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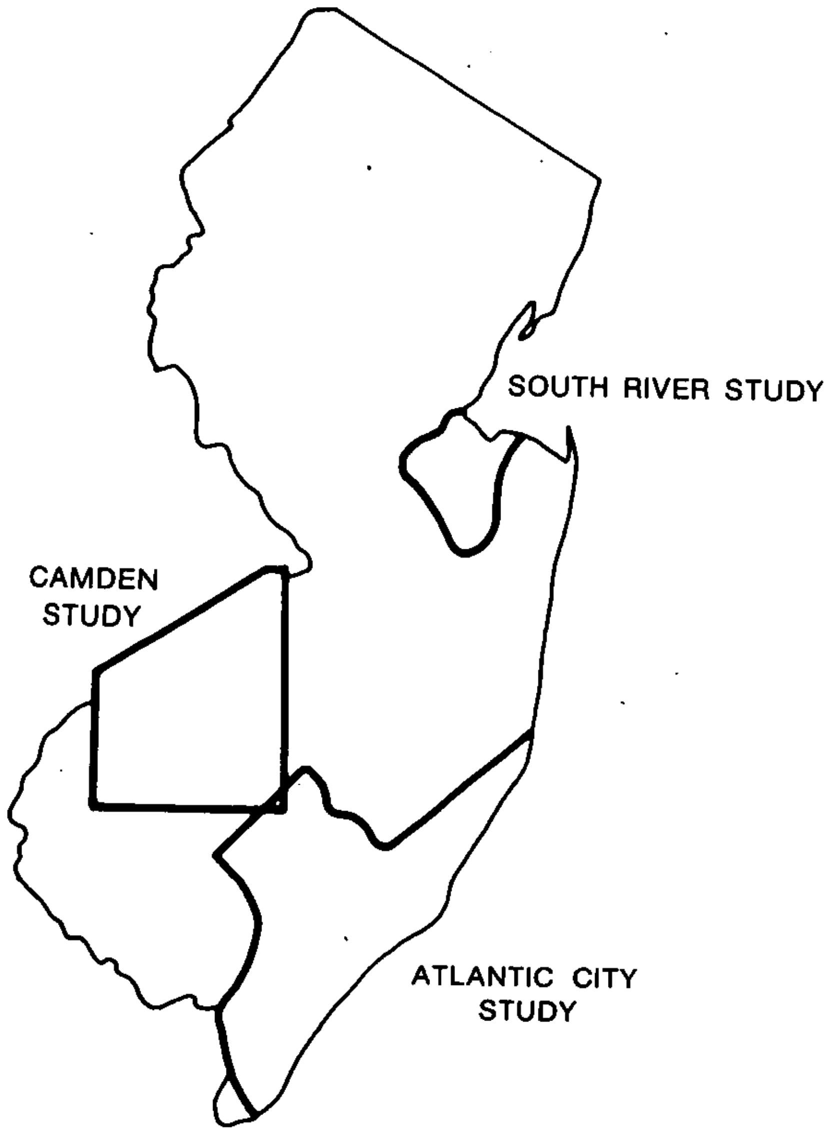
# Open-File Report 87-1

# Plan of Study for the New Jersey Bond Issue Ground-Water-Supply Investigations




N.J. Department of Environmental Protection • Division of Water Resources

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# PLAN OF STUDY FOR THE NEW JERSEY BOND ISSUE GROUND-WATER-SUPPLY INVESTIGATIONS

by
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Prepared by the
United States Geological Survey
in cooperation with the
New Jersey Department of Environmental Protection
Division of Water Resources

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STATE OF NEW JERSEY
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Department of Environmental Protection
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Geological Survey
Haig F. Kasabach, *State Geologist*

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## CONVERSION FACTORS AND ABBREVIATIONS

Data in this report are in inch-pound units. Inch-pound units are converted to metric (International System) units with the following factors:

| Multiply inch-pound unit | By | To obtain metric unit |
|---|---|---|
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| gallon (gal) | 3.785 | liter (L) |
| million gallons per day (Mgal/d) | 0.04381 | cubic meter per second ($m^3/s$) |

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

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## ABSTRACT

Ground water is the principal source of water supply in the Coastal Plain of New Jersey, and, in many areas, it is an abundant resource. In several areas, however, large withdrawals have resulted in declining ground-water levels and a reduction in the volume of water in storage. These conditions have increased the potential for water-supply shortages and for contamination of freshwater aquifers by encroaching saltwater. The U.S. Geological Survey, in cooperation with the New Jersey Department of Environmental Protection, has initiated comprehensive investigations of the ground-water supply in three areas of potential shortage and contamination. These areas are in the vicinity of Atlantic City, Camden, and South River. The chief objective of these investigations is to provide water-resources managers with the hydrologic data and analyses necessary to prudently manage the ground-water resources of each study area. This objective will be accomplished by upgrading the data bases on the geology, hydrology, and geochemistry of the ground-water systems; by developing a detailed understanding of the ground-water systems, principally through the use of digital models; and by implementing a standardized information management system. This report describes the background, organization, objectives, technical approach, work plans, and planned products of these investigations.

## INTRODUCTION

### Background

Ground water is the principal source of water supply in the Coastal Plain of New Jersey, and, in many areas, it is an abundant resource. However, large withdrawals in several localities have resulted in declining ground-water levels and storage, thereby increasing the potential for water-supply shortages. Localities of potential shortage include the Atlantic City, Camden, and South River areas.

In November 1981, the voters of New Jersey authorized a $350 million Water-Supply Bond Issue. This Bond Issue, administered by the New Jersey Department of Environmental Protection (NJDEP), provides funding for: (1) upgrading and consolidating privately owned water-supply systems; (2) constructing or improving system interconnections and surface-water storage facilities; (3) constructing various state-owned water-supply facilities and acquiring additional facilities; and (4) conducting studies of water supply and management to aid in the development of surface-water and ground-water resources. Localities selected for intensive ground-water resources studies are the Atlantic City, Camden, and South River areas (New Jersey Department of Environmental Protection, 1981). These studies, which began in 1983 and are scheduled to be completed in 1988, will be conducted cooperatively by the U.S. Geological Survey (USGS) and the New Jersey Department of Environmental Protection, Division of Water Resources, Geological Survey (NJGS).

## Purpose of this Report

The chief purpose of this report is to present for each study a description of the principal geohydrologic problems, the objectives of the investigation planned, and the technical approaches to the study that likely will be implemented. This report also includes detailed work plans for and a list of products anticipated from each study.

## Geohydrologic Setting

The Atlantic City, Camden, and South River areas are in the Coastal Plain of New Jersey (fig. 1), an area of approximately 4,200 $mi^2$ (square miles). The gravel, sand, silt, and clay deposits of the Coastal Plain form a wedge-shaped mass that thickens toward the southeast. These deposits range in age from Cretaceous to Holocene and are believed to be of marine, marginal marine, and continental origin (Zapecza, 1984). A generalized geohydrologic section (fig. 2) shows the principal aquifers and confining beds of the Coastal Plain of New Jersey. Table 1 presents information on the lithology and hydrologic characteristics of these aquifers and confining beds, and shows the relations between geologic units and geohydrologic units.

The Atlantic City study area covers 1,200 $mi^2$ and includes all of Atlantic County and parts of Ocean, Burlington, Cumberland, and Cape May Counties (fig. 1). The area is underlain by two principal freshwater aquifers--the surficial Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand of the Kirkwood Formation, which is commonly called the 800-foot sand. The Rio Grande water-bearing zone of the Kirkwood Formation is situated midway within the confining bed that separates the Kirkwood-Cohansey aquifer system from the 800-foot sand. Throughout most of the study area, however, the Rio Grande is an aquifer of minor importance. In the Atlantic City area, aquifers deeper than the 800-foot sand have not been developed for water supply, as they may contain brackish or saline water. In descending order, these undeveloped units include the Piney Point aquifer of Tertiary age, and units of Cretaceous age including the Wenonah-Mount Laurel aquifer, the Englishtown aquifer system, and the Potomac-Raritan-Magothy aquifer system (fig. 2; table 1).

The Camden study area comprises 700 $mi^2$ in parts of Camden, Burlington, Gloucester, Atlantic, and Salem Counties (fig. 1). The area is underlain by surficial sediments of Holocene age and, more importantly, by the three principal

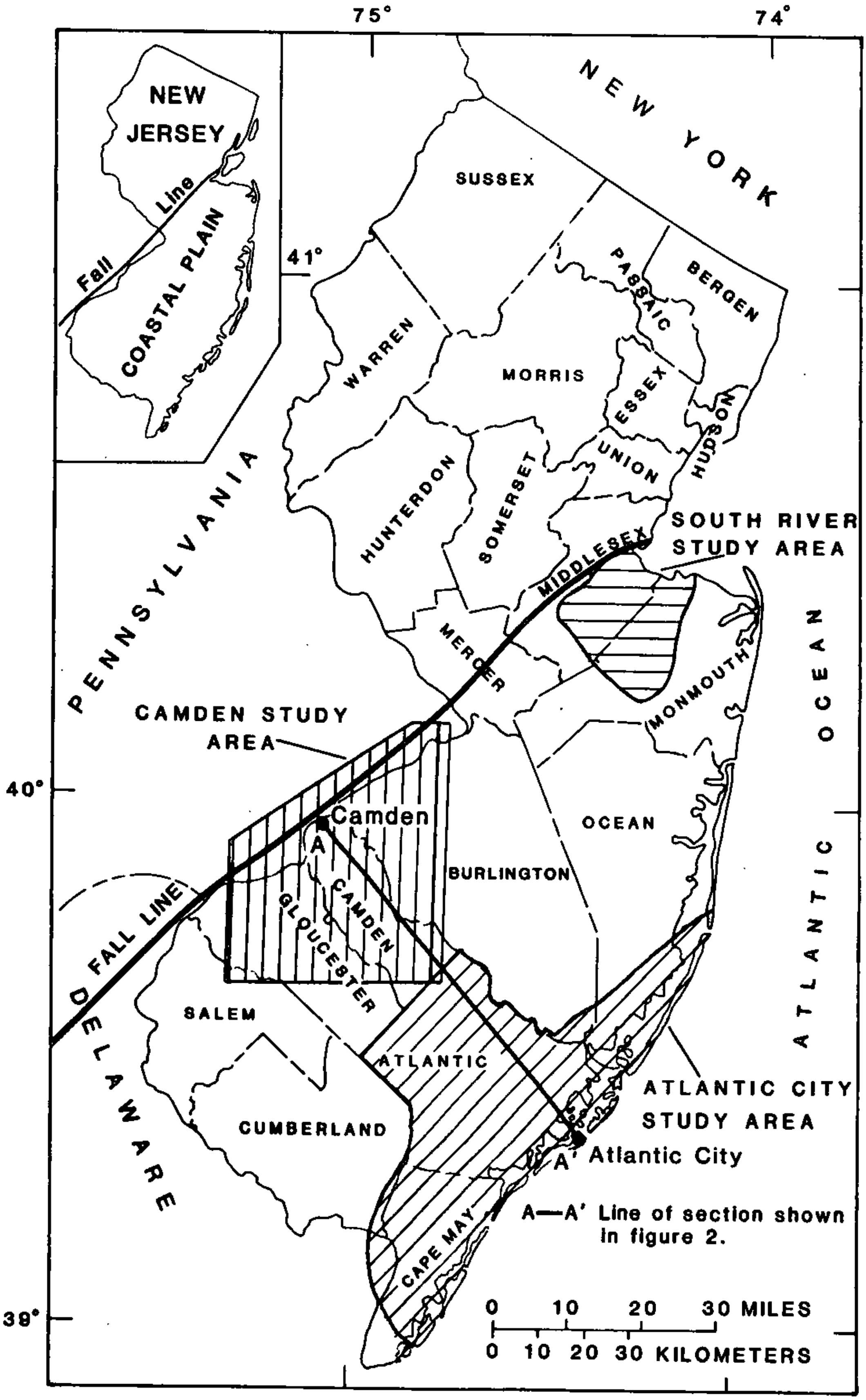



Figure 1.--Location of the Atlantic City, Camden, and South River study areas.

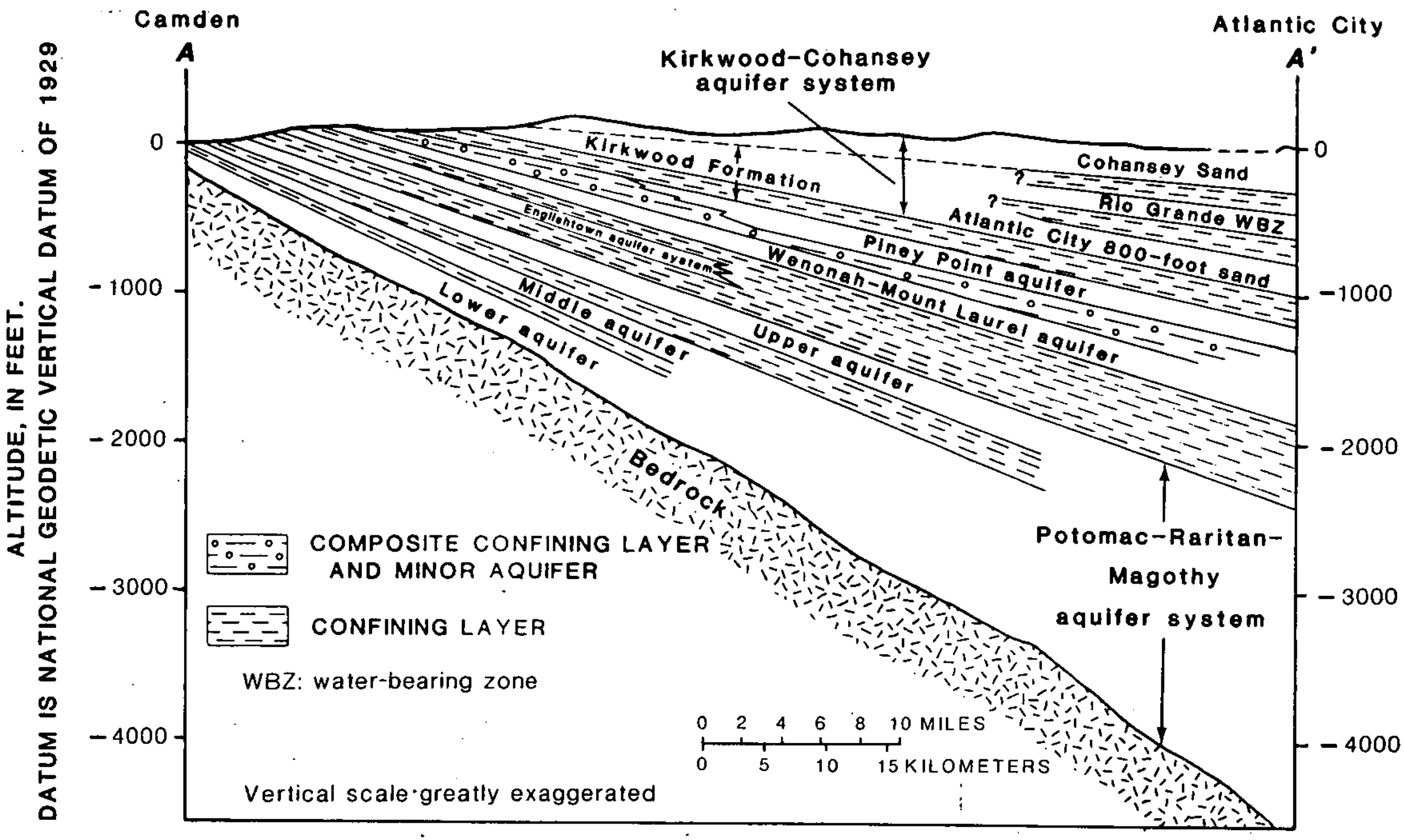



Figure 2.--Generalized geohydrologic section of the Coastal Plain of New Jersey. Location of section A-A' shown on figure 1.

