PRELIMINARY ASSESSMENT OF WATER QUALITY AND ITS RELATION TO HYDROGEOLOGY AND LAND USE: POTOMAC-RARITAN-MAGOTHY AQUIFER SYSTEM, NEW JERSEY

By Cynthia Barton, Eric F. Vowinkel, and John P. Nawyn

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CONVERSION OF INCH-POUND UNITS TO METRIC UNITS

For those readers who may prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply Inch-pound unit	By	To obtain Metric unit
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Temperature	
degree Celsius (°C)	°F = 1.8°C + 32	degree Fahrenheit (°F)

EXPLANATION OF SEA LEVEL

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

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ABSTRACT

The relation of water quality to hydrogeology and land use is evaluated with the Kruskal-Wallis test and frequency-of-detection method using water-quality analyses from 71 wells screened in or near the outcrop of the northern part of the Potomac-Raritan-Magothy aquifer system in New Jersey. The water-quality network is evaluated for variations in hydrogeologic conditions at sampled wells. Well depths, pumping rates, and the relative number of wells screened in unconfined and confined parts of the aquifer system did not differ significantly among land-use groups. However, wells in agricultural land have the greatest depths to water, and wells in undeveloped and urban lands are predominantly screened in the upper and middle aquifers, respectively. When the relation of hydrogeologic factors to water quality are evaluated independent of land use, shallow wells had the highest specific conductance and the highest concentrations of most major ions; wells screened in the unconfined part of the aquifer system had a higher concentration of dissolved organic carbon than wells screened in the confined part of the aquifer system.

Statistically significant differences in the water quality among land-use groups are determined when two methods are used to classify land use at a sampled well--a predominant land-use method and a presence-absence method. In ground water from undeveloped land, dissolved oxygen and nitrate concentrations were lowest, most trace metals concentrations were highest, and phenols were detected most frequently. In agricultural land, major ions and most trace metals concentrations were lowest, dissolved oxygen and copper concentrations were highest, and pesticides were most frequently detected. In urban land, nitrate concentrations were highest and orthophosphate, nitrite, and purgeable organic compounds were detected most frequently. These relations suggest that water quality is influenced by both natural land cover and human activities specific to each land use.

Statistical relations between water quality and land use in the northern area are compared to those from 179 wells in the outcrop of the same aquifer system in southern New Jersey. The water-quality/land-use relations are different in each area, especially with respect to most major ions, trace metals, and nutrients. These differences suggest that there are different processes controlling ground-water quality in each area and that these processes may be related to the presence of a Pinelands outlier in the northern area and induced recharge of the aquifer system from the Delaware River in the southern area. Frequencies of detection of purgeable organic compounds among land-use groups were similar in the northern and southern parts of the aquifer system suggesting that human activities produce similar patterns of ground-water contamination with respect to land use in each area.

INTRODUCTION

The U.S. Geological Survey Toxic Waste--Ground-Water Contamination Program is evaluating regional ground-water contamination in 14 areas across the Nation. The areas selected for ground-water-quality assessments cover a wide variety of environments in terms of climate, hydrogeology, and land use. The objectives of each study are to provide information on ground-water quality, with emphasis on organic substances and trace metals, and to statistically evaluate the relation of hydrogeology and land use to ground-water quality (Helsel and Ragone, 1984).

This report presents the preliminary results of the ground-water quality assessment in one of the areas, the outcrop of the Potomac-Raritan-Magothy aquifer system in New Jersey (fig. 1). This aquifer system is the primary source of water in the New Jersey part of the Atlantic Coastal Plain physiographic province (Vowinkel, 1984, p. 19, table 3). However, continuing industrial and residential growth in the outcrop of the aquifer system have resulted in increased ground-water withdrawals, changes in the patterns of ground-water flow and aquifer recharge (Walker, 1983, p. 13, 24-25), and local degradation of ground-water quality (Geraghty and Miller, Inc., 1976).

Purpose, Scope, and Approach

This report presents a preliminary assessment of the ground-water quality in the outcrop of the Potomac-Raritan-Magothy aquifer system in New Jersey in relation to hydrogeology and land use. The scope of this report includes compilation of information concerning the hydrogeology, ground-water levels, ground-water use, land use, and ground-water-quality; design of a sampling program to obtain ambient ground-water-quality data, particularly trace metals and organic contaminants; and development and testing of methods to statistically compare ground-water-quality analyses grouped by hydrogeologic factors and land use to evaluate the influence of human activities on ground-water quality. For this study, the outcrop of the aquifer system was divided into two parts (fig. 1). The northern part of the outcrop is in central New Jersey and is called the primary study area. The southern part of the outcrop extends along the Delaware River and is called the secondary study area. This study closely examines the ground-water quality of the primary study area and compares it with that of the secondary study area, to test the transfer value of the water-quality/land-use relations to areas of similar climate, hydrogeology, and land use.

The tested hypothesis is that ground-water quality is related to land use. The primary study area was classified into three land uses: undeveloped, agricultural, and urban. Water-quality data were grouped by land use using two methods to designate land use at a sampled well--a predominant land-use method and a presence-absence method. The water-quality network was evaluated for variations in local hydrogeologic conditions at sampled wells to determine if hydrogeologic conditions differed significantly among land-use groups. The relation of hydrogeologic factors, such as aquifer sampled, aquifer confinement, depth to water, well depth, and pumping rate, to water quality were statistically evaluated without considering the affects of land use. Water-quality characteristics and the concentrations of major ions, nutrients, trace metals, pesticides,

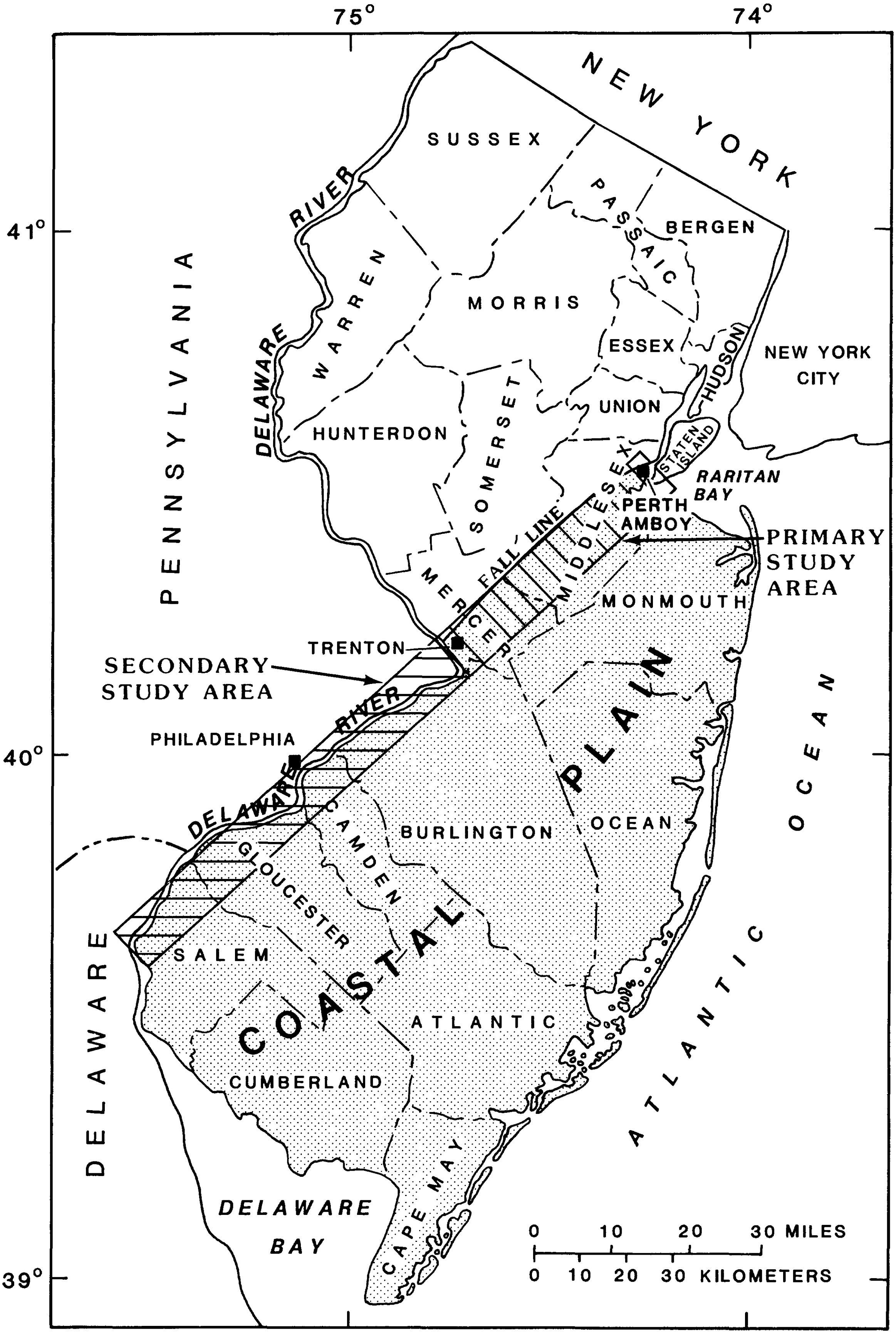

Figure 1.--Location of the primary and secondary study areas in the Coastal Plain of New Jersey.

and purgeable organic compounds were compared among groups using the Kruskal-Wallis test and frequency-of-detection method. The water-quality land-use relations determined for the primary area were compared to those determined for a secondary area. Statistical summaries of these analyses are presented in this report.

Previous Investigations

Studies of the Potomac-Raritan-Magothy aquifer system in central New Jersey have focused on hydrogeology and ground-water quality, emphasizing saltwater intrusion problems. Barksdale and others (1943), Geraghty and Miller, Inc. (1976), and Farlekas (1979) conducted investigations of ground-water resources in Middlesex County. Barksdale (1937) reported on the hydrogeology of the middle aquifer near South River and Appel (1962) studied both the upper and middle aquifers in the Raritan Bay area. Vecchioli and Palmer (1962), Widmer (1965), and the Delaware Valley Regional Planning Commission (1977) studied ground-water resources in Mercer County. Recent reports on the major aquifers in the New Jersey Coastal Plain include Walker's (1983) evaluation of water levels in the aquifer system and Zapecza's (1984) description of the hydrogeology of the aquifer system.

Studies of the water quality of the Potomac-Raritan-Magothy aquifer system have focused on defining ambient water quality and identifying iron, purgeable organic compounds, and saltwater contamination problems. Ambient ground-water quality studies on the Potomac-Raritan-Magothy aquifer system include: reports on water-quality data collected from 1923 to 1983 from the secondary study area by Fusillo and Voronin (1981), and Fusillo and others (1984); a report on water-quality data from Ocean and southern Monmouth Counties by Harriman and Voronin (1984); and an analysis of that data by Harriman and Sargent (1985). Langmuir (1969a, 1969b) reported on iron concentrations in the unconfined and confined parts of the aquifer system in southern New Jersey. Fusillo and others (1985) reported on the areal distribution of purgeable organic compounds in the secondary study area. Studies of the saltwater intrusion problems include Appel's (1962) study in the Raritan Bay area, Schaefer and Walker's (1981) investigation of saltwater intrusion in the upper aquifer also in the Raritan Bay area, and Schaefer's (1983) report on the distribution of chloride concentrations in the major aquifers of the New Jersey Coastal Plain.

Two studies have been published concerning the effects of land use on ground-water quality in New Jersey. Greenberg and others (1982) conducted an investigation of ground-water contamination throughout New Jersey and its relation to land use. No attempt was made to evaluate the effects of hydrogeologic factors on ground-water quality in that study. Fusillo and Hochreiter (1982) reported on purgeable organic compound contamination in the Potomac-Raritan-Magothy aquifer system in southern New Jersey and its relation to land use.

Acknowledgments

The authors are especially grateful to domestic, municipal, and industrial well owners in Mercer and Middlesex Counties who permitted access to their wells. We also want to thank the NJDEP for providing information on ground-water-contamination sites.

DESCRIPTION OF STUDY AREA

Hydrogeology

Physiography

The primary study area lies within the New Jersey part of the Atlantic Coastal Plain physiographic province and is bounded on the northwest by the Fall Line (fig. 1). This boundary separates the consolidated rocks of the Piedmont physiographic province from the unconsolidated sediments of the Coastal Plain. The primary study area lies almost entirely within the intermediate uplands subprovince of the Coastal Plain, as defined by Owens and Minard (1979, p. 4, fig. 3). The soils of the intermediate upland are typically sandy and well drained. However, in the northeast near South River there is a large poorly-drained area--an outlier of the central New Jersey Pinelands (McCormick and Forman, 1979, p. xl, fig. 4). Elevations in the study area primarily range from 100 to 180 feet above sea level, but are at or near sea level adjacent to the Delaware River and Raritan Bay. Generally, higher elevations are in the central part of the area. Locally, the area is strongly dissected by streams, and is characterized by a hilly topography, particularly adjacent to the Delaware River and Raritan Bay. The remaining land surface is relatively flat.

Lithology

The New Jersey Coastal Plain is underlain by a wedge of unconsolidated sediments that thickens and dips southeastward toward the Atlantic Ocean. The sediments range in age from Quaternary (youngest) to Cretaceous (oldest) and lie unconformably on pre-Cretaceous bedrock consisting of Jurassic and Triassic sedimentary and igneous rocks and lower Paleozoic and Precambrian metamorphic and igneous rocks (table 1). The oldest of the Coastal Plain sediments are the Potomac Group and Raritan and Magothy Formations of Cretaceous age, which together form the Potomac-Raritan-Magothy aquifer system. In the primary study area, the aquifer system does not include the Potomac Group (table 1); however, the term Potomac-Raritan-Magothy aquifer system is used for consistency with terminology used throughout New Jersey. This aquifer system consists predominantly of subaerial delta-plain deposits of interbedded clay, silt, sand, and gravel (Owens and Sohl, 1969, p. 255).

The Potomac-Raritan-Magothy aquifer system crops out in a narrow band, 3 to 6 miles wide, adjacent to the Delaware River in southern New Jersey from Salem to Burlington Counties, and extends northeastward into central New Jersey through Mercer and Middlesex Counties to Raritan Bay (fig. 1). Throughout most of New Jersey, including the secondary study area, the Potomac-Raritan-Magothy aquifer system consists of three major aquifers: the upper, middle, and lower (Zapecza, 1984, p. 14). However, these aquifers and the confining units that separate them are not continuous in outcrop. In the primary study area, the Potomac-Raritan-Magothy aquifer system contains only two aquifers--upper and middle (table 1). Figure 2 is a generalized map of the outcrop of the aquifer system in the primary study area. This map was compiled from maps developed by Barksdale and others (1943), Owens and Minard (1964), Widmer (1965), and Farlekas (1979), and additional information obtained from drillers' and geophysical logs.

Table 1.-- Geologic and hydrogeologic units in the primary study area.[1]

System	Geologic units		Hydrogeologic units	
Quaternary	Alluvial deposits		Undifferentiated	
Tertiary	Pensauken Formation		Undifferentiated	
	Bridgeton Formation			
	unconformity			
Cretaceous	Englishtown Formation		Englishtown aquifer system	
	Woodbury Clay		Merchantville-Woodbury confining unit	
	Merchantville Formation			
	unconformity			
	Magothy Formation	Amboy Stoneware Clay Member		
		Old Bridge Sand Member	Upper aquifer	Potomac-Raritan-Magothy aquifer system[2]
	Raritan Formation	South Amboy Fire Clay Member		
		Sayreville Sand Member		
		Woodbridge Clay Member	Confining unit	
		Farrington Sand Member	Middle aquifer	
		Raritan Fire Clay Member	Confining unit	
		unconformity		
Jurassic and Triassic	Newark Supergroup and diabase intrusives			
	unconformity			
Lower Paleozoic and Precambrian	Metamorphic and igneous rocks			

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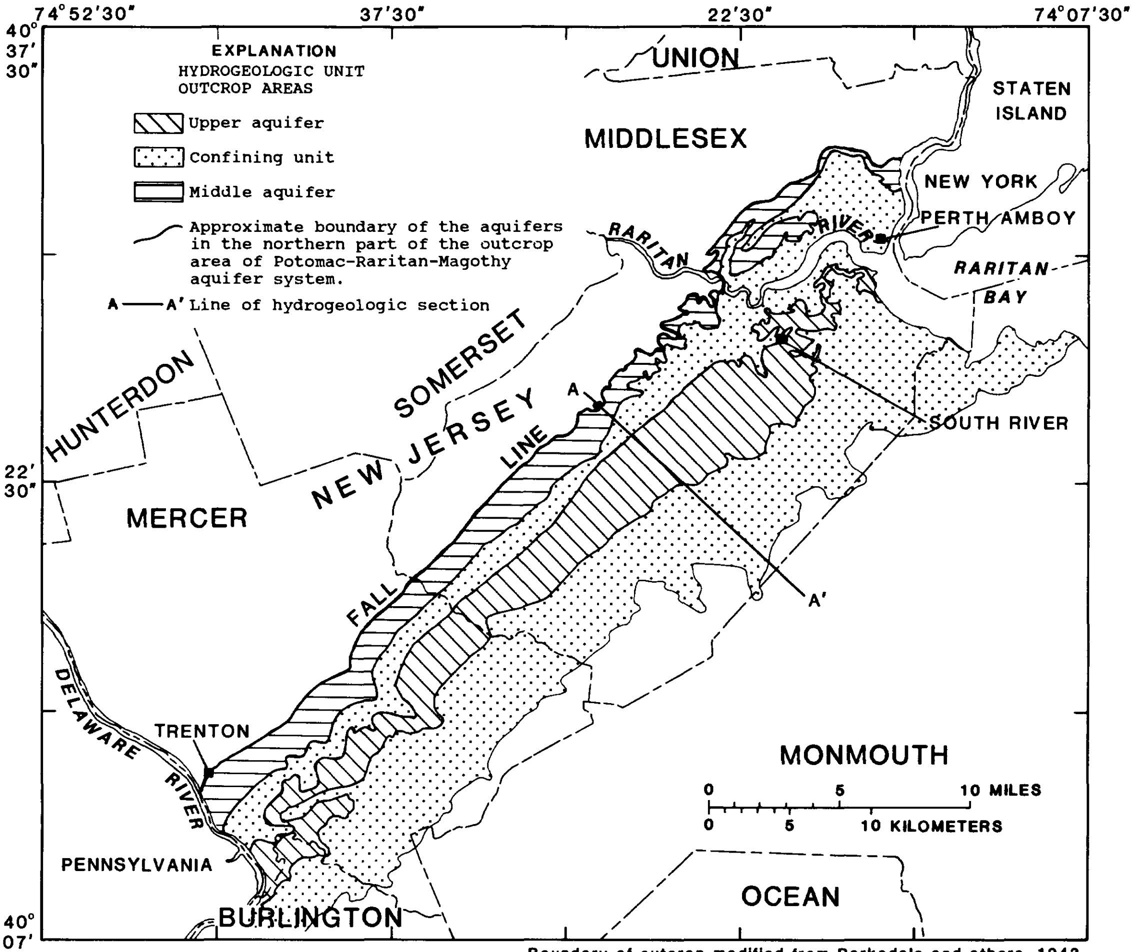
[1] Modified after Zapecza (1984), table 2.

[2] The aquifer system does not include the Potomac Group within the primary study area, but in order to maintain consistent terminology the aquifer-system name that is used in this report is that commonly used throughout New Jersey.



Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 2.--Generalized hydrogeologic unit outcrops and line of hydrogeologic section in the primary study area.

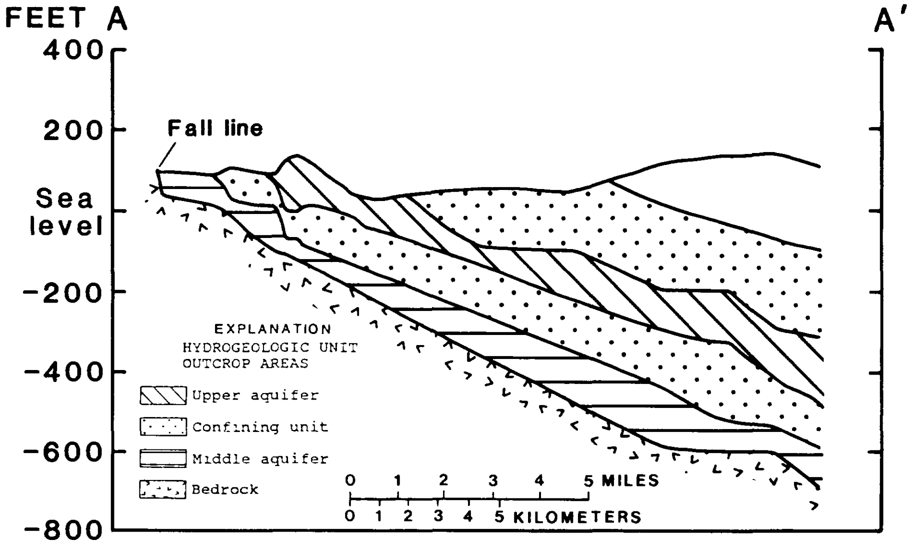


Figure 3.--Generalized hydrogeologic section in the primary study area. (Line of section shown in fig. 2).

Previous to this investigation, the Potomac-Raritan-Magothy aquifer system was not differentiated into aquifers and confining units in southwestern Middlesex or Mercer Counties. A generalized hydrogeologic section of the Potomac-Raritan-Magothy aquifer system in the primary area is illustrated in figure 3. The aquifer system generally strikes northeast-southwest and dips gently to the southeast at about 50 feet per mile. A detailed description of the hydrogeologic units from youngest to oldest follows.

The Merchantville-Woodbury confining unit overlies the upper aquifer and consists of the Woodbury Clay, the Merchantville Formation, and, where extensive, the Amboy Stoneware Clay Member of the Magothy Formation (table 1). The Woodbury Clay is a black, very micaceous, fossiliferous silty clay about 50 feet thick in Mercer County (Widmer, 1965; Owens and Sohl, 1969, p. 242). The Merchantville Formation consists of greenish-black, glauconitic, fossiliferous clay and silt averaging 50 to 60 feet thick and lies disconformably on the Magothy Formation (Owens and Sohl, 1969, p. 242). Together, these clays comprise the most extensive confining unit in the New Jersey Coastal Plain. Their combined thickness reaches a maximum of 370 feet in Monmouth County downdip of the primary study area.

The upper aquifer consists predominantly of the Old Bridge Sand Member of the Magothy Formation, and, therefore, is commonly called the Old Bridge aquifer in Middlesex and Monmouth Counties (Farlekas, 1979, p. 6). The upper aquifer consists of fine- to coarse-grained sand and gravel with interbedded layers of clay and silt. These sediments are multicolored, lignitic, pyritic, and micaceous (Owens and Sohl, 1969, p. 239). Where extensive, the Cretaceous-aged Sayreville Sand Member of the Raritan Formation is included in the upper aquifer. When in hydraulic connection with these Cretaceous deposits, Tertiary-aged sand and gravel of the Bridgeton Formation also are included in the upper aquifer. This aquifer has a maximum thickness of about 220 feet in Middlesex County.

The confining unit separating the upper and middle aquifers consists of the Woodbridge Clay Member of the Raritan Formation. The Woodbridge Clay Member consists of massive silty clays and thinly interbedded clays and fine sands, which contain abundant mica, lignite, root structures, and marginal-marine mollusks (Owens and Sohl, 1969, p. 239). Its thickness is variable, but generally increases southeast or downdip. It reaches a maximum thickness of about 290 feet in Middlesex County, but is believed to be absent in some localities within the primary study area (Geraghty and Miller, Inc., 1976; Roux and Althoff, 1980). Where absent, the upper and middle aquifers are hydraulically connected.

The middle aquifer consists of the Farrington Sand Member of the Raritan Formation, and is commonly called the Farrington aquifer in the northern part of the primary study area (Farlekas, 1979, p. 8). The lithology of this aquifer is similar to that of the upper aquifer (Zapecza, 1984, p. 12). The middle aquifer has a maximum thickness of about 160 feet in Middlesex County. Near the Raritan River in Middlesex County, the middle aquifer thins and is locally absent (Murashige and others, U.S. Geological Survey, written commun., 1985).

The confining unit beneath the middle aquifer consists partly of a discontinuous layer called the Fire Clay Member of the Raritan Formation and partly of bedrock. The Raritan Fire Clay Member is a massive, multicolored clay that directly overlies bedrock. The bedrock includes the Jurassic and Triassic Newark Supergroup, and lower Paleozoic and Precambrian metamorphic and igneous rocks. The Newark Supergroup consists of nonmarine sedimentary rocks and diabase. The sedimentary rocks are fine- to coarse-grained arkose of the Stockton Formation and red shale and sandstone of the Brunswick Formation. Most of the lower Paleozoic and Precambrian rocks are metamorphic and feldspathic; locally, the rocks are micaceous, particularly the schist and gneiss of the Wissahickon Formation (Vecchioli and Palmer, 1962).

Ground-water Movement

The source and age of ground water are important in evaluating the influence of land use on ground-water quality. The source and age of the water pumped from each well is site specific and can differ depending on the local hydrogeologic conditions, well construction, and pumping rates. Nevertheless, an estimate of the source and age of water was made by obtaining a detailed understanding of ground-water movement within the outcrop of the system and in the confined parts of the upper and middle aquifers.

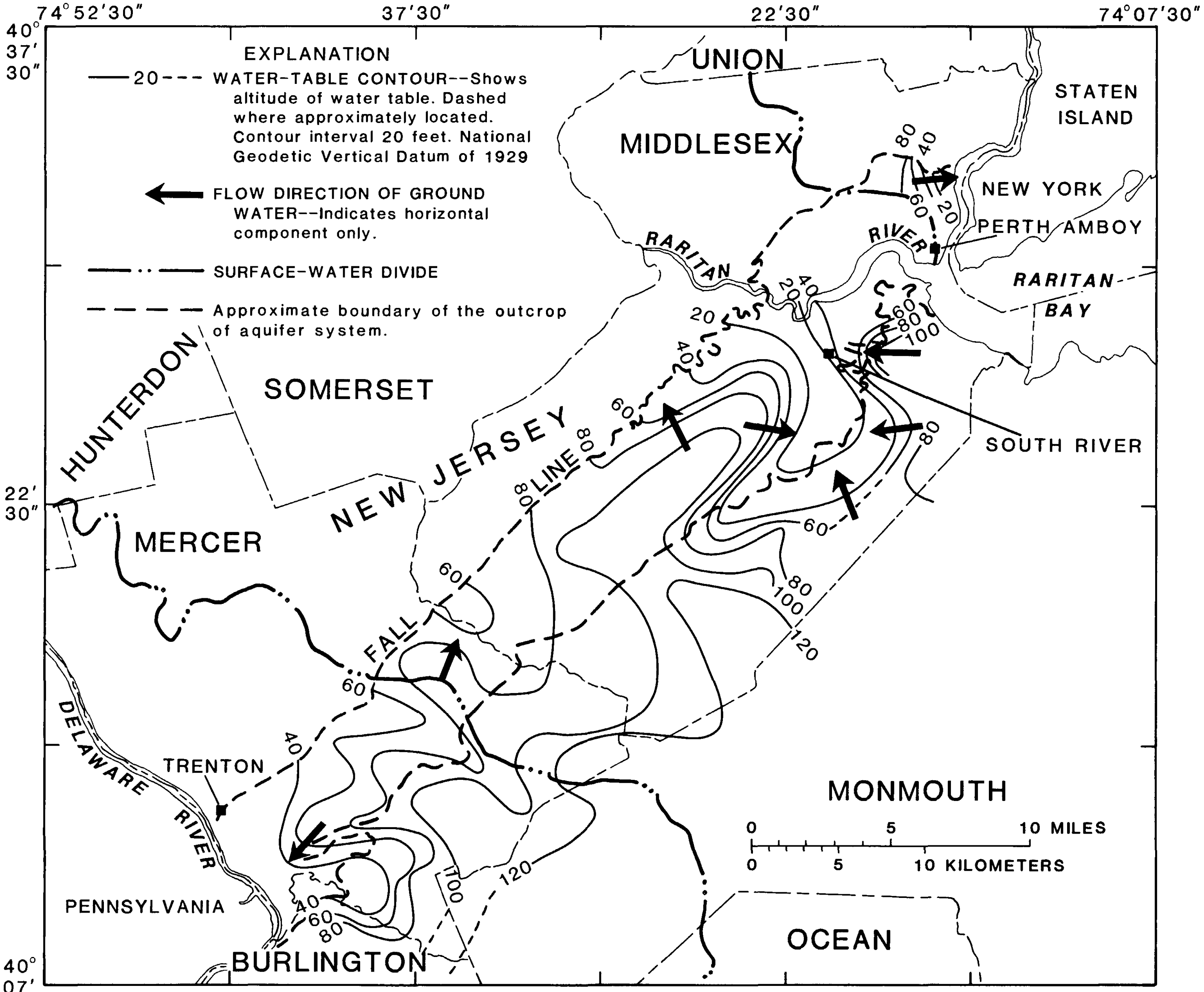
The principal source of recharge to the aquifer system in the primary study area is precipitation. The mean annual precipitation is about 44 inches. Long-term gaging records indicate that runoff averages about 19 inches per year (Vowinkel and Foster, 1981, p. 18, table 4). Because the terrain is generally flat and covered with sediments of a high porosity, surface-water runoff is low. Ground-water infiltration in the outcrop of the aquifer system was estimated at 12 to 20 inches per year (Barksdale, 1937, p. 16). Recharge to the deep confined part of the aquifer system was estimated at 9 to 17 percent of the average annual precipitation or 4 to 8 inches per year (Farlekas, 1979, p. 32). A mean hydraulic conductivity of 150 ft/d (feet per day) was estimated from 270 specific-capacity tests in the aquifer system. Results of 19 multiple-well aquifer tests conducted in the aquifer system yield hydraulic conductivities ranging from 150 to 250 ft/d. Transmissivity in the outcrop of the aquifer system ranges from about 2,000 to 6,000 cubic feet per day (Martin, 1987). In general, transmissivity increases downdip with increasing aquifer thickness.

