GROUND-WATER WITHDRAWALS FROM COASTAL PLAIN AQUIFERS FOR PUBLIC SUPPLY AND SELF-SUPPLIED INDUSTRIAL USE IN MIDDLESEX AND MONMOUTH COUNTIES, NEW JERSEY, 1901-85

By M.A. Horn and Lisa Bratton

U.S. GEOLOGICAL SURVEY

Water-Resources Investigation Report 90-4083

Prepared in cooperation with the

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL RESOURCES

West Trenton, New Jersey

1991

U.S. DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

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

Copies of this report can be
purchased from:

U.S. Geological Survey
Books and Open-File Reports
Federal Center
Box 25425
Denver, CO 80225

CONTENTS

APPENDIXES

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
million gallons per day (Mgal/d)	3,758	cubic meter per day

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

GROUND-WATER WITHDRAWALS FROM COASTAL PLAIN AQUIFERS FOR PUBLIC SUPPLY AND SELF-SUPPLIED INDUSTRIAL USE IN MIDDLESEX AND MONMOUTH COUNTIES, NEW JERSEY, 1901-85

by M.A. Horn and Lisa Bratton

ABSTRACT

Data on withdrawals of ground water for public supply and self-supplied industrial use from five major Coastal Plain aquifers in Middlesex and Monmouth Counties, New Jersey, during 1901-85 were analyzed for trends. The data used in this study were collected for previous Coastal Plain aquifer studies; however, the data have been updated and refined into a more consistent and reliable data set for Middlesex and Monmouth Counties. Water-withdrawal trends are discussed in terms of category of use, aquifer, and location. Withdrawals are summarized by the use categories of public supply and self-supplied industrial use. Withdrawals also are summarized by five major aquifers or aquifer systems: the middle and upper aquifers of the Potomac-Raritan-Magothy aquifer system, the Englishtown aquifer system, the Wenonah-Mount Laurel aquifer, and the Kirkwood-Cohansey aquifer system.

During 1901-50, ground water in these counties was developed extensively for both public supply and self-supplied industrial use. During the 1940's, withdrawals for public supply and self-supplied industrial use reached an average of 16.94 Mgal/d (million gallons per day) and 19.71 Mgal/d, respectively. The greatest increase in withdrawals was in the eastern part of Middlesex County and along the shore in Monmouth County. During this period, withdrawals for public supply in Middlesex County were primarily from the upper aquifer of the Potomac-Raritan-Magothy aquifer system, and withdrawals for self-supplied industrial use were primarily from the middle aquifer of the Potomac-Raritan-Magothy aquifer system. In Monmouth County, public suppliers withdrew about half their water from the upper aquifer of the Potomac-Raritan-Magothy aquifer system and the remainder from the Englishtown aquifer system, Wenonah-Mount Laurel aquifer, and Kirkwood-Cohansey aquifer system.

During 1951-85, the populations of both counties increased greatly as a result of suburban growth. Ground-water withdrawals for public supply doubled from 25.01 Mgal/d during the 1950's to 50.42 Mgal/d during the 1970's, whereas industrial withdrawals remained relatively constant at 25.0 Mgal/d. During 1981-85, the population of the parts of Middlesex and Monmouth Counties served by ground water from Coastal Plain aquifers remained constant, as did withdrawals for public supply (53.69 Mgal/d). Industrial withdrawals during this period declined to 19.25 Mgal/d.

During 1951-70, the upper aquifer of the Potomac-Raritan-Magothy aquifer system became the major aquifer for withdrawals in both counties (from 33.45 to 44.31 Mgal/d, or about 67 percent of the total) as public suppliers increasingly used this aquifer to serve suburban residents. Withdrawals from the middle aquifer of the Potomac-Raritan-Magothy aquifer system for public supply increased from 10.79 Mgal/d during the 1950's to 15.4 Mgal/d during the 1960's, or about 23 percent. During 1971-85, the

percentage of total withdrawals from the upper aquifer of the Potomac-Raritan-Magothy aquifer system decreased to about 57 percent, and withdrawals from the middle aquifer of the Potomac-Raritan-Magothy aquifer system increased to 32 percent, primarily because of increased withdrawals from the middle aquifer in Monmouth County.

INTRODUCTION

The demand for water for public supply and self-supplied industrial use in Middlesex and Monmouth Counties, New Jersey, has increased greatly since the beginning of the twentieth century because of increasing population and development. In 1985, 73 Mgal/d, or 51 percent of the water withdrawn in Middlesex and Monmouth Counties, was withdrawn from Coastal Plain aquifers. Because of these large withdrawals, ground-water levels in parts of these counties have declined considerably. The resulting steep, landward hydraulic gradients have caused local flow of saltwater from estuaries and bays into the freshwater aquifers (Leahy and others, 1987), and this saltwater intrusion threatens public and industrial water supplies.

In recognition of the problems of overproduction and saltwater intrusion and their potential effects on the anticipated continued growth of the area, the U.S. Geological Survey, in cooperation with the New Jersey Department of Environmental Protection, conducted a study in the South River area to investigate in detail the flow of ground water and the quality of water in the upper and middle aquifers of the Potomac-Raritan-Magothy aquifer system (Leahy and others, 1987). In order to simulate the flow of ground water from predevelopment times (before 1900) to the present, historical ground-water-withdrawal data by aquifer and time period were required. Information on historical ground-water withdrawals also is needed by regional and State water-resource planners and managers to help anticipate future trends in water withdrawals and design management plans to ensure sufficient water supplies. A water-withdrawal data base was developed for both the modeling effort and analysis of trends in ground-water withdrawals for public supply and self-supplied industrial use. The data base was used to store and analyze the data, prepare estimates where no records of withdrawals are available, and determine reliability of the data on a site-specific basis.

Purpose and Scope

This report describes trends in ground-water withdrawals from Coastal Plain aquifers in Middlesex and Monmouth Counties from 1901 through 1985. The withdrawal data presented here are average rates for each decade, in million gallons per day. Water-withdrawal trends are discussed in terms of category of use, aquifer, and location. The methods used for collecting, evaluating, and storing ground-water-withdrawal data also are described so that future investigators will have a basis for comparison. Withdrawals are summarized by the use categories of public supply and self-supplied industrial use. Public supply refers to water withdrawn by public and private water suppliers and delivered to multiple users for domestic, commercial, and industrial uses. Self-supplied industrial use refers to water withdrawn from a water source by a user for industrial purposes such as fabrication, processing, washing, and cooling (Solley and others, 1988). Self-supplied domestic use (water withdrawn from individual house wells for

household use) was not analyzed because the individual withdrawals were too small and too far apart to have any significant effect on the South River ground-water model. The other uses, commercial and irrigation, have comprised less than 2 percent of total withdrawals over time and are, therefore, not discussed. Withdrawals are also summarized for the five major aquifers in the study area: (1) the middle aquifer of the Potomac-Raritan-Magothy aquifer system (referred to in this report as the middle aquifer), (2) the upper aquifer of the Potomac-Raritan-Magothy aquifer system (referred to in this report as the upper aquifer), (3) the Englishtown aquifer system, (4) the Wenonah-Mount Laurel aquifer, and (5) the Kirkwood-Cohansey aquifer system. In this area, the middle aquifer is also referred to as the Farrington aquifer and the upper aquifer is also referred to as the Old Bridge aquifer (table 1). Together, these five aquifers comprise the Coastal Plain aquifer system.

Description of Study Area

Middlesex and Monmouth Counties cover 850 mi^2 in the east-central part of New Jersey (fig. 1), south and west of New York City. Middlesex County (312 mi^2) is divided into 25 municipal civil divisions (MCD's), and Monmouth County (538 mi^2) is divided into 53 MCD's (fig. 2). The Coastal Plain part of Middlesex and Monmouth Counties is approximately 730 mi^2 in extent. The study area is bounded on the north by the Fall Line through Middlesex County; on the east by the Arthur Kill, Raritan Bay, Sandy Hook Bay, and the Atlantic Ocean; on the south by Ocean and Burlington Counties; and on the west by Mercer and Somerset Counties. In 1980, approximately 810,000 people lived in the Coastal Plain area, and the average population density was 1,110 people per square mile. Density of population is highest along the northeastern border of the study area (fig. 9), which includes the New York City commuter area, established industrial areas, and the New Jersey shore areas.

Communities in the study area consist of four main types. Residential communities that are within commuting distance of New York City are found primarily in eastern and northern Middlesex County. Industrialized communities developed before 1800 are located in Middlesex County along the Raritan and South Rivers and the Arthur Kill. Summer resort communities are located along the Atlantic Coast of Monmouth County. Rural communities are beginning to be developed in the interior of Monmouth County and in western Middlesex County. Development in these four types of communities has occurred at different rates and during different times. The pattern of this development has had a substantial effect on withdrawals from Coastal Plain aquifers.

Ground water in Middlesex and Monmouth Counties is withdrawn from Coastal Plain unconsolidated sediments, Mesozoic sedimentary rocks, and Quaternary glacial deposits. This study concerns only the Coastal Plain part of Middlesex and Monmouth Counties, which is southeast of the Fall Line from Plainsboro to Carteret (fig. 3). The New Jersey Coastal Plain is a seaward-dipping wedge of unconsolidated sediments that range in age from Cretaceous to Holocene. These sediments are composed primarily of clay, silt, sand, and gravel that generally strike northeast-southwest and dip gently to the southeast from 10 to 60 ft/mi. The Coastal Plain deposits

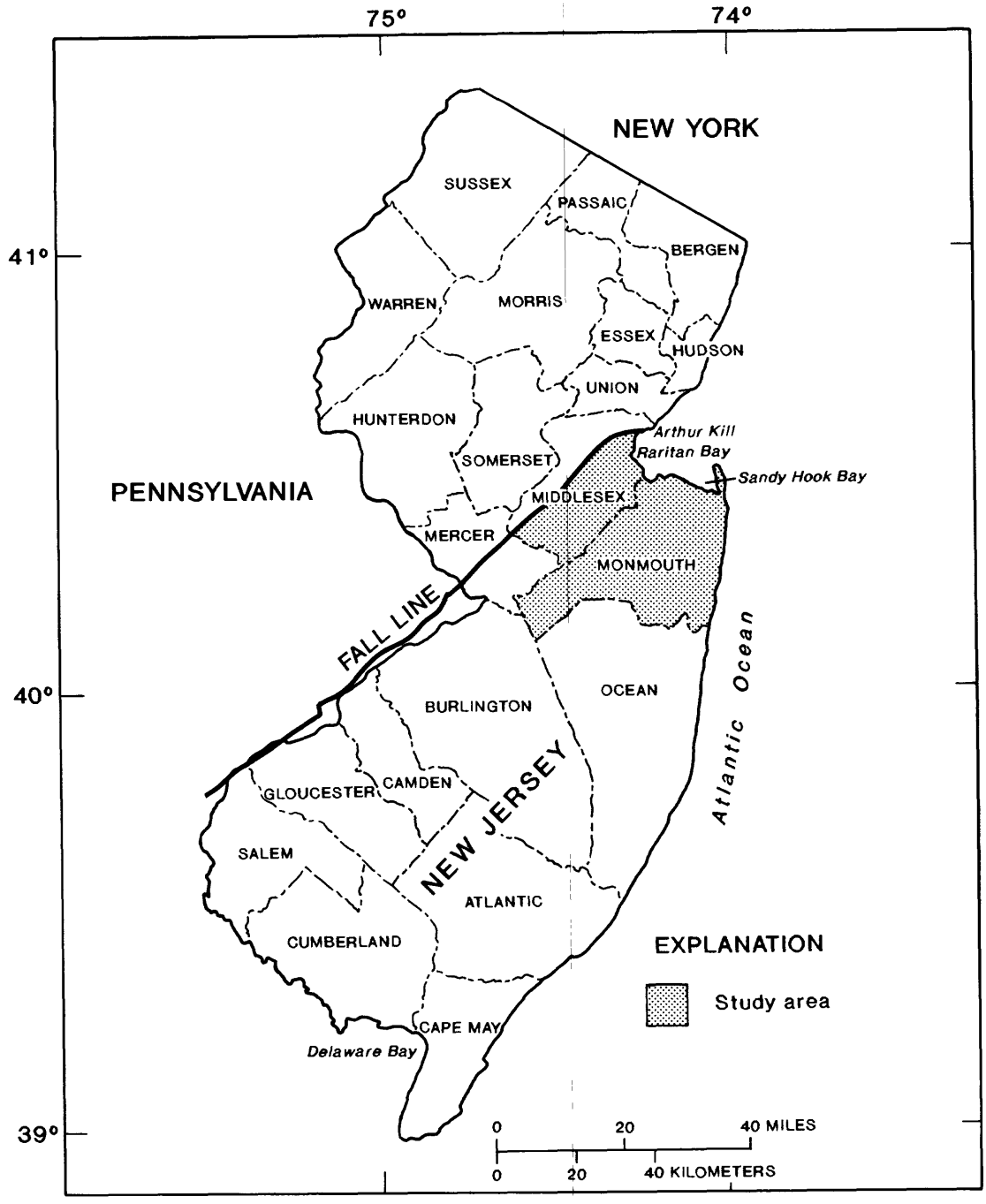
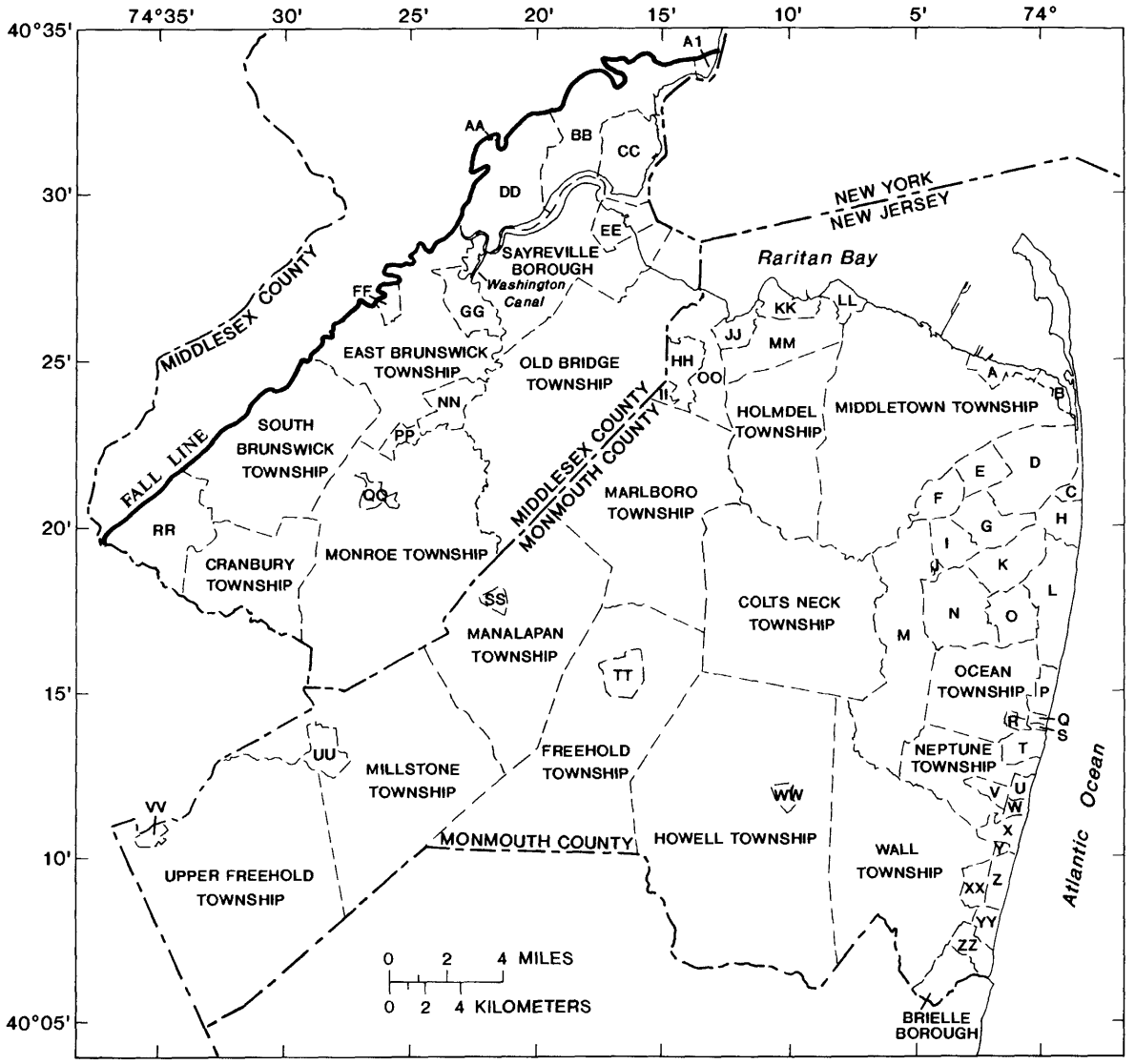


Figure 1.--Location of study area.



EXPLANATION

Municipal Civil Divisions

A Atlantic Highlands Borough
B Highlands Borough
C Sea Bright Borough
D Rumson Borough
E Fair Haven Borough
F Red Bank Borough
G Little Silver Borough
H Monmouth Beach Borough
I Shrewsbury Borough
J Shrewsbury Township
K Oceanport Borough
L Long Branch City
M Tinton Falls Borough
N Eatontown Borough
O West Long Branch Borough
P Deal Borough
Q Allenhurst Borough
R Interlaken Borough
S Loch Arbour Village
T Asbury Park City
U Bradley Beach Borough
V Neptune City Borough
W Avon-by-the-Sea
X Belmar Borough
Y South Belmar Borough
Z Spring Lake Borough
AA Metuchen Borough
BB Woodbridge Township
CC Perth Amboy City
DD Edison Township
EE South Amboy City
FF Milltown Borough
GG South River Borough
HH Matawan Borough
II Matawan Township
JJ Keyport Borough
KK Union Beach Borough
LL Keansburg Borough
MM Hazlet Township
NN Spotswood Borough
OO Aberdeen Township
PP Helmetta Borough
QQ Jamesburg Borough
RR Plainsboro Township
SS Englishtown Borough
TT Freehold Borough
UU Roosevelt Borough
VV Allentown Borough
WW Farmingdale Borough
XX Spring Lake Heights Borough
YY Sea Girt Borough
ZZ Manasquan Borough
A1 Carteret Borough

Figure 2.--Municipal civil divisions in the study area.

