MANAGEMENT OF GROUND WATER AND EVOLVING HYDROGEOLOGIC STUDIES IN NEW JERSEY: A HEAVILY URBANIZED AND INDUSTRIALIZED STATE IN THE NORTHEASTERN UNITED STATES

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4277

Prepared in cooperation with the
NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION
DIVISION OF WATER RESOURCES

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West Trenton, New Jersey

1985

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Mountain View Office Park
810 Bear Tavern Rd.
Suite 206
West Trenton, New Jersey 08628

Copies of this report can be purchased from:

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CONVERSION FACTORS

For use of readers who prefer to use metric (International System) units, conversion factor for terms used in this report are listed below:

Multiply	By	To Obtain
foot (ft)	0.3048	meter (m)
million gallons per day (Mgal/d)	3,785	cubic meters per day (m^3/d)
inch (in.)	25.40	millimeter (mm)
gallon (gal)	3.785	liter (L)
pound (lb)	453.6	gram (g)
square mile (mi^2)	2.590	square kilometer (km^2)

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ABSTRACT

New Jersey is the most densely populated and one of the most industrialized states in the United States. An abundance of freshwater and proximity to major northeastern metropolitan centers has facilitated this development. Pumpage of freshwater from all aquifers in the State in 1980 was 730 million gallons per day (2.76 million cubic meters per day).

Management and efficient development of the ground-water resources of the State are the responsibility of the New Jersey Department of Environmental Protection. Laws have been enacted and updated by the State legislature to manage water allocation and to control the disposal of hazardous wastes. Present resource management is guided by the New Jersey Water-Supply Master Plan of 1981. Funding for management activities is partially derived from the sale of state-approved bonds.

Effective planning and regional management require accurate and up-to-date hydrologic information and analyses. The U.S. Geological Survey, in cooperation with the New Jersey Geological Survey, is conducting three intensive ground-water studies involving the collection and interpretation of hydrologic data to meet the urgent water-management needs of New Jersey. These studies are part of a long-term cooperative program and are funded through the Water-Supply Bond Act of 1981. They began in 1983 and are scheduled to be completed in 1988.

The project areas are situated in the New Jersey part of the Atlantic Coastal Plain in and near Atlantic City, Camden, and South River. They range in size from 400 to 1,200 mi^2 (1,040 to 3,120 km^2). The studies are designed to define the geology, hydrology, and geochemistry of the local ground-water systems. The results of these studies will enable the State to address more effectively major problems in these areas such as declining water levels, overpumping, saltwater intrusion, and ground-water contamination resulting from the improper disposal of hazardous wastes.

Specific objectives of these studies by the U.S. Geological Survey are to (1) develop an accurate and up-to-date hydrogeologic data base, (2) design and implement a data-collection program and establish a computerized information

management system, (3) refine the conceptualization of the ground-water flow system, and (4) define the geochemistry of the aquifer system by conducting a water-quality appraisal. The objectives are accomplished by standard hydrogeologic methods. Information concerning hydrogeologic framework, ground-water levels, water use, hydraulic characteristics, and water quality in the study areas is compiled from all available sources. Additional data needed are collected through well inventories, surface geophysical surveys, water-quality samplings, water-level measurements, and a well-drilling program.

Interpretation of the flow system is based on the use of standard analytical techniques and digital flow modeling. Calibrated flow models will provide ground-water managers with a mechanism to develop and test regional water-supply strategies.

Definition of the geochemistry of the aquifer system is accomplished through a variety of methods which depend on the problems and available data in the particular study area. The approach includes statistical analysis of water-quality data, reaction-path modeling, and determination of the movement of chemical constituents using analytical and numerical modeling techniques.

A combined staff of 25 to 30 professionals and technicians from the New Jersey District office of the U.S. Geological Survey is committed to the three studies. The staff has specialists in geohydrology, numerical modeling, geochemistry, geophysics, and computer science. The findings of these studies will be published in data reports, interpretive reports, instructional manuals and journal articles.

INTRODUCTION

Location and Setting

New Jersey is located in the northeast part of the United States and is the most densely populated and one of the most industrialized states in the country. In 1980, over 7 million people resided in the 7,800-mi^2 (20,200 km^2) area of New Jersey. The northeast corridor which connects Washington, D.C., and Boston, Mass., crosses New Jersey as a narrow band trending northeastward from Delaware Bay to the Hudson River. Manufacturing, refining, and heavy industrial production are concentrated in the corridor. Elsewhere in the northwestern and southern parts of New Jersey, agriculture is the dominant activity.

The abundance of freshwater is one of the principal reasons for the industrial development of New Jersey. The source of this water is a long-term annual precipitation which averages 44 inches (1120 mm) per year. This precipitation provides recharge to surface-water bodies and the ground-water system. Surface water and the ground-water systems supply the State's water demands. In 1980, this demand was 2,900 Mgal/d (11 million m^3/d) (Solley and others, 1983).

The principal source of supply is ground water from sediments in the south and east. In contrast, a combination of surface and ground water is used in the northern part of the State. New Jersey has more than 16,000 wells that supply potable water (Tucker, 1981). In 1980, about 730 Mgal/d (2.76 million m^3/d) of freshwater was pumped from aquifers in New Jersey (Solley and others, 1983). Nearly 3.5 million people, 45 percent of New Jersey's population, depend on ground water for public supply.

The New Jersey Department of Environmental Protection, (NJDEP) currently has the responsibility for the protection, efficient management, and regulation of water resources. In 1947, the State was empowered to protect its ground-water resources (New Jersey Law, 1947, c. 375). This statute requires that a ground-water user obtain an allocation permit and report withdrawal information to the State.

During the drought in the northeast states of the mid-1960's, it became evident that regional water management was needed to protect and insure the efficient use of available water resources. In response to this need, the New Jersey legislature has updated State laws pertaining to water supply and water quality.

In 1981, the State of New Jersey completed a Statewide Water-Supply Master Plan (New Jersey Department of Environmental Protection, 1981). This plan defines the mechanism by which New Jersey regulates and manages water resources. In November 1981, the voters of New Jersey approved the Water-Supply Bond Act. This act, administered by the New Jersey Department of Environmental Protection, provides funding for water-supply purposes. An additional referendum passed in 1983 provides funding for ground-water studies to provide a scientific basis for management and development of water supplies. These studies are being conducted in part by the U.S. Geological Survey (USGS).

Purpose

This report[1] summarizes the mechanisms by which the State of New Jersey evaluates, regulates, manages, and develops its ground-water resources. The report (1) identifies major hydrogeologic problems affecting many of the ground-water systems of New Jersey, (2) presents and explains relevant State

[1]An early version was presented orally at a conference entitled "Studies of Analyses and Management of Hydrographic Basins" ("Esperienze Di Analisi E Gestione Di Bacini Idrografici") held in Rome, Italy in March 1985.

legislative measures, and (3) discusses the U.S. Geological Survey's supporting studies in the development of ground-water resources in New Jersey. A review of the ground-water studies funded by the Water-Supply Bond Act of 1983 which are currently in progress illustrates the level of technical analysis needed to address the principal hydrogeologic problems in New Jersey.

GROUND-WATER MANAGEMENT

Ground-water management in New Jersey has been accomplished through enactment of laws and statutes by the State legislature. These water laws can be divided into three broad categories (1) water allocation, (2) control of hazardous wastes, and (3) financing management activities.

Water Allocation

The present mechanism for managing the allocation of water is the New Jersey Water-Supply Management Act of 1981. This law replaced several allocation statutes that controlled surface and ground-water diversions. The law strengthened the allocation and diversion-permitting programs administered by NJDEP. This statute requires that before ground-water diversions may be increased a permit must be obtained from NJDEP. The NJDEP may require engineering, hydrologic, and geologic data on the planned diversion as a basis for evaluating the application. In support of the Water-Supply Management Act, the State developed the Statewide Water-Supply Master Plan. This document outlines the mechanisms through which some of the basic objectives of the Management Act are to be achieved. The Master Plan also defines special hydrologic situations that require greater regulatory control by NJDEP and provides guidelines for designating critical water-supply areas.

Hazardous Wastes

The New Jersey Solid Waste Management Act of 1970 provided the NJDEP with broad authority to regulate the storage and disposal of all types of wastes, and to regulate the design and operation of hazardous waste facilities. In 1981, the New Jersey Major Hazardous Waste Facilities Siting Act was enacted. This law established a Siting 'Commission responsible for designing and evaluating hazardous waste sites and charges the NJDEP with the responsibility of regulating and monitoring these sites. The criteria established for siting hazardous-waste-disposal facilities require consideration and protection of surface and ground-water resources (New Jersey Department of Environmental Protection, 1983).

