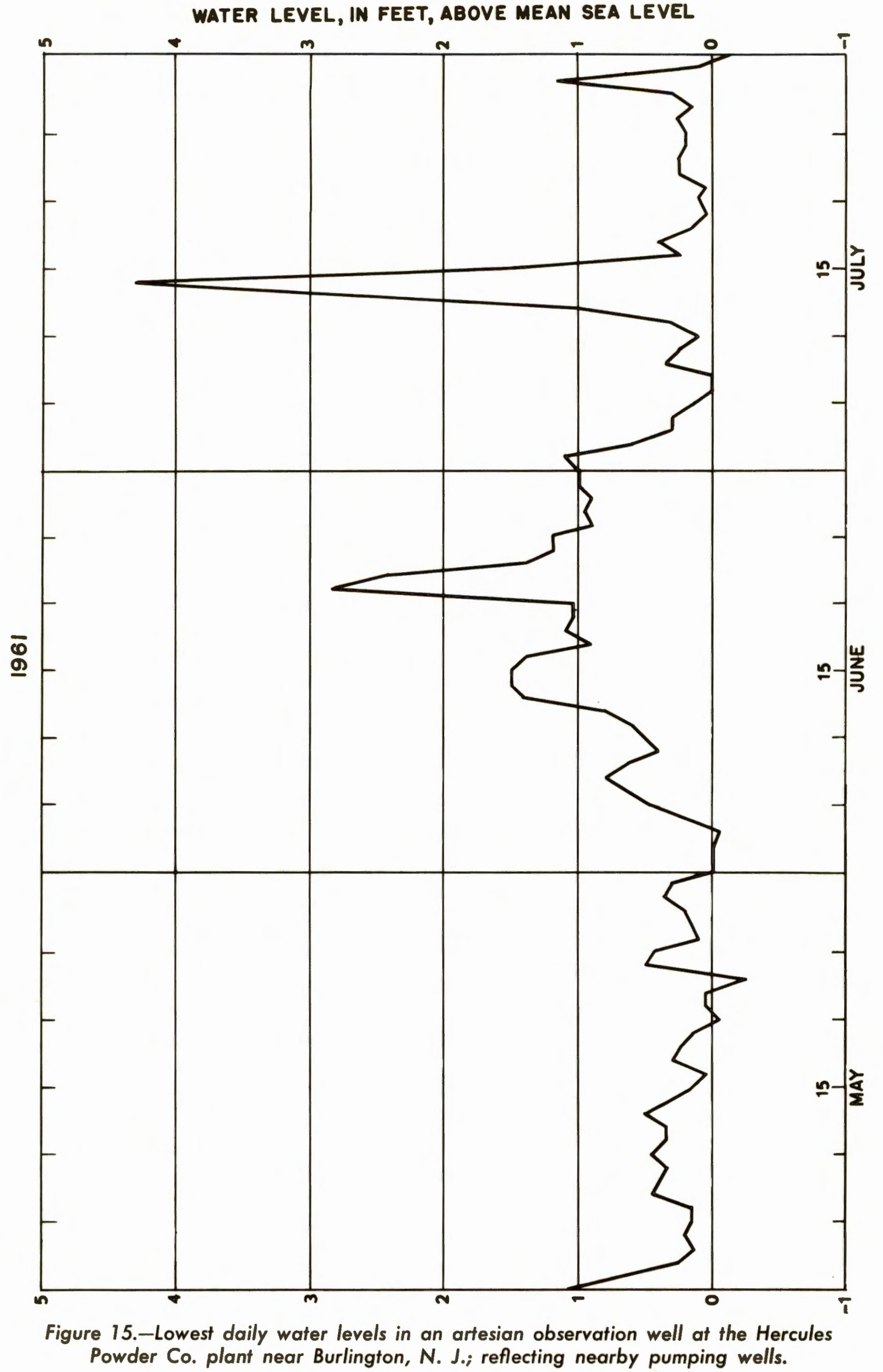


Figure 15.—Lowest daily water levels in an artesian observation well at the Hercules Powder Co. plant near Burlington, N. J.; reflecting nearby pumping wells.

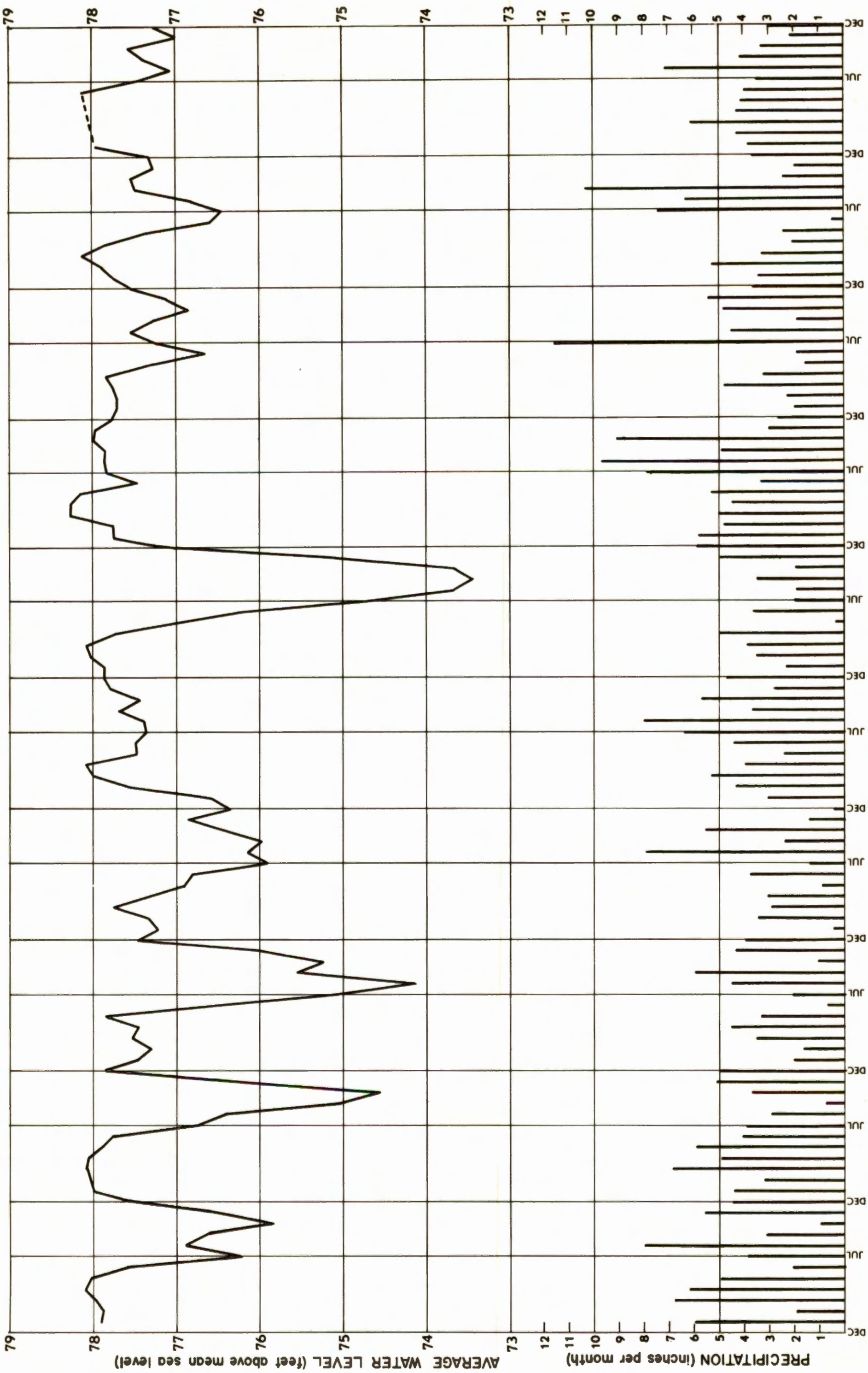


Figure 16.—Graph of long-term fluctuations of water levels in Penn State Forest observation well, and of monthly precipitation.

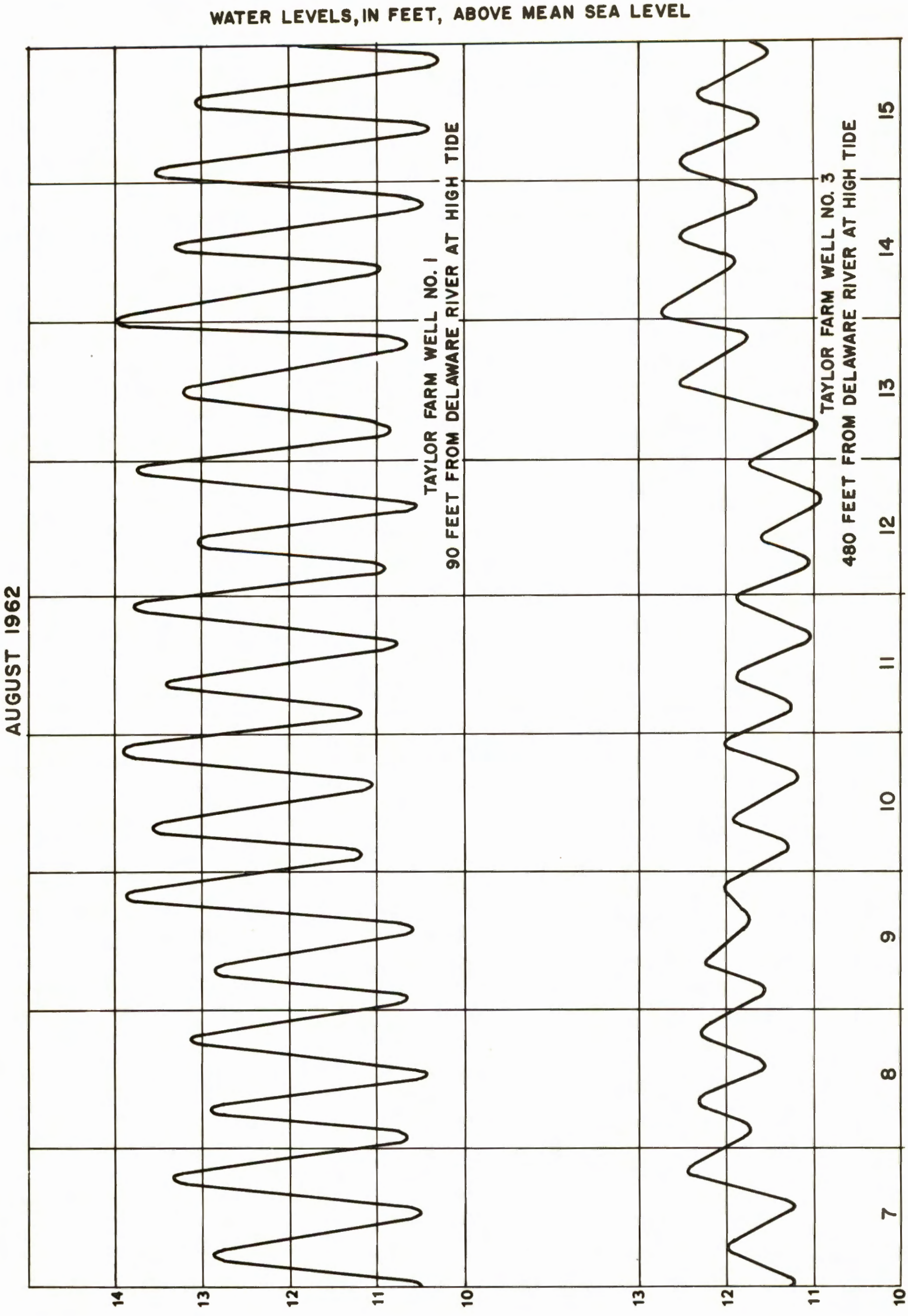


Figure 17.—Graph showing the tidal fluctuation of water levels in the Taylor Farm wells Cinnaminson Township, Burlington County, N. J.

For confined aquifers, the trends are similar, except that the short-term changes in water levels due to precipitation are absent. The remaining trends are similar to the unconfined aquifer trends, except that the water-level changes are generally of less magnitude.

Water levels in wells that are located adjacent to the tidal reaches of major streams show a cyclic fluctuation of water levels in response to the changes in river levels caused by the ocean tides. These water-level changes can amount to as much as 3 or 4 feet in wells located on the edge of the river, but the effect dies out within a distance of a few thousand feet from such streams. (See figure 17.)

AQUIFER CHARACTERISTICS

In a later section of this report, the hydrologic characteristics of the formations will be described. Various parameters are used in the evaluation of these characteristics. A discussion of these parameters is presented in this section of the report in order to aid the reader in his understanding of the data and conclusions. The following discussion is brief; references are given should the reader need additional information.

Mechanical Analysis

A mechanical analysis is the determination of the distribution of various particle sizes in a sediment sample. Particle sizes smaller than 0.0625 millimeters were determined by the hydrometer method of wet analysis, and sizes larger than 0.0625 millimeters were determined by wet-sieve analysis. (See Terzaghi and Peck, 1948, p. 17-19, for a further discussion.) The analyses were divided into groups according to their particle sizes. This classification system (table 4) is that used by the Geological Survey, and is essentially the same as the grade scale originally proposed by Wentworth (1922). As part of this investigation, mechanical analyses were made of about 41 samples. The classification is given in the following table.

Table 4.—Classification of clastic sediments by particle size (Wentworth, 1922).

Name		Diameter	
		Millimeters	*Inches*
Gravel	very coarse	32-64	1.26-2.52
	coarse	16-32	0.63-1.26
	medium	8-16	0.32-0.63
	fine	4- 8	0.16-0.32
	very fine	2- 4	0.08-0.16
Sand	very coarse	1- 2	0.04-0.08
	coarse	0.5- 1	0.02-0.04
	medium	0.25-0.5	0.01-0.02
	fine	0.125-0.25	0.005-0.01
	very fine	0.0625-0.125	0.0025-0.005
Silt (undivided)		0.004-0.0625	0.00016-0.0025
Clay (undivided)		less than 0.004	less than 0.00016

Permeability and Transmissibility

Permeability is the capacity of rock or soil material to transmit water under a head difference. The coefficient of permeability is defined as the rate of flow of water in gallons per day, through a cross-sectional area of 1 square foot of aquifer under a hydraulic gradient of 1 foot per foot at a temperature of 60°F. (See Wenzel, 1942.)

The coefficient of transmissibility is the rate of flow of water in gallons per day, through a vertical strip of the aquifer 1 foot wide, extending the full saturated thickness of the aquifer under a unit hydraulic gradient at 60°F. It can be obtained by multiplying the coefficient of permeability by the saturated thickness of the aquifer. (See Ferris, 1955, p. 3.) The following table shows the classifications of the coefficient of permeability and of transmissibility in terms of water-transmitting abilities in Burlington County.

Ability of material to transmit water	*Coefficient of Permeability gpd/sq ft*	*Coefficient of Transmissibility gpd/ft*
Excellent	over 1000	over 100,000
Fair to Good	100 to 1000	10,000 to 100,000
Poor	less than 100	less than 10,000

Coefficient of Storage

The coefficient of storage is 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 (Ferris, 1955, p. 5).

Expressed mathematically, it is dimensionless, and is usually expressed as a decimal fraction. Under water-table conditions, it is essentially equal to the specific yield of the aquifer.

The coefficient of storage affects the rate of lateral spread of the cone of depression around a pumping well, the rate of lateral growth being inversely proportional to its value. On the other hand, the coefficient of transmissibility affects both the radius of the cone and its depth, the radius for any given time increasing with increased transmissibility, and the depth being inversely proportional to the transmissibility. The rate of growth and the lateral extent of the cone of depression are independent of the rate of pumping; the rate of pumping affects only the depth of the cone (Theis, 1957, p. 10-11).

The coefficients of storage of aquifers in Burlington County generally range from 0.2 to 0.05 for water-table conditions and from 1 x 10^{-4} to 6 x 10^{-4} for artesian conditions.

Specific Capacity

Specific capacity of a well is the rate of yield per unit of drawdown, generally expressed in gpm/ft. The specific capacity is related to the coefficients of permeability, transmissibility, and storage of the aquifer but well losses reduce the measured value. High specific capacity indicates an aquifer of high transmissibility, and low specific capacity, a poorer aquifer. The correlation between transmissibility and specific capacity was first published by Theis and others (1954). The following table gives a rating for 12-inch diameter wells for use in Burlington County, on the basis of specific capacity. Artesian conditions are assumed, with a coefficient of storage of the aquifer of 2 x 10^{-4}, and the well having no well losses.

Ability to yield water	*Specific Capacity gpd/ft*
Excellent	over 40
Fair to good	5 to 40
Poor	less than 5

Well losses can be anticipated for most wells because of less-than-optimum construction and development. Therefore, a more realistic scale would be obtained by assuming a general well loss of 50 percent with a corresponding reduction of the specific capacity values of the table by one-half.

GROUND-WATER USE

Most of the ground-water pumpage is concentrated in the northern third of the county. The amount of pumpage for each aquifer in the municipal units is shown in figure 18. The pumpage is greatest between the Delaware River and the New Jersey Turnpike, where most of the industrial and public supply pumpage takes place.

More than half of the county ground-water pumpage can be classified as public supply. The following table shows the pumpage by various users in Burlington County.

User	*Percentage of total county pumpage*	*Pumpage (mgd)*
Public Supply	53	13.8
Industrial	24	6.2
Irrigation	1	.3
Others (mostly domestic and farm)	22	5.7
Total	100	26.0

QUALITY OF GROUND WATER

The chemical and physical characteristics of the ground water are influenced chiefly by the mineral composition of the sediments and soil material with which the water comes in contact and the length of time water remains in a particular geologic environment. From these, substances are dissolved which may form undesirable concentration of certain chemical constituents in ground water and in turn limit or prevent its use. The important constituents and properties of ground water in Burlington County as related to U. S. Public Health Service Standards (1962) are summarized in table 5. Several classifications on ranges of hardness-of-water have been reported but there appears to be no clear line of demarcation. The hardness-of-water classification used in this report is given in table 6. Most of the water pumped in Burlington County is classified as either soft or moderately hard.

Additional information on water quality may be obtained in publications by Hem (1959), and Rainwater and Thatcher (1960). Water analyses are given by Rush (1962) in the basic-data report that preceded this report as part of this county investigation. Most of the conclusions about water quality in this report are based on these and some additional data.

Table 6.—Hardness of water.

