NATURAL RADIOACTIVITY IN, AND INORGANIC CHEMISTRY OF, GROUND WATER IN THE KIRKWOOD-COHANSEY AQUIFER SYSTEM, SOUTHERN NEW JERSEY, 1983-89

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 92-4144

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West Trenton, New Jersey

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Weight	
pound (lb)	453.6	gram
	Volume	
gallon (gal)	3.785	liter
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)
	Flow	
million gallons per day (Mgal/d)	0.04381	cubic meters per second

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

Water-quality abbreviations:

mg/L - milligrams per liter
μg/L - micrograms per liter
pCi/L - picocurie per liter
mS/cm - microsiemens per centimeter at 25 degrees Celsius
DO - dissolved oxygen
DOC - dissolved organic carbon

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ABSTRACT

A study of the effects of geology, geochemistry, and land use on the distribution of naturally occurring radionuclides dissolved in ground water in the Kirkwood-Cohansey aquifer system in the Coastal Plain of New Jersey was conducted during 1988-89 in all or parts of Atlantic, Camden, Cumberland, Gloucester, and Salem Counties. The Kirkwood-Cohansey aquifer system is composed predominantly of quartz-sand and gravel of the Kirkwood Formation, the Cohansey Sand, and, in some places, the Bridgeton Formation and the Cape May Formation. The Cape May and Bridgeton Formations are predominantly gravel. Water samples were collected from 81 wells and were analysed for the concentrations of naturally occurring radionuclides and inorganic chemical constituents.

The sum of the concentrations of dissolved radium-226 and radium-228 in 26 of 81 water samples from the Kirkwood-Cohansey aquifer system was greater than the U.S. Environmental Protection Agency and New Jersey maximum contaminant level of 5 pCi/L (picocuries per liter), and ranged from less than 1.1 to 14.5 pCi/L; the median concentration was 3.85 pCi/L. The ratio of the concentration of radium-226 to the concentration of radium-228 in most samples was approximately 1:1, indicating that the aquifer matrix is not enriched in uranium relative to thorium. Gross alpha-particle activity was greater than the U.S. Environmental Protection Agency and New Jersey drinking-water regulation of 15 pCi/L in 12 of 81 samples. Gross alpha-particle activities ranged from 0.6 to 51 pCi/L; and the median activity was 12.2 pCi/L. Median concentrations of dissolved uranium and radon-222 were 0.03 micrograms per liter and 280 pCi/L, respectively, indicating that the aquifer matrix contains relatively little soluble uranium or its progeny.

Concentrations and activities of radionuclides were greatest in water samples from the outcrop area of the Bridgeton Formation, where agricultural land is prevalent within a 500-meter radius of the well head. The relation of the concentration of dissolved radium-226 and the gross alpha-particle activity to geology and land use is statistically significant and nonrandom. Leaching of uranium and radium from mineralogically immature sediments of the Bridgeton Formation may contribute some of these radionuclides to the ground water. Chemical processes associated with agricultural land use may enhance the mobility of these radionuclides.

Ground water of the Kirkwood-Cohansey aquifer system is dilute (median sum of dissolved-solids concentration, 45 milligrams per liter) and acidic (median pH, 4.90). The relation of the concentrations of most of the measured dissolved inorganic constituents to geology and land use is statistically significant and nonrandom. Concentrations of divalent cations, potassium, and the anions nitrate and chloride were as much as one order of magnitude greater in samples collected from areas where the Bridgeton Formation crops out and agricultural land is present than in samples collected from other areas. Most

of the outcrop area of the Bridgeton Formation has been developed for agricultural use. Increased concentrations of dissolved inorganic constituents, especially magnesium and nitrate, in ground water from areas of agricultural land probably result from the dissolution of liming agents, such as dolomite, and the dissolution and oxidation of ammonia-based fertilizers that are applied to agricultural land.

Concentrations of both dissolved radium-226 and radium-228 correlate positively at a greater than 95-percent confidence level with concentrations of many dissolved chemical constituents. The strongest positive correlations (correlation coefficients greater than +0.6) are with the following constituents, listed in order of decreasing significance: nitrate plus nitrite (as nitrogen), chloride, magnesium, barium, and potassium. Concentrations of radium-226 and radium-228 also correlate with concentrations of aluminum, strontium, and calcium, and the sum of dissolved solids. Radium concentrations are inversely correlated with pH, and the highest concentrations of radium-226 and radium-228 generally were found in ground water that had a pH less than 4.8. The positive correlation of concentrations of radium with concentrations of inorganic chemical constituents that are commonly added to soil in agricultural areas indicates that the leaching of radium from the aquifer material probably is enhanced by chemical processes that occur in the ground water as a result of the input of agricultural chemicals. High concentrations of nitrate and magnesium correlate with low pH in water samples from areas of agricultural land.

Rank order concentration of nitrate plus nitrite (as nitrogen) in ground water in the Kirkwood-Cohansey aquifer system is a significant (probability less than 0.01) predictor of rank order concentration of radium-226 plus radium-228 in a regression model. According to this model, ground water with a nitrate concentration greater than 5 milligrams per liter can be expected to contain total radium in a concentration greater than 5 pCi/L.

INTRODUCTION

Results of routine monitoring of radioactivity in public supply wells that tap the Kirkwood-Cohansey aquifer system in southern New Jersey indicated the presence of elevated gross-alpha particle activities and concentrations of radium in the ground water in Atlantic, Camden, Cumberland, Gloucester, and Salem Counties in southern Jersey (unpublished data on file at the Trenton, N.J., office of the New Jersey Department of Environmental Protection). In addition, gross alpha-particle activities and radium concentrations in samples from wells screened in the Kirkwood-Cohansey aquifer system in Washington Township, Gloucester County, New Jersey (unpublished data on file at the Trenton, N.J., office of the New Jersey Department of Environmental Protection) were found to be greater than the U.S. Environmental Protection Agency (USEPA) and New Jersey drinking-water regulations of 15 pCi/L and 5 pCi/L, respectively (U.S. Environmental Protection Agency, 1988; New Jersey Administrative Code, 1989). The distribution of elevated radionuclide concentrations in ground water (Zapecza and Szabo, 1988) indicates that elevated concentrations of radium are common in the Coastal Plain province of the eastern United States. These findings prompted an investigation of the presence and distribution of naturally occurring radionuclides in ground water in the Kirkwood-Cohansey aquifer system in southern New Jersey (fig. 1). This investigation was conducted by the U.S. Geological Survey (USGS) in cooperation with the New Jersey Department of Environmental Protection during 1988-89.

Purpose and Scope

This report describes the results of chemical analyses of 81 samples of ground water collected during June 1988 through March 1989 from the Kirkwood-Cohansey aquifer system in southern New Jersey. The report also describes the presence and distribution of gross alpha-particle and gross beta-particle activities and documents the concentrations of radium-226, radium-228, radon-222, and uranium in ground water in the aquifer system. The effects of the geology, geochemistry, and land use on the distributions of these radionuclides and selected inorganic chemical constituents are described.

Statistical summaries of chemical and radiochemical data are presented in tables and graphs. Concentrations of radionuclides are compared statistically to concentrations of other radionuclides and to concentrations of selected inorganic chemical constituents and chemical characteristics. A method for predicting the concentration of radium in ground water from the nitrate plus nitrite (as nitrogen) concentration is described. The data are evaluated in terms of whether the aquifer material or phosphate-bearing fertilizer is the likely predominant source of radium in solution.

Radioactivity in Ground Water

Naturally occurring radionuclides are found as trace elements in most rocks and soils. They dissolve in ground water as it percolates through rock and soil. If a radionuclide is highly soluble in water and is present in large amounts in rock and soil, it is likely to be present in large amounts in ground water also.

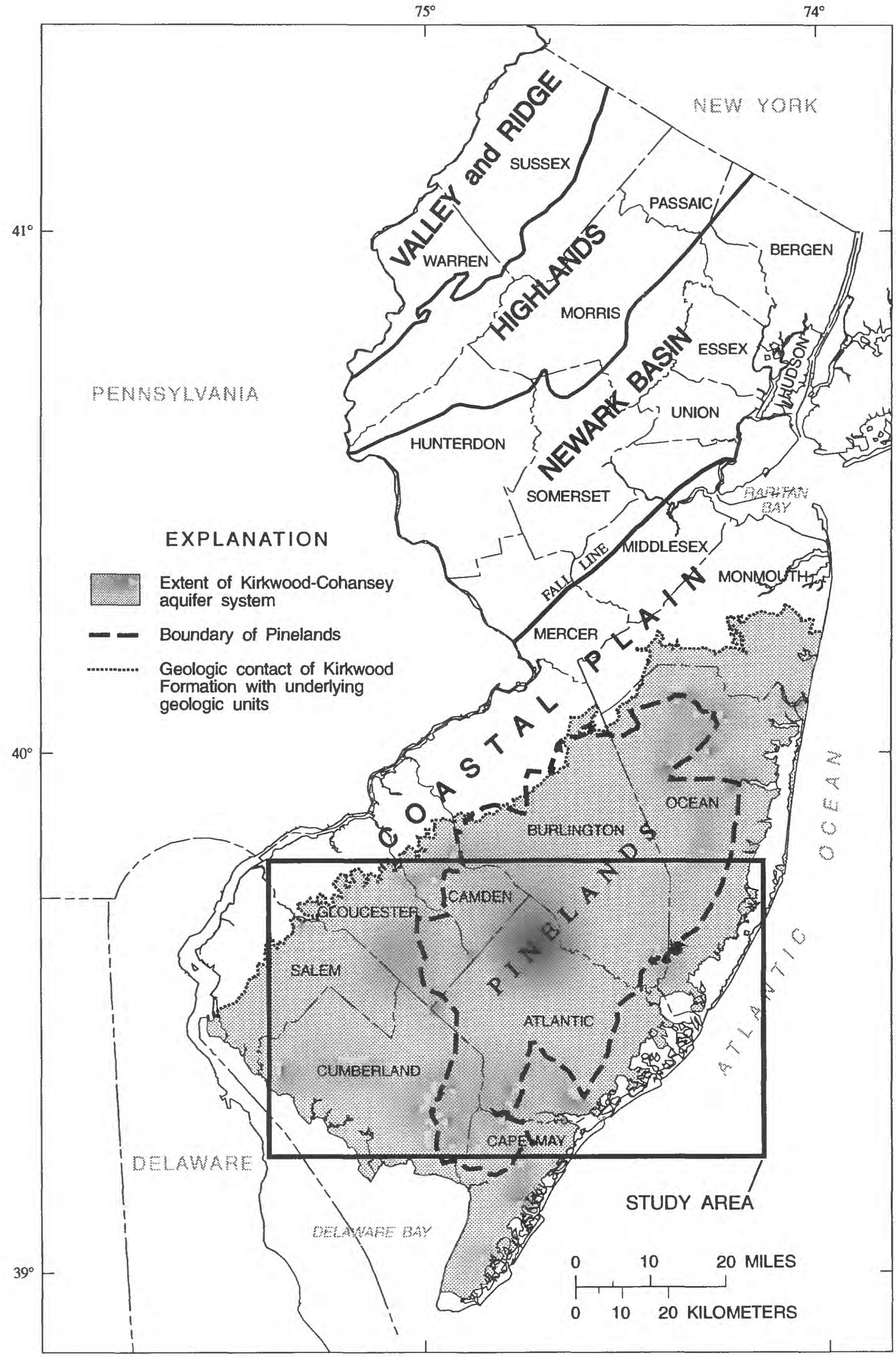


Figure 1. Location of study area.