Financing Management Activities

Funding for New Jersey's management and regulatory activities comes from a variety of sources, including revenues derived from the legislature and fees for permits and water allocation. A major source consists of special bond issues approved by the public, such as the New Jersey Hazardous Discharge Bond Act 1981. This act authorized the State to issue $100 million in bonds for the identification, cleanup and removal of hazardous discharges.

In November of 1981 and again in 1983, the public approved the $350 million Water-Supply Bond Issue. This bond issue provides funding for (1) refurbishing and consolidating existing water supply systems, (2) constructing and improving surface-water storage and purveyor interconnection, (3) restoring or replacing polluted ground-water-supply systems, and (4) conducting water-management feasibility studies and ground-water studies to develop additional supplies.

A major portion of the hydrologic analyses currently in progress in New Jersey is funded by State Water-Supply bonds. This bond funding provides for both water-management feasibility studies and ground-water studies. Water-management feasibility studies are designed to define future water demands, determine the practicability of conjunctive use of surface water and ground water, and provide engineering plans for efficient management of water supplies.

Ground-water studies are designed to enhance knowledge of the ground-water geohydrology of selected areas, and are conducted by the New Jersey Geological Survey (NJGS) in cooperation with the New Jersey District office of the USGS. Although the cooperation provided by the NJGS is primarily fiscal, several field activities will be conducted by the NJGS. A small percentage, less than 10 percent of the total bond issue funding, has been allotted to the NJGS for the ground-water projects. The USGS will receive approximately $6 million over 5 years to conduct the ground-water investigations.

EVOLVING HYDROGEOLOGIC STUDIES

Three ground-water studies are currently (1985) being funded by the Water-Supply Bond Act of 1981 and 1983. Studies are being conducted in and near the New Jersey communities of Atlantic City, Camden, and South River. These areas face potential water-supply crises due to declining water levels and degradation of water quality. They were chosen by the NJDEP as areas for five-year intensive ground-water investigations. These studies are presented to demonstrate the scope of hydrogeologic investigations being conducted in New Jersey.

The following section includes a brief description of the hydrogeology of these three study areas. The section also includes a discussion of (1) major hydrogeologic problems, (2) objectives of the evolving studies, (3) major technical approaches, (4) manpower requirements, and (5) planned publications.

Hydrogeologic Setting

The three study areas, Atlantic City, Camden, and South River (fig.1) are located in the 4,200-mi^2 (10,900 km^2) New Jersey Coastal Plain physiographic province.

The hydrogeologic framework of the New Jersey Coastal Plain consists of a seaward-dipping and seaward-thickening wedge of unconsolidated gravel, sand, silt and clay deposits (fig. 2). These deposits are as much as 6,500 ft (1,980 m) thick in Cape May County (Gill and Farlekas, 1976) and are classified as continental, marine, and marginal marine in origin (Zapecza, 1984). Several major aquifers and confining beds have been identified in the Coastal Plain deposits. The aquifers and confining units range in age from Cretaceous through Holocene (table 1). The relationship of geologic units and hydrogeologic units is shown in table 1.

The Atlantic City study area (fig. 1) covers 1,200 mi^2 (3,150 km^2) of the Coastal Plain including Atlantic County and parts of Ocean and Cape May Counties. The area is underlain by the surficial Kirkwood-Cohansey aquifer system, and the deeper Atlantic City 800-foot sand of the Kirkwood Formation (table 1). These aquifers are underlain by the Piney Point and Wenonah-Mount Laurel aquifers, and the Englishtown and Potomac-Raritan-Magothy aquifer systems. These lower units are unused and may contain saline water.

The Camden study area (fig. 1) covers 700 mi^2 (1,850 km^2) in Camden, Gloucester and Burlington Counties. It is underlain by surficial sediments of Holocene age, the three aquifers and two confining beds of the Potomac-Raritan-Magothy aquifer system. The Potomac-Raritan-Magothy aquifer system rests unconformably on crystalline rock basement. The depth to basement ranges from approximately sea level at Fall Line along the Delaware River to more than 2,000 ft (610 m) below sea level on the eastern side of the study area (Gill and Farlekas, 1976).

The South River Study area (fig. 1) covers 700 mi^2 (1,850 km^2) in parts of Monmouth and Middlesex Counties. It is underlain by unconsolidated deposits that rest unconformably on crystalline rock basement. The principal aquifers in the study area are the Farrington aquifer in the Farrington Sand Member of the Raritan Formation and the Old Bridge aquifer in the Old Bridge Sand Member of the Raritan Formation. These aquifers are mappable sands within the Potomac-Raritan-Magothy aquifer system (table 1). As in the Camden area, the depth to basement varies from less than 100 ft (30 m) above sea level along the Fall Line to more than 800 ft (240 m) below sea level at the eastern limit of the study area (Gill and Farlekas, 1976). The generalized hydrogeologic section (fig. 2) is similar to the hydrogeologic framework in the South River area except that the deeper two aquifers correspond to the Farrington and Old Bridge aquifers.

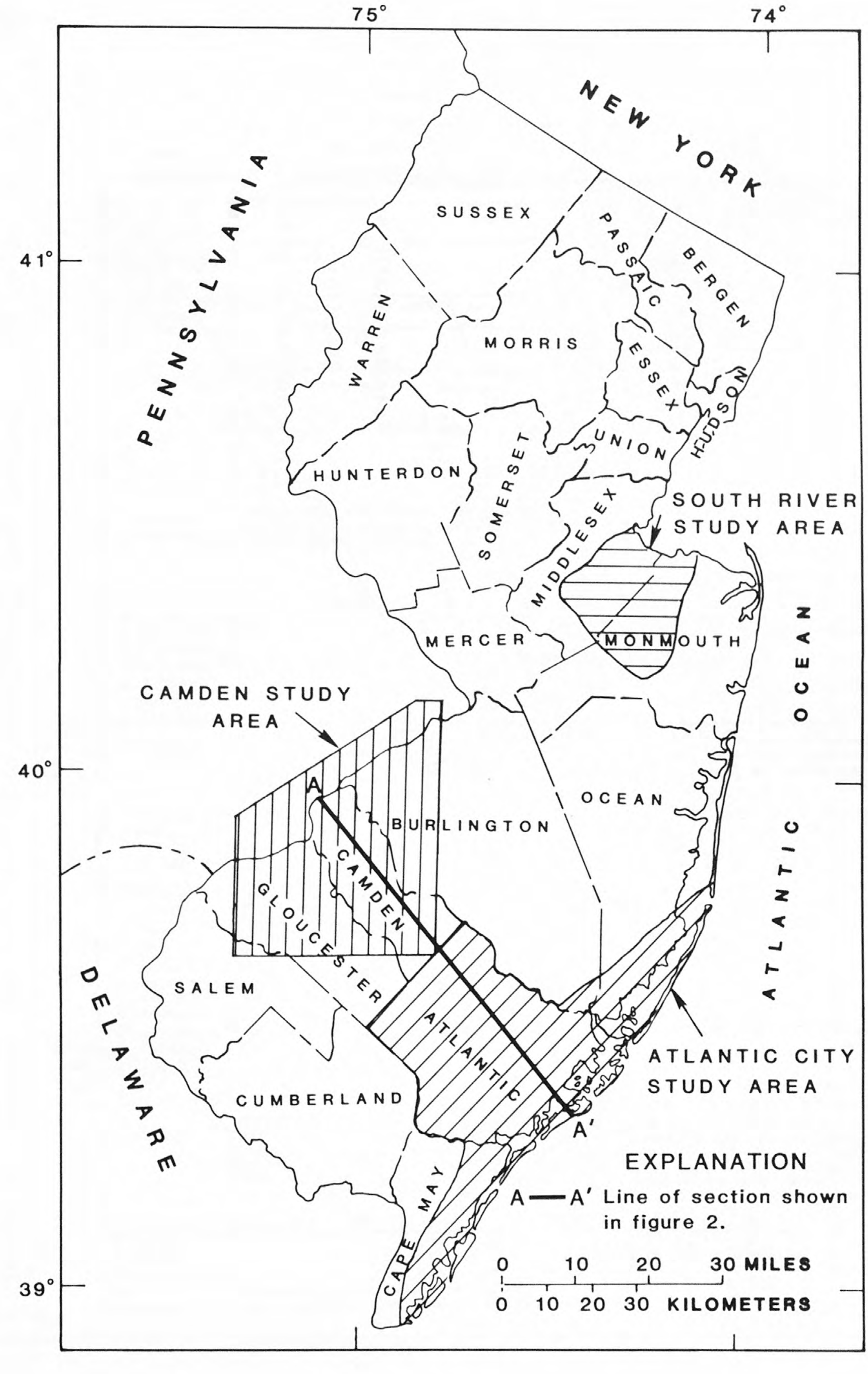


Figure 1.--Location of study areas in New Jersey.