Hardness range, ppm	*Rating*
0- 60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

Table 5.—Summary of the important constituents and properties of ground water in Burlington County, N. J.

Constituents and Properties	*1962 U. S. Public Health Service Standards*[1]	*Range in Burlington County*	*Effect of High Concentrations*	*Note*
Hardness	—	3-260 ppm	Excessive soap consumption	Caused mostly by calcium and magnesium. (See table 6)
Iron	0.3 ppm	0-16	Staining of plumbing fixtures and laundry, unpleasant taste	Can be removed with treatment by chemicals or aeration.
Manganese	.05	0-3.6	Staining of plumbing fixtures, laundry and cooked food	Will be removed by iron removal treatment.
Dissolved Solids	500	23-205	Loss of palatability	Index of total mineralization of the water.
Chloride	250	.8-31	Salty taste, corrosion of pipes and fixtures	Concentrations up to 1000 ppm may be physiologically safe.
Fluoride	2	0-1.9	Mottling of children's teeth	Will aid in the prevention of tooth decay if present at an optimum concentration of 1 ppm.
Nitrate	45	0-21	—	Water with nitrate concentration exceeding U. S. Public Health Standards should not be used in infant drinking or formula water. High nitrate concentrations indicate organic pollution.
Temperature	—	55-75°F	—	Water temperature in the first 200 feet below land surface is about equal to the mean annual air temperature of 53°F. Below this depth, the temperature gradually increases.

[1] These chemical substances should not be present in a water supply in excess of the listed concentrations, where other suitable supplies are available, according to the U. S. Public Health Service Standards.

Table 7.—Summary of the geologic formations and their hydrologic characteristics.

System	*Series*	*Formation*	*Symbol*	*Thickness*	*Lithology*	*Hydrologic Characteristics*
Quaternary	Recent	Alluvium and eolian sand	Qal	0-(?)	Clay, silt, and sand.	Too thin to be tapped for water.
	Pleistocene	Cape May	Qcm	0-40	Sand and gravel, local clay.	Usually hydraulically connected with overlain aquifers to increase the saturation thickness.
		Pensauken	Qps	0-40		
		Bridgeton	Qbr	0-40		
Tertiary	Pliocene(?)	Beacon Hill	Tbh	0-10	Gravel	Too thin to be tapped for water.
	Pliocene(?) and Miocene(?)	Cohansey Sand	Tch	0-365	Coarse grained sand and sandy silt.	Variable ability to store and yield water.
	Miocene	Kirkwood	Tkw	0-300	Very fine to coarse grained sand.	Excellent to poor ability to yield water.
	Eocene	Manasquan	Tmq	0-150	Clayey, fine grained glauconitic; quartz sand.	These formations function as confining beds.
		Vincentown	Tvt	0-200	Clayey calcarenite and clayey, glauconitic, quartz sand.	
	Paleocene	Hornerstown Sand	Tht	0-80		
Cretaceous		Red Bank Sand	Krb	0-50	Clayey glauconite sand.	
		Navesink	Kns	0-40		
		Mount Laurel Sand Wenonah	Knw	0-110	Silt and medium grained sand.	Good ability to store and yield water.
		Marshalltown	Kmt	0-45	Glauconitic, quartz sandy clay.	Confining bed.
		Englishtown Sand	Ket	0-80	Fine to medium grained quartz sand and clay.	Good to poor ability to yield water.
		Woodbury Clay	Kwb	0-80	Clay.	These formations function as confining beds.
		Merchantville	Kmv	0-100		
		Magothy Raritan	Kmr	30-2000	Medium to coarse grained sand and clay.	Excellent ability to store and yield water.
Early Paleozoic(?)		Wissahickon	Pzw	(?)	Schist.	Confining bed.

THE GEOLOGIC FORMATIONS AND THEIR HYDROLOGIC CHARACTERISTICS

The geologic formations which underlie Burlington County consist of variable thicknesses of sedimentary rocks ranging in age from Recent to Late Cretaceous. In turn these overlie a bedrock sequence of Metamorphic rocks of Early Paleozoic(?) age. A summary of the geologic formations and hydrologic characteristics is given in table 7.

EARLY PALEOZOIC(?) ROCKS

Wissahickon Formation

Stratigraphy

The Wissahickon Formation does not crop out in Burlington County, but along the Delaware River it is found at depths ranging from 50 to 150 feet. The formation is composed of several types of medium to coarse-grained metamorphic rocks, but consists largely of schist with muscovite, chlorite, and in some areas garnet. Shades of green and gray predominate. The formation is generally believed to have been sedimentary beds of sandstone, shale, and arkose, having subsequent metamorphic alteration. Although these materials have been deformed and recrystallized, the original banding of the sediments has been largely retained. The thickness of the formation is not known, but estimates range up to 8,000 feet.

Prior to the deposition of the overlying Raritan and Magothy Formations, extensive subaerial weathering produced a zone of weathered rock and soil at the undulating, topographic surface of the Wissahickon Formation. This weathered zone varies in thickness, ranging up to 100 feet. This zone is generally a soft, white to light greenish-gray clay with grains of quartz and mica intermixed. Generally the weathered zone becomes more micaceous and less clay-like with depth. It grades into the underlying unweathered schist or gneiss.

Hydrology

Several wells have penetrated the Wissahickon Formation in the area of Burlington County along the Delaware River. However, most of these were drilled to this formation in the evaluation of the overlying sedimentary sequence. In order to obtain a water supply specifically from the Wissahickon Formation, two known wells have been drilled, one at Beverly, the other at Riverside. Both failed to produce sufficient water to be useful to the owners even though it is reported that each well penetrated over 600 feet of the Wissahickon Formation.

The ground water occurs in the joints and fractures of the formation, but these openings apparently comprise a very small part of the total volume of the rock. The major source of water in the formation is from the overlying sands and gravels of the Raritan and Magothy Formations. Because of the poor past record and the geologic character of the formation, future development of the Wissahickon Formation as a source of ground water is unlikely.

MESOZOIC SEDIMENTS

Cretaceous System

Raritan and Magothy Formations

Stratigraphy.—The Raritan and Magothy Formations crop out in a 2-mile wide belt immediately southeast of the Delaware River (fig. 3). The outcrop area in Burlington County is approximately 48 square miles. The Raritan Formation lithology is extremely variable and therefore cannot be subdivided into the seven members reported in the Sayreville area, Middlesex County (Barksdale, 1943, p. 18). It has not been possible to separate the Raritan and Magothy completely because they lose some of the distinguishing characteristics described by Barksdale and others (1943, p. 64-140). Most of the outcrop area of these two formations in Burlington County is overlain by Pleistocene deposits, which further complicates any separation.

The Raritan Formation, in outcrop consists chiefly of light gray to white, cross-stratified, medium- to coarse-grained quartz sand, arkosic in part and interbedded with white to red and white variegated clays. Mechanical analyses made on sand samples taken from the Raritan and Magothy Formations in both the outcrop and the subsurface show the following percent particle size distribution:

	Clay-silt		*Sand*			*Gravel*	
Sample	*(undivided)*	*v. fine*	*fine*	*medium*	*coarse*	*v. coarse*	*(undivided)*
Cinnaminson Twp.-outcrop	10.0	3.1	16.7	49.5	16.3	2.3	2.1
Westampton Twp.-depth 405′	4.0	4.4	21.4	57.4	12.0	0.8	—

In outcrop, the Magothy Formation is similar to the Raritan Formation in having more sand than clay. However the clay beds of the Magothy Formation are generally dark and lignite bearing. Mica and pyrite are other accessory minerals of the Magothy Formation.

The Raritan and Magothy Formations thicken downdip to form a wedge-shaped unit. The thickness at Bordentown, near the outcrop area, is about 330 feet, whereas downdip near Wrightstown, it is over 600 feet thick. Farther downdip, greater thicknesses can be anticipated.

There appears to be little textural or compositional change in the sands and clays of the Raritan and Magothy Formations downdip. However, the relative proportions of these two dominant lithologies do change: the sand beds make up a smaller proportion of the formations downdip.

The Raritan and Magothy Formations are generally considered to be continental, near-shore deposits. However, it appears that the Raritan and Magothy Formations have a marine facies downdip. Horace G. Richards, Associate Curator of Geology and Paleontology, Academy of Natural Sciences, Philadelphia, (oral communications) points out that marine fossils were found in the Raritan Formation in the Transcontinental Gas Pipe Line well 16T between 1,648 and 1,658 feet below land surface and in Transcontinental Gas Pipe Line well 17T at a depth of 1,710 feet. Well 16T is in Bass River Township, Burlington County, whereas, well 17T is in Ocean County but within 3 miles of Woodland Township, Burlington County.

The Raritan and Magothy Formations unconformably overlie the Wissahickon Formation in most of the county. However, downdip, pre-Raritan sediments are probably present. The Raritan and Magothy Formations are overlain unconformably by the Merchantville Formation.

Hydrology.—The undifferentiated Raritan and Magothy Formations contain the most important and productive aquifers in Burlington County. Most of the industries adjacent to the Delaware River and most of the public water supplies and irrigation supplies throughout the county obtain ground water from these formations. Large-diameter wells tapping these formations yield up to 1,500 gpm. The specific capacities of 55 industrial, public-supply, and irrigation wells range from 2.4 to 86 gpm per foot and average 21 gpm per foot. The hydraulic characteristics and thickness of the water-bearing zones (and confining beds) in these formations vary greatly within short distances. The sand aquifers range in thickness from a few feet to about 100 feet, although the total thickness of the formation is generally much greater.

In the outcrop area adjacent to the Delaware River, two water-bearing zones are present. The upper zone, usually under water-table conditions, includes the water-bearing beds in the upper 70 feet of the formation. In most of the outcrop area, the formations are overlain by the Cape May Formation of Pleistocene age. This formation is generally in hydraulic continuity with the Raritan and Magothy water-table aquifer, resulting in a total saturated thickness of as much as 100 feet. The lower artesian zone, generally separated from the upper water-table zone by clay beds, is composed of the water-bearing beds in the lower part of the formations. It may be as much as 250 feet thick in the outcrop area, but commonly does not exceed 50 feet in thickness along the Delaware River between Palmyra and Burlington.

On Burlington Island, public-water supply wells tap the water-table zone. These wells yield up to 760 gpm with a specific capacity of 58 gpm per foot.

Throughout the Raritan and Magothy outcrop area, wells more commonly tap the lower artesian aquifer. In the Riverside and Burlington areas, many wells yield as much as 1,000 gpm from this lower zone. At Florence, artesian wells yield up to 620 gpm, whereas at Beverly, the yield is up to 1,200 gpm.

To the southeast, beyond the Raritan and Magothy outcrop area, all aquifers of these formations are under artesian conditions. In this area, the sand and clay beds are not identifiable as being continuous. Therefore the Raritan and Magothy cannot be divided into distinct water-bearing zones, and it is necessary to treat these several sand aquifers as a group (fig. 8). In the Wrightstown area, the aquifers of these formations are developed extensively for water supplies to serve Fort Dix, McGuire Air Force Base, and Wrightstown. These large-diameter wells will yield from 900 to 1,000 gpm. At Wrightstown, the cumulative thickness of the aquifers in the Raritan and Magothy Formations is 260 feet. At Birmingham, wells yield up to 1,000 gpm, at Mount Holly 1,200 gpm, and at Willingboro, yields of from 1,400 to 1,500 gpm are common. To the southeast of a line connecting Marlton, Medford, Birmingham, and the Wrightstown area, no wells tap the aquifers of the Raritan and Magothy Formations because there is no industrial or public-supply demand for large quantities of water. However, if this demand should arise, it could probably be satisfied by the aquifer of the Wenonah Formation and Mount Laurel Sand or by the Cohansey Sand, both at much shallower depths.

Laboratory analyses of the coefficient of permeability were made on two sand samples and one clay sample. These analyses had coefficients of permeability of 290 and 300 gpd per sq ft for the sands and 0.08 gpd per sq ft for the clay.

Several aquifer tests were made in various parts of the county to determine the hydraulic characteristics of the aquifers. The results of these tests are summarized in the following table:

Location	*Zone*	*Coefficient of transmissibility (gpd/ft)*	*Coefficient of permeability (gpd/ft^2)*	*Coefficient of storage (dimensionless)*
Burlington	upper	165,000	1,500	0.060
Burlington Twp.	lower	46,600 to 90,000	1,000 to 2,000	2.10×10^{-4}
Cinnaminson Twp.	lower	150,000	1,500	1.60×10^{-4}
Palmyra	lower	211,000 to 513,000	—	1.08×10^{-4} to 5.84×10^{-4}
Beverly	lower (?)	98,000 to 130,000	1,630 to 2,170	1.00×10^{-4} to 2.40×10^{-4}

The wide range of results of pumping tests is evidence of the variability of the geology and hydrology of these formations. At some distance from the outcrop, no pumping tests have been made; however similar coefficients can be anticipated.

In the heavily populated and industrialized area between the Delaware River and the New Jersey Turnpike of Burlington County, essentially all of the ground-water pumpage is from the Raritan and Magothy Formations. Two other areas of large withdrawal from these formations are at Mount Holly, and at Fort Dix and McGuire Air Force Base, both in New Hanover Township. (Fort Dix also obtains an average of 2 mgd of surface water from Greenwood Branch at New Lisbon.) It is estimated that 20 mgd of water are taken from these formations in Burlington County. This represents 80 percent of the total ground-water pumpage in the county.

Prior to development of the aquifers in the Raritan and Magothy Formations, much of the recharge to the aquifers was from precipitation on the high-level intake areas in Middlesex County. The water flowed to the southeast in response to natural gradients. The fresh water-salt water interface (fig. 19) in the southeastern part of the county (Barksdale and others, 1958, p. 110) is a boundary along which the fresh water is diverted with subsequent flow to the southwest into Burlington County from Ocean and Monmouth Counties.

With the growth in population of Burlington County and the increased need for water, the pumpage increased from the Raritan and Magothy Formations. Withdrawal of water locally from this aquifer changed the

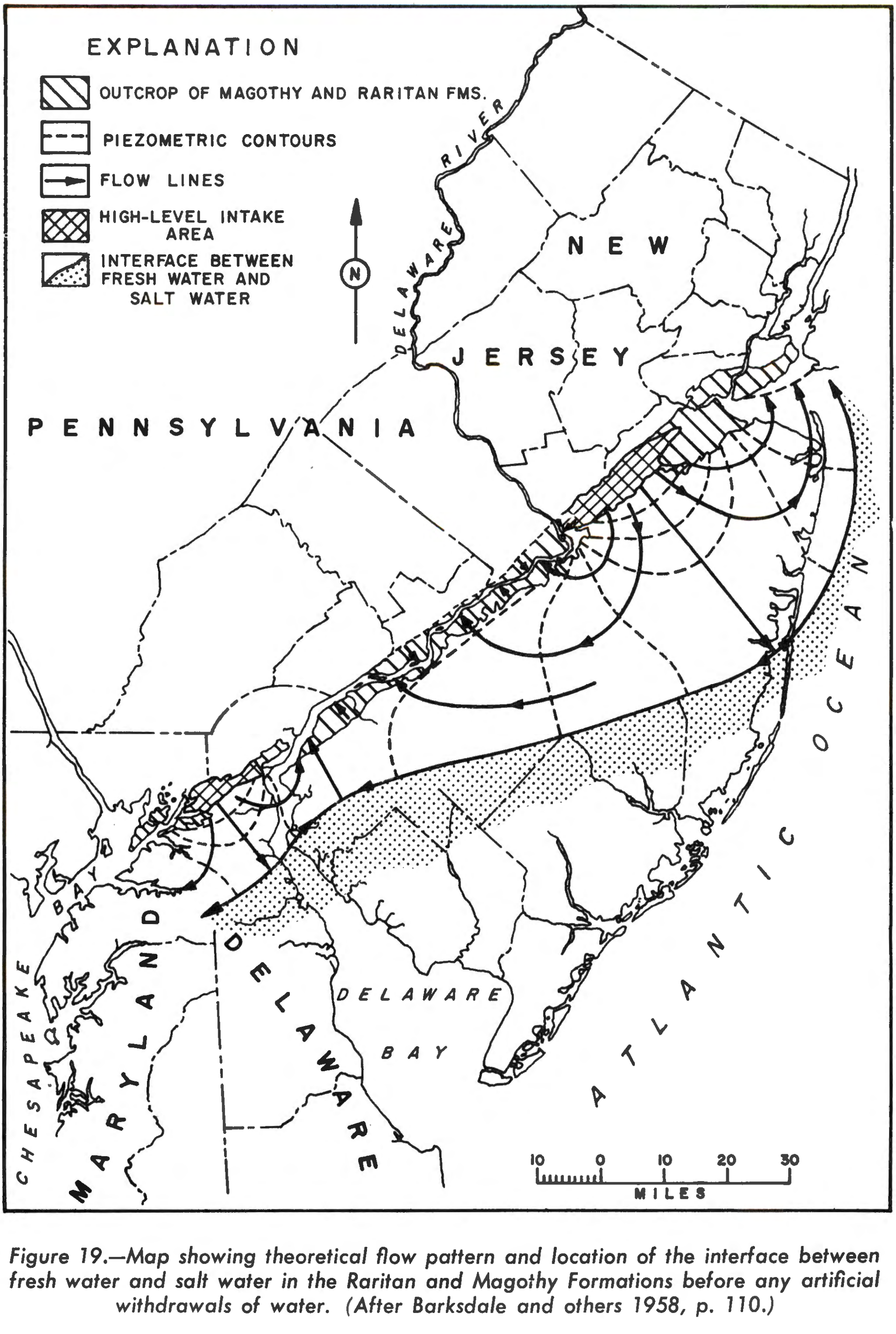


Figure 19.—Map showing theoretical flow pattern and location of the interface between fresh water and salt water in the Raritan and Magothy Formations before any artificial withdrawals of water. (After Barksdale and others 1958, p. 110.)

direction of flow in the vicinity of heavy pumpage. It has been demonstrated by aquifer tests that the normal flow of ground water toward the Delaware River in the aquifer has been reversed in the Beverly and Burlington areas for both the upper and lower water-bearing zones. This condition probably exists in all heavy-pumpage areas where the wells are located within a few hundred feet of the Delaware River. It has been found to be a favorable condition in Burlington County because of the induced artificial recharge from the river. This recharge can be very significant under favorable conditions: it amounts to over half the long-term withdrawal. The river water entering the aquifers is generally of satisfactory quality for all users.