Radioactive decay is the emission of an alpha particle (a nucleus of the helium atom) or beta particle (an electron) and energy in the form of gamma rays from the nucleus of a radioactive element. Each radioactive-decay product has its own unique half-life. One half-life is the time required for half of the initial amount of the radionuclide to decay. Chemical characteristics, solubility, and mobility of radioactive-decay products can differ considerably from those of the parent radionuclide.

Radionuclide Decay Series

Naturally occurring radionuclides are formed principally by the radioactive decay of naturally occurring uranium-238 and thorium-232, which are the long-lived parent elements of the radioactive-decay series that bear their names (fig. 2). The parent elements, uranium and thorium, produce intermediate radioactive daughter elements, such as radium and radon, which have shorter half-lives than the parent elements. A radioactive-decay series ends when a stable, nonradioactive element is produced. Uranium-238 decays through 17 radionuclides to become stable lead-206; thorium-232 decays through 12 radionuclides to become stable lead-208.

Uranium is highly soluble in oxidizing, bicarbonate-rich ground water (Langmuir, 1978) and, therefore, is present in detectable concentrations in most ground waters. Ground water containing uranium in concentrations greater than 15 μg/L (micrograms per liter) is present in widespread areas throughout the United States (Zapecza and Szabo, 1988; Cothern and others, 1983). Thorium, however, is not soluble and is rarely detected in ground water (Zapecza and Szabo, 1988).

Radium-226 and radium-228 from natural sources commonly occur in ground water (Zapecza and Szabo, 1988). Radium-226 and radium-228 are decay products of uranium-238 and thorium-232, respectively. Radium-226 has a long half-life (1,622 years) compared to that of radium-228 (5.75 years). Radium is a divalent cation that behaves chemically in a similar way to calcium, strontium, and barium. The primary health risk from ingestion of radium is bone cancer (Mays and others, 1985).

Radon-222, the radioactive decay product of radium-226, has a half-life of only 3.825 days. Radon is an inert gas that dissolves easily in ground water; therefore, concentrations of radon-222 commonly exceed the concentrations of other radionuclides in ground water (Zapecza and Szabo, 1988; Tanner, 1964). The primary health risk from ingestion of radon in water is cancer of the internal organs, whereas the primary health risk from inhalation is lung cancer (U.S. Environmental Protection Agency, 1991, p. 33,074-33,076).

Gross alpha-particle activity and gross beta-particle activity are measures of the total amount of radioactivity attributable to radioactive decay of alpha-emitting and beta-emitting radionuclides, respectively. Radium-226, isotopes of uranium, and radon-222 are the alpha-emitting radionuclides individually measured in this study.

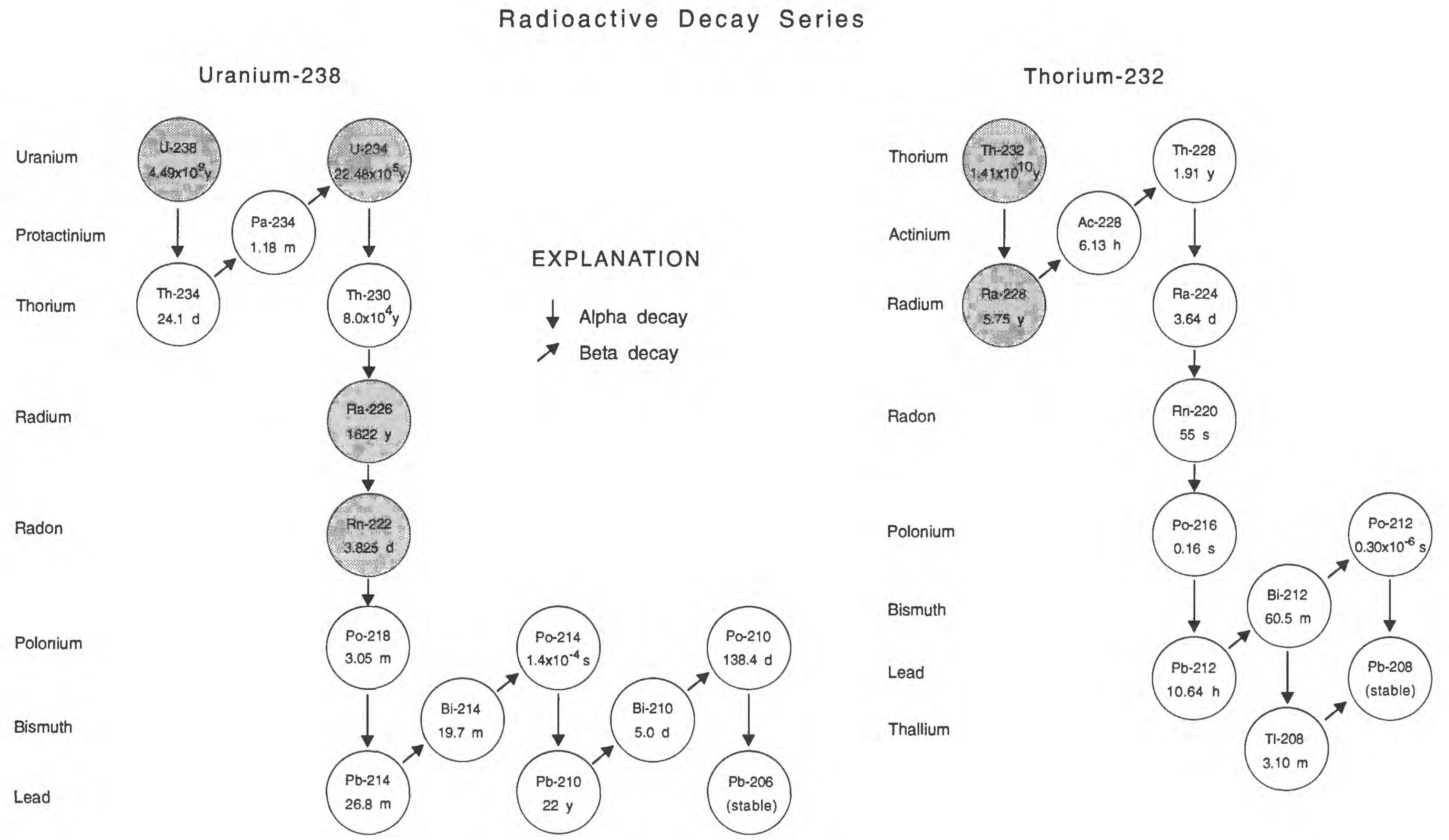


Figure 2. Diagram showing uranium-238 and thorium-232 radioactive decay series. (Radionuclides of interset in this study are shaded). [Times shown are half-lives: y, years; d, days; h, hours; m, minutes; s, seconds;]. (From Hall and others, 1985).

Reporting Radioactivity in Water

Gross radioactivity and radioactivity resulting from individual radionuclides in a water sample are determined by instruments that count either the gross amount of a type of radioactivity emitted by the sample, or the amount of radioactivity emitted by individual radionuclides. Therefore, the gross radioactivity and the radioactivity resulting from individual radionuclides in a sample of water are reported in units of picocuries per liter (pCi/L). One pCi/L is equivalent to 2.2 radioactive disintegrations per minute per liter of solution (water). Mass units per liter (milligrams per liter, for example) are not used, because it is the radioactivity that is measured, and not the chemical mass. Concentrations of uranium, however, are reported in terms of both mass units and in terms of radioactivity.

Because the rate of radioactivity decay varies, all measurements of radioactivity are associated with a degree of error (app. 2). The degree of error of the radioactivity measurement is the confidence interval expressed as two standard deviations--that is, 95 of 100 measurements of radioactivity of the sample would fall in the range denoted by the reported radioactivity, plus or minus the reported degree of error.

Instruments that count radioactivity record both the radioactivity of the ground-water sample and the background radioactivity during the time the radioactivity of the sample is being measured. When the radioactivity of a ground-water sample is so low that it cannot be distinguished from a measurement of normal background radiation with a 95-percent degree of confidence, the radioactivity of the sample is reported as being below the minimum reporting limit (MRL). Minimum reporting limits for gross-radioactivity measurements and for individual radionuclides are listed in table 2.

Drinking-Water Regulations for Radionuclides

Concentrations of radionuclides in public drinking-water supplies are regulated under Federal and State law (U.S. Environmental Protection Agency, 1988; N.J. Administrative Code, 1989); New Jersey has adopted the Federal regulations (N.J. Administrative Code, 1989). Under its interim primary drinking-water regulations, the USEPA has established maximum contaminant levels (MCL's) for radionuclides and gross alpha-particle activity; MCL's are the maximum allowable concentrations or activities of chemical constituents in public drinking water (U.S. Environmental Protection Agency, 1988).

The MCL for gross alpha-particle activity in drinking water is 15 pCi/L (U.S. Environmental Protection Agency, 1988). This MCL includes the alpha-particle activity of radium-226 but excludes those of uranium and radon.

Beta-particle activity in public drinking water cannot exceed 50 pCi/L, according to USEPA interim primary drinking-water regulations (U.S. Environmental Protection Agency, 1988). When beta-particle activity exceeds 50 pCi/L, the activity of individual beta-emitting radionuclides must be determined. Radium-228 is a beta-emitting radionuclide; however, the USEPA interim primary drinking-water regulation for radium includes radium-228.

The MCL for radium (5 pCi/L) is for the sum of the concentrations of radium-226 and radium-228 (U.S. Environmental Protection Agency, 1988). No interim primary drinking-water regulations exist for radon-222.

The USEPA has established a testing protocol for gross alpha-particle activity and concentrations of radium-226 and radium-228. Public-supply wells yielding ground-water samples with gross alpha-particle activity greater than 5 pCi/L must be tested for concentrations of radium-226 (U.S. Environmental Protection Agency, 1988). If the concentration of radium-226 exceeds 3 pCi/L in the sample, the water also must be tested for radium-228 concentration (U.S. Environmental Protection Agency, 1988).