Generalized contour maps of the water table and potentiometric surfaces of the confined parts of the upper and middle aquifers were developed from data from various sources. The water-table map was generated from water levels measured in wells at the time of their installation and from points of intersection between surface water and topographic contours. The potentiometric-surface maps of the confined parts of the aquifers were generated from data collected for the U.S. Geological Survey's observation well network and 1983 synoptic water-level measurement program (Eckel and Walker, 1986) and from additional water levels measured in wells at the time of their installation.

Figure 4 is the generalized map of the water table in the Potomac-Raritan-Magothy outcrop in the primary study area. A major surface-water divide separates flow toward either Raritan Bay or the Delaware River. The ground-water divide between the Raritan and Delaware River Basins has a similar configuration. Most of the water recharging the aquifer eventually discharges to local streams and then to the Delaware River or Raritan Bay. Water-table gradients vary within the study area. Steep gradients in the northeast indicate ground-water velocities of several feet per day. In contrast, ground-water velocities in some central areas are less than 1 ft/d. Assuming an average velocity of 1 foot per day and maximum linear flow paths of 8,000 feet, estimated from drainage basin maps, the age of the ground water in the outcrop of the aquifer system was estimated to be generally less than 20 years.

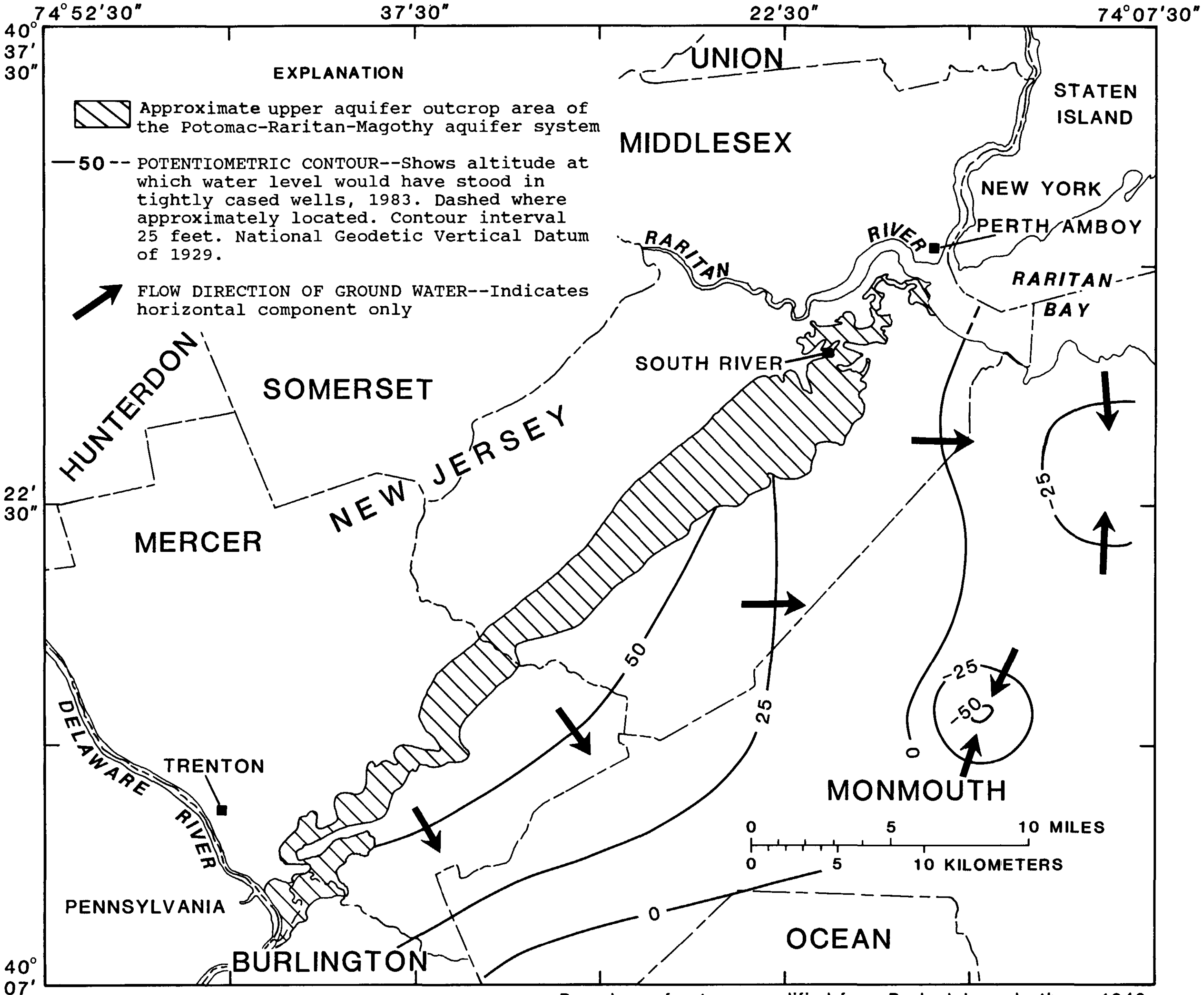
The confined parts of the upper and middle aquifers are primarily recharged by lateral flow from their outcrops and by vertical leakage through adjacent confining units. The generalized contour map of the potentiometric surface of the confined part of the upper aquifer in 1983 (fig. 5) indicates an east to southeasterly flow except near two regional cones of depression in Monmouth County, where ground water flows radially toward each cone. In central Monmouth County, the potentiometric surface in the center of the cone of depression is greater than 50 feet below sea level. Near Raritan Bay, the potentiometric surface in the center of the cone of depression is 40 feet below sea level. Generalized contours of the potentiometric surface of the confined part of the middle aquifer in 1983 are shown in figure 6. The general flow direction is southeasterly; however, near Raritan Bay, a regional cone of depression extends more than 75 feet below sea level.

Regional water-levels in the Potomac-Raritan-Magothy aquifer system (Walker, 1983, p. 13, 24-25; Schaefer and Walker, 1981, p. 8; Farlekas, 1979, p. 13, 22) have declined because of ground-water withdrawals. In the South River area, lowering of head has induced flow from the Raritan Bay and South River into the middle aquifer (Appel, 1962, p. 11-22). In central Middlesex County, lowering of head has induced flow from the upper aquifer to the middle aquifer through the Woodbridge confining unit (Roux and Althoff, 1980). In addition, the saltwater-freshwater transition zone in the Raritan Bay area has moved landward in response to water-level declines (Schaefer, 1983, p. 1).



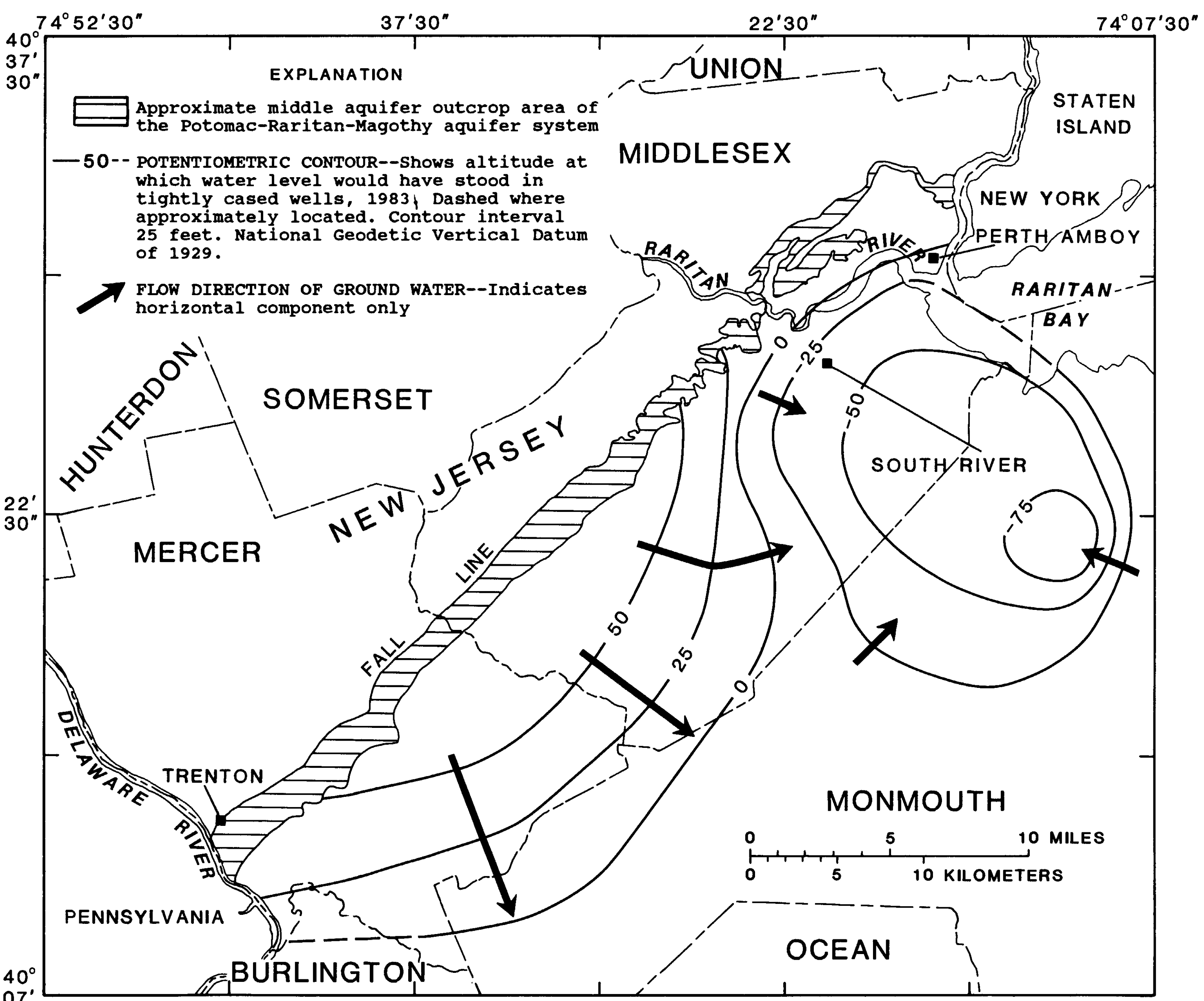
Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 4.--Generalized water table of the Potomac-Raritan-Magothy aquifer system in the primary study area.



Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 5.--Potentiometric surface of upper aquifer in the primary study area, 1983.



Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 6.--Potentiometric surface of middle aquifer in the primary study area, 1983.

Water Use

Ground water is the principal source of potable water in the Coastal Plain of Middlesex and Mercer Counties (Vowinkel, 1984, p. 22). In 1983, about 70 Mgal/d (million gallons per day) were pumped from the Potomac-Raritan-Magothy aquifer system in Mercer, Middlesex, and parts of Monmouth Counties. Figure 7 shows ground-water withdrawals from 1956 to 1983 by type of use. Withdrawals by public-supply purveyors in the area increased about 130 percent from 1956 to 1983. Self-supplied industrial usage accounted for more than half of the total pumpage prior to 1961. Since 1961, while industrial withdrawals remained constant or declined slightly, withdrawals by public-supply purveyors increased. Agricultural withdrawal data are not well documented; therefore, figure 7 is not representative of all agricultural pumpage.

The combined pumpage from the upper and middle aquifers increased by 33 Mgal/d from 1956 to 1980 (fig. 7). Most of this increase occurred before 1970. Withdrawals from the upper aquifer increased about 50 percent between 1956 and 1971, reaching a maximum rate of about 45 Mgal/d. From 1971 to 1983, withdrawals from the upper aquifer decreased about 20 percent to almost 36 Mgal/d. A large proportion of the withdrawals from the upper aquifer is from wells in the unconfined outcrop; however, pumpage from the deeper confined parts of the aquifer has been increasing since 1970. Withdrawals from the middle aquifer are primarily from the confined parts of the aquifer and have increased almost every year during the period of record. Pumpage in the outcrop of the middle aquifer was less than 1 Mgal/d in 1983.

Land Use

History of Development

Settlement adjacent to the Delaware River at Trenton and along Raritan Bay at Perth Amboy began as early as 1675. The population spread toward the central part of the area and the entire area was settled by 1715 (Wacker, 1979, p. 7, fig. 1). Two of the major factors controlling settlement and land-use distribution were the availability of good soil to support the predominantly agricultural society of that time and the area's proximity to the cities of Philadelphia and New York (Wacker, 1979, p. 20).

Prior to World War II, urban land was primarily concentrated in the old, industrialized areas near the cities of Trenton and Perth Amboy. Undeveloped and agricultural lands were primarily in the central part of the area. After World War II, population and the number of housing units rapidly increased (U.S. Bureau of Census, 1983c). From 1950 to 1980, the population of Middlesex County increased by approximately 125 percent and population density increased from 840 to 1,890 persons per square mile (U.S. Bureau of Census, 1952; 1983a; and 1983b). During the same period, Mercer County's population increased 33 percent and population density increased from 1,010 to 1,360 persons per square mile. Since the 1950's, the old urban centers have expanded outward through conversion of the undeveloped and agricultural land to urban land uses. From 1950 to 1980, Middlesex

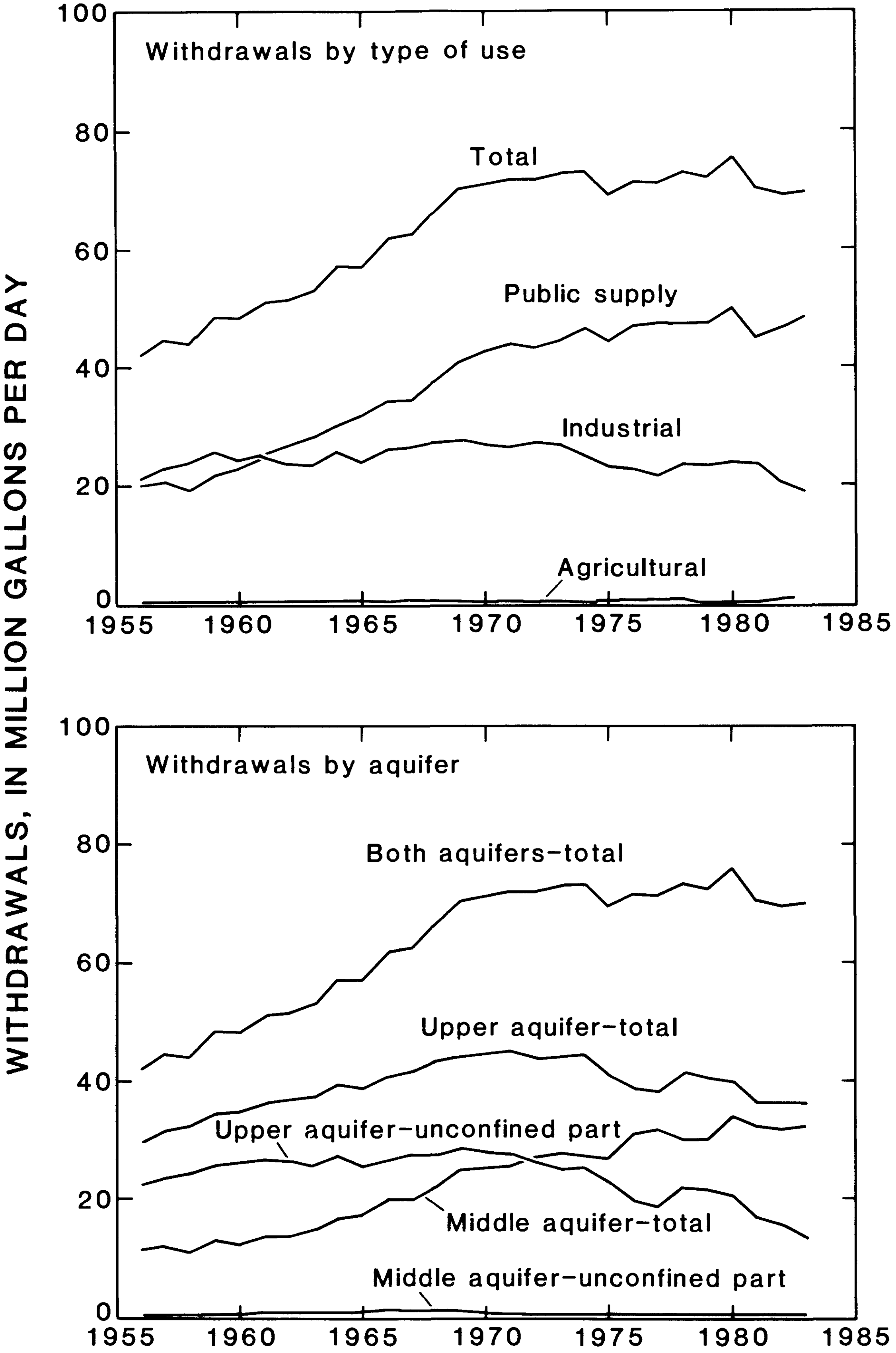


Figure 7.--Ground-water withdrawals from the Potomac-Raritan-Magothy aquifer system in Mercer, Middlesex and parts of Monmouth Counties (excludes domestic and unavailable grandfather rights withdrawals).

County had a 50-percent decrease in agricultural land; Mercer County, a 20-percent decrease (New Jersey Crop Reporting Service, 1957; 1980-1984; U.S. Bureau of Census, 1983c).

Classification

Land use in the study area was evaluated from maps based on 1974 data and the U.S. Geological Survey's land-use and land-cover classification system (Anderson and others, 1976). This classification system designates land use at two levels of detail. Level I groups include: urban or built-up land, agricultural land, forest land, water, wetland, and barren land. Each Level I group is further classified into two or more Level II groups. For example, urban land includes residential, commercial and services, industrial, transportation, and several other mixed-urban categories.

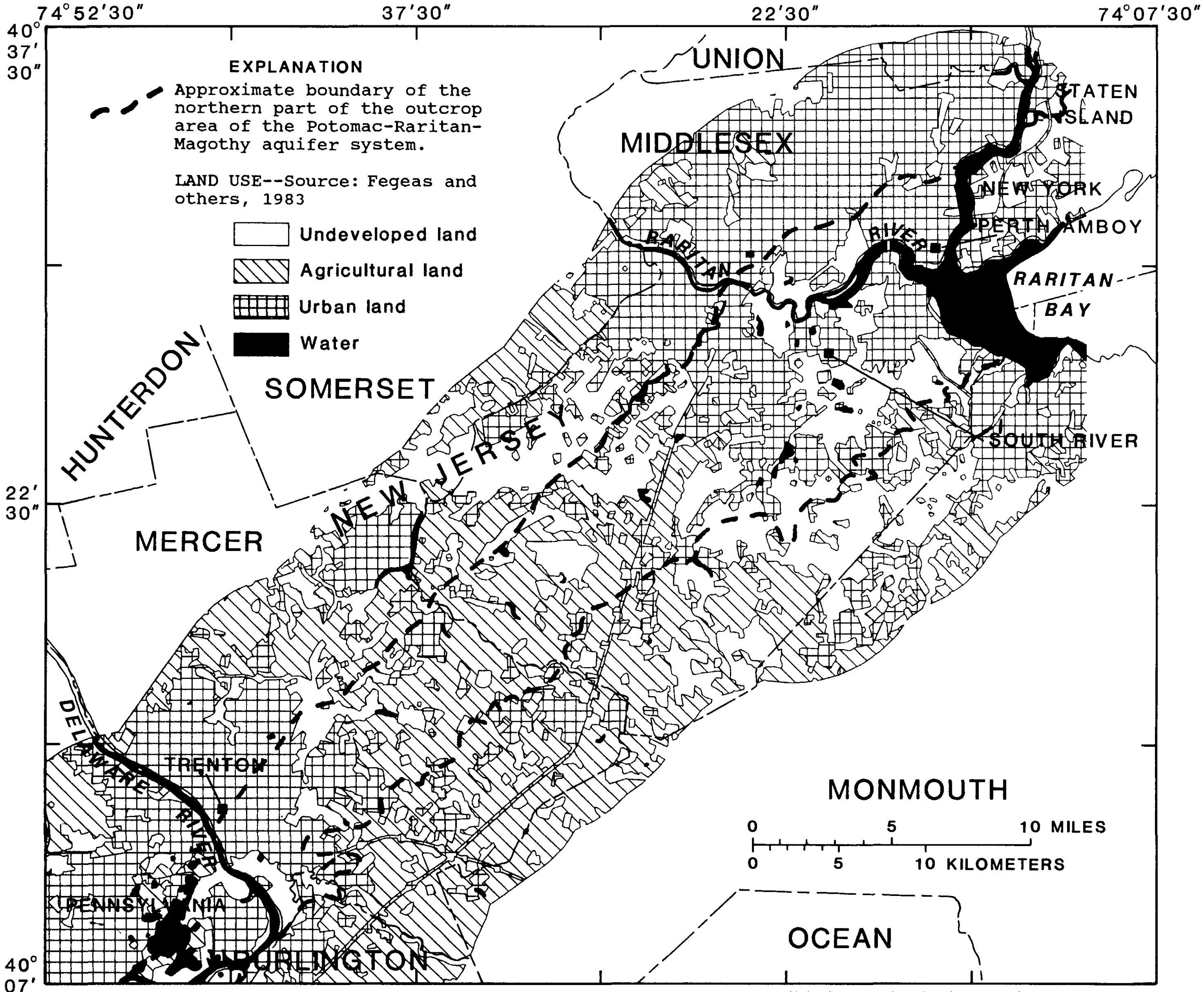
Land use in the primary (fig. 8) study areas was aggregated into three land-use groups: undeveloped, agricultural, and urban. All aggregated land-use maps presented in this report were developed from land-use maps developed by the U.S. Geological Survey using 1974 LANDSAT data, published at a scale of 1:250,000, and digitized by the National Cartographic Information Center (Fegeas and others, 1983). Photo-interpretation principles, land-use classification, and mapping specifications for LANDSAT data are described by Loelkes and others (1983). Land-use percentages at each well were estimated from maps developed for the New Jersey Land Oriented Reference Data System (LORDS) and published at a scale of 1:63,360 (1 inch = 1 mile) (New Jersey Department of Environmental Protection, 1975-76). Land use for these maps were interpreted from aerial photographs, EROS (Earth Resources Observation System) images, and topographic quadrangles. Land uses overlying each aquifer and confining unit in the primary study area also were estimated from the LORDS land-use maps as percentage of total land area (table 2).

Table 2.-- Land-use groups and outcrop percentages in the primary study area.

	Approximate land area (square miles)[2]				
Land use[1]	Upper aquifer	Confining unit	Middle aquifer	Total	Percentage[2] of outcrop
Undeveloped	18	19	10	47	33
Agricultural	21	9	9	39	28
Urban	17	22	15	54	39
Total	56	50	34	140	100

[1] The land-use groups are based on the U.S. Geological Survey land use and land cover classification system developed by Anderson and others, 1976. The agricultural and urban land uses represent Level I groups. The undeveloiped group is an aggregate of four Level I groups; forest land, water, wedland, and barren land.

[2] The land-use area and percentage of outcrop were estimated from the New Jersey Land Oriented Data Reference System (LORDS) overlay maps (New Jersey Department of Environmental Protection, 1975-1976).



Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 8.--Land use in the primary study area, 1974.

About 33 percent of the primary study area is undeveloped land consisting of four Level I categories: forest land (18 percent), wetlands (9 percent), barren land (3 percent), and water (3 percent). Native forest stands and areas of former farmland or orchards that have reverted back to forest cover constitute the forest land category. Wetlands occur along Raritan Bay, the Delaware and Raritan Rivers, and their tributaries. Areas bordering the numerous lakes and ponds and those prone to seasonal flooding also are classified as wetlands. The largest area of wetlands is near South River and is an outlier of the Pinelands (McCormick and Forman, 1979, p. xl, fig. 4). Rivers, lakes, ponds, and surface-water impoundments are classified as water. These Level I categories were combined because contamination as a result of human activities was expected to be minimal in each area.

Agricultural land comprises 28 percent of the primary study area and consists of cropland, pastures, orchards, and horticulture. Most farms in the area harvest potatoes, wheat, barley, soybeans, and garden vegetables. In addition, there are dairy and poultry farms throughout the area (New Jersey Crop Reporting Service, 1980-1984).

About 39 percent of the primary study area is urban land consisting of several Level II land-use categories including: residential and mixed-urban (25 percent), commerical and services (5 percent), industrial (4 percent), and transportation-communications-utilities (4 percent). Landfills (1 percent) also are included in the urban group. Level-II land uses were consolidated into one category prior to statistical analysis because the sample size for categories such as commercial and services was too small to evaluate statistically.

Sources of Ground-water Contamination

Ground water can be contaminated by various point and nonpoint sources. Point sources generally include landfills, industrial spills, industrial liquid-waste lagoons, industrial storage and transmission facilities, and animal feedlots. Nonpoint sources include road salts, domestic septic systems, pesticides and fertilizers applications, sewer leakage, and illegal discharges.