Recharge is available from two other sources: vertical leakage from other aquifers having higher hydraulic heads, and precipitation in the outcrop area. Local recharge within the outcrop area of the Raritan and Magothy Formations is possible if the formations are only partly saturated. Assuming an outcrop area in Burlington County of 48 square miles, the amount of potential recharge from this source is 41 mgd or 0.85 mgd per square mile of outcrop. This recharge figure is based on an average annual precipitation in the Raritan and Magothy outcrop area of about 44 inches (fig. 12), a mean annual water loss of about 26 inches (fig. 13), and a mean annual runoff of 18 inches (fig. 14) available for recharge in the outcrop area.

The rate of potential recharge from vertical leakage is probably in the order of 14 mgd. This is based on an average coefficient of permeability of 0.01 gpr /sq ft and a maximum thickness of 200 feet for the confining clays of the Raritan and Magothy Formations, the Merchantville Formation, the Woodbury Clay, and the Englishtown Formation. that separate the aquifers of the Raritan and Magothy Formations from the aquifer of the Englishtown Formation. The head difference between the two aquifers is considered to be 20 feet for this calculation although the range is from 20 to 60 feet over an area of about 520 square miles of Burlington County. Twenty feet was selected so that there would be no possibility of overstating the recharge from this source because of the use of an excessively large head difference.

The recharge available to Burlington County from Ocean, Monmouth and Mercer Counties as a result of flow, due to the ground-water gradients associated with the high level recharge area in Middlesex County, is in the order of 7 mgd. This quantity is based on an average total thickness of 250 feet of sand along a 28-mile front extending from the Delaware River near Bordentown to the fresh water-salt water interface located in the southeastern part of the county and for a sand with an average permeability of 1,000 gpd/sq ft. The average hydraulic gradient was assumed to be 1 foot per mile. On the basis of the above assumptions, a total of 62 mgd of ground water in the Raritan and Magothy Formations are available from all sources. This is exclusive of any induced artificial recharge from the Delaware River. Only 20 mgd currently are used.

However, it must be kept in mind that the amount of recharge available from vertical leakage is only an approximation. If the coefficient of permeability were only one-half of the given average value, the available recharge from this source would be 7 mgd. Limitations in the development of this resource would be local overdevelopment, contamination, and pollution of the aquifers.

Quality of water.—The water from the Raritan and Magothy Formations is generally of good chemical quality, except for local hardness and for high concentrations of iron. The concentrations of the remaining chemical constituents would not limit the use of the water for most purposes.

The water is soft or moderately hard in most of the northwestern half of the county where data are available. However, hardness is encountered in the Mount Holly to Marlton area. (See fig. 20.)

The concentrations of iron in the water from many wells are too high to meet U. S. Public Health Service Standards. (See Table 5, p. 27.) High iron concentrations are encountered in the part of the county extending from Maple Shade to an area midway between Burlington and Mount Holly. (See fig. 21.) In this part of the county, the concentrations of iron in the water generally exceed 10 ppm (parts per million) and ranges up to 16 ppm at Moorestown.

Throughout the county, the concentrations of dissolved solids are usually less than 140 ppm and range from 40 to 203 ppm.

All chloride concentrations are less than 20 ppm in Burlington County. Most samples of well water had concentrations less than 5 ppm. These relatively low chloride concentrations indicate no salt-water contamination from the Delaware River in the Raritan and Magothy Formations in the part of the county where it is being tapped for water supplies. During long periods of low flow in the Delaware River, salt water moves up the river along the river bottom and mixes partly with the river water. Under such conditions, the composition of the water increases in chloride content in the lower reaches of the river. However, the saline invasion does not extend beyond Camden.

Several important potential sources of dissolved substances in the ground water of the Raritan and Magothy Formations are recognized. The principal source is the soil and rock material through which the

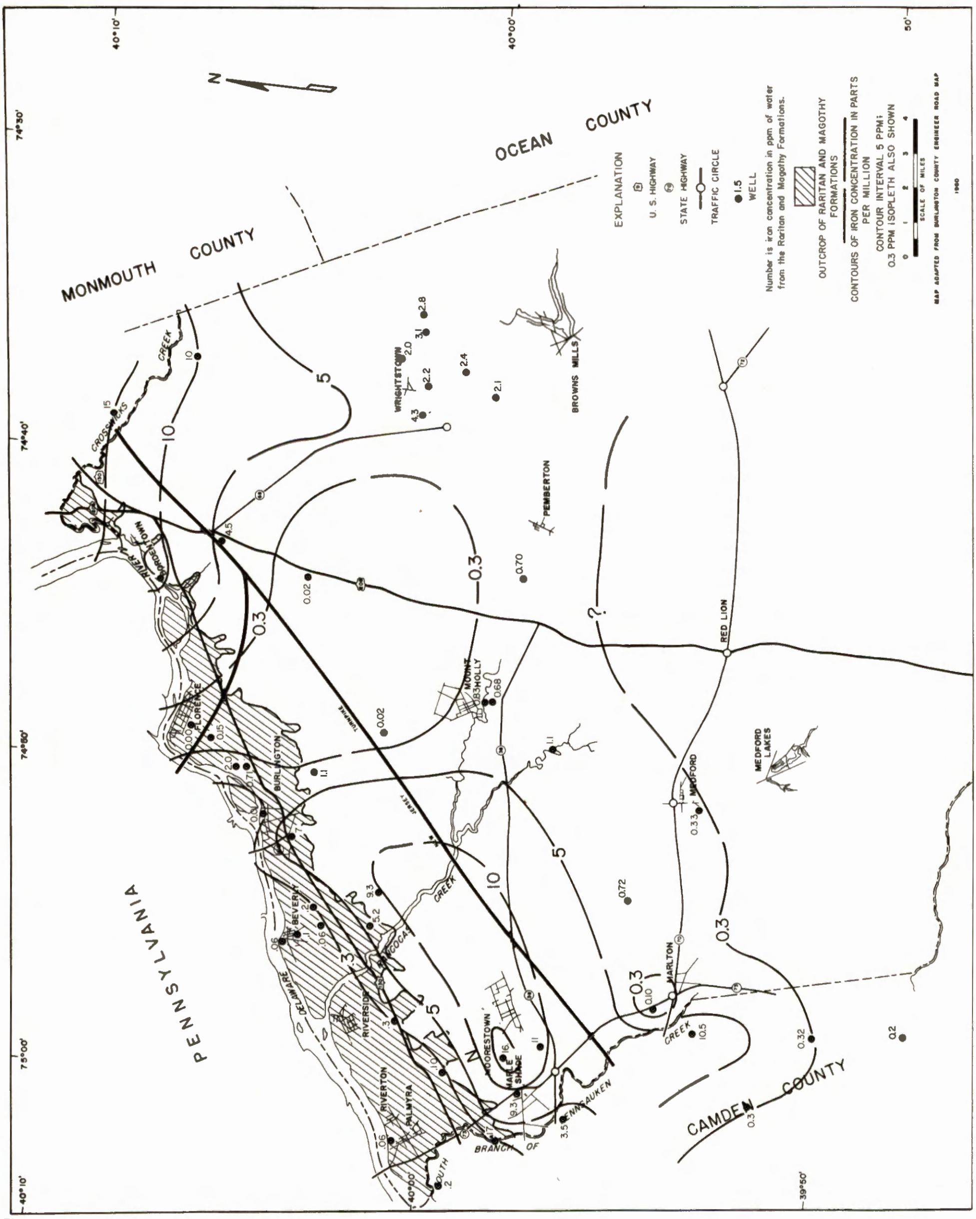


Figure 21.—Isopleths of iron concentration in water from the Raritan and Magothy Formations in Burlington County, N. J.

water flows. Two other possible sources are pollution from industrial waste and sewage, and infiltration of poor quality water from the Delaware River into the aquifer.

Industrial waste and sewage do not appear to be a direct pollution problem for this aquifer in Burlington County.

Infiltration of river water is another potential source of pollution to the aquifer along the Delaware River. At present however, the water of the Delaware River, with reference to dissolved substances, is generally equal to or better in quality than the water in the aquifer. Durfor and Keighton (1954, p. 35) report the following maximum and minimum values in chemical analyses of water of the Delaware River at Burlington between August 1949 and December 1952:

Mineral Content	*Maximum Values (ppm)*	*Minimum Values (ppm)*
Iron	0.28	0
Chloride	14	1.0
Fluoride	.2	0
Nitrate	11	1.2
Dissolved Solids	209	52
Hardness as $CaCO_3$	89	23

It is reported by Powell and others (1954, p. 22-30) that some sewage and industrial pollution occurs in the river, but it is not commonly detected in the chemical analyses. Such pollution is in the form of bacteria, organic compounds, such as phenols, tastes, and odors. However, there is apparently no evidence that industrial waste or sewage have ever reached the wells in Burlington County that induce large amounts of recharge from the Delaware River. The chemical analyses of Delaware River water at Burlington for the water year October 1956 to September 1957, as reported by Love (1960, p. 85), generally fall within the range of concentrations presented in the preceding table, indicating little if any change in the chemistry of the river water from the time of the earlier study. It can be concluded that, with no quality of water evidence to the contrary, the Delaware River at Burlington County is presently a desirable source of induced recharge to the aquifers of the Raritan and Magothy Formations.

Merchantville Formation and Woodbury Clay

Stratigraphy.—The Merchantville Formation and the Woodbury Clay crops out in irregularly shaped belts southeast to the outcrop of the Raritan and Magothy Formations (fig. 3). The outcrop areas of the Merchantville Formation and the Woodbury Clay in Burlington County are about 25 square miles and 44 square miles respectively. Much of the outcrop areas in Burlington County is overlain by a veneer of Pleistocene material.

The Merchantville Formation is characteristically a dark gray to black micaceous clay to clayey silt, but it includes beds and lenses of glauconite sand, especially near the top of the formation.

The Merchantville Formation thickens downdip to form a wedge-shaped unit. The thickness west of Jacksonville, near the outcrop area, is about 50 feet, whereas downdip near Harrisville the thickness is estimated to be 90 feet.

The Merchantville Formation unconformably overlies the Raritan and Magothy Formations and is conformably overlain by the Woodbury Clay. Fossils and glauconite found in the Merchantville Formation indicate that it is of marine origin.

The Woodbury Clay is characteristically a black, lignitic, micaceous clay with small amounts of glauconite sand near its base. It weathers to a light-chocolate color. The thickness of the Woodbury Clay west of Jacksonville, near the outcrop area, is approximately 80 feet. There appears to be little thickening of this formation downdip.

The Merchantville Formation grades upward into the Woodbury Clay with a decrease in quartz silt and glauconite sand. The difference between the formations, however, is small. The Woodbury Clay is unconformably overlain by the Englishtown Formation. Fossils and the glauconite found in the Woodbury Clay indicate that it is of marine origin.

Hydrology.—The Merchantville Formation and the Woodbury Clay function as confining beds separating the aquifer of the Raritan and Magothy Formations from that of the overlying Englishtown Formation. Recharge to the Raritan and Magothy Formations from the Englishtown Formation takes place as a result of vertical leakage through these formations. The combined thickness of the confining beds of these two formations ranges from 130 to 170 feet.

Englishtown Formation

Stratigraphy.—The Englishtown Formation crops out in an irregularly shaped belt southeast of the Woodbury Clay (fig. 3). The outcrop area in Burlington County is about 63 square miles. Southwest of Rancocas Creek, a veneer of Pleistocene material is found overlying much of the outcrop area.

In outcrop, the Englishtown Formation is characteristically a light gray to white, micaceous, lignitic, fine-grained quartz sand. Mechanical analysis of a typical outcrop sample taken 1 mile north of Columbus, shows 79 percent fine sand, 15 percent very fine sand, 4 percent clay and silt, and 1 percent medium sand. The sand is well sorted. Local concentrations of ironstone, such as near Centerton and Hartford, may be found throughout the formation.

Downdip, clay beds rather than sand make up much of the formation. From the interpretation of electric well logs, the greatest aggregate thickness of sand in the formation appears to be in a narrow east-west trending facies extending from Moorestown to the Pemberton area (fig. 22). State Highway 38 coincides with the axis of the western part of this sand facies area.

North of Wrightstown, a second east-west trending sand facies is mapped in the subsurface. Owing to lack of subsurface control, its shape and thickness are not well defined.

To the south or southwest of these two sand facies areas, the Englishtown Formation becomes less sandy, with a corresponding increase in clay thickness. The Englishtown Formation thickens downdip; the thickness at Hartford, near the outcrop area, is about 50 feet, whereas downdip near Harrisville, it is about 75 feet.

The Englishtown Formation unconformably overlies the Woodbury Clay and is unconformably overlain by the Marshalltown Formation. The formation is apparently both marine and nonmarine in origin. Few fossils are found in the outcrop area, but downdip the formation is probably marine. Examination of well logs indicates minor amounts of glauconite and fossils are present in the formation at numerous locations, mostly downdip from the outcrop. The outcrop and the adjacent area seem to be free of any significant amounts of either glauconite or fossils.

The presence of glauconite and the absence of fossils in the formation are considered indicative of a transitional environment. Where the fossils and glauconite are present, the formation is considered marine (fig. 22). The east-west trending sand facies appear to be a linear beach or bar deposit of a shore environment. The sand has a high degree of sorting, as indicated by the Columbus sample. The formation in the area to the south is considered a deposit of a shallow marine environment.

Hydrology.—The Englishtown Formation has an aquifer that is commonly tapped for minor water supplies in Burlington County. Few industrial, public, or irrigation supplies obtain water from this formation. It is tapped primarily for domestic use. Wells tapping this formation yield up to 110 gpm with a specific capacity of 1.3 gpm per foot. The hydrologic characteristics and the thickness of the water-bearing zone vary as a result of the facies changes within the formation. The aquifer ranges in thickness up to about 60 feet. In much of the county, not enough sand is present to be economically tapped for water.

In the outcrop area, water-table conditions prevail. In the areas where Pleistocene sand deposits overlie the formation, the Pleistocene deposits are in hydraulic continuity with the aquifer, resulting in a slightly increased saturated thickness.

To the southeast, beyond the Englishtown outcrop area, the aquifer is artesian. The only public water-supply wells tapping this formation are at Marlton and at Fort Dix. Two wells at Marlton yield about 100 gpm each with drawdowns of about 36 feet. At Fort Dix the two wells have an average yield of 45 and 60 gpm with drawdowns of 193 and 105 feet, respectively.

Permeability tests were made on two typical Englishtown Formation sand samples. These tests show a coefficient of permeability of 300 and 320 gpd per sq ft. The samples were from outcrops near Hartford and Columbus. Assuming an average coefficient of permeability of 300 gpd per sq ft, the aquifer at its maximum thickness would have a coefficient of transmissibility of about 18,000 gpd per ft.

Although, so far as known, no aquifer tests of the Englishtown Formation have been made in Burlington County, a test was made at Lakewood, in Ocean County, in 1959. Results of this test gave a coefficient of transmissibility of about 10,000 to 18,000 gpd per ft, a coefficient of storage of 2.7×10^{-4} to 2.0×10^{-4}, and a coefficient of permeability of about 270 gpd per sq ft for an aquifer thickness of 52 feet.

It can be concluded from these permeability and aquifer test data that the formation probably has a maximum coefficient of transmissibility of about 18,000 gpd per ft in the area of maximum sand-facies development. However, lower coefficients of transmissibility can be anticipated for most of the county.

Most of the wells tapping the Englishtown Formation are located in the outcrop area or within a few miles of it. No wells tap the aquifer south of State Highway 70 in Burlington County. Because the sand facies is poorly developed in the southern half of the county, it is unlikely that any large amounts of water could be obtained in this area in the future. Only 5 percent of the total ground-water pumpage of Burlington County is from the Englishtown Formation.

Seaber (1962, p. 41) indicates that the Englishtown Formation does not receive its major recharge from the outcrop area as was formerly believed. Rather, the principal intake areas are several miles downdip where the formation is confined by overlying clays. The recharge mechanism is vertical leakage through the overlying Marshalltown Formation from the Wenonah Formation and the Mount Laurel Sand. The two major areas of recharge center in Camden and Monmouth Counties.

With extensive development of the aquifer, the hydraulic gradients would be altered and additional recharge could be induced in the outcrop area. About 18 inches of runoff are available in the outcrop area for recharge. The rate of potential recharge from this source is 54 mgd or 0.85 mgd per square mile of outcrop, whereas that from vertical leakage is probably in the order of 69 mgd. This estimate is based on an average coefficient of permeability of 0.026 gpd per sq. ft. and a maximum thickness of 50 feet for the confining beds of the Marshalltown and Wenonah Formations that separate the aquifer of the Englishtown Formation from the aquifer of the Wenonah Formation and Mount Laurel Sand. The head difference between the two aquifers selected for this calculation is 10 feet although the range is from 10 to 40 feet over an area of 476 square miles.

The recharge available to Burlington County from Camden, Monmouth, and Ocean Counties—as a result of the flow due to the hydraulic gradients associated with the piezometric highs in Camden and Monmouth Counties—is indeterminate because of insufficient data. However, on the basis of the above assumption, a total of 123 mgd of ground water are potentially available from the Englishtown Formation without consideration of flow within the aquifer to Burlington County from adjacent counties. Only part of this 123 mgd actually will be available as long as there is any loss, through vertical leakage, to the aquifers of the Raritan and Magothy Formations, which have a lower hydraulic head.

It is estimated that only 1.3 mgd of ground water is obtained from the Englishtown by users in Burlington County.

It must be kept in mind, when considering these figures, that the aquifer in the Englishtown Formation has a low transmissibility, and therefore there is a need for wide distribution of moderate and low capacity wells to utilize fully the potential of this aquifer.

Quality of water.—The water from the Englishtown Formation is generally of fairly good chemical quality, except for hardness and high concentrations of iron. The concentrations of the remaining chemical constituents would not limit the use of the water for most purposes.

The water is soft to moderately hard in most of the county where data is available. However, hard water is found principally in the Moorestown and Marlton areas. (See fig. 23.)

The concentrations of iron in the water from many wells require treatment for removal to meet U. S. Public Health Service standards.