In 1991, the USEPA proposed new primary drinking-water regulations for radionuclides (U.S. Environmental Protection Agency, 1991). Under the proposed regulations, separate MCL's are to be established for radium-226 (20 pCi/L) and radium-228 (20 pCi/L) (U.S. Environmental Protection Agency, 1991, p. 33,051). Uranium and radon-222 would be regulated; the MCL for uranium is proposed to be 20 pCi/L, and the MCL for radon-222 is proposed to be 300 pCi/L (U.S. Environmental Protection Agency, 1991, p. 33,051). The regulation for gross alpha-particle activity would exclude radium-226 as well as radon-222 and uranium, but the MCL would remain at 15 pCi/L (U.S. Environmental Protection Agency, 1991, p. 33,051). Public-water-system monitoring requirements also would change to accommodate the new MCL's (U.S. Environmental Protection Agency, 1991, p. 33,103). These proposed regulations are subject to review by the USEPA and the public before they become a final rule and, until such time, the interim primary drinking-water regulations (U.S. Environmental Protection Agency, 1988) are enforceable.

Previous Investigations

Zapecza and Szabo (1989) reported elevated radium concentrations and gross alpha-particle activities in ground water in the Kirkwood-Cohansey aquifer system and noted that the highest concentrations of these radionuclides are associated with the outcrop area of the Bridgeton Formation. Aeroradiometric maps show that surficial gamma activities in southern New Jersey (J.S. Duval, U.S. Geological Survey, written commun., 1988) are relatively higher in the western part of the study area, where the Bridgeton Formation outcrop is present, than in the eastern part, where it is absent.

Several reports on the general ground-water chemistry and (or) hydrology of the Coastal Plain in southern New Jersey include descriptions of the Kirkwood-Cohansey aquifer system. Barksdale and others (1958) reported on the ground-water resources of the Delaware River basin in New Jersey and Pennsylvania, including parts of the study area of this investigation. The geology, hydrology, and ground-water quality of the aquifers of the New Jersey Coastal Plain were investigated in Camden County (Farlekas and others, 1976); Cumberland County (Rooney, 1971); Gloucester County (Hardt and Hilton, 1969); and Salem County (Rosenau and others, 1969). The extent and thickness of the Kirkwood-Cohansey aquifer system and other hydrogeologic units in the Coastal Plain of New Jersey were mapped by Zapecza (1989). The extent of the Bridgeton Formation and its environment of deposition were described by Owens and Minard (1979).

The geology, hydrology, and geochemistry of the New Jersey Pinelands, part of which lie within the study area of this investigation, have been studied in great detail. Rhodehamel (1970) calculated a water budget for the New Jersey Pinelands, including parts of the study area, and described the quality of water in the Kirkwood-Cohansey aquifer system. Rhodehamel (1973) investigated the hydrogeology of the Mullica River Basin, which is located in the study area. Lord and others (1990) reported results of chemical analyses of ground water, and soil water in the Kirkwood-Cohansey aquifer system, surface water, and precipitation at McDonalds Branch basin in Burlington County in the Pinelands, just outside the study area. Knobel (1985) reported results of chemical analyses of ground water from five states in the Coastal Plain.

Well-Numbering System

Information on the construction, altitude, owner, and location of wells included in this report are stored in the Ground-Water Site Inventory data base maintained by the U.S. Geological Survey. In this data base, wells are assigned a 6-digit unique well number that consists of a 2-digit county code followed by a 4-digit sequence number. County codes used in this study are 01 (Atlantic), 07 (Camden), 11 (Cumberland), 15 (Gloucester), and 33 (Salem). Well number 33-0469 is the 469th well inventoried in Salem County. Tables in this report are sorted by county and unique well number.

Acknowledgments

The authors thank Barker Hamill, Sonny Saroya, and Barbara Litt of the New Jersey Department of Environmental Protection and Donald Schneider of the Gloucester County Board of Health for cooperating in the dissemination of information to the public. The authors thank the well owners for allowing the USGS to sample their wells.

DESCRIPTION OF STUDY AREA

The study area is located in southern New Jersey in the Coastal Plain physiographic province (fig. 1). It includes all or parts of five counties--Atlantic, Camden, Cumberland, Gloucester, and Salem (fig. 1)--and is bounded on the west by the outcrop area of the Kirkwood Formation, on the south and southwest by the Delaware River bay and estuary, on the east by the Atlantic Ocean, and on the north by Burlington and Ocean Counties.

The outcrop area of the Cohansey Sand underlies more than half of the study area and extends beyond its northern, eastern, and southern boundaries. The outcrop area of the Cohansey Sand is located mostly in the eastern part of the study area in eastern Salem County and in Atlantic County. The Kirkwood Formation crops out only in a narrow band along the western boundary of the study area (fig. 1). The outcrop area of the Bridgeton Formation, which locally overlies the Cohansey Sand, covers nearly half of the study area and extends beyond its western and northern edges. The outcrop area of the Bridgeton Formation is located mostly in the western portion of the study area in western Salem County and in eastern Camden, Cumberland, and Gloucester Counties.

The study area is characterized by low altitude and relief; land surface ranges in altitude from sea level to a few hundred feet above sea level. Both the altitude and the relief of the land surface decrease eastward toward the Atlantic Ocean.

Land Use and Soils

In 1974, approximately half of the study area was agricultural land, according to land-use-coverage maps compiled by Fegeas and others (1983). Most of the agricultural land in the study area overlies areas where the Bridgeton Formation crops out. The rest of the study area is primarily urban or industrial land, or forests and wetlands.

Although the proportion of agricultural land has decreased since 1974 as a result of urban development, the effects of fertilizers, salts, and liming agents leached from agriculturally developed soils may still be detectable in ground water in the Kirkwood-Cohansey aquifer system, even in areas where urban development has taken place since 1974. This is a result of the slow rate of ground-water movement, which precludes flushing of the aquifer in such a short period of time.

The spatial distribution of land use significantly affects the quality of water in shallow unconfined aquifers, such as the Kirkwood-Cohansey aquifer system. Leachates from the land surface percolate directly to the water table, affecting the composition of the local ground water. Barton and others (1987) and Blickwedel and Wood (1989) documented correlations between the quality of ground water in the shallow unconfined aquifer of the Potomac-Raritan-Magothy aquifer system and land use in southwestern New Jersey. Louis and Vowinkel (1989) noted that the presence of inorganic chemicals associated with agricultural practices in water from the Kirkwood-Cohansey aquifer system is related to the presence of agricultural land.

Soils in the study area were mapped and studied by Johnson (1978), Markley (1962, 1966), and Powley (1969, 1978). The soil types present in the study area are controlled primarily by the underlying geologic source material, age of soil development, and degree of drainage. Most of the outcrop area of the Bridgeton Formation is in areas that are well-drained and are characterized by loamy, sandy, and gravelly soils (Johnson, 1978; Markley, 1962, 1966; Powley, 1969, 1978). These soils generally are medium to low in natural fertility, have low pH (less than 4.5 to 5.0), and are susceptible to leaching of soil nutrients (Johnson, 1978; Markley, 1962, 1966; Powley, 1969, 1978). Where the Cohansey Sand crops out in well-drained to excessively drained areas, loamy and sandy soils that are relatively infertile, have low pH (less than 3.6 to 4.4), and are susceptible to leaching have developed (Johnson, 1978; Markley, 1962, 1966; Powley, 1969, 1978). In low-lying, poorly drained areas, loamy organic soils have developed on the Cohansey Sand. The less acidic, moderately to well-drained, naturally fertile soils that develop from the Bridgeton Formation generally are more suitable for agricultural development, such as commercial vegetable crop production, than are soils that develop from the Cohansey Sand; however, the soils that have developed from the Cohansey Sand may be suitable for some agriculture, such as fruit crops. A large percentage of the study area underlain by the Bridgeton Formation is developed for agricultural use (Fegeas and others, 1983).

Irrigation of agricultural land commonly is necessary because of the low moisture capacity of the well-drained soils developed on the Bridgeton Formation. Irrigation tends to increase the leaching of nutrients (such as calcium, magnesium, and nitrate) from the soil.

Because soils developed on the Bridgeton Formation are well-drained and naturally low in nutrients, these soils require the application of large amounts of fertilizers and lime for optimal crop production. The amount of fertilizer and lime added to the soil varies depending on the crop. The dominant elements added to the soil by the application of dolomite are barium, calcium, carbon, magnesium, and strontium; elements added to the soil by the application of fertilizer are chloride, nitrogen, potassium, sodium, and sulfur.

Most manufactured fertilizers contain nitrogen in the form of ammonia (Severson and Shacklette, 1988). Animal wastes, which also are added to the soil as a source of nitrogen, contain nitrogen as both ammonia and urea compounds. Bacteria in the soil convert (oxidize) ammonia to nitrate through the process of nitrification.

Potassium is commonly added to cropland because little naturally occurring potassium is in a form that can be used by plants, even in potassium-rich soil. Sylvite (KCl), a potassium-bearing salt, is the most common potassium-bearing additive in fertilizer (Severson and Shacklette, 1988).

The soils developed on the Bridgeton Formation and the Cohansey Sand are strongly acidic, because the soils are predominantly quartzose. Acidic precipitation (pH values near 4.5 (Lord and others, 1990)) that infiltrates the soils is not neutralized because the Bridgeton Formation and Cohansey Sand contain no carbonate or basic silicate minerals. Lime is added to cropland to neutralize the acidity of the soils and to replace the divalent cations (for example, calcium and magnesium) that are leached naturally from the soil. The most commonly used source of lime is dolomite (Severson and Shacklette, 1988), which is a calcium and magnesium carbonate mineral. Dolomite contains, in addition to the major cationic components of calcium and magnesium, a suite of other divalent cations such as manganese, strontium, and barium as impurities. The pH of the soil and ground water is low (median, 4.90) in agricultural areas overlying the Bridgeton Formation and the Cohansey Sand despite the addition of large quantities of dolomite.

Kirkwood-Cohansey Aquifer System

Hydrogeologic Framework

The study area (fig. 1) is underlain by a seaward-dipping wedge of unconsolidated sediments of Cretaceous to Quaternary age. These sediments consist mostly of clay, silt, sand, and gravel and are of continental, coastal, or marine origin. The Coastal Plain sediments thicken seaward from a featheredge at the Fall Line (fig. 1) to more than 6,500 ft at the southern tip of Cape May County. This sedimentary wedge forms a complex ground-water system in which the sand and gravel function as aquifers and the silt and clay function as confining units. The geologic and hydrogeologic units in the Coastal Plain of New Jersey are listed in table 1.

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

[Modified from Zapecza, 1989, table 2.]