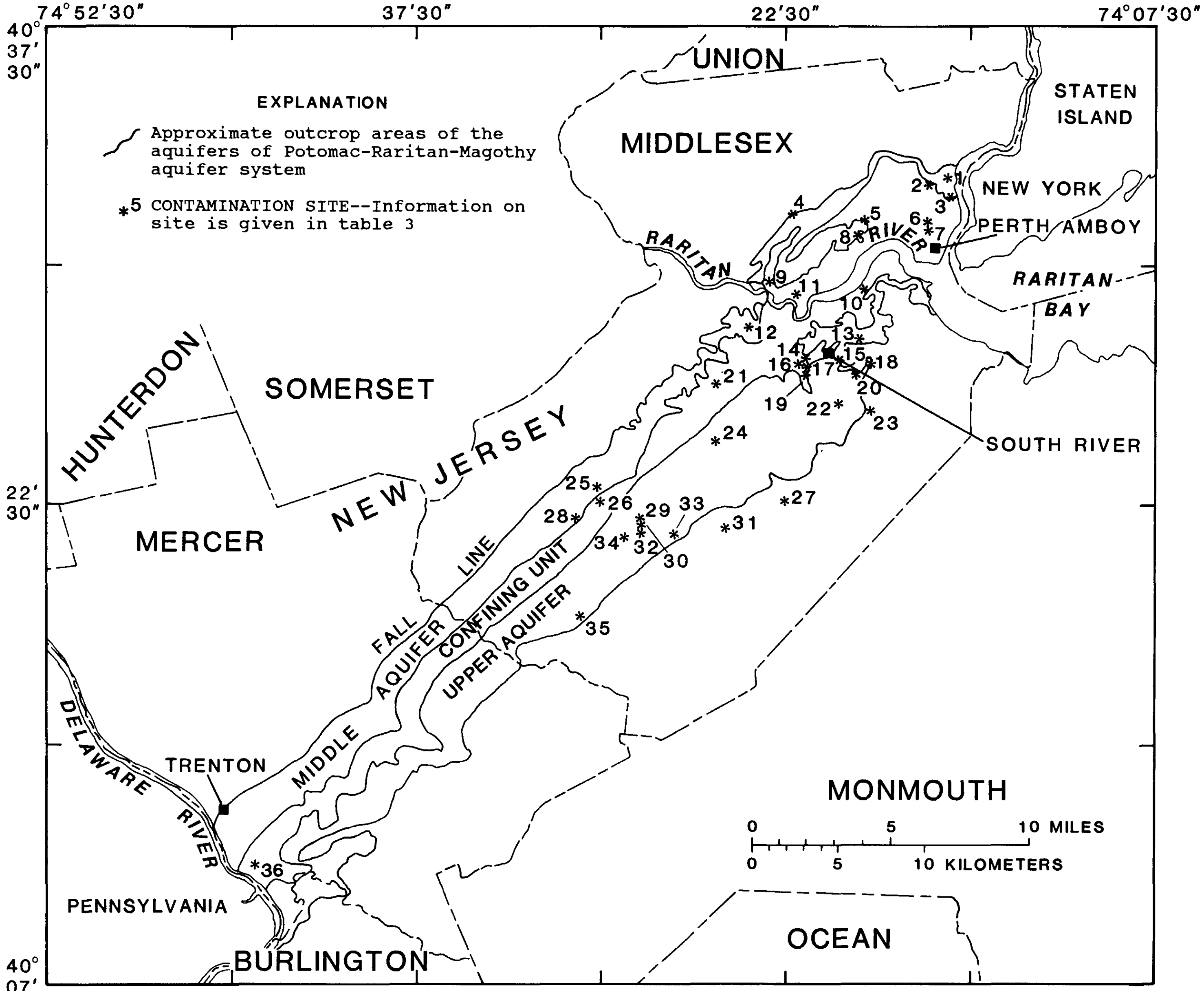
An inventory of ground-water contamination sites and contaminants detected was compiled to determine the types of ground-water contaminants and the areal distribution of contamination (fig. 9 and table 3). Data were obtained from the New Jersey Ground Water Pollution Index files (New Jersey Department of Environmental Protection, written commun., 1985); the Management Plan 1983-1986 for Hazardous Waste Site Cleanups in New Jersey (New Jersey Department of Environmental Protection, 1983); the Bureau of Environmental Evaluation and Risk Assessment files (New Jersey Department of Environmental Protection, written commun., 1985); the Emergency Remedial Response Information System (ERRIS) List (U.S. Environmental Protection Agency, written commun., 1985); and the National Priorities List (U.S. Environmental Protection Agency, 1984).

Thirty-six ground-water-contamination sites, located in or near the the outcrop of the northern part of the Potomac-Raritan-Magothy aquifer system, were identified from Federal and State files. All except one are located in Middlesex County. Of the 36, 17 are classified by the New Jersey Department of Environmental Protection as hazardous waste sites (Britton, 1984) and 8 are on the U.S. Environmental Protection Agency's 1984 National Priorities List. An additional 31 sites, where ground-water contamination is suspected, are currently being investigated by Federal and State agencies, but are not included in table 3 or figure 9.

Purgeable organic compounds, identified in ground-water at 28 of the 36 contamination sites, are the most commonly detected ground-water contaminants. In order of decreasing occurrence, the purgeable organic compounds that were detected include benzene, toluene, xylene, trichloroethylene, chloroform, 1,2-dichloroethane, 1,1,1-trichloroethane, and tetrachloroethylene. Trace metal concentrations above Federal and State primary drinking-water standards (U.S. Environmental Protection Agency, 1976b; 1977 and New Jersey Department of Environmental Protection, 1979) occurred in wells at 20 sites. Metal contaminants include lead, zinc, copper, chromium, arsenic, and cadmium. Pesticides were detected at 12 sites. Dieldrin, endrin, chlordane, DDD, DDE, and DDT were most frequently detected. Polychlorinated biphenyls (PCB's) were detected at 6 sites and phenols at 7 sites. Other categories of contaminants identified at the ground-water-contamination sites include nutrients, other hydrocarbons, plastic additives and monomers, acids or bases, and radioactive compounds.

Onsite wastewater disposal using septic systems or cesspools can be a source of contaminants, especially nitrates (Todd and McNulty, 1976; Perlmutter and Koch, 1972; Ragone and others, 1980, p. 46; U.S. Congress, 1984). Approximately 8,000 dwelling units are served by onsite wastewater disposal systems in the primary study area (U.S. Bureau of the Census, 1983a,b). Most of these are located in the central part of the primary study area.

Leaks or surface discharges from sewage-collection systems also can contaminate ground water. Approximately 30 percent of the outcrop is sewered (fig. 10). Most of the sewered areas are in the older urban centers near Trenton and Perth Amboy. Approximately 100 Mgal/d of wastewater, including discharges from industrial sources, is treated in Middlesex and Mercer Counties. Aging sewer lines, most more than 40 years old, are prone to more leaks than newer systems (Geraghty and Miller, Inc., 1976; Delaware Valley Regional Planning Commission, 1977).



Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 9.--Ground-water contamination sites in the primary study area.

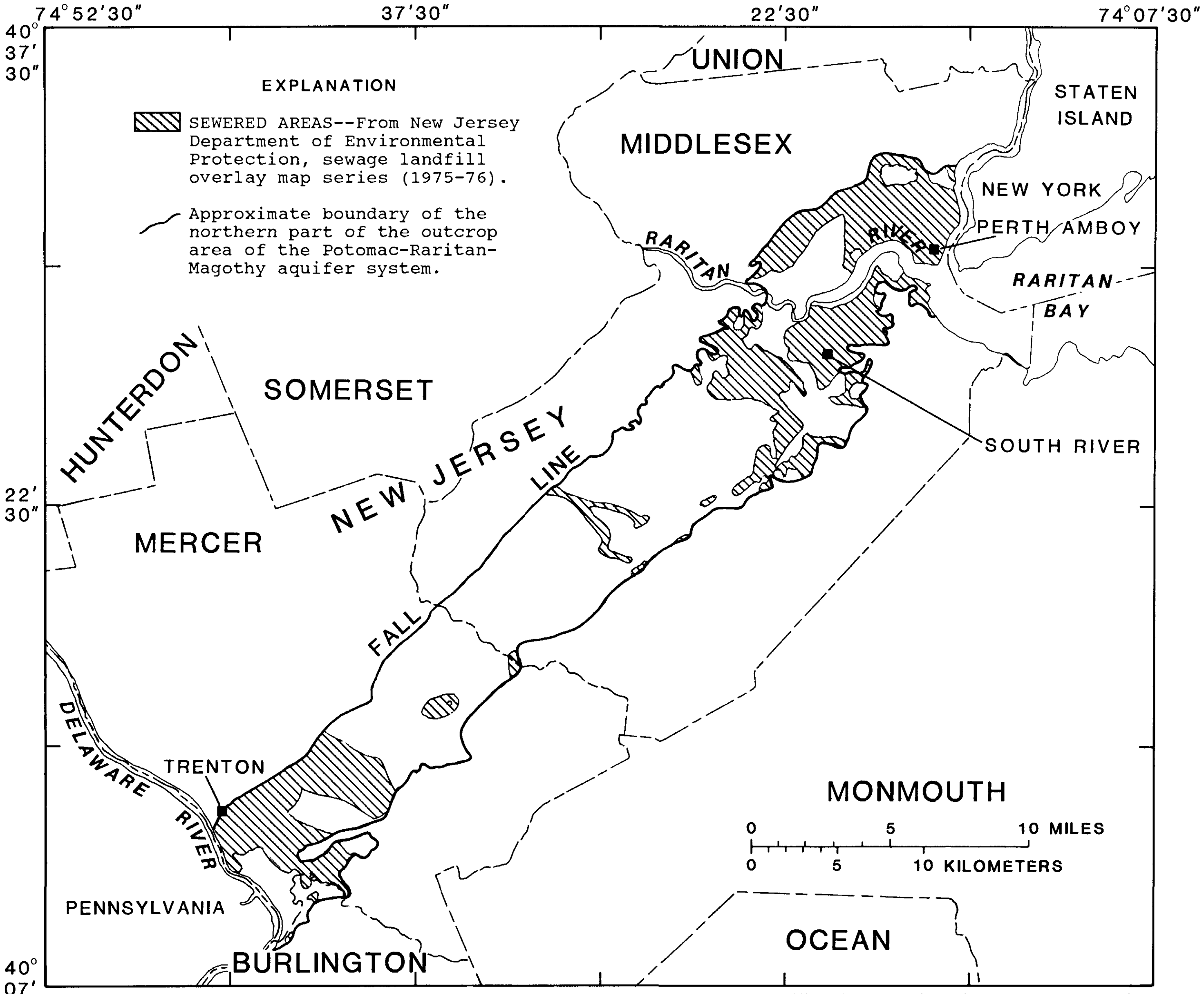
Table 3.- Ground-water contamination sites and identified contaminants.

[Locations of sites shown in fig. 9]

Map identifier	Purgeable organics	Pesticides	Phenols	PCB's	Other hydrocarbons	Metals	Nutrients	Acids or bases	Radioactive compounds	Plastic additives
1	-	-	-	-	-	X	-	-	-	-
2	X	X	-	-	-	-	-	-	-	-
3	-	X	-	-	-	X	X	-	X	-
4	X	-	-	-	X	-	X	X	-	-
5	X	-	X	-	X	-	-	-	-	-
6	X	?	-	X	-	-	-	-	-	-
7	-	-	-	X	-	-	-	-	-	-
8	X	X	X	X	X	X	X	X	-	X
9	X	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	X	-	X	-	-
11	X	X	X	-	-	X	-	X	-	-
12	X	-	X	-	X	X	-	-	-	-
13	X	X	-	-	-	-	-	-	-	-
14	-	-	-	-	-	X	X	-	-	-
15	X	-	X	-	X	X	-	X	-	-
16	X	X	-	-	-	-	-	-	-	-
17	X	-	-	-	X	-	-	-	-	-
18	X	X	-	-	-	-	-	-	-	-
19	X	-	X	-	-	X	-	-	-	-
20	X	-	-	-	-	X	X	X	-	-
21	X	-	-	-	-	-	-	-	-	-
22	X	-	X	-	X	X	-	-	-	-
23	X	?	-	X	-	X	-	-	-	-
24	-	-	-	-	X	-	-	-	-	-
25	X	X	-	X	-	X	-	-	-	-
26	X	-	-	-	-	X	-	-	-	-
27	X	-	-	-	-	X	-	-	-	X
28	X	-	-	-	-	X	X	-	-	-
29	X	-	-	X	-	X	X	-	X	X
30	X	-	-	-	-	X	-	-	-	-
31	X	-	-	-	-	-	-	-	-	-
32	X	-	-	-	-	X	-	-	-	-
33	X	-	-	-	-	-	-	-	-	-
34	-	X	-	-	-	-	-	-	-	-
35	-	X	-	-	-	-	X	X	-	-
36	X	-	-	-	-	X	-	-	-	-
All sites	28	12	7	6	8	20	8	7	2	3

Explanation
- = Contaminant not analyzed or detected at the site.
X = Contaminant identified in ground water at site.
? = Contaminant may be present at site but not confirmed.

Sources of information:
Britton, 1984; New Jersey Department of Environmental Protection, 1983;
U.S. Environmental Protection Agency, 1984



Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 10.--Areas served by public sewage treatment facilities in the primary study area.

DESCRIPTION OF WATER-QUALITY DATA-COLLECTION PROGRAM

Sampling Network

Existing chemical analyses of ground water were reviewed to assess the availability of water-quality data for the northern part of the Potomac-Raritan-Magothy aquifer system. Data were obtained from the U.S. Geological Survey WATSTORE file, U.S. Environmental Protection Agency STORET file, New Jersey Department of Environmental Protection Ground Water Pollution Index files, and consultants' reports. Most analyses in WATSTORE and STORET were collected to monitor saltwater intrusion in Middlesex County. Only a few chemical characteristics or constituents, such as chloride, hardness, iron, and pH are reported. Many trace metal and purgeable organic compound analyses are available in the Ground Water Pollution Index files and consultant's reports to Federal and State regulatory agencies; however, this information is not in a computerized format. In most cases these data are from site-specific pollution studies and are not representative of ambient ground-water quality. Differences in sampling techniques and laboratory methods and poorly documented quality-assurance procedures of existing data made it difficult to evaluate these data.

Because ambient ground-water-quality data were lacking, a sampling network was designed to generate data to evaluate the relation of land use to ground-water quality. The sampling network was designed to collect water that is representative of the three aggregated land uses and which had recently recharged the aquifer system. In addition, the sampling network was designed to avoid point-source contamination and minimize variations in other factors such as hydrogeologic conditions around the sampled well.

The sampling network consists of 71 wells, all of which existed prior to this study (table 4 and fig. 11). Thirty-seven wells are screened in the upper aquifer. Of these, 30 are in the unconfined part of the upper aquifer and 7 have some confining material above the screened interval. The remaining 34 wells are screened in the middle aquifer. Twenty-four are in the unconfined part of the middle aquifer and 10 have some confining material above the screened interval. The majority of the 17 wells with confining material above the screened interval are located within 1 mile of their respective outcrops. No wells were sampled within the disposal area of landfills or industrial lagoons. However, 15 wells are located within a quarter of a mile from an identified ground-water-contamination site (fig. 9). The sampling network includes a variety of well types: 57 withdrawal wells, 9 observation wells, 2 standby-emergency-supply wells, and 3 unused wells (table 4). Current use of the water from these wells includes: 20 public supply, 19 industrial, 16 domestic, 2 irrigation, 1 commercial, and 1 institutional. Twelve wells are not currently used for water supply. Most of the data from this sampling program are included in a report of ground-water quality in the South River Area by Harriman and others (U.S. Geological Survey, written commun., 1987).

Table 4.-- <u>Selected information on sampled wells in the primary study area</u>.

[Locations of wells shown on figure 11.]

1 USGS ID	2 Use of site	3 Use of water	Altitude of land surface (feet above sea level)	Top of screen (feet below land surface)	4 Bottom of screen (feet below land surface)	5 Static water level (feet below land surface)	6 Discharge rate (gals/min)	Aquifer	7 Unconfined or confined	8 Predominant land-use code	9 Undeveloped land (Y/N)	9 Agricultural land (Y/N)	9 Urban land (Y/N)
Mercer County (21)													
210053	W	H	85	67	79	16	15	Upper	U	B	N	Y	Y
210066	W	H	80	55	60	33	<10	Middle	C	B	N	N	Y
210075	W	P	76	120	137	28	1,012	Middle	C	B	Y	Y	Y
210076	U	H	85	67	70	34	20	Middle	U	B	Y	Y	Y
210077	W	H	65	80	83	6	15	Middle	U	B	Y	N	Y
210092	C	U	27	70	80	30	400	Middle	U	B	Y	N	Y
210109	W	H	95	71	74	35	20	Upper	U	A	Y	Y	Y
210122	W	P	100	75	126	5.7	317	Upper	U	A	Y	Y	Y
210124	W	H	80	59	62	24	<10	Middle	U	A	N	Y	Y
210222	C	T	54	60	80	26.5	400	Middle	U	B	N	N	Y
210226	W	C	50	45	51	10	60	Middle	U	B	N	N	Y
210234	W	H	87	173	175	85	20	Middle	C	B	Y	N	Y
210236	W	H	65	93	99	45	8	Middle	U	B	N	N	Y
210237	W	H	65	142	150	81	37	Upper	U	B	N	N	Y
210240	W	H	58	71	76		<10	Middle	U	B	Y	N	Y
Middlesex County (23)													
230015	W	P	95.3	-	110	15	100	Upper	U	B	Y	Y	Y
230024	W	I	115	-	152	-	1,000	Upper	C	A	N	Y	Y
230054	W	N	30	57	72	26	656	Upper	U	B	N	N	Y
230080	O	D	28	-	18	-	<10	Middle	U	B	N	N	Y
230089	U	N	70	-	26	7	108	Middle	U	B	N	N	Y
230094	W	P	60	183	193	24	128	Middle	C	U	Y	N	Y
230096	W	P	40	32	42	3	102	Upper	U	U	Y	N	Y
230100	W	P	45	118	129	1	750	Upper	C	U	Y	N	Y
230108	W	N	25	87	107	18	1,018	Upper	C	U	Y	N	Y
230121	W	N	18	75	85	18	1,270	Upper	U	U	Y	N	Y
230131	W	N	24	65	80	10	456	Upper	U	B	Y	N	Y
230145	W	P	30	80	120	17	602	Upper	C	B	Y	N	Y
230172	W	N	13	55	75	-	640	Upper	U	U	Y	N	Y
230177	W	N	10	52	67	16	700	Upper	U	U	Y	N	Y
230195	W	P	15	50	80	20	550	Upper	U	U	Y	N	Y
230227	W	N	132	168	198	64	650	Upper	C	B	N	Y	Y
230255	W	N	15	57	67	10	530	Middle	C	B	Y	N	Y
230266	O	U	40	87	96	38	<10	Middle	C	B	Y	N	Y
230292	O	U	106.9	93	104	20	<10	Upper	U	U	Y	Y	N
230311	W	H	110	104	107	30	12	Middle	U	A	Y	Y	N
230322	W	P	122	95	115	9	1,200	Middle	U	B	N	Y	Y
230325	W	N	111	101	116	24	200	Middle	C	U	Y	N	Y
230328	W	H	130	86	96	60	<10	Upper	U	U	Y	Y	N
230346	W	P	27	71	81	9	1,000	Upper	U	U	Y	N	Y
230366	W	P	63	79	89	49	375	Upper	U	U	Y	N	Y
230383	W	N	96.6	97	116	57	448	Upper	U	B	Y	N	Y
230441	O	U	6.4	49	52	2	44	Middle	U	U	Y	N	N
230442	W	P	32	63	78	10.9	50.9	Upper	U	U	Y	N	Y
230459	W	N	35	58	68	22	600	Upper	U	B	N	N	Y
230473	W	J	30	39	59	8	305	Middle	U	B	Y	N	Y
230478	W	N	9	45	60	4	120	Middle	U	B	N	N	Y
230494	W	P	23	83	97	12.9	530	Upper	U	B	Y	N	Y
230515	W	H	109	-	40	-	10	Upper	U	A	N	Y	Y
230522	W	N	25	53	63	24	312	Upper	U	B	N	N	Y
230523	W	J	50	46	61.5	14	140	Middle	C	B	Y	N	Y

Table 4.--Selected information on sampled wells--continued.

[Locations of wells shown on figure 11.]

USGS ID[1]	Use of site[2]	Use of water[3]	Altitude of land surface (feet above sea level)	Top of screen (feet below land surface)	Bottom of screen[4] (feet below land surface)	Static water level[5] (feet below land surface)	Discharge rate[6] (gals/min)	Aquifer	Unconfined or confined[7]	Predominate land-use code[8]	Undeveloped land (Y/N)[9]	Agricultural land (Y/N)[9]	Urban land (Y/N)[9]
Middlesex County (continued)													
230543	O	U	24.8	-	42	-	<10	Middle	U	B	N	N	Y
230548	O	U	16.9	-	36	-	<10	Middle	U	B	Y	N	Y
230549	W	P	23	70	111	10.7	430	Upper	C	U	Y	N	Y
230552	W	P	105	116	166	37	1,536	Middle	C	A	N	Y	N
230557	W	P	20	48	58	5	300	Upper	U	U	Y	N	Y
230565	W	P	130	165	197	77	980	Upper	C	B	Y	N	Y
230570	W	P	15	60	80	9	704	Upper	U	U	Y	N	N
230571	W	P	15	67	82	16	702	Upper	U	U	Y	N	N
230704	O	U	119.4	32	67	32.4	<10	Middle	U	B	N	Y	Y
230715	O	U	113.0	25	55	26.6	<10	Middle	U	A	N	Y	Y
230729	W	N	20	50	60	21	280	Upper	U	B	Y	N	Y
230732	U	U	100	-	40	-	<10	Middle	U	U	Y	N	Y
230733	O	U	20.3	18	28	0	<10	Middle	U	U	Y	N	Y
230734	W	N	100	96	120	40	100	Middle	U	B	N	Y	Y
230735	W	P	18	70	85	10	715	Upper	U	U	Y	N	N
230736	W	H	90	71	78	34	25	Middle	C	A	N	Y	N
230738	W	H	85	35	39	16	30	Middle	U	A	N	Y	Y
230739	W	H	105	100	110	24	70	Middle	U	U	Y	Y	Y
230740	W	H	100	47	55	15	50	Upper	U	A	N	Y	Y
230741	W	H	100	41	44	15	15	Upper	U	U	Y	N	N
230742	W	H	80	50	60	20	30	Upper	U	U	Y	Y	N

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[1] The sampled wells are located in figure 11 The USGS ID consists of a two digit county code (21 = Mercer and 23 = Middlesex) followed by a consecutive number assigned to that well. Only the consecutive number appears in the map on figure 11.

[2] Use of site codes: C - Standby, emergency supply O - Observation U - Unused W - Withdrawal

[3] Use of water codes:
C - Commercial D - Dewater H - Domestic I - Irrigation J - Industrial cooling
N - Industrial P - Public supply T - Institutional U - Unused

[4] The bottom of the screen is equivalent to the maximum well depth below land surface.

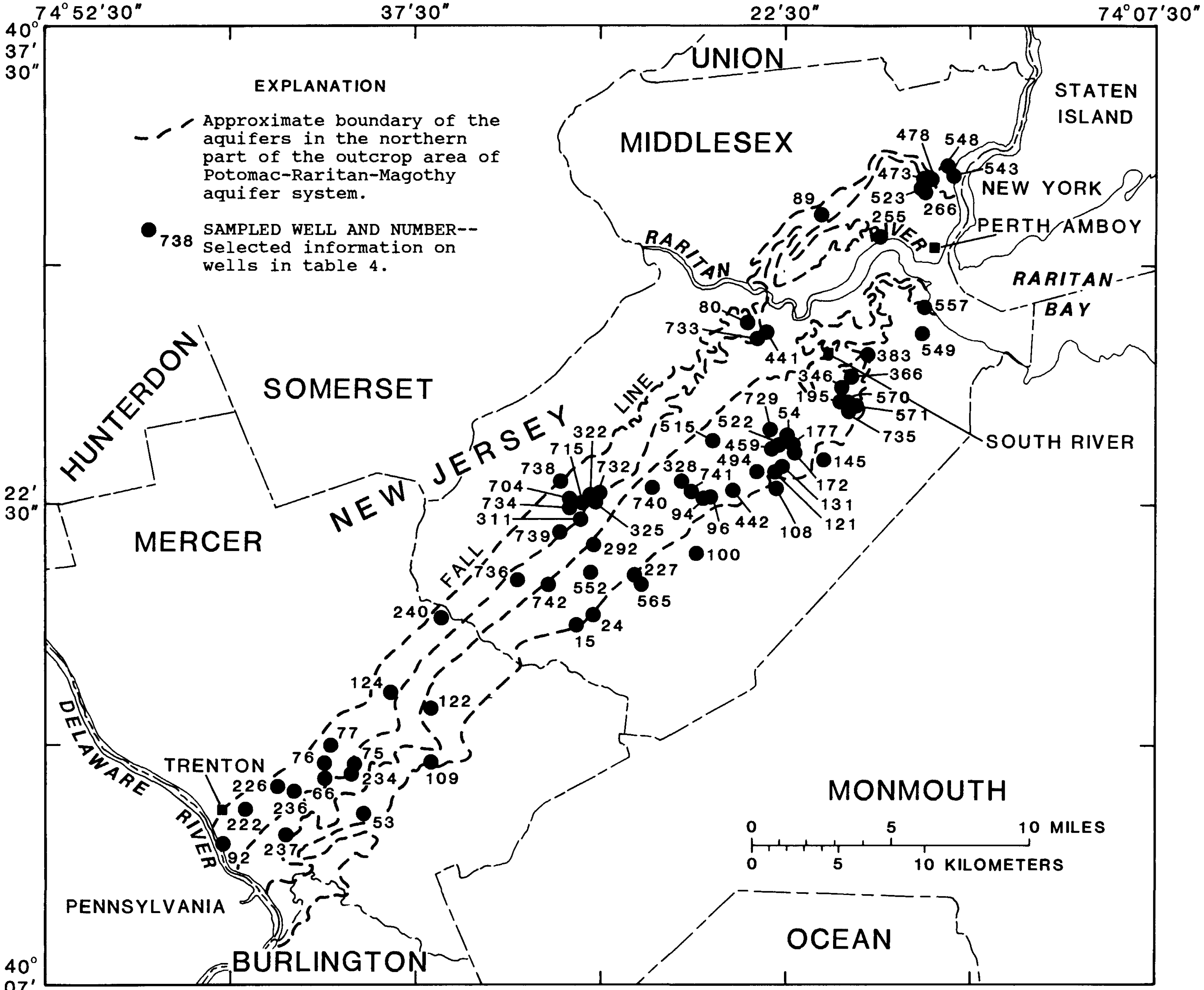
[5] The static water level was obtained from well records reported by drillers at the time of well construction.

[6] The discharge rate, in gallons per minute, represents the pumping rate determined by the driller at the time of well construction for the large capacity withdrawal wells. The discharge rate for observation wells was determined in the field at the time of sampling.

[7] This code indicates whether the screened interval of the well is unconfined (U) or confined (C).

[8] The predominant land-use code represents the land use with the most coverage within a 1/4-mile radius of the well. The codes are: U - Undeveloped land A - Agricultural land B - Urban or built-up land

[9] This column indicates whether the specified land use is present (Y) or absent (N) within a 1/4-mile radius of the well.



Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 11.--Location of sampled wells in the primary study area March-April, 1985.

Sampling Methods

Ground-water samples were collected from March 11 to April 19, 1985, using sampling procedures described by Wood (1976), Wershaw and others (1983), and Kish and Hochreiter (U.S. Geological Survey, written commun., 1985). Sampling procedures varied with the type of well sampled. Large-capacity wells equipped with vertical turbine pumps were sampled at discharge valves near the wellhead. Unused or standby wells were also sampled in this way. Domestic wells were sampled at spigots prior to discharging into holding tanks. Observation wells were sampled using portable submersible pumps.

Prior to sampling, a minimum of three casing-volumes of water were evacuated from the well. Pumping continued until temperature, pH, specific conductance, and dissolved oxygen stabilized. After stabilization, an incremental field titration using a pH meter was performed to determine alkalinity. Methods of sample preparation and preservation used are documented by Fishman and Friedman (1985) for dissolved and suspended inorganic constituents and by Wershaw and others (1983) for organic compounds.

Laboratory Methods

The characteristics and constituents analyzed in the field and lab and their detection limits are listed in table 5. All samples were refrigerated and all, except those for purgeable organic compounds, were mailed within 72 hours to the U.S. Geological Survey Central Laboratory in Doraville, Georgia. Replicate samples for purgeable organic compounds were analyzed by the U.S. Geological Survey New Jersey District Laboratory with a purge-and-trap gas chromatograph with a Hall[1] detector in series with a photo-ionization detector. Duplicate samples were then sent to the Central Laboratory in Georgia for gas chromatography/mass spectrometry (GC/MS) analysis. All Central Laboratory procedures are identified by Feltz and others (1984). Methods of sample preparation and analyses of dissolved and suspended inorganic constituents and physical characteristics of water are documented by Fishman and Friedman (1985). Wershaw and others (1983) describe the procedures used for analyzing organic compounds such as organic carbon, organic nitrogen, total recoverable phenols, pesticides, and purgeable organic compounds in water.

Quality Assurance

A quality-assurance program evaluates the accuracy of the water-quality data presented in this report. The internal quality-control program followed by the Central Laboratory is documented by Friedman and Erdmann (1982), Peart and Thomas (1983), and Wershaw and others (1983).

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[1] Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 5.--Water-quality characteristics and constituents analyzed in samples from the primary study area.