Table 1.--Relations between geologic units and geohydrologic units in the Coastal Plain of New Jersey

[Notes: w-bz, water-bearing zone, conf bd, confining bed]

| SYSTEM | SERIES | GEOLOGIC UNIT | LITHOLOGY | GEOHYDROLOGIC 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<br>Rio Grande w-bz<br>confining bed | Thick diatomaceous clay bed occurs along coast and for a short distance inland. A thin water-bearing sand is present in 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, fine-grained quartz sand. | | 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. | | 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. | | 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 equivalent to the Farrington aquifer. In the Dela. River Valley three aquifers are recognized. In the deeper subsurface, 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<br>middle aquifer<br>conf. bd | |
| | Lower Cretaceous | Potomac Group | Alternating clay, silt, sand, and gravel. | lower aquifer | |
| Pre-Cretaceous | | Bedrock | Precambrian and lower Paleozoic crystalline rocks, metamorphic schist and gneiss; locally Triassic and Jurassic basalt, sandstone and shale. | Bedrock confining bed | No wells obtain water from these consolidated rocks, except along Fall Line. |

(Modified from Zapecza, 1984)

aquifers and two confining beds of the Potomac-Raritan-Magothy aquifer system (fig. 2; table 1). The Potomac-Raritan-Magothy aquifer system rests unconformably on crystalline bedrock of pre-Cretaceous age. Depth to the bedrock surface ranges from zero ft (feet) in the western part of the area along the Fall Line to 2,500 ft at the eastern boundary of the study area (Zapecza, 1984).

The South River study area includes 400 $mi^2$ in parts of Middlesex and Monmouth Counties (fig. 1). The principal water-bearing units in this area are the Old Bridge and Farrington aquifers of Cretaceous age (table 1). In the northern Coastal Plain of New Jersey, the Old Bridge aquifer consists chiefly of the Old Bridge Sand Member of the Magothy Formation (Farlekas, 1979, p. 22), whereas the Farrington aquifer consists primarily of the Farrington Sand Member of the Raritan Formation (Farlekas, 1979, p. 8). These aquifers belong to the Potomac-Raritan-Magothy aquifer system, which rests unconformably on bedrock of pre-Cretaceous age. The depth to the bedrock surface varies from zero ft at the Fall Line to nearly 1,000 ft along the eastern border of the study area (Zapecza, 1984).

## ORGANIZATION OF STUDIES

The three studies have different as well as common aspects. Details of the individual studies are presented in subsequent sections of this report. This section summarizes the common aspects including geohydrologic problems, principal objectives, proposed technical approach, and planned products of the studies.

### Common Geohydrologic Problems

The sediments of the New Jersey Coastal Plain form a large reservoir for water. As this reservoir is relatively undeveloped, ground water is generally an under-utilized resource. For example, Rhodehamel (1970) estimated that 11 trillion gallons of ground water are stored in the Cohansey Sand (table 1) alone. This quantity of water is approximately 400 times greater than the present annual pumpage from that aquifer. Because the water-supply potential of the Coastal Plain deposits has not been realized fully, some additional development may be sufficient to satisfy future demand. Such demand likely will be due to: (1) increased development of public, industrial, and commercial water supplies; (2) increased pumpage for irrigation; (3) need for supplemental water during droughts; and (4) use of ground-water pumpage to augment low streamflow.

Before these ground-water resources are developed further, a clearer understanding of the hydrology of the various ground-water systems is needed. In many instances, information on the quantity, hydraulic properties, flow patterns, potential yield, and quality of water in the systems is lacking, and therefore, the systems are not well understood. Lack of such information has hampered regional water-resources planning, development, and management. Inadequate planning and management, and consequent random development, has caused many problems and increased the likelihood of occurrence for others. Overproduction and degradation of ground-water quality are the most serious of these problems. Localities affected significantly by such problems are the Atlantic City, Camden, and South River areas.

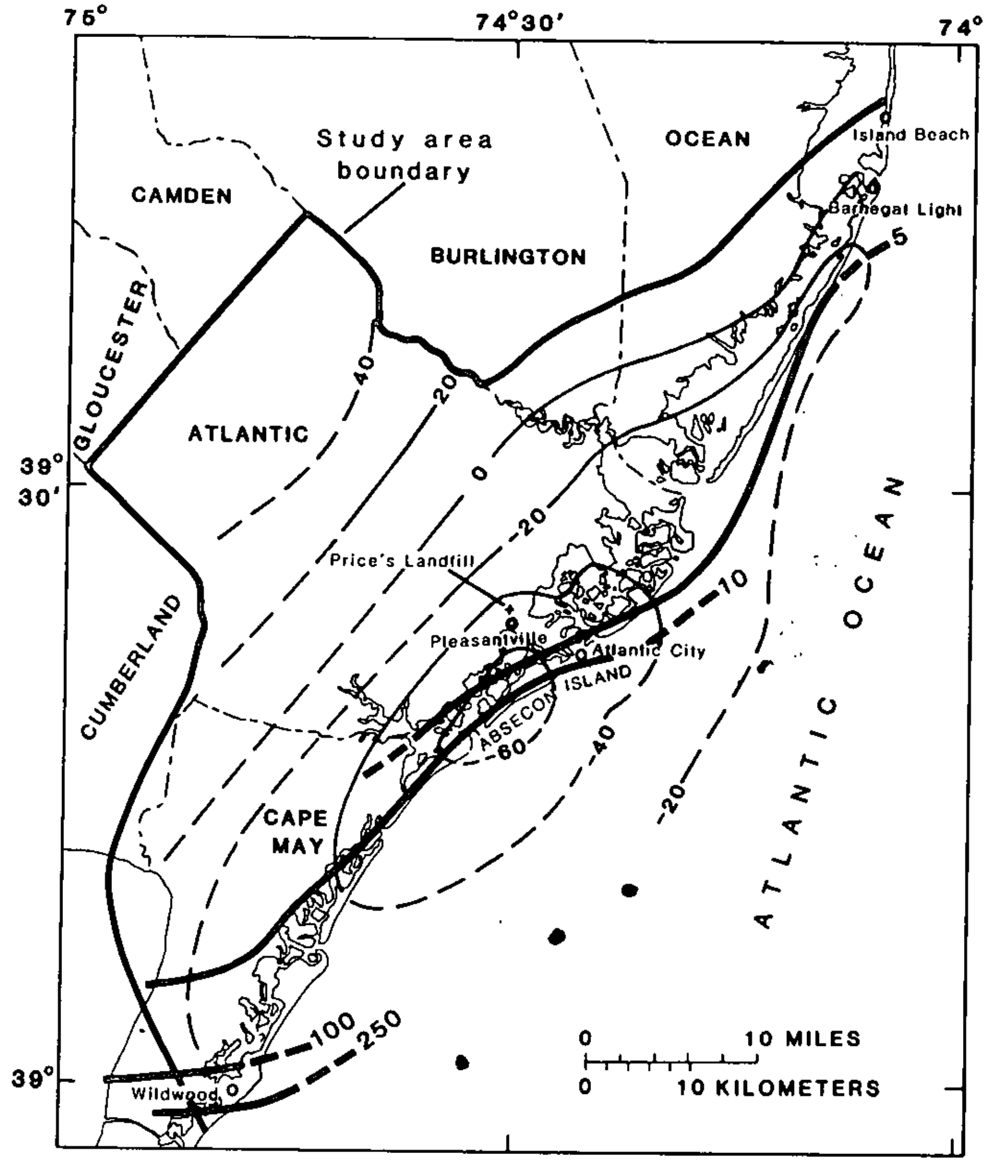
### Overproduction

In each of the study areas, intensive pumping has resulted in a significant decline of ground-water levels. Walker (1983) showed synoptic potentiometric surfaces during 1978 in the major aquifers of the New Jersey Coastal Plain. In the Atlantic City area, water levels in the 800-foot sand form a deep and areally extensive cone of depression; water levels were more than 60 ft below NGVD of 1929 (National Geodetic Vertical Datum of 1929) at several resort communities on Absecon Island (fig. 3). In the Camden area, large cones of depression are present in the lower, middle, and upper sand units of the Potomac-Raritan-Magothy aquifer system. In 1978, water levels at the centers of the cones of depression in the principal aquifers of this system were approximately 80 ft below NGVD of 1929 (figs. 4 and 5). In the South River area, areally extensive cones of depression are present in the Old Bridge and Farrington aquifers. In 1978, water levels at the pumping centers in the Old Bridge aquifer were more than 40 ft below NGVD of 1929 (fig. 6), whereas those in the Farrington aquifer were greater than 60 ft below NGVD of 1929 (fig. 7).

### Degradation of Ground-Water Quality

Development of ground-water resources has caused significant changes in the various hydrologic systems. In addition to declining water levels, the general direction and velocity of ground-water flow have been altered by pumping. Such alterations have already caused saltwater to migrate, or have increased the potential for its migration, into freshwater aquifers in parts of each study area. In the Atlantic City area, the 800-foot sand may be jeopardized by upconing of brackish or saline water thought to be present in the underlying Piney Point aquifer. Also, salty ground water from areas offshore may be migrating toward pumping centers in the 800-foot sand in response to a landward-sloping hydraulic gradient. Presently, the diffuse freshwater-saltwater interface in the 800-foot sand is offshore of Atlantic City, but its actual location and width are unknown.

In the Camden area, large withdrawals of ground water have lowered water levels and have greatly modified the natural flow system. Because of pumping, water from the Delaware estuary infiltrates locally into the Potomac-Raritan-Magothy aquifer system, and saline water from downdip areas migrates northwestward toward pumping centers. This migration has been evidenced by temporal increases in chloride concentrations in water from wells farther updip. In 1973, average ground-water




## EXPLANATION

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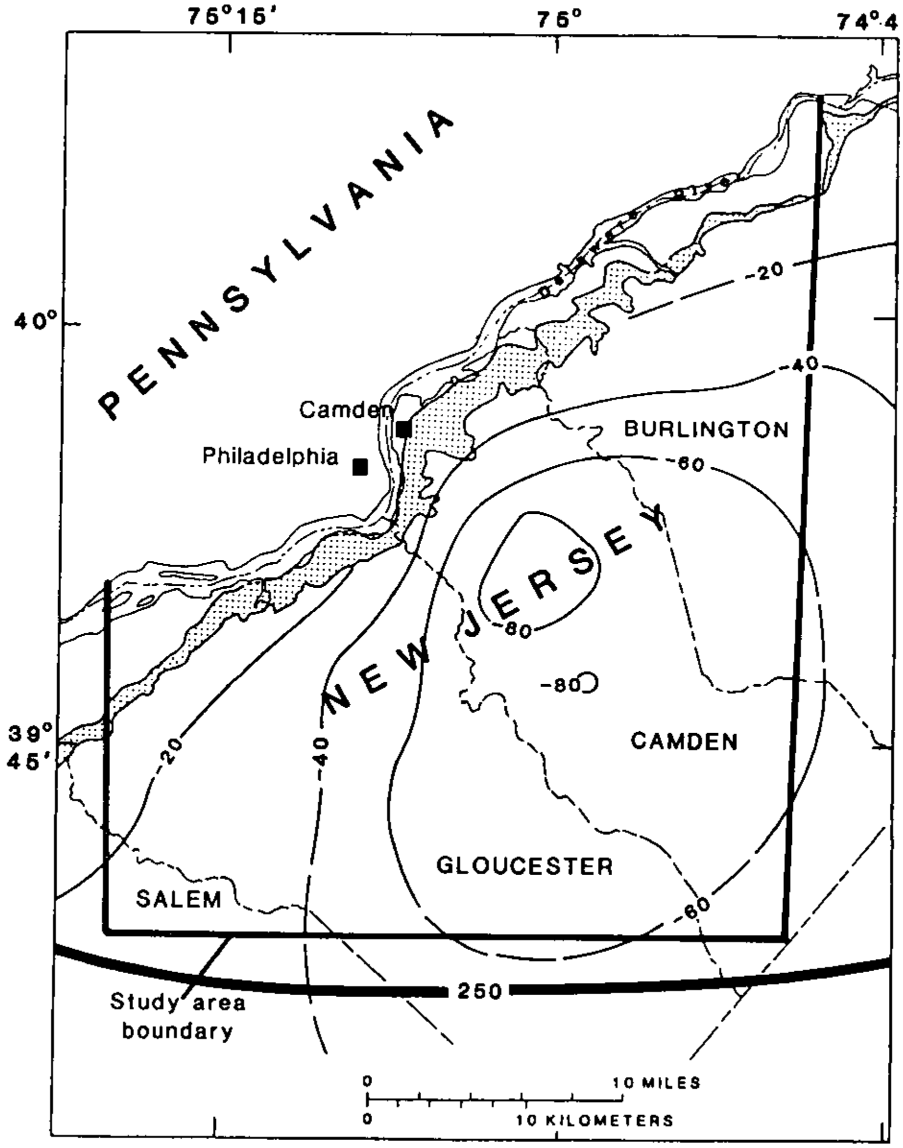
POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased wells in 1978. Dashed where approximately located. Contour interval 20 feet. Datum is National Geodetic Vertical Datum of 1929. (Modified from Walker, 1983)

—————— 250 — — —

LINE OF EQUAL CHLORIDE CONCENTRATION, 1980--Dashed where approximately located. Contour values 5, 10, 100, and 250 milligrams per liter. (Modified from Leggette, Brashears, and Graham, 1982).

Figure 3.--Potentiometric surface and chloride concentration of water in the Atlantic City 800-foot sand of the Kirkwood Formation.




EXPLANATION

Outcrop area of the Magothy Formation. Dashed where approximately located.

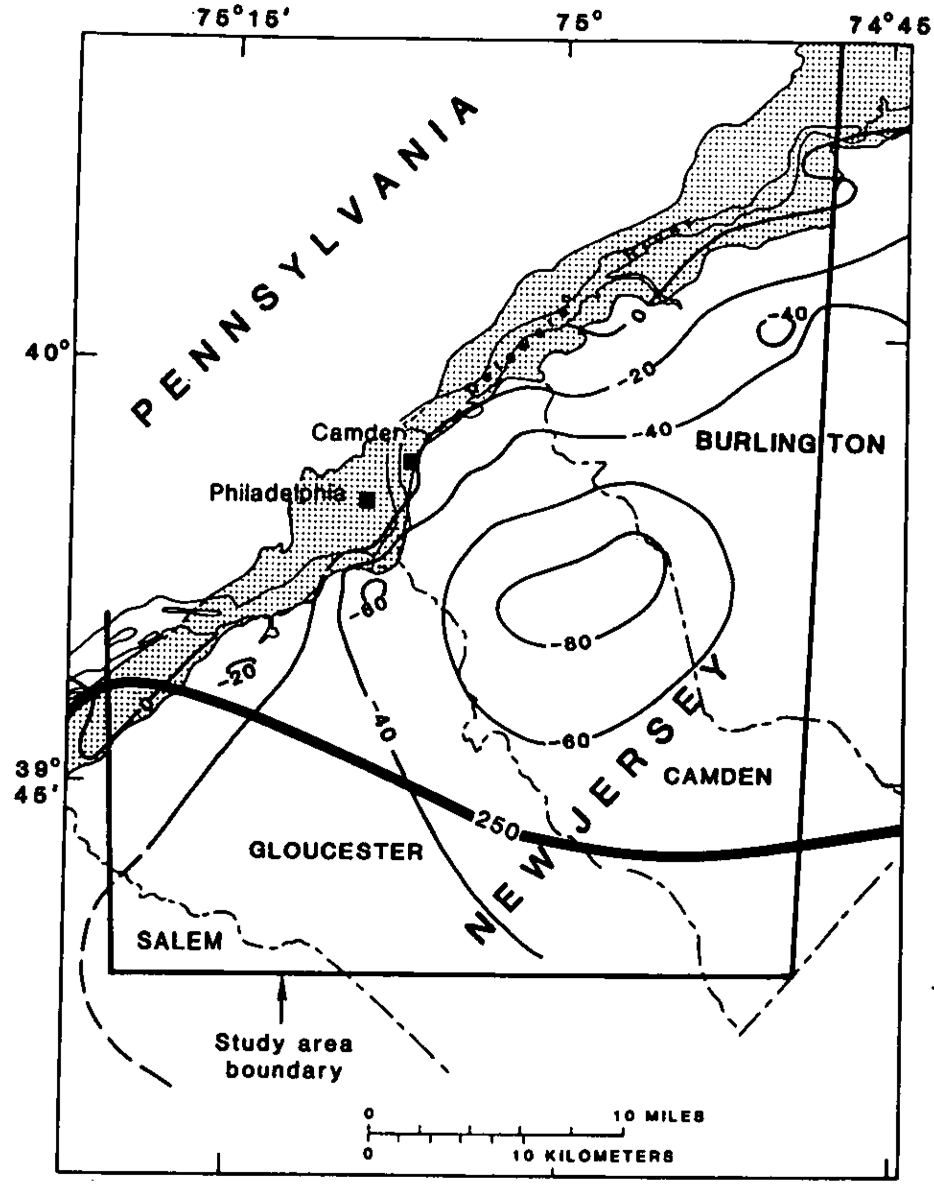
-20

POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased wells in 1978. Dashed where approximately located. Contour interval 20 feet. Datum is National Geodetic Vertical Datum of 1929. (Modified from Walker, 1983)

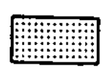
250

GENERALIZED LINE OF EQUAL CHLORIDE CONCENTRATION--Contour value 250 milligrams per liter. South and east of this line, chloride increases. (From Luzier, 1980, p. 6 and p. 12)

Figure 4.--Potentiometric surface and chloride concentration of water in the upper aquifer of the Potomac-Raritan-Magothy aquifer system in the Camden area.