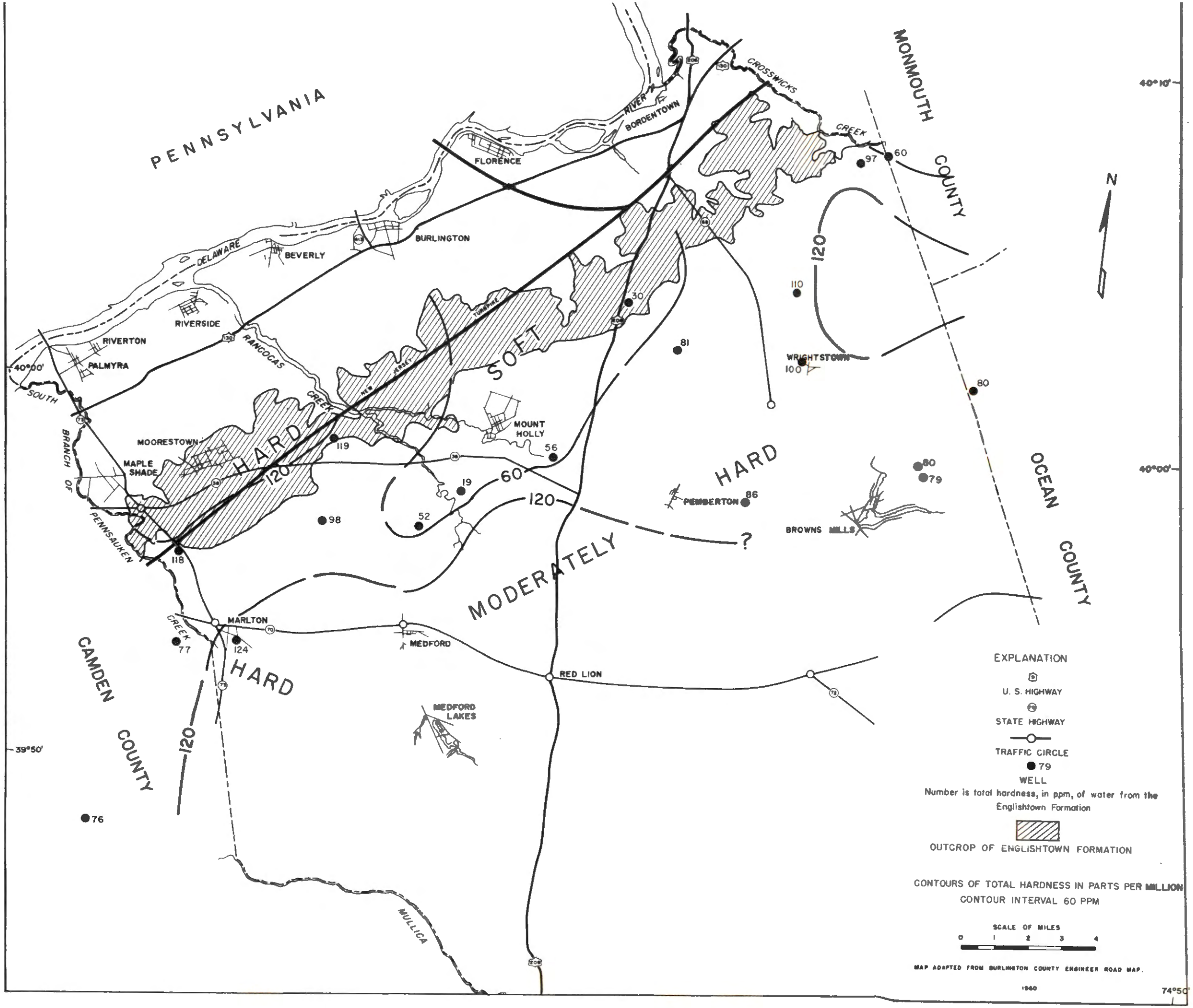


Figure 23.—Hardness of water from the Englishtown Formation in Burlington County, N. J.

High iron concentrations are found in and near the outcrop area northeast of Rancocas Creek, where concentrations of iron in the water exceed 10 ppm. (See fig. 24.)

The concentration of dissolved solids is generally between 110 and 160 ppm, and ranges from 50 to 166 ppm for 12 samples.

Chloride concentration was less than 5 ppm in most wells, with concentrations ranging up to 31 ppm. These relatively low chloride concentrations indicate that there is no salt-water contamination in the Englishtown Formation where it is tapped for water supplies in Burlington County.

The recharge areas in Camden, Monmouth, and Burlington Counties yield hard water from the Englishtown Formation, whereas water from the discharge areas yield softer water. It is concluded by Seaber (1962, p. 57) that the hardness, attributed principally to dissolved calcium and magnesium, is derived from the overlying formation of the recharge areas; the hardness decreases as the water flows through the aquifer toward the discharge area.

Seaber (1962, p. 57) discussed the relationship between high iron concentration of Englishtown water and low pH. The available data indicate that a simple pH test can be made in the field in order to estimate the concentration of dissolved iron. If the water discharging from a well has a pH of 8 or above, the water will probably have low iron concentrations and meet the U. S. Public Health Service standards. This same test can be used on the water from the other aquifers of Burlington County with the same general degree of certainty.

Industrial waste and sewage does not appear to be a pollution problem for this aquifer in Burlington County.

Marshalltown Formation

Stratigraphy.—The Marshalltown Formation crops out in an irregularly shaped belt southeast of the Englishtown Formation (fig. 3). The outcrop area in Burlington County is about 21 square miles. Much of the outcrop area is covered with a veneer of Pleistocene material.

The Marshalltown Formation is characteristically a dark gray to black, micaceous, glauconitic, quartz sandy clay to very clayey sand. The occurrence of chlorite is a diagnostic feature of this formation. Lignite fragments are very abundant in the basal beds. The Marshalltown Formation does not appear to thicken downdip. At Mount Holly, near the outcrop area, its thickness is 40 feet; downdip, near Harrisville, it is 41 feet thick.

The Marshalltown Formation unconformably overlies the Englishtown Formation and is conformably overlain by the Wenonah Formation.

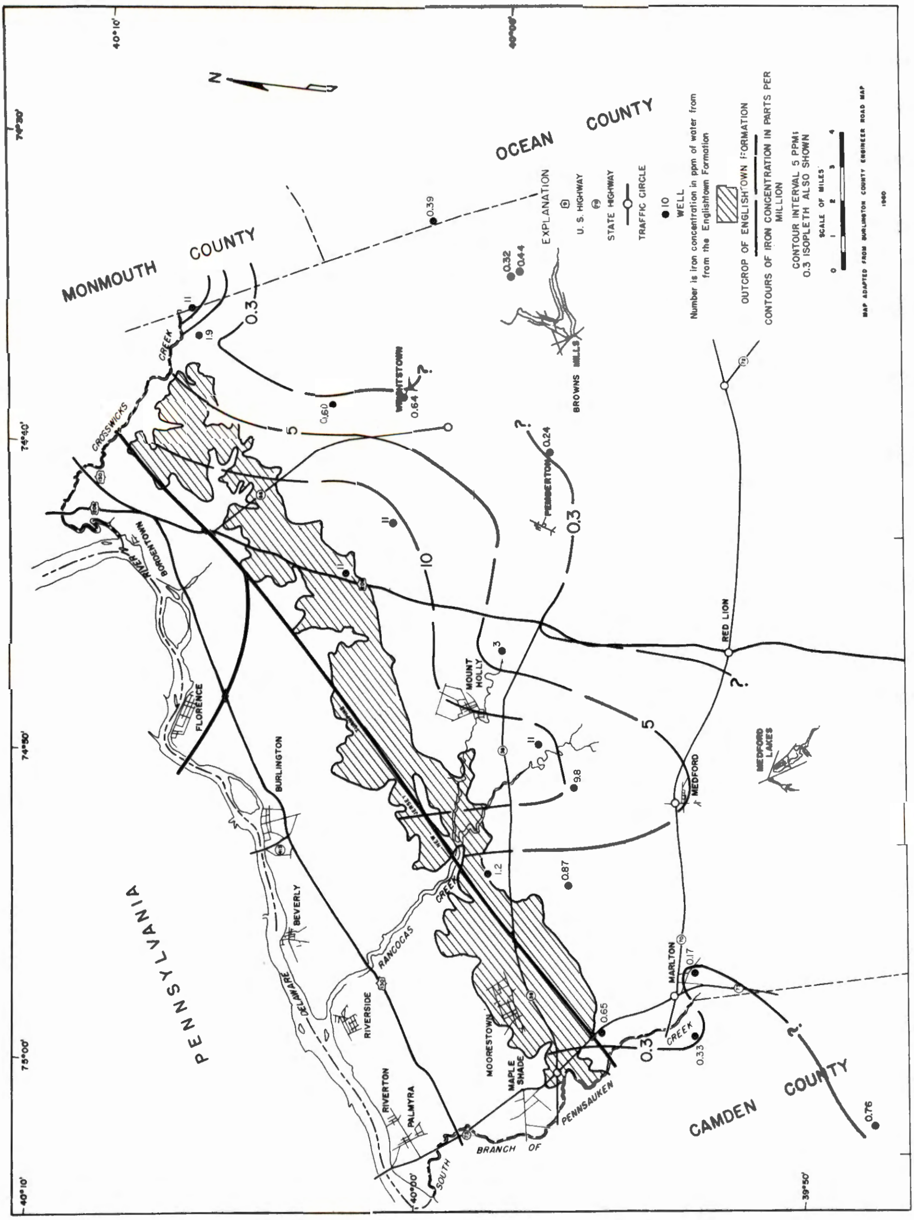


Figure 24.—Isopleths of iron concentration in water from the Englishtown Formation in Burlington County, N. J.

Fossils and glauconite found in the Marshalltown Formation indicate that it is of marine origin.

Hydrology.—The Marshalltown Formation functions as a confining layer between the Englishtown Formation and the overlying Wenonah Formation and Mount Laurel Sand. Recharge to the Englishtown Formation from the latter formations takes place as a result of vertical leakage through the Marshalltown. Where there are clay beds in the Wenonah Formation, the aggregate thickness of the relatively impermeable confining beds may be as much as 50 feet.

Laboratory analysis of two typical outcrop samples of the Marshalltown Formation indicated coefficients of permeability of 0.002 and 0.05 gpd per square foot.

Wenonah Formation and Mount Laurel Sand

Stratigraphy.—The Wenonah Formation and the Mount Laurel Sand crop out in a 2-mile wide belt southeast of the Marshalltown Formation (fig. 3). The outcrop area in Burlington County is about 48 square miles.

The Wenonah Formation and the Mount Laurel Sand, in Burlington County, are similar in lithology and are generally mapped as a geologic unit. It is characteristically a dark gray silt to medium quartz sand, with small amounts of glauconite, mica, and lignite. In general, the grain size and glauconite content increase upward in the unit, whereas the mica and lignite content decrease upward. The particle size distribution of the sand bed at the top of the unit, as exposed near Arneytown, is: sand, medium-grained, 58 percent; coarse-grained, 15 percent; fine-grained, 12 percent; very coarse-grained, 3 percent; and very fine-grained, 2 percent; very fine-grained gravel, 3 percent; and clay-silt, 7 percent.

The Wenonah Formation and Mount Laurel Sand is rather consistent in its thickness throughout Burlington County. The thickness of the unit at Birmingham is 94 feet, and at Marlton, 63 feet both near the outcrop area. Downdip, near Harrisville, the unit is about 100 feet thick.

The Wenonah Formation conformably overlies the Marshalltown Formation, and the Mount Laurel Sand is conformably overlain by the Navesink Formation. An unconformity separates Wenonah Formation and the Mount Laurel Sand (Minard and Owens, 1960). The abundance of shell fragments and glauconite found in the unit indicates that it is of marine origin.

Hydrology.—The undifferentiated Wenonah Formation and Mount Laurel Sand contain an important and rather productive aquifer. Most of the public water-supply wells southeast of a line connecting Fort Dix, Lumberton, Medford, and Marlton tap these formations, yielding up to 500 gpm. The specific capacities of 10 public-supply and irrigation wells range from 2.1 to 10.5 gpm per ft, and average 6.0 gpm per ft. The hydrologic character and aquifer thickness in this unit are rather consistent.

In the outcrop area, the aquifer is under water-table conditions. In the Lumberton-Mount Holly area and in the area west of Juliustown and southwest of Jobstown, Pleistocene deposits overlie the outcrop. These deposits are in hydraulic continuity with the aquifer and add to its saturated thickness. There is little development of the aquifer in its outcrop area.

Locally, a few miles downdip from the outcrop area, the unit is tapped by public irrigation and domestic water supplies. In the southeastern half of the county no wells tap the unit. The sand phase is well developed in this area, but the Cohansey Sand can be tapped for comparable supplies at a shallower depth.

Laboratory analysis was made on one outcrop sample from the Mount Laurel Sand. This sample had a coefficient of permeability of 160 gpd per sq ft. Assuming this coefficient of permeability for the aquifer, a coefficient of transmissibility of 9,000 to 16,000 gpd per ft. might be anticipated for an aquifer thickness of from 55 to 100 ft.

No aquifer tests, of the Wenonah Formation and Mount Laurel Sand, were made in Burlington County as part of this investigation or at any prior time. Results of pumping tests in Monmouth County indicate an average coefficient of transmissibility of 5,000 gpd per foot, an average coefficient of storage of 1.2×10^{-4}, and an average coefficient of permeability of 130 gpd per sq ft for 40 feet of sand. (Oral communication, Jablonski, 1962.) Because the aquifer averages about twice this thickness in Burlington County, the values for the coefficient of transmissibility, based on these Monmouth County aquifer tests, are about 10,000 gpd per foot. An estimate of the coefficient of transmissibility from the specific capacity of the large diameter wells is about 20,000 gpd per foot.

The various estimates of the coefficient of transmissibility range from 10,000 to 20,000 gpd per foot, with a safe assumed average coefficient of transmissibility of about 15,000 gpd per foot for this aquifer in Burlington County.

It is estimated that 3.3 mgd of water, or 13 percent of the total Burlington County pumpage, is taken from this unit. Nearly 60 percent of this 3.3 mgd is pumped in the Pemberton-Browns Mills area. Other locations of notable Wenonah Formation and Mount Laurel Sand pumpage are in the Vincentown-Medford Lakes area.

The Wenonah Formation and Mount Laurel Sand appears to receive its major recharge from two sources. Vertical leakage from overlying formations is probably the most important source of recharge; however, sufficient data are lacking for an accurate estimate of this recharge.

A small but distinct recharge area is located near the outcrop but centered downdip in the Wrightstown-Jacobstown area (fig. 25). The probable recharge in this high level intake area, as well as topographically high area, is vertical leakage. Because of the low formation permeability, the additional recharge from this area to the low water-level areas to the south and southwest is probably less than 100,000 gpd.

Figure 25 also shows an area of discharge. In this low-lying area adjacent to the tributaries of Rancocas Creek, the piezometric levels are generally 30 to 40 feet above sea level and above the land surface. Because of this higher-than-land-surface piezometric surface, water will be leaking vertically upward to the low-lying areas and discharged to the surface streams.

The piezometric contours for the formation indicate that some parts of the outcrop are recharge areas. Recharge takes place in the area of the outcrop between Pennsauken Creek and Rancocas Creek.

It must be kept in mind while analyzing these figures that the aquifer of this unit has a moderately low coefficient of transmissibility. Therefore there will be a need for a wide distribution of moderate- and high-yield wells to fully utilize the potential of this aquifer.

With more extensive development, the hydraulic gradients will be altered and additional recharge will be induced in the outcrop area. The rate of potential recharge to the aquifer from this source is about 41 mgd or .85 mgd per sq mi of outcrop. This is based on 18 inches of runoff available for recharge over 48 square miles of outcrop. Additional recharge will be induced from vertical leakage. However, it is not possible to estimate the rate of recharge because of variations in the confining bed thickness and permeability. In addition, sufficient water-level data are not available for the overlying aquifers to determine the head differential between aquifers.

The water-yield potential of the Wenonah Formation and Mount Laurel Sand is in excess of 41 mgd with only 3.3 mgd presently being pumped from the aquifer. Only part of this water-yield potential will actually be available as long as there is maintained a hydraulic gradient causing the flow of water, through vertical leakage, to the lower hydraulic head aquifer of the Englishtown Formation and to the surface and Rancocas Creek tributaries.

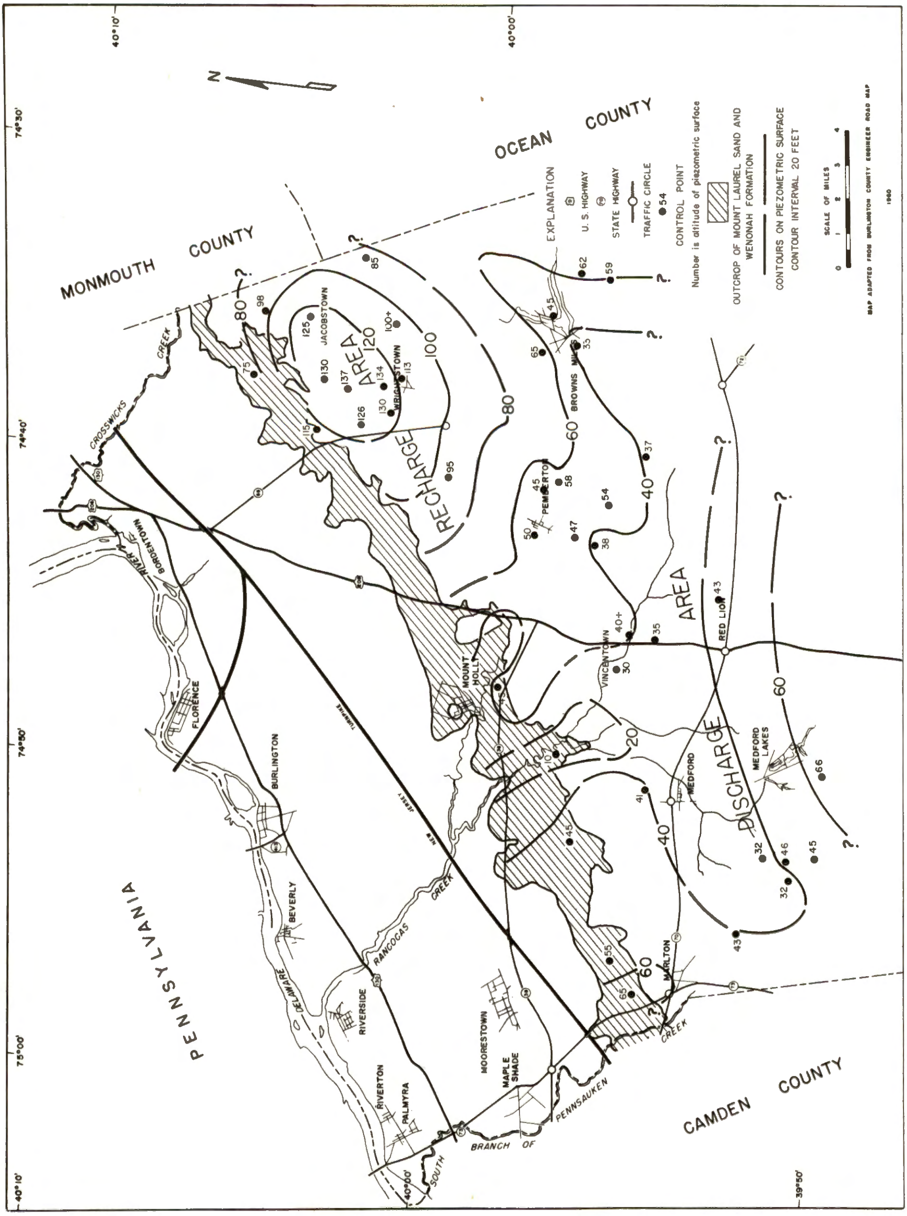


Figure 25.—Map of Burlington County, N. J. showing piezometric contours for the Wenonah Formation and Mount Laurel Sand, based upon the earliest record for each control point.