Characteristics	Detection limit
pH (field) 0.1 unit	
temperature (field)	0.1° Centigrade
specific conductance (field)	1. µS/cm (microsiemens per centimeter)
dissolved oxygen (field)	0.1 mg/L (milligrams per liter)
alkalinity (field)	0.1 mg/L
dissolved solids (lab)	1. mg/L

Constituents	Detection limit
Major ions (dissolved)	mg/L
chloride	0.1
sulfate	0.2
calcium	0.02
magnesium	0.01
potassium	0.1
sodium	0.2
silica	0.006
Metals (dissolved)	µg/L (microgram per liter)
aluminum	10.
barium	2.
beryllium	0.5
cadium	1.
chromium	10.
cobalt	3.
copper	10.
iron	3.
iron (total)	10.
lead	10.
lithium	4.
molybdenum	10.
strontium	0.5
vanadium	6.
zinc	3.
Nutrients (dissolved)	mg/L
phosphorous, orthophosphate	0.01
nitrogen, nitrite	0.01
nitrogen, nitrate	0.1
nitrogen, ammonia	0.01
nitrogen, ammonia + organic N	0.1
Organic compounds	
organic carbon (dissolved)	0.1 mg/L
total recoverable phenols	1. µg/L
purgeable organics (total)	3. µg/L
benzene	
bromoform	
carbon tetrachloride	
chlorobenzene	
chlorodibromomethane	
chloroethane	
chloroform	
dichlorobromomethane	
dichlorodifluoromethane	
ethylbenzene	
methylbromide	
methylene chloride	
tetrachloroethylene	
toluene	
trichloroethylene	
trichlorofluoromethane	
vinyl chloride	
1,1 - dichloroethylene	
1,1 - dichloroethane	
1,1,1 - trichloroethane	
1,1,2 - trichloroethane	
1,1,2,2 - tetrachloroethane	
1,2 - dichloropropane	
1,2 - dichloroethane	
1,3 - dichloropropylene	
1,2 - transdichloroethylene	
2 - chloroethylvinyl-ether	
Organic compounds (continued)	
pesticides (total)	µg/L
organochlorine insecticides	
aldrin	0.01
chlordane	0.1
DDD	0.01
DDE	0.01
DDT	0.01
dieldrin	0.01
endosulfan	0.01
endrin	0.01
gross PCB	0.1
gross PCN	0.1
heptachlor	0.01
heptachlor epoxide	0.01
lindane	0.01
methoxychlor	0.01
mirex	0.01
perthane	0.1
toxaphene	1.0
organophosphorus insecticides	0.01 µg/L
diazinon	
ethion	
malathion	
methyl parathion	
methyl trithion	
parathion	
trithion	
triazine herbicides (total)	0.1 µg/L
ametryne	
atrazine	
cyanazine	
prometone	
prometryne	
propazine	
simazine	
simetryn	

The program involves analyzing a large proportion of samples to evaluate accuracy and precision. The Central Laboratory also is checked by the U.S. Geological Survey - Water Resources Division's Quality Assurance Program, which submits standard samples for analysis and reports tabulated statistics on the results (Janzer, U.S. Geological Survey, written commun., 1985).

The independent quality-assurance program developed for this project utilized standards and replicates. Six standard-reference water samples, obtained from the Office of the Regional Research Hydrologist of the U.S. Geological Survey, were submitted to the Central Laboratory for analysis during the same time as the 71 water samples collected for this study. The same procedures were used for all samples. Analyses of the standard-reference water samples for water-quality characteristics, major ions, and trace metals yielded concentrations within two standard deviations from the mean concentrations reported by the Office of the Regional Research Hydrologist (Janzer, U.S. Geological Survey, written commun., 1985). Only one analysis, for chloride, yielded a concentration greater than 2 standard deviations from the mean.

Six replicate samples were submitted blind to the Central Laboratory. Replicates chosen were those expected to have significant concentrations of nutrients or pesticides. Replicate analyses of water-quality characteristics, major ions, trace metals, purgeable organic compounds, nutrients, and pesticides yielded concentrations which were within 5 percent of each other. In one instance, reported replicate concentrations of 4 constituents--cobalt, total iron, nitrogen as nitrate plus nitrite, and orthophosphate--were different by greater than 5 percent and were more than an order of magnitude different. In this case, nutrient analyses were repeated by the laboratory.

Replicates of 51 of the 71 samples, including 15 identified by the District as having concentrations of POC's, were sent to the Central Laboratory for verification and determination of concentration levels. For the 15 samples with POC concentrations greater than 3 μg/L, replicate analyses by the Central Laboratory showed the same POC's, with concentrations the same order of magnitude as those determined in the District. For the remaining samples, no POC concentrations were detected above 3 μg/L when analyzed by the District or by the Central Laboratory.

ASSESSMENT OF GROUND-WATER QUALITY

The quality of ground water is influenced by many factors: the chemical composition of precipitation; land cover including slope, soil type, vegetation, and land use; the lithology of formations traversed by circulating ground water; and ground-water flow patterns and residence times. Many characteristics and constituents contribute to the quality of water, including temperature, pH, dissolved solids, specific conductance, major ions, nutrients, trace metals, and organic compounds. The factors that affect the solubility of constituents and the partitioning of constituents between water and the materials of the aquifer include temperature, pressure, pH, and the concentration of dissolved gases, such as oxygen and carbon dioxide.

In this report, local hydrogeologic conditions and land use at sampled wells are assessed to statistically evaluate the relation of land use to ground-water quality under conditions of similar hydrogeology. The hydrogeologic conditions evaluated are the aquifer sampled, aquifer confinement, depth to water, well depth, and pumping rate. The relation of undeveloped, agricultural, and urban land use to ground-water quality is evaluated. Two methods are used to classify land use at sampled wells. The Kruskal-Wallis test and frequency-of-detection method are used to compare ground-water quality by these factors.

Methods of Assessment

Statistical Methods

A preliminary assessment of water quality in the northern outcrop of the Potomac-Raritan-Magothy aquifer system in central New Jersey was made by applying descriptive and nonparametric statistics to the water-quality data collected from the 71 wells of the sampling network. The descriptive statistics calculated include the median, third quartile (Q3), and first quartile (Q1) of constituent concentrations. These were used to measure the central tendency and variability of the data within each group. Boxplots were used to visually compare the medians, Q1, Q3, and probable outliers, which may represent contamination. Another descriptive statistic used to evaluate the water quality among groups is frequency of detection. To determine frequency of detection, the percentage of constituent detections within a group are calculated. This percentage is then compared among groups.

Nonparametric statistics were used to evaluate water quality among groups because sample size was small and the water-quality data sets generally lacked normal or log-normal distributions. The use of these types of statistics are described in more detail in Helsel and Ragone (1984) and Conover (1980). The Kruskal-Wallis test is a nonparametric method for comparing the mean rank of the total sample population to those of two or more independent groups, based on one factor (Ryan and others, 1985, p. 98a-b). This method was used to test the null hypothesis that the concentrations of water-quality constituents are similar in all land-use groups. The alternative is that at least one of the land-use groups has different water quality. Differences between the mean rank of a group and the mean rank for all observations were considered significant at or above a 0.95 significance level. In cases where the frequency of detection of a constituent is low, the Kruskal-Wallis test has a lower power to detect differences between groups due to the large number of ties in rank (Helsel, U.S. Geological Survey, oral commun., 1986).

When the Kruskal-Wallis test indicated a significant difference between groups, a multiple comparisons test (Ryan and others, 1985, p. 98b) was used to indicate if the mean rank of a group is higher or lower than the mean rank for all observations. Groups with mean ranks greater than two standard deviations from the mean rank of the total population were considered significantly different.

Land-Use Methods

The relation of ground-water quality to land use was evaluated by comparing the quality of water from wells which were divided into three groups by land use: undeveloped, agricultural, and urban. Two methods were used to classify land use at a well--the predominant land-use method and the presence-absence method. Because most of the sampled wells are supply wells that are screened in the unconfined aquifer, a 1/4-mile radius around each well was assumed to represent the major part of the area of diversion caused by pumping. Method I, the predominant land-use method, assumes that the predominant land use in the area of diversion has the most significant affect on water quality. When this method was used, the percent of undeveloped, agricultural, and urban land within a 1/4-mile radius of the well was estimated. Then, the land use with the highest percentage was assigned as the predominant land use for that well (table 4). The influences of other land uses are minimized when this method is used.

Because the primary study area contains few sites with one predominant land use, a second method was used for designating land use at a well. Method II involves a presence-absence procedure. For example, those wells with any urban land within a 1/4-mile radius of the well were tested against those with none. This method tests the influence of a land use on water quality even when it is not the predominant land use in the area of diversion. This is particularly important when area of a land use is strongly dependent on land-use type, and also may be important in the case of point-source contamination. However, when this method is used, the relation between water quality and land use may be weakened or obscured if the water quality is primarily influenced by other more predominant land uses. When Method II is used, comparison of the results of statistical analyses among the three land-use groups is not valid because an individual well may be classified in more than one land-use group.

Relation to Hydrogeology

It was difficult to control variation of hydrogeologic factors within the experimental design because existing wells were sampled to test the influence of land use on ground-water quality. For example, land uses are not equally distributed between the upper and middle aquifers; some of the wells have confining material above the screened interval; and the depth to water, well depth, and pumping rate differ from well to well. These factors may influence the quality of the sampled ground water and may bias the comparison by land use. Therefore, the Kruskal-Wallis test was used to determine if the wells are similarly distributed within land-use groups, designated by both methods, with regards to these hydrogeologic factors (table 6). In addition, the Kruskal-Wallis test was used to evaluate the influence of each hydrogeologic factor on water quality without consideration to the influence of land use. The results of these statistical analyses are discussed in the following sections.

Table 6.-- Summary of results of Kruskal-Wallis test on hydrogeologic factors at sampled wells in the primary study area by land-use group.

Land-use method	Aquifer sampled	Aquifer confinement	Well[2] depth	Depth[2] to water	Pumping[2] rate
	Significance level of hydrogeologic factor[1]				
Method I (Predominant land use)	0.975	<0.75	<0.75	0.90	0.75
Method II (Present/Absent)					
Undeveloped	.95	<.75	.90	.75	.75
Agricultural	<.75	<.75	.75	.95	.75
Urban	<.75	<.75	<.75	<.75	<.75

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[1] The significance level indicates the level of confidence that a hydrogeologic condition is significantly different at the wells of one or more land-use groups. The value is determined using the H-value adjusted for ties in rank, from the Kruskal-Wallis test, and a Chi-square distribution table (Ryan and others, 1985).

[2] Boxplots showing the distribution of well depth (fig. 12), depth to water (fig. 13), and pumping rate (fig. 14) are presented for each land-use group.

Upper and Middle Aquifers

In the sampling network, 37 wells are screened in the upper aquifer and 34 are in the middle aquifer. The distribution of wells screened in the upper and middle aquifers within the total sampling network were compared to the distribution within each land-use group by the Kruskal-Wallis test (table 6). Results indicate that wells within the undeveloped and urban land-use groups are predominantly screened in one aquifer. When Method I was used to designate land use at a well, 76 percent of the wells in predominantly undeveloped land are screened in the upper aquifer. At wells where urban land is the predominant land use, 63 percent of the wells are screened in the middle aquifer. Similarly when Method II was used, a significantly greater number of wells in areas where undeveloped land is present are screened in the upper aquifer than are wells in areas where undeveloped land is absent. When either method was used, wells in agricultural land are similarly distributed between the upper and middle aquifers. Because wells in undeveloped and urban land-use groups are predominantly screened in one aquifer, differences in water quality between aquifers may reflect differences due to land use.

Descriptive statistics and results of the Kruskal-Wallis test comparing water quality between aquifers are presented in table 7. Results indicate that there are some significant differences in the water quality between the upper and middle aquifers. The pH and alkalinity are lower and concentrations of many trace metals, dissolved organic carbon, and phenols are higher in the upper aquifer. Purgeable organic compounds are detected more frequently in the middle aquifer. These differences are probably related to the distribution of land uses on the outcrop of each aquifer (table 2).

Although there are some differences in water quality between the upper and middle aquifers, their major-ion chemistry is similar and probably reflects their similar lithology. Because both aquifers have similar major-ion chemistry, no consideration was given to the aquifer sampled when evaluating the effects of land use on water quality. Descriptive statistics of the water quality for all sampled wells are shown in table 8. The median concentrations of constituents listed are considered to be representative of the water from the northern part of the outcrop of the Potomac-Raritan-Magothy aquifer system in New Jersey.

Aquifer Confinement

At 17 sampled wells, some confining material is present in the deposits above the screened interval. Most of these wells are situated within 1 mile of the outcrop of the aquifer in which they are screened, and in most cases, the confining bed above the screened interval is thin. Nevertheless, the water quality at these wells, in part, may be influenced by the presence of the overlying confining material. Water recharging the aquifer system near these wells may flow through and interact with material of the confining unit.

The number of wells screened in the unconfined and confined parts of the aquifer system within each land-use group were compared using the Kruskal-Wallis test (table 6). No significant difference was indicated when either Method I or II was used to designate land use at a well. Therefore, aquifer confinement of the sampled wells was not considered when evaluating the influence of land use on water quality.

Descriptive statistics and results of the Kruskal-Wallis tests comparing water-quality data grouped by aquifer confinement are summarized in table 9. The concentrations of water-quality characteristics, major ions, most trace metals, and nutrients were similar in wells in unconfined and confined parts of the aquifer system. Of the trace metals, only beryllium and cadmium concentrations significantly differed between the two groups (table 9). The concentration of dissolved organic carbon was significantly higher in wells in the unconfined part of the aquifer system. Dissolved organic carbon in ground water originates from either surface organic matter or from kerogen, the fossilized organic matter in the geologic material of the aquifer (Thurman, 1985, p. 15). The higher concentrations in wells in the unconfined aquifer system may indicate that the organic carbon is derived primarily from land-surface sources.

Table 7.-- Summary of water-quality data from the primary study area by aquifer.

Characteristic[1] or constituent	Aquifer								Signif-[4] icance level	Which[5] aquifer is higher
	Upper (37 wells)				Middle (34 wells)					
	Percentage[2] above detection	Concentration[3]			Percentage[2] above detection	Concentration[3]				
		Median	Q1	Q3		Median	Q1	Q3		
Characteristics										
pH (field)	100	4.7	4.4	5.3	100	5.1	4.8	5.8	0.990	M
temperature (field)	100	12.0	11.7	12.8	100	13.5	11.9	14.1	.999	M
specific conductance (field)	100	173	135	216	100	162	99.2	289	<.75	
dissolved oxygen (field)	100	2.8	0.3	6.9	100	5.6	0.5	7.3	.90	
alkalinity (CaCO3) (field)	54	3.0	<1.0	6.5	68	4.8	2.8	14.7	.95	M
dissolved solids (lab)	100	99.0	77.5	140	100	99.5	54.7	172	<.75	
Constituents (dissolved)										
Major ions										
chloride	100	15.0	10.4	23.5	100	16.5	8.9	100.3	<.75	
sulfate	100	28.0	11.0	40.0	100	9.4	0.7	53.5	<.75	
calcium	100	5.9	4.4	8.4	100	7.2	2.6	20.3	<.75	
magnesium	100	3.5	2.6	5.7	100	4.5	2.7	8.4	.75	
potassium	100	2.0	1.4	2.3	100	2.2	1.2	2.6	<.75	
sodium	100	8.3	5.5	12.5	100	7.1	4.6	14.0	<.75	
silica	100	8.5	6.8	10.0	100	9.4	7.5	13.0	.75	
Trace metals										
aluminum	86	220	10	900	59	20	10	70	.990	U
barium	100	72	47	104	100	80	47	145	<.75	
beryllium	43	<0.5	<0.5	1.7	47	<0.5	<0.5	1.0	<.75	
cadmium	14	<1	<1	<1	3	<1	<1	<1	.75	
chromium	19	<10	<10	<10	47	<10	<10	10	.975	M
cobalt	84	10	6	23	44	<3	<3	10.5	.995	U
copper	51	10	<10	20	59	25	<10	120	.75	
iron	100	770	72	6,350	100	88	28	710	.95	U
iron (total)	100	940	140	7,800	100	290	130	2,475	.95	U
lithium	68	11	<4	19	56	6	<4	12	.90	
lead	49	<10	<10	25	18	<10	<10	<10	.975	U
manganese	100	94	33	135	97	38	14	205	.75	
molybdenum	3	<10	<10	<10	0	<10	<10	<10	<.75	
strontium	100	62	100	100	100	67	100	140	<.75	
vanadium	0	<6	<6	<6	0	<6	<6	<6	<.75	
zinc	100	32	23	110	97	21	12	62	.95	U
Nutrients										
phosphorus, orthophosphate	14	<0.01	<0.01	<0.01	18	<0.01	<0.01	<0.01	<.75	
nitrogen, nitrite	8	<0.01	<0.01	<0.01	9	<0.01	<0.01	<0.01	<.75	
nitrogen, nitrate	73	0.3	0.1	4.5	76	2.3	0.2	4.8	<.75	
nitrogen, ammonia	68	0.05	0.01	0.2	50	<0.01	<0.01	0.07	<.75	
nitrogen, ammonia + organic	100	0.5	0.3	1.0	100	0.5	0.2	0.7	.975	U
Organic Compounds (total)										
organic carbon (dissolved)	100	1.2	0.9	1.6	100	0.9	0.6	1.2	.975	U
total recoverable phenols	43	<1	<1	1	18	<1	<1	<1	.95	U
total all purgeable organics	11	<3	<3	<3	32	<3	<3	10.4	.95	M
total all pesticides	8	-	-	-	12	-	-	-	<.75	

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[1] Concentration units and detection limits are given in table 5. Only the percentage above detection is given for total pesticides because of variable detection limits. Only 65 sites were analyzed for pesticides.

[2] The percentage above detection is calculated by dividing the number of samples with a concentration equal to or exceeding the detection limit by the total number of samples in that group and multiplying by 100.

[3] Q1 and Q3 represent the first and third quartiles.

[4] The significance level is determined using the H-value adjusted for ties in rank, from the Kruskal-Wallis test, and a Chi-square distribution table (Ryan and others, 1985).

[5] The aquifer with concentrations that are significantly higher at a .95 confidence level or greater are flagged as: U = Upper; M = Middle.

Table 8.-- Summary of water-quality data for the northern part of the outcrop area of the Potomac-Raritan-Magothy aquifer system.

Characteristic[1] or constituent	All sites (71 wells)			
	Percentage[2] above detection	Concentration[3]		
		Median	Q1	Q3
Characteristics				
pH (field)	100	5.0	4.5	5.6
temperature (field)	100	12.2	11.8	13.5
specific conductance (field)	100	172	114	241
dissolved oxygen (field)	100	3.6	0.4	7.0
alkalinity (CaCO3) (field)	61	4.0	1.0	9.4
dissolved solids (lab)	100	99	69	150
Constituents (dissolved)				
Major ions				
chloride	100	16.0	9.5	25.0
sulfate	100	23.0	5.1	40.0
calcium	100	6.7	4.1	11.0
magnesium	100	3.7	2.7	6.7
potassium	100	2.1	1.3	2.5
sodium	100	8.2	5.3	13.0
silica	100	8.7	7.3	11.0
Trace metals				
aluminum	79	40	10	410
barium	100	75	47	120
baryllium	45	<0.5	<0.5	1.4
cadmium	8	<1	<1	<1
chromium	32	<10	<10	<10
cobalt	65	7	<3	19
copper	55	10	<10	70
iron	100	230	45	3,700
iron (total)	100	470	140	5,900
lithium	62	8	4	15
lead	34	<10	<10	<10
manganese	99	62	23	140
molybdenum	1	<10	<10	<10
strontium	100	62	35	100
vanadium	0	<6	<6	<6
zinc	97	29	15	83
Nutrients				
phosphorus, orthophosphate	15	<0.01	<0.01	<0.01
nitrogen, nitrite	8	<0.01	<0.01	<0.01
nitrogen, nitrate	75	1.7	0.1	4.7
nitrogen, ammonia	63	0.03	<0.01	0.11
nitrogen, ammonia + organic N	99	0.5	0.3	0.9
Organic Compounds (total)				
organic carbon (dissolved)	100	1.1	0.8	1.5
total recoverable phenols	32	<1	<1	<1
total all purgeable organics	21	<3	<3	<3
total all pesticides	11	-	-	-

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[1] Concentration units and detection limits are given in table 5. Only percentage of detections are given for total pesticides because of variable detection limits. Only 65 sites were analyzed for pesticides.

[2] The percentage above detection is calculated by dividing by the number of samples with a concentration equal to or exceeding the detection limit by the total number of samples and multiplying by 100.

[3] Q1 and Q3 represent the first and third quartiles.

Table 9.-- Summary of water-quality data from the primary study area by aquifer confinement and well depth.

Characteristic[1] or constituent	Aquifer confinement				Well depth (feet below land surface)			
	Median concentration				Median concentration			
	Unconfined (54 wells)	Confined (17 wells)	Signif-[2] icance level	Which[3] group is higher	<80ft (40 wells)	≥80ft (31 wells)	Signif-[2] icance level	Which[4] group is higher
Characteristics								
pH (field)	5.0	5.0	<0.75		5.0	5.0	<0.75	
temperature (field)	12.4	11.9	<.75		13.1	11.9	.995	C
specific conductance (field)	173	142	.75		195	118	.999	C
dissolved oxygen (field)	3.5	5.0	<.75		4.0	3.2	<.75	
alkalinity (CaCO3) (field)	3.6	7.0	<.75		4.3	3.8	<.75	
dissolved solids (lab)	106	97	<.75		115	79	.995	C
Constituents (dissolved)								
Major ions								
chloride	16.0	12.0	.90		23.0	12.0	.999	C
sulfate	27.5	11.0	.75		28.0	11.0	.95	C
calcium	6.9	5.9	<.75		7.9	4.3	.995	C
magnesium	3.8	3.2	.75		5.6	2.9	.999	C
potassium	2.2	1.6	.75		2.2	1.7	.90	
sodium	8.5	6.5	.90		10.4	6.5	.995	C
silica	8.9	8.2	<.75		9.4	7.9	.90	
Trace metals								
aluminum	55	10	.90		50	30	<.75	
barium	76	61	.75		77	63	.90	
baryllium	0.5	<0.5	.975	A	<0.5	<0.5	<.75	
cadmium	<1	<1	.975	B	<1	<1<	.75	
chromium	<10	<10	<.75		<10	<10	<.75	
cobalt	7	<3	.90		8	4	0.75	
copper	10	10	<.75		10	10	<.75	
iron	315	82	<.75		240	2,307	<.75	
iron (total)	480	140	.75		475	470	<.75	
lithium	7	11	.75		6	11	.95	D
lead	<10	<10	<.75		<10	<10	<.75	
manganese	82	40	.75		96	37	.95	C
molybdenum	<10	<10	.90		<10	<10	<.75	
strontium	63	62	<.75		66	48	.995	C
vanadium	<6	<6	<.75		<6	<6	<.75	
zinc	28	30	<.75		26	32	<.75	
Nutrients								
phosphorus, orthophosphate	<0.01	<0.01	.75		<0.01	0.01	<.75	
nitrogen, nitrite	<0.01	<0.01	<.75		<0.01	<0.01	<.75	
nitrogen, nitrate	1.83	1.0	<.75		2.3	1.0	<.75	
nitrogen, ammonia	0.03	0.04	<.75		0.03	0.04	<.75	
nitrogen, ammonia + organic N	0.5	0.4	<.75		0.7	0.4	.90	
Organic Compounds (total)								
organic carbon (dissolved)	1.1	0.9	.975	A	1.1	0.9	.990	C
total reoverable phenols	<1	<1	.75		<1	<1	<.75	
total purgeable organics	<3	<3	.75		<3	<3	<.75	
total pesticides	-	-	.75		-	-	<.75	

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[1] Concentration units and detection limits are given in table 5. Only 65 sites analyzed for pesticides.

[2] The significance level is determined using the H-value adjusted for ties in rank, from the Kruskal-Wallis test, and a Chi-square distribution table (Ryan and others, 1985).

[3] The group with concentrations that are significantly higher at a .95 confidence level or greater are flagged as: A = Unconfined; B = Confined

[4] The group with concentrations that are significantly higher at a .95 confidence level or greater are flagged as: C = < 80 feet; D = > 80 feet.

Well Depth

Water quality can change significantly with depth. Most of the water entering the well is derived from the same depth as the screened interval, although there is some vertical movement as the cone of depression forms. The lengths of flow paths from land surface to well screen increase with depth. Thus, the possibility for dilution, dispersion, sorption, biodegradation, or chemical alteration of a constituent during transport increases.

The depth of wells within each land-use group were compared when both Methods I and II were used to designate land use at a well (table 6). The results of the Kruskal-Wallis test indicate no significant differences in well depths among land-use groups when either method was used. However, some difference was indicated at a slightly lower significance level (>0.95). When Method II was used, the median depth of wells in areas where undeveloped land is present is greater than in wells where this land use is absent (figure 12). Although not statistically significant, this difference may be responsible for differences determined when comparing water quality by land-use groups.

Water-quality data for wells less than or equal to the median depth of 80 feet were compared to those that were deeper (table 9). The concentrations of most trace metals and nutrients are similar regardless of well depth (table 9). However, specific conductance and the concentrations of dissolved solids, dissolved organic carbon, and most major ions are highest in wells that are less than 80 feet deep. A decrease in the concentrations of major ions and dissolved organic carbon with depth suggests introduction of these constituents at the land surface.

Depth to Water

The depth to water below land surface influences water quality. The longer the distance from the land surface to the water table, the greater the possibility for sorption, biodegradation, volatilization, or oxidation of constituents before entering the ground water. Sixty-two sampled wells have water-level measurements (table 4) for comparison. The depth to water was determined from static-water levels measured at the time the wells were installed.

The depth to water was compared among land-use groups using both Methods I and II to designate land use at a well (table 6 and fig. 13). Results of the Kruskal-Wallis test indicate that there are some differences in the depths to water among the wells in each land-use group. When Method I was used, depths to water did not differ among land-use groups at a 0.95 or greater significance level. However, the median depth to water in wells from predominantly undeveloped land is about 16 feet compared to 27 feet where agricultural land is the predominant land use. When Method II was used, the depth to water in wells where agricultural land is present is significantly deeper than in wells where it is absent. These variations in depth to water between wells of undeveloped and agricultural land may result in some differences in water quality when the data is grouped and compared on the basis of land use.

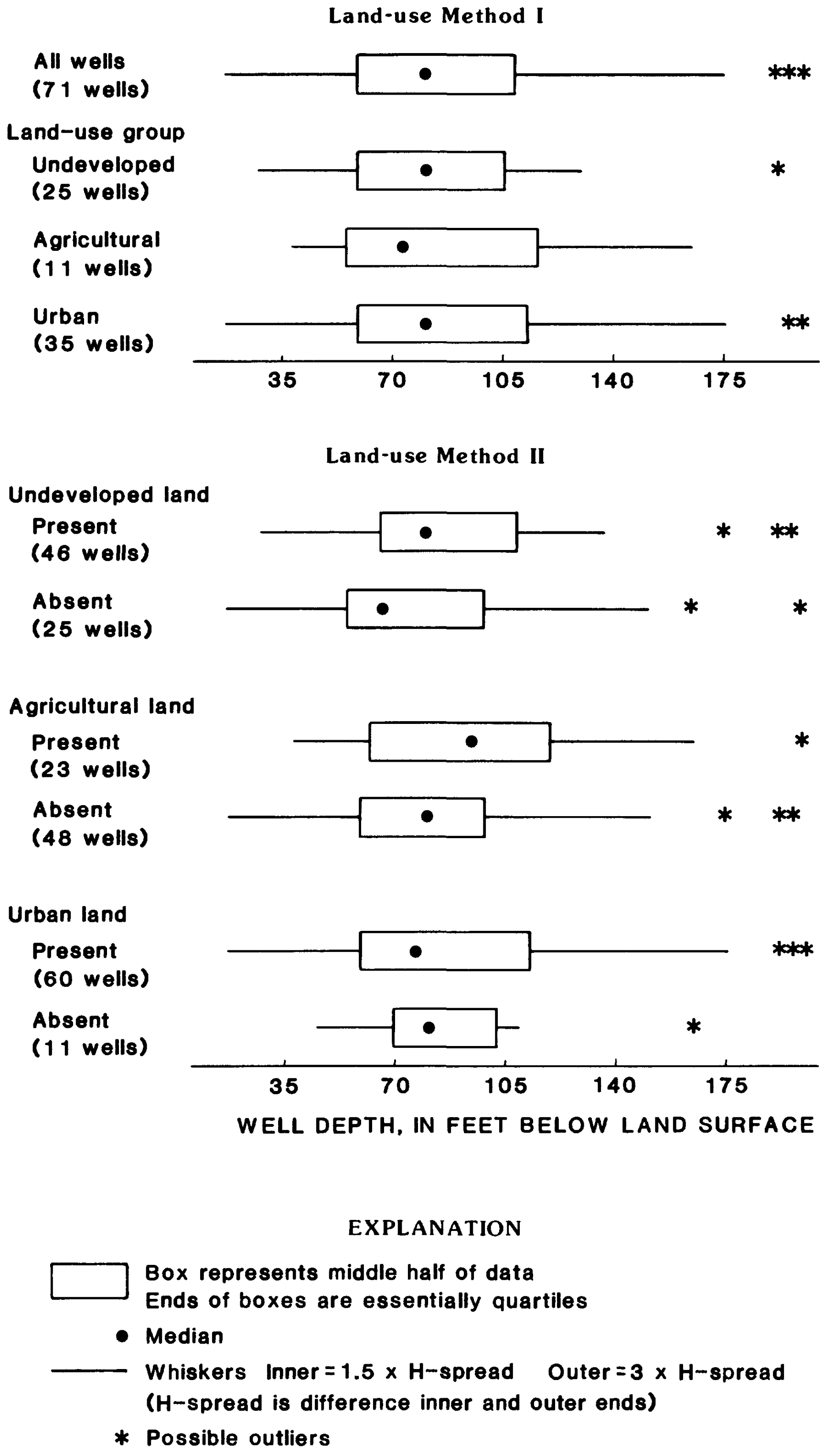

Figure 12.--Boxplots of depth of sampled wells in the primary study area by land use.