EXPLANATION



Outcrop area of the Raritan Formation and Potomac Group, undifferentiated. Dashed where approximately located.

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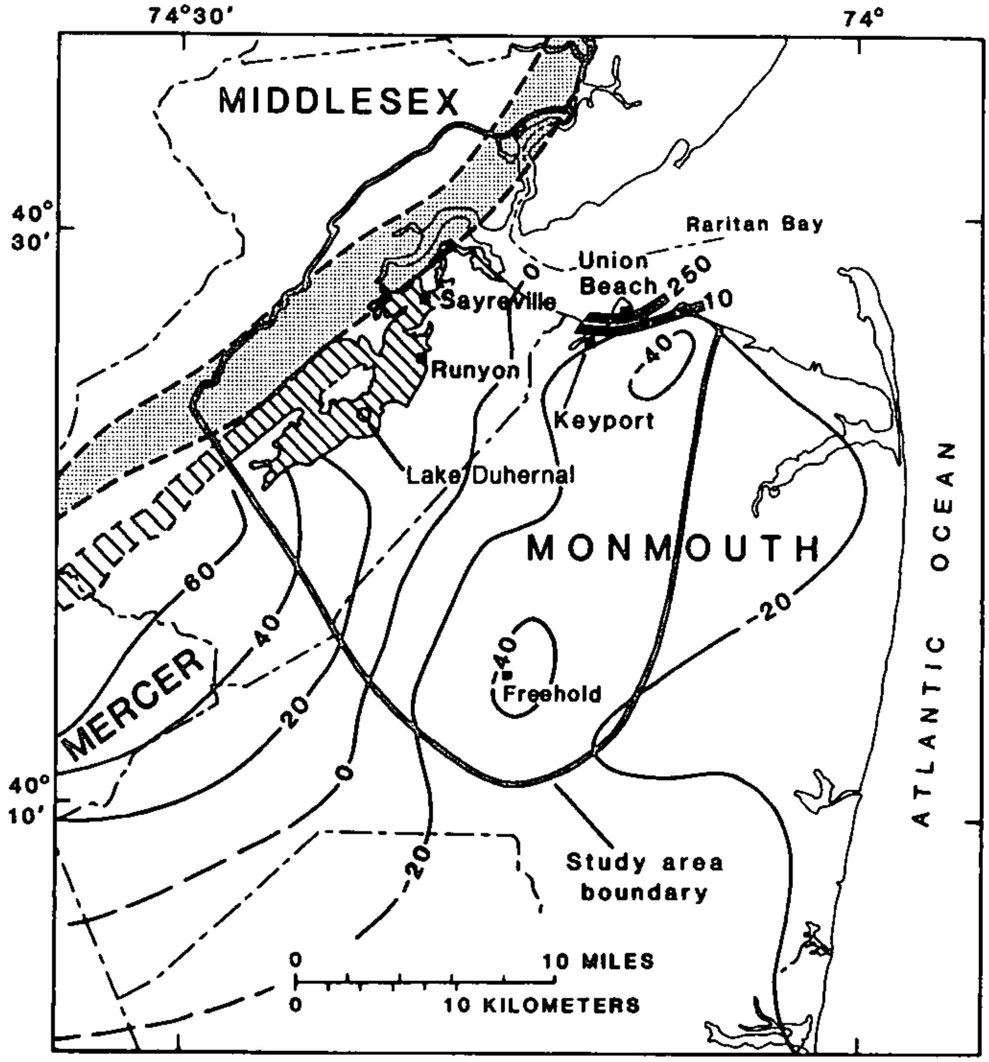
POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased wells in 1978. Dashed where approximately located. Contour interval 20 feet. Datum is National Geodetic Vertical Datum of 1929. (Modified from Walker, 1983)

━━━ 250 ━━━

GENERALIZED LINE OF EQUAL CHLORIDE CONCENTRATION--Contour value 250 milligrams per liter. South and east of this line, chloride increases. (From Harbaugh and others, 1980)

Figure 5.--Potentiometric surface and chloride concentration of water in the lower aquifer of the Potomac-Raritan-Magothy aquifer system in the Camden area.




## EXPLANATION

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

Approximate subsurface extent of Palisades Diabase Sill.

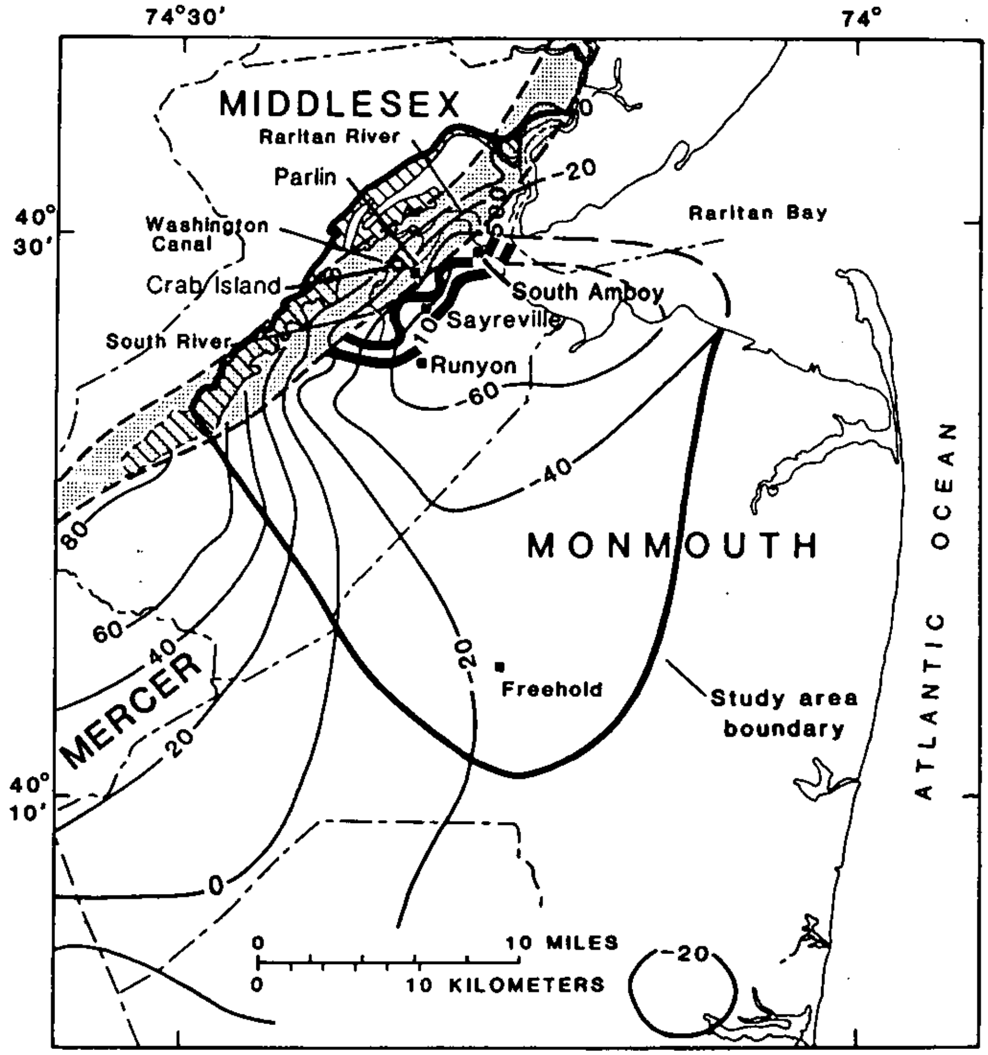
-20

POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased wells in 1978. Dashed where approximately located. Contour interval 20 feet. Datum is National Geodetic Vertical Datum of 1929. (Modified from Walker, 1983)

250

LINE OF EQUAL CHLORIDE CONCENTRATION, 1977--Contour values 10 and 250 milligrams per liter. (From Schaefer and Walker, 1981)

Figure 6.--Potentiometric surface and chloride concentration of water in the Old Bridge aquifer in the South River area.




EXPLANATION

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

Approximate subsurface extent of Palisades Diabase Sill.

-20

POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased wells in 1978. Dashed where approximately located. Contour interval 20 feet. Datum is National Geodetic Vertical Datum of 1929. (Modified from Walker, 1983)

250

LINE OF EQUAL CHLORIDE CONCENTRATION, 1977--Contour values 10 and 500 milligrams per liter. (From Schaefer, 1983)

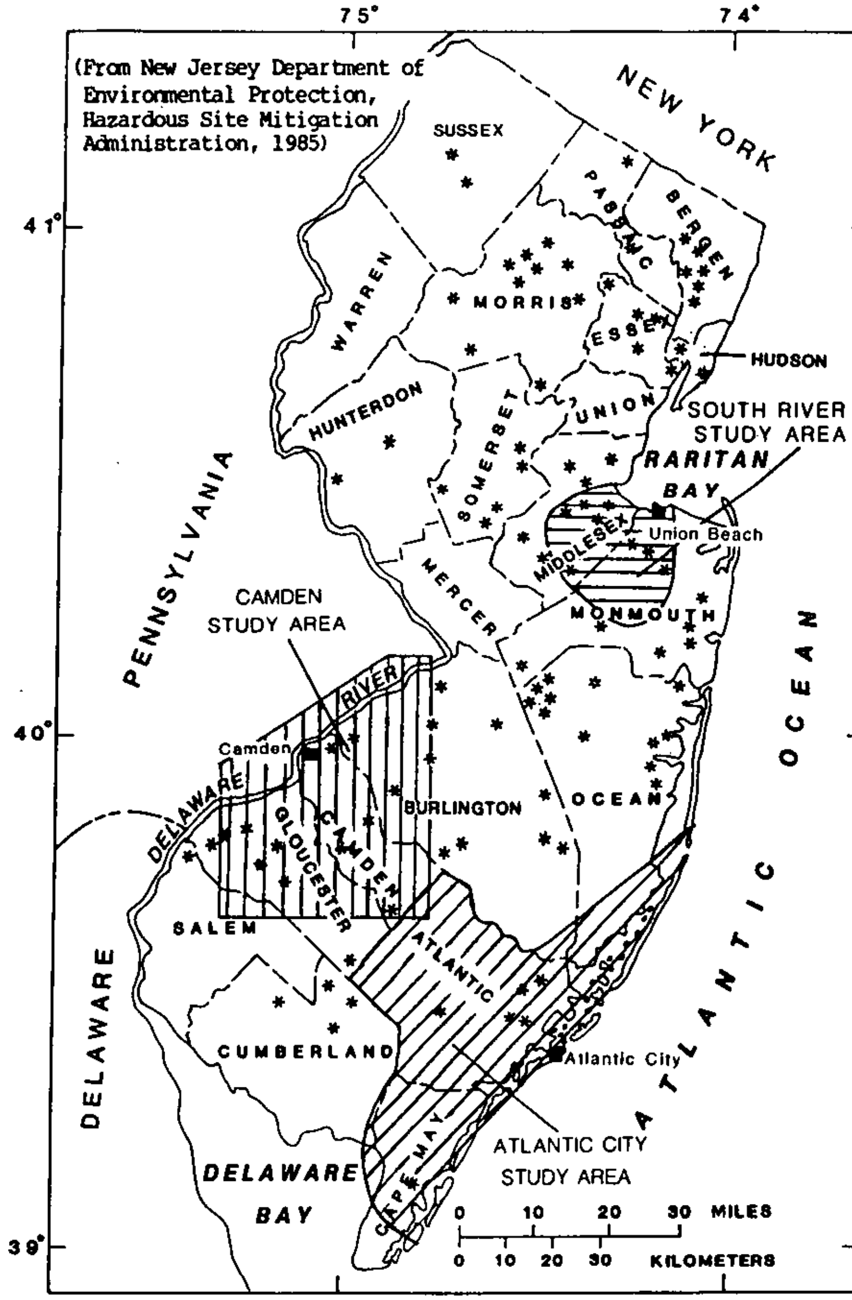
Figure 7.--Potentiometric surface and chloride concentration of water in the Farrington aquifer in the South River area.

velocities along the interface between freshwater and saline water ranged approximately from 20 to 268 ft per year (Luzier, 1980, p. 63); consequently, the saline water is probably migrating updip at about the same rates.

In the South River area, large withdrawals from and resulting water-level declines in the Old Bridge and Farrington aquifers have greatly affected the natural ground-water flow system. Pumping has caused the infiltration of saltwater through submerged areas of aquifer outcrop and has increased the potential for lateral movement of saltwater from downdip areas toward pumping centers. Schaefer and Walker (1981) described the infiltration of saltwater through submerged outcrop areas into the Old Bridge aquifer near Keyport and Union Beach, Monmouth County (fig. 6). Barksdale (1937) noted the potential for saltwater infiltration into the Farrington aquifer near the Washington Canal in Middlesex County (fig. 7). Appel (1962) documented the increase in chloride concentrations during 1943-58 in ground water in the outcrop area of the Farrington aquifer near South River and South Amboy. Based on chloride concentrations measured in 1977 and 1981, Schaefer (1983) concluded that saltwater in the Farrington aquifer has continued to migrate toward the southeast, away from recharge areas along the Washington Canal, South River, Raritan River, and Raritan Bay. In coastal parts of Monmouth and Ocean Counties, water levels in the Old Bridge and Farrington aquifers have declined below sea level (Walker, 1983). Luzier (1980, p. 6) showed that the transition zone between freshwater and saltwater in these aquifers lies an unknown distance offshore of Monmouth County, but that it is present onshore farther south near Island Beach (fig. 3), Ocean County. Thus, the steep head gradients caused by large withdrawals may initiate lateral flow of this saltwater toward pumping centers in the South River area.