Quality of water.—The water from the Wenonah Formation and Mount Laurel Sand is generally of excellent chemical quality, except for hardness. The concentrations of remaining chemical constituents would not limit the use of the water for most purposes.

The water is generally hard at the outcrop, but the total hardness is believed to decrease in a downdip direction.

Iron concentrations in the water at the outcrop are high enough to require removal to meet U. S. Public Health Service standards. Two turbid-water samples, taken near Medford and north of Wrightstown, had high iron concentrations, but it is believed that this iron was in the form of suspended particles, adding to the turbidity, and not in solution.

The concentration of dissolved solids in most wells is generally less than 160 ppm, having a range from 100 to 205 ppm for 12 samples.

Chloride concentration was less than 5 ppm in most wells; concentrations ranged up to 25 ppm. These relatively low chloride concentrations indicate that there is no salt-water contamination in the Wenonah Formation and Mount Laurel Sand where it is tapped for water in Burlington County.

Industrial waste and sewage do not appear to be a pollution problem for this aquifer in Burlington County.

Navesink Formation

Stratigraphy.—The Navesink Formation crops out in an irregularly shaped belt southeast of the Mount Laurel Sand outcrop (fig. 3). The outcrop area, in Burlington County, is approximately 23 square miles. Only a small part of the formation outcrop, along the north and south branches of Rancocas Creek, is overlain with a veneer of Pleistocene material.

The Navesink Formation is characteristically a clayey glauconite sand to glauconitic, micaceous, sandy clay, having the mica and clay content of the formation increasing upward. The formation is very micaceous, and has a very prominent shell zone occurring at its base. This shell zone is one of the best marker horizons in Burlington County and the New Jersey Coastal Plain. Additional shells occur throughout the formation.

The Navesink Formation does not appear to thicken appreciably downdip. The thickness of the formation at Medford, near the outcrop area is 37 feet, and near Harrisville, 40 feet. The Navesink Formation conformably overlies the Mount Laurel Sand. The Navesink Formation in most of Burlington County is the uppermost unit of the Cretaceous System. However, in the Jacobstown-Arneytown area, the Red Bank

Formation of Cretaceous age is present and conformably overlies the Navesink Formation. Elsewhere, the Red Bank Formation is absent, and the Navesink Formation is unconformably overlain by the Hornerstown Formation of Tertiary age. Fossils and glauconite found in the Navesink Formation indicate that it is of marine origin.

Hydrology.—The Navesink Formation functions as a confining layer overlying the aquifer in the Wenonah Formation and Mount Laurel Sand. Recharge to the Wenonah Formation and Mount Laurel Sand takes place as a result of vertical leakage through this formation. Laboratory analysis of a typical outcrop sample taken near Arneytown gave a coefficient of permeability of 15 gpd per sq ft. Insofar as known, no wells in Burlington County tap this formation for a water supply.

Red Bank Sand

Stratigraphy.—The Red Bank Sand crops out in the Jacobstown-Arneytown area of Burlington County. Its outcrop extends northeastward from this area into Monmouth County where it is much thicker. The outcrop, in Burlington County, is an irregularly shaped area of about one to two square miles (fig. 3). The outcrop, in the county, is not overlain by any Pleistocene deposits.

The Red Bank Sand is characteristically composed of two unnamed units—a lower, thin, glauconite sandy clay having minor amounts of pyrite, lignite and mica, and an upper unit, a thicker quartz sand with small amounts of clay, glauconite and mica. From outcrop near Arneytown, a sample had the following particle size distribution: sand, medium-grained, 29 percent; fine-grained, 18 percent; very fine-grained, 16 percent; coarse-grained, 8 percent; and very coarse-grained, 2 percent; clay-silt, 27 percent. The thickness of the Red Bank Sand, as measured by Owens and Minard (1960, p. 9), in the Cookstown area ranges up to 50 feet.

The Red Bank Sand conformably overlies the Navesink Formation and is unconformably overlain by the Hornerstown Sand.

Hydrology.—The Red Bank Sand supplies many domestic wells with water in Monmouth County, but is there considered of only minor importance as an aquifer. Because of its very limited extent in Burlington County, it can be considered to be of practically no hydrologic significance. No wells are known to tap it in Burlington County. Laboratory analysis of an outcrop sample taken near Arneytown gave a permeability of 1 gpd per sq ft. Yields of wells, in Monmouth County, range up to 25 gpm. (Oral communication, Jablonski, 1962.)

CENOZOIC SEDIMENTS

Tertiary System-Paleocene Series

Hornerstown Sand

Stratigraphy.—The Hornerstown Sand crops out in an irregularly shaped belt southeast of the Red Bank Sand and the Navesink Formation (fig. 3). The outcrop area, in Burlington County, is approximately 25 square miles. Only small areas of the outcrop are covered by Pleistocene deposits. The greatest area of Pleistocene cover is southeast of Lumberton.

The Hornerstown Sand is characteristically a glauconite sand with a dark green clay matrix. It can be distinguished from the similar glauconite deposits of Cretaceous age on the basis of the color of the clay matrix. The similar Cretaceous deposits, such as the Navesink Formation have a clay matrix that is black.

The Hornerstown Sand appears to thicken downdip to form a wedge-shaped unit. The formation thickness at Wrightstown is 29 feet and at Medford 21 feet, both near the outcrop area, whereas 71 feet of Hornerstown Sand is encountered in the Transcontinental Gas Pipe Line Corporation well 1T near Chatsworth. This writer estimates that the formation has a thickness of 65 feet at Harrisville.

The Hornerstown Sand unconformably overlies the Navesink Formation in most of Burlington County. However, in the vicinity of Arneytown, the Hornerstown Sand unconformably overlies the Red Bank Sand. The Hornerstown Sand, in most of Burlington County, is overlain by the Vincentown Formation; however, in the Marlton area and the Sykesville-Cookstown area the onlapping Kirkwood Formation covers the Vincentown and Manasquan Formations and extends onto the Hornerstown Sand, forming an unconformity. Fossils and the very high glauconite content, of the Hornerstown Sand, indicate it is of marine origin.

Hydrology.—The Hornerstown Sand functions as a confining layer in conjunction with the adjacent formations. Recharge to the Wenonah Formation and Mount Laurel Sand takes place as a result of vertical leakage through this formation. Laboratory analyses of two outcrop samples, taken between Arneytown and New Egypt, gave coefficients of permeability of 0.7 and 0.02 gpm per sq ft. No wells in Burlington County are known to tap this formation for a water supply.

Vincentown Formation

Stratigraphy.—The Vincentown Formation crops out generally in a 1-mile to 2-mile wide belt immediately southeast of the outcrop of the Hornerstown Sand (fig. 3). In the Marlton area and the Sykesville-

Cookstown area, the formation is covered by the onlapping Kirkwood Formation and is not exposed at the surface. The outcrop area is approximately 21 square miles. The outcrop is generally free of any Pleistocene cover except in the Medford and Vincentown area. Here, Pleistocene material covers some of the low lying area adjacent to the south branch of Rancocas Creek.

The Vincentown Formation has been divided into two members. The lower member is characteristically a gray, glauconitic, slightly clayey quartz sand with small amounts of mica. It can be described as a medium sand, but poorly sorted. From outcrop between Jacobstown and New Egypt in Ocean County, a typical sample had the following particle size distribution: sand, coarse-grained, 9 percent; medium-grained, 46 percent; fine-grained, 34 percent; very fine-grained, 3 percent; and clay-silt, 8 percent. Toward the southwest this member becomes more clayey. The upper member is characteristically a light brown to light gray, clayey calcarenite. This member is characterized by its abundant sand-size fragments of bryozoa, foraminifera, and corals.

The Vincentown Formation thickens downdip to form a wedge-shaped unit. The thickness at Wrightstown, near the outcrop area, is 30 feet; whereas, downdip near Harrisville, the thickness increases to about 185 feet.

The contact relationship of the Vincentown Formation to the underlying Hornerstown Sand and the overlying Manasquan Formation is indefinite. Minard and Owens (oral communication) suggest that the Vincentown Formation may rest unconformably on the Hornerstown Sand and that the Vincentown Formation is overlain unconformably(?) by the Manasquan Formation. Fossils and glauconite found in the Vincentown Formation indicate that it is of marine origin.

Hydrology.—The Vincentown Formation is of minor importance as an aquifer in Burlington County. Only a few wells tap this formation. Two of these wells are in the Browns Mills-Wrightstown area. The most recently drilled of the two, at McGuire Air Force Base, yields 35 gpm from an aquifer 25 feet thick. Downdip and to the southwest the permeability decreases, due to a reduction in the particle-size of the aquifer. In these nonproductive areas the formation can, at best, be considered marginal between an aquifer and an aquiclude, but it generally is considered a confining bed along with the underlying Navesink Formation and Hornerstown Sand and the overlying Manasquan Formation.

Laboratory analysis of a typical outcrop sample taken between Jacobstown and New Egypt gave a coefficient of permeability of 160 gpd per sq. ft. A sand 25 feet thick would have a coefficient of transmissibility of 4,000 gpd per ft.

Teritary System-Eocene Series

Manasquan Formation

Stratigraphy.—The Manasquan Formation crops out in an intermittent belt immediately southeast of the outcrop of the Vincentown Formation (fig. 3). The outcrop area of the Manasquan Formation in Burlington County is 18 square miles. The Manasquan Formation is mapped principally in the Burlington County area, being absent or covered by the Kirkwood Formation in most of the rest of the New Jersey Coastal Plain. The Manasquan Formation outcrop is covered by a Pleistocene veneer mainly in the Vincentown area; however most of the outcrop is free of Pleistocene cover.

The Manasquan Formation is described by Owens and Minard (1960, p. 25-26) as being a clayey, quartz-glauconite sand, similar to the Hornerstown Sand, except the latter has less clay and quartz sand. Manasquan Formation samples, taken from two test wells drilled as part of this county investigation, were olive-gray, glauconitic, clayey sand having small amounts of mica and shell fragments. Mechanical analyses were made on six samples. A typical sample gave the following percent particle-size distribution: gravel, 1 percent; sand, very coarse-grained, 3 percent; coarse-grained, 3 percent; medium-grained, 12 percent; fine-grained, 36 percent; very fine-grained, 20 percent; silt, 8 percent; and clay, 17 percent. Test wells were drilled, in 1961, at Coyle Airport, Woodland Township and at a location 3 miles southeast of Oswego Lake, Bass River Township (see fig. 4). The Manasquan Formation was encountered at a depth of 420 feet at Coyle Airport; the drilling stopped at 595 feet. The Manasquan Formation was encountered at 460 feet at the Oswego Lake well site, whereas the total drilling depth was 625 feet. The formation appears to have a moderate variation in lithology.

The Manasquan Formation thickens downdip to form a wedge-shaped unit. The formation thickness at Browns Mills, near the outcrop, is from 10 to 15 feet; whereas downdip, near Harrisville, it is about 270 feet thick.

The Manasquan Formation overlies the Vincentown Formation with a contact relationship of indefinite nature. The contact between the Manasquan Formation and the overlying Kirkwood Formation is unconformable. Fossils and glauconite found in the Manasquan Formation indicate that it is of marine origin.

Hydrology.—The Manasquan Formation functions as a confining layer, along with the Vincentown and Navesink Formations and the Hornerstown Sand, between the aquifer of the underlying Wenonah Formation and Mount Laurel Sand and the overlying aquifers of the Kirkwood

Formation and Cohansey Sand. Recharge to the Wenonah Formation and the Mount Laurel Sand takes place as a result of vertical leakage through this formation. Laboratory analyses, of 6 samples from 3 locations, gave a range for coefficients of permeability of from 0.3 to 120 gpd per sq ft with most grouped between 4 and 6 gpd per sq ft. Only a few wells are known to tap the Manasquan Formation for water in Burlington County.

Tertiary System-Miocene Series

Kirkwood Formation

Stratigraphy.—The Kirkwood Formation crops out in an irregularly shaped belt southeast of the Manasquan Formation, the Vincentown Formation, and the Hornerstown Sand (fig. 3). The outcrop area in Burlington County is approximately 110 square miles.

The Kirkwood Formation in outcrop in the Columbus quadrangle, as described by Owens and Minard (1962), is made up of two units, a basal unit of brownish-black clayey silt to very fine-grained quartz sand, and a thicker upper unit of very light gray to light yellow orange, very fine- to fine-grained well sorted quartz sand. Muscovite, ilmenite, and lignite are important, minor constituents of both units. Small amounts of glauconite were found in the basal unit.

In test wells drilled near Oswego Lake in Bass River Township and at Coyle Airport in Woodland Township, the Kirkwood was found to be made up of three units. The lower unit is characteristically a light olive-gray, very sandy silt having small amounts of muscovite, glauconite and chert as accessory minerals. Shell fragments were also observed. The middle unit is a light gray to yellowish-orange, coarse-grained quartz sand and gravel. Muscovite, lignite, and feldspar are accessary minerals. The upper unit is a light gray, very silty sand. Muscovite and lignite are accessory minerals.

The Kirkwood Formation thickens downdip to form a wedge-shaped unit. The thickness of the formation in the outcrop in the Columbus quadrangle, as reported by Minard and Owens (1962), is as much as 50 feet; the basal unit measuring as much as 15 feet. Downdip, at Coyle Airport, the thickness of the formation is 205 feet, at Oswego Lake well site 285 feet, and at Harrisville 250 feet.

The Kirkwood Formation unconformably overlaps the Hornerstown Sand, the Vincentown Formation, and the Manasquan Formation in Burlington County, and is unconformably overlain by the Cohansey Sand. Fossils and glauconite, found in the formation, indicate it is of marine origin.

Hydrology.—The Kirkwood Formation is of minor importance as a useful aquifer in Burlington County. It is tapped only by small diameter wells for domestic-water supplies, and then usually only in the formation outcrop area. Where it is covered by the overlying Cohansey Sand, the latter is utilized because of its shallower depth.

In summary, the laboratory analyses indicate that in the Coyle Airport and Oswego Lake areas the formation has high abilities to transmit water. In and near the outcrop, this ability appears to be lower. Water-level and recharge data are generally lacking, but the small amount of data indicates that recharge is principally from percolation into the formation in the upland areas from the overlying Cohansey Sand. Movement is probably toward the lowland areas where the water is discharged mostly to Rancocas Creek, Mullica River, and Bass River either directly or by vertical leakage upward through the overlying sediments.

No aquifer tests have been made on this formation in Burlington County. At Ancora State Hospital in Camden County, aquifer test data indicate an average coefficient of transmissibility of 10,500 gpd per foot, a coefficient of storage of 3×10^{-4}, and a coefficient of permeability of about 170 gpd per sq ft. It is assumed that the water-bearing properties of the formation at Ancora are better than those that generally exist near outcrop in Burlington County, but poorer than those downdip. The formation, at Coyle Airport and at the Oswego Lake test-well site, has a coefficient of transmissibility of about 130,000 gpd per ft.

The total ground-water pumpage from the Kirkwood Formation in Burlington County is estimated to be 63,000 gpd, or about one-fourth of one percent of the total pumpage in this county.

The Kirkwood Formation is capable of extensive development as a source of water in Burlington County. However, it has been found economical to drill to the Wenonah Formation and Mount Laurel Sand in the Kirkwood Formation outcrop area where it has poor water-transmitting characteristics. In the area where the Cohansey Sand overlies the Kirkwood Formation, this upper formation is preferred to the Kirkwood Formation because all ground-water needs are very small and can be satisfied from a near-surface aquifer.

Quality of water.—The water from the Kirkwood Formation is generally of excellent chemical quality as indicated by analyses of water from eight scattered wells. However, iron concentration was high enough in some of the water samples to cause staining of laundry and plumbing fixtures. The concentrations of the remaining chemical constituents would not limit the use of the water for most purposes.

The concentrations of iron in the water from some wells require treatment for removal. Iron concentrations range from 0.02 to 2.9 ppm. The water is generally very soft; only one sample had a hardness in excess of 32 ppm. This sample, having a hardness of 86 ppm, was from a well at Browns Mills. The concentration of dissolved solids is usually less than 60 ppm with a range from 31 to 137 ppm.

Chloride concentrations were less than 4 ppm for all samples. There is probably no salt-water contamination in this aquifer anywhere in the county. The only anticipated place of possible salt-water contamination is the Green Bank-New Gretna area. However a well tapping the Kirkwood Formation at New Gretna yields water with a chloride concentration of only 4 ppm, indicating no known contamination from the nearby brackish and saline water of this marshy area.

Tertiary System-Miocene(?) and Pliocene(?) Series

Cohansey Sand and Beacon Hill Gravel

Stratigraphy.—The Cohansey Sand crops out in all of the southeastern half of Burlington County, to the southeast of the Kirkwood Formation (fig. 3). The outcrop area in Burlington County is approximately 380 square miles or 46 percent of the total county area.