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

▨ Aquifer of interest in this study

The Kirkwood-Cohansey aquifer system, the principal source of potable water in the study area, is predominantly an unconfined aquifer that underlies an area of approximately 3,000 mi^2 southeast of the updip limit of the outcrop of the Kirkwood Formation (Zapecza, 1989, p. B19). In the study area, this aquifer system is composed of hydraulically connected sediments of the Kirkwood Formation and Cohansey Sand, and, depending on location, can include overlying deposits of the Bridgeton Formation and the Cape May Formation.

The Kirkwood Formation, lower to middle Miocene in age, is a marine unit that forms the basal part of the Kirkwood-Cohansey aquifer system. In coastal areas, thick diatomaceous clay beds with interbedded zones of sand and gravel are dominant (Zapecza, 1989, p. B19); in the subsurface, updip from the coast, the lithology of the Kirkwood Formation changes to fine- to medium-grained quartz sand and silty sand. Regionally extensive clay beds are present only in the basal part of the formation (Zapecza, 1989, p. B19). Deposits of the Kirkwood Formation typically are micaceous, and carbonaceous shell material is abundant locally (Owens and Sohl, 1969, p. 252).

The Cohansey Sand, middle Miocene in age, is a marginal marine deposit composed predominantly of light-colored, medium- to coarse-grained quartz sand with some gravel and silt. Thin interbedded clay layers are common locally. Clay layers as much as 25 ft thick are known to be present within the Cohansey Sand (Hardt and Hilton, 1969, p. 28; Rosenau and others, 1969, p. 50); however, these relatively thick clay layers are localized in extent (Zapecza, 1989, p. B-19). The Cohansey Sand has virtually no weatherable silicate minerals (Owens and Sohl, 1969); the unit contains only small amounts of potassium and sodium feldspars. The Cohansey Sand contains secondary kaolinite, gibbsite, and silica (Owens and others, 1983; Owens and Sohl, 1969).

The Bridgeton Formation crops out discontinuously throughout most of the study area, typically at topographic highs. Surficial deposits of the Bridgeton Formation generally are as much as 30 to 50 ft thick in parts of Camden, Gloucester, Salem, Cumberland, and Atlantic Counties (Owens and Minard, 1979, p. D14). The Bridgeton Formation was deposited in river channels of the ancestral Hudson River that traversed the outcrop area of the Cohansey Sand (fig. 3) (Owens and Minard, 1979, p. D-17; Martino, 1981, p. 1).

The Bridgeton Formation is a feldspathic, quartz-rich sand and gravel formation that contains both potassium and sodium feldspars. Clast composition and paleocurrent indicators suggest that the sediments of the Bridgeton Formation were derived from crystalline and sedimentary rocks of the Hudson River Valley, the Reading Prong, and the Newark Basin. Lithic fragments from these uraniferous terrains have been identified by Martino (1981), especially in the western portion of the outcrop area of the Bridgeton Formation in Gloucester, Camden, Salem, and Cumberland Counties (fig. 1). Because its source area is uraniferous, the sands and gravels of the Bridgeton Formation have the potential to be richer in minerals containing uranium (and thorium) than the relatively pure quartz sands of the Cohansey Sand, particularly in the western part of the outcrop area where the Bridgeton Formation is thickest and contains the least mineralogically mature gravel (fig. 3).

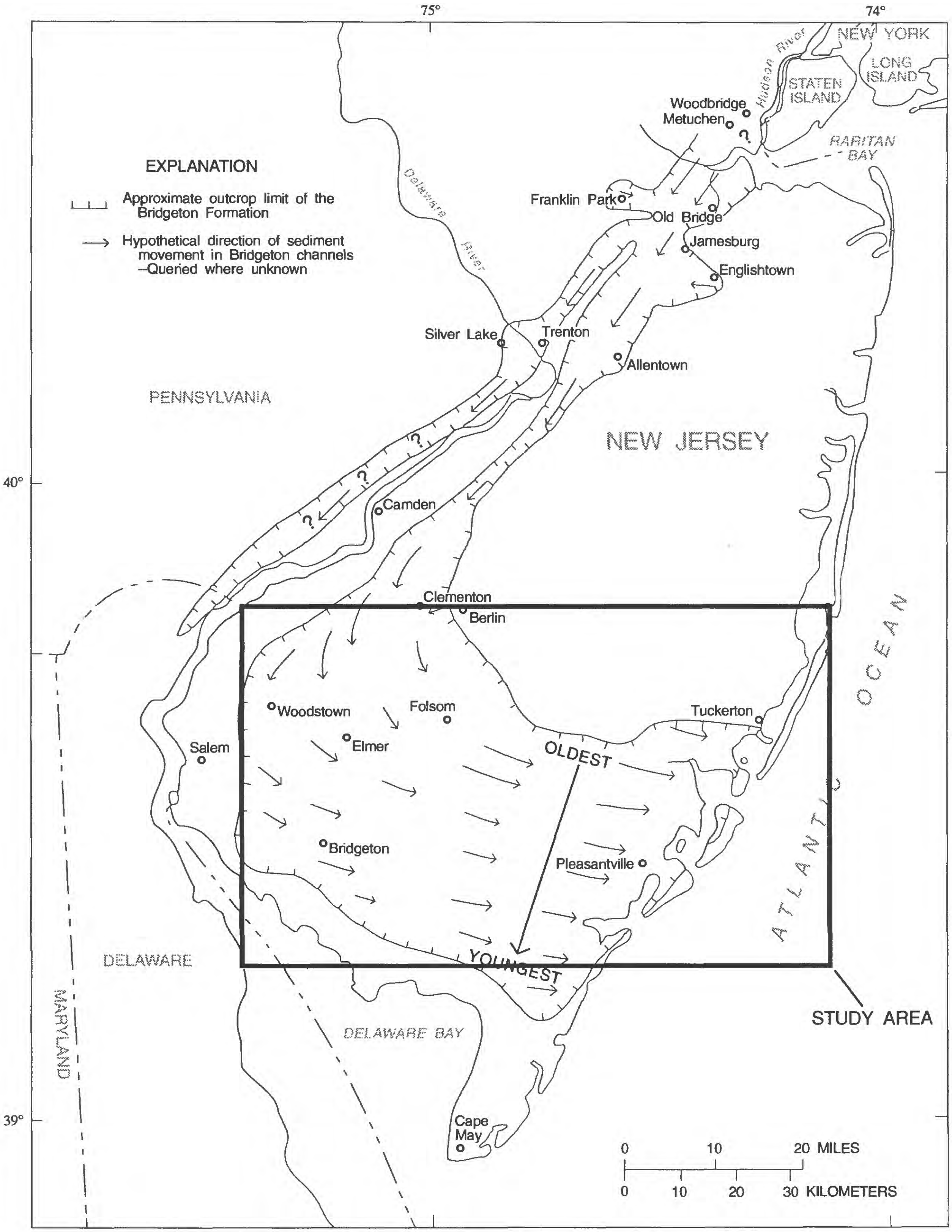


Figure 3. Source of sediments of the Bridgeton Formation and original area of deposition in southern New Jersey. (From Owens and Minard, 1979, fig.15)

The effects of extensive leaching of minerals from the Bridgeton Formation are exhibited by the mineralogy of both the clay and the sand. Owens and others (1983, p. F35) note that the mineral assemblage gibbsite-goethite-hematite-halloysite, the alteration toward iron and aluminum oxides, the degradation of kaolinite to halloysite, and the decrease in concentrations of weatherable minerals from the base to the top of the formation indicate that leaching of the formation has occurred over a long period of time.

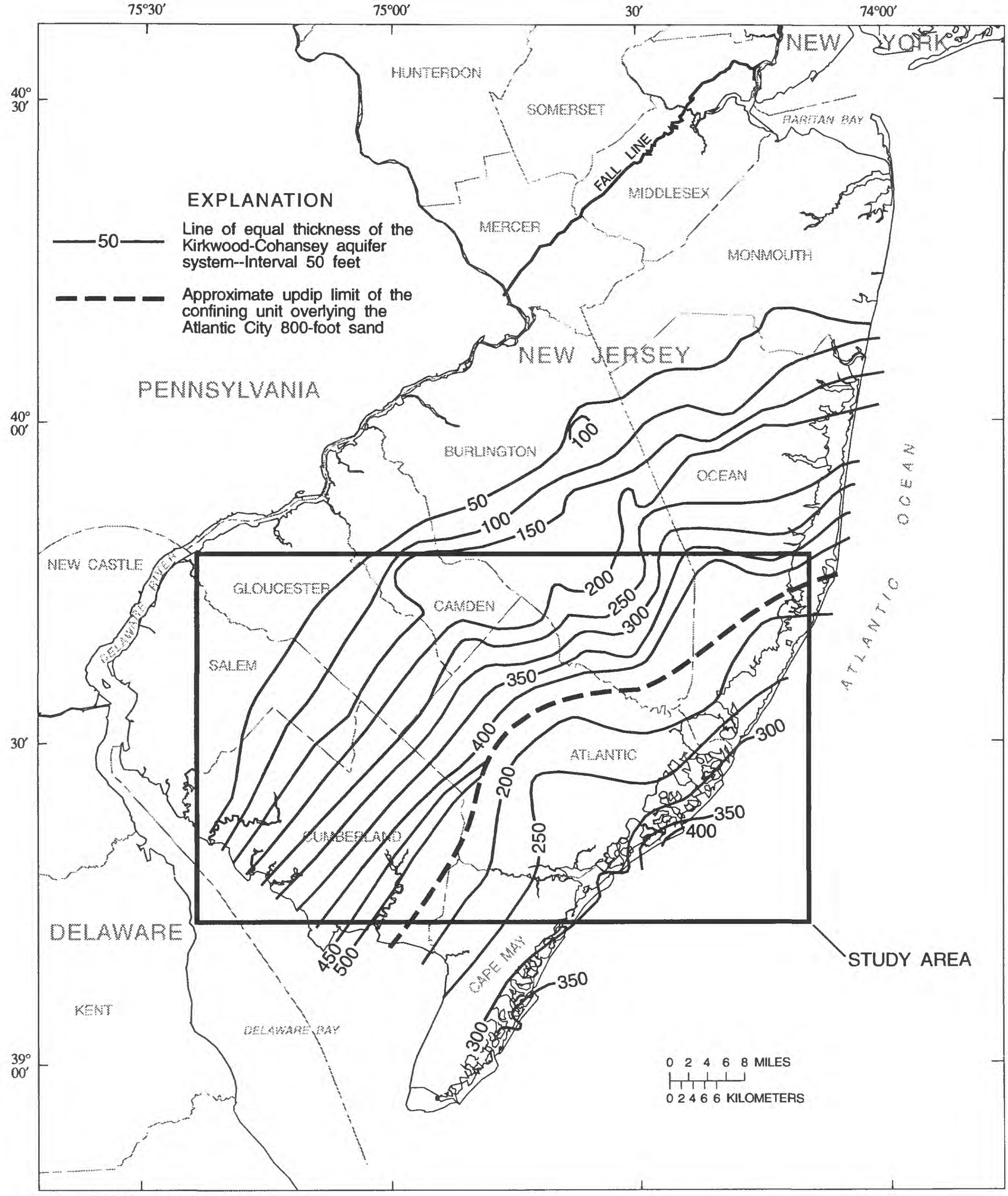
The thickness of the Kirkwood-Cohansey aquifer system is determined in part by the extent of the confining unit overlying the Atlantic City 800-foot sand of the Kirkwood Formation (figs. 4 and 5). The unconfined aquifer thickens downdip from less than 50 ft at the Kirkwood Formation outcrop area to more than 400 ft near the edge of the confining unit overlying the Atlantic City 800-foot sand. In areas where the confining unit is present in the subsurface, the aquifer thickness ranges from less than 200 ft along the northwestern extent of the confining unit to approximately 400 ft in the Atlantic City area. Because the Kirkwood-Cohansey aquifer system is a surficial aquifer system, the thickness map can be used to approximate the total depth of the aquifer below land surface.