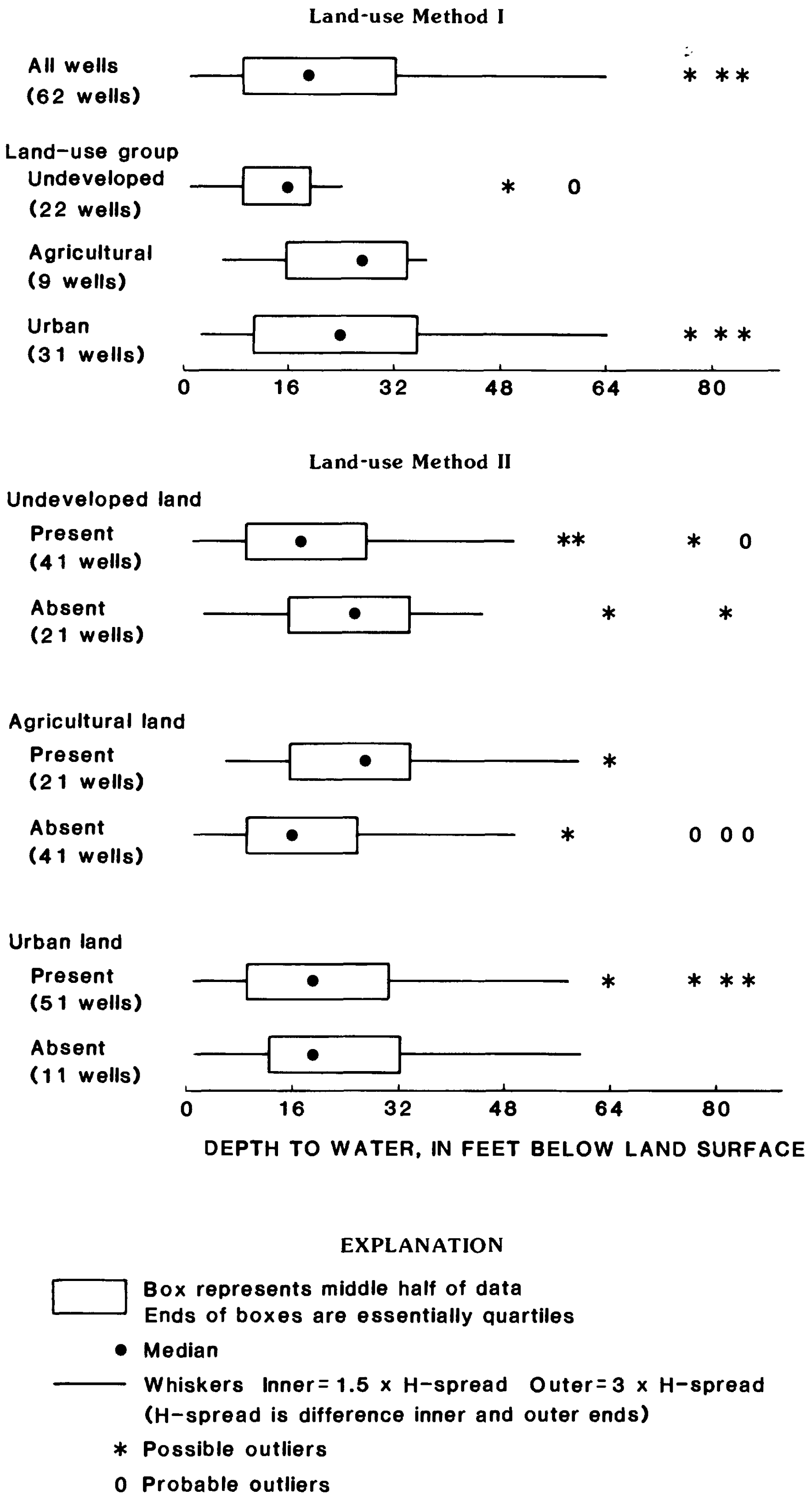

Figure 13.--Boxplots of depth to water at sampled wells in the primary study area by land use.

The median depth to water for all wells was 20 feet. Water quality at wells with depths to water of 20 feet or less were compared to those that exceed 20 feet (table 10). Most of the major ions concentrations are similar in all wells regardless of depth to water. However, specific conductance and the concentrations of dissolved solids, sulfate, cobalt, iron, nitrogen as ammonia (hereafter discussed as ammonia), and dissolved organic carbon are highest and the concentration of nitrogen as nitrate (hereafter discussed as nitrate) is lowest in wells with shallow depths to water. Water quality in wells with shallow depths to water may be primarily influenced by biological and chemical processes typical of wetlands environments (Given, 1975).

Pumping Rate

Well pumping rates and pumping duration may influence water quality. At higher pumping rates over long periods of time, water is drawn towards the well from greater distances. Under these pumping conditions, water quality could be influenced in several ways. For example, older water could be drawn from deeper parts of the aquifer or contaminated water could be drawn from distance sources. On the other hand, drawing in larger volumes of water could dilute a local point-source contaminant to concentrations below detection limits. The pumping rate of sampled wells, determined at the time of installation, range from less than 10 to more than 1,500 gals/min (table 4). Public and industrial-supply wells have high pumping rates and long pumping periods. Conversely, domestic and observation wells have low pumping rates and are pumped for short periods.

The pumping rates of the sampled wells were compared among land-use groups using both Methods I and II to designate land use at a well (table 6 and fig 14). Although the median pumping rate of wells in agricultural land is lowest, results of the Kruskal-Wallis test indicate that the distribution of well pumping rates are similar among land-use groups when either method was used. Hence, variations in pumping rates among wells of each land-use group are not considered when water-quality data is grouped and compared on the basis of land use.

The sampled wells were separated into three pumping-rate groups: less than 100, 100 to 500, and greater than 500 gallons per minute. Water-quality data were compared among pumping-rate groups by using the Kruskal-Wallis test (table 10). The values of most characteristics and concentrations of organic compounds are similar in all pumping-rate groups. However, the concentrations of some major ions, trace metals, and nutrients differ significantly among pumping-rate groups. The pH and concentration of copper are highest and concentrations of cobalt, lithium, and ammonia are lowest in wells with the lowest pumping rates. Concentrations of sulfate, sodium, cobalt, and strontium are highest in wells with intermediate pumping rates. Concentrations of magnesium, copper, and strontium are lowest and the concentration of lithium is highest in wells with the highest pumping rates. These results are difficult to interpret but, in part, may occur because certain well types are predominantly sampled in each land-use area. For example, domestic wells with low pumping rates were generally sampled in agricultural land.

Table 10.-- Summary of water-quality data from the primary study area by depth to water and pumping rate.

	Depth to water (feet below land surface)				Pumping rate (gallons/minute)				
	Median concentration				Median concentration				
Characteristic[1] or constituent	≤20ft (30 wells)	>20ft (32 wells)	Signif-[2] icance level	Which[3] group is higher	≤100 (33 wells)	100-500 (17 wells)	≥500 (21 wells)	Signif-[2] icance level	Which[4] group is different
Characteristics									
pH (field)	5.0	4.9	<0.75		5.3	4.8	4.8	0.95	C
temperature (field)	12.3	12.3	<.75		13.0	13.2	12.0	.90	
specific conductance (field)	185	124	.975	A	155	190	160	.75	
dissolved oxygen (field)	0.5	6.1	.995	B	5.7	3.8	0.7	.90	
alkalinity (CaCO3) (field)	2.0	3.5	<.75		4.8	3.4	1.8	.75	
dissolved solids (lab)	115	77	.975	A	96	113	97	<.75	
Constituents (dissolved)									
Major ions									
chloride	15.5	14.5	<.75		14.0	24.0	16.0	.90	
sulfate	31.5	9.4	.995	A	11	38	27	.95	D
calcium	6.9	5.9	<.75		7.1	8.3	5.2	.75	
magnesium	3.9	3.2	.75		4.7	4.0	2.9	.95	C -E
potassium	2.2	2.0	<.75		2.0	2.2	2.0	<.75	
sodium	7.8	7.5	<.75		6.0	12.0	8.3	.95	-C D
silica	8.4	8.9	<.75		8.9	9.2	7.5	.90	
Trace metals									
aluminum	85	40	<.75		20	290	120	.75	
barium	72	77	<.75		75	78	63	<.75	
beryllium	<0.5	<0.5	<.75		0.5	0.6	<0.5	.75	
cadmium	<1	<1	<.75		<1	<1	<1	.99	
chromium	<10	<10	<.75		<10	<10	<10	<.75	
cobalt	14	4	.995	A	4	11	8	.975	-C D
copper	<10	<10	.90		30	<10	<10	.995	C -E
iron	2,950	72	.999	A	95	450	2,500	<.75	
iron (total)	3,350	260	.995	A	430	480	2,700	<.75	
lithium	12	9	.75		<1	1.1	1.5	.975	-C E
lead	<10	<10	<.75		<10	<10	<10	.75	
manganese	93	38	.90		50	130	56	.75	
molybdenum	<10	<10	<.75		<10	<10	<10	<.75	
strontium	61	65	<.75		62	98	45	.95	D -E
vanadium	<6	<6	<.75		<6	<6	<6	<.75	
zinc	38	26	.75		25	36	30	<.75	
Nutrients									
phosphorus, orthophosphate	<0.01	<0.01	<.75		<0.01	<0.01	<0.01	<.75	
nitrogen, nitrite	<0.01	0.01	<.75		<0.01	<0.01	<0.01	<.75	
nitrogen, nitrate	0.13	3.69	.995	B	2.5	0.29	0.18	.75	
nitrogen, ammonia	0.10	0.01	.999	A	<0.01	0.02	0.07	.95	-C E
nitrogen, ammonia + organic N	0.7	0.4	.995	A	0.4	0.6	0.5	<.75	
Organic Compounds (total)									
organic carbon (dissolved)	1.3	0.9	.995	A	0.9	1.1	1.3	<.75	
total recoverable phenols	<1	<1	.75		<1	<1	<1	<.75	
total purgeable organics	<3	<3	<.75		<3	<3	<3	<.75	
total pesticides	-	-	<.75		-	-	-	<.75	

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[1] Concentration units and detection limits are given in table 5. Median concentrations not determined for total pesticides because of variable detection limits. Only 65 sites were analyzed for pesticides.

[2] The significance level is determined using the H-value adjusted for ties in rank, from the Kruskal-Wallis test, and a Chi-square distribution table (Ryan and others, 1985).

[3] The group with concentrations that are significantly higher at a .95 confidence level or greater are flagged as:
A = depth of well ≤ 20 feet; B = depth of well > 20 feet.

[4] The group with concentrations that are significantly higher or lower at a .95 confidence level or greater are flagged as:
C = Pumping rate ≤ 100 gals/min; D = pumping rate 100 - 500 gals/min; E = pumping rate ≥ 500 gals/min.
If the code is preceded by a negative sign (-), then the concentrations within the group are significanly lower.

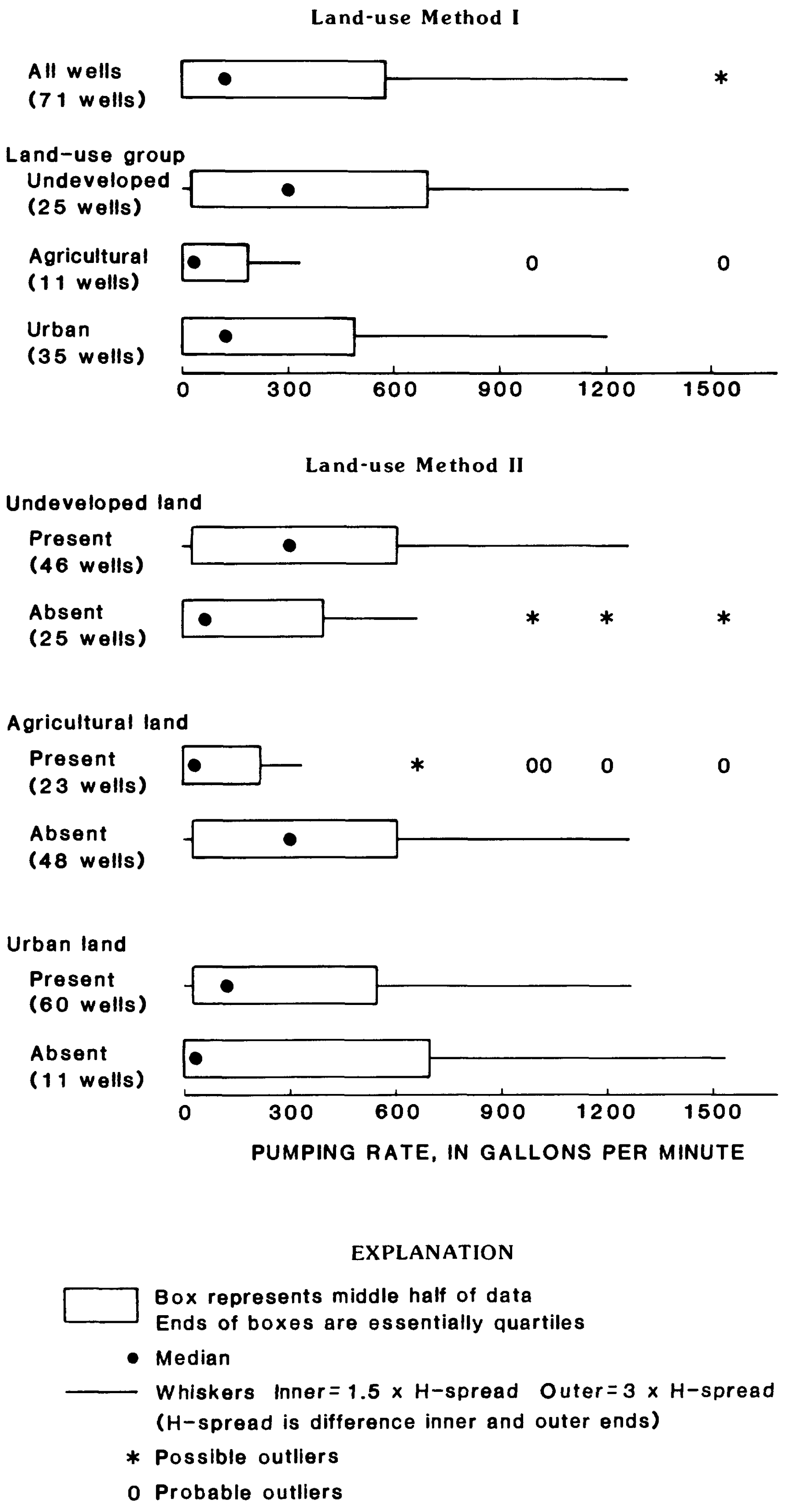

Figure 14.--Boxplots of pumping rates of sampled wells in the primary study area by land use.

Relation to Land Use

The relation of ground-water quality to land use was evaluated by comparing the quality of water from wells land use: undeveloped, agricultural, or urban. Two methods were used to classify land use at a well and were previously discussed. Table 11 summarizes water-quality data for wells representing undeveloped, agricultural, and urban land when Method I was used. Tables comparing water-quality data, grouped using the presence-absence criteria of Method II, are provided in the appropriate sections: undeveloped (table 12); agricultural (table 13); and urban (table 14). The tables include the percentage of samples within each land-use group with concentrations above the detection limit and median, first quartile, and third quartile concentrations for each characteristic and constituent. The results of the Kruskal-Wallis test are given by reporting the significance level of the test as determined by Chi-square distribution tables. Results of the multiple comparisons test are reported by indicating which land-use group has a mean rank that is significantly higher or lower than that of the total population. The results of Method I are discussed first, followed by the results of Method II. Similar results, when either land-use method was used, are identified next. Selected constituents that show differences in concentration or frequency of detection among land-use groups are discussed in detail within each land-use section in the following order: field characteristics, major ions, metals, nutrients, and organic compounds.

Undeveloped Land

In theory, undeveloped land is least affected by human activities than the other land uses. However, the proximity of landfills and evidence of illegal dumping of contaminants in undeveloped land increases the possibility that contamination would appear in the ground water from this land. Therefore, detection of some contaminants, such as purgeable organic compounds, was expected.

When Method I was used to designate land use at a well, the predominant land use at 25 sites is undeveloped. Water-quality data from these sites were compared with data from wells representing agricultural and urban land uses (table 11). The results of the Kruskal-Wallis test indicate that there are no significant differences in the concentrations of most major ions or organic compounds between wells from undeveloped land and those from the total sample population. However, concentrations of dissolved oxygen, magnesium, barium, chromium, and nitrate are significantly lower and concentrations of aluminum, beryllium, cobalt, dissolved iron, total iron, and zinc are significantly higher in wells located in predominantly undeveloped land. Although the Kruskal-Wallis test did not indicate that phenol concentrations differ among land-use groups, phenols were detected most frequently in wells in undeveloped land when Method I was used.

Table 11.-- Summary of water-quality data from the primary study area by land use designated by Method I.

	Land-use group							
	Undeveloped (25 wells)				Agricultural (11 wells)			
Characteristic[1] or constituent	Percentage[2] above detection	Concentration			Percentage[2] above detection	Concentration[3]		
		Median	Q1	Q3		Median	Q1	Q3
Characteristics								
pH (field)	100	4.5	4.2	5.5	100	5.0	4.7	5.4
temperature (field)	100	12.0	11.5	12.7	100	11.2	11.9	13.3
specific conductance (field)	100	172	99	237	100	142	121	221
dissolved oxygen (field)	100	0.5	0.3	6.2	100	6.3	3.1	8.6
alkalinity (CaCO3) (field)	44	<1.0	<1.0	6.9	64	3.4	2.2	6.8
dissolved solids (lab)	100	93	70	122	100	113	54	139
Constituents (dissolved)								
Major ions								
chloride	100	16.0	8.8	26.0	100	12.0	8.7	21.0
sulfate	100	28.8	8.0	45.0	100	7.8	0.6	23.0
calcium	100	4.8	4.1	7.6	100	7.5	2.2	17.0
magnesium	100	3.2	2.2	4.7	100	4.0	2.7	8.5
potassium	100	1.8	1.3	2.3	100	2.3	1.2	2.8
sodium	100	8.4	5.0	12.5	100	6.2	3.8	13.0
silica	100	7.9	8.1	12.0	100	10.0	8.1	12.0
Trace metals								
aluminum	92	300	<10	1,500	45	<10	<10	80
barium	100	60	32	88	100	75	47	190
beryllium	64	0.9	<0.5	2.0	27	<0.5	<0.5	0.9
cadmium	8	<1	<1	<1	9	<1	<1	<1
chromium	12	<10	<10	<10	45	<10	<10	10
cobalt	100	17	6	27	18	<3	<3	3
copper	48	<10	<10	30	82	20	<10	130
iron	100	2,800	320	6,350	100	23	6	75
iron (total)	100	3,200	500	7,800	100	130	50	150
lithium	60	10	4	20	64	12	4	17
lead	44	<10	<10	10	36	<10	<10	30
manganese	100	100	43	185	100	31	12	100
molybdenum	0	<10	<10	<10	9	<10	<10	<10
strontium	100	45	31	86	100	61	30	130
vanadium	0	<6	<6	<6	0	<6	<6	<6
zinc	100	69	25	200	100	20	13	83
Nutrients								
phosphorus, orthophosphate	12	<0.01	<0.01	<0.01	9	<0.01	<0.01	<0.0
nitrogen, nitrite	0	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.0
nitrogen, nitrate	56	0.14	0.1	1.7	100	2.5	0.5	5.8
nitrogen, ammonia	72	0.07	0.01	0.27	55	0.02	0.01	0.0
nitrogen, ammonia + organic N	100	0.7	0.4	1.2	100	0.5	0.3	0.7
Organic Compounds								
organic carbon (dissolved)	100	1.2	0.9	1.6	100	0.9	0.5	1.1
total recoverable phenols	46	<1	<1	1.5	9	<1	<1	<1
total purgeable organics	16	<3	<3	<3	9	<3	<3	<3
total pesticides	5	-	-	-	21	-	-	-

Table 11.--Summary of water-quality data from the primary study area by land use disignated by Method I (Continued)

	Urban (35 wells)					
Characteristic[1] or constituent	Percentage[2] above detection	Concentration[3] Median	Q1	Q3	Sig-[4] nifi-cance level	Which[5] group is differ-ent
Characteristics						
pH (field)	100	5.1	4.8	5.6	0.90	
temperature (field)	100	13.2	11.9	13.6	0.90	
specific conductance (field)	100	180	114	275	<.75	
dissolved oxygen (field)	100	5.0	1.2	7.0	.975	-A B
alkalinity (CaCO3) (field)	71	5.2	2.8	13.6	.90	
dissolved solids (lab)	100	112	72	172	<.75	
Constituents (dissolved)						
Major ions						
chloride	100	16.0	9.5	28.0	<.75	
sulfate	100	24.0	5.7	51.0	.75	
calcium	100	7.5	4.4	20.0	.90	
magnesium	100	4.5	2.9	9.2	.95	-A C
potassium	100	2.2	1.4	2.5	<.75	
sodium	100	12.6	5.3	15.0	<.75	
silica	100	9.1	7.4	12.0	.90	
Trace metals						
aluminum	80	40	<10	290	.975	A -B
barium	100	85	62	120	.95	-A C
beryllium	37	<0.5	<0.5	0.9	.95	A
cadmium	9	1	1	1	<.75	
chromium	43	<10	<10	10	.975	-A
cobalt	51	6	<3	10	.99	A -B
copper	54	<10	<10	90	.75	
iron	100	98	45	860	.999	A -B
iron (total)	100	460	150	2,700	.995	A -B
lithium	43	7	4	12	<.75	
lead	26	<10	<10	20	<.75	
manganese	100	43	21	130	.90	
molybdenum	0	<10	<10	<10	<.75	
strontium	100	76	47	140	.90	
vanadium	0	<6	<6	<6	<.75	
zinc	94	25	13	36	.995	A C
Nutrients						
phosphorus, orthophosphate	20	<0.01	<0.01	<0.01	<.75	
nitrogen, nitrite	17	<0.01	<0.01	<0.01	.90	
nitrogen, nitrate	80	3.6	0.1	5.0	.99	-A C
nitrogen, ammonia	63	0.02	0.01	0.07	.90	
nitrogen, ammonia + organic N	91	0.4	0.2	0.7	.75	
Organic Compounds						
organic carbon (dissolved)	100	1.1	0.7	1.4	.90	
total recoverable phenols	29	<1	<1	<1	.90	
total purgeable organics	29	<3	<3	7.5	.75	
total pesticides	12	-	-	-	<.75	

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[1] Concentration units and detection limits are given in table 5. Only the percent above detection is given for total pesticides because of the variable detection limit. Only 65 sites were analyzed for pesticides.

[2] The percentage above detection is calculated by dividing the number of samples with a concentration equal to or exceeding the detection limit by the total number of samples in that group and multiplying by 100.

[3] Q1 and Q3 represent the first and third quartiles.

[4] The significance level is determined using the H-value adjusted for ties in rank, from the Kruskal-Wallis test, and a Chi-square distribution table (Ryan and others, 1985).

[5] The group with concentrations that are significantly different at a .95 confidence level or greater are flagged as: A = Undeveloped; B = Agricultural; C = Urban. If the code is preceded by a negative sign (-) the median rank concentration is two standard deviations lower than the concentrations for all groups.

When Method II was used to designate land use at a well, 46 sites have some undeveloped land within a 1/4-mile radius of the sampled well. Water-quality data at these sites were compared with 25 sites having no undeveloped land within a quarter of a mile of the well (table 12). The Kruskal-Wallis test indicates that there is no difference in the concentrations of the major ions or organic compounds between the two groups. However, water temperature and the concentrations of dissolved oxygen, barium, nitrogen as nitrite (hereafter discussed as nitrite), and nitrate are significantly lower in wells near undeveloped land. In addition, the concentration of cobalt, iron, and zinc are higher in wells where undeveloped land is present. Similar to Method I, phenols are detected more frequently in wells near undeveloped land.

When either Method I or II was used, the Kruskal-Wallis test indicated that the concentrations of major ions and organic compounds in ground water from undeveloped land are not significantly different than those in ground water from wells with other land uses. However, the concentrations of dissolved oxygen, barium, and nitrate are lowest and the concentrations of cobalt, iron, and zinc are highest in the ground water from undeveloped land compared to ground water from other land-uses when either method was used. Although the Kruskal-Wallis test did not show that the concentrations of phenols are significantly different among land-use groups, phenols were detected most frequently in undeveloped land when either method was used to designate land use at a well.

According to the results of the Kruskal-Wallis test, the pH of the ground water is not different among the three land-use groups at a significance level of 0.95 or greater. Nevertheless, when the predominant land-use criteria of Method I was used, the median pH of water from wells in undeveloped land (4.5) is lower than that in either agricultural (5.0) or urban land (5.1) (table 11 and fig. 15). Although the significance level of the Kruskal-Wallis test on this data is only 0.90, the difference in pH is noted because it may control the concentrations of other constituents in the ground water by influencing solubilities. For example, trace metals such as iron are generally more soluble at lower pH (Hem, 1985, p. 80).

Dissolved oxygen concentration is lowest in undeveloped land when either land-use method is used. When Method I was used the median dissolved oxygen concentrations in undeveloped land is 0.5 mg/L (milligrams per liter) compared to 6.3 mg/L in agricultural land and 5.0 mg/L in urban land (table 11). When Method II was used, the median dissolved oxygen concentration in undeveloped land is 2.8 mg/L compared to 6.3 mg/L for sites with no undeveloped land (table 12). The higher median dissolved oxygen concentration, obtained when Method II is used, occurs because of the greater influence of other land uses when using this method. Low dissolved oxygen concentration in ground water from undeveloped land may occur because of oxygen consumption during breakdown of organic material (Given, 1975, p. 61, 79), which is plentiful in the wetlands of the primary area. Significantly lower dissolved oxygen concentrations may influence the solubilities of other constituents. For example, iron is more soluble when the concentration of dissolved oxygen is low (Hem, 1985, p. 81).

Table 12.--Summary of water-quality data from the primary study area for undeveloped land designated by Method II.