In addition to saltwater intrusion, the improper management of inorganic and organic chemical wastes has resulted in the degradation of ground-water quality in parts of each study area. Estimates of the extent of shallow ground-water contamination nationwide from point sources range from 1 to 2 percent of the total volume of the resource (Pye and others, 1983). Although this percentage represents only a small fraction of the total, a significant volume of ground water, particularly that in urbanized parts of the study areas, may be contaminated. Figure 8 shows that the three study areas contain a total of 25 hazardous waste disposal sites included on the U.S. Environmental Protection Agency's National Priorities (Superfund) List of September 1985. The National Priorities List is a compilation of top-priority hazardous waste sites identified under the guidelines of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (U.S. Public Law 96-510).

In the Atlantic City area, the well field at Pleasantville, operated by the Atlantic City Municipal Utilities Authority, has been jeopardized by the migration of toxic contaminants from the




## EXPLANATION

* Hazardous waste disposal site on National Priorities (Superfund) List of September 1985.

Figure 8.--Location of hazardous waste disposal sites in New Jersey included on the National Priorities List of September 1985.

nearby Price's Landfill[1] (Gray and Hoffman, 1983). In the Camden area, ground water has been contaminated by point and nonpoint sources. The point sources include disposal sites containing industrial and municipal wastes. The nonpoint sources include salty recharge water induced during droughts from the Delaware estuary and tidal reaches of its tributaries. In addition to sources in New Jersey, contaminants in ground water from the Philadelphia area may be migrating toward the Camden area in response to head gradients caused by withdrawals in New Jersey (see figs. 4 and 5). The effects of contaminant migration from disposal sites on ground-water quality in the South River area are of great concern. However, because only limited information is available for several of these sites, the extent and severity of contamination are generally unknown.

## Principal Objectives

The major thrust of the Bond Issue ground-water supply investigations is to provide water-resources officials with the hydrologic data and analyses necessary for effectively managing the ground-water reserves of each study area. Data including information on geohydrologic framework; ground-water levels, use, and quality; and aquifer system hydraulic properties have been collected for each study area since the early 1900's. Data analysis by statistical and analytical techniques has resulted in descriptions of the geohydrology and definition of the principal hydrologic processes occurring in these areas. Simulation or modeling of ground-water flow has been used previously to determine the effects of overproduction in the Camden and South River regions (Luzier, 1980; Harbaugh and others, 1980; and Farlekas, 1979). In 1984, part of the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) program modeled the ground-water flow system of the Coastal Plain of New Jersey. Although these various studies simulated ground-water flow, they did not address specifically the transport of solute (Martin, M., U.S. Geological Survey, written commun., 1984).

As with all modeling investigations, these studies were also limited by the availability and quality of input data, and by the assumptions upon which the models were based. For example, the model of the South River area (Farlekas, 1979) simulated flow in only the Farrington aquifer, a part of a multiaquifer system. Previous modeling of the Camden area evaluated regional ground-water flow, but did not define specifically the local hydraulic interactions between the Delaware estuary and the Potomac-Raritan-Magothy aquifer system. Similarly, the New Jersey subregional RASA model evaluated large-scale ground-water flow. Although the results of these studies provide valuable insight into the behavior of the regional aquifer systems, the models were not designed to investigate system behavior on a local scale.

[1] The use of firm names in this report is for location purposes only, and does not impute responsibility for any present or potential effects on the natural resources.

In the last decade, great advances have been made in the development and practical implementation of ground-water flow and solute-transport models. Such models, when calibrated, can be used by water-resources managers to forecast the hydrologic effects of various development alternatives. However, model predictions reflect the behavior of the hydrologic system only if the model properly represents the various hydrologic processes, and if the data used in model design and calibration adequately characterize the geohydrologic system. Data available at the onset of the present studies are insufficient to properly design the models needed to assess the consequences of water-resources development in each study area.

Therefore, the principal objectives of the three studies are to: (1) upgrade the hydrologic data base with accurate information on geohydrologic framework; ground-water levels, use, and quality; and aquifer system hydraulic properties; (2) design and implement comprehensive data-collection programs to enhance existing data bases; (3) with digital modeling, develop a better understanding of the ground-water flow systems; and (4) conduct water-quality appraisals to define more accurately the geochemistry of the aquifer systems. The results of these studies will aid the NJDEP in making prudent water-management decisions for the Atlantic City, Camden, and South River study areas. The results also will enable the NJDEP to develop water-supply strategies to prevent or mitigate ground-water contamination by saltwater sources and human activities.

## Overall Approach

The approach to the three investigations has similarities as well as differences. The overall approach is similar in order to accomplish the principal objectives. The individual approaches will differ in order to meet the needs of the particular study. The overall approach includes developing a data base of existing information, collecting additional data, modeling ground-water flow, and appraising ground-water quality. Data-base development will include establishing an information management system, and acquiring and storing in computer files additional geologic and hydrologic data. The same information management system will be used by the three studies; subsequently, it probably will become the standard for other projects in the NJGS and in the USGS New Jersey district office. Additional data will be acquired as needed from the files of federal, state, and local government agencies and private firms. This phase of work will require the greatest effort for the Camden and South River studies because more data are available for those areas than for the Atlantic City area.

Collection of additional data is planned through various field activities, an exploratory drilling program, and a surface- and marine-geophysics program. The field work will involve collecting information on ground-water levels, use, and quality; aquifer system hydraulic properties; and ground-water discharge to streams. This phase of work will require the greatest effort for the Atlantic City study because of the general lack of data on that area. The drilling and geophysics programs will be conducted chiefly by the NJGS with their own equipment. However, for drilling to depths greater than 1,000 ft, contracting with private firms is anticipated.

Digital models will be developed to improve the present understanding of hydrologic processes and the ground-water flow system in each study area. The models will be used to determine the location of recharge areas, the volume of ground-water recharge and discharge, and the direction and velocity of flow in the fresh ground-water systems. The calibrated flow models will be used to assess the consequences of alternative ground-water development schemes. As simulation techniques have not been applied specifically to aquifers in the Atlantic City area, a model will be developed to simulate that regional ground-water flow system. To extend the work of previous simulation studies of the Camden area, the model to be developed for this study will be used to examine in detail the interaction between the ground-water system and the Delaware estuary. Modeling for the South River study will be used to investigate ground-water flow in the outcrop areas of the Old Bridge and Farrington aquifers, and to evaluate the degree of hydraulic connection between these aquifers.

The approach to ground-water quality appraisal varies for each study depending on the availability of data and on the particular water-quality problems. Ambient water quality in the Kirkwood-Cohansey aquifer system in Atlantic County and the location and rate of movement of the freshwater-saltwater interface in the 800-foot sand of the Kirkwood Formation will be evaluated by the Atlantic City study. The quality of water in minor aquifers, the use of geochemical techniques including isotopes as tracers, and the description of the chief geochemical processes occurring in the aquifer system will be addressed by the Camden study. The occurrence and distribution of trace elements and volatile organic compounds in the outcrop areas of the Old Bridge and Farrington aquifers, saltwater intrusion, and the migration of chloride in ground water are the chief water-quality aspects of the South River study. For each study, ground-water quality will be appraised by implementing comprehensive sampling programs and monitoring networks, and by analyzing data with statistical and modeling techniques.

## Planned Products

The significant findings of each study are to be released as: (1) data reports, which will provide basic information on geohydrology and ground-water quality; (2) interpretive reports, which will explain the flow system, the principal hydrologic processes, and the probable effects of various ground-water development schemes; and (3) instructional manuals, which will present information on techniques for data acquisition, management, and analysis.

Data reports may include maps of:
1. Water tables and potentiometric surfaces.
2. Structure contours on and thickness of geohydrologic units.
3. Selected water-quality parameters.
4. Quantity and distribution of ground-water withdrawals.
5. Aquifer system hydraulic properties.

Data reports also may present cross sections of geohydrologic units, as well as records of wells and water-quality analyses.

Interpretive reports may include analyses of:
1. The ground-water flow systems.
2. Transport of conservative solutes.
3. Effects of changing stresses on the ground-water flow systems.

Instructional manuals may include information such as:
1. Maintenance, use, and management of computerized data bases.
2. Collection of ground-water samples.
3. Design of monitoring-well networks.
4. Application of geophysical techniques to ground-water studies.

These reports will be the chief means of disseminating information on each study. Reports may be produced jointly by both or either the NJGS and the USGS. Occasionally, selected information may be released in oral presentations, journal articles, and in other media.

## ATLANTIC CITY AND VICINITY STUDY

### Location of Study Area

The area of study encompasses approximately 1,200 $mi^2$, including all of Atlantic County and parts of Ocean, Burlington, Cumberland, and Cape May Counties; it includes barrier-island communities from Island Beach on the north to Wildwood on the south (fig. 3). In this report, the study area is commonly referred to as the Atlantic City region. Atlantic City and neighboring municipalities on Absecon Island are the localities of principal interest.

### Geohydrologic Framework

The study area is in the Coastal Plain of New Jersey, which is composed of unconsolidated deposits of gravel, sand, silt, and clay. The principal freshwater aquifers formed by these deposits are of Tertiary age and, in descending order, include the surficial Kirkwood-Cohansey aquifer system and the Atlantic City

800-foot sand of the Kirkwood Formation, which is commonly referred to as the 800-foot sand (fig. 2; table 1). The Rio Grande water-bearing zone of the Kirkwood Formation is situated midway within the confining bed that separates the Kirkwood-Cohansey aquifer system from the 800-foot sand. Throughout most of the study area, however, the Rio Grande is an aquifer of minor importance. In the Atlantic City area, aquifers deeper than the 800-foot sand have not been developed for water supply, as they may contain brackish or saline water. In descending order, these undeveloped units include the Piney Point aquifer of Tertiary age, and units of Cretaceous age including the Wenonah-Mount Laurel aquifer, the Englishtown aquifer system, and the Potomac-Raritan-Magothy aquifer system (fig. 2; table 1).

In the study area, the Cohansey Sand and the underlying upper part of the Kirkwood Formation form the Kirkwood-Cohansey aquifer system (table 1). Although these two units are components of this composite aquifer system, they are not differentiated individually because of their similar geologic and hydrologic properties. The Kirkwood-Cohansey aquifer system thickens toward the southeast and, near Atlantic City, it is approximately 400 ft thick (Zapecza, 1984). This aquifer system is the principal source of water supply in parts of the study area on the mainland. However, on the barrier islands and along the coastal fringe, the system contains brackish or salty water and cannot be used as a source of water supply.

The Atlantic City 800-foot sand of the Kirkwood Formation is a highly permeable artesian aquifer. It is situated between an overlying thick massive confining bed and an underlying relatively thin confining bed. At Atlantic City, the overlying confining bed is approximately 300 ft thick, the 800-foot sand is more than 150 ft thick, and the underlying confining bed is approximately 125 ft thick (Zapecza, 1984). The 800-foot sand is, with few exceptions, the sole source of water supply for the barrier-island communities in the study area. The Piney Point aquifer lies beneath the basal confining bed of the 800-foot sand. Little is known about the hydraulic properties and quality of water in this deeper aquifer.

## Geohydrologic Problems

The introduction of legalized gambling in Atlantic City in 1977 has resulted in renewed growth of the area's economy, population, and demand for water. The Statewide Water-Supply Master Plan (New Jersey Department of Environmental Protection, 1981) indicates that a steady increase in ground-water pumpage, as well as contamination of ground water by saltwater and leachate from disposal sites, likely will accompany this redevelopment.

Pumpage from the Atlantic City 800-foot sand of the Kirkwood Formation is the principal source of water supply for the barrier-island communities in the study area. Figure 9 illustrates the trend in withdrawals from the 800-foot sand from 1956-80 in Atlantic, Ocean, and Cape May Counties, and shows that pumpage more than doubled during that 25-year period. In 1980, withdrawals from the 800-foot sand averaged 21 Mgal/d (million gallons per day), with pumpage in Atlantic County accounting for almost half of that total (Vowinkel, 1984, p. 24). According to the Atlantic County 208 Water Quality Management Planning Agency (1979, p. II-34), the demand for water in Atlantic and Cape May Counties is likely to increase by nearly 22 percent during the period from 1975 until the year 2020. This rate of increase is approximately 6 percent higher than the corresponding rate expected overall for the state of New Jersey.

Under prepumping conditions, it is likely that water in the 800-foot sand flowed chiefly toward the southeast to discharge areas offshore. However, subsequent large withdrawals of water caused the development of a regional cone of depression and altered the local rate and direction of ground-water flow. In 1978, water levels in the deepest part of the cone were more than 60 ft below NGVD of 1929 (fig. 3). These levels can be expected to decline further if larger volumes of water are pumped from the aquifer to meet the increasing demands.

The majority of the municipal water purveyors in coastal parts of the Atlantic City region withdraw their supplies from the 800-foot sand. In addition, two casino hotels in Atlantic City are currently satisfying their total requirements for water with their own wells in that aquifer, and several other casinos have applied to the NJDEP for diversion rights to withdraw water from the 800-foot sand. Because little is known about the possible effects of increasing pumpage, the future status of these existing and requested diversion rights is uncertain. However, increasing pumpage probably will accelerate the rate of saltwater migration from areas offshore toward the pumping centers. Contamination of the 800-foot sand by saltwater would have disastrous consequences throughout the Atlantic City area, as none of the coastal resort communities except Atlantic City and Wildwood have direct emergency interconnections with water supplies from the mainland.

At several localities in the study area, water in the Kirkwood-Cohansey aquifer system has been contaminated by leachate from landfills and by toxic chemical liquids and sludges that were disposed of improperly. Many of these landfills are in abandoned gravel pits with relatively high water tables. Because the contents of many landfills are at or below the water table, there is a high probability of local ground-water contamination. At several sites, leachate has contaminated ground water with volatile organic compounds and inorganic chemical species including trace elements.

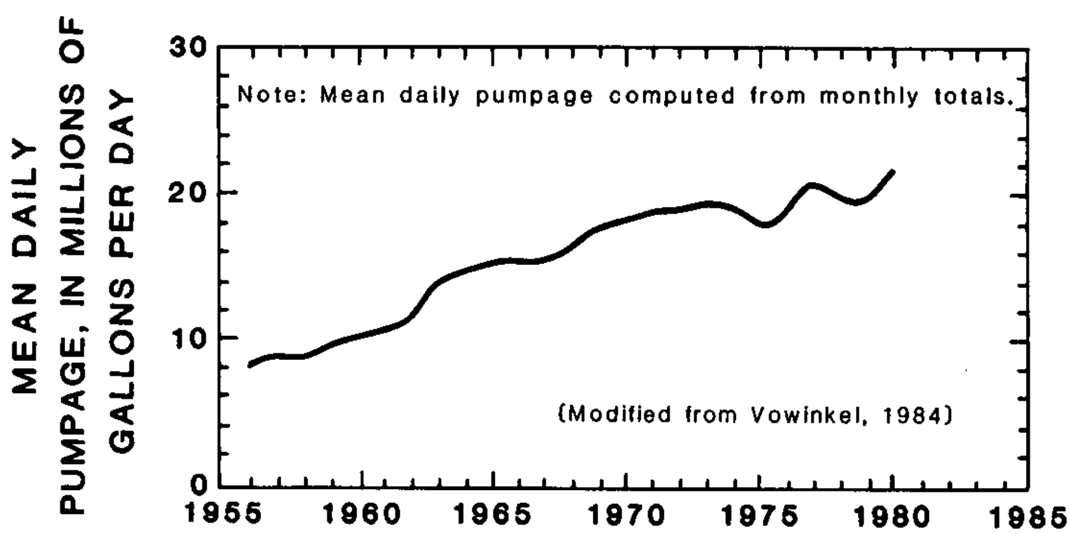



Figure 9.--Pumpage from the Atlantic City 800-foot sand of the Kirkwood Formation in Atlantic, Ocean, and Cape May Counties, New Jersey, 1956-80.