A regional confining unit in the basal part of the Kirkwood Formation (fig. 4) averages about 100 ft in thickness throughout the study area and separates the Kirkwood-Cohansey aquifer system from deeper confined aquifers (Zapecza, 1989, p. B-20).

Hydrology

The Kirkwood-Cohansey aquifer system is predominantly unconfined, although perched water tables and semiconfined conditions caused by the presence of local clay beds may exist locally. Ground water flows from areas of high elevation to areas of low elevation, such as streams and swamps. Actual ground-water flow patterns probably are complex and are affected by local heterogeneities in the aquifer material and by seasonal changes in precipitation, evapotranspiration, and water use. In a conceptual model, Rhodehamel (1970) divided the ground-water-flow system of the Kirkwood-Cohansey aquifer system into shallow, local flow systems and deeper, regional flow systems (fig. 6). Flow paths in the shallow system are much shorter than those in the deeper system. In this model, little mixing of ground water from the shallow and deep flow systems occurs, except in some recharge and discharge areas where flow is vertical. Because ground-water flow is highly stratified and flow paths in the shallow system tend to be short, it is difficult to establish that two or more wells in the sampling network intersect a single flow path.

The altitude of the water table ranges from less than 10 ft above sea level near the coast to more than 140 ft above sea level in areas of topographic highs in Gloucester and Camden Counties (Rooney, 1971; Farlekas and others, 1976; P.J. Lacombe, U.S. Geological Survey, written commun., 1989). The altitude of the water table can fluctuate by as much as 3 ft during the year as a result of changes in precipitation and evapotranspiration.



Base modified from U.S. Geological Survey digital data, 1:100,000, 1983, Universal Transverse Mercator projection, zone 18

Figure 4. Thickness of the Kirkwood-Cohansey aquifer system, southern New Jersey. (Modified from Zapecza, 1989, pl.24)

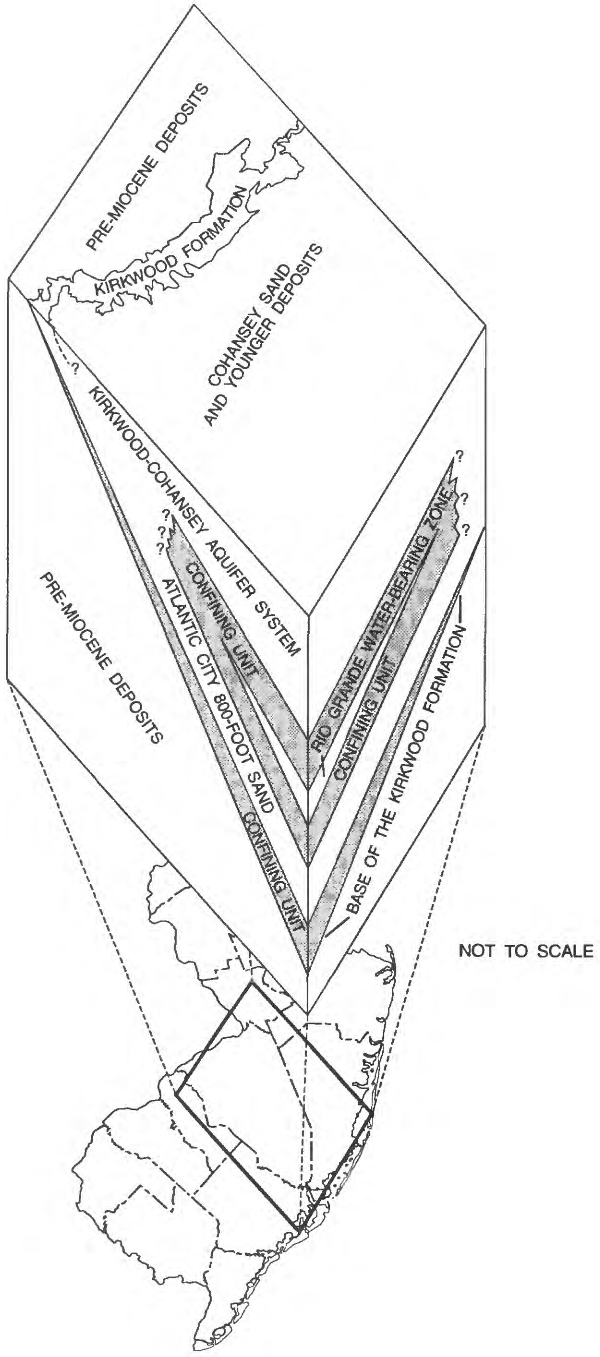


Figure 5.--Relation of the Kirkwood-Cohansey aquifer system to confined aquifers within the Kirkwood Formation, southern New Jersey. (Modified from Zapecza, 1989, fig. 5).

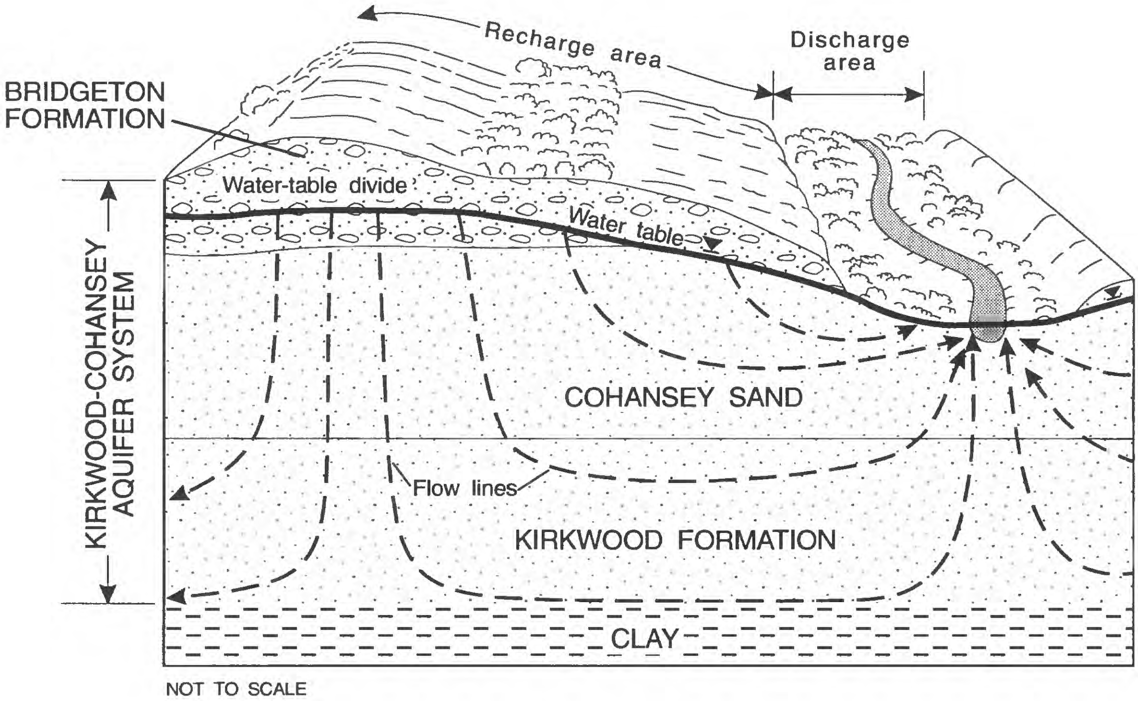


Figure 6. Generalized hydrogeologic section through the Kirkwood-Cohansey aquifer system and idealized ground-water-flow lines, southern New Jersey.

Recharge to the aquifer system is through percolation of precipitation that falls directly on the outcrop area of the aquifer system. Average annual precipitation over the study area ranges from 38 to 45 in. (R.D. Schopp, U.S. Geological Survey, written. commun., 1978). Little recharge is attributable to lateral flow from outside the study area (Rooney, 1971, p. 43). Deep parts of the aquifer are recharged by leakage from above. Water is lost from the system by evapotranspiration, ground-water discharge to streams, and pumpage.

The Cohansey, Maurice, Mullica, and Great Egg Harbor Rivers and many smaller streams cross the study area from west to east (fig. 1). Surface water in the study area drains into either the Atlantic Ocean or the Delaware River basin. Generalized water-table maps for parts of the study area (Rooney, 1971, fig. 8; Rhodehamel, 1973, fig. 9; P.J. Lacombe, U.S. Geological Survey, written commun., 1989; J.S. Clark, U.S. Geological Survey, written commun., 1989) and analyses of streamflow data for the Mullica and Maurice Rivers (Rhodehamel, 1973; P.J. Lacombe, U.S. Geological Survey, written commun., 1989) indicate that most streams in the study area are gaining streams. Rhodehamel (1970, p. 14) estimates that ground-water discharge accounts for 89 percent of the total annual stream discharge in the New Jersey Pinelands.

Water Use

The Kirkwood-Cohansey aquifer system is the primary source of water for public-supply, industrial, agricultural, and domestic uses in the study area. More than 200 public-supply and 100,000 private domestic wells draw water from the aquifer system. On the basis of pumpage information reported to the New Jersey Department of Environmental Protection (NJDEP), more than 70 Mgal/d of ground water was withdrawn from the aquifer system for public-supply, agricultural and industrial use in 1980 (Zapecza and others, 1987, p. 102). In addition, approximately 35 Mgal/d is withdrawn from the aquifer system for private domestic uses (New Jersey Department of Environmental Protection, 1987, p. 26). An estimated 60 percent of the more than 100 Mgal/d that was withdrawn from the Kirkwood-Cohansey aquifer system in 1987 was withdrawn from the study area.