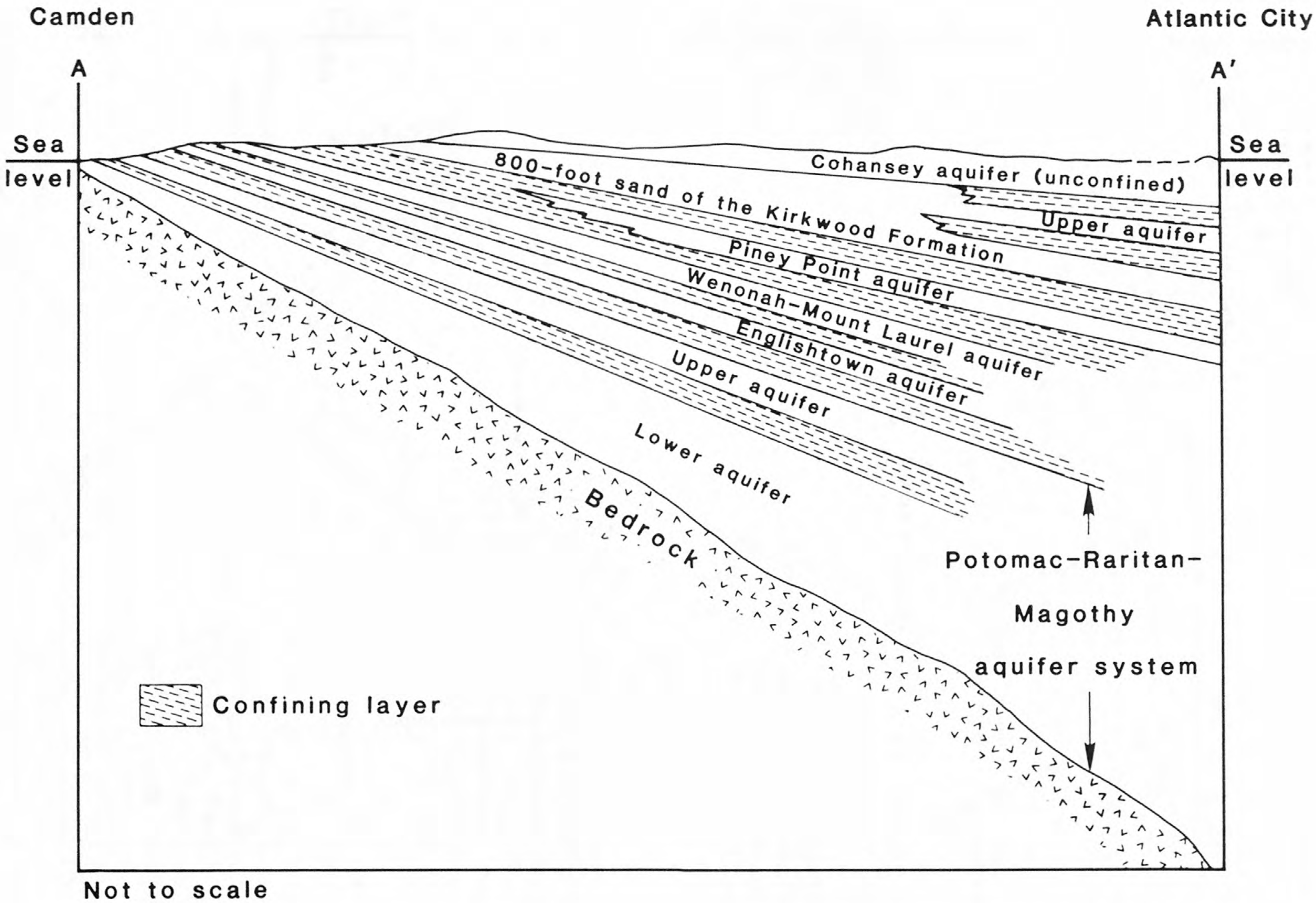


Figure 2.--Generalized hydrogeologic section of the Coastal Plain in New Jersey (Location of section shown in fig. 1).

Table 1.--Geologic and hydrogeologic units in the Coastal Plain of New Jersey (From Zapecza, 1984)

SYSTEM	SERIES	GEOLOGIC UNIT	LITHOLOGY	HYDROGEOLOGIC UNIT	HYDROLOGIC CHARACTERISTICS
Quaternary	Holocene	Alluvial deposits	Sand, silt, and black mud.	Undifferentiated	Surficial material, often hydraulically connected to underlying aquifers. Locally some units may act as confining beds. Thicker sands are capable of yielding large quantities of water.
		Beach sand and gravel	Sand, quartz, light-colored, medium- to coarse-grained, pebbly.		
	Pleistocene	Cape May Formation	Sand, quartz, light-colored, heterogeneous, clayey, pebbly.		
Tertiary	Miocene	Pensauken Formation			
		Bridgeton Formation		Kirkwood-Cohansey aquifer system	A major aquifer system. Ground-water occurs generally under water-table conditions. In Cape May County the Cohansey Sand is under artesian conditions.
		Beacon Hill Gravel	Gravel, quartz, light colored, sandy.		
		Cohansey Sand	Sand, quartz, light-colored, medium to coarse-grained, pebbly; local clay beds.		
		Kirkwood Formation	Sand, quartz, gray and tan, very fine- to medium-grained, micaceous, and dark-colored diatomaceous clay.	confining bed Rio Grande w-bz confining bed	Thick diatomaceous clay bed occurs along coast and for a short distance inland. A thin water-bearing sand occurs within the middle of this unit.
				Atlantic City 800-foot sand	A major aquifer along the coast.
				Composite confining bed	Alloway Clay member or equivalent
	Eocene	Piney Point Formation	Sand, quartz and glauconite, fine- to coarse-grained.	Piney Point aquifer	Yields moderate quantities of water locally.
		Shark River Formation	Clay, silty and sandy, glauconitic, green, gray and brown, fined-grained quartz sand.	Composite confining bed	Poorly permeable sediments.
		Manasquan Formation			
	Paleocene	Vincentown Formation	Sand, quartz, gray and green, fine- to coarse-grained, glauconitic, and brown clayey, very fossiliferous, glauconite and quartz calcarenite.	Vincentown aquifer	Yields small to moderate quantities of water in and near its outcrop area.
		Hornerstown Sand	Sand, clayey, glauconitic, dark green, fine- to coarse-grained.	Composite confining bed	Poorly permeable sediments.
Cretaceous	Upper Cretaceous	Tinton Sand	Sand, quartz, and glauconite, brown and gray, fine- to coarse-grained, clayey, micaceous.		
		Red Bank Sand		Red Bank sand	Yields small quantities of water in and near its outcrop area.
		Navesink Formation	Sand, clayey, silty, glauconitic, green and black, medium- to coarse-grained.	Composite confining bed	Poorly permeable sediments.
		Mount Laurel Sand	Sand, quartz, brown and gray, fine- to coarse-grained, slightly glauconitic.	Wenonah-Mount Laurel aquifer	A major aquifer.
		Wenonah Formation	Sand, very fine- to fine-grained, gray and brown, silty, slightly glauconitic.		
		Marshalltown Formation	Clay, silty, dark greenish gray, glauconitic quartz sand.	Marshalltown-Wenonah confining bed	A leaky confining bed.
		Englishtown Formation	Sand, quartz, tan and gray, fine- to medium-grained; local clay beds.	Englishtown aquifer system	A major aquifer. Two sand units in Monmouth and Ocean Counties.
		Woodbury Clay	Clay, gray and black, micaceous silt.	Merchantville-Woodbury confining bed	A major confining bed. Locally the Merchantville Fm. may contain a thin water-bearing sand.
		Merchantville Formation	Clay, glauconitic, micaceous, gray and black; locally very fine-grained quartz and glauconitic sand.		
		Magothy Formation	Sand, quartz, light-gray, fine- to coarse-grained; local beds of dark-gray lignitic clay.	Potomac-Raritan-Magothy aquifer system: upper aquifer	A major aquifer system. In the northern Coastal Plain the upper aquifer is equivalent to the Old Bridge aquifer and the middle aquifer is the equivalent of the Farrington aquifer. In the Dela. River Valley three aquifers are recognized. In the deeper sub-surface, units below the upper aquifer are undifferentiated.
		Raritan Formation	Sand, quartz, light-gray, fine- to coarse-grained, pebbly, arkosic, red, white, and variegated clay.	conf bd middle aquifer	
	Lower Cretaceous	Potomac Group	Alternating clay, silt, sand, and gravel.	conf bd lower aquifer	
Pre- Cretaceous		Bedrock	Precambrian and lower Paleozoic crystalline rocks, metamorphic schist and gneiss; locally Triassic basalt, sandstone and shale.	Bedrock confining bed	No wells obtain water from these consolidated rocks, except along Fall Line.

w-bz--water bearing zone
conf bd--confining bed

The unconsolidated deposits of the New Jersey Coastal Plain are a vast ground-water reservoir. Rhodehamel (1970) has estimated that 11 trillion gallons (42 billion cubic meters) of ground water is stored in only one Coastal Plain aquifer, the Cohansey Sand. This is about 400 times the quantity pumped from this aquifer in 1984. Because the water-supply potential of the Coastal Plain deposits is underutilized, additional development may provide enough water to meet existing and foreseeable future needs. These needs will probably include (a) increased development of public, industrial, and commercial water supplies, (b) increased pumpage for agricultural use, (c) supplemental water supplies during drought periods, and (d) augmentation of streamflow during periods of low flow.