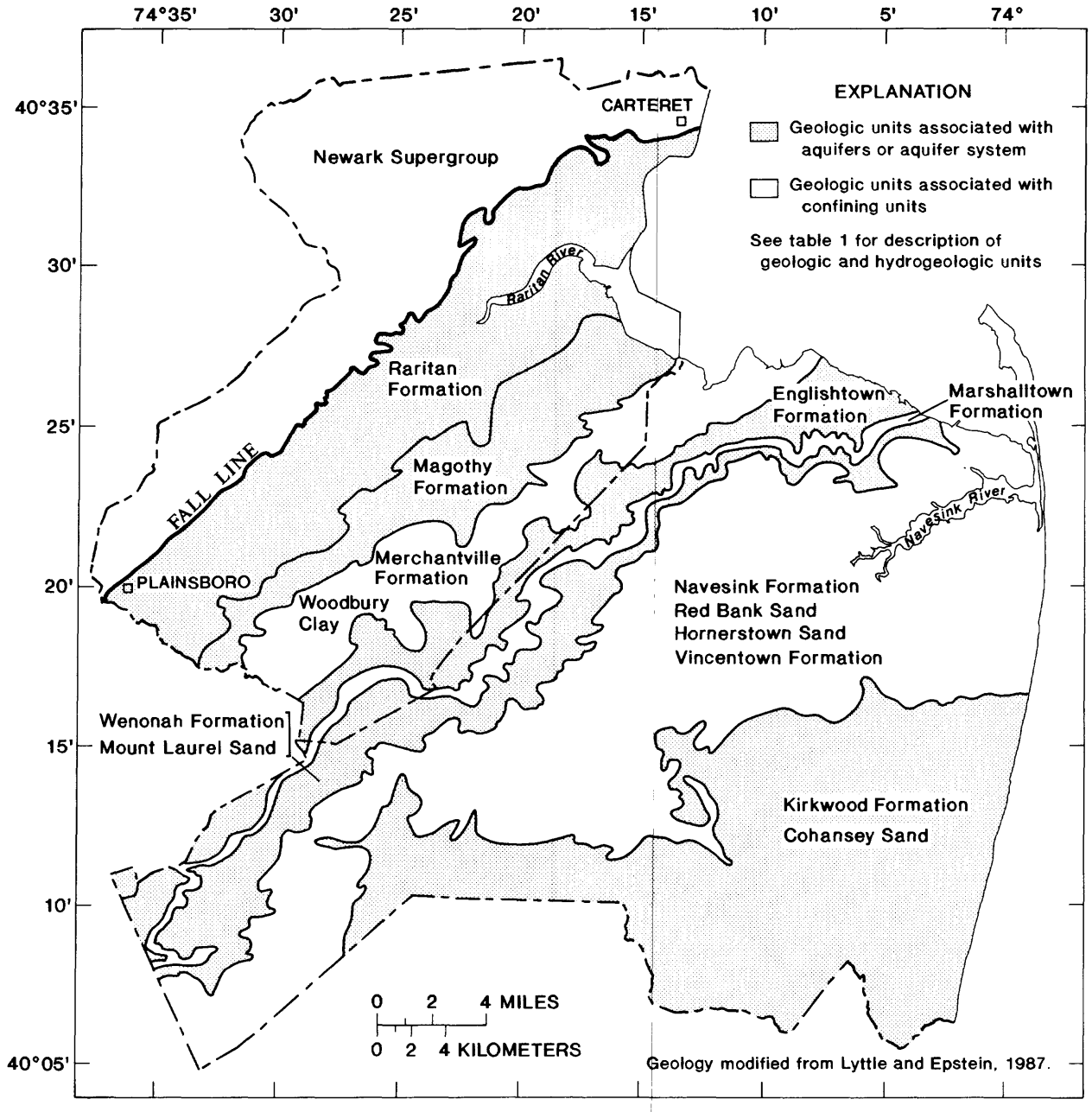


Figure 3.--Hydrogeology of Coastal Plain in Middlesex and Monmouth Counties.

thicken seaward from a featheredge along the Fall Line to more than 1,600 ft at the border between Monmouth and Ocean Counties (Zapecza, 1989). Underlying these sediments are pre-Cretaceous rocks.

The Coastal Plain consists of one interrelated hydrogeologic system that includes several aquifer systems, aquifers, and confining units. Figure 3 shows the geologic formations associated with the hydrogeologic units from which more than 0.01 Mgal/d of water is withdrawn in the Coastal Plain. Four of the five major aquifers and aquifer systems in the Coastal Plain are present in the study area: the Kirkwood-Cohansey aquifer system; the Wenonah-Mount Laurel aquifer; the Englishtown aquifer system; and the Potomac-Raritan-Magothy aquifer system, which includes the upper and middle aquifers. Only the lower part of the Kirkwood-Cohansey aquifer system, the Atlantic City 800-foot sand, is absent in the study area. The aquifers and confining units are described in table 1. The hydrogeologic properties of the Coastal Plain aquifers and confining units are described in detail by Zapecza (1989).

Previous Investigations

The water resources and amounts of water withdrawn in Middlesex and Monmouth Counties have been studied and described in reports for nearly a century. Vermeule (1894) first inventoried and described the resources (primarily surface water) used for water supply in New Jersey. Beginning about 1900, the dependence on ground water for public supply increased and resulted in localized ground-water problems requiring investigation. In Monmouth County, Thompson (1930) investigated the ground-water supplies near Asbury Park by reviewing data on well depths, well diameters, and interconnections between communities. In Middlesex County, water-level declines of as much a 110 ft in some places prompted an investigation by Barksdale (1937), who concluded that this decline was attributable to large withdrawals by the municipalities of Perth Amboy, South Amboy, and South River and by three major industries in the South River area. He also examined the effect of these large withdrawals and dredging of the Washington Canal on saltwater intrusion into the middle aquifer. This report was followed by a report by Barksdale and others (1943) that focused on water withdrawals from the middle and upper aquifers for all of Middlesex County.

Water withdrawals in both counties increased after World War II as population, industrial production, and residential development increased. In 1961, the Monmouth County Planning Board published a report on water withdrawals throughout the County. An inventory in Monmouth County of small-capacity wells by Jablonski (1959) and high-capacity public-supply and selected irrigation wells by Jablonski (1960) provided a source for determining withdrawals. This was followed by an interpretive report (Jablonski, 1968) on the ground-water resources of Monmouth County. Appel (1962) assessed saltwater intrusion into the middle and upper aquifers in the Sayreville area of Middlesex County. Seven years later, Hasan and others (1969) discussed saltwater intrusion in the upper aquifer in the Sayreville area.

Table 1.--Geologic and hydrogeologic units in the Coastal Plain of New Jersey

[Modified from Zapecza, 1989, table 2]

SYSTEM	SERIES	GEOLOGIC UNIT	LITHOLOGY	HYDROGEOLOGIC UNIT	HYDROLOGIC CHARACTERISTICS
Quaternary	Holocene	Alluvial deposits	Sand, silt, and black mud.	Undifferentiated	Surficial material, commonly hydraulically connected to underlying aquifers. Locally some units may act as confining units. 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 unit	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.
				Rio Grande water bearing zone	
				Confining unit	
				Atlantic City 800-foot sand	A major aquifer along the coast.
	Oligocene	Piney Point Formation / Shark River Formation	Sand, quartz and glauconite, fine-to coarse-grained.	Confining unit	Poorly permeable sediments.
	Eocene			Piney Point aquifer	Yields moderate quantities of water.
		Manasquan Formation	Clay, silty and sandy, glauconitic, green, gray and brown, fine-grained quartz sand.	Confining unit	Poorly permeable sediments.
	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.	Confining unit	Poorly permeable sediments.
Cretaceous	Upper Cretaceous	Tinton Sand	Sand, quartz, and glauconite, brown and gray, fine-to coarse-grained, clayey, micaceous.	Composite confining unit	
		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.	Confining unit	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-Wenonah confining unit	A leaky confining unit.
		Marshalltown Formation	Clay, silty, dark greenish gray, glauconitic quartz sand.		
		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 unit	A major confining unit. Locally the Merchantville Formation 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. Includes Old Bridge Sand Member.	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 Delaware 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. Includes Farrington Sand Member.	Confining unit / Middle aquifer / Confining unit	
	Lower Cretaceous	Potomac Group	Alternating clay, silt, sand, and gravel.	Lower aquifer	
Pre-Cretaceous		Bedrock	Precambrian and lower Paleozic crystalline rocks, metamorphic schist and gneiss locally Triassic sandstone, shale and Jurassic diabase.	Bedrock confining unit	No wells obtain water from these consolidated rocks, except along Fall Line.

Detailed studies of the Potomac-Raritan-Magothy aquifer system in the New Jersey Coastal Plain were done by Gill and Farlekas (1976) and of the middle aquifer in Middlesex and Monmouth Counties were done by Farlekas (1979). Vowinkel and Foster (1981) characterized the hydrologic conditions, including withdrawals, in the Coastal Plain of New Jersey. Ground-water-withdrawal data for 1956-80 were compiled by Vowinkel (1984) and for 1918-55 were compiled by Zapecza and others (1987). Both data sets were used in the U.S. Geological Survey's Northern Atlantic Coastal Plain Regional Aquifer-System Analysis (RASA) to simulate ground-water flow and water levels in the major aquifers in the New Jersey Coastal Plain. Zapecza (1989) described the hydrogeologic framework of the New Jersey Coastal Plain as part of the Northern Coastal Plain RASA.

METHODS OF STUDY

Most of the ground-water-withdrawal data used in this report were collected for previous regional studies. The South River ground-water study required highly refined withdrawal data for the model being developed for the study area. Methods were developed to refine the ground-water-withdrawal data already collected for the study area and to update withdrawals through 1985. Once the data requirements were defined, a comprehensive plan was developed to collect, evaluate, store, and retrieve the data. Previously collected data were reviewed to derive a preliminary list of water users and well descriptions. These data were supplemented with more recent data, combined withdrawals were disaggregated, and pumpage was estimated back to the completion of the well. Data were evaluated and coded for reliability, and missing information was estimated. Finally, the data were coded, verified, and entered into a computerized data base. These procedures are discussed in detail in the following sections.

Data Collection

The data used in this report were developed as four separate sets: 1901-17, 1918-55, 1956-80, and 1981-85. The methods used to develop the 1918-55 data set are described in Zapecza and others (1987), and the methods used to develop the 1956-80 data set are described in Vowinkel (1984). A summary of their methods and a brief description of the methods used to develop the 1901-17 and 1981-85 data sets are presented below.

Actual ground-water-withdrawal data were not readily available for the years before 1956. Zapecza and others (1987) compiled a list of wells for each public supplier and self-supplied industry active during 1918-55 and identified their associated physical, hydrologic, and geologic data from computerized and manual records. A compilation of public-supply data from State records provided total yearly pumpage by public supplier from 1918 through 1955. Best estimates for yearly withdrawals from each aquifer were generated on the basis of the total yearly pumpage reported by owners, the number of wells operating each year, and the aquifers in which they were screened. Similarly, industrial-withdrawal data were compiled from early ground-water reports and records. For each major industry, best estimates were made on the basis of the number of wells, the dates that the wells were first used, and the percentage of water withdrawn by the early wells from the overall total withdrawn by the company in 1956. Zapecza and others

(1987) considered irrigation withdrawals before 1956 insignificant for use in the ground-water model. These data are published in Zapecza and others (1987, p. 82-93).

The 1901-17 data set was derived primarily from the 1918-55 data set. The methods and sources used by Zapecza also were used to estimate withdrawals back to the date of construction for each well. No records for pumpage in Middlesex or Monmouth Counties before 1901 were found.

The primary source of the 1956-80 ground-water-withdrawal values is data reported to the New Jersey Division of Environmental Protection, Division of Water Resources (NJDEP-DWR). The data include monthly withdrawal rates for individual wells or well fields in the Coastal Plain with pump capacities of 100,000 gallons per day or greater for the period 1956-80. Vowinkel (1984, p. 5) estimates that about 80 percent of the withdrawal data is based on metered pumpage, which is reported by well owners to the NJDEP-DWR on a quarterly basis. About 10 percent of the data consists of estimates of hours of operation by the owner, and about 10 percent of the data consists of estimates of unreported or missing data. These data are published in Zapecza and others (1987, p. 18-81).

Data for the first 3 years of the fourth data set (1981-85) also were collected from NJDEP-DWR to update the New Jersey part of the RASA model (Battaglin and Hill, 1988). These data were supplemented by a complete inventory of all permitted water users for Middlesex and Monmouth Counties for 1984 and 1985.

Data Evaluation and Estimation

Further analysis was required to refine these data into a more reliable and consistent data set. The 1918-55 data set consisted primarily of single withdrawal values for all wells of a given owner that tapped the same aquifer; values were not available for individual wells. Some data in the 1956-80 and 1981-85 data sets also were aggregated by owner and aquifer. In some cases, a single value was reported for all wells of a given owner regardless of the aquifer used. The grid spacing in the RASA model was large enough that these summaries by aquifer and user were acceptable; however, model requirements for the South River study dictated that the aggregate totals for each user be separated into withdrawal values for individual wells.

In order to generate individual well-withdrawal data from these totals, the historical records were carefully reexamined to determine whether pumpage data were available for individual wells. If data were not available, then the descriptions of the individual wells were examined to determine well depth and diameter, pump size, and dates of operation. These data for each well were compared with data for the other wells and with the pumpage data for the user as a whole. Individual well pumpage was then developed on the basis of the best available information. Pumpage values for all wells were then estimated for the period from date of well construction to abandonment or to the present. Annual pumpage data for each well were assigned a numeric reliability code on the basis of the quality of available information (table 2). These codes helped to target wells for

Table 2.--Reliability codes for pumpage data

[NJDEP, New Jersey Department of Environmental Protection; RASA, Regional Aquifer-System Analysis]

Code	Definition
	DATA FROM NJDEP ALLOCATION FILES
1	Reported as a disaggregated value
2	Disaggregated on the basis of available pumping pattern
3	Disaggregated by dividing by the number of wells
	RASA DATA (PRE-1956)
4	Available as a disaggregated value
5	Disaggregated on the basis of available pumping pattern
6	Disaggregated by dividing by the number of wells
	NEW ESTIMATES BY PROJECT PERSONNEL
7	Based on known pumpage data within 10 years of estimate
8	Based on known pumpage data between 10 and 30 years of estimate
9	No available pumpage data within 30 years of estimate

which more information was needed and to resolve problems in reconciling observed and simulated water levels.

Development of a Water-Withdrawal Data Base

A water-withdrawal data base was developed that would meet the needs of (1) the ground-water model to be used in the South River study and (2) the current analysis of withdrawal trends. Because the time intervals for the ground-water model had not been designated, it was necessary to store withdrawal data for every year. Subsequent programming was used to group years together as required for the model. The general file structure of the data bases is illustrated in figure 4. The file descriptions are listed in appendixes A through D.

A well-description data base contains data on well location, operation dates, identification number(s), aquifer, and reliability of the aquifer designation for all nondomestic wells in Middlesex and Monmouth Counties (app. A). A series of pumpage data bases for each decade contain pumpage and reliability data (app. B). Data computerized in the U.S. Geological Survey's Ground Water Site Inventory were transferred into the well-description data base. Data in the 1918-55, 1956-80, and 1981-83 pumpage files for Middlesex and Monmouth Counties were transferred into the pumpage data bases. The refined annual pumpage data and reliability code also were entered into the pumpage data bases. The entries in the well-description data base were studied, and data for Coastal Plain wells used for public supply or self-supplied industrial withdrawals were transferred into a second well-description data base (app. C). Basic descriptive data from this data base were combined with pumpage data that had been aggregated and averaged over 10-year intervals (app. D) and were used in generating the statistics for this report.

GROUND-WATER WITHDRAWALS BY CATEGORY OF USE, 1901-85

The main categories of ground-water withdrawals in Middlesex and Monmouth Counties are public supply and self-supplied industrial use. Average withdrawals by decade for these two categories are listed in table 3 and shown in figure 5. Early in the twentieth century, withdrawals were primarily for public supply. Withdrawals for self-supplied industry increased until the 1940's, when they surpassed withdrawals for public supply. After the 1940's, withdrawals for public supply increased faster than withdrawals for self-supplied industry, and this trend continued into the early 1980's. Industrial self-supplied withdrawals peaked at 26.4 Mgal/d during the 1960's and then decreased to 19.3 Mgal/d during the early 1980's.

Public Supply

Ground-water withdrawals for public supply have been segregated into four groups that are based primarily on geographic area. Each of these groups is composed of public suppliers that have similar patterns of growth and development. Three of these groups supply ground water solely to (1) Monmouth County shore communities, (2) Monmouth County interior communities,

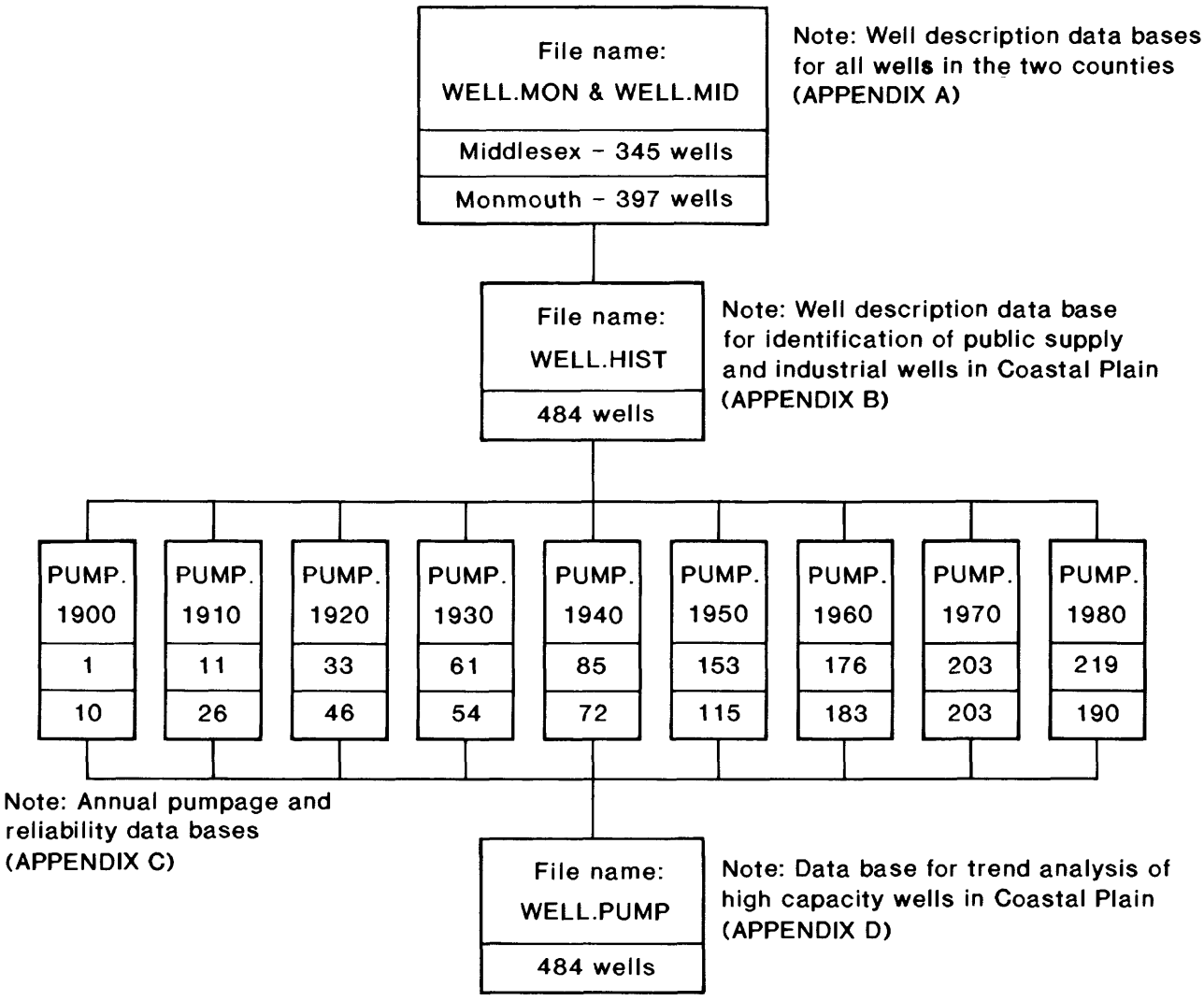


Figure 4.--Structure of water-withdrawal data base.