Other aquifers used for water supply in the study area are the Potomac-Raritan-Magothy aquifer system, Englishtown aquifer system, and Wenonah-Mount Laurel aquifer. The Potomac-Raritan-Magothy aquifer system is the primary source of water supply for all of Camden, Gloucester, and Salem Counties (Vowinkel, 1984); however, most of the ground water from this aquifer system is withdrawn outside the area of investigation, nearer to areas of heavy industrial and urban development (Vowinkel, 1984, fig. 5). Within the study area, the Englishtown aquifer system is used for water supply only in Camden County; the Wenonah-Mount Laurel aquifer is used only in Camden, Gloucester, and Salem Counties (Vowinkel, 1984, fig. 5).

Parts of Atlantic, Camden, Gloucester, and Salem Counties are in the Water Supply Critical Area designated by the New Jersey Department of Environmental Protection (New Jersey Department of Environmental Protection, 1986). Annual withdrawals from the Potomac-Raritan-Magothy aquifer system within the Critical Area may be limited to reduce the effects of long-term overuse of the aquifer system.

Reductions in the use of the Potomac-Raritan-Magothy aquifer system could lead to increased withdrawals from the Kirkwood-Cohansey aquifer system as water suppliers seek alternate sources of water.

METHODS OF INVESTIGATION

Sampling Network

Ground-water samples were collected from 81 wells in the study area from June 1988 to March 1989. The wells include 68 withdrawal wells, 11 observation wells, and 2 test or back-up wells (app. 1). Of the 68 withdrawal wells sampled, 17 are used for public water supply, 19 are used for domestic supply, 10 are used for institutional water supply (at schools or hospitals), 6 are used for irrigation, 6 are used for industrial supply, and 10 are used for other purposes (app. 1).

The density of samples collected was highest in the western part of the study area, where the Bridgeton Formation is present, because ground water in this area was reported to contain elevated gross alpha-particle activities and concentrations of radium (unpublished data on file at the office of the New Jersey Department of Environmental Protection, Trenton, N.J.; Zapecza and Szabo, 1989). Geologic data were, however, inadequate to identify the geologic formations in which the wells were screened.

The concentration of radium in a single sample was assumed, on the basis of a study by Michel and Moore (1980), to be representative of the concentration of radium in water produced from the well. These investigators noted little seasonal variation in concentrations of radium in samples collected from withdrawal wells in an aquifer hydrologically similar (shallow unconfined conditions in sandy material) to the Kirkwood-Cohansey aquifer system.

Sample Collection

Samples were collected after a minimum of three casing volumes of water had been removed from the well, and when the pH, temperature, and specific conductance did not vary by more than 5 percent in three consecutive sets of measurements made at fixed time intervals to ensure the collection of fresh water from the aquifer. Pumping rates generally were about 6 gallons per minute for domestic or observation wells; rates of several hundred gallons per minute were common for irrigation and public-supply wells. Samples from withdrawal wells were collected as close to the well head as possible, prior to water treatment or filtering systems. Observation wells were pumped with a portable 1/3-horsepower submersible pump at a rate of approximately 6 gallons per minute; the pump was set about 30 ft below the static water level. Dissolved oxygen, Eh, pH, specific conductance, and temperature of the water were measured at 5-minute intervals during pumping of each well according to methods described by Wood (1976).

Methods for collection and preservation of ground-water samples were similar to those described by Wood (1976). Ground-water samples collected for analysis for radon-222 were collected in potassium-free glass, liquid-scintillation vials containing premeasured amounts of mineral-oil-based scintillation cocktail and were shipped to the laboratory immediately after collection (U.S. Environmental Protection Agency, 1978). Samples collected for analysis for radionuclides, common cations, and trace elements were filtered through a 0.45-micrometer filter and acidified immediately after collection. Samples collected for analysis for nutrients and common anions were filtered through a 0.45-micrometer filter and chilled; mercuric chloride was added to nutrient samples as a preservative. Samples collected for analysis for dissolved organic carbon were filtered through a 0.10-micro-meter silver filter and chilled.

Sample Analysis

Alkalinity (as calcium carbonate, by incremental titration), dissolved oxygen, Eh, pH, specific conductance, and temperature of ground-water samples were measured in the field according to methods described by Wood (1976). All samples were analyzed at the USGS National Water-Quality Laboratory in Arvada, Colorado, for nutrients, common ions, trace elements, and radionuclides. Constituents were determined; the reporting limits for each analysis are listed in table 2.

Concentrations of nutrients were determined by use of colorimetric techniques outlined by Fishman and Friedman (1985); the method used for nitrogen (as nitrate plus nitrite) was equivalent to accepted USEPA methods (Fishman and Friedman, 1985; U.S. Environmental Protection Agency, 1979b). Concentrations of dissolved organic carbon were determined by using methods described by Wershaw and others (1987). Concentrations of common cations and trace elements were determined by use of atomic emission spectroscopy with an inductively-coupled argon radio frequency plasma torch (ICP), except potassium, which was determined by means of atomic-absorption spectroscopy (Fishman and Friedman, 1985). Chloride concentrations were determined by using colorimetric methods, and sulfate concentrations were measured by means of turbidimetry (Fishman and Friedman, 1985).

Concentrations and activities of radionuclides were determined by use of standard methods approved by the USEPA (Krieger and Wittaker, 1980). Gross radioactivity of ground-water samples was measured as gross alpha-particle activity and gross beta-particle activity. Specific radionuclides determined in ground-water samples include radium-226, radium-228, and radon-222. The concentrations of individual isotopes of uranium were determined in 27 selected samples. In the remaining samples, only the gross chemical concentration of uranium was determined.

Gross alpha-particle activity and gross beta-particle activity were determined by using procedures approved by the USEPA (Krieger and Whittaker, 1980). Filtered ground-water samples are evaporated to dryness; the residues are deposited on a stainless-steel planchet and dried in a desiccator. Residues are weighed to ensure that they are of masses that will not impair counting efficiency. Gross alpha-particle activity and gross beta-particle activity are then counted in a low-background alpha-beta-particle counter for 100 minutes. Efficiency corrections for the counter are made with natural uranium and thorium-230 standards for gross alpha-particle activity, and with cesium-137 and strontium-90 standards for gross beta-particle activity (Thatcher and others, 1977).

Table 2.--Analytical method and minimum reporting limits for field and laboratory measurements of physical and chemical properties, inorganic chemical constituents, and radionuclides determined in water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89

[mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, not applicable. All constituents dissolved unless noted otherwise.]

Physical and chemical properties	Reporting limit
Alkalinity (as $CaCO_3$)	1 mg/L
Dissolved oxygen	.5 mg/L
pH	--
Specific conductance	10 µS/cm
Water temperature	--

Nutrients	Reporting limit (mg/L)
Ammonia, as nitrogen	0.010
Ammonia + organic nitrogen	.10
Nitrite, as nitrogen	.010
Nitrite + nitrate, as nitrogen	.10
Orthophosphate, as phosphorous	.010

Major ions and silica	Reporting limit (mg/L)
Calcium	0.02
Chloride	.10
Magnesium	.01
Potassium	.10
Silica	.01
Sodium	.20
Sulfate	.20

Table 2.--Analytical method and minimum reporting limits for field and laboratory measurements of physical and chemical properties, inorganic chemical constituents, and radionuclides determined in water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89--Continued

Trace elements	Reporting limit (μg/L)
Aluminum	10
Arsenic	1
Barium	1
Cadmium	1
Chromium	5
Cobalt	3
Copper	10
Iron	3
Lead	10
Lithium	4
Manganese	1
Mercury	0.1
Molybdenum	10
Nickel	10
Strontium	1
Silver	1
Vanadium	6
Zinc	3

Radionuclides	Reporting limit (in pCi/L unless stated otherwise)
Gross alpha-particle activity	0.1
Gross beta-particle activity	.1
Radium-226	.01
Radium-228	1.0
Radon-222	80
Uranium-238	.10
Uranium-234	.10
Uranium	.01 μg/L

Concentrations of radium-226 were determined by means of the radon-222-deemanation method approved by the USEPA (Krieger and Whitaker, 1980; Thatcher and others, 1977). Radium in ground-water samples is coprecipitated with barium sulfate. Radium yield (the percent of radium that coprecipitates with the barium sulfate) is monitored with a radioactive barium-133 tracer added to the solution in known quantities before precipitation of the barium sulfate. The precipitate is then added to a radon-222 bubbler. Radon-222 is ingrown from the radioactive decay of radium-226 for 2 weeks, then purged with a helium-gas carrier into a zinc sulfide-coated alpha-scintillation cell. The radon-222 activity is counted for 200 minutes. Radium-226 activity is calculated from the measured radon-222 activity. The amount of radioactive decay between time of collection and analysis is calculated on the basis of the half-life of radium-226 (1,620 years), so that analytical results represent radium-226 activity at the time of sample collection.

Concentrations of radium-228 were determined by beta-counting actinium-228 (Krieger and Whittaker, 1980). Radium-228 is coprecipitated with barium sulfate. Radium yield is monitored with radioactive barium-133 tracer. The radium precipitate is stored for 2 weeks to allow ingrowth of actinium-228 from the radioactive decay of radium-228. Actinium-228 is then separated from the sample by coprecipitating it with yttrium hydroxide. Actinium-228 activity is counted for 200 minutes in a low-level beta counter. Radium-228 activity is then calculated from the measured actinium-228 activity. The amount of radium-228 decay between the time of sample collection and the time of sample analysis is calculated on the basis of the half-life of radium-228 (5.8 years), so that the analytical results represent radium-228 activity at the time of sample collection.

Determinations of radon-222 concentrations in ground-water samples were made within 48 hours of collection by using liquid-scintillation methods (U.S. Environmental Protection Agency, 1978; Prichard and Gesell, 1977). Radon-222 activities of two water samples treated with premeasured, mineral-oil-based liquid scintillator are calculated by measuring the activities of five short-lived beta-emitting progeny for 100 minutes with a liquid-scintillation beta counter. The average activity of the two analyses is reported. The amount of decay between the time of sample collection and the time of sample analysis is calculated on the basis of the half-life of radon-222 (3.8 days), and the analytical results are adjusted to represent radon-222 activity at the time of sample collection.

Uranium concentrations were determined by means of laser-induced phosphorescence (Bushaw, 1983). The water sample is added to boiling phosphoric acid to form the uranium-phosphate complex ion. Excited by a laser, the uranium-phosphate complex ion phosphoresces with sufficient intensity and for a sufficiently long time that the intensity of the phosphoresence can be measured. The intensity of the phosphoresence is proportional to the mass of the uranium in solution. Uranium concentration is determined by comparing the intensity of the phosphoresence of the sample to that of known uranium standards. Uranium concentration is reported in micrograms per liter (μg/L) because it is the mass of the uranium that is measured.

Radioactivity resulting from each uranium isotope was determined by means of alpha-spectroscopy as detailed by Osmond and Cowart (1976) and Thatcher and others (1977). Uranium from a sample is trapped on an anion-exchange resin, eluted, and electrodeposited on a stainless-steel filament. Radioactivities of the individual uranium isotopes are determined by means of alpha-spectrometry by using a multichannel alpha-spectral analyzer.