Hydrogeologic Problems

Insufficient knowledge of the hydrogeology is one of the major problems in the Coastal Plain of New Jersey. Before the ground-water resources can be further developed, a more thorough understanding is needed. In many instances, a thorough knowledge of the storage, potential yield, flow pattern, hydraulic characteristics, and quality of ground water in the system is lacking. This lack of information has hampered regional water-resource planning and management. In turn, inadequate planning and management have led to inadequate, or totally unplanned development that has created many existing problems, and conditions for potential problems. Among the most significant of these problems are overpumping and degradation of water quality. Three areas of the Coastal Plain acutely affected by these problems are the Atlantic City, Camden, and South River areas.

In parts of these areas, improper disposal and containment of inorganic and organic chemical wastes have led to the local degradation of ground-water quality. The three areas contain at least 17 hazardous waste sites that are included in the National Priorities List[1] issued by the U.S. Environmental Protection Agency in December of 1981 and are eligible for federal superfund monies (fig. 3).

In the Atlantic City study area, a municipal well field is threatened by the movement of contaminants from a nearby landfill (Grey and Hoffman, 1983). In the Camden study area, both point and nonpoint sources of contamination are identified problems. The point sources include landfills containing petrochemical, other industrial and municipal wastes. The nonpoint sources include induced ground-water recharge from the potentially contaminated Delaware River. Fusillo and others (1985) have documented the areal distribution of degraded ground water in the

[1]The National Priorities List are a compilation of top priority hazardous-waste sites identified under the guidelines of the Comprehensive Environment Response, Compensation and Liability Act of 1980 (U.S. Public Law, 96-510).

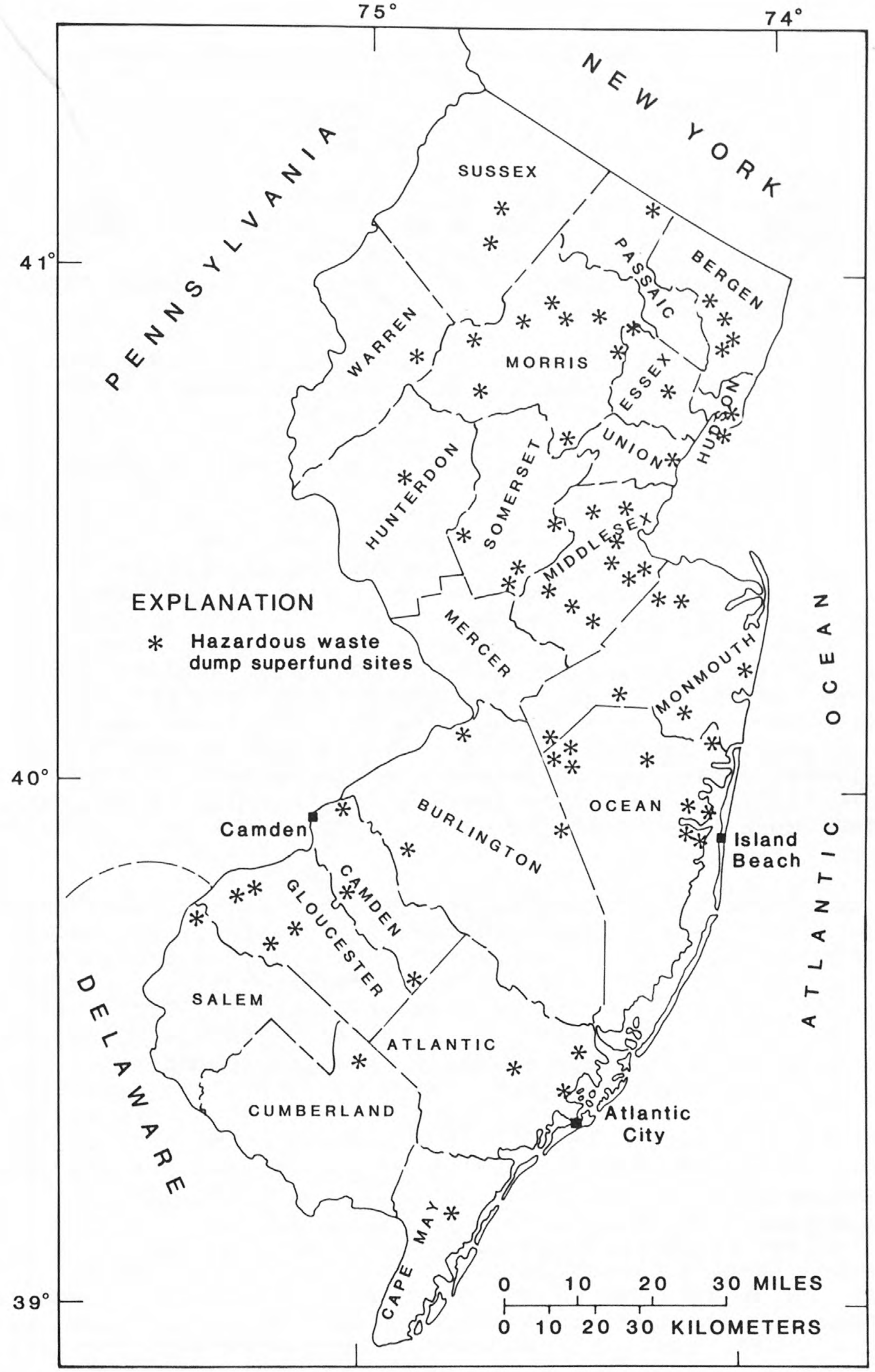


Figure 3.--Location of hazardous-waste sites in New Jersey on the National Priorities list in 1981 (From Sadat and others, 1983).

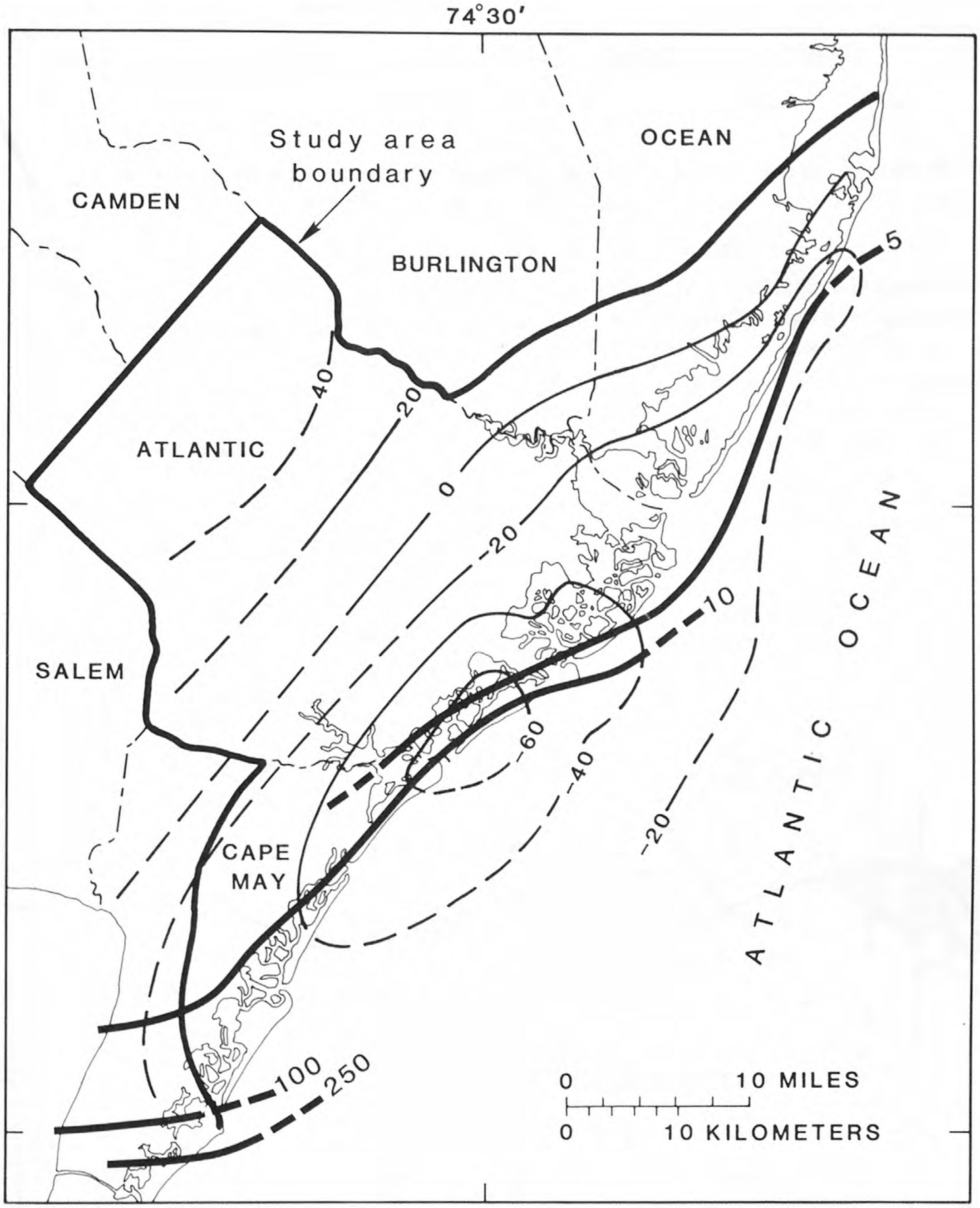
outcrop area of the Potomac-Raritan-Magothy aquifer system adjacent to the Delaware River. In addition to sources in New Jersey, contamination sources in the Philadelphia area may be degrading ground-water quality in the Camden area.