From May 1971 through November 1972, millions of gallons of uncontained industrial wastes were disposed of at Price's Landfill (fig. 3) in Pleasantville (New Jersey Department of Environmental Protection, 1984, p. 103). Through the use of a digital flow model, Gray and Hoffman (1983, p. 9) concluded that these contaminants were migrating in the ground water of the Kirkwood-Cohansey aquifer system toward the nearby public-supply wells of the Atlantic City Municipal Utilities Authority. As a precautionary measure, and at significant expense, the Authority relocated their well field to another site nearly 3 mi (miles) northwest of Pleasantville, and terminated withdrawals from the Pleasantville well field. Because the toxic wastes at this landfill and at several other disposal sites in the study area have yet to be recovered and disposed of properly, they continue to threaten the quality of local ground-water supplies. As pointed out by these examples, the Kirkwood-Cohansey aquifer system is particularly vulnerable to contamination resulting from activities at the land surface.

Very little is known about the background quality of water in the Kirkwood-Cohansey aquifer system in the study area, except in the few localities where site-specific investigations have been conducted. More information is needed on the quality of shallow ground water in order to develop and implement prudent water-management strategies for the Atlantic City region. Because of existing or potential shortages and contamination of ground water, in 1985 the NJDEP solicited from private firms a request for proposals to evaluate supply, distribution, financial, and institutional problems related to the ground-water resources of the region.

## Previous Studies

Reports by Woolman (1890-1902) on artesian wells in New Jersey recorded much of the original information on the geology and ground-water hydrology of the study area. Woolman correlated water-bearing zones penetrated by wells in the Coastal Plain of New Jersey and Delaware. Thompson (1928), who reported on the ground-water supplies of the Atlantic City region, presented a general outline of the hydrology of the various freshwater aquifers, and discussed the potential problem of saltwater encroachment into the Atlantic City 800-foot sand of the Kirkwood Formation. According to Thompson (1928, p. 115), the prepumping location of the freshwater-saltwater interface in the 800-foot sand was approximately 4 mi offshore of Atlantic City. Barksdale and others (1936), in a more comprehensive treatment, defined the ground-water hydrology of the Atlantic City region and concluded that saltwater was probably being induced landward toward pumping wells in the 800-foot sand because of a steep hydraulic gradient in that direction. More recently, Leggette, Brashears, and Graham, Inc. (1982) reiterated the probable shoreward migration of the saltwater and suggested its possible landward arrival within a few years. May (1985) proposed the use of injection wells to recharge the 800-foot sand at Absecon Island. These wells would be used to supplement water supply and to reduce the likelihood of saltwater intrusion by arresting or reversing present ground-water level declines.

As part of the modeling activities of the RASA program of the U.S. Geological Survey, the geohydrologic framework, geochemistry, and nature of ground-water flow in the principal aquifers of the northern Atlantic Coastal Plain are being investigated in detail (Meisler, 1980). The aquifers under study by the New Jersey subregional RASA modeling program (Meisler, 1980) include those in the Atlantic City region. Zapecza (1984) defined the geohydrologic framework of the New Jersey Coastal Plain and illustrated with a series of sections and maps the stratigraphic relations among the component geohydrologic units.

Gill (1962) described the occurrence, available quantity, and chemical quality of ground water in Cape May County, and delineated areas of existing or potential saltwater intrusion into the freshwater aquifers. Clark and others (1968) presented a general summary of the geohydrology of Atlantic County; this report lists records of selected wells and contains results of 36 laboratory inorganic determinations on water samples from some of those wells. Schaefer (1983) presented information on chloride concentrations in water from selected monitoring wells in the coastal parts of Atlantic County and other counties, and concluded "that although (presently) there is no evidence in the Atlantic City area of lateral saltwater intrusion in the 800-foot sand from a seaward direction, ... the probability of this occurrence is as significant today (1983) as it was in the 1930's." To date, the sparse data in these reports constitute nearly all of the information available on the quality of ground water in Atlantic County.

## Description of Study

### Purpose and Scope

The chief purposes of this study are to (1) define the nature of ground-water flow in the Kirkwood-Cohansey aquifer system and in the Atlantic City 800-foot sand of the Kirkwood Formation, and (2) assess the likelihood of saltwater intrusion into the 800-foot sand in the Atlantic City area. Selected results of the study will be used to prepare a detailed, calibrated model of regional ground-water flow. Subsequently, the NJDEP may use this model to guide decisions regarding ground-water diversions and water management in the Atlantic City region.

### Objectives

The principal objectives of the Atlantic City and vicinity study are to:

1. Define the geohydrologic framework, particularly the thickness and extent of the confining bed overlying the 800-foot sand of the Kirkwood Formation.

2. Ascertain the hydraulic properties of the Kirkwood-Cohansey aquifer system, the 800-foot sand, and associated confining beds.

3. Bracket the position of the freshwater-saltwater interface in the offshore part of the 800-foot sand near Atlantic City.

4. Develop a detailed conceptual model of regional ground-water flow.

5. Assess regional water-quality conditions in the Kirkwood-Cohansey aquifer system and in the 800-foot sand, as well as local conditions in the Piney Point aquifer.

6. Prepare and maintain a standardized management system for hydrologic information.

## Approach

This study will address the objectives by assessing and compiling geologic and hydrologic data from various sources and by collecting additional data. These data then will be used to analyze and interpret hydrologic processes and to evaluate water-quality conditions. The results of this investigation will be released in published reports, oral presentations, and in other media.

### Assessment of Geologic and Hydrologic Data

Few comprehensive reports have been released on the geology and ground-water hydrology of the Atlantic City region. However, the basic information contained in these reports and that from other sources will constitute the starting point for this more comprehensive investigation. Initially, geologic and hydrologic data will be evaluated and compiled. The chief sources of such information are the files of the USGS, particularly those on ground-water levels, water quality, water use, and well records. Related files, chiefly those containing borehole geophysical logs and data on aquifer system lithology, stratigraphy, and hydraulic properties, also will be assessed.

The files of the NJDEP, along with those of other government agencies and private firms, will be examined for additional geologic and hydrologic data. Selected information from these sources will be evaluated, compiled, and entered into the various data bases for subsequent use during the interpretive phase of the study.

## Collection of Additional Data

Data will be collected during the second phase of this study to define the geohydrologic framework and to characterize the ground-water flow system. Information on the geohydrologic framework will be gathered by reviewing well records and logs, and by conducting an inventory of water wells in Atlantic County and vicinity. The inventory will be important because data are sparse on ground-water levels, well yields, and quality of ground water in the study area.

Present knowledge of the geohydrologic framework is inadequate to evaluate the hydraulic interrelationships of the principal aquifers and their associated confining beds. Of particular interest is the determination of the thickness and extent of the confining bed overlying the 800-foot sand. Where this bed is present, it impedes ground-water flow between the Kirkwood-Cohansey aquifer system and the 800-foot sand; where it is absent, these aquifers are connected hydraulically and behave as a single unconfined aquifer. Information will be obtained by drilling exploratory boreholes in areas where such information is lacking, then logging and analyzing drilled or cored lithologic samples. Various geophysical surveys also will be conducted in the boreholes. Several of these boreholes will be finished as wells for monitoring ground-water levels and water quality. In addition, the NJGS will conduct comprehensive surface-geophysical investigations for this study. The results of these investigations, particularly those involving seismic and electrical techniques, will be correlated with data from the borehole surveys so that lithology and aquifer system hydraulic properties in areas not drilled can be assessed.

In selected parts of the study area, the hydraulic properties of the Kirkwood-Cohansey aquifer system and the 800-foot sand will be evaluated with single-well pumping tests and multiple-well aquifer tests. The results of these tests will be used to calibrate the ground-water flow model, and, in conjunction with data on ground-water levels, will be used to refine the present concept of regional ground-water flow.

Because the freshwater-saltwater interface in the 800-foot sand is offshore of Atlantic City, little is known about its present location and width. Existing digital models, particularly the New Jersey subregional RASA model, have been unable to address with certainty the nature of this interface. These models have been constrained by the lack of information on water levels, hydraulic properties, and quality of water in the offshore part of the 800-foot sand and its associated confining beds.

A marine well-drilling program is planned as a major component of this study. The primary objective of this program is to bracket and monitor the position of the freshwater-saltwater interface in the 800-foot sand near Atlantic City.

Secondary objectives are to obtain the geologic and hydrologic information required to represent adequately with a digital model the offshore part of the flow system. Plans are to construct two wells, each approximately 1,000 ft deep, to address these and other subordinate objectives.

Marine test wells are the only direct means of locating and monitoring the position of the freshwater-saltwater interface in the 800-foot sand and for collecting related data. Two such wells directly offshore of Atlantic City are proposed for this study. The first well will be constructed about 2 mi offshore. If the freshwater-saltwater interface is present there, then the second well will be constructed approximately 1 mi offshore. However, if the interface is not present 2 mi offshore, then the second well will be constructed about 5 mi offshore. By siting test wells at these locations, the position of the saltwater front can be bracketed and monitored. If the freshwater-saltwater interface in the 800-foot sand is present within 5 mi of shore and is migrating landward, water suppliers utilizing the aquifer in the Atlantic City area would be notified. If the interface lies more than 5 mi offshore, then it poses no short-term threat to the drinking-water supply, if ground-water withdrawals are maintained at present rates.

During marine drilling, lithologic samples will be collected on regular intervals. After each borehole has been completed to the required depth, electric logs and other geophysical logs will be collected. Subsequently, the boreholes will be screened and cased. Each completed well will be developed and pumped to determine yield, specific capacity, and aquifer hydraulic properties. During the pumping test, water samples for complete chemical analysis will be collected at predetermined times. Additional water samples for analyses of major ions will be collected hourly and specific conductance will be measured continuously for the duration of the test. At the conclusion of testing and sampling, each offshore well is to be outfitted with several differential pressure transducers and specific conductance sensors. Measurements of head and specific conductance will be made periodically by retrieving the sensor connectors that are stored on the seafloor, attaching them to the appropriate instruments aboard ship, and monitoring the downhole sensors. These measurements will be made until all the sensors become inoperative.

Because data are sparse on the quality of ground water in much of the Atlantic City region, a substantial number of water samples will be collected and analyzed for this study. Enough samples will be gathered so that the regional distribution of various chemical species in the Kirkwood-Cohansey aquifer system and in the 800-foot sand can be characterized. As part of the exploratory drilling program, plans are to construct one well in the Piney Point aquifer near Atlantic City. Samples from this well and from a few other wells in the study area will be collected to assess local water-quality conditions in the Piney

Point aquifer. If the aquifer contains water of poor quality, then it is possible that this water may leak upward through the confining bed and eventually contaminate local freshwater supplies in the 800-foot sand. However, if the Piney Point contains a sufficient quantity of freshwater, then the aquifer would be an attractive alternative source of water supply.

The study of water-quality conditions in the Kirkwood-Cohansey aquifer system and in the 800-foot sand will focus on the spatial distribution of major ions, nutrients, selected trace elements, volatile organic compounds, and, in agricultural areas, pesticides. The investigation of conditions in the 800-foot sand also will look into any time-dependent changes in water quality that may be caused by pumping stress on the aquifer. Sampling of water from the Kirkwood-Cohansey aquifer system and the 800-foot sand will be conducted in a synoptic manner. Water samples from the Piney Point aquifer will be analyzed for the same categories of constituents cited previously, excluding pesticides.

## Analysis and Interpretation of Hydrologic Processes

The various geologic and hydrologic data from previous studies and those collected for this study will be used to refine the present concept of ground-water flow in the Atlantic City region, and to develop a calibrated ground-water flow model. This model will be designed to simulate flow in the Kirkwood-Cohansey aquifer system, in the 800-foot sand, and in the Piney Point aquifer. The use of areal and cross-sectional models is planned as a means of understanding the complex behavior of the regional flow system. The lateral boundaries of the areal model will be represented by fluxes computed by the New Jersey subregional RASA model. After the model prepared for the present study has been calibrated, it can be used to assess how the various aquifers will respond to development.

The water-quality data will be interpreted with various statistical and analytical techniques. Data on the Kirkwood-Cohansey aquifer system will be interpreted statistically to ascertain the general relations between land use and ground-water quality. Data on the 800-foot sand will be interpreted in terms of the evolution of ground-water quality. This evolution will be described by the concept of hydrochemical facies (Back, 1960), which states that the facies present reflect the overall effects of chemical processes occurring between the ground water and the minerals of the lithologic framework. Because the ground-water flow patterns modify the facies and their distribution (Back, 1966, p. 11), the results of the facies analysis will be interpreted in conjunction with the flow-velocity field computed by the calibrated model. This interpretation may provide some insight into the nature of mass transport in the aquifer system. The simulated ground-water flow field near landfills and other disposal sites likewise will form the basis for estimating the local rate and direction of contaminant migration.

## Planned Products

The various written products expected to result from this study can be classified as data reports and interpretive reports. Anticipated principal reports on the Atlantic City and vicinity study include a compilation of verified records of wells and ground-water quality; maps of the synoptic water table in the Kirkwood-Cohansey aquifer system; maps of the synoptic potentiometric surface in the 800-foot sand, representing conditions of minimum and maximum pumping stress; and reports on the marine-drilling program, including a description of planning and logistical aspects of the program, and a summary of scientific findings. Interpretive reports summarizing the principal aspects of the study, especially the results of the model simulation of regional ground-water flow, will be prepared during the later stages of the investigation.

# CAMDEN AND VICINITY STUDY

## Location of Study Area

The area of study occupies approximately 700 $mi^2$ in parts of Camden, Burlington, and Gloucester Counties; it includes the Camden metropolitan area as well as small parts of Atlantic and Salem Counties (fig. 1). In addition, those parts of Pennsylvania along the Delaware estuary that are underlain by unconsolidated sediments connected hydraulically to the aquifer system in New Jersey are considered to be part of the study area.

## Geohydrologic Framework

The Camden study area is underlain by unconsolidated sediments of the Coastal Plain, which rest unconformably on the surface of the crystalline basement rock. These sediments range in age from Early Cretaceous to Holocene, and are chiefly of marine origin. The Coastal Plain deposits crop out in the northwestern part of the study area and dip toward the southeast, forming a wedge-shaped mass that thickens seaward. The crystalline rocks consist chiefly of schist of pre-Cretaceous age. The Fall Line (fig. 1) demarcates the surficial boundary between the Coastal Plain sediments and the crystalline rocks.

The Potomac-Raritan-Magothy aquifer system (table 1) is the principal source of ground water in the Camden area. Figure 4 shows the location of the outcrop area of the Magothy Formation in the Camden area, and figure 5 shows the location of the outcrop area of the Raritan Formation and the Potomac Group sediments. The sections in figures 10 and 11 show the thickness and dip of the units of the Potomac-Raritan-Magothy aquifer system and the other geohydrologic units in the study area.