Table 3.--Ground-water withdrawals from Coastal Plain aquifers in Middlesex and Monmouth Counties, by category of use

[Mgal/d, million gallons per day. The percentages of use in the two categories do not add to 100 percent because there are other categories of use not included in this table. Totals in this table may not agree with totals in other tables because of independent rounding. Data from New Jersey Department of Environmental Protection Bureau of Water Allocation and U.S. Geological Survey files]

Years	Public supply		Self-supplied industrial use		Total withdrawals
	Mgal/d	Percent	Mgal/d	Percent	Mgal/d
1901-10	0.67	100	0	0	0.67
1911-20	5.04	91	.47	8	5.55
1921-30	12.72	79	3.33	20	16.18
1931-40	12.03	56	9.41	43	21.66
1941-50	16.94	46	19.71	53	37.09
1951-60	25.01	51	23.82	48	49.50
1961-70	39.01	59	26.38	40	66.40
1971-80	50.42	66	25.01	33	76.16
1981-85	53.69	73	19.25	26	73.55

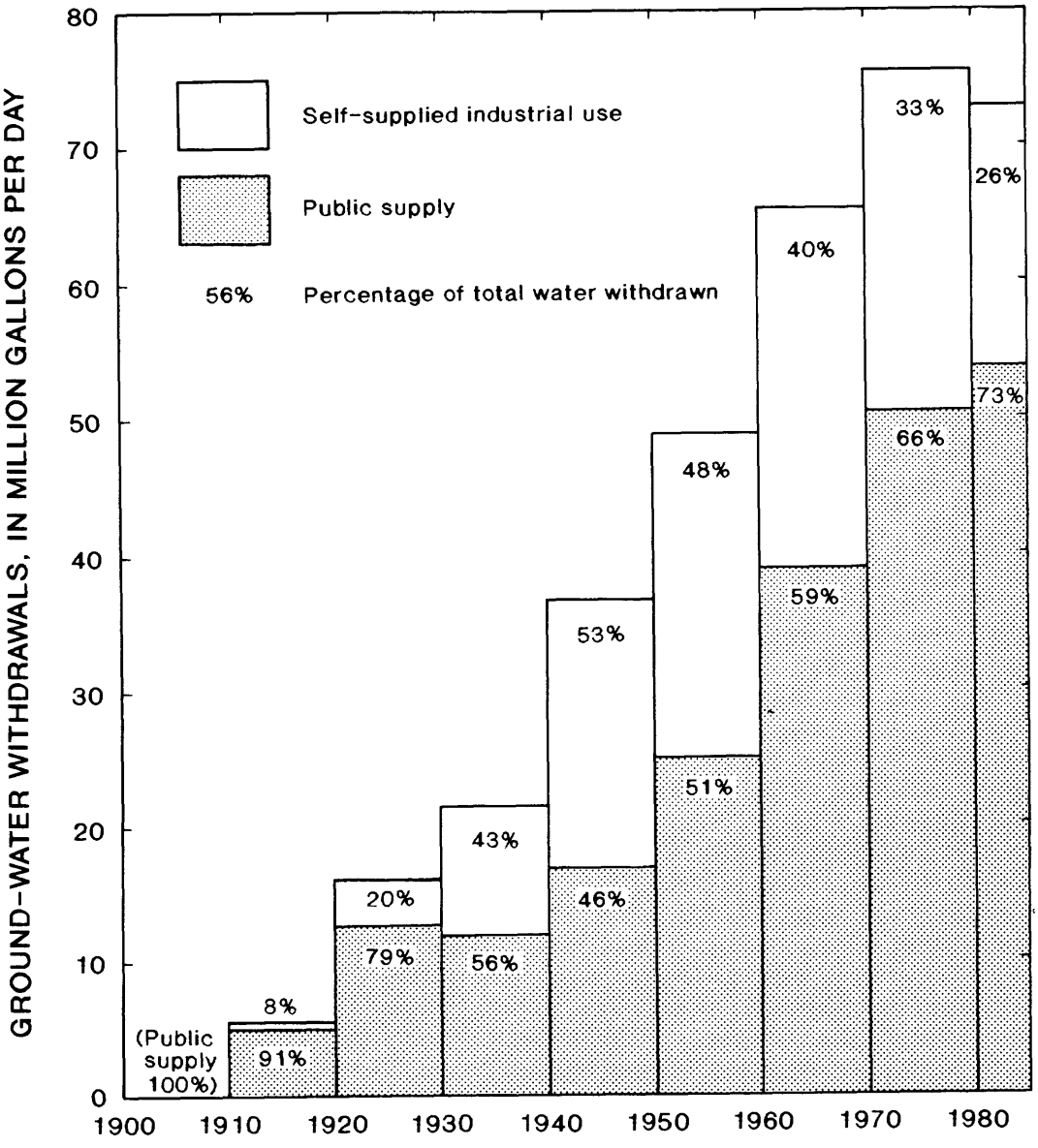


Figure 5.--Ground-water withdrawals from Coastal Plain aquifers in Middlesex and Monmouth Counties, by category of use.

and (3) Middlesex County communities. The fourth group consists of public suppliers in both counties that have "combined sources" of water; these suppliers use surface water, water purchased from other communities, or ground water from non-Coastal Plain aquifers in addition to water from Coastal Plain aquifers. The categorization of public suppliers into these four groups and their withdrawals are presented in table 4. Because many of these public suppliers are municipal water companies, the geographic distribution of these suppliers generally can be determined from the information in table 4 and figure 2. Withdrawals and percentages of total withdrawals by group are shown in figure 6.

During the decade 1901-10, all reported ground-water withdrawals were in the Monmouth County shore communities (about 0.66 Mgal/d), and the largest withdrawal was by the Red Bank Borough Water Department (Red Bank WD) (table 4). Although all four groups withdrew ground water during 1911-20, 60 percent of the total was withdrawn by the two suppliers with combined sources (fig. 5). Perth Amboy City Department of Public Works (Perth Amboy City DPW) withdrew 2.84 Mgal/d (from Old Bridge Township); this was about 56 percent of all public-supply withdrawals (5.05 Mgal/d). The other 14 suppliers were located primarily in the Monmouth County shore communities; of these suppliers, Red Bank WD withdrew the largest volume (0.55 Mgal/d).

By the 1920's, ground-water withdrawals by public suppliers in the study area increased to 12.74 Mgal/d. Perth Amboy City DPW remained the largest withdrawer with 7.36 Mgal/d, or 58 percent of total withdrawals. The three suppliers with combined sources accounted for 68 percent of all public-supply withdrawals. Most of the remaining withdrawals were from 13 Monmouth County shore communities. During the 1930's, withdrawals remained approximately the same. Two of the three suppliers with combined sources significantly decreased ground-water withdrawals; Perth Amboy City DPW decreased ground-water withdrawals by 23 percent to 5.70 Mgal/d and Monmouth Consolidated Water Company (Monmouth Consolidated WC) decreased withdrawals by 80 percent to 0.13 Mgal/d. These decreases may have resulted either from large industrial users shutting down during the depression or from a heavier reliance on other sources. Public-supply withdrawals by the other three groups of suppliers increased by more than 30 percent during this time.

A comparison of population data with ground-water withdrawals in the 1930's provides some insight into how water was withdrawn. Direct comparisons between the two sets of numbers must be made cautiously because the populations reported (New Jersey Department of Labor, 1984) are for single years and are represented as points, whereas the withdrawals reported are averages for entire decades and are represented by bars. Population data for the study area by group and totals are presented in figure 7. A comparison of figures 6 and 7 reveals that, during the 1930's, about 83 percent of withdrawals by communities depending solely on Coastal Plain aquifers were in the shore communities, which had 54 percent of the population. This may be because a larger percentage of people in the shore communities were served by public suppliers than in the other two communities. In addition, publicly supplied industrial and commercial users were more likely to be in the shore communities, as these communities are older than the interior communities and are less likely to be completely residential.

Table 4.--Ground-water withdrawals from Coastal Plain aquifers for public supply in Middlesex and Monmouth Counties

[All values in million gallons per day; --, withdrawal less than 0.005 million gallons per day; Boro, Borough; DPW, Department of Public Works; MUA, Municipal Utilities Authority; TWP, Township; WC, Water Company; WD, Water Department. Totals in this table may not agree with totals in other tables due to independent rounding. Data from New Jersey Department of Environmental Protection Bureau of Water Allocation and U.S. Geological Survey files]

Public supplier	Time period								
	1901-10	1911-20	1921-30	1931-40	1941-50	1951-60	1961-70	1971-80	1981-85
PUBLIC SUPPLIERS FOR COMMUNITIES ALONG THE SHORE IN MONMOUTH COUNTY									
Aberdeen TWP MUA	--	--	--	--	--	--	0.66	1.06	0.89
Aberdeen TWP WD	--	0.06	0.09	0.20	0.07	0.24	.56	.87	.84
Allenhurst Boro WD	--	--	.18	.16	.14	.14	.15	.13	.15
Atlantic Highland WD	--	.08	.21	.18	.35	.61	.62	.61	.61
Avon Borough WD	--	--	.08	.17	.23	.20	.23	.31	.23
Belmar Borough WD	0.16	.27	.48	.57	.83	1.23	.83	.93	.78
Brielle Borough WD	--	--	--	.03	.10	.21	.22	.46	.58
Highlands Borough WD	.03	.25	.18	.30	.40	.33	.42	.58	.61
Keansburg Borough MUA	.02	.15	.27	.65	.88	1.23	1.46	1.45	1.29
Keyport Borough WD	--	.09	.39	.49	.64	.96	1.07	.87	.80
Manasquan Borough WD	.04	.08	.16	.32	.38	.56	.55	.71	.68
Matawan Borough WD	--	--	--	--	.16	.42	.75	1.21	.88
Red Bank Borough WD	.41	.55	.70	.73	1.13	1.34	1.41	1.67	1.69
Sea Girt Borough WD	--	.02	.11	.18	.28	.31	.33	.34	.29
West Keansburg WC	--	--	--	--	--	.13	1.43	3.06	3.35
Spring Lake Boro WD	--	.16	.46	.38	.46	.51	.52	.59	.54
Spring Lake Hghts B WD	--	--	--	--	--	.13	.34	.58	.60
Union Beach Boro WD	--	--	.02	.11	.18	.41	.53	.80	.68
Wall Township WD	--	--	--	--	--	.04	.82	1.47	1.54
Subtotal	0.66	1.71	3.33	4.47	6.23	9.00	12.90	17.70	17.03
PUBLIC SUPPLIERS FOR COMMUNITIES IN THE INTERIOR OF MONMOUTH COUNTY									
Adelphia WC	--	--	--	--	--	--	--	0.09	0.14
Allentown Borough WD	--	--	--	--	--	--	--	.03	.13
Englishtown Boro WD	--	--	--	--	--	--	0.03	.08	.09
Farmingdale Boro WD	--	--	0.01	0.02	0.03	0.04	.09	.21	.20
Freehold Borough WD	--	0.11	.37	.47	.66	.67	.95	1.54	1.45
Freehold Township WD	--	--	--	--	--	--	.32	1.47	1.96
Gordon's Corner WC	--	--	--	--	--	--	.56	2.39	3.35
Howell TWP WD(Aldrich)	--	--	--	--	--	.02	.34	.47	.72
Manalapan Township WD	--	--	--	--	--	--	--	.04	.06
Marlboro Township MUA	--	--	--	--	--	--	--	.28	1.36
NAD-Earle WD	--	--	--	--	.06	.13	.14	.12	.10
Parkway WC	--	--	--	--	--	--	.08	.14	.20
Roosevelt Borough WD	--	--	--	--	--	.05	.09	.13	.10
Subtotal	--	0.11	0.38	0.49	0.75	0.91	2.60	6.99	9.86
PUBLIC SUPPLIERS FOR COMMUNITIES IN MIDDLESEX COUNTY									
Cranbury TWP WD	--	0.01	0.02	0.04	0.06	0.07	0.12	0.13	0.14
Helmetta Borough	--	--	--	--	--	--	.01	.03	.04
Monroe TWP MUA	--	--	--	--	--	--	.21	.86	1.47
New Jersey WC	--	.03	.06	.05	.09	.17	.33	.41	.43
South River Boro WD	--	.17	.29	.31	.41	.69	1.09	1.43	1.26
Spotswood Boro WD	--	--	--	--	--	.11	.40	.64	.67
Subtotal	--	0.21	0.37	0.40	0.56	1.04	2.16	3.50	4.01
PUBLIC SUPPLIERS WITH COMBINED WATER SOURCES IN MIDDLESEX AND MONMOUTH COUNTIES[1]									
East Brunswick TWP WD	--	--	--	--	--	0.66	1.60	2.27	1.82
Elizabethtown WC	--	--	--	--	--	--	--	--	.29
Monmouth Consolidated WC		0.18	0.62	0.13	0.17	2.04	3.55	1.36	2.07
Old Bridge TWP MUA	--	--	--	--	.03	.24	1.79	4.34	5.13
Perth Amboy City DPW	--	2.84	7.36	5.70	8.12	9.58	10.35	7.29	5.36
Sayreville Boro WD	--	--	--	--	--	.22	2.38	3.95	4.34
South Amboy City WD	--	--	.68	.85	1.06	1.11	.88	.71	.41
South Brunswick TWP WD	--	--	--	--	--	--	.44	1.83	3.08
Subtotal	--	3.02	8.66	6.68	9.38	13.85	20.99	21.75	22.50
TOTAL	0.66	5.05	12.74	12.04	16.92	24.80	38.65	49.94	53.40

[1] All of these public suppliers except Monmouth Consolidated WC are in Middlesex County.

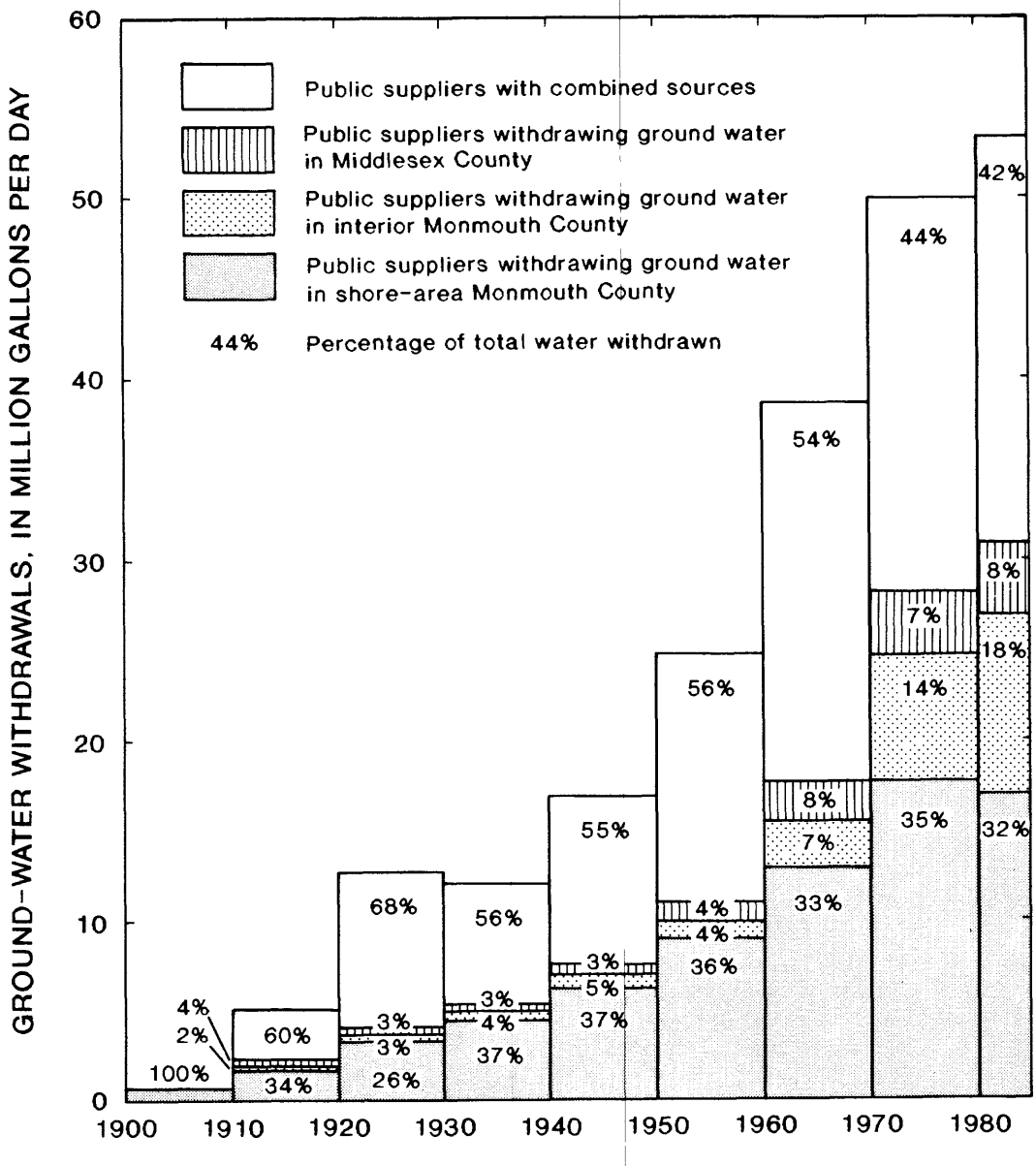


Figure 6.--Ground-water withdrawals from Coastal Plain aquifers in Middlesex and Monmouth Counties, by public suppliers.