Quality Assurance

To determine the precision of the results of the laboratory analyses, successive samples were collected from five wells (wells 1-0168, 1-0285, 11-0013, 11-0020, and 11-0369) and were submitted "blind" to the laboratory. Results of chemical analyses of successive ground-water samples are in appendix 2.

Results of analyses of the successive samples were compared. If concentrations of nutrients and inorganic constituents were outside suggested precision limits (Friedman and Erdman, 1982), discrepancies were noted and data verifications and (or) reruns of the analyses were requested. All results of analyses for nutrients and inorganic constituents were within suggested precision limits, except concentrations of zinc in samples from well 1-0168; the concentration measured in the first sample was 59 μg/L, and the concentration measured in the second sample was 18 μg/L. Zinc concentrations determined by rerunning the analyses of these samples were 12 and 13 μg/L, respectively. Precision limits were not exceeded for any radiochemical constituent for any of the five pairs of successive samples.

Accuracy of radiochemical measurements was monitored by quality-assurance personnel at the USGS laboratory. Known USEPA standards were analyzed along with the samples. If the concentration of the constituent in the standard was not determined within the two standard deviation error (2 sigma) limit (about plus or minus 10 percent), the samples with which the standard was submitted were reanalyzed.

Data were reviewed to verify the results of the radiochemical analyses. Repeat analyses were requested for determination of radium-226 and radium-228 if the ratio of their concentrations was significantly greater than or less than one (this was the case for 8 samples). If the sum of radium-226 and radium-228 concentration was greater than the maximum contaminant level of 5 pCi/L (U.S. Environmental Protection Agency, 1988), then the analysis for the radium isotope with the greater concentration was repeated, or both radium isotopes were redetermined. Because radium-226 is an alpha emitter, the concentration of radium-226 alone cannot exceed that of the gross alpha particles. Therefore, if the radium-226 concentration exceeded the gross alpha-particle activity, the radium-226 analysis was repeated. If the radium-226 concentration was confirmed, the gross alpha-particle activity was redetermined.

As an additional check on the quality of the inorganic chemical data, ion balances were computed for all ground-water analyses. If the difference between the sum of the charges of anions and cations exceeded plus or minus 5 percent, analyses of selected major ions were repeated (Friedman and Erdman, 1982), and, if necessary, the correct concentrations were substituted for the incorrect concentrations in the data base. Repeat analyses were also made if the concentration of a given constituent was considered subjectively to be unusually high or low for the geographic area from which the sample was collected.

Nearly identical results were obtained for radiochemical and inorganic chemical analyses of five sets of successive samples, indicating that a high degree of precision was attained by the laboratory for all analyzed constituents, with the possible exception of zinc. The results of this quality-assurance work indicate that the 81 analyses completed during this study are both accurate and precise within suggested limits (Friedman and Erdman, 1982).

Statistical Analysis

Descriptive statistical summaries, including the 10th, 25th, 50th (median), 75th, and 90th percentiles, were calculated for selected chemical constituents. Results of all analyses for inorganic chemical constituents in ground water from the Kirkwood-Cohansey aquifer system done by the USGS during 1983-89 were included in the summaries. Chemical data used in this report but not reported in app. 2 are stored in WATSTORE, the USGS computerized water-quality data base. The geographic distribution of geologic outcrop areas and the dominant land use (agriculture) were delineated to determine the relation of the geochemistry to geographic and geologic features. The well network was then divided into four well-location classes: (A) wells that contain part of the Bridgeton Formation outcrop area and agricultural land within a 500 m radius of the well head, (B) wells that contain part of the Bridgeton Formation outcrop area but no agricultural land within a 500 m radius of the well head, (C) wells that do not contain part of the Bridgeton Formation outcrop area but do contain agricultural land within a 500 m radius of the well head, and (D) wells that do not contain either part of the Bridgeton Formation outcrop area or agricultural land within a 500 m radius of the well head. Descriptive statistical summaries of each class of wells were calculated for selected chemical constituents and were plotted as boxplots.

The Kruskal-Wallis non-parametric statistical test was applied among the classes of data to determine whether the composition of ground water from areas where the Bridgeton Formation crops out is significantly different from that in areas where the Bridgeton Formation is absent, and to determine whether the presence of agricultural land significantly affects the chemistry of ground water. Data in each of the four well-location classes were ranked so that the number 1 was assigned to the smallest observation, 2 to the second smallest, and so on. Ties were assigned the average rank of the tied values. All of the observations for which the concentrations of the constituents were less than the analytical reporting limit were tied at rank 1. Corrections were made for tied values in the ranked data set. Constituents for which the ranked values were different for the two classes being compared were identified by means of a chi-square significance value less than 0.05, and the class with the higher median ranked value was recorded. Spatial autocorrelation of the data, observed for most inorganic chemical constituents (especially nitrate and divalent cations) may have resulted in a slight overstatement of the significance of these groupings (Cliff and Ord, 1981, p. 186).

Results of the Kruskal-Wallis test indicating significant relations (greater than 95-percent confidence level) are most likely valid, despite the disparity in the number of samples from wells in agricultural and nonagricultural land. The paucity of samples from non-agricultural areas causes the medians for the analytical data to be statistically less significant than the medians calculated for larger populations, such as the samples from agricultural areas. However, the narrow ranges of concentrations of radionuclides and other inorganic constituents in samples from wells in nonagricultural areas indicate that the samples collected, although small in number (13), probably are representative of the chemistry of the ground water in these areas. On the other hand, the range of concentrations of radionuclides and inorganic constituents is large for samples from wells in agricultural areas, indicating that the collection of large numbers of samples is necessary for the results of statistical analysis of constituent concentrations in water from wells in these areas to be representative of the ground-water chemistry. Most of the samples collected (68) were from wells in areas of agricultural land and, therefore, are probably statistically representative of the chemistry of the ground waters in these areas.

The relations between total radium (the sum of radium-226 and radium-228) concentrations in ground water and the concentrations of other geochemical constituents and characteristics were investigated by use of Spearman rank correlations, a non-parametric correlation technique (Conover, 1980). The magnitude of the correlation coefficients were considered only if the significance value of the correlation was less than 0.05. Regression methods were used to develop a predictive model for ranks of the total radium concentrations from ranks of concentrations of inorganic chemical constituents. This technique is described by Iman and Conover (1979). The regression model was constructed to allow the prediction of total radium concentrations on the basis of the concentration of another geochemical constituent in solution (nitrate plus nitrite, as nitrogen) that is determined more easily and less expensively than that of radium.

Calculation of Geochemical Speciation

Geochemical speciation of water samples was calculated by use of the geochemical-speciation computer program, SOLMINEQ88 (Kharaka and others, 1988). This program is used to calculate aqueous species distributions and mineral saturation indices in water on the basis of mass balance and chemical equilibria. The program can be used to calculate new species distributions and other chemical characteristics (such as pH, Eh, and alkalinity) for many chemical reactions, such as the equilibration of a solution with a mineral, or the dissolution of a specified amount of a mineral in a solution of a specified starting chemistry.

NATURAL RADIOACTIVITY AND INORGANIC CHEMISTRY

The geographical distribution of gross alpha-particle and gross beta-particle activities and of concentrations of radium-226, radium-228, radon-222, and uranium in water of the Kirkwood-Cohansey aquifer system was evaluated by plotting these activities and concentrations on a map showing the location of the sampled wells. Concentrations of radionuclides are statistically compared to the concentrations of other radionuclides and to concentrations of selected inorganic chemical constituents. The effects of geology (presence or absence of Bridgeton Formation within 500 m of the well locations) and land use (presence or absence of agricultural land within 500 m of the well locations) on the distribution of the radionuclides and selected inorganic chemical constituents are evaluated statistically. The water chemistry is evaluated for evidence that neither adsorption nor coprecipitation with barite limit dissolved radium concentrations in this aquifer. Radium isotope ratios are examined as to whether they suggest that the aquifer material or phosphate fertilizer is the most likely source of the dissolved radium.

Radionuclides

Radionuclide concentrations and activities are listed in appendix 2. In 26 of the 81 wells from which water samples were analyzed for radium-226 and radium-228, the sum of radium-226 and radium-228 concentrations exceeded the interim primary drinking-water regulation of 5 pCi/L (U.S. Environmental Protection Agency, 1988) (fig. 7; table 3). Gross alpha-particle activity exceeded the interim primary drinking-water regulation of 15 pCi/L in 12 of the 81 well water samples.

Statistical Summary

A statistical summary of radionuclide concentrations and activities, including the 10th, 25th, 50th, 75th, and 90th percentiles, is presented in table 4. Descriptive statistics are given for the whole data set and for the four classes of wells developed on the basis of the presence or absence of the Bridgeton Formation and agricultural land within a 500-m radius of the well head. Variations in the concentrations of radon-222, radium-226, and radium-228 among these well-location classes are depicted in boxplots (fig. 8). The median concentrations of radon-222, radium-226, radium-228, and uranium were 280 pCi/L, 1.7 pCi/L, 1.9 pCi/L, and 0.03 μg/L, respectively.

The median concentration of radon-222 in ground water in the study area (280 pCi/L) is similar to, but slightly less than the nationwide, population-weighted average of 420 pCi/L (Cothern, 1987, p. 156). Seventy percent of the samples contained radon-222 in concentrations between 200 and 2,000 pCi/L. Concentrations of radon-222 in the ground water show local variability indicating that the amount of uranium or radium-226 within the aquifer matrix also varies locally. Concentrations of uranium did not exceed 1 μg/L in any of the samples, and thus were at least an order of magnitude below any of the proposed MCL's for this constituent (Cothern and others, 1983; Mays and others, 1985; U.S. Environmental Protection Agency, 1991).

Because the concentration of uranium in ground water from the Kirkwood-Cohansey aquifer system is so low, dissolved uranium is not the source of most of the dissolved alpha-particle activity. Rather, dissolved alpha-emitting progeny of uranium, especially radium-226, are the dominant sources of gross alpha-particle activity in the ground water.