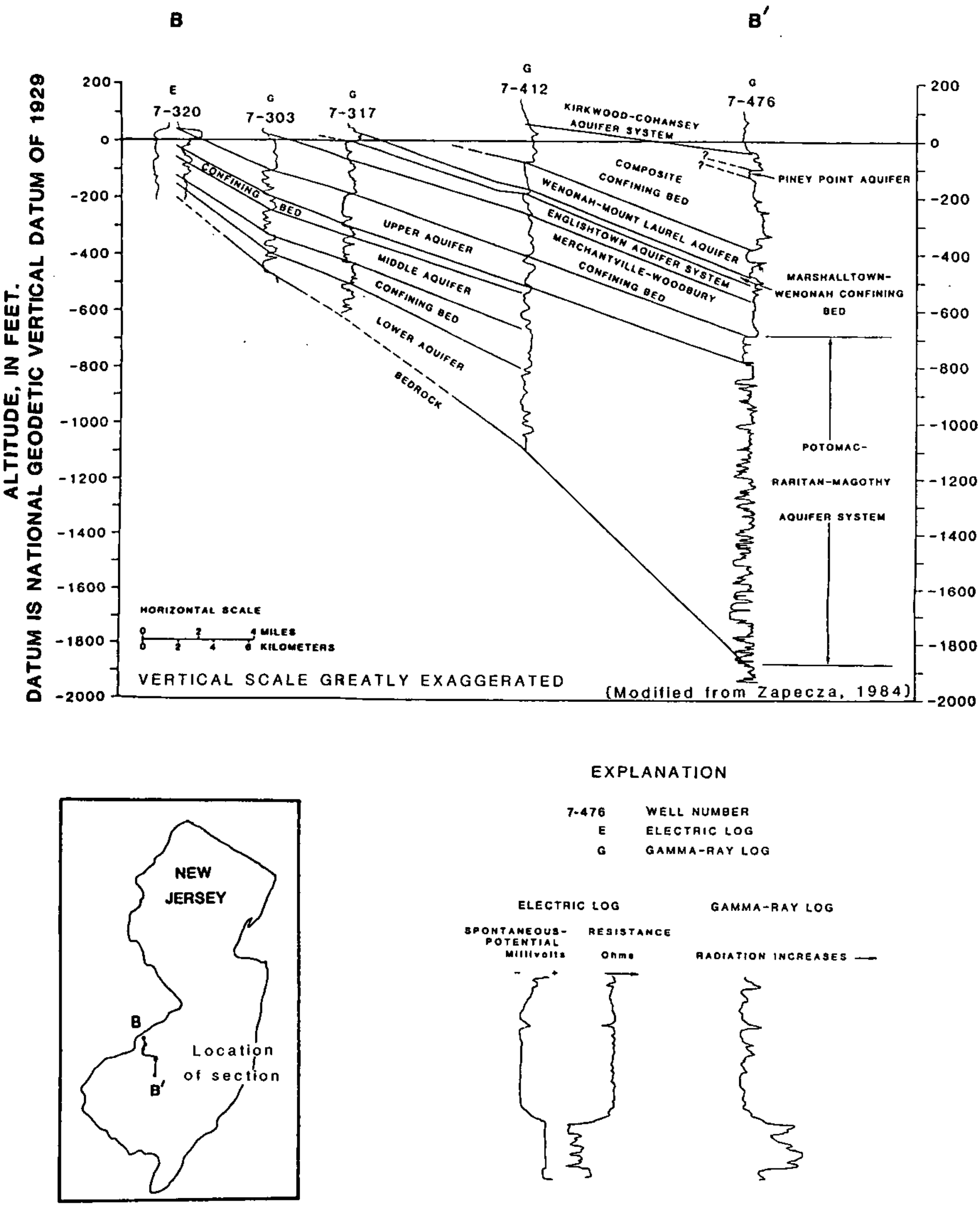



Figure 10.--Geologic section of the Camden area: downdip.

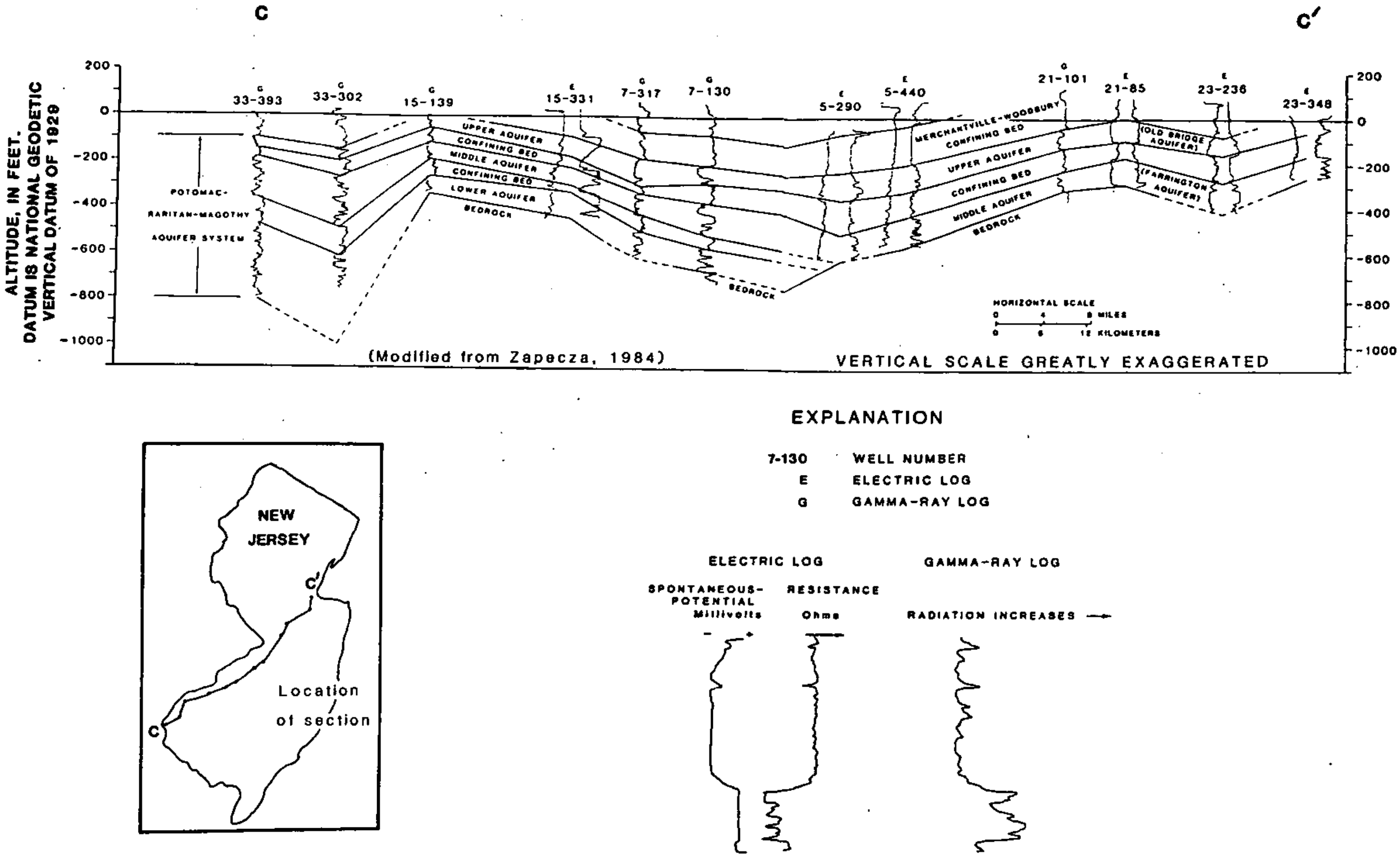



Figure 11.--Geologic section of the Camden area: parallel to strike.

## Geohydrologic Problems

In the Camden area, population, industrialization, and water use have increased steadily during the last century. In 1898, ground water was developed as the principal source of public supply for the city of Camden because the quality of the surface-water supply from the Delaware estuary began to deteriorate (Farlekas and others, 1976). Figure 12 shows the trend from 1897-1980 in pumpage from the Potomac-Raritan-Magothy aquifer system in Camden County.

At present, all water supplies in Camden County are derived from ground water, as are most supplies in adjoining Gloucester and Burlington Counties. In 1980, pumpage from the Potomac-Raritan-Magothy aquifer system averaged 75, 28, and 39 Mgal/d, respectively, in these counties (Vowinkel, 1984, p. 19). Most of the withdrawals in Gloucester County are from wells near Camden County. At projected rates of growth, from 1975 until the year 2000, an estimated increase of 53 percent in water-supply demand is anticipated (Camp Dresser McKee, Inc., 1982, p. 3-52).

Chiefly because of widespread industrialization, manmade contaminants and contaminants induced by human activities are present in several ground-water supplies of the Camden area. The study area contains 31 landfills and 66 sites of contamination by industrial sources. Eleven of these sites are on the U.S. Environmental Protection Agency's National Priorities (Superfund) List of September 1985 (fig. 8).

Because of the large-scale development of water supplies from the Potomac-Raritan-Magothy aquifer system, ground-water levels have declined to more than 100 ft below predevelopment levels in some parts of the study area. Figure 13 shows the decline of the potentiometric surface between 1900 and 1968 in Camden County. Figures 4 and 5 show that in 1978, water levels in both the upper and lower aquifers of the Potomac-Raritan-Magothy aquifer system were as much as 80 ft below NGVD of 1929. Such widespread declines have caused commensurate changes in the regional flow system. Prior to ground-water development, the outcrop area of the Potomac-Raritan-Magothy aquifer system in the Camden area was a natural ground-water discharge area. Subsequent large withdrawals resulted in the formation of deep and extensive cones of depression, and eventually caused ground-water flow directions to be reversed. Consequently, parts of the former discharge area have been converted into recharge areas.

## Previous Studies

Farlekas and others (1976), Hardt and Hilton (1969), and Rush (1968) conducted studies of the ground-water hydrology of Camden, Gloucester and Burlington Counties, respectively. These studies addressed the availability and quality of ground water

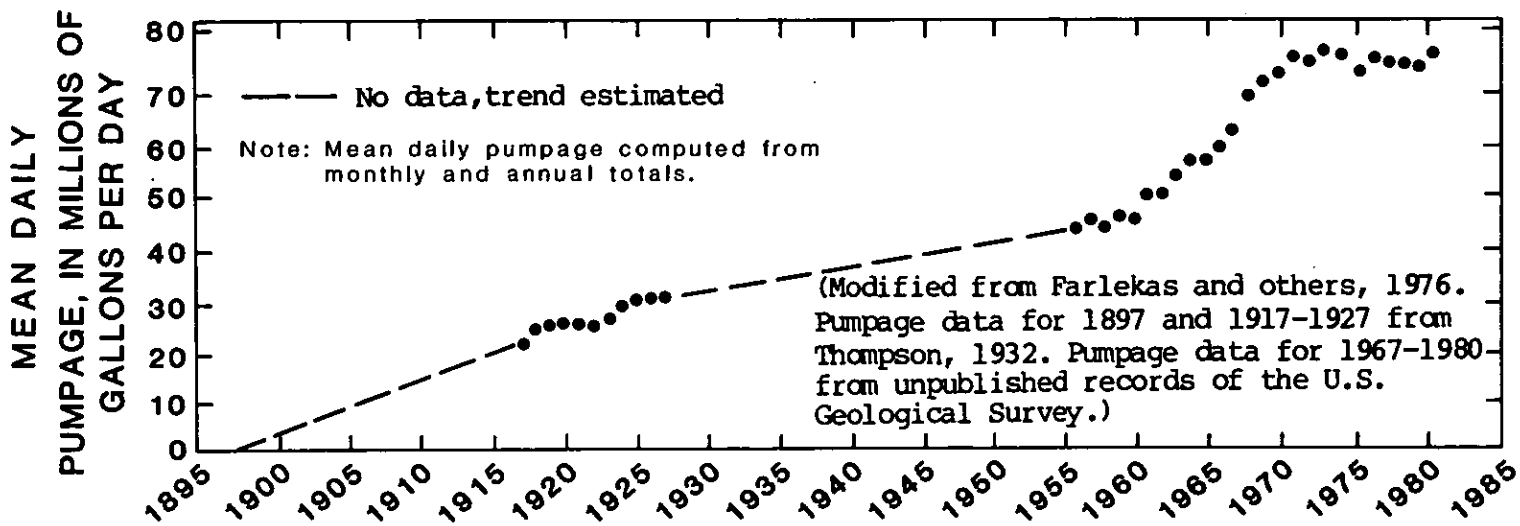



Figure 12.--Pumpage from the Potomac-Raritan-Magothy aquifer system in Camden County, New Jersey, 1897-1980.

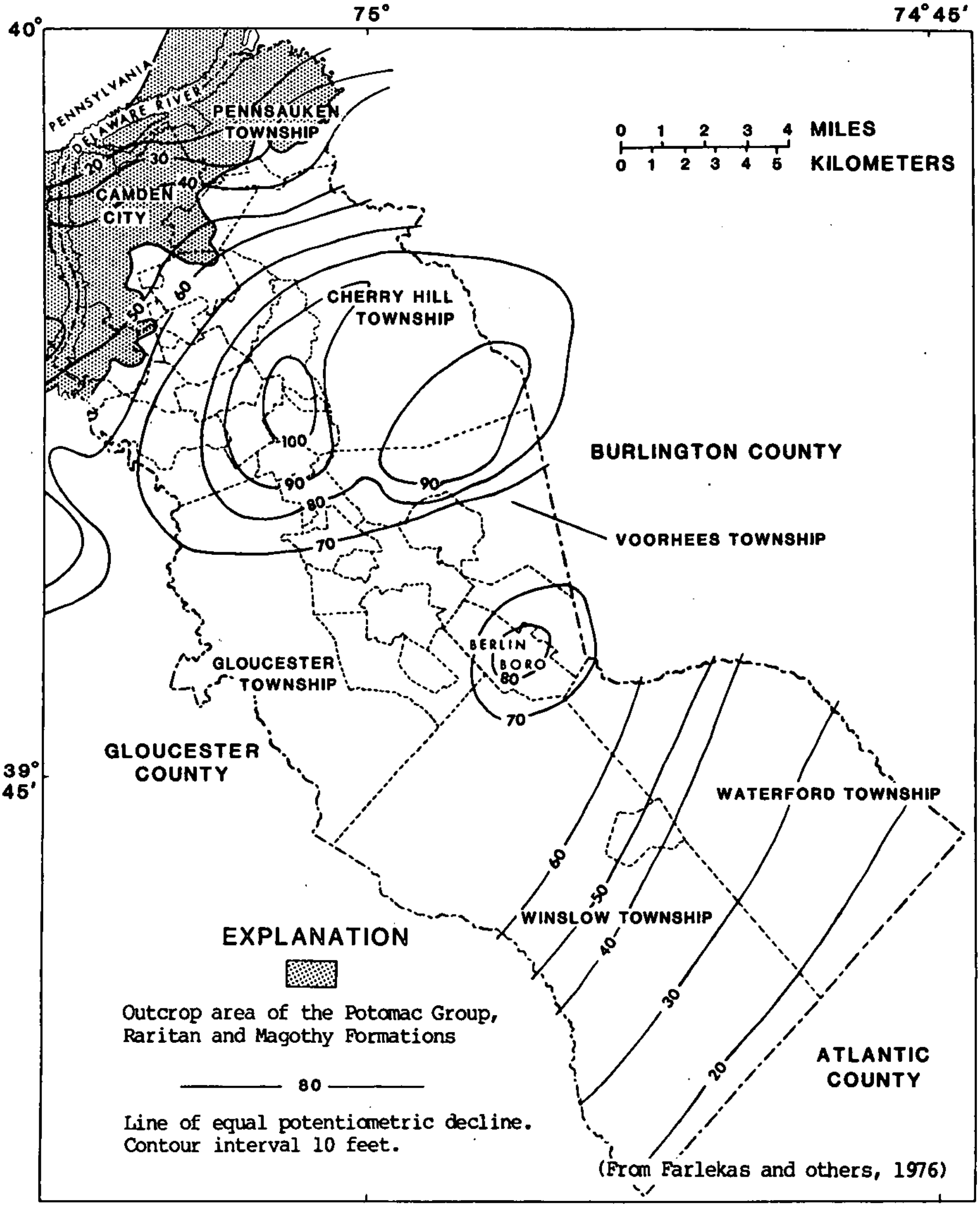



Figure 13.--Potentiometric decline of the Potomac-Raritan-Magothy aquifer system in Camden County, New Jersey, 1900-68.

and were based chiefly on analysis and interpretation of ground-water levels, aquifer tests, water-use data, and water-quality data.

Fusillo and others (1985), Fusillo and Voronin (1981), Langmuir (1969), Donsky (1963), and Rush (1962) conducted reconnaissance studies of ground-water quality in the Camden area. Water samples, chiefly from the Potomac-Raritan-Magothy aquifer system, were collected for each study and analyzed for various chemical constituents including organic compounds and trace elements. Fusillo and others (1984) presented ground-water quality data for that part of the Potomac-Raritan-Magothy aquifer system in southwestern New Jersey. A study by Hochreiter (1982) determined the chemical composition of water and bottom sediments in the Delaware estuary and several of its tributaries.