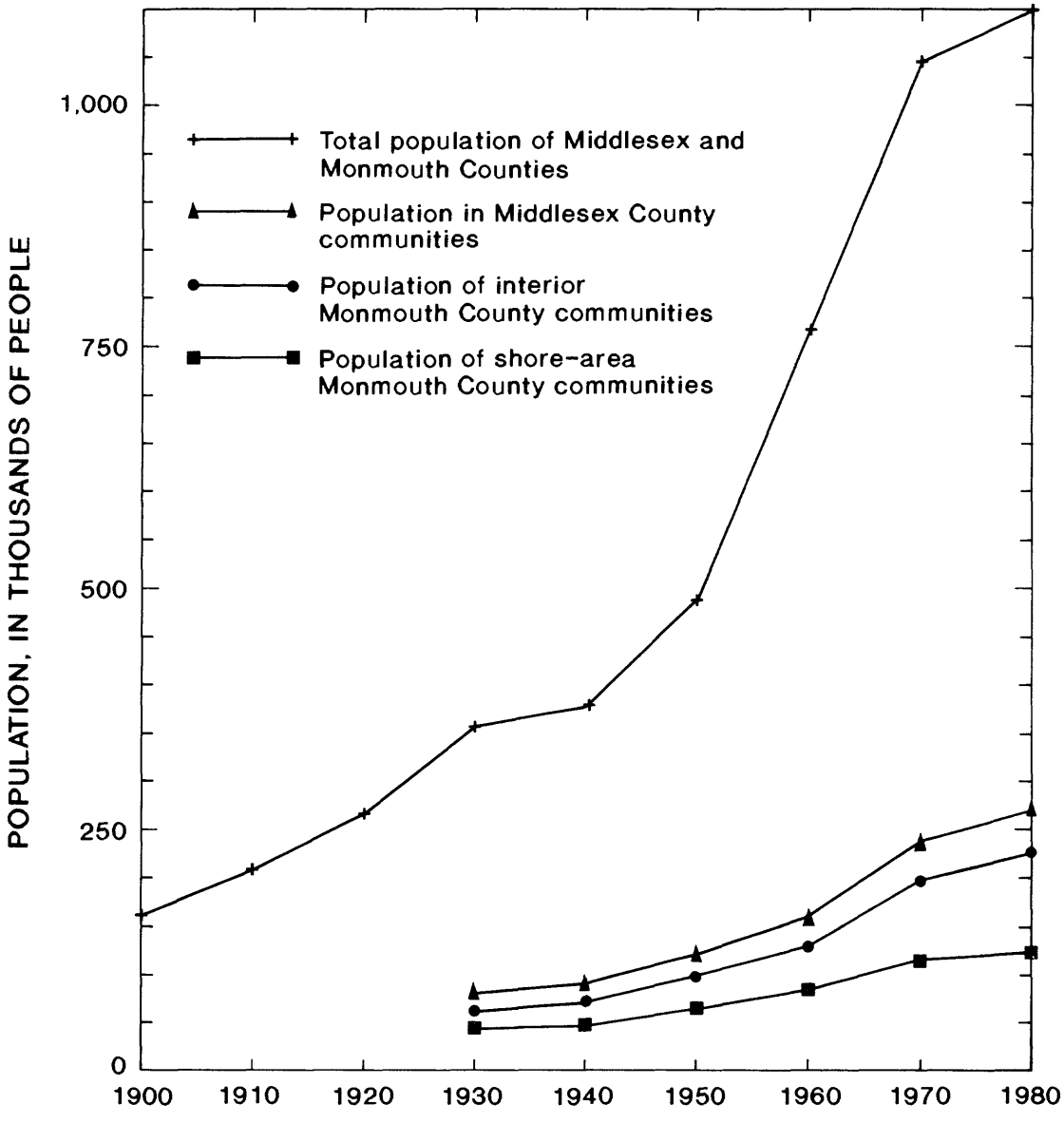


Figure 7.--Population in Middlesex and Monmouth Counties from 1901 through 1980, by communities.

The areal distribution of ground-water withdrawals for public supply and the population of the study area for every other decade from 1941 through 1985 are shown in figures 8 and 9, respectively. During the 1940's, water demands associated with World War II resulted in a 41-percent increase in public-supply withdrawals, from 12.04 to 16.92 Mgal/d; one-half of this increase was attributable to the Perth Amboy City DPW (8.12 Mgal/d total). Figure 8A illustrates the geographic distribution of withdrawals by MCD. The Perth Amboy City DPW withdrew the most water (greater than 8 Mgal/d, from Old Bridge Township), followed by Red Bank WD (1.13 Mgal/d) and South Amboy WD (1.06 Mgal/d, from Sayreville Township). (See fig. 2 for location of MCD's.) Freehold Borough Water Department withdrew nearly 0.7 Mgal/d from Freehold Township. Figure 9A illustrates the geographic distribution of population in 1940. Population centers without correspondingly large ground-water withdrawals indicate areas where an alternate source of supply is used. For example, Neptune Township, Asbury Park City, and Long Branch City obtained water from Monmouth Consolidated WC (primarily surface water). The rate of population growth in the study area through the 1940's and 1950's was about 32 percent for each decade. In the 1950's, ground-water withdrawals increased by 47 percent; most of this increase was in the Middlesex County communities that had a corresponding rate of population growth, primarily Spotswood Township and South River Borough.

During the 1960's, withdrawals increased by 56 percent (from 24.80 to 38.65 Mgal/d), the largest rate of increase since 1920. In terms of groups, the largest increase was for the suppliers with combined sources; in that group, Perth Amboy City DPW, with 10.35 Mgal/d in withdrawals, continued to withdraw the most ground water. Withdrawals by Perth Amboy City DPW combined with those of Old Bridge Township Municipal Utilities Authority (Old Bridge MUA) totaled 12.14 Mgal/d and made Old Bridge Township the MCD with the largest withdrawals. In the same general area, withdrawals in Sayreville Borough totaled 3.26 Mgal/d because of the combined withdrawals of Sayreville Borough Water Department (Sayreville WD) and South Amboy City Water Department. Figure 9B shows that population also was concentrated in that general area.

A second population center is in northeastern Monmouth County. Water demands in this area in the 1960's were met primarily by Monmouth Consolidated WC, whose primary source of ground-water supply is in Neptune Township. Monmouth Consolidated WC had the second largest withdrawals of the public suppliers with combined sources at that time (3.55 Mgal/d).

The greatest percentage of increase in ground-water withdrawals from the 1950's to the 1960's was in the Monmouth County interior communities (186 percent). The fact that this rate of growth exceeded the rate of population growth (88 percent) may indicate a considerable change from self-supplied domestic withdrawals to public supply. For example, the development of four new public suppliers during this decade accounted for 1.0 Mgal/d of the 1.7-Mgal/d increase. The second greatest percentage increase (108 percent) was in the Middlesex County communities (fig. 8A and 8B). This increase was attributable more to an increase in the distribution area of established public suppliers (South River Water Department and Spotswood Borough Water Department increased withdrawals by 0.7 Mgal/d) than to development of new public suppliers (0.2 Mgal/d).

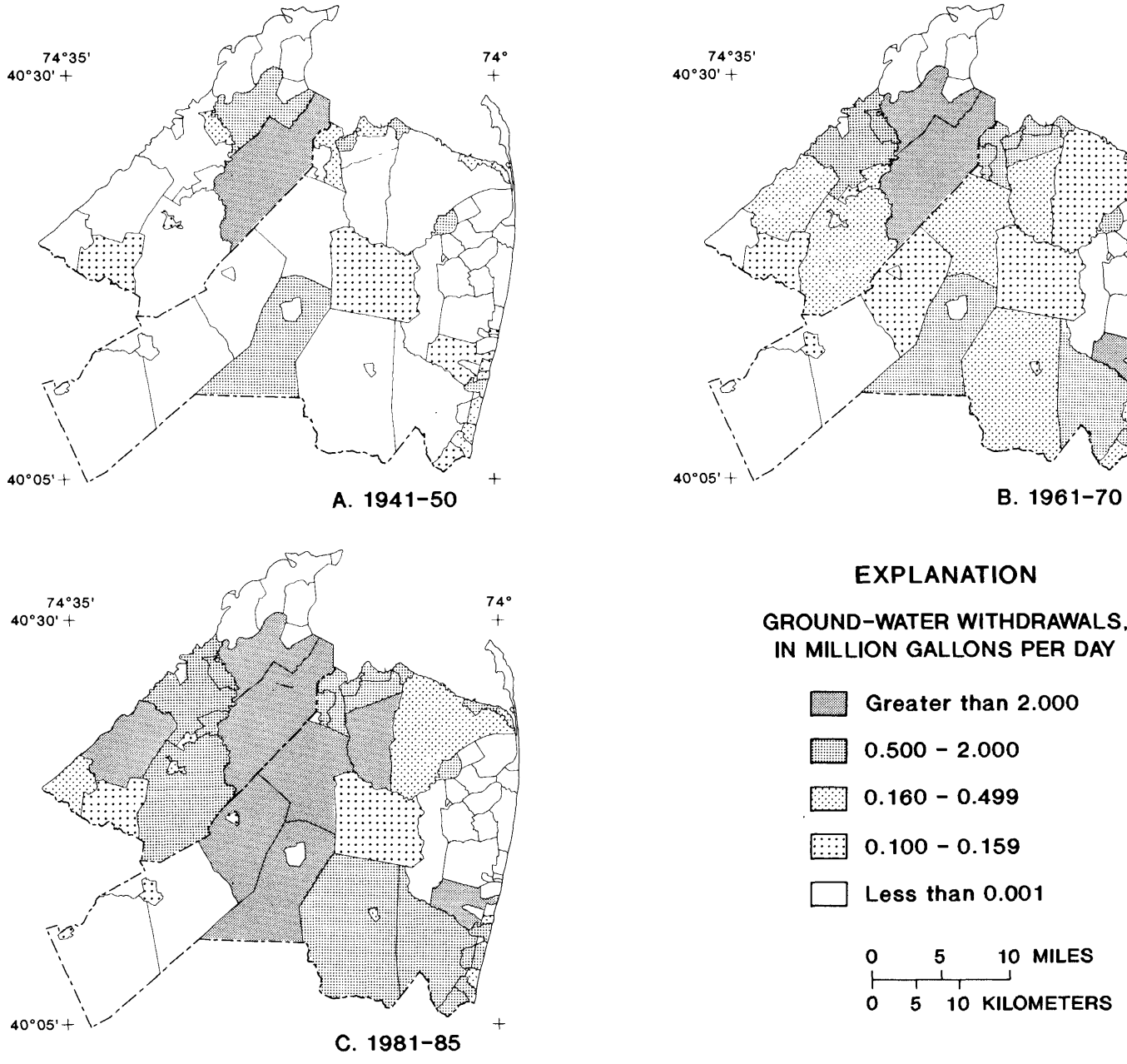


Figure 8.--Withdrawals from Coastasl Plain aquifers for public supply in Middlesex and Monmouth Counties, by municipal civil division, (A.) 1941-50, (B.) 1961-70, and (C.) 1981-85 (locations of municipal civil divisions shown in fig. 2).

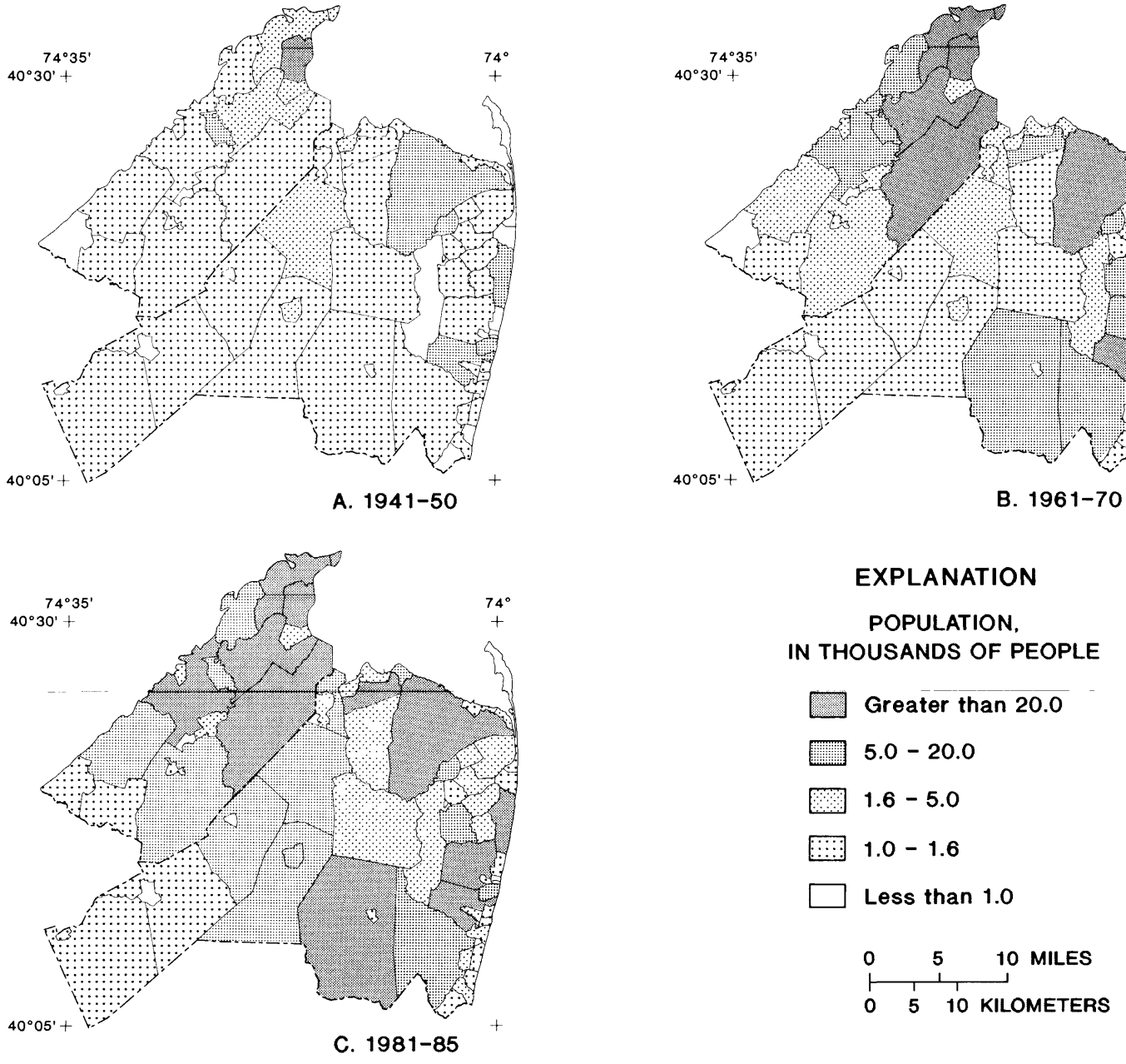


Figure 9.--Population, by municipal civil division, (A.) 1941-50, (B.) 1961-70, and (C.) 1981-85 (locations of municipal civil divisions are shown in fig. 2).

During the 1970's, ground-water withdrawals increased 29-percent overall, from 38.65 to 49.94 Mgal/d. This was followed by a 7-percent increase in the first half of the 1980's, to 53.4 Mgal/d.

The largest increase by both withdrawal rate and percentage was in the Monmouth County interior communities. Expanding water companies accounted for an increase of 5.57 Mgal/d from the 1960's through the early 1980's, whereas new water companies accounted for an increase of 1.69 Mgal/d. Figure 8C shows withdrawal rates by MCD for 1981-85. More than 2.0 Mgal/d was withdrawn from three MCD's as a result of withdrawals by Gordon's Corner Water Company (from Manalapan and Marlboro Townships), and the municipal water departments of Freehold Borough and Township (from Freehold Township) and Marlboro Township (from Marlboro Township).

Ground-water withdrawals in the shore communities also increased substantially from the 1960's through the early 1980's. This was primarily a result of the increase in withdrawals by West Keansburg Water Company (now called Shorelands Water Company) from 0.13 Mgal/d in the 1960's to 3.35 Mgal/d in the 1980's; this water was withdrawn primarily from Holmdel Township. From 1981-85, ground-water withdrawals in the shore communities decreased by 10 percent despite continued population growth; public suppliers may have used water from Monmouth Consolidated WC, which relies heavily on surface supply in addition to the ground-water withdrawals in Neptune Township.

All of the Middlesex County communities that relied solely on ground water from Coastal Plain aquifers increased their ground-water withdrawals from the 1960's through the early 1980's. The largest was in Monroe Township as a result of withdrawals by the Monroe Township Municipal Utilities Authority.

As a group, the public suppliers with combined sources increased withdrawals only a small amount from the 1960's through the early 1980's. Perth Amboy City DPW, although still withdrawing the largest amount, decreased pumpage by 48 percent (about 5.0 Mgal/d) from the amount withdrawn in the 1960's. In contrast, Old Bridge MUA increased withdrawals by 3.3 Mgal/d to a total of 5.13 Mgal/d. Sayreville WD increased withdrawals from 2.38 to 4.34 Mgal/d (in Sayreville Borough), and South Brunswick Municipal Utilities Authority increased withdrawals from 0.44 to 3.08 Mgal/d from sources in South Brunswick Township.