The Cohansey Sand is described at outcrop in the Columbus quadrangle by Owens and Minard (1962) as being a light gray to yellowish brown, medium- to coarse-grained, ilmenitic, pebbly, quartz sand with local pink and white kaolinitic beds in the upper part of the formation. They found pebbles in the formation up to 4 inches in diameter. Ironstone is locally present, such as at Taylor Mountain and at Arneys Mount. A characteristic feature of the formation in outcrop is its common horizontal and cross stratification.

Previously little was known about the lithology of the Cohansey Sand downdip. Past workers have frequently underestimated the thickness of this formation in the downdip area of Burlington County. The test wells drilled at Coyle Airport and near Oswego Lake gave information of the lithology and thickness of the formation in an area where essentially no dependable subsurface geologic information was previously available. The information obtained from the two test wells drilled in this county, and the two drilled nearby, in Ocean County, was very useful in gaining a better understanding of the lithology of the Cohansey Sand. (See figure 4 for well locations.)

The lithology of the formation is variable, ranging from clayey quartz silts to gravelly quartz sand. At Coyle Airport the formation is 215 feet thick. The lower two-thirds of the formation is composed of thick gravelly quartz sand beds and thinner silt beds. The upper third is mostly sandy silt. At the Oswego Lake test-well site, the formation is essentially a silty, fine- to medium-grained quartz sand except for two coarse-grained quartz-sand beds in the 55 to 100 foot-depth interval, separated by 15 feet of silty sand. At this site, the formation is 175 feet thick.

In the northwest part of the outcrop area, the formation thins to a featheredge. Downdip its thickness depends greatly on the altitude of the land surface. The formation probably does not exceed a maximum thickness of 250 feet in the county.

The Cohansey Sand unconformably overlies the Kirkwood Formation. No fossils or glauconite are found in the Cohansey Sand to indicate any marine environment. It is therefore generally assumed that the Cohansey Sand is a fresh-water deposit. However any further understanding of its nature is subject to various interpretations. Markewicz and others (1958) interpret the Cohansey Sand as being a large alluvial fan deposit. Its common coarse texture and often poor sorting and crossbedding fit this interpretation. However Owens and Minard (1960, p. 27) discount their hypothesis on the grounds that the formation is too widespread. They favor a hypothesis of beach deposition. This writer does not observe the high degree of sorting commonly associated with beach deposits, but nevertheless favors this interpretation.

The Cohansey Sand is overlain by the Beacon Hill Gravel of Pliocene(?) in age (fig. 3). It occurs as a capping gravel on only the highest hills, where it is a gravelly sand, commonly indurated with iron oxide.

Hydrology.—The Cohansey Sand is one of the important aquifers in Burlington County. It is essentially untapped, but it has a good potential in some areas.

The Cohansey Sand has no confining beds overlying it, so that most of the formation, if not all of it, is under water-table conditions. A few of the highest hills are capped with the younger Beacon Hill Gravel, but it is in hydraulic continuity with the Cohansey Sand. In the low-lying Green Bank-New Gretna area, the sands and gravels of the Cape May and Bridgeton Formation add to the saturated thickness of the aquifer. These two formations may be present in other parts of the Cohansey Sand outcrop area, but there is difficulty in separating them.

Laboratory analyses were made on outcrop and subsurface samples to determine the hydraulic properties of the formation. Laboratory analyses of hydrologic properties were made for several lithologic samples. The results of these analyses are listed in the following table.

Location	*Coefficient of Permeability (gpd per sq ft)*	*Coefficient of Transmissibility (gpd per ft)*
Browns Mills	(?)	—
Coyle Airport	130	28,000
Oswego Lake	86	15,000

An aquifer test was made 2 miles northwest of Batsto, on the Burlington County-Atlantic County line. This test was part of a water-resources evaluation of the Wharton Tract carried on separate from this investigation by the U. S. Geological Survey with the cooperation of the New Jersey Department of Conservation and Economic Development. It was determined at this site that the coefficient of transmissibility is 150,000 gpd per ft; the coefficient of storage 0.2, and the coefficient of permeability about 1,000 gpd per sq. ft. These values for the Cohansey Sand, compared with results of pumping tests at Browns Mills, Coyle Airport, and Oswego Lake, demonstrate the variability of the formation. At Linwood, Atlantic County, the coefficient of transmissibility and coefficient of storage had values of 98,000 gpd per ft. and 5.1×10^{-4}, respectively; at Seabrook, Cumberland County, their range is from 129,000 to 220,000 gpd per ft. and from 2.5×10^{-4} to 4.5×10^{-4}, respectively.

The Cohansey Sand is tapped by only low-yield wells for domestic and agricultural water supplies in the five-township area of the extreme southeastern part of Burlington County (fig. 18). The total pumpage from this formation is estimated to be 579,000 gpd or about 2.3 percent of the total county pumpage.

The water enters the aquifer directly from precipitation in the topographically high areas and moves toward low-level areas where it is ultimately discharged into Rancocas Creek; Mullica, Wading, and Bass Rivers. The potential recharge to the aquifer is 358 mgd or .95 mgd per sq. mi. This estimate is based on an average runoff of 21 inches per year available for recharge over a 380 sq. mi. area of the formation outcrop in the county. Only part of this recharge will actually be available as long as there is maintained a hydraulic gradient causing the flow of water to the surface streams of the area.

Quality of water.—The water from the Cohansey Sand is generally of good chemical quality except for common high concentrations of iron. The concentrations of the remaining chemical constituents would not limit the use of the water for most purposes.

Iron concentrations in the aquifer vary from 0 to 49 ppm, as indicated by analyses of water from 25 wells. There is no recognizable pattern of variation in concentrations. At the Wharton Tract aquifer-test site, near Batsto, the range in iron concentrations is from about 5 to 49 ppm.

Only five of the water samples collected had concentrations of iron low enough to meet the drinking-water standards of the U. S. Public Health Service; the rest would need treatment for iron removal. The water is very soft, with a hardness usually less than 15 ppm and ranging from 2 to 48 ppm. The concentration of dissolved solids is usually less than 50 ppm and ranging from 16 to 144 ppm.

Chloride concentrations are less than 16 ppm, indicating no salt-water contamination in the area of any of the wells sampled. Chloride concentrations in water from three shallow wells in the Green Bank-New Gretna area, where potential contamination would most likely be anticipated, were less than 10 ppm. However, in the marshy areas near Great Bay, salt-water contamination can be expected.

In most respects, the chemical quality of the water from the Cohansey Sand and the Kirkwood Formation are very similar. However, it appears that they can be separated on the basis of the concentration of dissolved silica. The Cohansey Sand yields water averaging 5.0 ppm silica with a range of from 1 to 7.0 ppm. The Kirkwood Formation water can be distinguished by its higher concentration of silica averaging 23 ppm and ranging from 10 to 34 ppm.

SUMMARY AND CONCLUSIONS

The future growth and economic development of Burlington County are dependent to a large extent on the ground-water supply. During the last few years, the number of industrial establishments and the population have increased rapidly. Much of the development has been in the area between the Delaware River and the New Jersey Turnpike. However, an increasing number of industrial and housing areas are developing in the remainder of the northwestern half of the county. The southeastern half of the county still remains sparsely populated, with little industry and population except those related to agriculture.

In Burlington County, nearly all of the water supplies are derived from ground-water sources. Surface water is used by some industrial establishments along the Delaware River and by Fort Dix at New Lisbon. However, future water supplies will come principally from ground-water sources.

All of the ground water is derived from precipitation occurring within this and adjoining counties. The ground water flowing into the county can be intercepted and used, but presently much of this gain is to adjacent counties and to the Delaware and other rivers.

In the areas adjacent to larger streams, such as the Delaware River, recharge to the aquifer from the streams will take place if there is hydraulic continuity between the streams and the aquifers. Along the Delaware River, this is an important source of water for public supply and industrial users. In such cases, nearly all the water pumped from wells is from induced recharge from the river.

Precipitation in Burlington County amounts to about 45 in. per yr. Of this amount, about 25 in. per yr. represents "nature's take." It is water-loss due principally to evaporation and transpiration. The remaining 20 in. per yr. is runoff; water that is rejected by the aquifers because they are essentially full of water. This rejected water, about 790 mgd, is potentially available for ground-water development. Compared to the current gross usage of 26 mgd in 1960, an additional 764 mgd of ground water will potentially be available for development in the county. However, most of this potential recharge will continue to be rejected unless water levels decline greatly with extensive development. Then only will more of this rejected recharge enter the aquifers and be available for ground-water development.

Moderate to large amounts of water can be pumped economically anywhere in the county, the source being the four main aquifers. The Cohansey Sand, in some areas, represents the largest, and yet untapped, source of water to supply future needs. However this aquifer is generally under water-table conditions and therefore extremely susceptible to contamination from the surface. Therefore care is required for its proper development. The Kirkwood Formation appears to have good potential in its downdip area, where it has good hydraulic properties. The Raritan and Magothy Formations are well developed in the area adjacent to the Delaware River, but additional development is possible from river recharge to the aquifer and if proper well spacing is practiced. Downdip, where this aquifer is less utilized, its potential is greatest. However, beyond a distance of about 12 miles from the Delaware River, the shallower aquifer of the Wenonah Formation and Mount Laurel Sand is present and can be tapped for moderate to large volumes of excellent quality water, with shallower, less expensive wells. In the area beyond a distance of about 20 miles from the Delaware River, needs can best be met with large volumes of ground water from the Cohansey Sand and the Kirkwood Formation.

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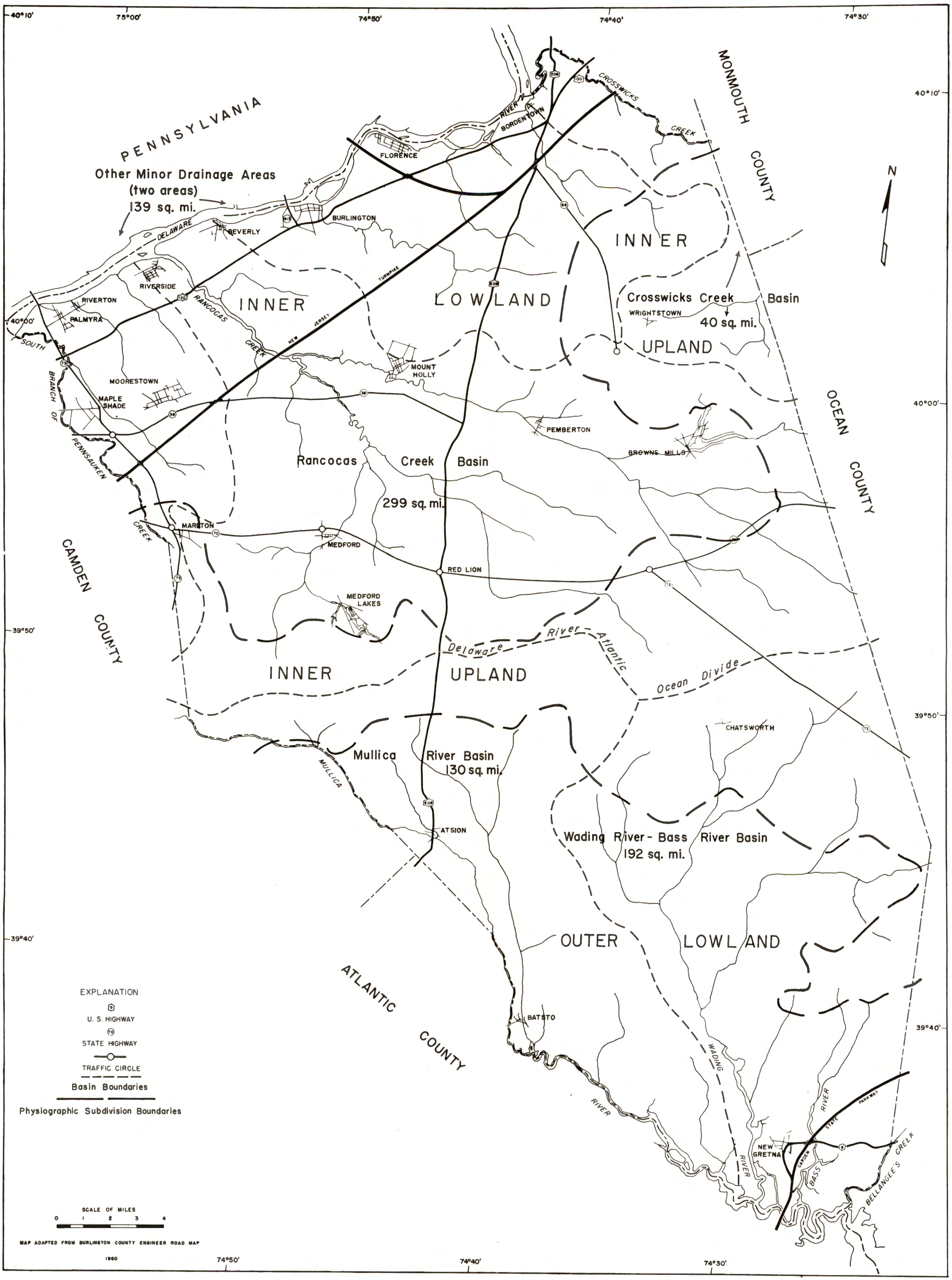

Figure 2.—Physiographic map of Burlington County, N. J.

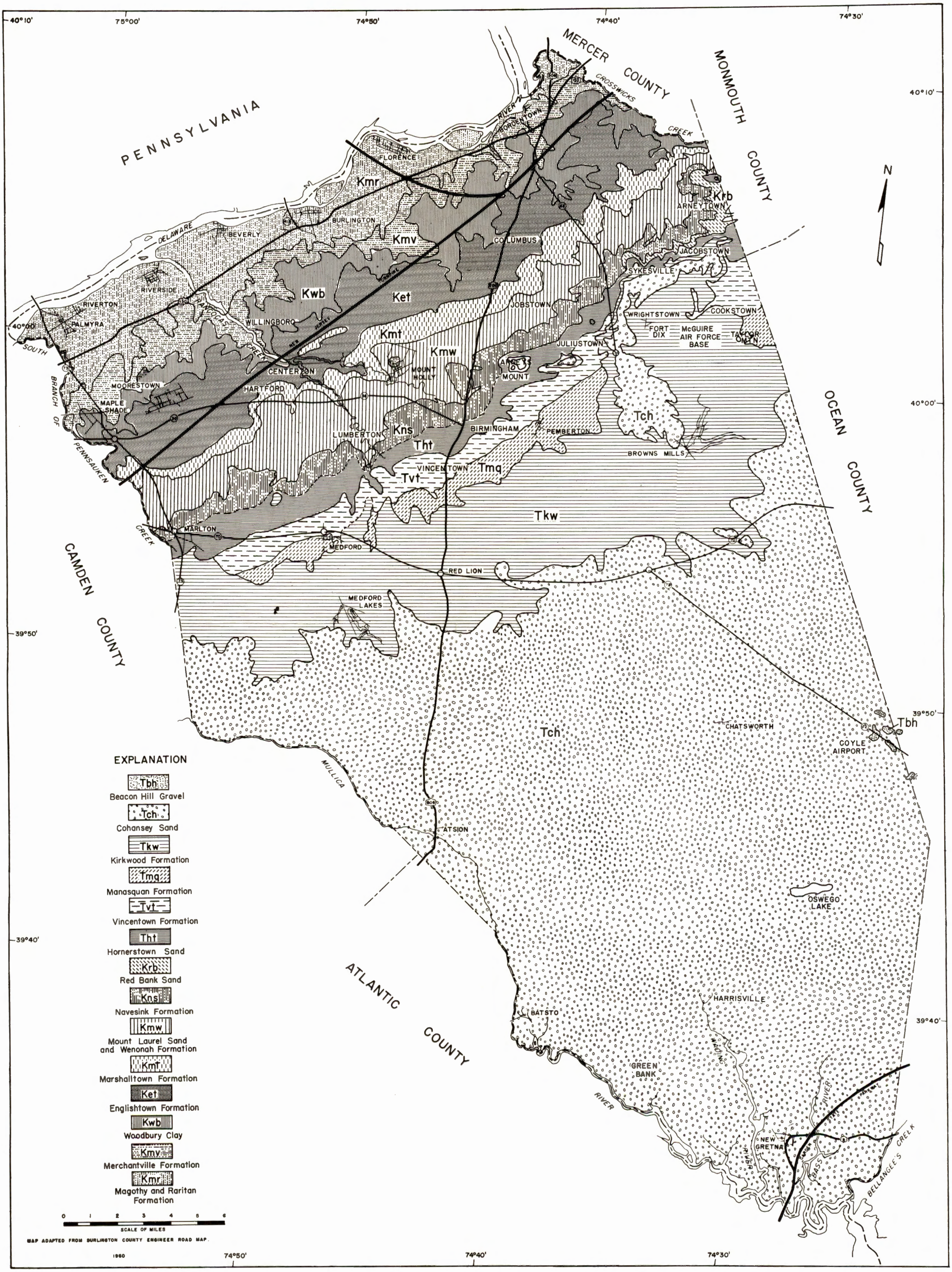

Figure 3.—Pre-Quaternary map of Burlington County.