	Undeveloped land									
	Present (46 wells)				Absent (25 wells)					
	Percentage[2] above detection	Concentration[3]			Percentage[2] above detection	Concentration[3]				
Characteristic[1] or constituent		Median	Q1	Q3		Median	Q1	Q3	Signif-[4] icance level	Which[5] group is higher
Characteristics										
pH (field)	100	4.9	4.4	5.5	100	5.0	4.8	5.7	0.75	
temperature (field)	100	12.0	11.5	13.5	100	13.0	12.1	13.9	.975	O
specific conductance (field)	100	173	100	245	100	168	122	240	<.75	
dissolved oxygen (field)	100	2.8	0.3	6.8	100	6.3	3.0	8.1	.975	O
alkalinity (CaCO3) (field)	63	3.6	<1.0	7.8	56	4.8	2.2	13.1	<.75	
dissolved solids (lab)	100	98	69	147	100	103	67	155	<.75	
Constituents (dissolved)										
Major ions										
chloride	100	15.5	8.2	26.0	100	16.0	10.4	24.5	<.75	
sulfate	100	28.0	5.5	49.8	100	22.0	2.9	34.0	.75	
calcium	100	5.7	4.1	9.7	100	7.5	3.7	16.5	<.75	
magnesium	100	3.5	2.5	6.1	100	4.7	2.8	8.7	<.75	
potassium	100	2.0	1.3	2.4	100	2.2	1.3	2.7	<.75	
sodium	100	7.8	5.3	13.0	100	8.8	5.0	13.0	<.75	
silica	100	8.4	7.3	11.0	100	9.2	7.4	12.0	.90	
Trace metals										
aluminum	85	60	<10	625	64	30	<10	150	.75	
barium	100	64	37	95	100	96	61	120	.95	O
beryllium	52	<0.5	<0.5	1.8	32	<0.5	<0.5	0.8	.90	
cadmium	7	<1	<1	<1	12	<1	<1	<1	<.75	
chromium	24	<10	<10	<10	48	<10	<10	<10	.90	
cobalt	80	10	4	22	36	3	<3	8	.995	U
copper	50	10	<10	30	64	10	10	120	.75	
iron	100	770	84	6,275	100	51	13	370	.995	U
iron (total)	100	1,200	150	6,800	100	170	120	470	.990	U
lithium	61	9	4	17	64	7	4	15	<.75	
lead	35	<10	<10	10	32	<10	10	25	<.75	
manganese	100	91	25	160	100	34	17	110	<.75	
molybdenum	0	<10	<10	<10	4	<10	<10	<10	.75	
strontium	100	61	32	123	100	90	38	100	<.75	
vanadium	0	<6	<6	<6	0	<6	<6	<6	<.75	
zinc	98	37	20	110	96	22	12	34	.975	U
Nutrients										
phosphorus, orthophosphate	15	<0.01	<0.01	0.01	16	<0.01	<0.01	0.01	<.75	
nitrogen, nitrite	4	<0.01	<0.01	<0.01	16	<0.01	<0.01	<0.01	.95	U
nitrogen, nitrate	65	0.2	<0.1	4.6	92	2.6	1.2	4.9	.95	O
nitrogen, ammonia	67	0.05	<0.01	0.14	60	0.02	0.01	0.05	.90	
nitrogen, ammonia + organic N	96	0.45	0.28	0.92	92	0.50	0.30	0.80	<.75	
Organic Compounds										
organic carbon (dissolved)	100	1.1	0.9	1.5	100	1.0	0.6	1.6	<.75	
total recoverable phenols	36	<1	<1	1	16	<1	<1	<1	<.75	
total purgeable organics	17	<3	<3	<3	28	<3	<3	10.2	.75	
total pesticides	10	-	-	-	12	-	-	-	<.75	

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[1] Concentration units and detection limits are given in table 5. Only percentage above detection is given for total pesticides because of variable detection limits. Only 65 sites were analyzed for pesticides.

[2] The percentage above detection is calculated by dividing the number of samples with a concentration equal to or exceeding the detection limit by the total number of samples in that group and multiplying by 100.

[3] Q1 and Q3 represent the first and third quartiles.

[4] The significance level is determined using the H-value adjusted for ties in rank, from the Kruskal-Wallis test, and a Chi-square distribution table (Ryan and others, 1985).

[5] The group with concentrations that are significantly higher at a .95 confidence level or greater are flagged as: U = Undeveloped; O = Other.

The concentrations of several trace metals, especially iron, differ significantly among land-use groups. Iron, cobalt, and zinc concentrations are highest in ground-water from undeveloped land. Iron exceeded the Federal and State secondary drinking-water guideline of 300 µg/L (U. S. Environmental Protection Agency, 1976b, 1977; and New Jersey Department of Environmental Protection, 1979) in 34 sampled wells. About 75 percent of the wells in predominantly undeveloped land, designated by Method I, exceeded the secondary drinking-water guideline for iron. At the 25 sites where the predominant land use is undeveloped, the median dissolved iron concentration is 2,800 µg/L (micrograms per liter). In contrast, the median concentration is 23 µg/L in wells in agricultural land and 98 µg/L in urban land (fig. 15 and table 11). When Method II was used, 27 of the 34 wells exceeding the secondary drinking-water guideline for iron have some undeveloped land within a quarter of a mile of the well. The median dissolved iron concentration is 770 µg/L in wells where undeveloped land is present and 51 µg/L in wells where undeveloped land is absent (fig. 15 and table 12). The relatively high iron concentration in the ground water in undeveloped land is probably the result of the presence of wetlands in the Pinelands outlier, which typically have waters with high iron concentrations (Given, 1975, p. 58-59). Increased solubility of iron in wetlands may be because of the relatively low pH, low concentration of dissolved oxygen, and high concentration of organic material that may complex with relatively insoluble compounds of iron to form more soluble compounds (Hem, 1985, p.78).

Nitrate concentration is lowest in water from wells in undeveloped land when either method was used to designate land use at a well. When Method I was used, the median nitrate concentration in ground water in undeveloped land is 0.14 mg/L compared to 2.5 mg/L for wells in agricultural land and 3.6 mg/L for wells in urban land. When Method II was used, the median nitrate concentration in ground water from undeveloped land is 0.2 mg/L, similar to that determined when Method I was used. Relatively low nitrate concentrations were expected in ground water from undeveloped land, because the primary source of elevated nitrate concentrations in the ground water is human activity. In addition, any nitrate transported through the unsaturated zone is subject to losses through fixation, concentration during evaporation, and(or) uptake by plants and microorganisms (Ragone and others, 1980, p. 46-54; Hem, 1985, p. 124). This is especially the case in undeveloped land where there is a large amount of plants and microorganisms. Moreover, in undeveloped land where wetlands are present and dissolved oxygen concentration is low or absent, any nitrate not utilized by plants can be reduced to nitrous oxide or nitrogen gas by anaerobic bacteria (Brock, 1974, p. 563; Hem, 1985, p. 124).

In general, the concentrations of organic compounds did not differ among land-use groups at a 0.95 or greater significance level. In part, this may occur because many of these compounds are not detected frequently. Although a relatively high concentration of dissolved organic carbon was expected in ground water from undeveloped land because of the presence of organic materials in the wetlands, no significant difference in the concentrations of dissolved organic carbon among land-use groups was indicated. However, as expected, synthetic organic compounds were not detected frequently.

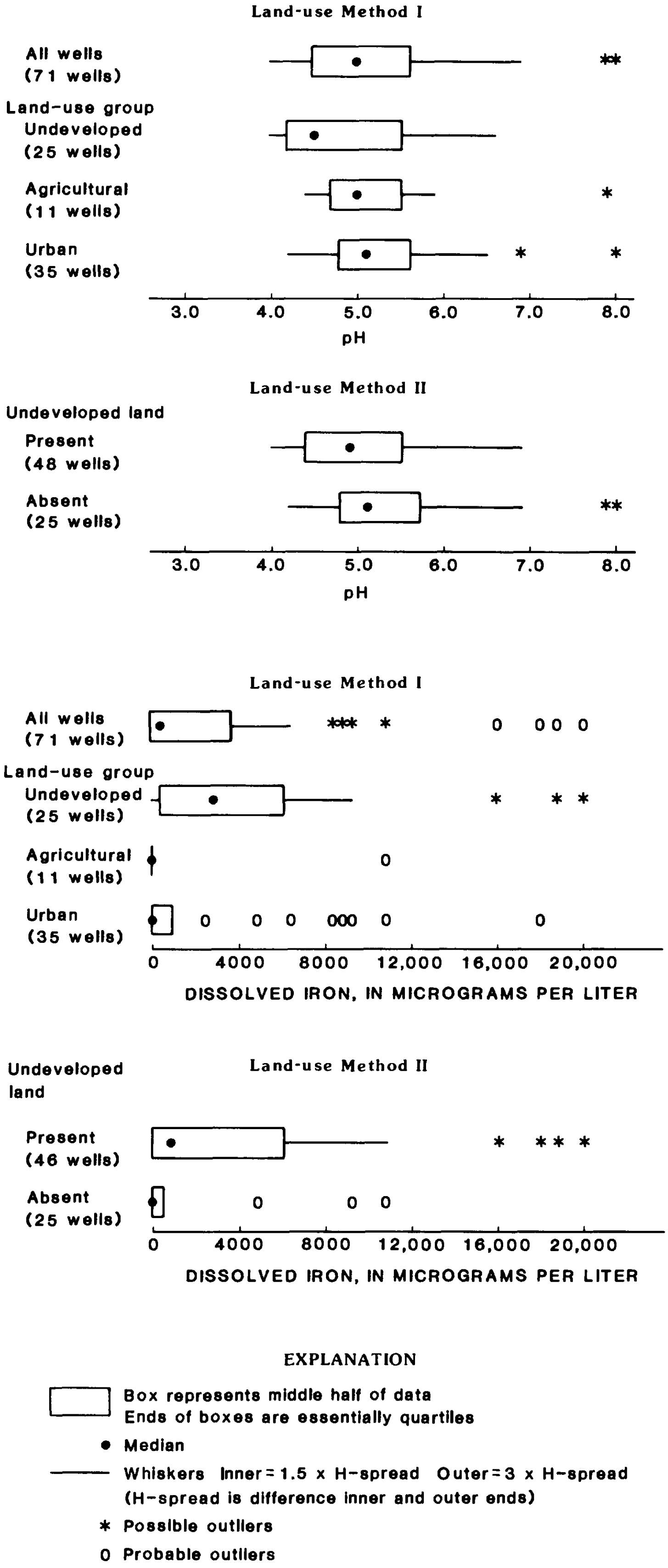


Figure 15.--Boxplots of the pH and iron concentrations in ground water of the primary study area by land use.

Pesticides were detected least frequently in ground water from undeveloped land, classified by either method (tables 8, 11, and 12, fig. 16). Purgeable organic compounds are detected less frequently in undeveloped land than in urban land, but are detected more frequently than in agricultural land (fig. 16).

Phenols are detected more frequently in ground water from undeveloped land, when either method was used to designate land use at a well (fig. 17). When Method I was used, phenols were detected in 44 percent of the wells in undeveloped land, 9 percent of the wells in agricultural land, and 29 of the wells in urban land. When Method II was used, phenols were detected in 39 percent of the wells where undeveloped land is present, but in only 16 percent of the wells where undeveloped land is absent (table 12). The occurrence of phenols in ground water may result from contamination by human activities or from natural breakdown of organic material in wetland environments (Given, 1975, p. 67). Because 17 of the 22 sites with detectable concentrations of phenols have undeveloped land within a quarter of a mile of the well (figure 17), and because most of the measured phenol concentrations are low (range <1 to 11 μg/L), most of the phenols detected in the sampled wells are probably naturally produced rather than synthetic.

Generally, the ground-water quality in undeveloped land overlying the outcrop of the northern part of the Potomac-Raritan-Magothy aquifer system is characterized as having the lowest concentrations of dissolved oxygen, barium, and nitrate and highest concentrations of trace metals, especially iron, cobalt, and zinc. In addition, phenols are detected most frequently. Pesticides are detected least frequently in ground water from undeveloped land, and purgeable organic compounds are detected more frequently in undeveloped land than in agricultural land. This ground-water quality appears to be primarily influenced by the presence of wetlands in the Pinelands outlier. Waters in these wetlands environments typically have high concentrations of organic material and high dissolved organic carbon concentrations. Breakdown of the organic material consumes dissolved oxygen and causes the formation of organic acids that may lower the pH of the ground water. The low pH, low dissolved oxygen concentration, and organic complexing may increase the solubility of trace metals. Any nitrate in the ground water would be subject to losses through uptake by plants which primarily use nitrogen in its oxidized form. Reduction of nitrate to nitrite and other reduced forms of nitrogen by microorganisms also may occur. Breakdown of organic material also will cause the formation of phenols. The presence of purgeable organic compounds within the ground water indicates that human activities may influence ground-water quality in undeveloped land.

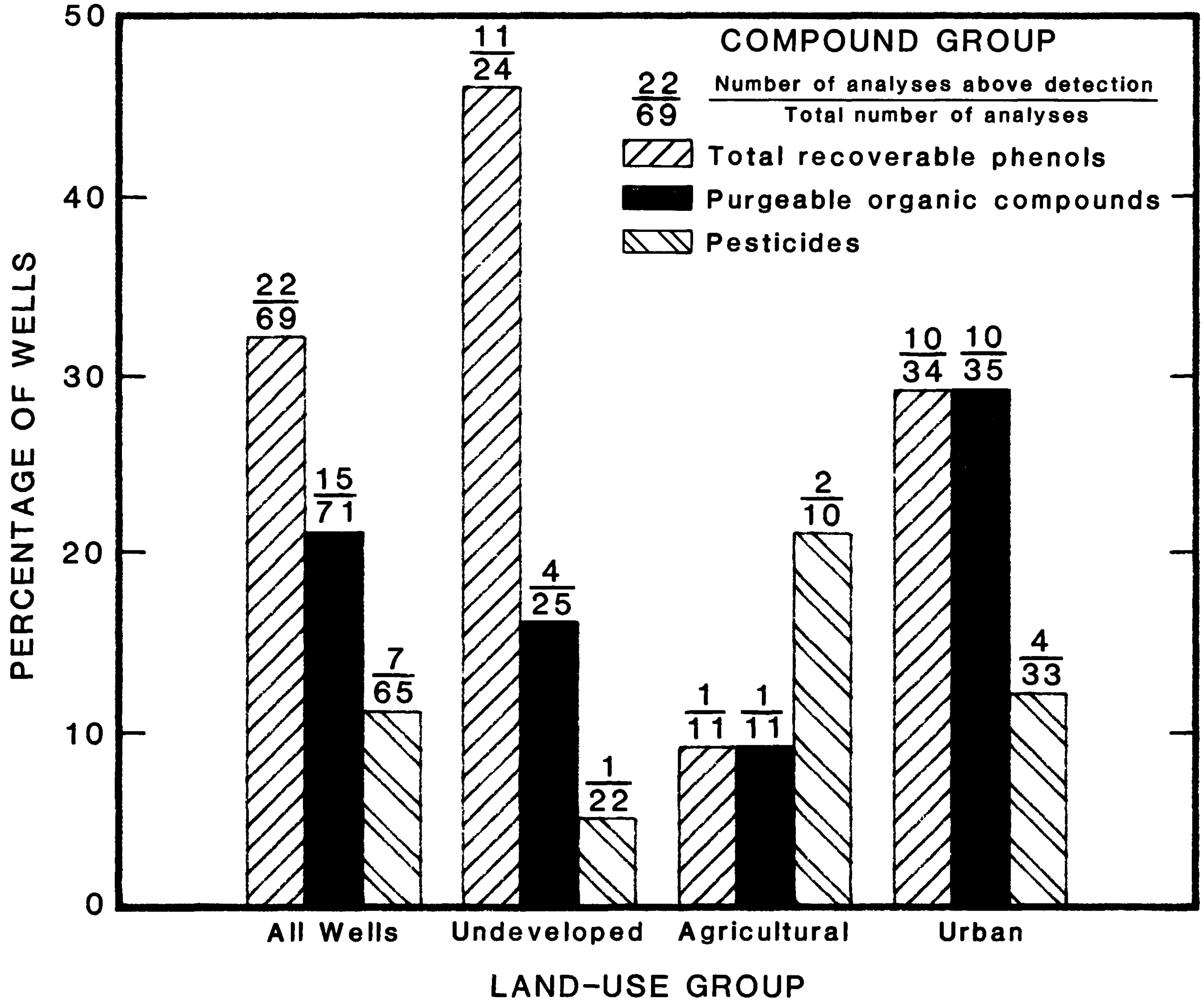
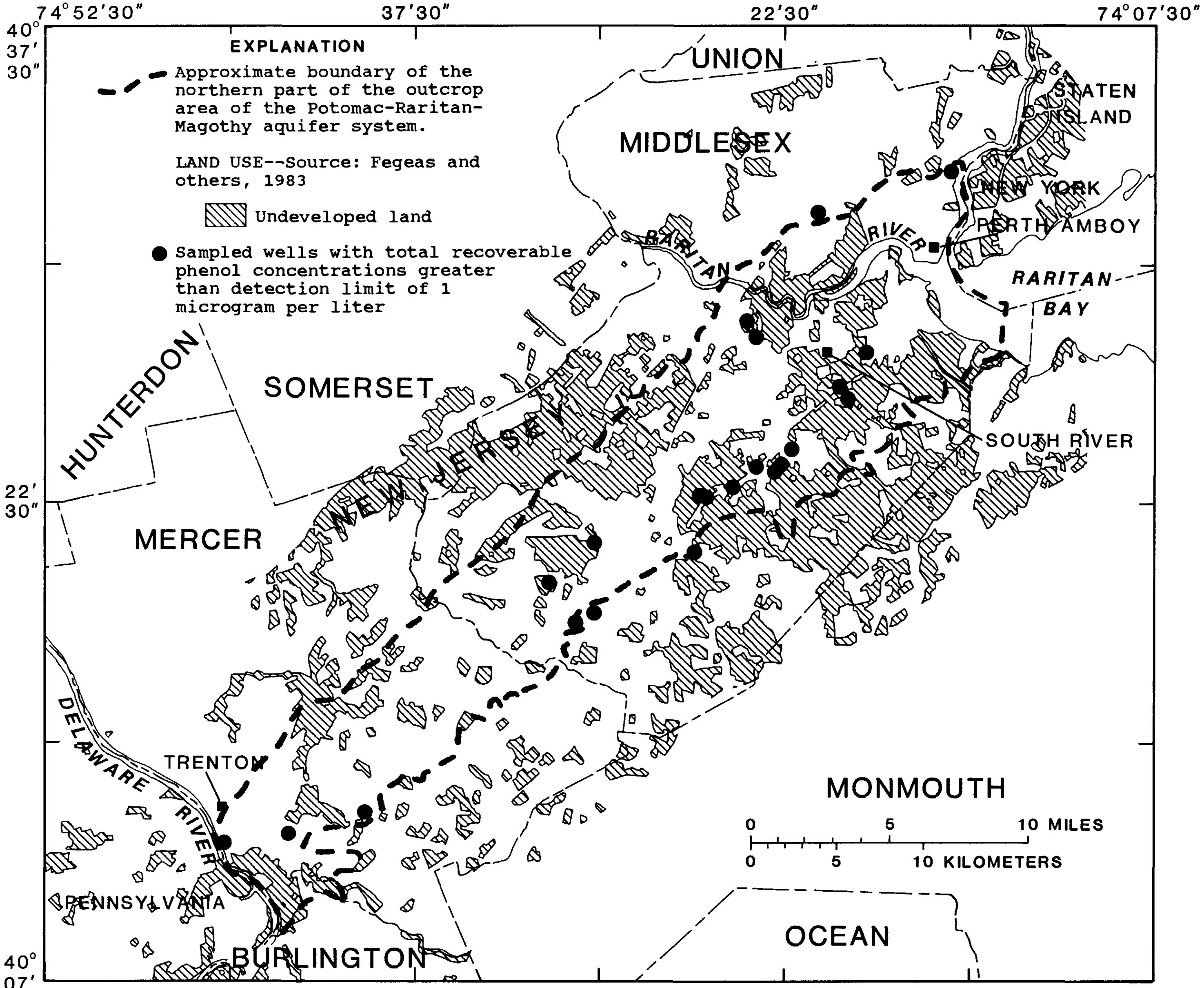


Figure 16.--Frequencies of detection of phenols, pesticides and purgeable organic compounds in ground water of the primary study area by land use.



Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 17.--Location of wells with detectable concentrations of phenols relative to undeveloped land.

Agricultural Land

Ground-water quality in agricultural land may be affected by fertilizers, which are applied to land to increase plant growth, and pesticides, which are applied to control weeds and insects. The types of fertilizers and pesticides used are numerous and depend on natural land cover and type of crop. Within the study area, fertilizers containing nitrates are applied extensively to crops in agricultural land (Cooperative Extension Service, 1984, p. 8-9). Therefore, the concentrations of nitrate in the ground water are expected to be high. Because agricultural lands are generally unsewered, nitrates also may be added to the ground water by domestic septic systems. Because of the application of pesticides to crops, detectable concentrations of pesticides also are expected in the ground water. Ground-water contamination by other types of synthetic organic compounds, such as purgeable organic compounds, are expected to be minimal. The soils of agricultural lands within the study area are generally sandy and well drained; therefore, the concentration of dissolved oxygen in the ground water is expected to be relatively high. In addition, certain constituents, such as chloride, sodium, and iron, are toxic to plants at high concentrations. Therefore, concentrations of these constituents are expected to be low in the ground water of agricultural land.

When Method I was used to designate land use at a well, agriculture is the predominant land use at 11 sites (table 11). At these sites, the Kruskal-Wallis test indicates that there is no significant difference in the concentrations of the major ions and organic compounds from those in the total sample population. However, concentrations of aluminum, cobalt, and dissolved and total iron are lower, and the concentration of dissolved oxygen is higher in agricultural land than in undeveloped or urban land. Nitrate concentration is higher in agricultural land than in undeveloped land, but is lower than in urban land. Pesticides are detected more frequently in wells in agricultural land than in wells in undeveloped or urban land (fig. 16).

When Method II was used to designate land use at a well, 23 sites have some agricultural land within a quarter of a mile from the sampled well. Concentrations of constituents at these sites were compared against those 48 wells that do not have any agricultural land within the 1/4-mile radius (table 13). The Kruskal-Wallis test indicated that specific conductance and concentrations of chloride, sulfate and sodium are lower in wells where agricultural land is present than in wells where it is absent. Concentrations of several trace metals, including aluminum, cobalt, iron, and manganese are lower in wells having some agricultural land within a 1/4-mile radius. Also, the concentration of dissolved organic carbon is lower and the concentrations of dissolved oxygen, copper, nitrate, and pesticides are higher in wells where agricultural land is present. Pesticides are detected more frequently in wells where agricultural land is present.

Ground-water from agricultural land was significantly different than that from other land uses when both methods were used. More differences were determined by Method II. This may be because depths to water are deeper in wells where agricultural land is present than in wells where it is absent (table 6 and fig. 13). Nevertheless, when either method is used, the concentration of dissolved oxygen is highest and the

Table 13.-- Summary of water-quality data from the primary study area for agricultural land designated by Method II.

	Agricultural land									
	Present (23 wells)				Absent (48 wells)					
		Concentration[3]				Concentration[3]				
Characteristic[1] or constituent	Percentage[2] above detection	Median	Q1	Q3	Percentage[2] above detection	Median	Q1	Q3	Signif-[4] icance level	Which[5] group is higher
Characteristics										
pH (field)	100	5.1	4.8	5.6	100	4.9	4.4	5.5	<0.75	
temperature (field)	100	12.2	11.9	13.3	100	12.3	11.7	13.6	.75	
specific conductance (field)	100	122	94	221	100	182	148	269	.99	O
dissolved oxygen (field)	100	7.0	3.1	8.6	100	2.8	0.3	6.6	.999	A
alkalinity (CaCO3) (field)	83	4.8	2.7	6.8	50	3.6	<1.0	12.9	<.75	
dissolved solids (lab)	100	79	55	139	100	108	77	158	.75	
Constituents (dissolved)										
Major ions										
chloride	100	13.0	8.7	18.0	100	19.0	9.9	32.0	.975	O
sulfate	100	5.7	0.5	23.0	100	28.0	12.8	54.5	.999	O
calcium	100	5.5	2.2	10.0	100	7.2	4.4	11.8	.75	
magnesium	100	3.7	2.7	7.6	100	3.8	2.6	6.6	<.75	
potassium	100	2.3	1.3	2.8	100	2.0	1.3	2.5	<.75	
sodium	100	5.4	4.4	8.2	100	8.0	6.5	14.8	.99	O
silica	100	9.8	6.9	12.0	100	8.5	7.3	10.8	<.75	
Trace metals										
aluminum	70	20	<10	60	83	125	10	700	.975	O
barium	100	81	47	120	100	73	45	108	<.75	
beryllium	39	<0.5	<0.5	0.7	48	<0.5	<0.5	1.8	.75	
cadmium	4	<1	<1	<1	10	<1	<1	<1	<.75	
chromium	39	<10	<10	10	8	<10	<10	<10	<.75	
cobalt	39	<3	<3	7	77	10	<3	21	.995	O
copper	74	70	<10	150	46	<10	<10	30	.99	A
iron	100	45	9	230	100	555	85	6,425	.999	O
iron (total)	100	150	110	550	100	915	197	7,000	.990	O
lithium	52	6	4	16	77	9	4	15	<.75	
lead	35	<10	<10	<10	13	<10	<10	18	<.75	
manganese	96	35	17	97	100	97	26	190	.95	O
molybdenum	4	<10	<10	<10	0	<10	<10	<10	.75	
strontium	100	61	35	100	100	72	35	120	<.75	
vanadium	0	<6	<6	<6	0	<6	<6	<6	<.75	
zinc	100	22	13	36	96	34	15	110	.75	
Nutrients										
phosphorus, orthophosphate	4	<0.01	<0.01	<0.01	20	<0.01	<0.01	<0.01	.75	
nitrogen, nitrite	4	<0.01	<0.01	<0.01	10	<0.01	<0.01	<0.01	.75	
nitrogen, nitrate	91	2.6	0.5	5.0	67	0.6	<0.1	4.2	.95	A
nitrogen, ammonia	57	0.02	<0.01	0.07	69	0.05	<0.01	0.13	.75	
nitrogen, ammonia + organic N	96	0.5	0.3	0.7	94	0.5	0.3	1.0	<.75	
Organic Compounds (total)										
organic carbon	100	0.9	0.6	1.0	100	1.3	0.9	1.7	.999	O
total recoverable phenols	22	<1	<1	<1	35	<1	<1	1	.75	
total purgeable organics	17	<3	<3	<3	23	<3	<3	<3	<.75	
total pesticides	23	-	-	-	5	-	-	-	.975	A

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[1] Concentration units and detection limits are given in table 5. Only percentage above detection is given for total pesticides because of variable detection limits. Only 65 sites were analyzed for pesticides.

[2] The percentage above detection is calculated by dividing the number of samples with a concentration equal to or exceeding the detection limit by the total number of samples in that group and multiplying by 100.

[3] Q1 and Q3 represent the first and third quartiles.

[4] The significance level is determined using the H-value adjusted for ties in rank, from the Kruskal-Wallis test, and a Chi-square distribution table (Ryan and others, 1985).

[5] The group with concentrations that are significantly higher at a .95 confidence level or greater are flagged as: A = Agricultural; O = Other.

concentrations of aluminum, cobalt, and iron are lowest in ground water from agricultural land. Pesticides are detected most frequently in ground water from agricultural land when either method was used.

Dissolved oxygen concentration is highest in wells in agricultural land when either method was used to designate land use at a well. When Method I was used, the median dissolved oxygen concentration in agricultural land is 6.3 mg/L, compared to 0.5 mg/L in undeveloped land and 5.0 mg/L in urban land. When Method II was used, the median dissolved oxygen concentration in wells near agricultural land is 7.0 mg/L, compared to 2.8 mg/L in wells where agricultural land is absent. Relatively high concentrations of dissolved oxygen in ground water from agricultural land may occur because soils in these lands are sandy and well drained. Water entering the ground-water system as recharge can be expected to contain dissolved oxygen at concentrations similar to those of surface water in contact with the atmosphere. During transport below the land surface, the water encounters oxidizable material. Reaction with this material decreases the concentration of dissolved oxygen. Relatively rapid transport of ground water through more permeable soils in agricultural land may not provide the time necessary for extensive oxidation; therefore, the water may retain a relatively high dissolved oxygen concentration.