The general pattern of ground-water withdrawals from Coastal Plain aquifers was affected differently by the public suppliers with combined sources than by the public suppliers that served only their immediate areas. The public suppliers with combined sources of water influenced total withdrawals because of the relative ease with which they could substantially increase or decrease withdrawals over a short period of time. This effect was particularly noticeable during the early part of the century, when ground-water withdrawals began. These suppliers initially constructed distribution systems while using other sources of water. When ground water from Coastal Plain aquifers was later developed as an additional source, it could be delivered immediately at a high rate to users by means of the existing distribution systems. For example, Perth Amboy City DPW, which originally withdrew surface water in 1894 (Vermeule, 1894), began

supplementing the surface-water supply in 1918 with 10 Mgal/d of ground water. New public suppliers generally withdrew less than 0.2 Mgal/d during the first years of operation. Public suppliers with combined sources of water continued to affect total ground-water withdrawals, as the amount withdrawn could fluctuate significantly (by 80 percent or more) over a short period of time because it supplemented other sources of water.

Withdrawals by suppliers with combined sources accounted for greater than 50 percent of all ground-water withdrawals from 1911 through 1930, and 25 to 32 percent from 1931 through 1985. These suppliers were responsible for the rapid increase in total withdrawals from 1911 through 1930, and for the smaller increase during the 1930's. From the 1940's through the 1960's, this group increased their withdrawals by about 50 percent per decade. During the 1970's and early 1980's, however, withdrawals increased on the average only 3 to 4 percent per decade.

The smaller public-supply systems tended to serve their immediate areas and have steadily increased withdrawals over time. Most of the early development of public-supply systems occurred in the Monmouth County shore communities. Water withdrawals by this group tended to increase at a steady rate from the early 1900's through the 1960's, but remained constant from the 1970's through the early 1980's. The Monmouth County interior communities were primarily rural, and withdrawals for public supply were minimal until the 1960's. During the 1960's, the number of new public suppliers nearly doubled as a result of residential, commercial, and light-industrial development. This rapid growth continued through the early 1980's. The Middlesex County communities are located primarily in the southwestern part of the County. Although half of the public suppliers in this group began withdrawing water in the 1910's, withdrawals increased very little from that time until the 1950's. The increase in withdrawals from the 1950's on corresponded with population increases, which occurred first in the middle of Middlesex County and then expanded outward.

Self-Supplied Industrial Use

Trends in ground-water withdrawals for self-supplied industrial use have been influenced primarily by (1) the Duhernal companies of E.I. duPont de Nemours & Company (duPont)[1], Hercules Powder Company (Hercules), and National Lead Company (National Lead); (2) the Anheuser-Busch Company (Anheuser-Busch); and (3) the Peter J. Schweitzer Company (Schweitzer), which is now Kimberly-Clark Corporation. All of these industries are in Middlesex County. The Duhernal companies--although independent and competitive companies--are considered as one industry in this report because their withdrawals became interdependent after they formed the Duhernal Water Company in 1938. Withdrawals for self-supplied industrial use began early in the twentieth century (table 5). During the 1920's, the Duhernal companies accounted for 64 percent of all withdrawals for self-supplied industrial use. They continued to be the largest industrial users of self-supplied ground water over the next 60 years, through the first half of the

[1] The use of industry or 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.

1980's. Figure 10 indicates both the trend for self-supplied industrial withdrawals and the relative importance of these three industries. The ground-water withdrawals, in million gallons per day and as percentages, are presented in table 5.

Before the beginning of World War I, in 1914, only a few industrial plants in the study area were using ground water. The favorable location of the region for export trade resulted in a sudden increase in industrial activity during the war and a corresponding increase in self-supplied withdrawals for industry (Barksdale, 1937). Unfortunately, records for industrial withdrawals are sketchy; for 1911-20, the only recorded withdrawals for self-supplied industrial use were 0.42 Mgal/d by Nixon Nitration Works (Nuodex) and 0.05 Mgal/d by American Cyanamid.

Once the industries were established in the area, the development of new and improved manufacturing processes and products continued to increase the demand for ground water (Barksdale and others, 1943). In the 1920's ground-water withdrawals for self-supplied industrial use were estimated at 3.33 Mgal/d; principal users were duPont (1.21 Mgal/d), Hercules (0.93 Mgal/d), and Nuodex (0.9 Mgal/d).

During the 1930's, withdrawals by duPont, Hercules, and National Lead from the middle aquifer in the Sayreville area had increased significantly (to 7.76 Mgal/d). By 1935, a decrease in water levels prompted an intensive study (Barksdale, 1937), the result of which indicated danger of saltwater intrusion. Subsequent investigations showed that saltwater intrusion was well advanced and that a decrease in water supply from the middle aquifer was imminent unless the rate of pumping could be reduced substantially.

In 1938, the three companies formed the Duhernal Water Company to share the cost of developing the new water supply. New wells were installed in the upper aquifer in Old Bridge Township near Spotswood Borough, and Duhernal Lake was developed as a recharge lake for this aquifer. The Duhernal Water Company currently (1990) manages both the newer wells in Old Bridge Township and the old wells at the three plants. The well field is managed so that withdrawals from the middle aquifer do not cause water levels to fall below a specified critical level. The demands of the three companies are met by supplementing the middle aquifer supply as needed with water from the upper aquifer and with water that has been recycled within the plants. If a plant cannot use its own recycled water, then the recycled water is sent through the interconnected plant buildings to a plant with less stringent water-quality requirements. The system went online in 1938. During the 1930's, withdrawals by the three Duhernal companies accounted for 82 percent (7.76 Mgal/d) of total self-supplied industrial withdrawals (9.41 Mgal/d).

During the 1940's, withdrawals for self-supplied industrial use approximately doubled to 19.71 Mgal/d. Increased demand brought on by World War II led to a 14.38-Mgal/d rate of withdrawal by the Duhernal companies. These withdrawals were primarily from Old Bridge Township (fig. 11A); the rest were from Sayreville Borough. The two other major pumping centers were South Brunswick Township (Anheuser-Busch, 0.73 Mgal/d) and Edison Township (Nuodex, 0.57 Mgal/d). During the 1950's, total withdrawals for self-supplied industrial use increased by 21 percent to 23.82 Mgal/d.

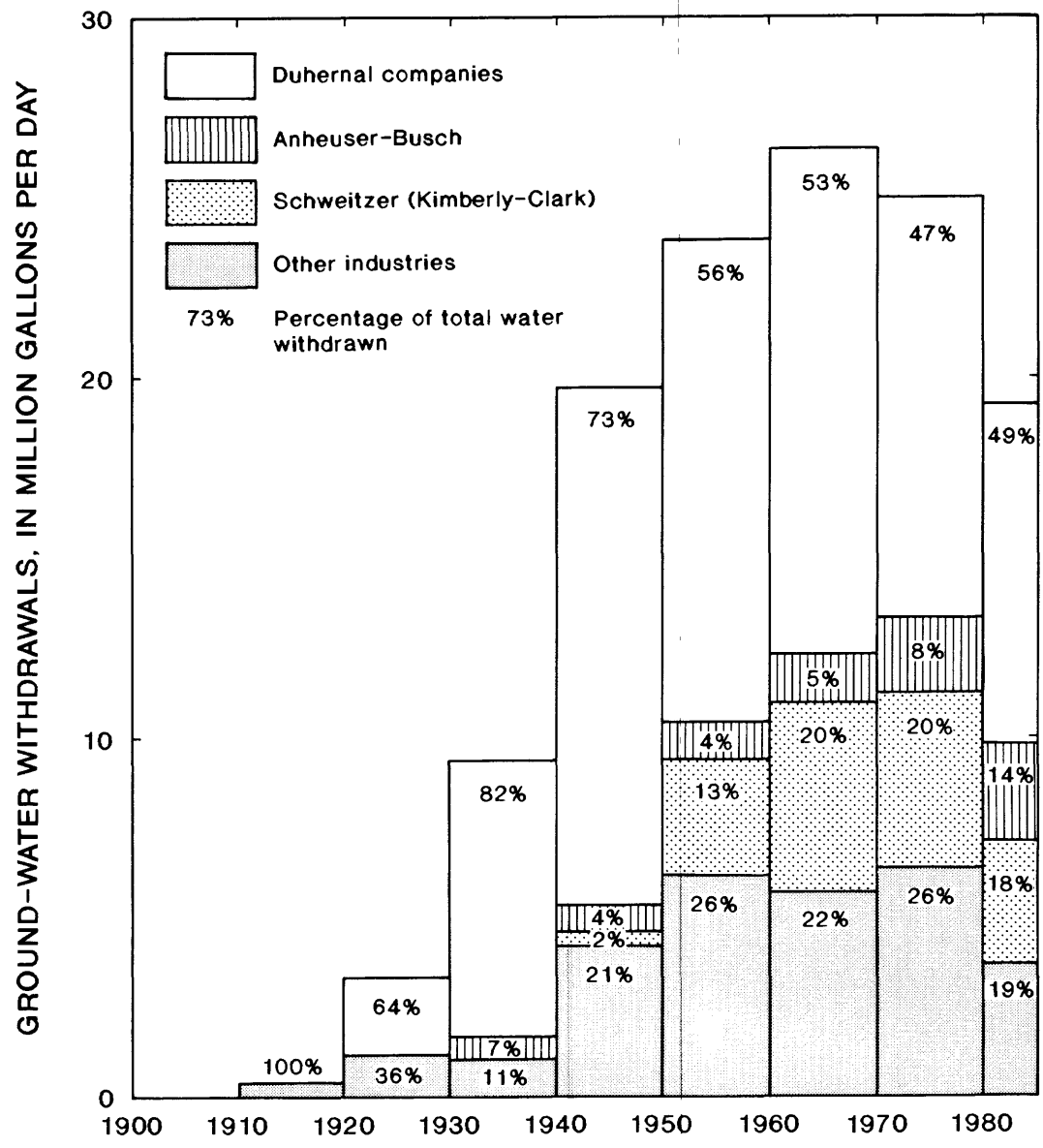


Figure 10.--Ground-water withdrawals from Coastal Plain aquifers for self-supplied industrial use in Middlesex and Monmouth Counties.

Table 5.--Ground-water withdrawals from Coastal Plain aquifers for self-supplied industrial use in Middlesex and Monmouth Counties

[Mgal/d, million gallons per day; --, withdrawal less than 0.005 Mgal/d. Totals in this table may not agree with totals in other tables due to independent rounding. Data from New Jersey Department of Environmental Protection Bureau of Water Allocation, and U.S. Geological Survey files]

Years	Duhernal[1] companies		Anheuser-Busch		Schweitzer (Kimberly-Clark)		Other industries		Total
	Mgal/d	Percent	Mgal/d	Percent	Mgal/d	Percent	Mgal/d	Percent	Mgal/d
1901-10	--	0	--	0	--	0	--	0	--
1911-20	--	0	--	0	--	0	0.47	100	0.47
1921-30	2.14	64	--	0	--	0	1.19	36	3.33
1931-40	7.76	82	0.62	7	--	0	1.03	11	9.41
1941-50	14.38	73	.73	4	0.39	2	4.21	21	19.71
1951-60	13.41	56	1.01	4	3.18	13	6.22	26	23.82
1961-70	14.07	53	1.32	5	5.29	20	5.70	22	26.38
1971-80	11.66	47	2.09	8	4.88	20	6.38	26	25.01
1981-85	9.40	49	2.67	14	3.47	18	3.70	19	19.25

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

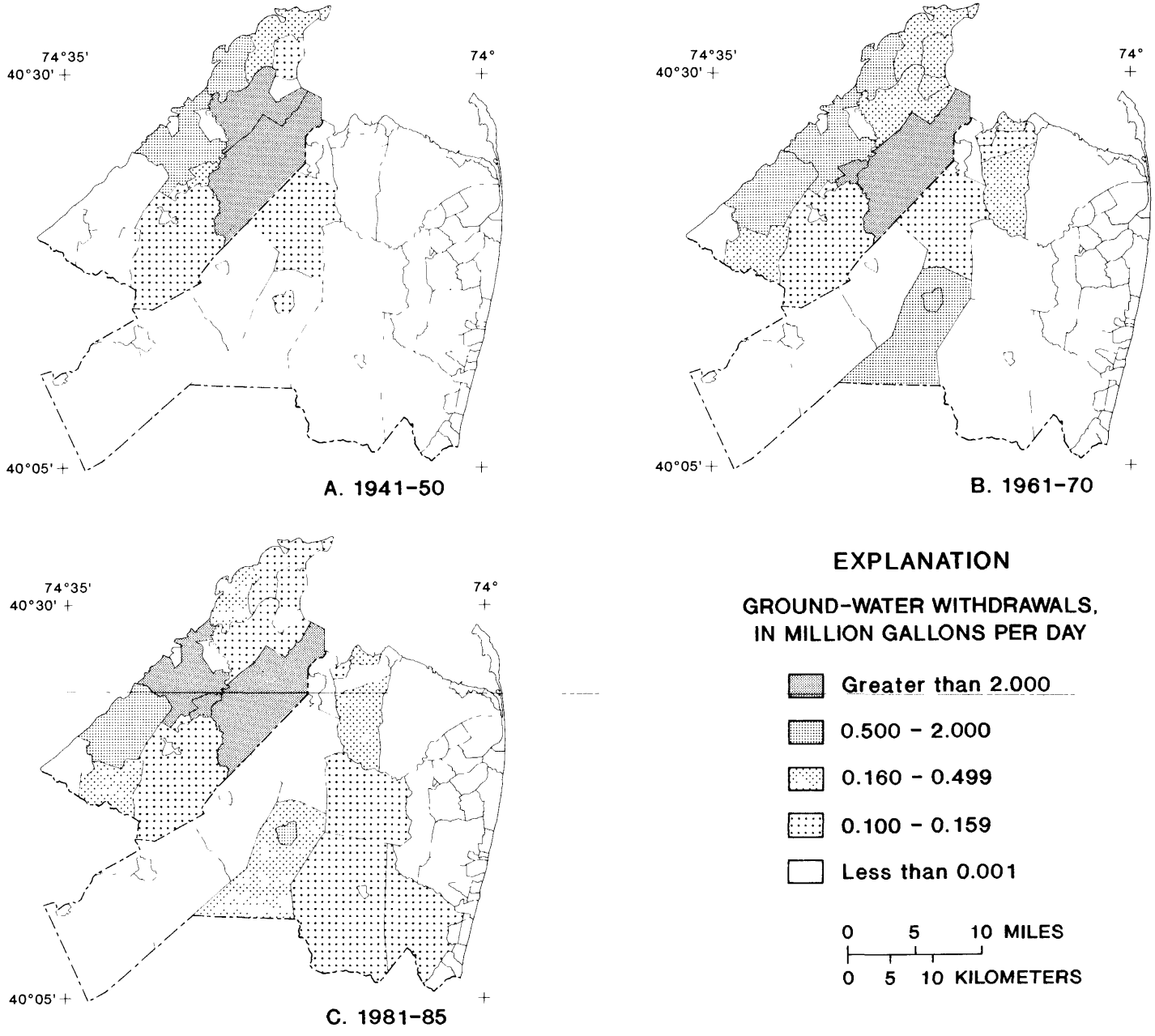


Figure 11.--Withdrawals from Coastal Plain aquifers for self-supplied industrial use in Middlesex and Monmouth Counties, by municipal civil division, (A.) 1941-50, (B.) 1961-70, and (C.) 1981-85 (locations of municipal civil divisions are shown in fig. 2).

During the 1960's, withdrawals for self-supplied industrial use increased by only 11 percent over withdrawals during the 1950's, but they were distributed over more of the study area (fig. 11B). The Duhernal companies' withdrawals from Old Bridge Township (13.41 Mgal/d) continued to predominate, followed by withdrawals by Schweitzer from Spotswood Borough (5.29 Mgal/d). North of these areas, in a band across Middlesex County, water was withdrawn from East Brunswick Township (1.32 Mgal/d by Anheuser-Busch), South Brunswick Township (1.05 Mgal/d by seven industries), Edison Township (0.62 Mgal/d, primarily by Nuodex), and Perth Amboy City (0.35 Mgal/d by Chevron Oil). Substantial withdrawals for self-supplied industrial use began in Monmouth County in Freehold Borough (0.66 Mgal by Nestle Company) and Freehold Township (0.61 Mgal/d by 3M and Brockway Glass). During the 1970's, withdrawals for self-supplied industrial use decreased by about 5 percent to 25.01 Mgal/d. Declines in withdrawals were greatest for the Duhernal companies and Schweitzer.

Withdrawals for self-supplied industrial use decreased by 30 percent to 19.25 Mgal/d during the first half of the 1980's. The three major industries (the Duhernal companies, Anheuser-Busch, and Schweitzer) continued to dominate and accounted for 81 percent of all withdrawals for self-supplied industrial ground water. Withdrawals in Old Bridge Township (fig. 11C) decreased by 24 percent (to 9.4 Mgal/d, all by the Duhernal companies) and in Spotswood Borough decreased by 40 percent (to 3.47 Mgal/d, all by Schweitzer). Smaller decreases occurred in South Brunswick Township (to 0.52 Mgal/d), Freehold Township (to 0.28 Mgal/d), Edison Township (to 0.19 Mgal/d), and Perth Amboy City (to 0.15 Mgal/d). Small increases in withdrawals occurred primarily in East Brunswick Township (to 2.67 Mgal/d, all by Anheuser-Busch) and Freehold Borough (to 1.01 Mgal/d, all by Nestle Company). Although withdrawals by self-supplied industries were less during 1981-85 than during the 1970's, the withdrawals were distributed over a larger part of the study area, particularly in the southeastern part of Monmouth County.

The decreases in self-supplied industrial withdrawals beginning in the 1970's were caused by a number of factors. Some of the older industries either closed or moved to new locations outside the study area as wells drilled in the early 1900's were shut down because of age or contamination. Other industries decreased production as demand decreased and operating costs increased. The development of water-conserving manufacturing processes also contributed to the decline in withdrawals. New and improved processes early in the century increased productivity and the size and number of plants in the study area. Improvements later in the century were aimed at reducing the volume of water needed as the costs for withdrawing, treating, and discharging wastewater soared.

The general pattern of ground-water withdrawals from Coastal Plain aquifers was affected substantially by the Duhernal companies, Anheuser-Busch, and Schweitzer. From the 1930's through the 1950's, these companies withdrew about 80 percent of the self-supplied ground water for industrial use, and about 40 percent of total ground water withdrawn in the study area. From the 1960's to the first half of the 1980's, withdrawals by these industries continued to comprise about 80 percent of the self-supplied ground-water withdrawals for industrial use, but declined to about 25 percent of total ground-water withdrawals.