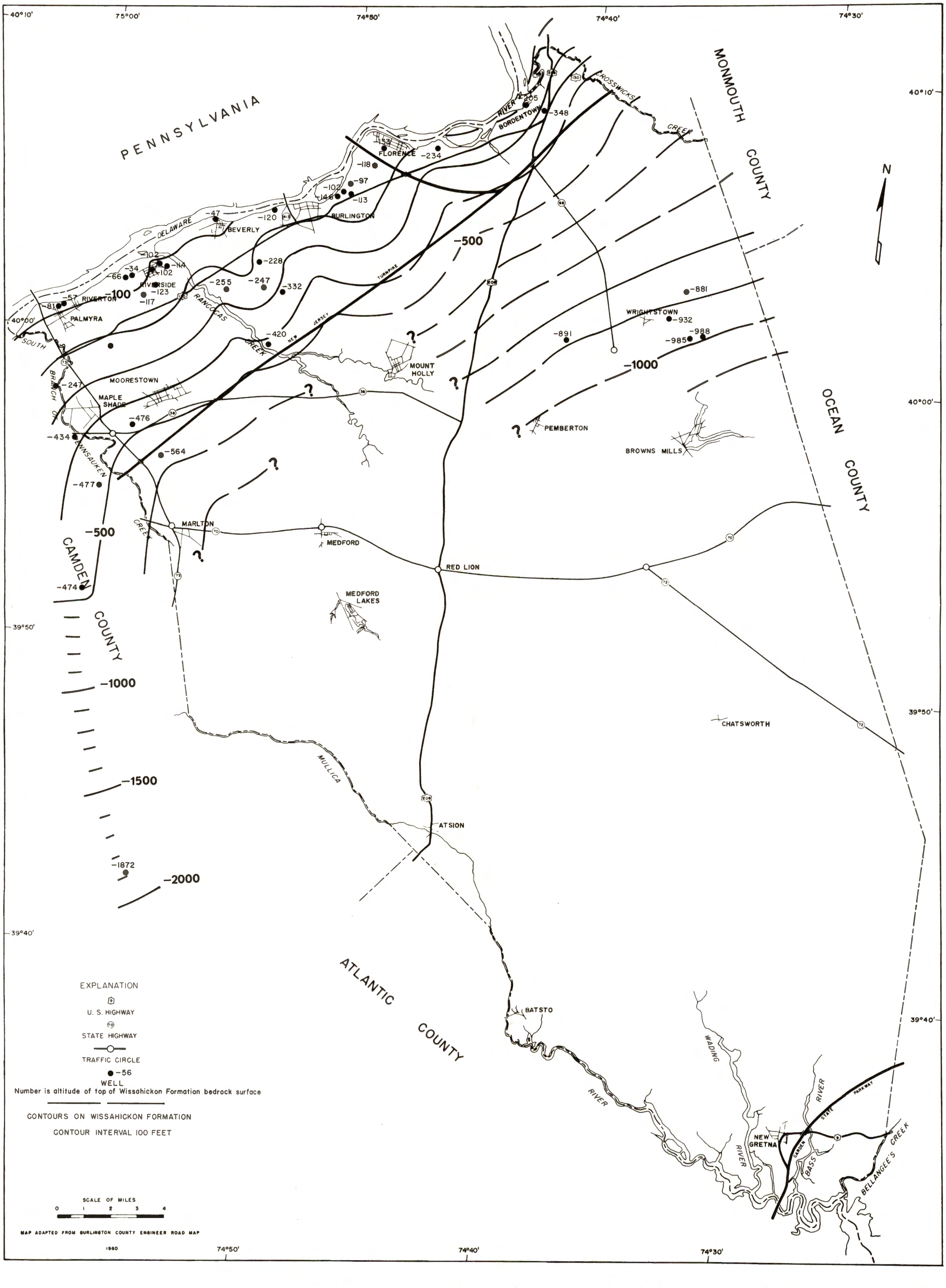

Figure 7.—Structural contour map of the top of the Wissahickon Formation in Burlington County, N. J.

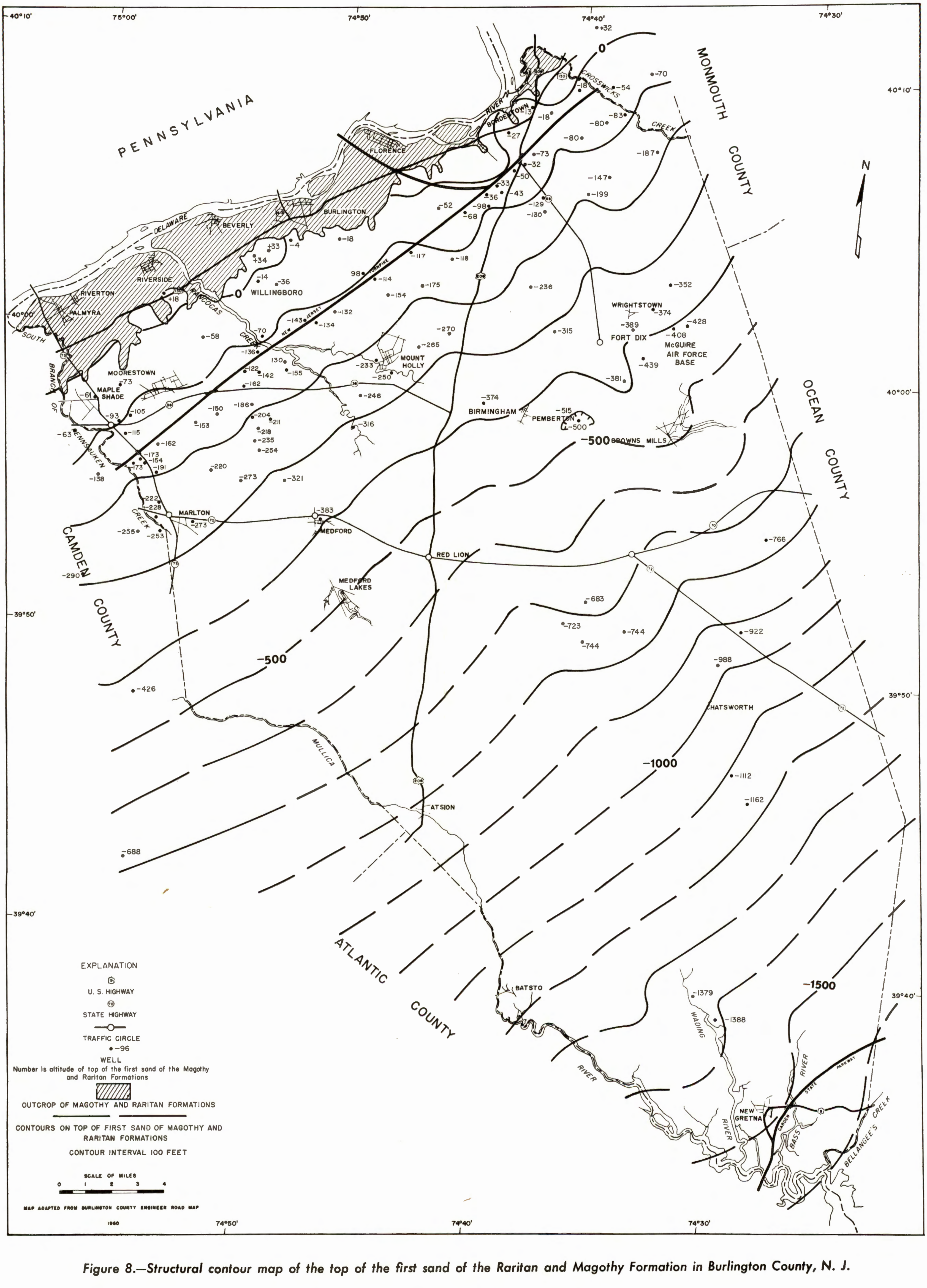

Figure 8.—Structural contour map of the top of the first sand of the Raritan and Magothy Formation in Burlington County, N. J.

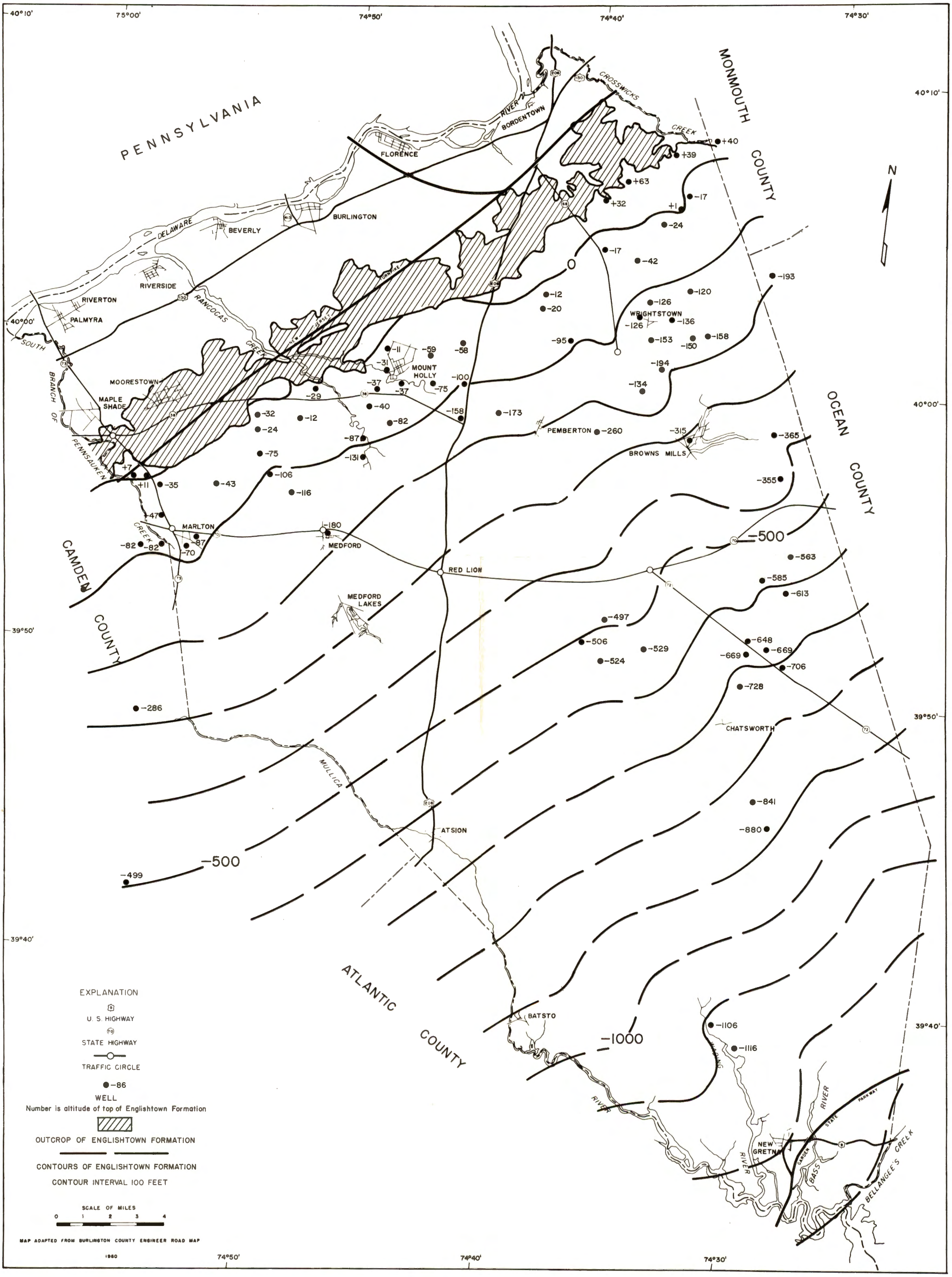

Figure 9.—Structural contour map of the top of the Englishtown Formation in Burlington County, N. J.

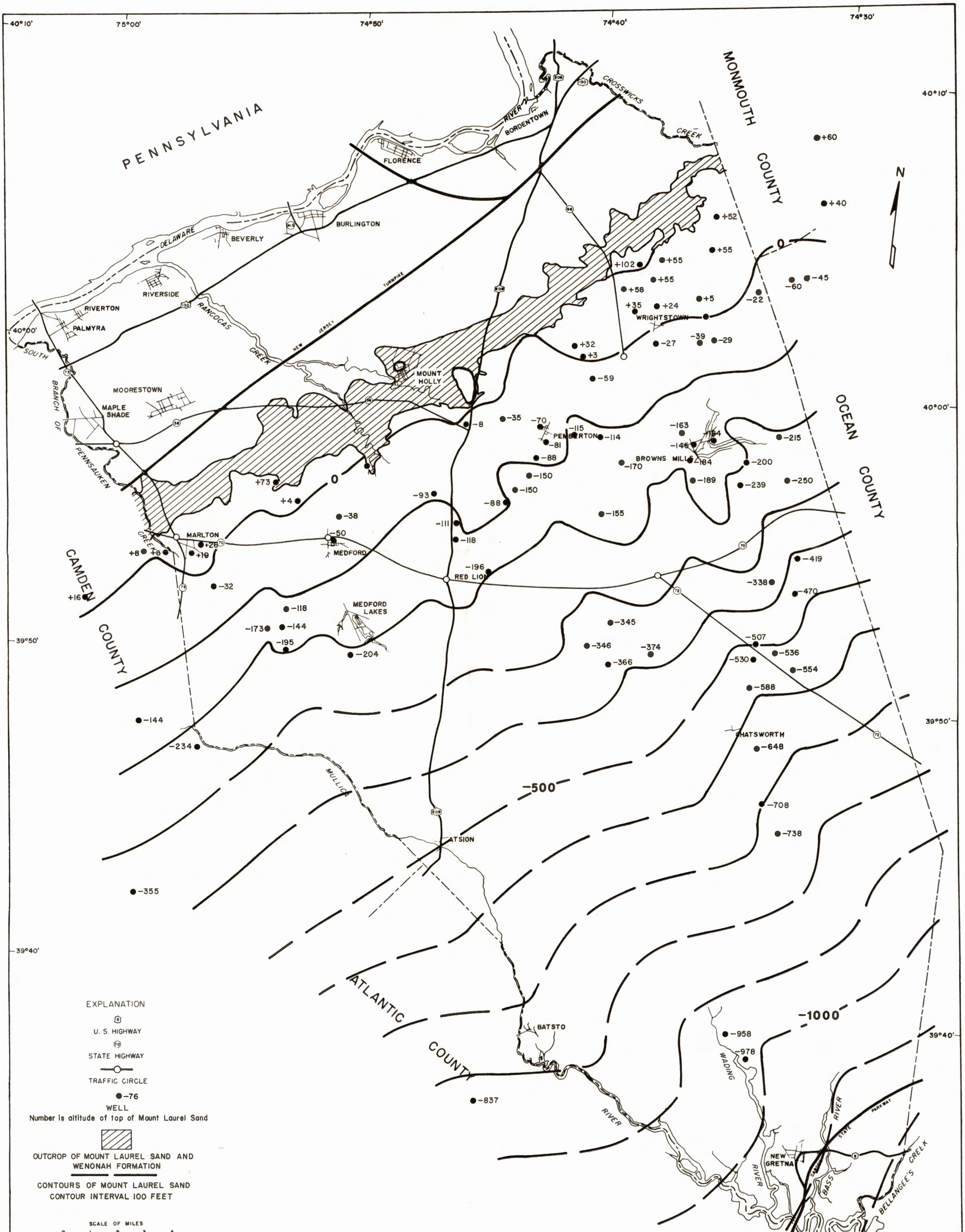

Figure 10.—Structural contour map of the top of the Mount Laurel Sand in Burlington County, N. J.

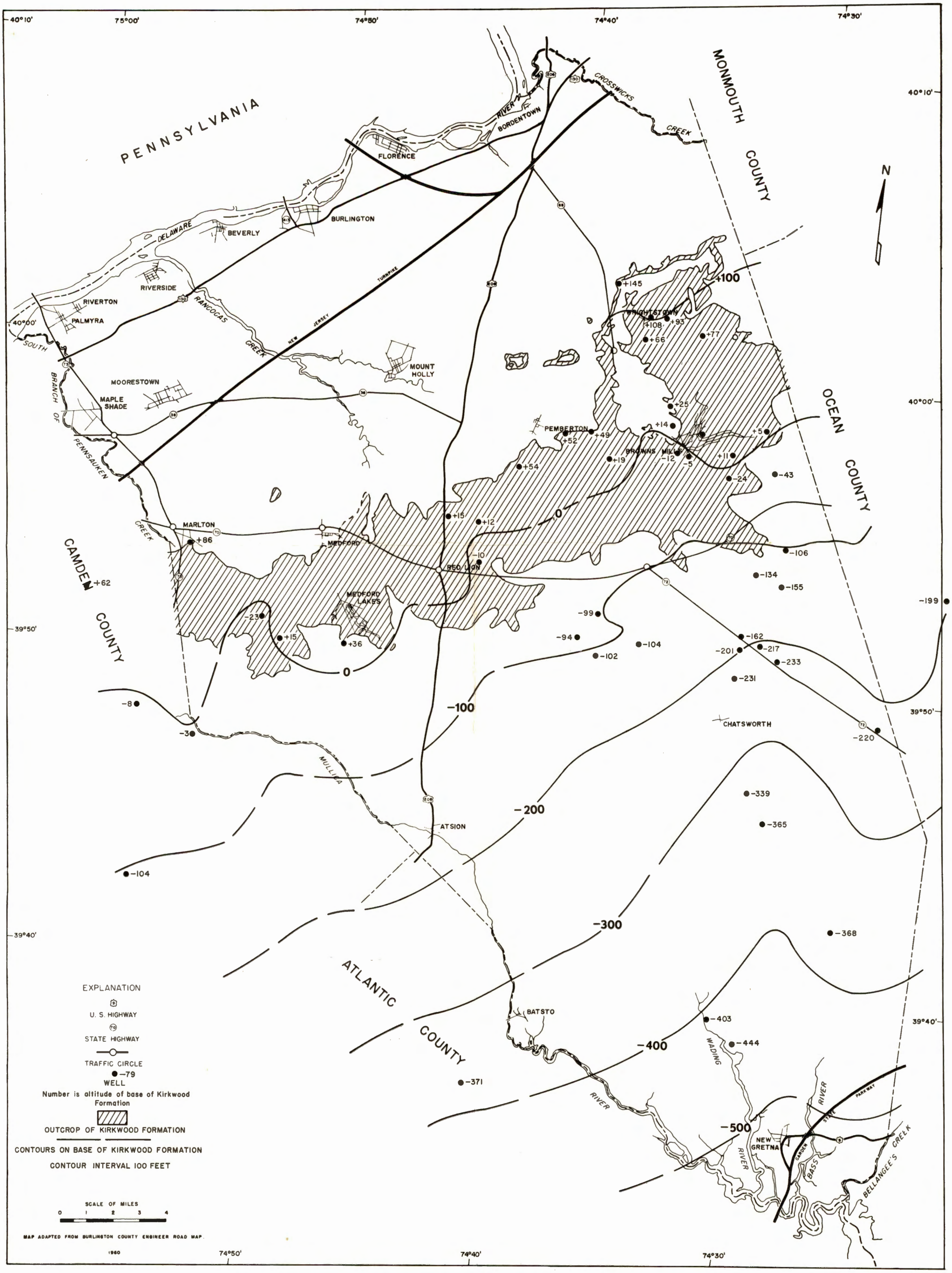

Figure 11.—Structural contour map of the base of the Kirkwood Formation in Burlington County, N. J.