In the South River study area several landfills contain toxic chemicals. Numerous consultants have investigated the geohydrology of some of these sites, for example the Lone Pine Landfill (Fred C. Hart Associates, Inc., 1982). However, the effect of local contamination on the regional water quality of the study area is unknown.

In each of the areas, heavy pumpage has significantly lowered ground-water levels. Walker (1983) showed these lowered potentiometric surfaces for 1978 in the Atlantic City, Camden and South River areas (figs. 4-8). In the Atlantic City area, water levels in the 800-foot sand of the Kirkwood Formation show an areally extensive cone of depression that is more than 70 ft (24 m) below sea level at the seashore communities of Margate and Ventnor (fig. 4). In the Camden area, the lower and upper aquifers of the Potomac-Raritan-Magothy aquifer system have large cones of depression. The deepest part of the potentiometric surfaces in 1978 were more than 80 ft (24 m) below sea level in both aquifers (figs. 5 and 6). In the South River area, the middle aquifer (Farrington aquifer) and upper aquifer (Old Bridge aquifer) of the Potomac Raritan-Magothy aquifer system have areally extensive cones of depression. The lower aquifer of the Potomac-Raritan-Magothy aquifer system is absent in the area. The lowest point on the potentiometric surface in 1978 was more than 70 ft (21 m) below sea level in the Farrington aquifer (fig. 7) and more than 40 ft (12 m) below sea level in the Old Bridge aquifer (fig. 8).

Development of ground-water resources in the study areas has caused other significant changes in the hydrologic system. The direction and velocity of ground-water movement also have been altered by pumpage. A significant result has been the movement of saline water into the freshwater aquifer system in all three areas. Aquifers in the vicinity of Atlantic City may be threatened by the upward movement of salty ground water from the deeper Piney Point aquifer, and by lateral movement of salty ground water in the 800-foot sand of the Kirkwood Formation. The freshwater-saltwater transition zone in the 800-foot sand is located offshore of Atlantic City; however its precise position is unknown.

Lowered water levels have caused the infiltration of Delaware Estuary water into the Potomac-Raritan-Magothy aquifer system in the Camden area. Also, saline water has moved toward pumping centers along the regional saltwater interface which is assumed to be the 250 mg/L chloride concentration line (fig. 5).



EXPLANATION

—— -20 ——

Potentiometric contour, shows altitude at which water would have stood in tightly cased wells in 1978. Dashed where approximate. Interval 20 feet. Datum is sea level. (From Walker, 1983).

▬▬ ▬ ▬ 250

Line of equal chloride concentration, 1980, in milligrams per liter. (Modified from Legette, Brashears and Graham, 1982).

Figure 4.--Potentiometric surface and chloride concentration of water in the 800-foot sand of the Kirkwood Formation in the Atlantic City area.

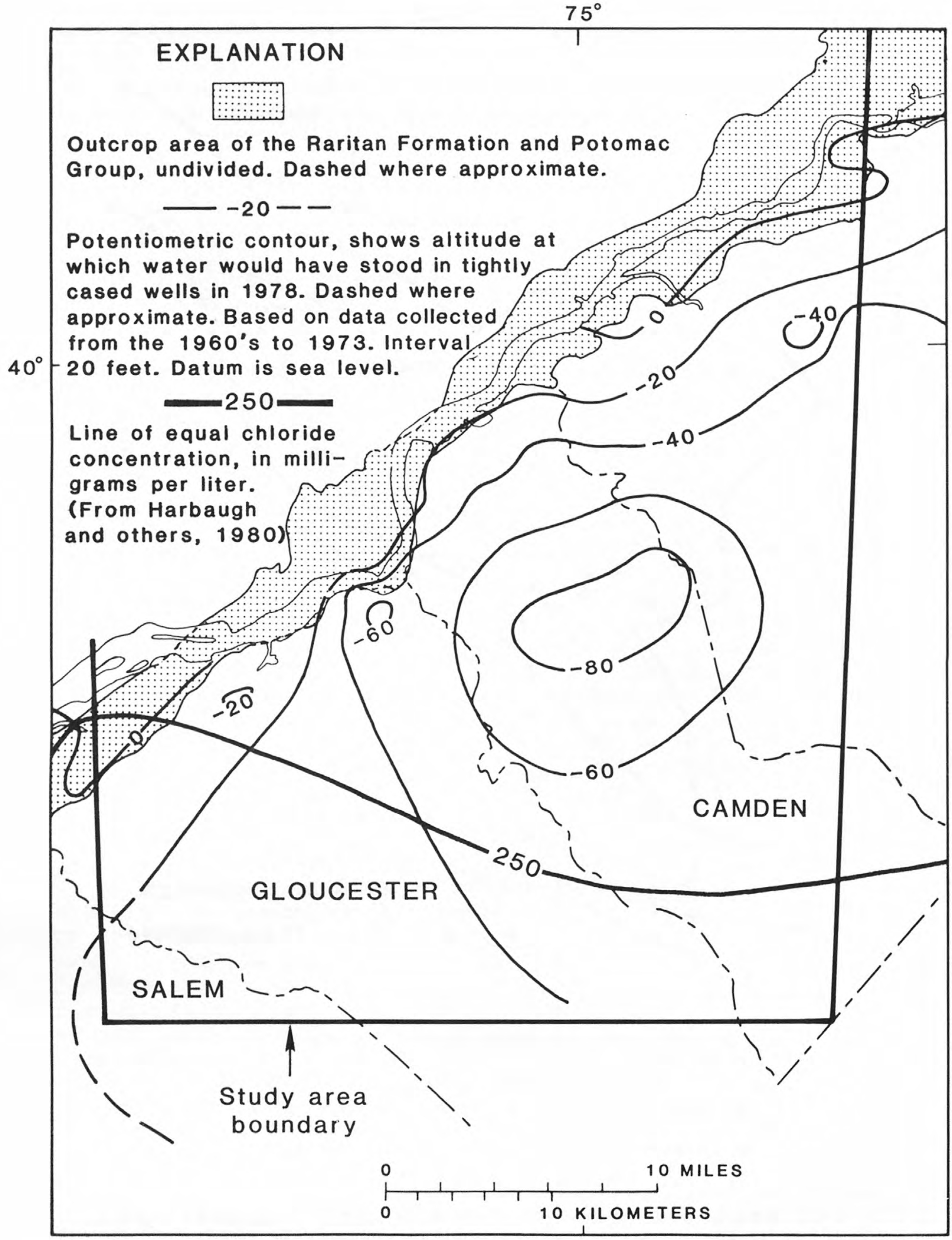


Figure 5.--Potentiometric surface and chloride concentration of water in the lower aquifer of the Potomac-Raritan-Magothy aquifer system in the Camden area (Potentiometric contours from Walker, 1983).