GROUND-WATER WITHDRAWALS BY AQUIFER, 1901-85

The three groups that directed the major trends in the ground-water withdrawals from Coastal Plain aquifers (public suppliers with combined sources, public suppliers dependent solely on Coastal Plain aquifers, and major self-supplied industries) had an even more pronounced effect on the pattern of withdrawals for individual aquifers. Ground-water withdrawals by the public suppliers with combined sources are solely from the upper and middle aquifers, primarily in the northeastern Coastal Plain area of Middlesex County. This group accounts for about half of the increase in withdrawals from the middle aquifer from the 1960's to the first half of the 1980's. Ground-water withdrawals for self-supplied industrial use during 1931-60 were primarily from the middle aquifer. During 1961-85, withdrawals from the middle aquifer were partially replaced by withdrawals from the upper aquifer. Most of the public suppliers in Middlesex County also withdrew from the upper and middle aquifers.

In Monmouth County, public suppliers withdrew about half their water from the upper aquifer and the remainder from the Englishtown aquifer system, the Wenonah-Mount Laurel aquifer, and the Kirkwood-Cohansey aquifer system. Use of the three latter, shallower aquifers was particularly prevalent during the early development of public-supply systems in the Monmouth County shore communities. The major factors affecting this pattern of withdrawals by aquifer are aquifer characteristics (such as permeability, thickness, and areal extent), population density, availability of other sources of supply (surface or other ground-water sources, or transfers from other public suppliers), saltwater intrusion or contamination, and cost.

Ground-water withdrawals by aquifer, in million gallons per day and as percentages, are presented in table 6 and figure 12. Withdrawals from 1901 through 1910 were predominately from the Englishtown aquifer system because it was the uppermost reliable aquifer for the Monmouth County shore communities. Throughout the study area, however, withdrawals from the Englishtown aquifer system were surpassed, during 1911-20, by withdrawals from the much more extensive and thicker upper aquifer. Withdrawals from the middle aquifer during the 1930's were greater than from any other aquifer (49 percent of total withdrawals), primarily because of withdrawals for self-supplied industrial use. At that time, however, saltwater intrusion in the middle aquifer in the Sayreville area became a problem; thereafter, withdrawals from the upper aquifer increased until it became the predominant aquifer. Withdrawals from each of the five aquifers are discussed below, in general order of decreasing rate of withdrawal.

Middle Aquifer of the Potomac-Raritan-Magothy Aquifer System

Water from the middle aquifer of the Potomac-Raritan-Magothy aquifer system, also known as the Farrington aquifer (table 1), is withdrawn in the northwestern part of the Coastal Plain (fig. 13). During 1911-20, recorded withdrawals of 0.56 Mgal/d from the middle aquifer accounted for 10 percent of total recorded withdrawals from Coastal Plain aquifers (fig. 14). During the 1920's, withdrawals from the middle aquifer increased nearly tenfold to 5.36 Mgal/d, about 33 percent of total withdrawals. These increases were

Table 6.--Ground-water withdrawals from Coastal Plain aquifers in Middlesex and Monmouth Counties, by aquifer

[PRM, Potomac-Raritan-Magothy aquifer system; Mgal/d, million gallons per day; <, less than. Totals in this table may not agree with totals in other tables due to independent rounding. Data from New Jersey Department of Environmental Protection Bureau of Water Allocation and U.S. Geological Survey files]

Years	Middle aquifer of PRM		Upper aquifer of PRM		Englishtown aquifer system		Wenonah-Mount Laurel aquifer		Kirkwood-Cohansey aquifer system		Total withdrawal
	Mgal/d	Percent	Mgal/d	Percent	Mgal/d	Percent	Mgal/d	Percent	Mgal/d	Percent	Mgal/d
1901-10	0	0	0.05	8	0.57	86	0	0	0.04	6	0.66
1911-20	.56	10	3.72	67	1.07	19	.10	2	.10	2	5.55
1921-30	5.36	33	8.19	51	2.05	13	.35	2	.23	1	16.18
1931-40	10.51	49	8.47	39	2.06	9	.15	1	.47	2	21.66
1941-50	11.05	30	22.11	60	3.10	8	.16	<1	.67	2	37.09
1951-60	10.79	22	33.45	67	4.14	8	.30	1	.82	2	49.50
1961-70	15.38	23	44.31	67	4.88	7	1.10	2	.73	1	66.40
1971-80	23.47	31	44.46	58	5.88	8	1.23	2	1.12	1	76.16
1981-85	23.96	33	41.86	57	5.38	7	1.10	1	1.25	2	73.55

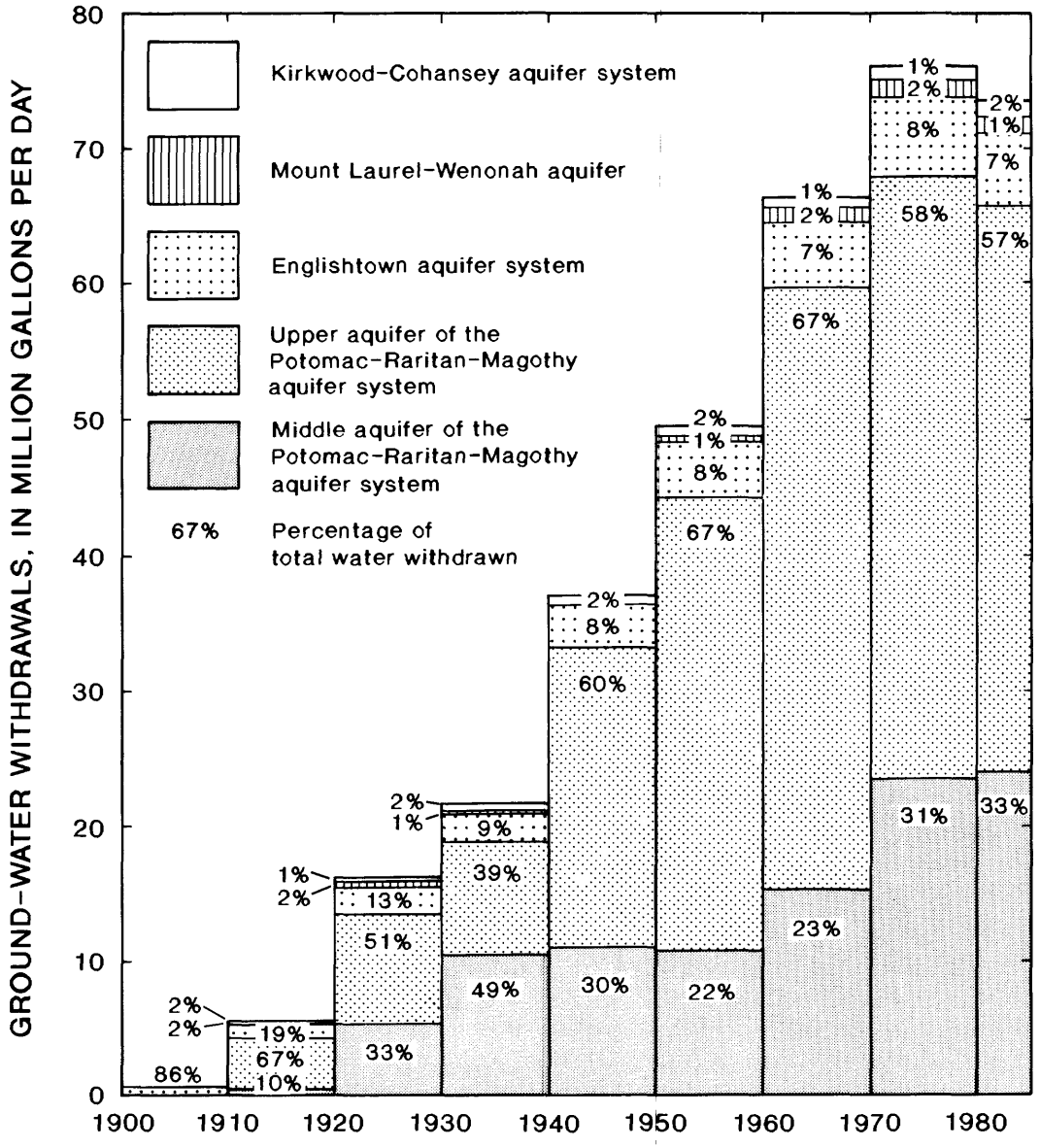


Figure 12.--Withdrawals from Coastal Plain aquifers in Middlesex and Monmouth Counties, by aquifer.

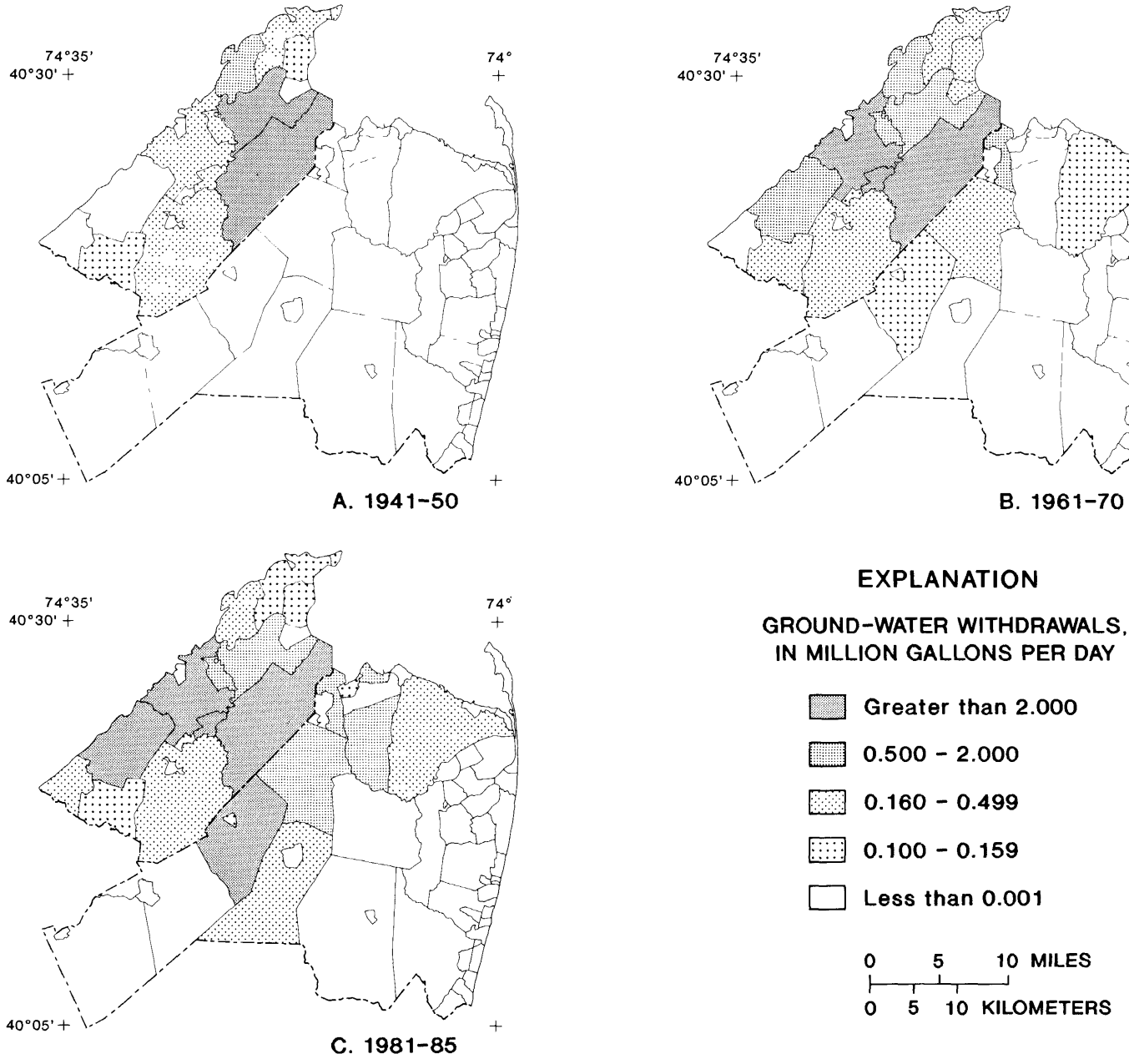


Figure 13.--Withdrawals from the middle aquifer of the Potomac-Raritan-Magothy aquifer system, by municipal civil division, (A.) 1941-50, (B.) 1961-70, and (C.) 1981-85 (locations of municipal civil divisions are shown in fig. 2).

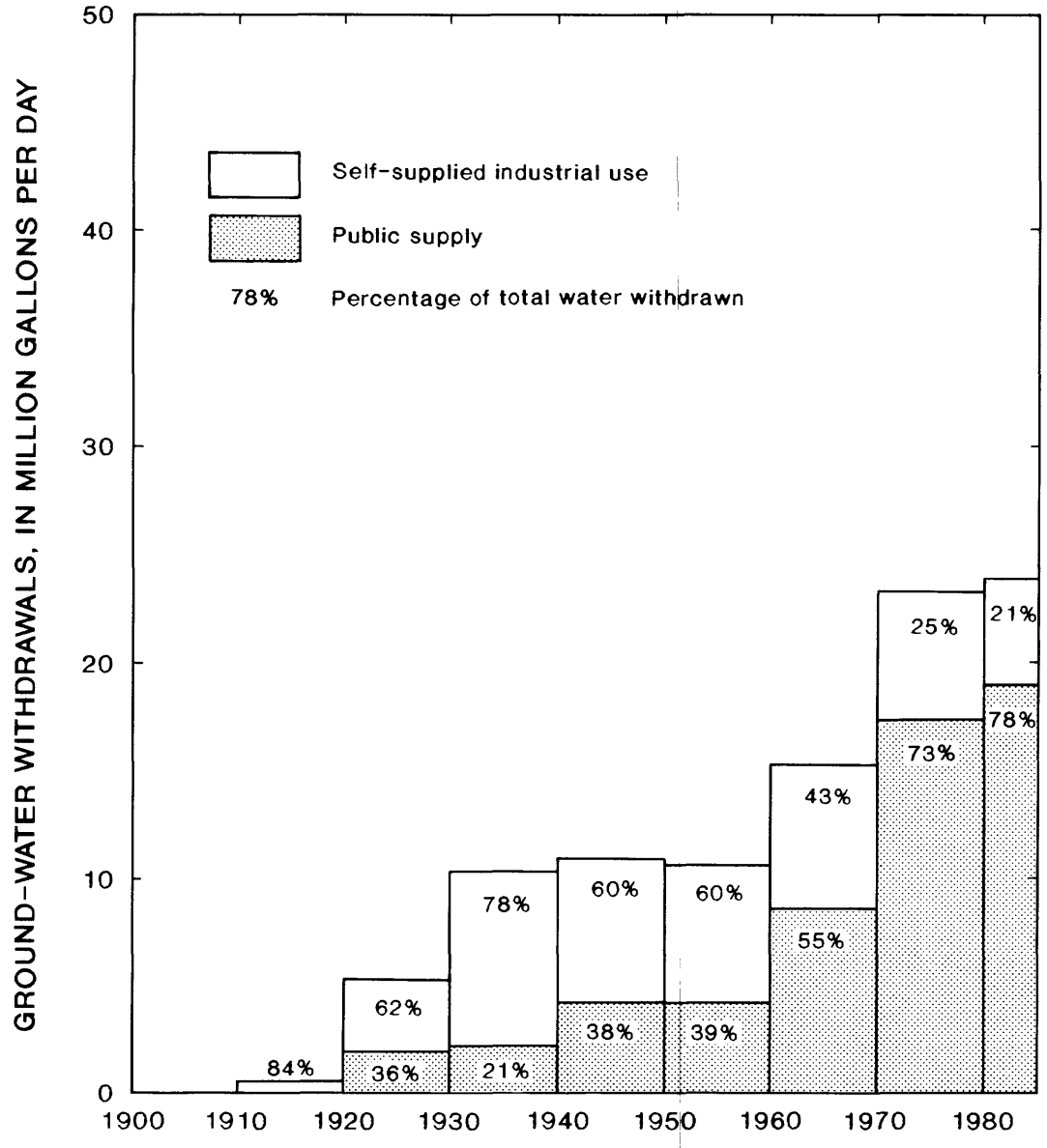


Figure 14.--Withdrawals from the middle aquifer of the Potomac-Raritan-Magothy aquifer system, by category of use.

largely the result of increasing withdrawals for self-supplied industrial use by duPont (1.21 Mgal/d), Hercules (0.93 Mgal/d), Nixon Nitration Works (now called Nuodex, 0.9 Mgal/d), and one public supplier, Perth Amboy City DPW (1.77 Mgal/d). These users accounted for 90 percent of the withdrawals from the middle aquifer. During the 1930's, withdrawals from this aquifer nearly doubled to 10.51 Mgal/d, about 49 percent of total withdrawals. During this time, withdrawals from the middle aquifer exceeded those from all other aquifers. Withdrawals for self-supplied industrial use continued to dominate as duPont (3.19 Mgal/d), Hercules (3.05 Mgal/d), National Lead (0.62 Mgal/d), and Nuodex (0.53 Mgal/d)--plus the public supplier, Perth Amboy City DPW (2.0 Mgal/d)--accounted for 90 percent of withdrawals from the middle aquifer.

During the 1940's, withdrawals from the middle aquifer increased by only 5 percent over those in the 1930's, to 11.05 Mgal/d. The demands of World War II on industry did not greatly increase withdrawals from the middle aquifer even though the withdrawals were primarily for self-supplied industrial use (62 percent of total withdrawals) (fig. 14). This was partly because the decrease in the water levels and advancing saltwater intrusion in the mid-1930's led to increased development of the upper aquifer instead of the middle aquifer, particularly by the Duhernal companies. Withdrawals from the middle aquifer in Sayreville Borough (fig. 13A) by the Duhernal companies peaked during the 1930's at 6.86 Mgal/d and decreased during the 1940's to 5.23 Mgal/d. Nuodex continued to be a major user, withdrawing 0.57 Mgal/d in Edison Township. Public suppliers (primarily Perth Amboy City DPW, which withdrew 3.77 Mgal/d from Old Bridge Township) accounted for 38 percent of withdrawals from the middle aquifer.