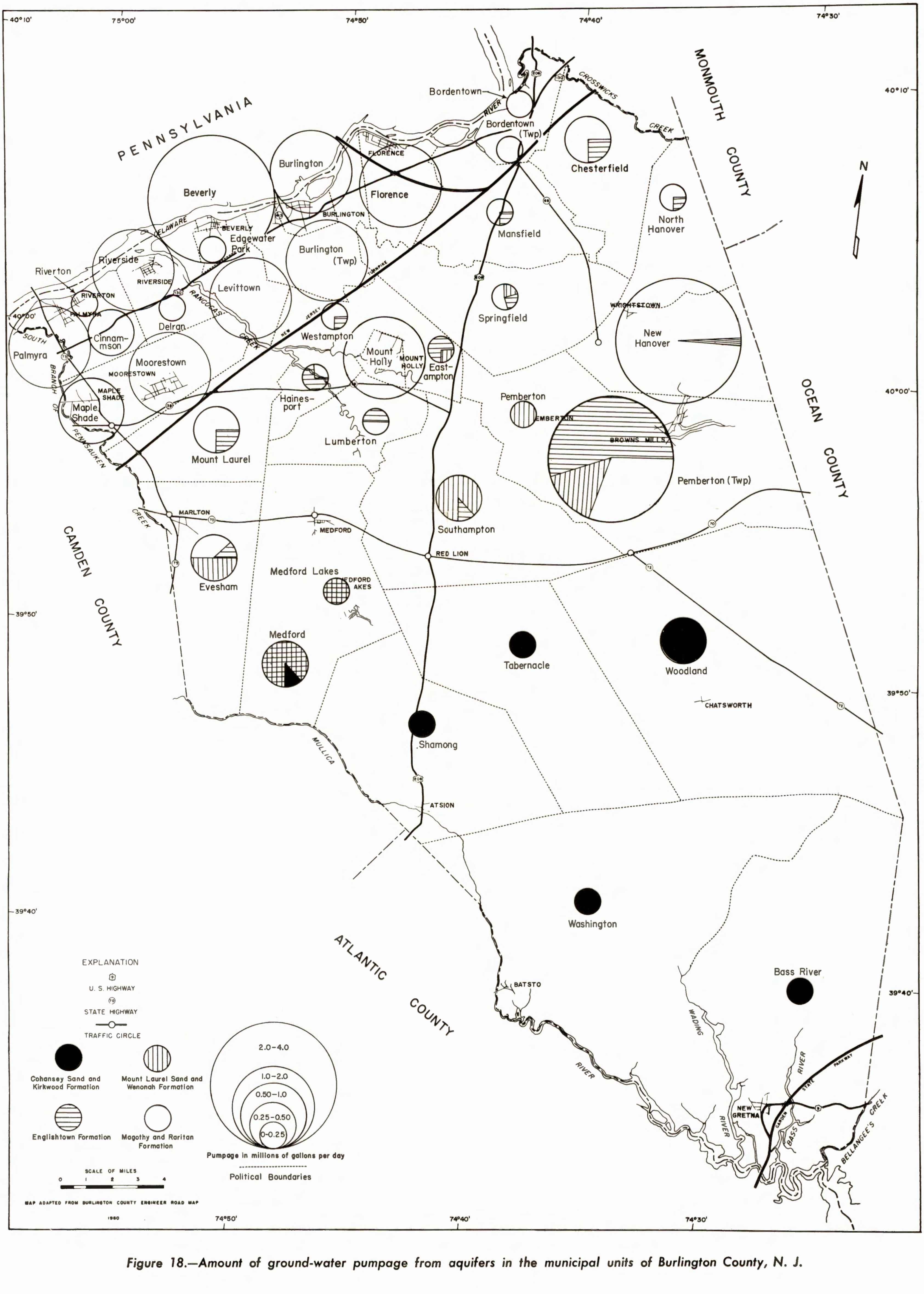

Figure 18.—Amount of ground-water pumpage from aquifers in the municipal units of Burlington County, N. J.

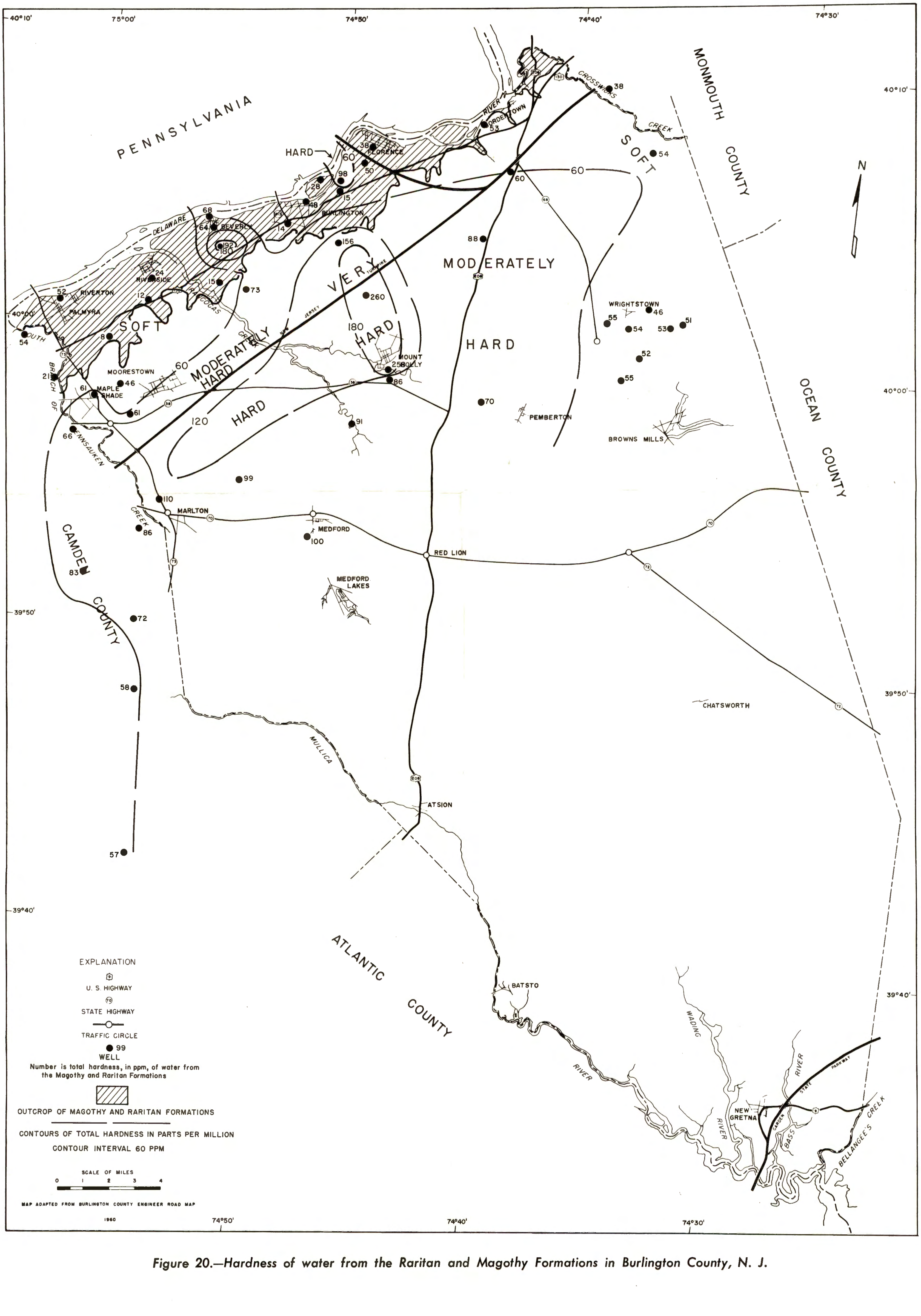

Figure 20.—Hardness of water from the Raritan and Magothy Formations in Burlington County, N. J.

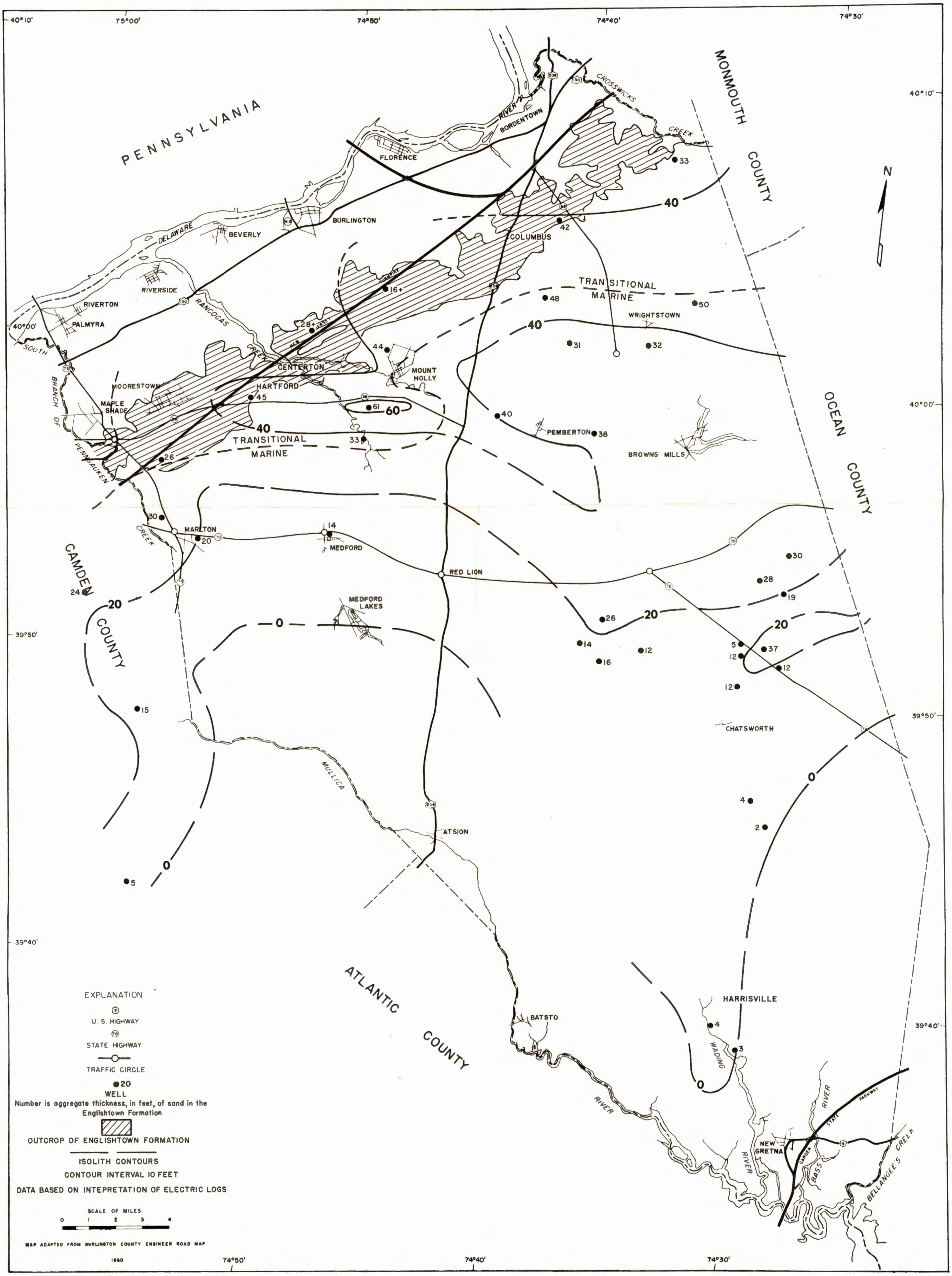

Figure 22.—Isolith map of the sand facies of the Englishtown Formation in Burlington County, N. J.

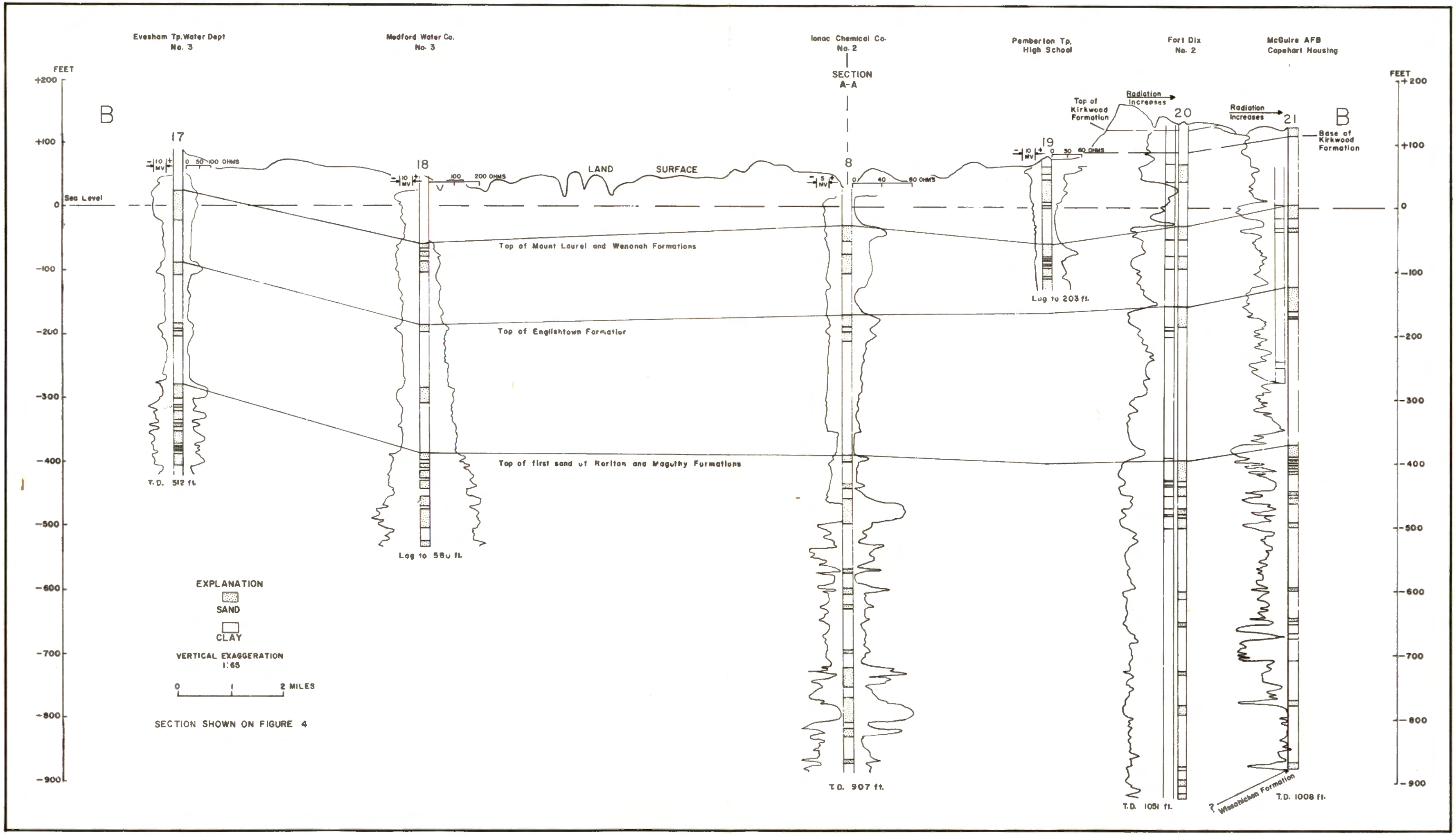

Figure 5.—Cross section showing the structure of Burlington County in the general direction of strike of the formations.

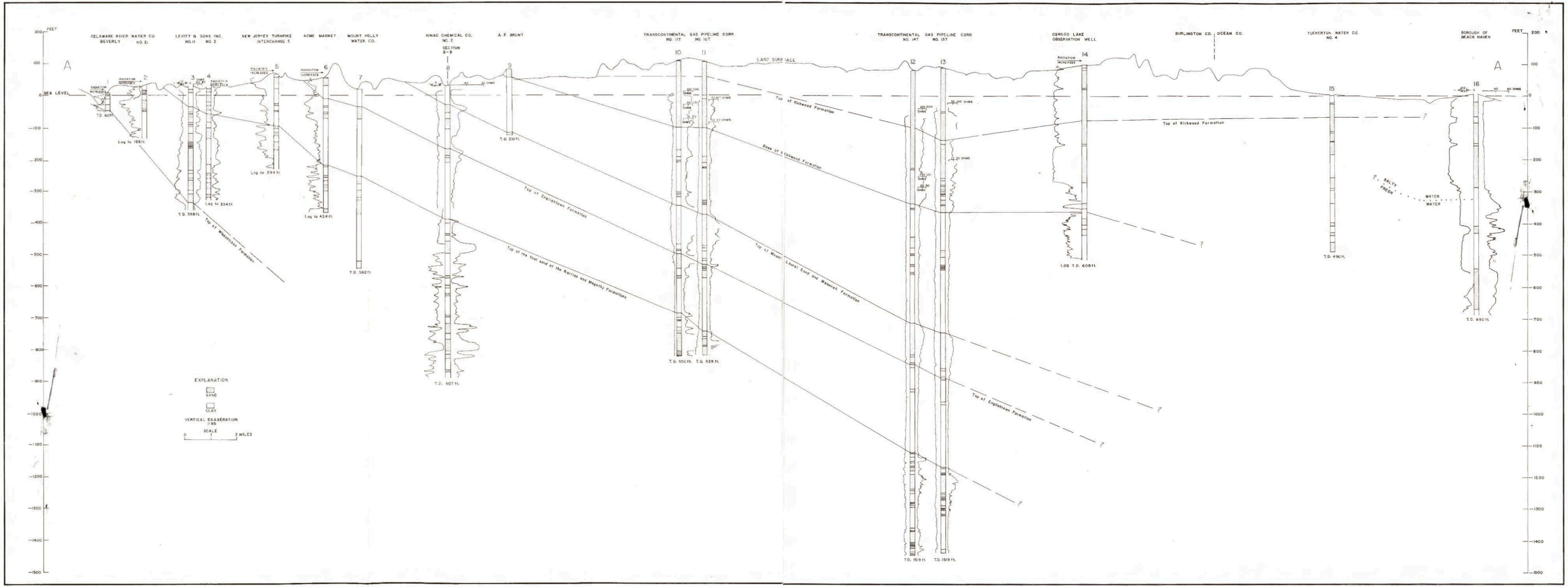

Figure 6.—Cross section showing the structure of Burlington County in the general direction of true dip of the formations.