Luzier (1980) developed a model of ground-water flow in the Potomac-Raritan-Magothy aquifer system, which included the Camden area, to evaluate the effects of increasing water use. Using Luzier's model, Harbaugh and others (1980) tested various conjunctive-use strategies and predicted the movement of saltwater from downdip areas toward the pumping centers in the Camden area. The New Jersey subregional RASA modeling program includes a detailed investigation of the geohydrologic framework, geochemistry, and regional flow systems of major aquifers in the New Jersey Coastal Plain (Meisler, 1980). A model prepared by a consultant to the Delaware River Basin Commission (Camp Dresser McKee, Inc., 1982) was used to simulate flow in that part of the Coastal Plain of New Jersey, Pennsylvania, and Delaware that lies within the Delaware River basin. However, estimates from this model on the rate and distribution of leakage from the Delaware estuary generally do not agree with those by Luzier (1980). Zapecza (1984) prepared maps of structure contours and thickness of the principal aquifers and confining beds of the New Jersey Coastal Plain. These reports and the results of the previous simulation studies will provide much of the background required for the modeling aspects of this study.

## Description of Study

### Purpose and Scope

The chief purpose of this study is to examine in detail the flow of ground water in the Potomac-Raritan-Magothy aquifer system, as the flow system is not well understood. The study will determine the geologic framework and hydraulic properties of the aquifer system, characteristics of flow, interaction of the aquifer system with the Delaware estuary and overlying aquifers, and water use. The findings of the investigation will be used to develop a detailed model of ground-water flow in the Camden area. This study also will assess the need for and feasibility of modeling contaminant transport on a local scale.

## Objectives

The principal objectives of the Camden and vicinity study are to:

1. Define the geohydrologic framework.

2. Determine the location and rate of interchange of water between the Potomac-Raritan-Magothy aquifer system and both the Delaware estuary and other aquifers.

3. Quantify the amount of vertical leakage into or from units of the Potomac-Raritan-Magothy aquifer system.

4. Develop a detailed conceptual model of ground-water flow.

5. Appraise water quality in aquifers other than those of the Potomac-Raritan-Magothy aquifer system. This appraisal will focus on the Kirkwood-Cohansey aquifer system, the Wenonah-Mount Laurel aquifer, and the Englishtown aquifer system.

6. Assess the feasibility of simulating contaminant transport on a local scale in the Potomac-Raritan-Magothy aquifer system.

7. Prepare and maintain a standardized management system for hydrologic data.

## Approach

In order to satisfy the objectives, this study will assess and compile geologic and hydrologic data from various sources, collect additional data, analyze and interpret hydrologic processes, and appraise ground-water quality. The results of the study will be disseminated in reports, oral presentations, and in other media.

### Assessment of Geologic and Hydrologic Data

Geologic and hydrologic data from various sources will be evaluated and compiled. Files of the USGS, including those on water quality, water use, ground-water levels, and well records constitute the principal sources of such data. Supplemental files, particularly those containing information on borehole geophysical logs, lithology, and surface geophysical investigations, also will be evaluated.

The files of the NJDEP will be examined for additional information on well locations, ground-water levels, and water quality. The chief sources of such information are the records of permits granted for well drilling and withdrawal of ground water. Data from the files of other government agencies and private firms also will be evaluated and compiled as needed.

Particularly, information collected by a private consultant to the NJDEP as part of the Camden and Vicinity Water Supply Feasibility Study is likely to be of great value to this study. The purpose of the Feasibility Study is to determine if the Camden area should be designated a critical water-supply area, as defined by the Statewide Water-Supply Master Plan (New Jersey Department of Environmental Protection, 1981), and to evaluate alternative water supplies for the area.

## Collection of Additional Data

Additional geologic and hydrologic data will be collected as needed to define the local geohydrologic framework and the ground-water flow system. Information on the geohydrologic framework will be obtained as part of the exploratory drilling program by analyzing lithologic samples and conducting geophysical surveys in the completed boreholes. Results of the surface geophysical investigations conducted by the NJGS will be correlated with those from the downhole surveys, so that lithology and aquifer system hydraulic properties in areas not drilled may be evaluated.

Water levels in the major aquifers of the Camden area will be measured on a synoptic basis and, in conjunction with long-term hydrographs, will be analyzed to determine the character of the ground-water flow system. Several aquifer tests will be conducted at representative locations to assess the hydraulic properties of the Potomac-Raritan-Magothy aquifer system.

After the water-quality data base has been evaluated, areas of insufficient representation or resolution will be identified and sampled. This study will focus on the distribution of organic compounds and trace elements in the less-developed aquifers of the Camden area. Although the Potomac-Raritan-Magothy aquifer system is the principal source of water supply for the area, it is likely that the other aquifers will be developed further as the demand for water increases. However, because of the large amount of data available on the quality of ground water in the area, sampling will be limited.

## Analysis and Interpretation of Hydrologic Processes

Geologic and hydrologic data from the assessment and collection activities will be used to prepare a conceptual model of ground-water flow in the Potomac-Raritan-Magothy aquifer system. Subsequently, three aspects of the flow system will be investigated in detail because of their relative importance and the present lack of understanding: (1) determining the hydrologic interaction between the Delaware estuary and the Potomac-Raritan-Magothy aquifer system; (2) estimating the rate and quantity of leakage within the units of the Potomac-Raritan-Magothy aquifer system; and (3) estimating the quantity of leakage between the Potomac-Raritan-Magothy aquifer system and the other aquifers.

Hydrologic interactions between the Delaware estuary in the Camden area and the Potomac-Raritan-Magothy aquifer system partly determine the nature of the ground-water flow system. Because the estuary traverses the outcrop area of the aquifer system, and because ground-water levels have been lowered by large withdrawals, some surface water infiltrates into the ground-water system. Consequently, induced recharge locally affects ground-water levels and quality. In order to determine the location and rate of interchange of water, the hydraulic properties of the aquifers and the estuary-bottom deposits must be evaluated, as direct measurements of the interchange are not feasible. Because the Delaware estuary near Camden is relatively wide and deep, conventional discharge or seepage measurements to determine the location and amount of water loss cannot be made, as the error inherent in such measurements may exceed the quantity of seepage. Installation of seepage meters in the bottom deposits to directly measure the interchange is not feasible because of the depth, velocity, and turbidity of estuary water. Consequently, several techniques for indirectly measuring the hydraulic properties of the aquifers and the estuary-bottom deposits, thus enabling computation of the rate of leakage, will be implemented in this study. These techniques include analysis of aquifer test data; use of chemical tracers, such as the stable isotopes of hydrogen and oxygen; synoptic measurement of the temperature of estuary water, bottom deposits, and ground water; and precise determination of local surface-water and ground-water levels.

Selected reaches of the Delaware estuary will be studied to estimate the seepage loss. In each test reach, an aquifer test involving wells on the shore and in the estuary will be conducted to quantify the amount of infiltration induced from the estuary. Pumping tests of the estuary wells also will be conducted to determine the hydraulic conductivity of the bottom deposits.

Water samples from wells near the Delaware estuary will be analyzed for concentrations of the stable isotopes of hydrogen and oxygen. Samples of water from the estuary and from wells at various distances from it will be analyzed for background concentrations of these isotopes. By comparing concentrations, the proportion of surface water in the ground-water samples can be estimated, thus enabling determination of the importance of surface-water infiltration as a source of recharge.

Synoptic measurements of the temperature of estuary water, bottom deposits, and ground water will be made in an attempt to identify localities with high rates of induced infiltration. Small temperature gradients in the bottom sediments would suggest areas of significant infiltration.

Aquifer tests at selected sites are planned to determine the rate and quantity of leakage within the units of the Potomac-Raritan-Magothy aquifer system, and between these units and overlying aquifers. A three-dimensional digital model of ground-water flow in the Potomac-Raritan-Magothy aquifer system and in the overlying aquifers will be developed for this study. This model will be used to simulate ground-water flow in the entire study area and to provide an understanding of the regional flow system. After the model has been calibrated, it can be used to evaluate the hydrologic consequences of various ground-water management alternatives. The model boundaries will be specified-flux boundaries using fluxes from the New Jersey subregional RASA model. This interrelation of flow models will result in a fine-grid discretization of localities of interest in the study area, without compromising the true boundary conditions of the flow system.

Because ground water is the chief source of supply for the Camden area, and because chemical contaminants are present in the Potomac-Raritan-Magothy aquifer system and possibly in the less-developed aquifers of the area, an understanding of solute transport in the ground-water system is highly desirable. Such an understanding requires knowledge of the sources of contamination, as well as knowledge of the rate and direction of contaminant movement. For this study, solute transport on a local scale will be studied in a preliminary manner by analyzing the ground-water velocity field computed by the digital flow model, so that the general rate and direction of transport may be estimated. Transport also may be evaluated by using a model designed specifically for that purpose.

### Planned Products

The chief products of this study will be data reports and interpretive reports. Principal reports on the Camden and vicinity study are likely to include a compilation of basic hydrologic data, maps of the potentiometric surfaces in the Potomac-Raritan-Magothy aquifer system, a summary of the results of the stable-isotope program for determining the source of recharge water, and a discussion of the hydrologic interactions between the Potomac-Raritan-Magothy aquifer system and the Delaware estuary. During the later phases of the study, a comprehensive report will be prepared summarizing the principal aspects of the investigation.

## SOUTH RIVER VICINITY STUDY

### Location of Study Area

The area of study comprises 400 $mi^2$ in parts of Middlesex and Monmouth Counties, a region along the northern boundary of the New Jersey Coastal Plain (fig. 1). This region is bounded on the northwest by the outcrops of the Old Bridge and Farrington aquifers; on the northeast by the Keyport-Union Beach area, including nearshore parts of Raritan Bay; on the south by the area immediately south of Freehold; and on the southwest by the area near the common intersection of Monmouth, Middlesex, and Mercer Counties.

## Geohydrologic Framework

The area to be investigated is underlain by unconsolidated deposits of gravel, sand, silt, and clay that unconformably overlie crystalline basement rock. These sediments were deposited during Early Cretaceous to Holocene time in marine, fluvio-deltaic, and fluvial environments (Farlekas, 1979). The thickness of this wedge-shaped sediment mass ranges from a featheredge along the Fall Line to approximately 1,000 ft in downdip areas toward the southeast (Zapecza, 1984). The Fall Line (fig. 1) demarcates the landward extent of the Coastal Plain deposits.

Most ground water used in the South River area is withdrawn from the Old Bridge Sand Member of the Magothy Formation (Farlekas, 1979, p.22), which in this report is called the Old Bridge aquifer, and from the Farrington Sand Member of the Raritan Formation (Farlekas, 1979, p. 8), which herein is called the Farrington aquifer. In other parts of the New Jersey Coastal Plain, the Old Bridge and Farrington aquifers are referred to as the upper and middle aquifers, respectively, of the Potomac-Raritan-Magothy aquifer system. The Old Bridge aquifer consists chiefly of medium-grained sand that locally contains interbeds of clayey silt (Farlekas, 1979, p. 22). The Farrington aquifer is composed mainly of fine- to coarse-grained sand that locally may contain clay beds (Barksdale and others, 1943, p. 104-105); it is commonly overlain by the Woodbridge Clay Member of the Raritan Formation, which varies in thickness from approximately 50 ft in its outcrop area to nearly 200 ft farther downdip (Farlekas, 1979, p. 20). The Old Bridge and Farrington aquifers, along with their associated confining beds, are Cretaceous in age and form part of the Potomac-Raritan-Magothy aquifer system; they are of principal interest to this study. The thickness of the Potomac-Raritan-Magothy aquifer system in the study area ranges from a featheredge along the Fall Line in Middlesex County to 600 ft in Monmouth County (Farlekas, 1979, p. 5). The aquifer system is confined above by, in ascending order, the Merchantville Formation and the Woodbury Clay, which together form the most extensive confining bed in the New Jersey Coastal Plain (Zapecza, 1984). The aquifer system is confined below by the pre-Cretaceous bedrock.

The Merchantville-Woodbury confining bed ranges in thickness from a few feet in Middlesex County to more than 300 ft in Monmouth County (Farlekas, 1979). Basal clays of the Potomac-Raritan-Magothy aquifer system also may confine the lowermost water-bearing units of the aquifer system. Another geologic feature in the area that may act as a barrier to ground-water flow is the Palisades diabase sill, which is present beneath the outcrop area of the Potomac-Raritan-Magothy aquifer system.

## Geohydrologic Problems

Because of increasing population and development of the South River area, the demand for water for public supply, industrial, and agricultural uses has increased greatly in recent years. Withdrawal of water from the Old Bridge aquifer began in 1902 with the construction of the first public supply wells; since then, the Old Bridge has become the most productive aquifer in Middlesex County (Farlekas, 1979). According to Barksdale (1937), withdrawals from the Farrington aquifer began in 1897 at the Perth Amboy well field in Runyon, Middlesex County. Figure 14 shows the trend from 1951-83 in pumpage from the Old Bridge and Farrington aquifers in Middlesex and Monmouth Counties.

Due to these large withdrawals, ground-water levels throughout the study area have declined considerably, causing significant changes in the regional ground-water flow system. In some areas, water-level declines have been great enough to cause the reversal of natural ground-water flow directions. Water levels measured in 1978 (Walker, 1983) in the Old Bridge aquifer at two localities in Monmouth County were 40 ft or more below NGVD of 1929 (fig. 6), a decline of more than 70 ft below predevelopment levels. Water levels in the Farrington aquifer in parts of Middlesex and Monmouth Counties were 60 ft or more below NGVD of 1929 (fig. 7), representing a decline of over 100 ft below predevelopment levels (Walker, 1983).

The steep, landward head gradients resulting from large ground-water withdrawals have caused the local flow of saltwater from estuaries and bays into the freshwater aquifers. Chloride contamination of the Old Bridge aquifer was first identified in 1970 near Keyport and Union Beach, Monmouth County (Schaefer and Walker, 1981). Saltwater probably infiltrates directly, as well as indirectly, into the Old Bridge aquifer in these areas, and the resulting elevated levels of chloride have caused the abandonment of several water-supply wells. According to H. G. Fairbanks (U.S. Army Corps of Engineers, written commun., 1936), saltwater contamination of the Farrington aquifer was first detected in 1926 in the vicinity of the outcrop area near the confluence of the South and the Raritan Rivers.

In recognition of the problems of overproduction and saltwater intrusion, and their potential effects on the expected continued growth of the area, the NJDEP has designated the South River study area as a critical water-supply area, as defined by the Statewide Water Supply Master Plan (New Jersey Department of Environmental Protection, 1981). Designation as a critical area allows the NJDEP to mandate allocation and rate structures on a regional scale in order to protect or rehabilitate affected water supplies, or to establish suitable replacement supplies.