In the 1950's, the rate of withdrawal remained about the same as in the 1940's, but it increased 43 percent to 15.38 Mgal/d during the 1960's. The areal distribution of these withdrawals is shown in figure 13B. Withdrawals from the middle aquifer accounted for about 22 percent of total Coastal Plain withdrawals in the 1950's and 1960's. Withdrawals for self-supplied industrial use accounted for 43 percent of withdrawals from this aquifer. During the 1960's, the Duhernal companies continued to decrease their withdrawals from the middle aquifer in Sayreville Borough to 2.4 Mgal/d, and Nuodex decreased withdrawals from this aquifer in Edison Township to 0.35 Mgal/d. Several new users that started withdrawing from the middle aquifer in the 1940's, including Schweitzer (2.3 Mgal/d in Spotswood Borough), increased withdrawals through the 1960's, however. Public suppliers--primarily for Perth Amboy City DPW (2.75 Mgal/d in Old Bridge Township)--accounted for 55 percent of withdrawals from the middle aquifer. East Brunswick Township Water Department (1.6 Mgal/d in East Brunswick Township) was among several new public suppliers that began using the middle aquifer at this time. Withdrawals from the middle aquifer expanded into western Middlesex County and northwestern Monmouth County.

During the 1970's, withdrawals from the middle aquifer increased by 53 percent. In the early 1980's, withdrawals increased by an additional 2 percent (to 23.96 Mgal/d), primarily because of increased withdrawals for public supply. Withdrawals from the middle aquifer accounted for 33 percent of all Coastal Plain aquifer withdrawals in the study area. The areal distribution of withdrawals for 1981-85 is shown in figure 13C. Withdrawals by public suppliers accounted for about 80 percent of withdrawals from the

middle aquifer. Public-supply usage continued to expand; eight public suppliers each withdrew more than 1 Mgal/d during 1981-85. Withdrawals for self-supplied industrial use accounted for only about 20 percent of withdrawals from the middle aquifer. Kimberly-Clark (formerly Schweitzer) became the largest industrial user (2.12 Mgal/d in Spotswood Borough). Withdrawals from the middle aquifer continued to expand into western Middlesex County and into a larger part of northern Monmouth County.

Upper Aquifer of the Potomac-Raritan-Magothy Aquifer System

Withdrawals from the upper aquifer of the Potomac-Raritan-Magothy aquifer system (fig. 15), also known as the Old Bridge aquifer (table 1), were the most extensive of those from any of the five aquifers. Withdrawals from the upper aquifer totaled less than 0.1 Mgal/d from 1901 through 1910 and comprised about 8 percent of recorded withdrawals from Coastal Plain aquifers in the study area (table 6). During 1911-20, withdrawals from the upper aquifer totaled 3.72 Mgal/d and accounted for 67 percent of all Coastal Plain withdrawals in the study area. All withdrawals were for public supply (fig. 16); Perth Amboy City DPW accounted for approximately three-fourths (2.84 Mgal/d) of all withdrawals from the upper aquifer. Withdrawals more than doubled (8.19 Mgal/d) during the next decade as 15 water suppliers used the upper aquifer. Perth Amboy City DPW withdrew 68 percent (5.59 Mgal/d) of the total. During the 1930's, withdrawals remained generally constant at 8.5 Mgal/d, which was 39 percent of total Coastal Plain aquifer withdrawals. Perth Amboy City DPW's withdrawals dropped to 3.7 Mgal/d (44 percent) and no new public suppliers began withdrawals from the upper aquifer. On the other hand, four new major industrial users withdrew 1.24 Mgal/d, or 15 percent of the total pumpage from the upper aquifer.

During the 1940's, withdrawals from the upper aquifer more than doubled to 22.11 Mgal/d. This was the largest increase in rate over a decade for any aquifer (table 6). Withdrawals from the upper aquifer accounted for 60 percent of total withdrawals. The tremendous increase in withdrawals from this aquifer resulted from a number of factors, the most important of which were increased industrial demand, saltwater intrusion into the middle aquifer, and increased population.

World War II increased the demands on self-supplied water for industry from 9.41 Mgal/d during the 1930's to 19.71 Mgal/d during the 1940's. For the upper aquifer, this resulted in an increase in withdrawals for self-supplied industrial use from 1.24 Mgal/d in the 1930's (15 percent of the total upper aquifer pumpage) to 12.99 Mgal/d in the 1940's (59 percent of the total upper aquifer pumpage). Withdrawals by the Duhernal companies from the upper aquifer accounted for 32 percent of all Coastal Plain aquifer withdrawals in the study area, as well as 54 percent of all upper aquifer withdrawals.

The second major reason for this increase was saltwater intrusion in the middle aquifer and the subsequent development of the upper aquifer. In the 1930's, total withdrawals by the Duhernal companies were 7.76 Mgal/d, of which 92 percent were from the middle aquifer. During the 1940's, total

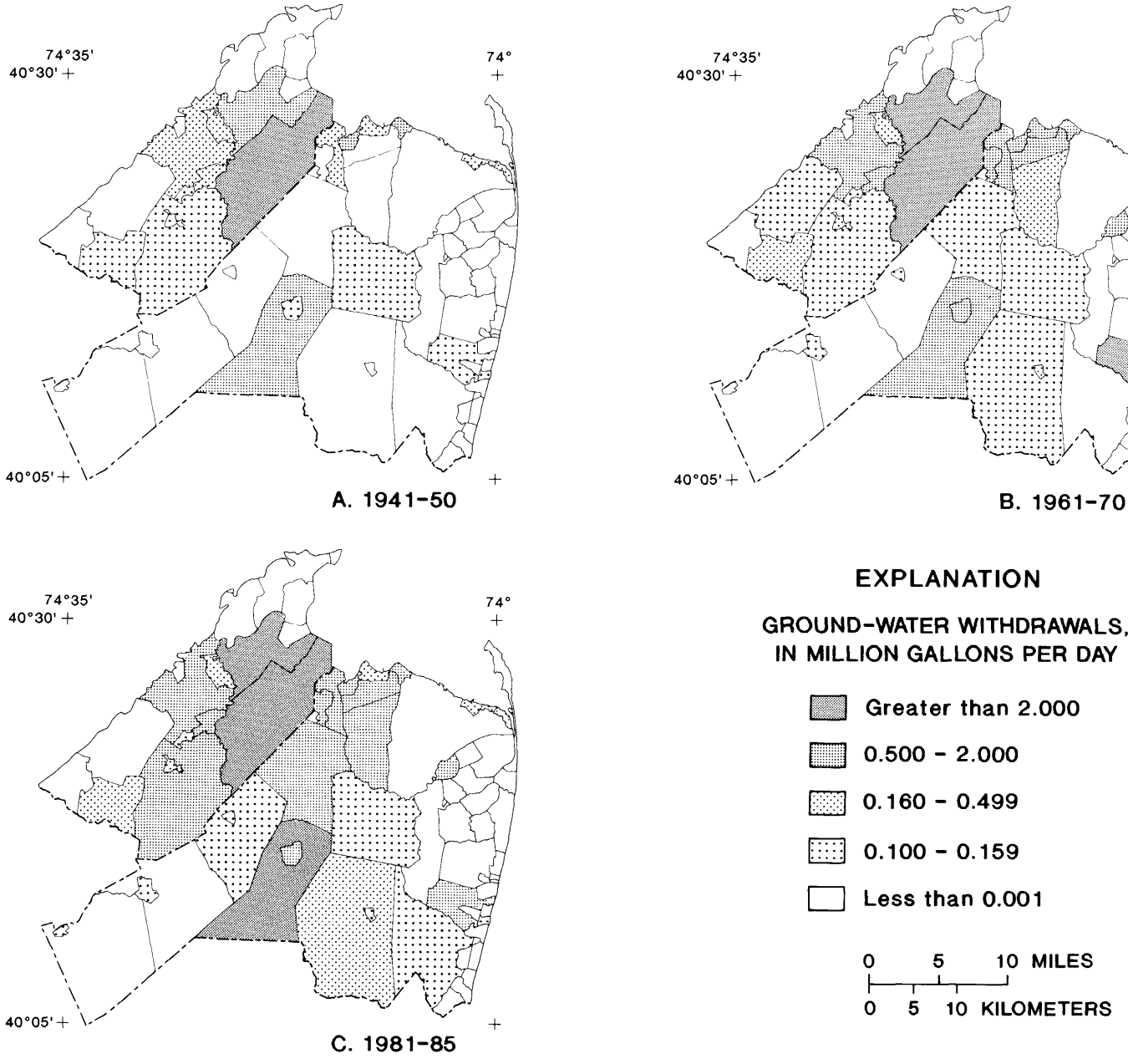


Figure 15.--Withdrawals from the upper aquifer of the Potomac-Raritan-Magothy aquifer system, by municipal civil division, (A.) 1941-50, (B.) 1961-70, and (C.) 1981-85 (locations of municipal civil divisions are shown in fig. 2).

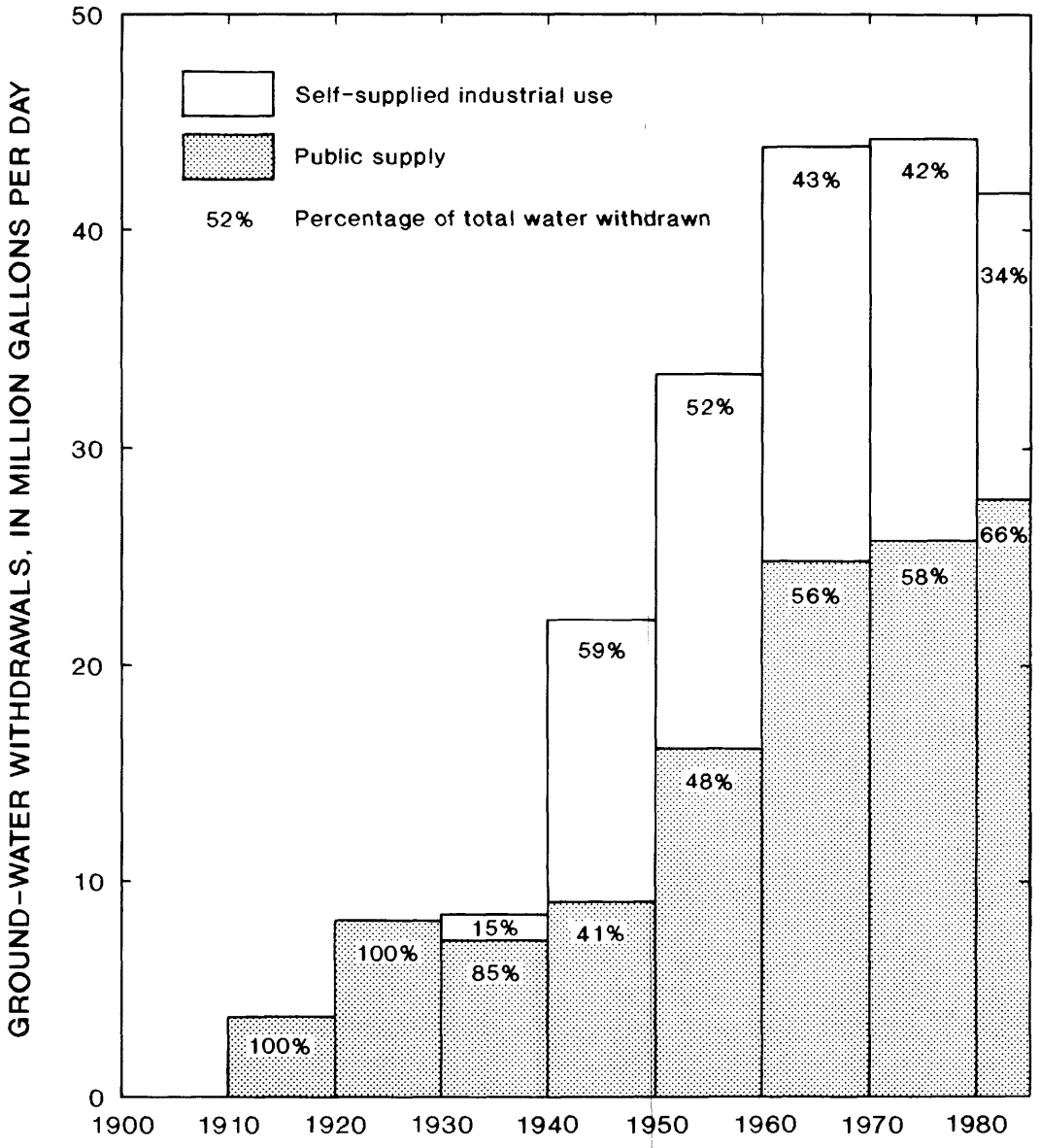


Figure 16.--Withdrawals from the upper aquifer of the Potomac-Raritan-Magothy aquifer system, by category of use.

withdrawals by the Duhernal companies were 14.38 Mgal/d, of which only 31 percent were from the middle aquifer.

The third major reason for the increase in upper aquifer pumpage was population increases in areas where the upper aquifer was the most economically feasible source of water, primarily Middlesex County and northwestern Monmouth County. During 1941-50, 18 water suppliers, as well as the military post at Earle (Colts Neck Township) (fig. 15A), used the upper aquifer in 20 MCD's throughout Middlesex and Monmouth Counties. Perth Amboy City DPW still dominated public-supply withdrawals with 4.35 Mgal/d or 20 percent of all upper aquifer withdrawals. The largest withdrawal per MCD was in Old Bridge Township and was attributable to the combined withdrawals of the Duhernal companies and Perth Amboy City DPW.

Withdrawals from the upper aquifer increased by approximately 11 Mgal/d each decade through the 1950's and 1960's and totaled 44.31 Mgal/d, or 67 percent of total withdrawals, in the 1960's. Figure 15B shows the areal distribution of upper aquifer pumpage in the 1960's. Water was withdrawn from the upper aquifer in 30 MCD's, most of which were in Monmouth County. About one-third of the increase from the 1940's resulted from increases in withdrawals for self-supplied industrial use, primarily by Schweitzer (2.99 Mgal/d from Spotswood Borough) and Nestle's (0.66 Mgal/d from Freehold Borough), but also by nine new industries, each of which began pumping more than 0.1 Mgal/d in the 1960's. Public-supply withdrawals accounted for the remaining 16-Mgal/d increase. The number of public suppliers using the upper aquifer increased from 19 to 42. Of these 42 water suppliers, 7 used the upper aquifer as their only source of supply. The combined withdrawals of the Duhernal companies, Perth Amboy City DPW, and Old Bridge MUA in Old Bridge Township totaled almost 22 Mgal/d, and constituted the largest concentration of pumpage in the study area. This township alone accounted for 50 percent of the total withdrawals from the upper aquifer.

Withdrawals from the upper aquifer remained approximately the same during the 1970's as in the 1960's and decreased by 6 percent in the early 1980's to 41.86 Mgal/d, or 57 percent of total withdrawals. Figure 15C shows the areal distribution of upper aquifer pumpage during 1981-85. The number of MCD's in which ground water was withdrawn from the upper aquifer increased slightly in Monmouth County. Increased withdrawals by Anheuser-Busch (1.7 Mgal/d) and Nestle's (1.0 Mgal/d) were masked by major decreases in withdrawals by the Duhernal companies (8.6 Mgal/d) and Schweitzer (1.5 Mgal/d); the result was an overall decrease of 5.2 Mgal/d in withdrawals for self-supplied industrial use. This decrease was offset by an increase in the withdrawal by established public suppliers, plus additional withdrawals by two new suppliers. Of the 44 water suppliers active during the early 1980's, 29 (66 percent) used the upper aquifer for water supply and 9 (20 percent) used it as their only source of supply. The combined withdrawals of the Duhernal companies, Perth Amboy City DPW, and Old Bridge MUA in Old Bridge Township totaled about 15.5 Mgal/d and continued to be the largest concentration of pumpage in the study area. This township accounted for 37 percent of withdrawals from the upper aquifer.

Englishtown Aquifer System

Withdrawals from the Englishtown aquifer system within the study area are concentrated in Monmouth County (fig. 17) primarily where this aquifer system is the uppermost major aquifer (fig. 3). Red Bank WD and Belmar Borough Water Department (Belmar WD) withdrew water from the Englishtown aquifer system from 1901 through 1910 (0.57 Mgal/d). Their withdrawals accounted for 86 percent of the recorded withdrawals from all Coastal Plain aquifers in the study area during that decade. Two population centers existed at that time--one along the shore and the other in the northern part of the study area. The Englishtown aquifer system was the most used ground-water source probably because it was the uppermost reliable aquifer for the shore communities (the primary source of water for the northern population center was surface water). Despite the increasing dependence on the upper aquifer thereafter, both the amount withdrawn and the number of water companies using the Englishtown aquifer system increased steadily through the 1970's (table 6). Withdrawals from the Englishtown aquifer system increased from 1.07 Mgal/d during 1911-20 to 3.1 Mgal/d during 1941-50. Figure 17A shows the distribution of withdrawals from the Englishtown aquifer system in the 1940's. Red Bank WD and Belmar WD were the largest users of the Englishtown aquifer system during this time.

From the 1940's through the 1970's, withdrawals from the Englishtown aquifer system continued to increase at a rate of approximately 1 Mgal/d per decade, from 3.1 Mgal/d in the 1940's to 5.88 Mgal/d in the 1970's. Figure 17B shows withdrawals from the Englishtown aquifer system during the 1960's. The increasing number of public suppliers was joined by an increasing number of industries as use of the aquifer system increased in both amount and geographical extent. Red Bank WD and Belmar WD were joined by Spring Lake Water Department (Spring Lake WD) and two industries in Holmdel Township. During the early 1980's (fig. 17C), withdrawals decreased by approximately 10 percent (5.38 Mgal/d) as Red Bank WD stopped using the Englishtown aquifer system and as other users reduced their withdrawals. The largest withdrawals from the Englishtown aquifer system were concentrated in MCD's in the southeastern corner of Monmouth County, specifically by Belmar WD, Spring Lake WD, Brielle Borough Water Department, and Wall Township Water Department (Wall TWD). Withdrawals from the Englishtown aquifer system during 1981-85 accounted for about 7 percent of all Coastal Plain aquifer withdrawals in the study area.