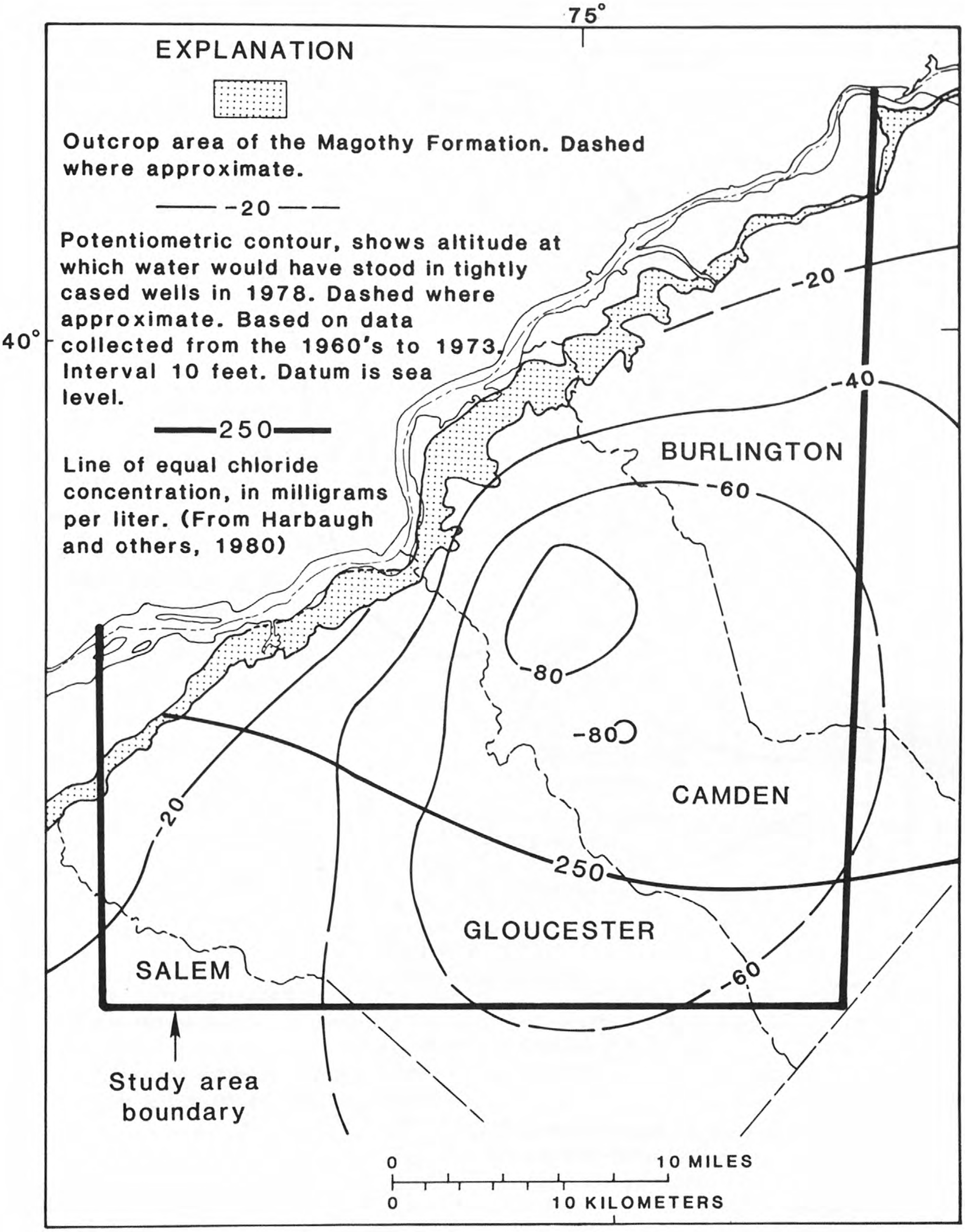
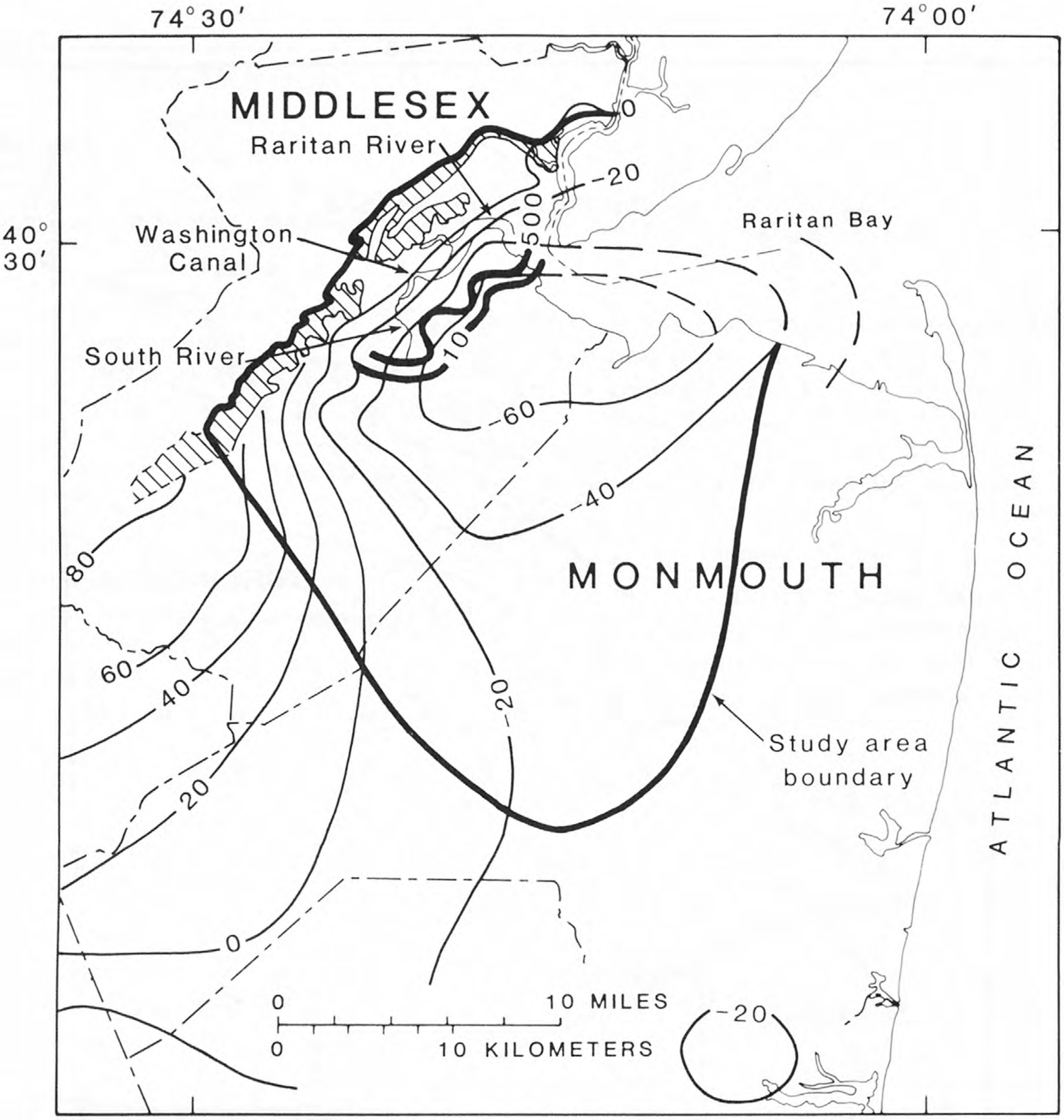


Figure 6.--Potentiometric surface and chloride concentration of water in the upper aquifer of the Potomac-Raritan-Magothy aquifer system in the Camden area (Potentiometric contours from Walker, 1983).