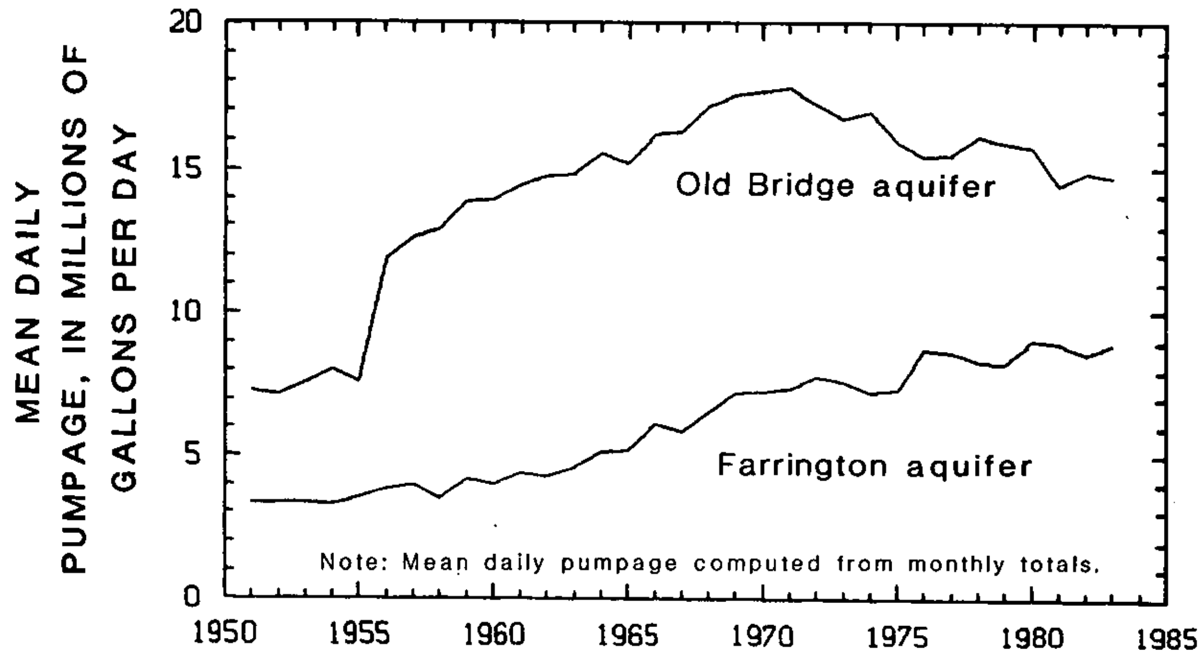



Figure 14.--Pumpage from the Old Bridge and Farrington aquifers in Middlesex and Monmouth Counties, New Jersey, 1951-83.

## Previous Studies

The geology and ground-water resources of the Old Bridge and Farrington aquifers of the northern Coastal Plain of New Jersey have been studied since 1937. Barksdale (1937) described the geohydrology of the Parlin area, and concluded that the safe freshwater yield of the Farrington was controlled by the quantity of saltwater that entered the aquifer through the Washington Canal and the Raritan estuary. In 1943, Barksdale and others presented the results of an investigation of the geology and ground-water resources of Middlesex County. The results of this study showed that: (1) the Old Bridge aquifer had been developed to about its safe yield, and suggested that further development should be preceded by the construction of a tidal dam on the South River to make available fresh surface water for induced recharge; and (2) the Farrington aquifer was already overdeveloped in several localities, as indicated by saltwater encroachment. Jablonski (1968) presented data on test borings and water-supply wells in Monmouth County. Geraghty and Miller (1976) presented a general description of the ground-water hydrology of Middlesex County. A report by Walker (1983) contains maps of the potentiometric surface during 1978 of the Old Bridge and Farrington aquifers (therein called the upper and middle aquifers, respectively, of the Potomac-Raritan-Magothy aquifer system). Barksdale and DeBuchananne (1946) discussed the feasibility of artificially recharging the Old Bridge aquifer at the Perth Amboy Water Works in Runyon and at Lake Duhernal on the South River (see fig. 6 for locations). Appel (1962), using a flow-net analysis, investigated saltwater encroachment into the Raritan Formation in the Sayreville area of Middlesex County and enumerated the benefits of constructing a tidal dam on the South River. Hasan and others (1969) discussed the water-resources of the Old Bridge aquifer in the Sayreville area, Middlesex County. Remson and Fungaroli (1969), using a digital ground-water flow model, studied the potential effects of surface-water flow into the Raritan Formation that could result by forming a freshwater reservoir on the Raritan River immediately upstream of Crab Island. To date, none of these proposed engineering works have been constructed.

Several of the previously cited reports contain sections on water quality. In addition, Seaber (1963) includes data on chloride concentrations in water samples collected from 1923-61 from wells in the study area. The report by Schaefer and Walker (1981) describes saltwater intrusion into the Old Bridge aquifer near Keyport and Union Beach, and presents data on chloride concentrations in water from local wells. Schaefer (1983) presents data by county on chloride concentrations in water from the principal Coastal Plain aquifers in coastal parts of central and southern New Jersey.

Farlekas (1979) developed a two-dimensional, finite-difference model of ground-water flow in the Farrington aquifer to simulate the effects of historical and planned development.

The model results demonstrated a dynamic interaction between the Old Bridge and Farrington aquifers. Based on a projected linear increase in pumpage, the model predicted ground-water levels of more than 150 ft below NGVD of 1929 by the year 2000. A principal source of recharge to the Farrington aquifer, determined by model water-budget computations, is downward leakage from the Old Bridge aquifer through the Woodbridge Clay. Presently, the RASA program is studying, with a digital model, the nature of ground-water flow in 10 important aquifers of the New Jersey Coastal Plain. The results of these previous simulation studies likely will provide much of the background information required for the modeling aspects of this investigation.

## Description of Study

### Purpose and Scope

The major purpose of this study is to investigate in detail the flow of ground water and the quality of water in the Old Bridge and Farrington aquifers. The principal aspects of the investigation include: (1) determining the geologic framework and hydraulic properties of these aquifers and their associated confining beds; (2) investigating the extent and severity of saltwater encroachment in the Old Bridge aquifer in the Keyport-Union Beach area and in the Farrington aquifer in the Sayreville-South Amboy area; and (3) assessing the ground-water quality, with particular emphasis on the distribution and concentration of chloride in coastal aquifers. The water-quality assessment will provide background information against which future changes can be measured.

The results of the investigation will be used to construct a detailed ground-water flow model of the study area so that the effects of present withdrawals and future development can be evaluated. Data on chloride concentrations in areas affected by saltwater intrusion will provide input for planned solute transport models.

### Objectives

The chief objectives of the South River and vicinity study are to:

1. Define the geohydrologic framework.

2. Determine the hydraulic properties of the Old Bridge and Farrington aquifers and their associated confining beds.

3. Evaluate the nature of the hydraulic connection between the Old Bridge and Farrington aquifers, the relations between the Old Bridge aquifer and Raritan Bay, the interaction between the Farrington aquifer and salty surface-water bodies including the Washington Canal and

the lower reaches of the Raritan and South Rivers, and the hydrologic significance of the Palisades diabase sill.

4. Prepare a detailed conceptual model of regional ground-water flow.

5. Assess general water quality in the Old Bridge and Farrington aquifers, with emphasis on the distribution of chloride in areas significantly affected by saltwater intrusion.

6. Determine the nature of chloride migration in areas affected by saltwater intrusion.

7. Prepare and maintain a standardized management system for hydrologic information.

## Approach

This study will take place in three phases, each having different emphasis: (1) assessment of geologic and hydrologic data; (2) collection of additional data; and (3) analysis and interpretation of hydrologic processes. Tasks from these phases may be undertaken concurrently. The results of the investigation will be disseminated in various media, chiefly written reports and oral presentations.

### Assessment of Geologic and Hydrologic Data

Information from previous studies and other sources will form the starting point for this investigation. Data from several sources on the geology and hydrology of the study area will be evaluated and compiled. The principal source of such information is the files of the USGS, particularly those on well records, water quality, ground-water levels, and water use. Other files, especially those containing results of surface-geophysical investigations and marine-geophysical investigations, borehole geophysical logs, and information on aquifer system lithology, stratigraphy, and hydraulic properties will be searched for data that may be of importance to this study.

The files of the NJDEP, as well as those of other government agencies and private firms, will be checked for basic or supplemental geologic and hydrologic data. Selected information from these sources will be assessed, compiled, and entered into the appropriate data bases.

Preliminary analysis of the information gathered during the first phase of the study will guide data collection during the second phase. The geohydrologic framework will be determined through the use of data from borehole-, surface-, and marine-geophysical investigations. Particular emphasis will be placed on evaluating the effect of the Palisades diabase sill on the hydrology of the Farrington aquifer. Existing information on the depth of the sill will be compiled as control for subsequent data-collection activities involving surface- and marine-geophysical techniques. Available information on the geohydrology of the Raritan Bay area also will be used for preliminary assessment of local ground-water/surface-water relations. Areas where additional geohydrologic information is needed will be identified by several techniques including kriging (Karlinger and Skrivan, 1980) and trend analysis. The hydraulic properties of the Old Bridge and Farrington aquifers and their associated confining beds will be characterized initially by reviewing appropriate information in technical reports and selectively reinterpreting, with alternative techniques, data from reliable well-acceptance and aquifer tests. Ground-water quality data, particularly that on common inorganic constituents and organic compounds, and information on chloride migration, will be reviewed. Following this review, the need for additional data will be evaluated.

## Collection of Additional Data

During the second phase of this study, additional data on the geology and hydrology of the South River area will be collected to gain a better understanding of the geohydrologic framework and ground-water flow system. Present knowledge of the regional geohydrology is inadequate to define the hydraulic relations of the aquifers and their associated confining beds. Therefore, this investigation proposes to study and interpret geohydrology in terms of its control on the regional ground-water flow system. A major aspect of this study will be to determine the areal extent of the Palisades diabase sill and to evaluate its effect on ground-water flow in the northwestern part of the study area. This is of particular importance, as saltwater has already intruded into the Farrington aquifer in coastal areas near the sill. At present, any hydrologic effects the sill may have on intrusion are unknown. Plans are to evaluate the geologic and hydrologic conditions with surface- and marine-geophysical techniques.

Excavation of the Washington Canal may have contributed to local chloride contamination of ground water in the Farrington aquifer, as the incised aquifer was exposed to the overlying saltwater. Similarly, the Old Bridge aquifer has been contaminated locally by chloride because of a hydraulic connection with Raritan Bay. In both instances, the degree and extent of the hydraulic connection between the surface-water bodies and the ground-water systems must be determined to properly simulate ground-water recharge, flow, and discharge. Marine-geophysical techniques will be a principal means of evaluating this connection.

Selected information on the geohydrologic framework will be acquired by conducting a water-well inventory in localities where data on stratigraphy, ground-water levels, well yield, and ground-water quality are lacking or need better definition. Well records presently in the files of the USGS will be updated with the information collected during the inventory, and records of selected wells not yet in the files will be added.

Additional information on the geohydrologic framework will be obtained by drilling test wells and boreholes in areas of sparse data. The drilled or cored samples will be logged and analyzed, and geophysical investigations will be conducted in the boreholes. Several of the boreholes will be completed as observation wells for water-level measurements and water-quality sampling. Geophysical studies will be conducted to evaluate the thickness and type of sediment beneath coastal surface-water bodies and to determine the configuration and extent of the major confining beds. Results of the borehole surveys will be correlated with those from the surface- and marine-geophysical investigations so that lithology and aquifer system hydraulic properties in localities not drilled can be estimated.

Multiple-well aquifer tests will be conducted, where necessary, to better define the hydraulic properties of the Old Bridge and Farrington aquifers and to aid in calibrating the ground-water flow model. A test of the Old Bridge aquifer in the Union Beach area (fig. 6) is planned to evaluate the relations between fresh and salty ground water, and to help determine the means by which saltwater enters the freshwater system. Also, water levels in the Old Bridge and Farrington aquifers will be measured on a synoptic basis during minimum (late winter) and maximum (late summer) pumping stress. Information on aquifer system hydraulic properties, in conjunction with the data on water levels, will be used to assess the behavior of the ground-water flow system.

Evaluating ground-water quality in parts of the South River area was a major component of several of the previous studies. However, except for chloride monitoring, which has continued periodically (for example, Schaefer, 1983), water-quality investigations have not been ongoing. Recently, Fusillo and others (1984) analyzed ground-water samples from parts of the study area for major ions, as well as for selected trace elements and volatile organic compounds. In a similar manner, this study will investigate the distribution of these same constituents in the Potomac-Raritan-Magothy aquifer system in localities not sampled by Fusillo and others (1984). This study also will determine the distribution of manmade chemical contaminants in the ground water.

## Analysis and Interpretation of Hydrologic Processes

During the third phase of this study, geologic and hydrologic data from the previous two phases will be used to refine the concepts of the geohydrologic framework of and ground-water flow in the Old Bridge and Farrington aquifers. For example, information on the composition, thickness, and integrity of confining beds, together with data on head gradients, will be used to estimate the rate and quantity of vertical leakage. Information on the type and distribution of bottom sediments in Raritan Bay will be evaluated to help characterize the relations between the surface-water and ground-water systems. A calibrated three-dimensional model of regional ground-water flow will result from these and related data analyses and interpretations. This model will simulate the dynamic interactions of these aquifers with their associated confining beds and with surface-water bodies. Model boundaries will be specified fluxes computed by the New Jersey subregional RASA model. By using these specified boundary fluxes, localities of particular interest may be discretized with a fine model grid without compromising the actual boundary conditions of the flow system. Subsequently, the calibrated model will be used to assess the effects of various development schemes on the ground-water system and to produce a refined water budget.

The evolution of water quality in the Old Bridge and Farrington aquifers will be determined according to the concept of hydrochemical facies (Back, 1960; 1966). In addition, the quality of pore water extracted from cores of confining-bed material will be evaluated. This information, along with the results of the flow simulations, will be integrated into a unified interpretation of regional ground-water quality and flow.

An assessment of the movement of chloride in the Old Bridge aquifer in the Keyport-Union Beach area and in the Farrington aquifer in the Sayreville-South Amboy area will be another major product of this study. The results of the test drilling, flow modeling, and water-quality sampling will be interpreted conjunctively to characterize the migration of chloride. If warranted by these interpretations, chloride migration in one or both of these localities may be simulated with a transport model.

## Planned Products

Principal reports on the South River vicinity study are expected to include a compilation of basic hydrologic data; maps of structure contours on and thickness of the various aquifers and their associated confining beds, including those underlying coastal surface-water bodies; a structure-contour map of the top of the Palisades diabase sill; and maps of the potentiometric surface in the Old Bridge and Farrington aquifers. A comprehensive interpretive report will be prepared to summarize the principal aspects of the investigation, particularly, the simulation of regional ground-water flow and the assessment of chloride migration.

SUMMARY

In the Coastal Plain of New Jersey, ground water is the principal source of water supply. In many areas it is an abundant resource, but in other areas, large withdrawals have resulted in declining ground-water levels and a reduction in the volume of water in storage. These conditions have increased the potential for shortages and for contamination of freshwater aquifers by encroaching saltwater. Localities of potential shortage and contamination include the Atlantic City, Camden, and South River areas. In order to address these critical problems, the USGS, in cooperation with the New Jersey Department of Environmental Protection, instituted comprehensive studies of the ground-water resources of each of these areas. These studies began in 1983 and are scheduled to be completed in 1988.

In order to develop additional ground-water resources in these three areas, more data are needed on the volume, hydraulic properties, flow patterns, potential yield, and quality of water. Inadequate information of this type has hampered regional water-resources planning and management and has led to existing and potential problems. Overproduction and degradation of ground-water quality are the most serious of these problems. Proper management of these ground-water supplies requires data sufficient to characterize the flow systems and analytical techniques, including modeling, that satisfactorily represent aquifer-system behavior. Information presently available on the ground-water systems of the Atlantic City, Camden, and South River areas, as well as an understanding of the stresses on these systems, is inadequate for proper characterization, representation, and management of the water resources.

The chief objective of the Bond Issue ground-water supply investigations is to provide resource managers with the hydrologic data and analyses necessary for effectively managing the ground-water supplies of each study area. Plans are to accomplish this objective by upgrading the geologic and hydrologic data bases; by developing a detailed understanding of the ground-water systems, mainly through the use of digital models; and by implementing a standardized information management system. The overall approach to the studies consists chiefly of an assessment of existing geologic and hydrologic data, collection of additional data, and analysis and interpretation of hydrologic processes. The approach followed by each study will include all of these phases, although the amount of emphasis on each will vary. Planned products of these investigations include data reports, interpretive reports, and instructional manuals.

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