Wenonah-Mount Laurel Aquifer

Withdrawals from the Wenonah-Mount Laurel aquifer are concentrated in the southeastern part of Monmouth County, primarily where it is the uppermost major aquifer (fig. 3). Historically, the Wenonah-Mount Laurel aquifer has supplied a small percentage of the total ground-water withdrawals in the study area. Its contribution has ranged from less than 1 percent to 2 percent of the total. Monmouth Consolidated WC withdrew water from the Wenonah-Mount Laurel aquifer at the rate of about 0.1 Mgal/d during 1911-20 and tripled withdrawals during 1921-30 to 0.3 Mgal/d; however, the company virtually abandoned its wells thereafter. Avon-by-the-Sea Water Company began withdrawing from the Wenonah-Mount Laurel aquifer during the 1930's at a rate of 0.2 Mgal/d; this rate remained constant through the 1940's. During the 1950's, total withdrawals from the aquifer doubled as

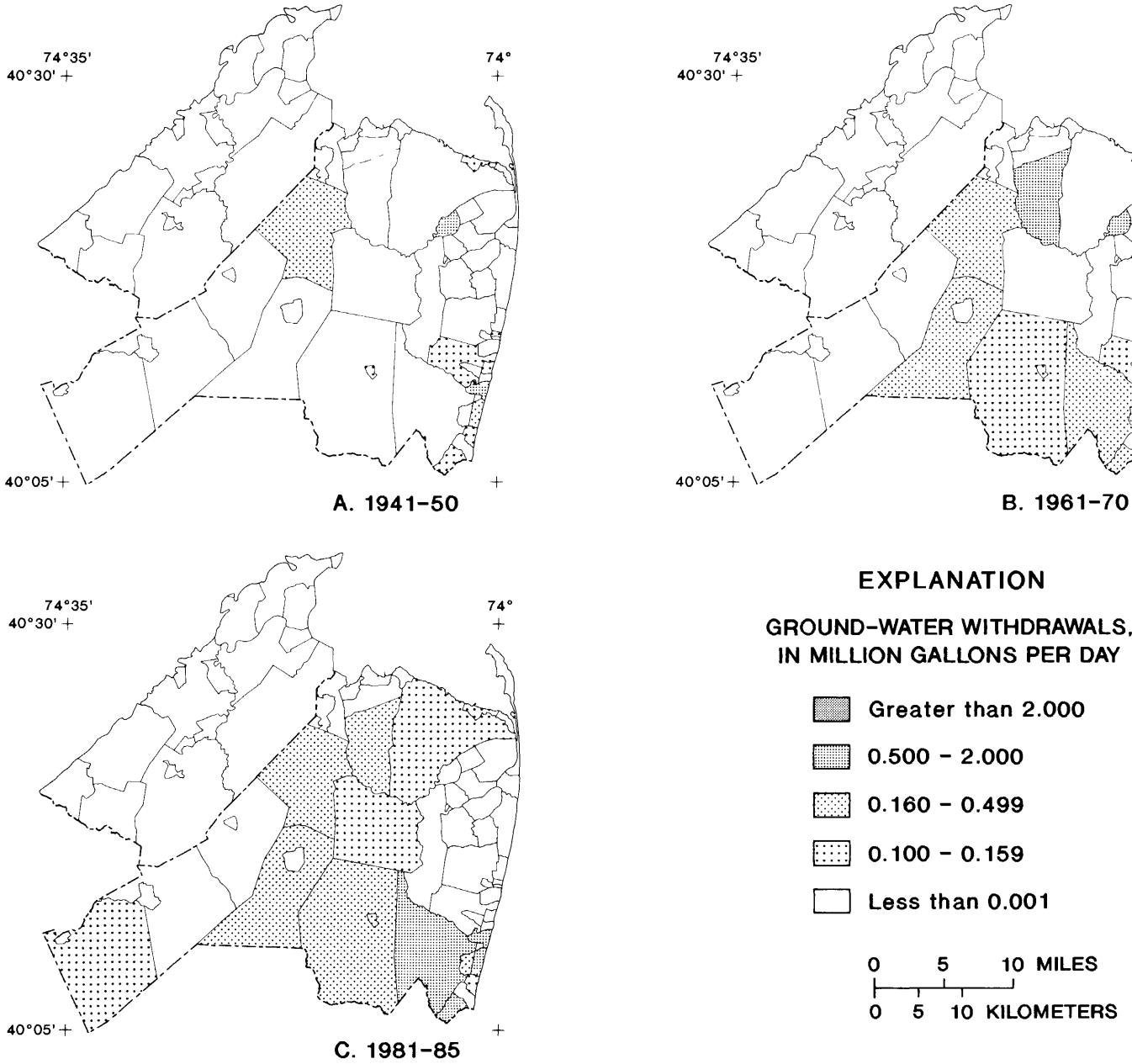


Figure 17.--Withdrawals from the Englishtown aquifer system, by municipal civil division, (A.) 1941-50, (B.) 1961-70, and (C.) 1981-85 (locations of municipal civil divisions are shown in fig. 2).

Wall TWD, Monmouth Consolidated WC, Spring Lake Heights Water Department, and Howell Township Water Department (Howell TWD) began using wells completed in the Wenonah-Mount Laurel aquifer. Withdrawals by all five water companies increased during the 1960's so that total withdrawals more than tripled to 1.1 Mgal/d. Withdrawals remained fairly constant, fluctuating about ±11 percent through the early 1980's. Almost three-fourths of the withdrawals from the Wenonah-Mount Laurel aquifer in the early 1980's were by Wall TWD and Howell TWD. In the 1980's, withdrawals from the Wenonah-Mount Laurel aquifer accounted for about 1 percent of all Coastal Plain withdrawals in the study area (table 6).

Kirkwood-Cohansey Aquifer System

Withdrawals from the Kirkwood-Cohansey aquifer system are concentrated in the southeastern corner of Monmouth County, primarily where it is the uppermost major aquifer (fig. 3). Records of withdrawals from the Kirkwood-Cohansey aquifer system began during 1901-10 by the Manasquan Water Department at the rate of 0.04 Mgal/d (table 6). The Sea Girt Water Department began withdrawing water from the Kirkwood-Cohansey aquifer system during 1911-20, more than doubling withdrawals from the aquifer system (0.10 Mgal/d). Withdrawals from this aquifer system continued to increase until the 1950's (0.82 Mgal/d) and constituted about 2 percent of all ground-water withdrawals from the Coastal Plain aquifers at that time. Withdrawals decreased by 11 percent in the 1960's to 0.73 Mgal/d, but increased in the 1970's by 53 percent to 1.12 Mgal/d and increased again in the early 1980's to 1.25 Mgal/d. Withdrawals during 1981-85 were by the Manasquan Water Department, accounting for 50 percent of the total, and by the Sea Girt Water Department, Howell TWD, and Parkway Water Company. Withdrawals from the Kirkwood-Cohansey aquifer system in the early 1980's accounted for almost 2 percent of all Coastal Plain withdrawals in the study area.

SUMMARY

Trends in ground-water withdrawals from 1901 through 1985 in the Coastal Plain part of Middlesex and Monmouth Counties were influenced by three major user groups. The first group consists of eight public suppliers that depended on surface water, purchased water, or water from non-Coastal Plain aquifers in addition to water from Coastal Plain aquifers. Perth Amboy City Department of Public Works, Old Bridge Municipal Utilities Authority, and Sayreville Water Department were the three largest of these suppliers. The second group consists of three major industries that withdrew Coastal Plain ground water--the Duhernal companies, Anheuser-Busch, and Schweitzer--which accounted for most of the withdrawals for self-supplied industrial use. The third group consists of the remaining public suppliers and self-supplied industries in Middlesex and Monmouth County that were dependent on water from Coastal Plain aquifers.

During 1901-50, ground water in Middlesex and Monmouth Counties was developed extensively for both public supply and self-supplied industrial use. During the 1940's, withdrawals for public supply and self-supplied industrial use reached 16.94 Mgal/d and 19.71 Mgal/d, respectively. Greatest development of ground-water withdrawals occurred in the eastern part of Middlesex County and along the shore in Monmouth County. During this period, public suppliers in Middlesex County withdrew primarily from

the upper aquifer and industries withdrew from the middle aquifer. In Monmouth County, public suppliers withdrew about half their water from the upper aquifer of the Potomac-Raritan-Magothy aquifer system and the remainder from the Englishtown aquifer system, the Wenonah-Mount Laurel aquifer, and the Kirkwood-Cohansey aquifer system.

During 1951-85, the populations of both counties increased greatly as a result of suburban growth. Ground-water withdrawals for public supply increased from 25.01 Mgal/d during the 1950's to 50.42 Mgal/d during the 1970's, whereas withdrawals for self-supplied industrial use remained relatively constant at 25.0 Mgal/d. During 1981-85, the population of the parts of Middlesex and Monmouth Counties served by ground water from Coastal Plain aquifers remained constant, as did withdrawals for public supply (53.69 Mgal/d). Withdrawals for self-supplied industrial use declined to 19.25 Mgal/d.

During 1951-70, the upper aquifer of the Potomac-Raritan-Magothy aquifer system became the major aquifer in both counties, with withdrawals increasing from 33.45 Mgal/d to 44.31 Mgal/d, or about 67 percent of the total, as public suppliers increasingly used this aquifer to serve suburban residents. Withdrawals from the middle aquifer of the Potomac-Raritan-Magothy aquifer system for public supply increased from 10.79 Mgal/d during the 1950's to 15.38 Mgal/d during the 1960's, or about 23 percent. During 1971-85, the percentage of total withdrawals from the upper aquifer of the Potomac-Raritan-Magothy aquifer system decreased to about 57 percent, and withdrawals from the middle aquifer of the Potomac-Raritan-Magothy aquifer system increased to 32 percent, primarily as a result of increased withdrawals from the middle aquifer of the Potomac-Raritan-Magothy aquifer system in Monmouth County.

REFERENCES CITED

Appel, C.A., 1962, Salt-water encroachment in aquifers of the Raritan Formation in the Sayreville area, Middlesex County, New Jersey with section on the proposed tidal dam on the South River: New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply Special Report 17, 47 p.

Barksdale, H.C., 1937, Water supplies in the Number 1 sand in the vicinity of Parlin: New Jersey State Water Policy Commission Special Report 7, 33 p.

Barksdale, H.C., Johnson, M.E., Schaefer, E.J., Baker, R.C., and DeBuchananne G.D., 1943, Ground-water supplies of Middlesex County: New Jersey Water Policy Commission Special Report 8, 160 p.

Battaglin, W.A., and Hill, M., 1988, Simulated effect of future withdrawals on water levels in the northeastern Coastal Plain aquifers of New Jersey: U.S. Geological Survey Water-Resources Investigations Report 88-4199, 58 p.

Farlekas, G.M., 1979, Geohydrology and digital-simulation model of the Farrington aquifer in the northern Coastal Plain of New Jersey: U.S. Geological Survey Water-Resources Investigations Report 79-106, 55 p.

Gill, H.E., and Farlekas, G.M., 1976, Geohydrologic maps of the Potomac-Raritan-Magothy aquifer system in the New Jersey Coastal Plain: U.S. Geological Survey Hydrologic Investigations Atlas HA-557, 2 sheets, scale 1:500,000.

Hasan, Asghar, Kasabach, H.F., and Malone, J.E., 1969, Water resources of the Sayreville area, Middlesex County, New Jersey: New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply Water Resources Circular 20, 32 p.

Jablonski, L.A., 1959, Records of wells and ground-water quality in Monmouth County, New Jersey: New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply Water Resources Circular 2, 47 p.

_____ 1960, Factual data for public-supply wells and selected irrigation wells in Monmouth County, New Jersey: New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply Water Resources Circular 4, 28 p.

_____ 1968, Ground-water resources of Monmouth County, New Jersey: New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply Special Report 23, 117 p.

Leahy, P.P., Paulachok, G.N., Navoy, A.S., and Pucci, A.A., Jr., 1987, Plan of Study for the New Jersey Bond Issue ground-water-supply investigations: New Jersey Geological Survey Open-File Report 87-1, 53 p.

Lyttle, P.T., and Epstein, J.B., 1987, Geologic Map of the Newark 1° x 2° Quadrangle, New Jersey, Pennsylvania, and New York: U.S. Geological Survey Miscellaneous Investigations Series Map I-1715, 2 sheets, scale 1:250,000.

New Jersey Department of Labor, 1984, New Jersey Population Trends 1790 to 1980: Division of Planning and Research, 15 p.

Solley, W.B., Merk, C.F., and Pierce, R.R., 1988, Estimated use of water in the United States in 1985: U.S. Geological Survey Circular 1004, 82 p.

Thompson, D.G., 1930, Ground water supplies in the vicinity of Asbury Park: New Jersey Department of Conservation and Development Bulletin 35, 50 p.

Vermeule, C.C., 1894, Report on water-supply: Geological Survey of New Jersey, v. 3, 352 p.

Vowinkel, E.F., 1984, Ground-water withdrawal from the Coastal Plain of New Jersey, 1956-1980: U.S. Geological Survey Open-File Report 84-226, 32 p.

Vowinkel, E.F., and Foster, W.K., 1981, Hydrogeologic conditions in the Coastal Plain of New Jersey: U.S. Geological Survey Open-File Report 81-405, 39 p.

Zapecza, O.S., 1989, Hydrogeologic framework of the New Jersey Coastal Plain: U.S. Geological Survey Professional Paper 1404-B, 49 p., 24 pl.

Zapecza, O.S., Voronin, L.M., and Martin, Mary, 1987, Ground-water withdrawal and water-level data used to simulate regional flow in the major Coastal Plain aquifers of New Jersey: U.S. Geological Survey Water-Resources Investigations Report 87-4038, 120 p.

APPENDIXES

APPENDIX A

Description of data base for well-description data

Starting column	Item name	Width	Type	Number of decimals	Alternate name
1	NJ-UNIQUE-ID	6	CHARACTER	-	UID
7	SITE-ID	15	CHARACTER	-	SID
22	LATITUDE	6	CHARACTER	-	LAT
28	LONGITUDE	6	CHARACTER	-	LON
34	TOWNSHIP	20	CHARACTER	-	TWP
54	SOWNER	20	CHARACTER	-	OWNER
74	LOCAL-ID	14	CHARACTER	-	LOCID
88	YEAR-COMPL	4	CHARACTER	-	CYR
92	YEAR-STANDBY	4	CHARACTER	-	SYR
96	YEAR-ABANDONED	4	CHARACTER	-	AYR
100	WATER-USE	1	CHARACTER	-	UW
101	ALTITUDE-FT	7	NUMBER	2	ALT
108	WELL-DEPTH-FT	7	NUMBER	2	DW
115	AQUIFER-CODE	5	CHARACTER	-	AQUCODE
120	AQUIFER-REL	1	CHARACTER	-	RAQU
121	DATA-REL	1	CHARACTER	-	DREL
122	AVG-PUMP-REL	1	CHARACTER	-	RPUMP
123	HYDROLOGIC-UNIT	8	CHARACTER	-	HYDROU
131	CASING-DIA-IN	5	NUMBER	1	MCDIA
136	PERMIT-NUM	7	CHARACTER	-	PNUM
143	GRID-NUM	7	CHARACTER	-	GNUM
150	WATER-ALLOC-NUM	5	CHARACTER	-	WANUM
155	STAN-INDUS-USE	4	CHARACTER	-	SIUC
159	WATER-USER-NUM	5	CHARACTER	-	WUNUM
164	SUB-BASIN	6	CHARACTER	-	SBASIN
170	FIRST-PUMP	4	CHARACTER	-	FPUMP
174	LAST-PUMP	4	CHARACTER	-	LPUMP
	** REDEFINED ITEMS **				
1	COUNTY	2	CHARACTER	-	CO
137	ATLAS-SHEET	2	CHARACTER	-	ATLAS

APPENDIX B

Description of data base for pumpage data

Starting column	Item name[1]	Width	Type	Number of decimals	Alternate name
1	NJ-UNIQUE-ID	6	CHARACTER	-	UID
7	AN-1971	6	NUMBER	1	
13	R-1971	1	CHARACTER	-	
14	AN-1972	6	NUMBER	1	
20	R-1972	1	CHARACTER	-	
21	AN-1973	6	NUMBER	1	
27	R-1973	1	CHARACTER	-	
28	AN-1974	6	NUMBER	1	
34	R-1974	1	CHARACTER	-	
35	AN-1975	6	NUMBER	1	
41	R-1975	1	CHARACTER	-	
42	AN-1976	6	NUMBER	1	
48	R-1976	1	CHARACTER	-	
49	AN-1977	6	NUMBER	1	
55	R-1977	1	CHARACTER	-	
56	AN-1978	6	NUMBER	1	
62	R-1978	1	CHARACTER	-	
63	AN-1979	6	NUMBER	1	
69	R-1979	1	CHARACTER	-	
70	AN-1980	6	NUMBER	1	
76	R-1980	1	CHARACTER	-	

[1] AN-, Annual pumpage; R-, reliability of annual pumpage.

APPENDIX C

Description of data base used in selection of wells for analysis

Starting column	Item name	Width	Type	Number of decimals	Alternate name
1	NJ-UNIQUE-ID	6	CHARACTER	-	UID
7	LATITUDE	6	CHARACTER	-	LAT
13	LONGITUDE	6	CHARACTER	-	LON
19	TOWNSHIP	20	CHARACTER	-	TWP
39	SOWNER	20	CHARACTER	-	OWNER
59	YEAR-COMPL	4	CHARACTER	-	CYR
63	WATER-USE	1	CHARACTER	-	UW
64	AQUIFER-CODE	5	CHARACTER	-	AQUCODE
69	HYDROLOGIC-UNIT	8	CHARACTER	-	HYDROU
77	FIRST-PUMP	4	CHARACTER	-	FPUMP
81	LAST-PUMP	4	CHARACTER	-	LPUMP
	** REDEFINED ITEMS **				
1	COUNTY	2	CHARACTER	-	CO

APPENDIX D

Description of data base used in generating the statistics for this report

Starting column	Item name	Width	Type	Number of decimals	Alternate name
1	NJ-UNIQUE-ID	6	CHARACTER	-	UID
7	TOWNSHIP	20	CHARACTER	-	TWP
27	SOWNER	20	CHARACTER	-	OWNER
47	WATER-USE	1	CHARACTER	-	UW
48	AQUIFER-CODE	5	CHARACTER	-	AQUCODE
53	HYDROLOGIC-UNIT	8	CHARACTER	-	HYDROU
61	DEC-1900	6	NUMBER	3	
67	R-1900	1	CHARACTER	-	
68	DEC-1910	6	NUMBER	3	
74	R-1910	1	CHARACTER	-	
75	DEC-1920	6	NUMBER	3	
81	R-1920	1	CHARACTER	-	
82	DEC-1930	6	NUMBER	3	
88	R-1930	1	CHARACTER	-	
89	DEC-1940	6	NUMBER	3	
95	R-1940	1	CHARACTER	-	
96	DEC-1950	6	NUMBER	3	
102	R-1950	1	CHARACTER	-	
103	DEC-1960	6	NUMBER	3	
109	R-1960	1	CHARACTER	-	
110	DEC-1970	6	NUMBER	3	
116	R-1970	1	CHARACTER	-	
117	DEC-1980	6	NUMBER	3	
123	R-1980	1	CHARACTER	-	
	** REDEFINED ITEMS **				
1	COUNTY	2	CHARACTER	-	CO