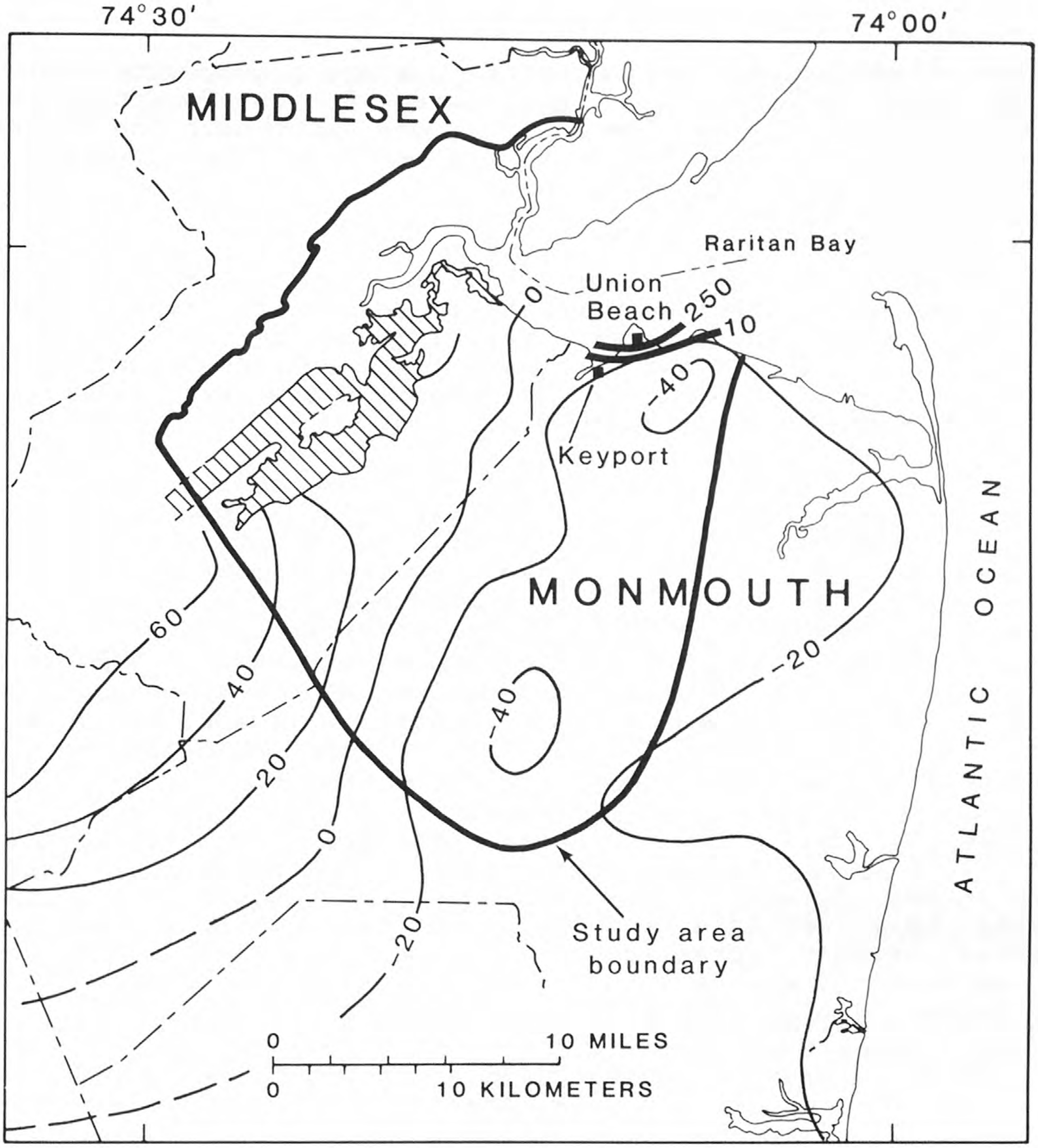
EXPLANATION

Outcrop area of the Farrington Sand Member of the Raritan Formation. Dashed where approximate.

500 Line of equal chloride concentration in 1977, in milligrams per liter. Interval variable. (From Schaefer, 1983)

—— -20 — — Potentiometric contour, shows altitude at which water would have stood in tightly cased wells in 1978. Dashed where approximate. Interval 20 feet. Datum is sea level (From Walker, 1983).

Figure 7.--Potentiometric surface and chloride concentration of water in the Farrington aquifer in the South River area.



EXPLANATION

Outcrop area of the Old Bridge Sand Member of the Magothy Formation. Dashed where approximate.

250 Line of equal chloride concentration in 1977, in milligrams per liter. Interval variable. (From Schaefer and Walker, 1981)

—— -20 —— —— Potentiometric contour, shows altitude at which water would have stood in tightly cased wells in 1978. Dashed where approximate. Interval 20 feet. Datum is sea level. (From Walker, 1983).

Figure 8.--Potentiometric surface and chloride concentration of water in the Old Bridge aquifer in the South River area.

Luzier (1980, p. 63) estimated the average ground-water velocity along this interface to be between 20 and 268 ft/yr (6 and 82 m/yr) in 1973. If the salty ground water near the interface moves with the same velocity as the fresh ground water, then salty ground water is moving toward pumping centers in the Camden area at these rates.

In the South River study area, declining water levels in the Farrington and Old Bridge aquifers of the Potomac-Raritan-Magothy aquifer system have caused the infiltration of saline water through submerged outcrop areas of the aquifers, and increased the potential for lateral movement of the regional saltwater transition zone towards pumping centers.

As early as 1937, Barksdale (1937) noted the potential for saltwater infiltration of the Farrington aquifer in the vicinity of the Washington Canal in Middlesex County. Appel (1962) documented the increase in chloride concentrations from 1943 to 1958 near the outcrop of the Farrington aquifer in the South River and South Amboy areas. More recently, Schaefer (1983) inferred from chloride concentrations determined in 1977 and 1981 that saltwater in the Farrington aquifer at the submerged outcrop areas along the Washington Canal, South River, Raritan River, and Raritan Bay (see fig. 7) continued to move southeastward toward pumping centers.

In the Old Bridge aquifer, infiltration of salty water in the vicinity of Keyport and Union Beach, Monmouth County in the 1970's was documented by Schaefer and Walker (1981). Water levels have declined in the Old Bridge aquifer, reversing the natural seaward hydraulic gradient and causing landward movement of saltwater from the submerged outcrop in Raritan Bay (Schaefer and Walker, 1981, p. 16).

Water levels in the Farrington and Old Bridge aquifers have also declined in the coastal areas, and are below sea level in Monmouth and Ocean Counties (Walker, 1983). The transition zone between fresh and salty ground water in the Farrington and Old Bridge aquifers is offshore in Monmouth County but crosses the shoreline in the vicinity of Island Beach (fig. 3) in Ocean County (Luzier, 1980, p. 6). The landward head gradient may be causing the lateral movement of salty water towards pumping centers.

Principal Objectives

The major thrust of these evolving studies is to provide water-resource managers with requisite hydrologic data and related interpretation as a basis for effective management of the ground-water resources in the study areas. Ground-water data on water levels, water use, hydrogeologic framework, hydraulic characteristics and water quality have been collected in the study areas since the early 1900's. Interpretation of these data has involved both statistical and analytical techniques. These data and interpretations will provide a starting point for these investigations. Historic data will be verified and the results of previous investigations will help define the scope and complexity of the current studies.

Simulation of ground-water flow has been extensively used to assess the impact of overpumping in the Camden and South River areas (Luzier, 1980; Harbaugh and others, 1980; Farlekas, 1979). Recently (1984), the Regional Aquifer System Analysis (RASA) study has investigated the ground-water flow system of the entire Coastal Plain of New Jersey. The flow of fresh ground water was simulated in these studies, but the transport of solutes, primarily chloride, was not addressed (M. Martin, U.S. Geological Survey, written communication, 1984).

These studies, as are all modeling studies, are limited by the data and assumptions upon which the models were designed. For example, the model designed for the South River area (Farlekas, 1979) simulated flow in the Farrington aquifer which is only part of a multi-aquifer system. The previous modeling efforts in the Camden area have examined regional aspects of the ground-water flow system, but were not designed to specifically define local hydrologic interaction between the Delaware River and the Potomac-Raritan-Magothy aquifer system. The RASA study was designed to define the geohydrology of the entire New Jersey Coastal Plain system. Although these models provide valuable insights into the hydraulics of the regional system, they cannot be used to examine the details of a local hydrologic system. A detailed analysis is needed by State regulatory officials to effectively manage the ground-water resources of these areas in the future.

Great advances have been made in the past decade in the theoretical development and design of both ground-water flow and solute transport models. Calibrated models can be used to forecast the hydrologic effects of various management alternatives. The forecasts, however, are reliable only if the hydrologic processes in the system are accurately simulated and the data used in the design and calibration of the model are extensive enough to accurately depict the geohydrologic system. The geohydrologic data available in 1984 are insufficient to design and construct flow models and perhaps even the solute transport models that are needed to assess the consequences of the complex resource management alternatives for each of the study areas.

Therefore, the principal objectives of the three studies are to (1) upgrade the hydrologic data base with accurate data, including ground-water levels, lithologic information, and ground-water quality, (2) design and implement a data-collection program to enhance existing data bases and establish an information-management system, (3) develop a more complete understanding of the ground-water flow system through digital modeling, and (4) conduct a water-quality appraisal to more accurately define the geochemistry of the aquifer system.

The results of these studies will aid the NJDEP in making regional water-management decisions for the Atlantic City, Camden, and South River study areas. The results will also enable NJDEP to more effectively choose among alternative ground-water diversions, prevent or mitigate contamination from land or saltwater sources, and develop a water-supply strategy that will minimize long-term detrimental effects on the hydrologic system.

Overall Approach

The approach used is individually designed to address the hydrologic problems of each study area. All major phases in the overall approach are addressed in each of the studies but with varying degrees of emphasis, completed at different times during the study and accomplished through the use of technical approaches of varying complexity.