The concentrations of aluminum, cobalt, and dissolved and total iron are lowest in the ground water from agricultural land when either method was used to designate land use at a well. Copper concentration is highest in ground water from agricultural land only when Method II was used to designate land use at a well. The median concentration in wells where agricultural land is present is 70 μg/L, compared to less than the detection limit of 10 μg/L in wells where it is absent (table 13 and fig. 18). Higher copper concentration in ground water in agricultural land may be caused by the use of copper sulfate as a fungicide prior to the development of dithiocarbamates (McEwen and Stephenson, 1979, p. 75-76).

When the predominant land-use criteria of Method I was used, nitrate is detected at or above 0.1 mg/L in 100 percent of the wells in agricultural land (table 11). Median nitrate concentration in agricultural land (2.5 mg/L) (fig. 18) is intermediate between that in undeveloped and urban lands. When the presence-absence criteria of Method II was used, nitrate was detected in 91 percent of the wells where agricultural land is present, but in only 67 percent of the wells where agricultural land is absent (table 13). Median nitrate concentration is 2.6 mg/L in wells near agricultural land and 0.6 mg/L in wells where there is no agricultural land (fig. 18). The distribution of nitrate concentration for all sampled wells is mapped in figure 19. Eight of the 13 sampled wells with concentrations exceeding 5 mg/L have agricultural land within a quarter of a mile of the well. Nitrate concentration exceeded the Federal drinking-water standard of 10 mg/L (U.S. Environmental Protection Agency; 1976a, 1976b) at two sites. Both sites have agricultural land within a 1/4-mile radius of the well. Relatively high nitrate concentrations in the ground water from agricultural land is probably due to the application of fertilizers containing nitrates and to the disposal of wastes using septic systems.

Except for pesticides, concentrations of organic compounds were lowest and detected least frequently in ground water from agricultural land. Dissolved organic carbon concentration is lowest in water from wells

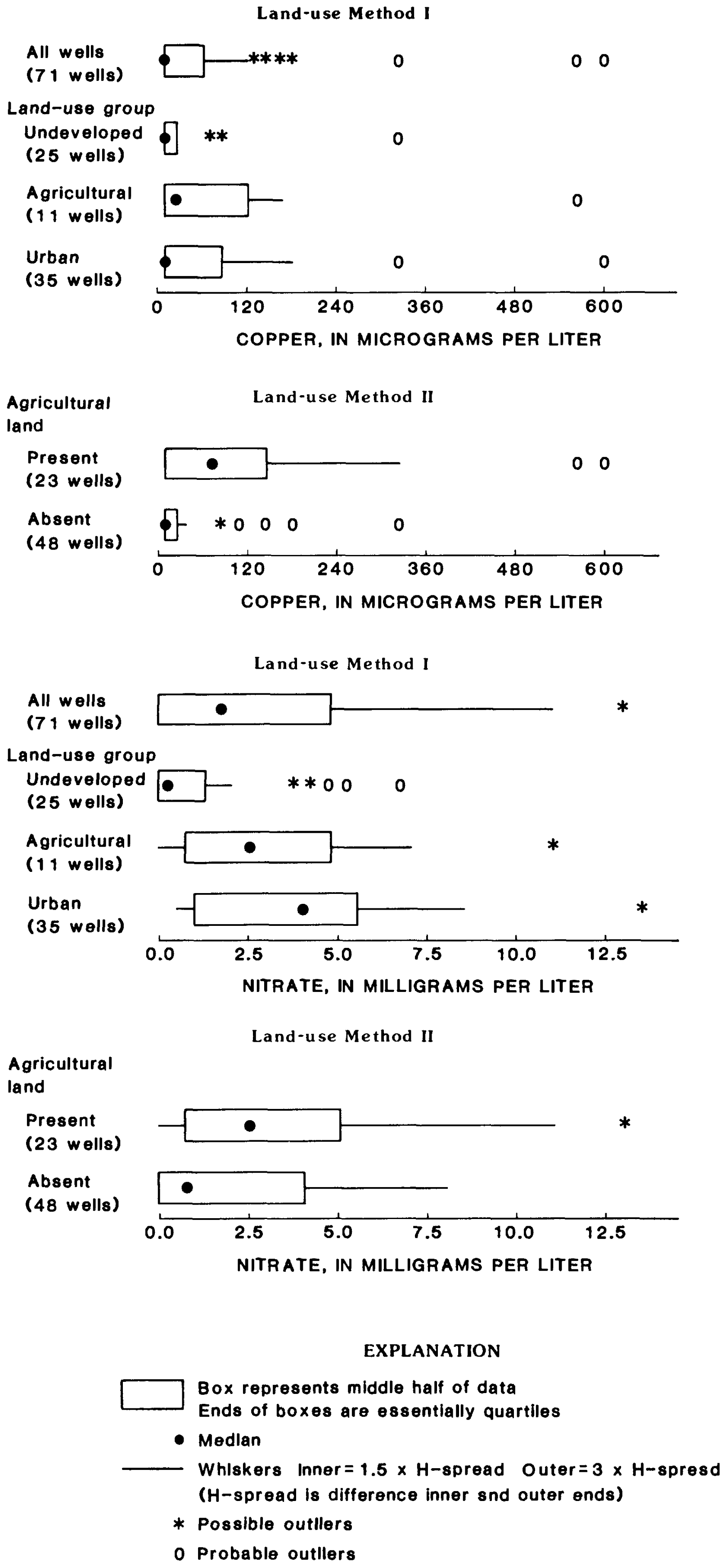
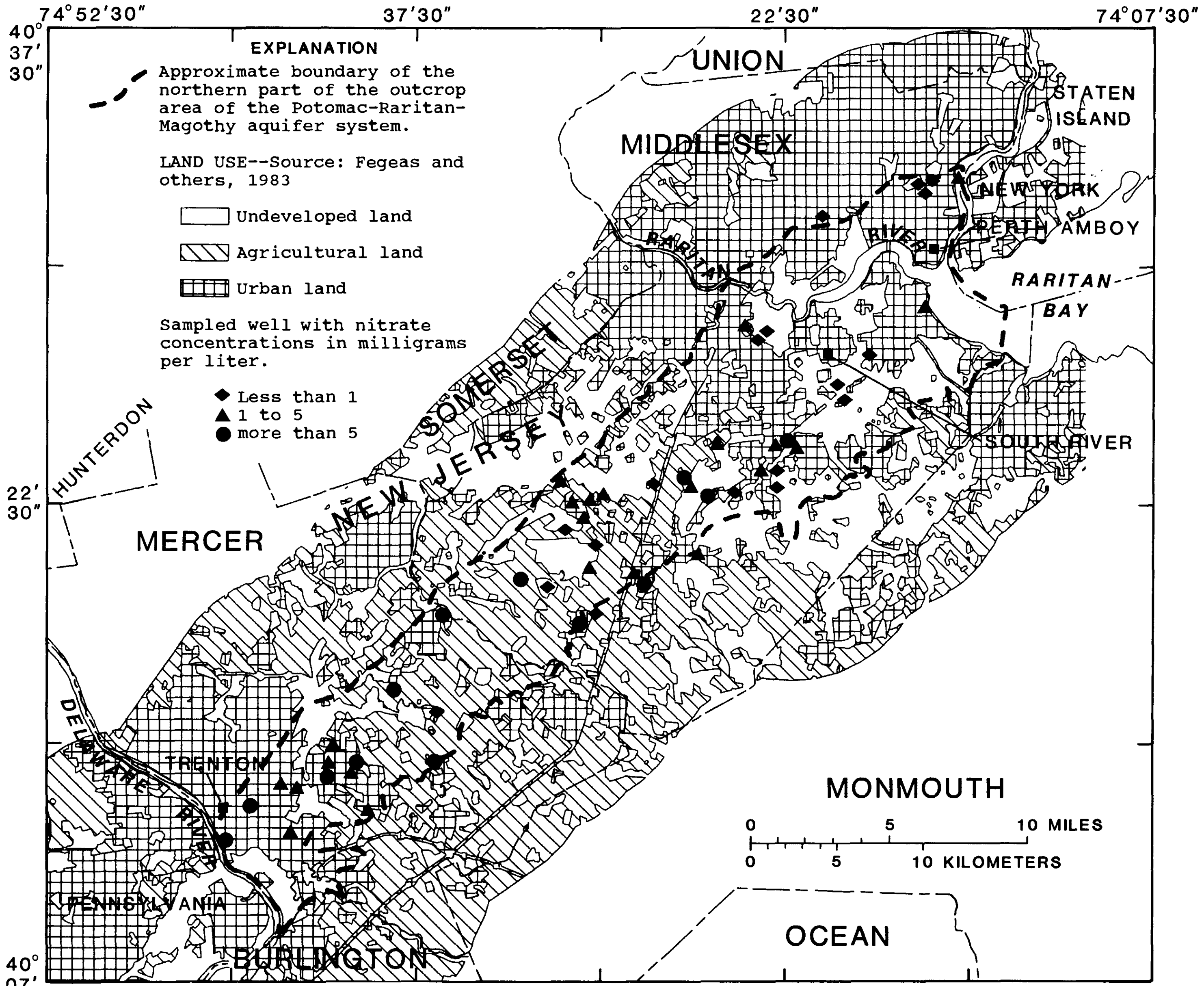


Figure 18.--Boxplots of copper and nitrogen as nitrate concentrations in ground water of the primary study area by land use.



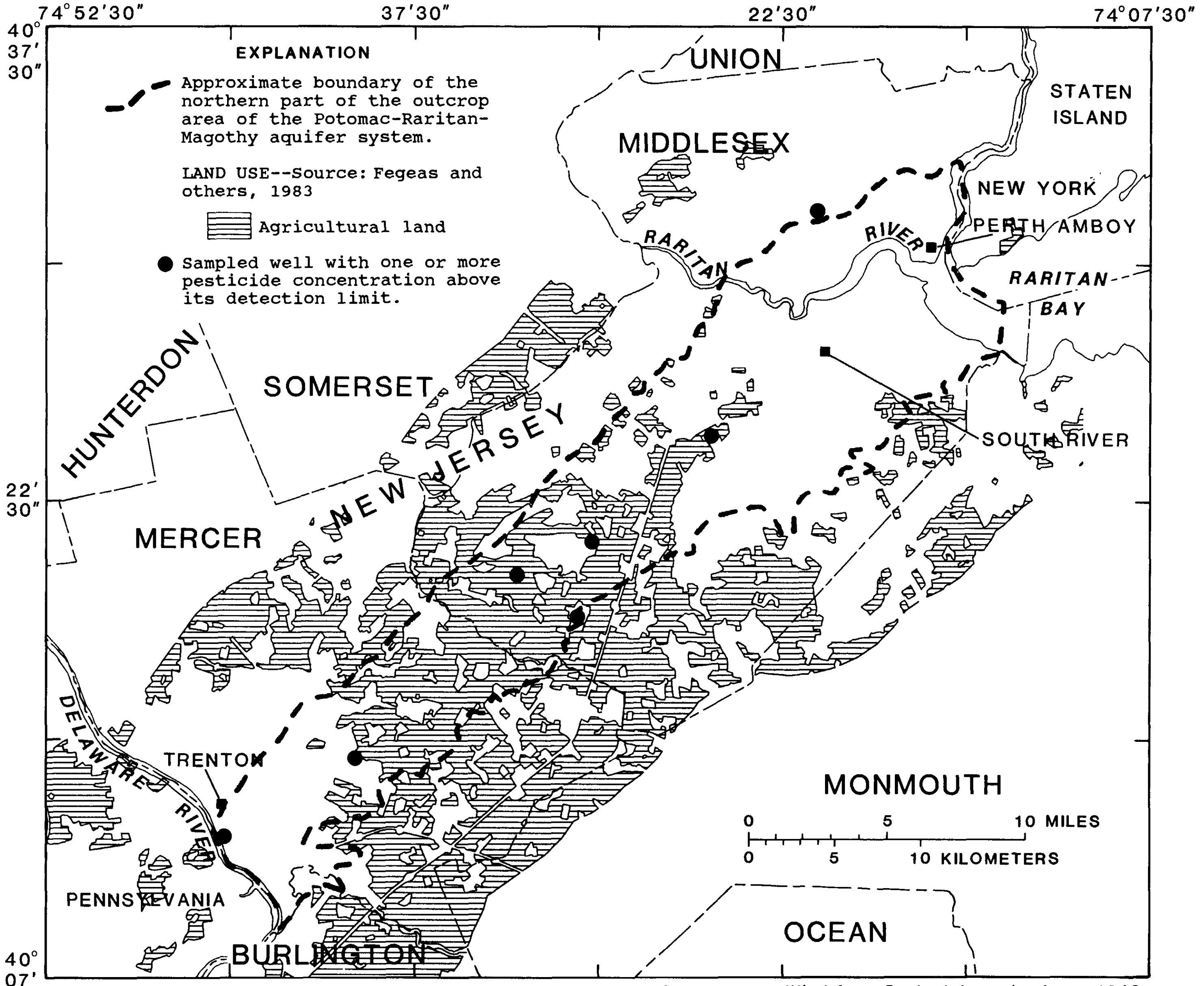
Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 19.--Distribution of nitrogen as nitrate concentration in ground water of the primary study area relative to land use.

representing agricultural land when either method was used. When Method II was used, the median dissolved organic carbon concentration in wells near agricultural land is 0.9 mg/L, compared to 1.3 mg/L at wells with no agricultural land within a 1/4-mile radius. When either method was used, phenols and purgeable organic compounds were detected least frequently in ground water from agricultural land.

Organochlorine, organophosphate, and triazine pesticides were analyzed in samples from 66 wells in the network. Water from 7 of the 66 wells (approximately 11 percent) had a detectable concentration of at least 1 pesticide. Triazines herbicides, including atrizine and simazine, were detected in five wells at concentrations at or near the detection limit. No organophosphorus insecticides were detected, but three organochlorine insecticides were detected at low concentrations: lindane (0.09 μg/L), DDD (0.07 μg/L), and dieldrin (0.02 μg/L). Two compounds--atrizine and dieldrin--were detected at one site. When Method II was used, the concentration of total pesticides in wells near agricultural land is higher than in wells where agricultural land is absent. However, because the detection frequency of pesticides is low, the power of the Kruskal-Wallis test is low, so results may be suspect. Nevertheless, pesticides were detected most frequently in ground water from agricultural land when either method was used. When Method I was used, pesticides were detected in 20 percent of the wells in agricultural land, 4 percent of the wells in undeveloped land, and 12 percent of the wells in urban land (table 11 and fig. 16). When Method II was used, 23 percent of the wells where agricultural land is present contained a detectable concentration of a pesticide, compared to only 5 percent of the wells where agricultural land is absent (table 13). Five of the seven sites with a detectable concentration of some pesticide have some agricultural land within a quarter of a mile of the well (fig. 20).

In general, the ground water in agricultural land overlying the outcrop of the northern part of the Potomac-Raritan-Magothy aquifer system may be characterized as having the highest concentrations of dissolved oxygen and copper, the lowest concentrations of major ions and trace metals, and a higher concentration of nitrate than is found in undeveloped land. Purgeable organic compounds and phenols are detected least frequently in ground water from agricultural land, and pesticides are detected most frequently. This water quality, which differs significantly from that in undeveloped land, is influenced, in part, by a different natural land cover than is present in undeveloped areas. At the time of settlement of the primary study area, land with sandy, well-drained soils was generally chosen for agriculture. Wetlands environments, such as in the Pinelands outlier, were generally left undeveloped (Wacker, 1979, p. 4-11). Hence, ground-water quality in agricultural land was probably naturally different than that in undeveloped land, prior to settlement of the primary study area. In addition, ground-water quality in agricultural land also is influenced by human activities. Relatively high concentrations of nitrates and the occurrence of pesticides indicate ground-water contamination in agricultural land caused by the application of fertilizers and pesticides and the disposal of septic wastes.



Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 20.--Location of wells in the primary study area with detectable concentrations of pesticides relative to agricultural land.

Urban Land

Ground-water quality in urban land is influenced by many land-use activities, including residential, industrial, and landfills. In addition, urban development has replaced previously undeveloped or agricultural land; therefore, past land uses may influence the water quality in areas classified as urban. For these reasons, a higher frequency of detection and greater variability in concentration of ground-water contaminants are expected in urban land compared to undeveloped or agricultural land. Constituents expected to be detected frequently in the ground water of urban land include nitrates and phosphates, which are common in sewage effluent, and purgeable organic compounds; some of which are in petroleum products and cleaning solvents used in industrial and residential areas.

When Method I was used to designate land use at a well, the predominant land use at 35 wells is urban. As indicated by the Kruskal-Wallis test (table 11), the concentrations of only a few constituents in wells from urban land are significantly different from those of the total sample population. The concentration of zinc is lowest and the concentrations of magnesium, barium, and nitrate are highest in urban land. In addition, orthophosphate, nitrite, and purgeable organic compounds were detected more frequently in wells from urban land when Method I was used (table 11 and fig. 16).

When Method II was used, some urban land is present within a 1/4-mile radius of 60 wells. Water-quality data at these sites were compared to the 11 sites where urban land is not present within a quarter of a mile of the well (table 14). The Kruskal-Wallis test indicated that beryllium was the only constituent whose concentration was significantly different in wells from urban land than in the total sample population. The concentration of beryllium is significantly lower in wells where urban land is present than in wells where it is absent. Similar to Method I, orthophosphate, nitrite, and purgeable organic compounds were detected more frequently in water from wells with urban land within a 1/4-mile radius of the well.

The results of the Kruskal-Wallis test, when either method was used, show few significant differences in the water quality of urban land compared to other land uses. In urban land, the concentrations of most field characteristics, major ions, and trace metals did not differ from other land-use groups at the 0.95 significance level. When either method was used, orthophosphate, nitrite, and purgeable organic compounds were detected most frequently in ground water from urban land.

One significant difference in the water quality in urban land compared to other land uses is the nitrate concentration (fig. 18). When Method I was used, the median concentration of nitrate in wells in urban land is 3.6 mg/L, compared to 2.5 mg/L in agricultural land and 0.14 mg/L in undeveloped land. Nitrate concentration did not differ significantly by land-use group when Method II was used. However, the median concentration at wells with urban land within a quarter of a mile of the well is 2.1 mg/L, compared to 0.1 mg/L at wells where urban land is absent. The higher nitrate concentration in the ground water in urban land is probably caused by contamination by several human activities including seepage from septic systems, leaky sewer pipes, and application of fertilizers to lawns.

Table 14.-- Summary of water-quality data from the primary study area for urban land designated by Method II.

Characteristic[1] or constituent	Urban land								Signif-[4] icance level	Which[5] group is higher
	Present (60 wells)				Absent (11 wells)					
	Percentage[2] above detection	Concentration[3]			Percentage[2] above detection	Concentration[3]				
		Median	Q1	Q3		Median	Q1	Q3		
Characteristics										
pH (field)	100	5.0	4.5	5.5	100	5.4	4.2	5.9	<0.75	
temperature (field)	100	12.7	11.9	13.6	100	11.9	10.6	12.3	.90	
specific conductance (field)	100	210	119	240	100	186	86	259	<.75	
dissolved oxygen (field)	100	4.1	0.4	7.0	100	0.7	0.4	6.8	<.75	
alkalinity (CaCO3) (field)	63	3.9	<1.0	9.2	45	6.0	<1.0	13.2	<.75	
dissolved solids (lab)	100	98	70	151	100	116	69	150	<.75	
Constituents (dissolved)										
Major ions										
chloride	100	15.5	9.6	24.8	100	23.0	3.6	28.0	<.75	
sulfate	100	23.5	4.3	39.8	100	11.0	5.1	65.0	<.75	
calcium	100	6.8	4.1	11.8	100	5.5	3.3	8.5	<.75	
magnesium	100	3.7	2.7	6.6	100	3.8	2.4	7.6	<.75	
potassium	100	2.1	1.3	2.5	100	1.8	1.3	2.4	<.75	
sodium	100	8.3	5.3	12.8	100	7.1	4.8	13.0	<.75	
silica	100	8.7	7.3	11.0	100	9.5	6.8	12.0	<.75	
Trace metals										
aluminum	82	45	<10	385	64	20	10	1700	<.75	
barium	100	76	49	118	100	73	34	130	<.75	
beryllium	40	<0.5	<0.5	0.9	73	1.4	<0.5	1.9	.95	O
cadmium	10	<1	<1	<1	0	<1	<1	<1	.75	
chromium	33	<10	<10	10	27	<10	<10	<10	<.75	
cobalt	63	7	3	17	73	13	3	54	.75	
copper	57	10	<10	38	45	<10	<10	120	<.75	
iron	100	140	40	2,950	100	2,800	75	6,200	.75	
iron (total)	100	405	132	3,425	100	3,500	430	7,100	.75	
lithium	62	7	4	15	64	10	4	18	<.75	
lead	32	<10	<10	18	45	<10	<10	<10	<.75	
manganese	100	91	25	160	91	34	17	110	<.75	
molybdenum	10	<10	<10	<10	0	<10	<10	<10	.75	
strontium	100	63	35	115	100	60	30	100	<.75	
vanadium	0	<6	<6	<6	0	<6	<6	<6	<.75	
zinc	100	37	20	110	89	82	12	34	.90	
Nutrients										
phosphorus, orthophosphate	17	<0.01	<0.01	<0.01	9	<0.01	<0.01	<0.01	.75	
nitrogen, nitrite	10	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.1	.75	
nitrogen, nitrate	80	2.1	0.1	4.6	45	0.1	<0.1	4.8	.75	
nitrogen, ammonia	63	0.03	<0.01	0.1	73	0.05	<0.01	0.2	<.75	
nitrogen, ammonia + organic N	93	0.5	0.3	0.9	100	0.4	0.3	0.7	<.75	
Organic Compounds										
organic carbon (dissolved)	100	1.1	0.8	1.6	100	0.9	0.8	1.4	<.75	
total recoverable phenols	33	<1	<1	1	27	<1	<1	<1	<.75	
total purgeable organics	23	<3	<3	<3	9	<3	<3	<3	.75	
total pesticides	9	-	-	-	20	-	-	-	<.75	

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[1] Concentration units and detection limits are given in table 5. Only number of detections are given for total pesticides because of variable detection limits. Only 65 sites were analyzed for pesticides.

[2] The percentage above detection is calculated by dividing the number of samples with a concentration equal to or exceeding the detection limit by the total number of samples in that group and multiplying by 100.

[3] Q1 and Q3 represent the first and third quartiles.

[4] The significance level is determined using the H-value adjusted for ties in rank, from the Kruskal-Wallis test, and a Chi-square distribution table (Ryan and others, 1985).

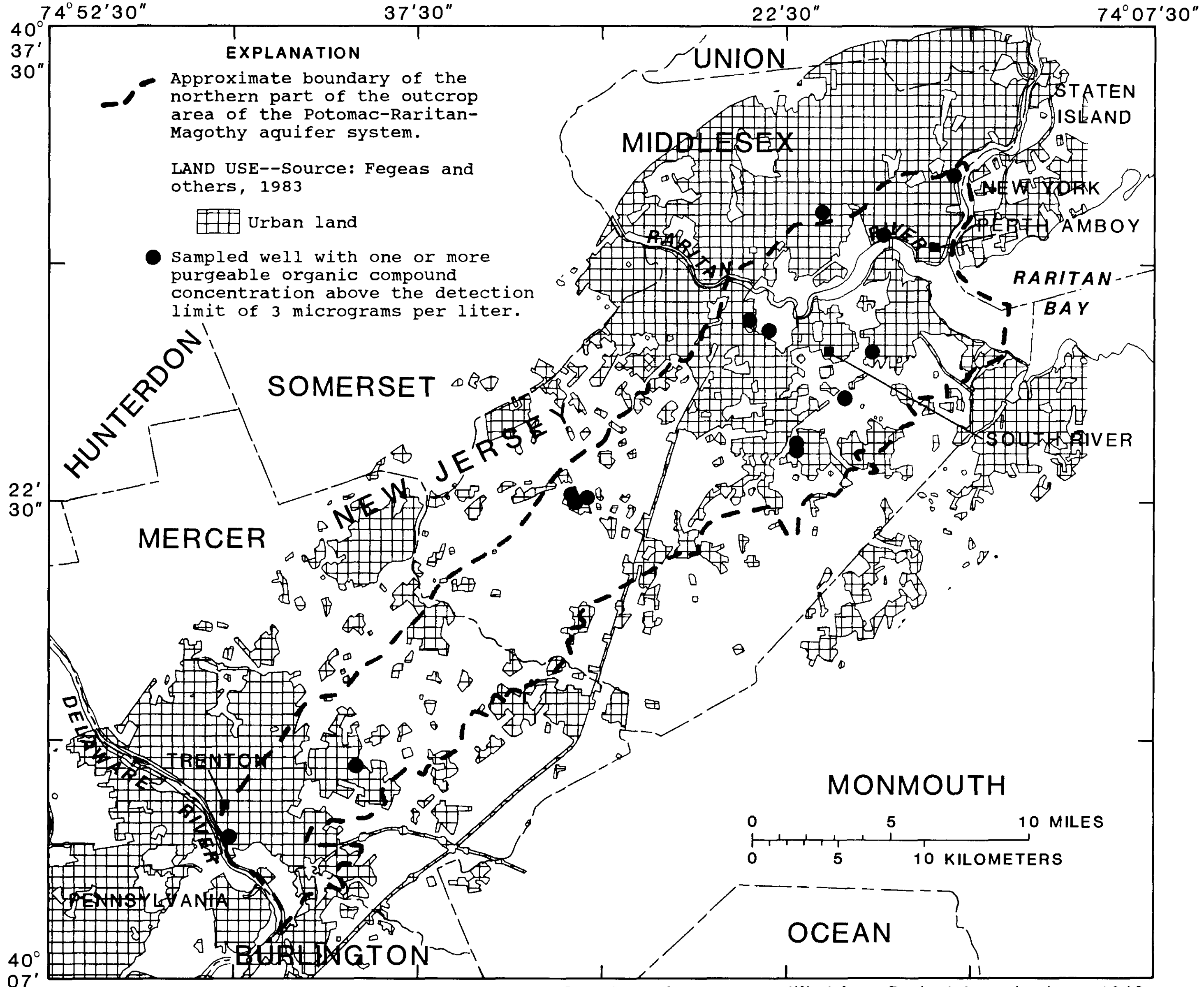
[5] The group with concentrations that are significantly higher at a .95 confidence level or greater are flagged as:
O = Other.

The mean rank concentrations of nitrite and orthophosphate did not differ by land-use group using the Kruskal-Wallis test, probably because they were not detected frequently. Median concentrations for both compounds are below the detection limit for all land-use groups. Nevertheless, when these compounds were detected, they were commonly associated with wells representing urban land. Nitrite was detected in only 6 of the 71 wells tested. All 6 sites were designated as urban when either method was used. The sources of nitrite and other reduced forms of nitrogen in the ground water from urban land are the same as those sources of nitrate previously discussed. Although nitrite would normally be oxidized to nitrate under surface conditions, significant amounts of nitrite can be present in ground water (Hem, 1985, p. 126).

When Method I was used, orthophosphate was detected in 20 percent of wells in urban land, compared to 12 percent of the wells in undeveloped land and 9 percent of the wells in agricultural land. When Method II was used, orthophosphate was detected in 17 percent of the wells where urban land is present, compared to 9 percent of the wells where it is absent. The analytical procedure used to determine the amount of phosphorus in the ground water converts all the phosphorus present to orthophosphate, its most stable oxidized form, prior to measurement. Phosphorus may be introduced into the ground water through dissolution of phosphoritic minerals and skeletal material, mining of phosphorite deposits, processing and application of phosphate fertilizers and organophosphorus insecticides, and synthesis of organic phosphates by plants and animals (Hem, 1985, p. 126). However, probably the most important source of phosphorous in the ground water in the primary study area is through seepage from septic and sewer systems, because phosphorus is always present in animal metabolic waste and sodium phosphate is used as a component in detergents (Hem, 1985, p. 126).

Fifteen of the 71 sampled wells have detectable concentrations of purgeable organic compounds. The total concentrations of purgeable organic compounds ranged from the detection limit of 3 μg/L to 673 μg/L. Four samples exceeded the 100 μg/L State drinking-water guidelines for total purgeable organic compound concentration (New Jersey Department of Environmental Protection, 1979). In order of decreasing occurrence, the purgeable organic compounds detected are tetrachloroethylene, benzene, 1,1,1-trichloroethane, toluene, 1,1-dichloroethylene, chlorobenzene, 1,2-transdichloroethylene, chloroform, and trichloroethylene.