The overall approach includes four main phases (1) development of a data base from existing data, (2) collection of additional data, (3) ground-water flow modeling, and (4) a ground-water quality appraisal. The first phase includes the design and implementation of an information-management system and the acquisition and computer storage of geologic and hydrologic data. The information-management system is identical for all three studies and the standard for other projects undertaken by the New Jersey District of the USGS. Historical data are acquired by searching the files of the USGS, the NJDEP, local municipal governments and appropriate nongovernmental sources. These data are evaluated, and if of satisfactory quality, are incorporated into the resulting data base. This requires more work in Camden and South River studies because more data are available for these areas than for Atlantic City.

The second phase consists of the collection of additional data. It involves three programs: (1) traditional drilling, (2) surface-geophysical exploration, and (3) field-data collection. The NJGS provides drilling and geophysical services. Some of the drilling deeper than 200 ft (61 m) will be contracted to the private sector. The design of the drilling and geophysics programs is developed cooperatively by the NJGS and USGS project staffs. Technical assistance for the programs is provided by USGS staff members.

Additional field data are collected as emerging needs are recognized. These include synoptic water-level measurements, synoptic water-quality samplings, water-use information, and measurements of ground-water discharge to streams. USGS project staff collect the field data. Data collection is most intensive in the Atlantic City study because of a paucity of available data.

The third phase in the overall approach consists of the development of ground-water-flow models. These models are necessary to improve the understanding of hydrologic processes and the flow system in the three areas. In addition, standard statistical and analytical techniques are applied as appropriate to define the geohydrology of these areas.

Three-dimensional ground-water-flow models will be used to determine areas and volumes of ground-water recharge and discharge, and the direction and velocity of ground-water flow throughout the freshwater system. The calibrated flow models will be capable of simulating the consequences of alternative ground-water withdrawal scenarios.

In extending the work of earlier modeling studies (Luzier, 1980; Camp Dresser and McKee Inc., 1982), the Camden study focuses on the interaction of the Delaware River and the ground-water system. The South River study is examining in detail ground-water flow in the outcrop areas of the Farrington and Old Bridge aquifers and the hydraulic connection between them. In contrast, flow modeling has not been used extensively to evaluate ground-water flow for the Atlantic City study area. Therefore, a ground-water model is planned to simulate regional flow conditions in this area.

The fourth phase in the overall approach consists of a ground-water-quality appraisal. Its aspects differ for each area depending on previous studies, the availability of historical water-quality data, and the local water-quality problems.

The appraisals are based on (1) implementation of appropriate water-quality sampling programs, (2) completion of required geochemical analysis, including reaction-path modeling, (3) design and calibration of variable density or solute transport models, and (4) design of water-quality monitoring networks based on items (1), (2) and (3).

The appraisal for the Atlantic City area consists of defining ambient ground-water quality and evaluating the lateral movement of the offshore saltwater interface. Ambient ground-water quality of the Kirkwood and Cohansey aquifers is determined by water-quality sampling throughout the area. The area is delineated according to the physical and chemical characteristics of the ground water. This delineation is the basis for ascertaining future changes in the ground-water quality. Evaluation of the movement of the offshore saltwater interface is to be based on the results of a flow model.

The appraisal of Camden (1) defines present water quality in minor aquifers (the major aquifers have been recently studied by Fusillo and Voronin (1981), (2) uses isotopes and other geochemical techniques to define areas of recharge from the Delaware River to the Potomac-Raritan-Magothy aquifer system, (3) models the transport of chloride or other appropriate chemical constituent in a selected part of the aquifer system, and (4) defines the geochemical processes that are occurring in selected parts of the area.

The appraisal of the South River area (1) defines the occurrence and distribution of organic constituents and trace metals in the outcrop areas of the Farrington and Old Bridge aquifers, (2) defines the areal distribution and historical trends of saltwater intrusion, and (3) models the transport of chlorides due to saltwater intrusion in selected parts of the area.

Manpower Requirements

The three studies are 5-year efforts and require a combined staff from the New Jersey District office of the USGS of approximately 25 to 30. The projects require professional and technical staff with expertise in a wide variety of disciplines including geohydrology, geochemistry, numerical modeling, geophysics, and computer science.

A project coordinator provides overall technical and operational supervision. A project chief and an assistant for each of the studies provide detailed planning and technical direction. The project chiefs have technical specialities but by interaction will develop technical expertise in modeling, geohydrology, and geochemistry. In addition, staff positions with specialties in geochemistry and geophysics provide technical support to all the projects. A senior hydrologic technician acts as liason to the NJGS to insure a coordinated drilling and surface-geophysical effort.

Additional staff members include computer aids for entry of new data into information management systems, and for maintainence of data bases. As many as 15 staff members are needed to collect field data, compile existing hydrologic data, and assist in the drilling and surface-geophysical program.

Planned Publications

Pertinent findings in each study are to be published. The publications can be divided into three major categories: (1) data reports, which provide basic information about the geohydrology and ground-water quality of each area, (2) interpretive reports, which define the flow system, the dominant hydrologic processes, and effects of potential stresses in each area, and (3) instructional manuals, which explain operational aspects of the information management system, techniques for continued acquisition of accurate data, and use of ground-water models.

Data reports may include, if appropriate, the following maps and data:

(1) potentiometric surfaces
(2) structure-contour, thickness, and geohydrologic sections
(3) selected water-quality constituents
(4) quantity and distribution of ground-water withdrawals
(5) aquifer and confining-bed hydraulic properties

Interpretive reports may include analyses of the following:

(1) the ground-water flow system
(2) solute transport in localized areas
(3) effects of changing stresses on the ground-water flow system
(4) various surface geophysical techniques as applied to the study areas.

Instructional manuals may include the following topics:

(1) maintenance, use and management of the computerized data base and ground-water flow models
(2) collection of ground-water samples for water-quality analysis
(3) development of monitoring-well networks for continued collection of accurate data for inclusion in data base.

In addition, journal articles describing new techniques or unique geohydrologic situations can be prepared as they develop.

SUMMARY

New Jersey is the most densely populated and one of the most industrialized states in the country. Ground water is used extensively as a water resource and provides drinking water to nearly 3.5 million people or 45 percent of the State's population. In 1980, about 730 Mgal/d (2.76 million m^3/d) of freshwater was withdrawn from aquifers in New Jersey.

The New Jersey legislature has recognized the importance of ground water through the enactment of several statutes designed to help efficiently manage, regulate, and develop the state's ground-water resources. The NJDEP is responsible for implementing these statutes. This legislation can be divided into three broad categories; water allocation, control of hazardous wastes, and financing management activities.

The principal statute for managing ground-water allocation is the New Jersey Water-Supply Management Act of 1981. The Water-Supply Master Plan was based on this statute. Among the most important hazardous-waste statutes are the Solid Waste Management Act of 1970 and the Hazardous Waste Facilities Siting Act of 1981. New Jersey's management and regulatory activities are financed by permitting and allocation fees, and by special voter-approved bond issues. Notable examples of bond funding include the New Jersey Hazardous Discharge Bond Act of 1981 and the Water-Supply Bond Act of 1981.

The aquifers of the New Jersey Coastal Plain form an areally extensive ground-water reservoir. In some parts of the Coastal Plain, ground water is plentiful whereas in others, development has resulted in potential water shortages. Three ground-water projects funded by the Water-Supply Bond Act are focused on the Atlantic City, Camden, and South River areas. The USGS, in cooperation with the NJGS, is pursuing a 5-year study of each of these areas.

Further development of the ground-water resources of these three areas is hampered by a lack of accurate and detailed information on the system's storage, potential yield, flow pattern, and water quality. This in turn has hindered planning and regional management of ground water. Moreover it has led to unplanned development and created or exacerbated many existing and potential problems. Among the most significant of these problems are overpumping of aquifers and contamination of the ground water from the land surface. These problems can be overcome only if the proper hydrologic data and analyses are available to water managers. Available geohydrologic data and a detailed knowledge of stresses acting on the ground-water system of New Jersey are insufficient to thoroughly define and understand the dominant hydrologic processes and hydraulics of the system.

The objectives of the three studies are to (1) upgrade the hydrologic data base, (2) design and implement a data-acquisition network and an information-management system, (3) develop an understanding of the ground-water flow system, and (4) define the geochemistry of the aquifer system.

The overall approach in all the studies includes four main phases (1) data-base development, (2) additional data collection, (3) ground-water flow modeling, and (4) a ground-water-quality appraisal. Each study emphasizes the phase most important in accomplishing its principal objective. The 5-year studies require a combined staff of 25 to 30 professionals and technicians from the New Jersey District office of the U.S. Geological Survey. These individuals have expertise in geohydrology, numerical modeling, geochemistry, geophysics and computer science. The planned publications embodying the results include (1) data reports, (2) interpretive reports, (3) instructional manuals and (4) journal articles.

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☆ U. S. GOVERNMENT PRINTING OFFICE: 1986-O-612-863