When either land-use method was used, the concentrations of purgeable organic compounds were not significantly different in urban land than in other land uses. This may be due to the low frequency of detection of these compounds. Nevertheless, purgeable organic compounds were detected most frequently in urban land when either method was used. When Method I was used, purgeable organic compounds were detected in 29 percent of the wells in urban land, in 16 percent of the wells in undeveloped land, and in 9 percent of the wells in agricultural land (table 11 and fig. 16). When Method II was used, purgeable organic compounds were detected in 23 percent of the wells where urban land is present and in 9 percent of the wells where urban land is absent (table 14). Fourteen of the 15 sites with a detectable concentration of some purgeable organic compound have some urban land within a 1/4-mile radius of the well (fig. 21).



Boundary of outcrop modified from Barksdale and others, 1943; Owens and Minard, 1964; Widmer, 1965; and Farlekas, 1979

Figure 21.--Location of wells in the primary study area with detectable concentrations of purgeable organic compounds relative to urban land.

In general, the ground-water quality in urban land overlying the outcrop of the northern part of the Potomac-Raritan-Magothy aquifer system may be characterized as having the highest concentrations of nitrate. Also, orthophosphates, nitrite, and purgeable organic compounds were detected most frequently. Similar concentrations of major ions and trace metals in urban land compared to other land uses may be due to the history of urban development within the study area. At the time of settlement of the primary study area, urban centers developed near the Raritan Bay and along the Delaware River and, later, grew centrally. Industrial development has generally concentrated in undeveloped wetlands. Residential areas spread centrally and replaced agricultural land. Hence, changing land use may be one explanation for the observed water quality for urban land, which is a combination of the water quality in undeveloped and agricultural lands. In addition, ground-water quality in urban land also is influenced by human activities. High concentrations of nitrates and the occurrence of orthophosphates, nitrites, and purgeable organic compounds suggest that urban land-use activities have contaminated the ground water.

Comparison of Land-use Methods

The results of the Kruskal-Wallis test on water-quality data grouped by land use designated by each method are summarized on table 15. For each land-use group, constitutents whose mean rank concentrations were higher (H) or lower (L) at a 0.95 or greater significance level than those of the total sample population are noted on the table. Comparison of the statistical results using each method must be done with caution. As previously mentioned, when Method II is used, one well can be classified in more than one land-use group, thereby making any comparison among undeveloped, agricultural, and urban groups invalid.

Kruskal-Wallis tests comparing water-quality data grouped by Method I and II yielded the same results approximately 84 percent of the time. Agreement of both methods suggests that those relations are characteristic of the water quality in that land use. If both methods indicated a significant difference in the concentration of a constituent, a larger difference in the median concentration was generally determined when Method I was used to designate the land-use groups. Likewise, when the test indicated that the concentration of a constituent was significantly lower in one land-use group, the median concentration was lower when Method I was used to designate the land-use groups. This occurs because Method I minimizes the influence of other land uses.

No contradictions occurred in terms of whether a constituent had the highest or lowest concentration for a particular land-use group. However, for one constituent, two different land-use groups were indicated as having the highest concentration. When Method I was used, the concentration of nitrate is highest in predominantly urban lands; but, when Method II was used, there is no significant difference in nitrate concentration in wells where urban land is present, compared to wells where urban land is absent. However, nitrate concentration was significantly higher in areas where agricultural land is present than in areas where agricultural land is absent. These results indicate that in both lands there are activities that are sources of nitrate in ground water.

Table 15.-- Summary of the results of the Kruskal-Wallis tests on water-quality data from the primary study area by land use.

This table is a summary of the results for the Kruskal-Wallis test for two land-use classification methods as presented in tables 11, 12, 13, and 14. The symbols represent:

-, No difference in concentration compared to the total population;
H, concentrations in this group are significantly higher than the total population at a .95 confidence level or greater;
L, concentrations in this group are significantly lower than the total population at a .95 confidence level or greater.

Characteristic or constituent	Land-use group					
	Undeveloped		Agricultural		Urban	
	Method		Method		Method	
	I	II	I	II	I	II
Characteristics						
pH (field)	-	-	-	-	-	-
temperature (field)	-	L	-	-	-	-
specific conductance (field)	-	-	-	L	-	-
dissolved oxygen (field)	L	L	H	H	-	-
alkalinity (CaCO3) (field)	-	-	-	-	-	-
dissolved solids (lab)	-	-	-	-	-	-
Constituents (dissolved)						
Major ions						
chloride	-	-	-	L	-	-
sulfate	-	-	-	L	-	-
calcium	-	-	-	-	-	-
magnesium	L	-	-	-	H	-
potassium	-	-	-	-	-	-
sodium	-	-	-	L	-	-
silica	-	-	-	-	-	-
Trace metals						
aluminum	H	-	L	L	-	-
barium	L	L	-	-	H	-
beryllium	H	-	-	-	-	L
cadmium	-	-	-	-	-	-
chromium	L	-	-	-	-	-
cobalt	H	H	L	L	-	-
copper	-	-	-	H	-	-
iron	H	H	L	L	-	-
iron (total)	H	H	L	L	-	-
lithium	-	-	-	-	-	-
lead	-	-	-	-	-	-
manganese	-	-	-	L	-	-
molybdenum	-	-	-	-	-	-
strontium	-	-	-	-	-	-
vanadium	-	-	-	-	-	-
zinc	H	H	-	-	L	-
Nutrients						
phosphorus, orthophosphate	-	-	-	-	-	-
nitrogen, nitrite	-	L	-	-	-	-
nitrogen, nitrate	L	L	-	H	H	-
nitrogen, ammonia	-	-	-	-	-	-
nitrogen, ammonia + organic N	-	-	-	-	-	-
Organic Compounds (total)						
organic carbon (dissolved)	-	-	-	L	-	-
total recoverable phenols	-	-	-	-	-	-
total purgeable organics	-	-	-	-	-	-
total pesticides	-	-	-	H	-	-

Both land-use methods were useful in evaluating the relation between land use and water quality. The methods compliment each other in their ability to determine differences in the ground-water quality of land-use groups. These differences may be related to the natural land cover prior to settlement of the area or to contamination caused by human activities associated with a particular land use. Method I is favored to characterize the water quality of a land use, because the affects of other land uses are minimized. Method II is useful in identifying the land use that contains the probable source of a ground-water contaminant, because it considers the influence of a land use on water quality even when it is not the predominant land use. This is particularly important when area of a land use is strongly dependent on land-use type.

Comparison of Primary and Secondary Areas

Comparing results between two areas of similar climatic, hydrogeologic, and land-use setting may provide a test of the transfer value of the water-quality/land-use relations. Similar frequencies of detection and concentration distributions of water-quality characteristics and constituents among land-use groups would suggest that the factors affecting water quality in the primary study area are similar to those of the secondary area. Therefore, extrapolation of the findings to larger geohydrologic and climatic regions may be valid. Dissimilar results may indicate that different factors are controlling water quality.

Selected water-quality data from 179 wells in the outcrop of the Potomac-Raritan-Magothy aquifer system in southern New Jersey (fig. 1), the secondary study area, were compared by land use, designated by Method I. Summary statistics and the results of the Kruskal-Wallis test and frequency-of-detection method are presented in table 16. These wells were sampled from 1980 through 1982 for major ions, trace metals, nutrients, and purgeable organic compounds (Fusillo and others, 1984). The most recent analysis for a constituent at each well was used for the statistical comparison. An aggregated land-use map of the secondary area is shown on figure 22. The secondary area is approximately 50 percent urban, 40 percent agricultural, and 10 percent undeveloped.

In general, the water-quality data in the primary and secondary areas did not show similar relations among the land-use groups. Temperature, specific conductance, and the concentrations of dissolved solids and most of the major ions were highest in urban land of the secondary area (table 16). In contrast, none of these characteristics or constituents differed among the land-use groups in the primary area (table 11). Water-quality characteristics and major-ion chemistry indicate that there are different processes controlling shallow ground-water quality in the two areas. The influence of the Pinelands outlier in the primary area and induced recharge from the Delaware River in the secondary area are probably responsible for some of the differences.

Trace-metal concentrations were similar in the land-use groups of the secondary area, whereas the concentrations of aluminum, beryllium, cobalt, iron, and zinc were significantly higher in undeveloped land of the primary area. As previously mentioned, high trace metal concentrations in undeveloped land in the primary area appear to be related to low pH and low

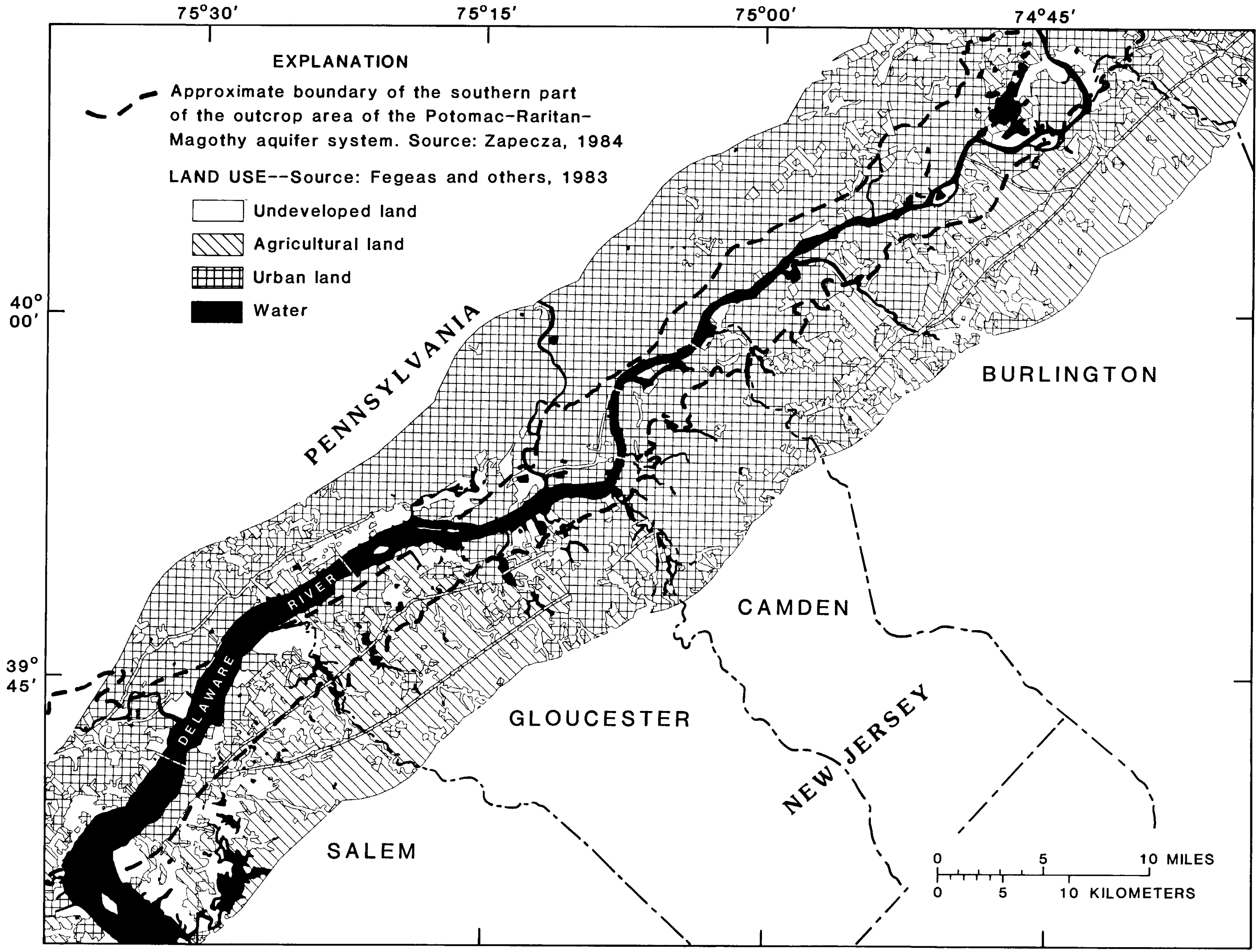


Figure 22.--Land use in the secondary study area, 1974.

Table 16 -- Summary of water-quality data in secondary area by predominant land use designated by Method I

Characteristic or constituent[1]	Land-use group									
	Undeveloped					Agricultural				
	Number of wells[2]	Percentage above detection[3]	Concentration[4]			Number of wells	Percentage above detection[3]	Concentration[4]		
			Median	Q1	Q3			Median	Q1	Q3
Characteristics										
pH (field)	13	100	6.5	5.7	6.9	29	100	5.7	5.3	6.6
temperature (field)	13	100	14.0	13.5	14.3	29	100	14.0	13.5	14.5
specific conductance(fld)	13	100	205	109	371	29	100	206	130	300
dissolved oxygen (field)	7	100	0.2	0.2	3.6	4	100	0.4	0.2	0.5
alkalinity (CaCO3)(field)	13	100	54.0	11	102	28	100	26.5	4.2	65
dissolved solids (lab)	13	100	132	68	220	29	100	125	83	198
Constituents										
Major ions										
chloride	13	100	14.0	3.7	22.5	29	100	15.0	6.2	30.5
sulfate	13	100	16.0	5.5	42.5	29	100	27.0	4.2	46.5
calcium	13	100	11.0	5.3	19.5	29	100	7.8	5.4	15.5
magnesium	13	100	3.0	1.9	8.0	29	100	3.8	2.2	7.7
potassium	13	100	8.6	4.5	32.0	29	100	8.9	3.4	26.0
sodium	13	100	3.0	1.9	8.0	29	100	3.8	2.2	7.7
silica	13	100	13.0	10.5	18.5	29	100	11.0	8.8	14.0
Trace metals										
aluminum	7	29	<100	<100	100	6	67	100	<100	250
barium	10	100	85	63	100	26	100	60	50	95
beryllium	10	40	<0.5	<0.5	1.0	26	100	<0.5	<0.5	<0.5
cadmium	10	80	3	1.5	3.5	26	65	2	<1	4
chromium	7	86	10	10	10	6	100	10	10	10
cobalt	10	70	3	<3	12	26	58	5	<3	24
copper	10	100	<10	<10	<10	26	27	<10	<10	10
iron	13	100	2,800	278	8,100	29	100	4,600	274	14,000
lithium	10	100	17	8	27	26	88	12	7	16
manganese	13	100	140	50	305	29	100	99	48	315
molybdenum	10	10	<10	<10	<10	26	12	<10	<10	<10
strontium	10	100	155	112	458	26	100	155	76	335
vanadium	10	10	<6	<6	<6	26	15	<6	<6	<6
zinc	10	90	14	6	44	26	81	18	16	47
Nutrients										
phosphorus, orthophosphate	13	54	<0.01	<0.01	0.08	29	41	<0.01	<0.01	0.1
nitrogen, nitrate	7	14	<0.01	<0.01	<0.01	6	50	<0.01	<0.01	0.0
nitrogen, nitrite + nitrate	13	100	0.1	0.05	0.5	29	86	0.1	0.01	3.3
nitrogen, ammonia	7	71	0.25	<0.01	1.40	6	100	0.23	0.08	4.8
nitrogen, ammonia + organic	7	86	1.3	0.3	1.6	6	100	1.0	0.3	9.0
Organic Compounds[7]										
organic carbon (dissolved)	13	100	1.2	0.7	3.5	28	100	1.9	0.9	3.0
total purgeable organics	15	13	<3	<3	<3	30	7	<3	<3	<3

Table 16.--Summary of water-quality data in secondary area by predominant land use designated by Method I (Continued)

	Land-use Group						
	Urban						
Characteristic or constituent[1]	Number of wells[2]	Percentage above detection[3]	Concentration[4]			Significance level[5]	Which group is different[6]
			Median	Q1	Q3		
Characteristics							
pH (field)	133	100	6.3	5.4	6.7	<0.75	
temperature (field)	132	100	14.5	14.0	15.0	.990	-A
specific conductance(fld)	132	100	318	202	539	.990	-B
dissolved oxygen (field)	68	100	0.5	0.2	3.2	<.75	
alkalinity (CaCO3)(field)	131	100	57.0	14.0	106	.75	
dissolved solids (lab)	131	100	190	116	291	.975	-B
Constituents							
Major ions							
chloride	132	100	20.0	21.0	46.0	.975	-A
sulfate	132	100	23.0	22.0	53.8	<.75	
calcium	133	100	16.0	8.7	27.0	.995	-B
magnesium	133	100	6.3	3.5	10.0	.975	-B
potassium	133	100	18.0	8.8	43.5	.995	-B
sodium	133	100	6.3	3.5	10.0	.975	-A
silica	132	100	10.0	7.4	12.0	.995	A
Trace metals							
aluminum	77	38	<100	<100	100	.90	
barium	108	100	70	50	100	<.75	
beryllium	108	23	<0.5	<0.5	1.0	<.75	
cadmium	108	72	2	<1	4	<.75	
chromium	77	84	10	<10	10	<.75	
cobalt	108	54	5	<3	17	<.75	
copper	108	12	<10	<10	10	<.75	
iron	131	100	2,600	65	9,700	<.75	
lithium	108	81	8	5	121	.975	A
manganese	132	100	165	65	810	.75	
molybdenum	108	18	<10	<10	<10	<.75	
strontium	108	100	185	82	540	<.76	
vanadium	108	10	<6	<6	<6	<.75	
zinc	108	81	14	7	36	<.75	
Nutrients							
phosphorus, orthophosphate	130	44	<0.01	<0.01	0.02	<.75	
nitrogen, nitrate	76	14	<0.01	<0.01	<0.01	.75	
nitrogen, nitrite + nitrate	131	95	0.1	.07	2.5	<.75	
nitrogen, ammonia	76	76	0.36	0.2	1.28	<.75	
nitrogen, ammonia + organic	76	86	0.6	0.2	1.6	<.75	
Organic Compounds[7]							
organic carbon (dissolved)	127	10	1.6	0.8	2.6	<.75	
total purgeable organics	133	38	<3	<3	<3	.75	

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[1] Concentration units and detection limits are given in table 5. Aluminum detection limit is 100 μg/L.

[2] Not every characteristic or constituent was sampled at all wells. The number of wells represents the most recent time a well was sampled for a particular characteristic or constituent.

[3] The percentage above detection is calculated by dividing the number of samples with a concentration equal to or exceeding the detection limit by the total number of samples in that group.

[4] Q1 and Q3 represent the first and third quartiles.

[5] The significance level is determined using the H-value adjusted for ties in rank, from the Kruskal-Wallis test, and a Chi-square distribution table (Ryan and others, 1975).

[6] The group with concenrations that are significantly higher or lower at a .95 confidence level or greater are flagged as: A = Undeveloped B = Agricultural C = Urban. If the code is preceded by a negative sign (-) the group's concentration is significantly lower.

[7] Total recoverable ophenols and pesticides were not analyzed at these wells.

concentrations of dissolved oxygen. The median pH in undeveloped land in the primary area is 4.5; in the secondary area, it is 6.5. In the primary area, dissolved oxygen concentrations are significantly lower in undeveloped land than in other land uses. In the secondary area, there is no significant difference in dissolved oxygen concentrations among land-use groups. Hence, there is a significant difference in the water quality in undeveloped lands of the primary and secondary areas, probably caused by the Pinelands outlier in the primary area.

The frequency of detection of purgeable organic compounds in each land-use group was similar in both areas (fig. 23). This suggests that human activities produce similar patterns of ground-water contamination in both areas. In both areas, purgeable organic compounds were detected in less than 10 percent of the wells in agricultural land, in about 15 percent of the wells in undeveloped land, and in about 28 percent of the wells in urban land. Within the secondary area, about 90 percent of the wells with a detectable concentration of a purgeable organic compound had some urban land within a quarter of a mile of the well, compared to 93 percent of the wells in the primary area. The types of purgeable organic compounds detected in both areas also were similar. The most commonly detected compounds in the secondary area were trichloroethane, tetrachloroethylene, benzene, toluene, and 1,2-trans-dichloroethylene.

SUMMARY AND CONCLUSIONS

The relation of water quality to hydrogeology and land use was evaluated with the Kruskal-Wallis test and the frequency-of-detection method using water-quality analyses from 71 wells screened in or near the outcrop of the northern part of the Potomac-Raritan-Magothy aquifer system in New Jersey. The relation of ground-water quality to land use was evaluated by comparing the quality of water from wells which were divided into three groups by land use: undeveloped, agricultural, and urban. Two methods were used to classify land use at a well. Method I, the predominant land-use method, used the land use with the greatest percent within a 1/4-mile radius of the well. Method II used a presence-absence procedure based on the 1/4-mile radius.

The water-quality network was assessed for variations in hydrogeologic conditions at sampled wells prior to evaluating the relation of land use to ground-water quality. Well depths, pumping rates, and the relative number of wells in the confined and unconfined parts of the aquifer system did not differ significantly among land-use groups. However, wells from undeveloped land are predominantly screened in the upper aquifer and wells in urban land are in the middle aquifer. Wells in agricultural land have the greatest depths to water. When the influence of each hydrogeologic factor on water quality was evaluated without considering land use, shallow wells had the highest specific conductance and the highest concentrations of many major ions; wells screened in the unconfined part of the aquifer system had a higher concentration of dissolved organic carbon than wells screened in the confined part of the aquifer system.

Ground-water in undeveloped land had the lowest concentrations of dissolved oxygen and nitrate and the highest concentrations of trace metals; phenols were detected most frequently, and pesticides were detected least

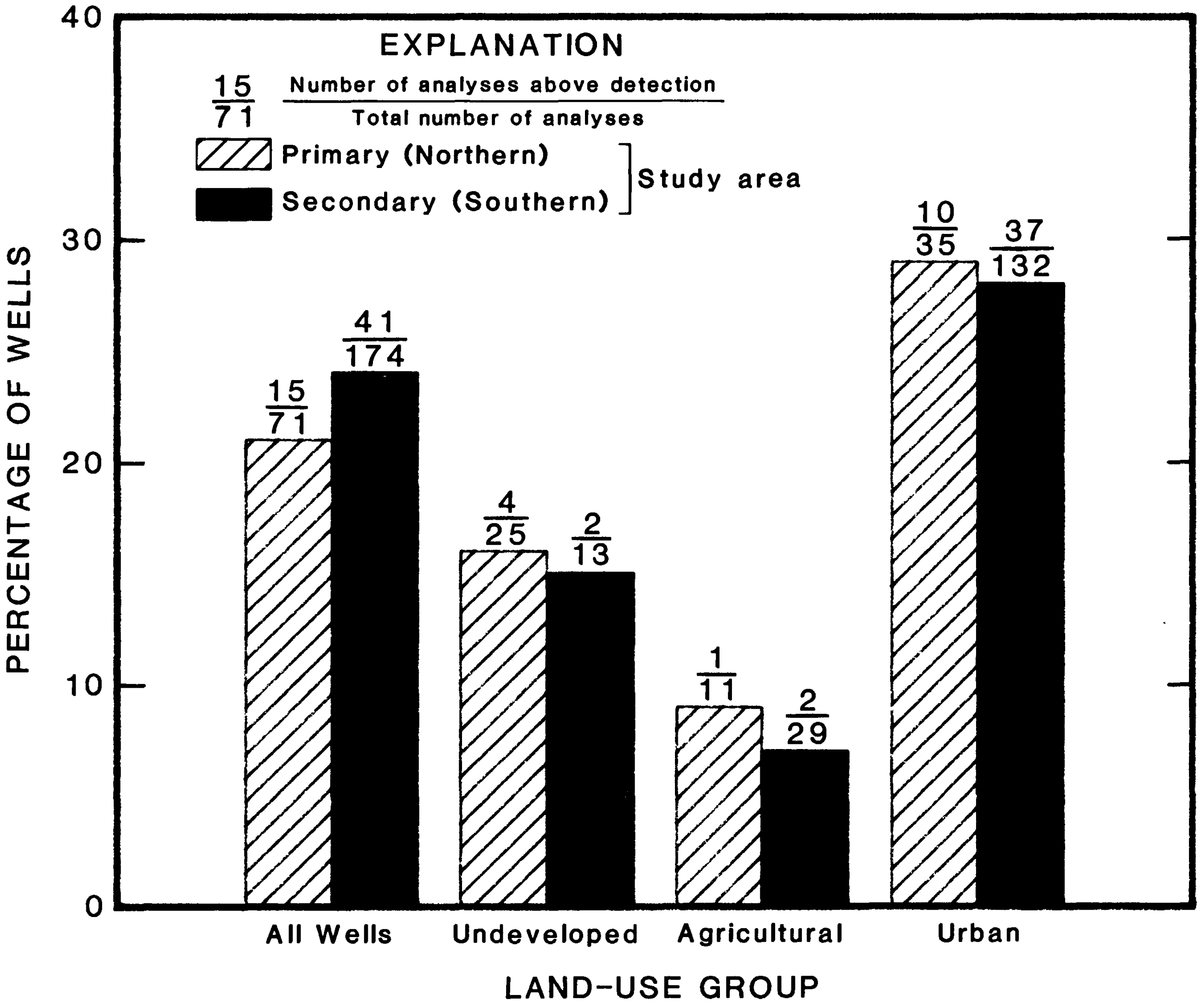

Figure 23.--Frequencies of detection of purgeable organic compounds in the primary and secondary study areas by land use designated by Method I.

frequently. This water quality is typical of water from wetlands environments and is probably influenced by the presence of the Pinelands outlier. In addition, a higher frequency of detection of purgeable organic compounds in undeveloped land than in agricultural land indicates that there is some ground-water contamination by human activities in this land.

Ground water in agricultural land had the lowest concentrations of major ions and trace metals and the highest concentrations of dissolved oxygen and copper; phenols and purgeable organic compounds were detected least frequently. This suggests that ground-water quality in agricultural land is influenced by the natural land cover of sandy, well-drained soils. In addition, pesticides were detected most frequently in ground water in agricultural land and nitrate concentrations were higher in these areas than in undeveloped land. This suggests that ground-water quality in agricultural land also is influenced by the application of fertilizers and pesticides and the disposal of septic wastes.

Ground water in urban land had major ion and trace metal concentrations that are similar to those in the ground water from areas with other land uses. However, nitrate concentrations were highest and orthophosphate, nitrate, and purgeable organic compounds were detected most frequently in urban land. These relations suggest that water quality in urban land is, in part, a combination of the ground-water quality in undeveloped and agricultural lands, which were replaced by urban development. However, relatively high concentrations of nitrates and the occurrence of purgeable organic compounds indicate that water quality also is influenced by the human activities associated with urban development, including industrial and residential activities.

Water-quality statistics generated for the primary study area were compared to data from 179 wells in a secondary area, the outcrop of the same aquifer system in southern New Jersey. Comparison of water-quality data indicate that, for the most part, different factors control water quality in the primary and secondary areas. Statistical tests indicate that the concentrations of major ions, trace metals, and nutrients do not show similar relations among land-use groups in the primary and secondary areas. This is probably due to the presence of the Pinelands outlier in the primary area and induced recharge of the aquifer system from the Delaware River in the secondary area. However, the frequency of detection of purgeable organic compounds among land-use groups within both areas is similar. This indicates that human activities in both areas produce a similar pattern of ground-water contamination by purgeable organic compounds with respect to land uses.

General conclusions concerning the methods of classifying land use at a well site and the results of statistical analyses of water-quality data are as follows:

- Before testing the relation between water quality and land use, the distribution of wells with respect to local hydrogeologic conditions needs to be considered.

- When compared by the Kruskal-Wallis test or the frequency-of-detection method, the concentrations of many characteristics and constituents differed among the ground waters of undeveloped, agricultural, and urban land use. These differences were caused by both natural land cover and human activities specific to each land use.

- The predominant land-use method (Method I) is favored for characterizing general water quality of an area with a specific land use because the effects of other land uses are minimized.

- Comparison of water-quality data between land-use groups classified by a presence-absence procedure (Method II) is favored for identifying probable sources of contamination because this method considers all neighboring land uses even though they may not be predominant. This especially is important when area of a land use is strongly dependent on land-use type and in the case of point-source contamination.

- The distribution of purgeable organic compound contamination among land-use groups in the primary and secondary study areas was similar. This suggests that human activities produce similar patterns of ground-water contamination with respect to land use.

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