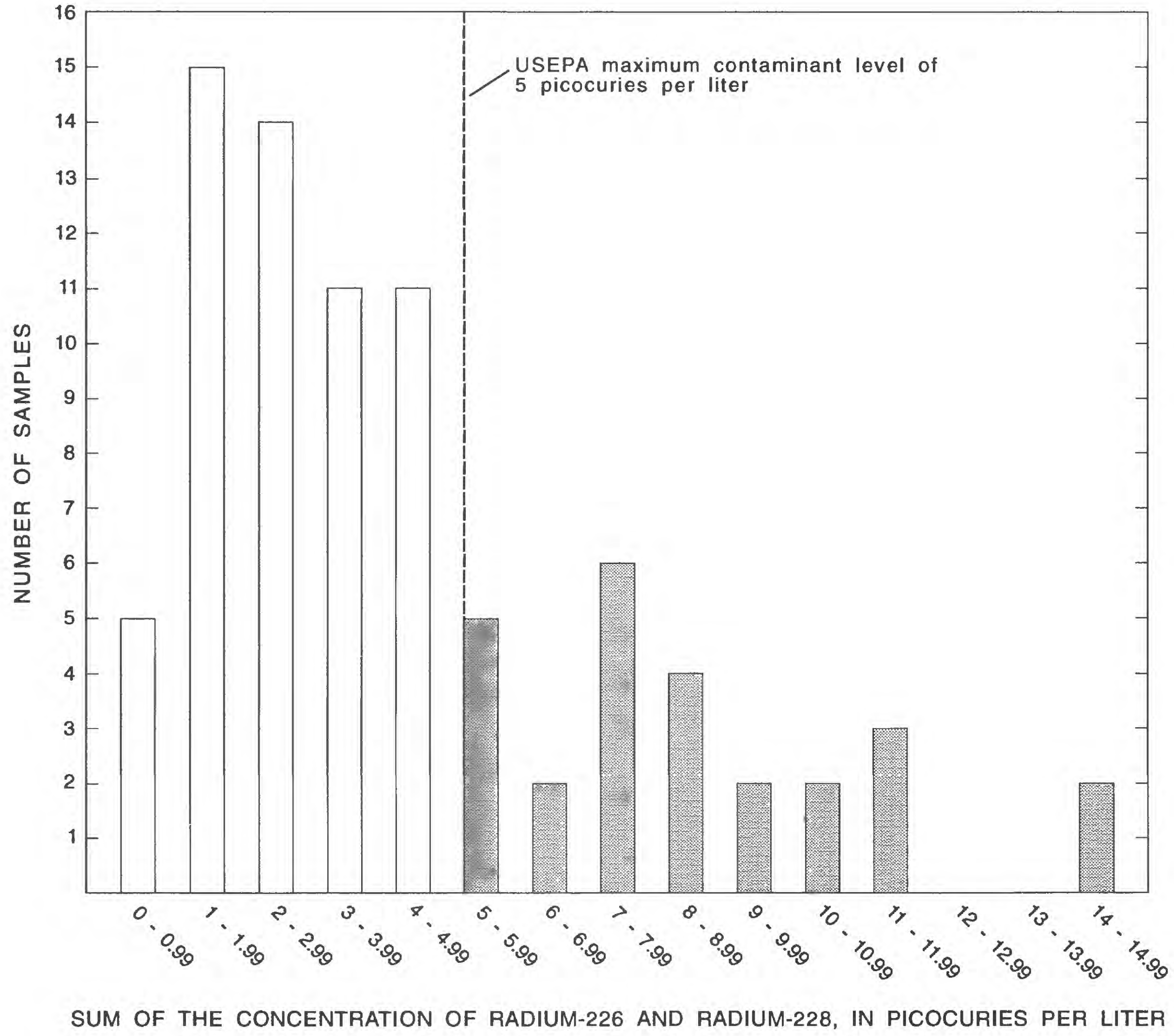


Figure 7.--Histogram of the sum of the concentrations of radium-226 and radium-228 in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. [USEPA, United States Environmental Protection Agency]

Table 3.--Summary of number of water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89, in which radionuclide concentrations or activities exceeded drinking-water regulations or proposed regulations

[pCi/L, picocuries per liter]

Radio-chemical constituent	Drinking-water regulation or proposed regulation (pCi/L)	Number of samples analyzed	Number of samples in which concentration or activity exceeded drinking-water regulation or proposed regulation
Radon-222	300 (1)	76	35
Radium-226 plus radium-228	5 (2)	81	26
Gross-alpha particle activity (including radium, excluding uranium and radon)	15 (2)	81	12

(1) Proposed maximum contaminant level (U.S. Environmental Protection Agency, 1991).

(2) U.S. Interim Primary Drinking-Water Regulation (U.S. Environmental Protection Agency, 1988)

Table 4.--Statistical summary of concentrations of radionuclides in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89, grouped by presence or absence of the Bridgeton Formation outcrop area and agricultural land within a 500-meter radius of the well head

[µg/L, micrograms per liter; pCi/L, picoCuries per liter]

Chemical constituent and group well-location class	10th percentile	25th percentile	Median	75th percentile	90th percentile	Number of measurements
Radium-228 (pCi/L)						
All wells	<1	1.1	1.9	3.3	4.6	81
Bridgeton Formation, agriculture	<1	1.3	2.1	3.8	5.3	44
Bridgeton Formation, no agriculture	<1	1.1	1.5	2.2	2.3	4
No Bridgeton Formation, agriculture	<1	1.0	1.5	3.1	3.3	25
No Bridgeton Formation, no agriculture	<1	1.0	1.7	2.6	3.3	8
Radium-226 (pCi/L)						
All wells	.4	.8	1.7	2.9	4.8	81
Bridgeton Formation, agriculture	.5	1.0	2.4	4.1	5.9	44
Bridgeton Formation, no agriculture	.1	.1	.3	1.1	1.3	4
No Bridgeton Formation, agriculture	.1	.6	1.4	2.0	3.5	25
No Bridgeton Formation, no agriculture	.1	.4	1.6	2.0	2.1	8
Radon-222 (pCi/L)						
All wells	82	180	280	390	510	79
Bridgeton Formation, agriculture	84	190	300	410	510	38
Bridgeton Formation, no agriculture	110	140	240	310	330	4
No Bridgeton Formation, agriculture	<80	200	290	390	840	22
No Bridgeton Formation, no agriculture	<80	95	210	320	510	8
Uranium (µg/L)						
All wells	<.01	<.01	.03	.08	.18	80
Bridgeton Formation, agriculture	<.01	.02	.04	.14	.20	43
Bridgeton Formation, no agriculture	<.01	<.01	<.01	.02	.02	4
No Bridgeton Formation, agriculture	<.01	<.01	.03	.06	.14	25
No Bridgeton Formation, no agriculture	<.01	<.01	.03	.06	.07	8

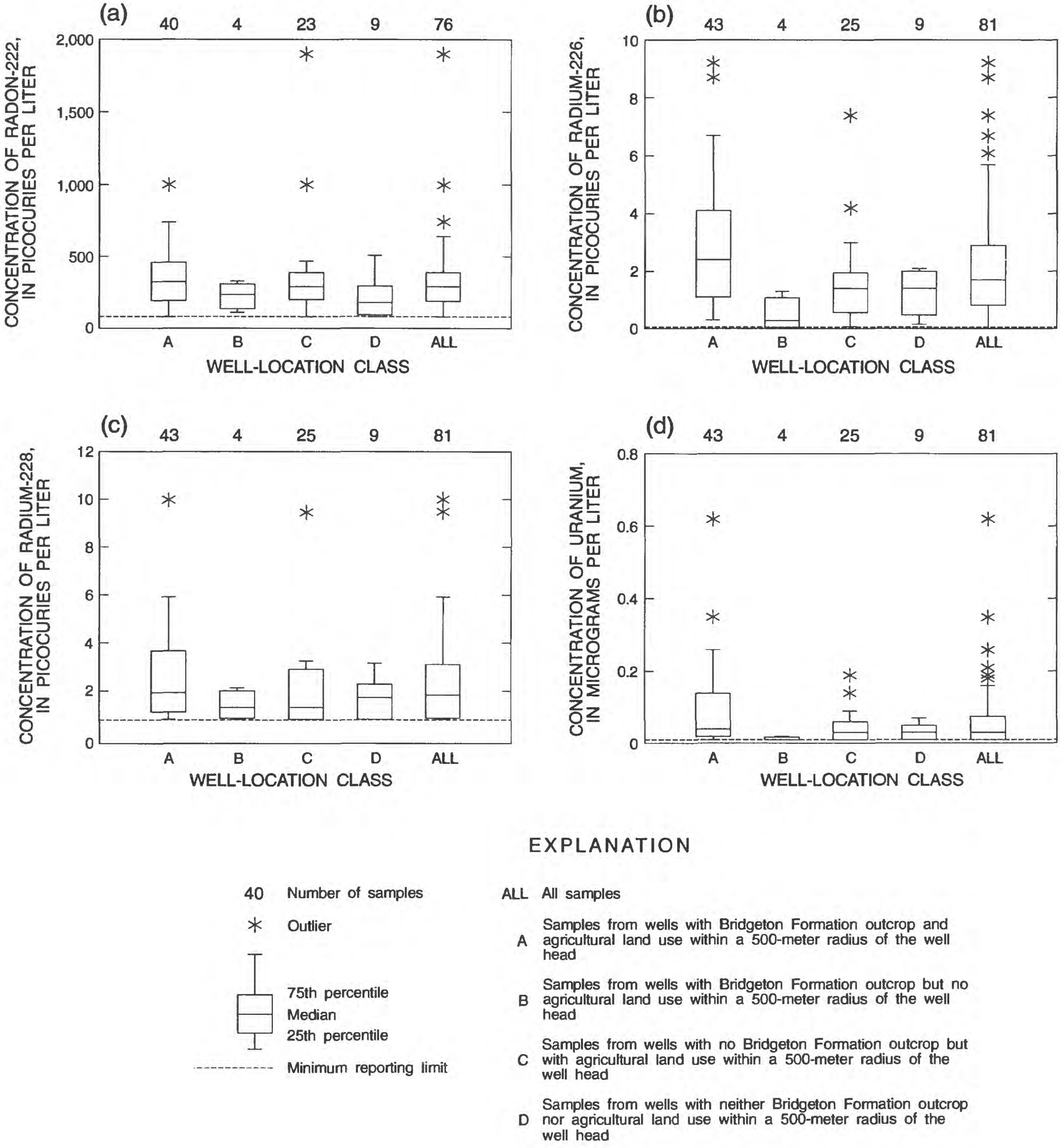


Figure 8. Concentrations of (a) radon-222, (b) radium-226, (c) radium-228, and (d) uranium in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89, grouped by presence or absence of the Bridgeton Formation outcrop area and agricultural land within a 500-meter radius of the well head. [Minimum Reporting Limits in picocuries per liter, unless otherwise noted: Radon-222,80; Radium-226, 0.01; Radium-228, 1.0; and uranium, 0.01 micrograms per liter].

The concentration of radon-222 was approximately two orders of magnitude greater than the concentration of radium-226 in the ground-water samples. This disparity in the concentrations of the two radionuclides indicates that the source of radon-222 in the ground water cannot be radium-226 dissolved in the ground water and that only a fraction of the total amount of radium-226 in the aquifer material has gone into solution. Therefore, the source of radon-222 must be radium-226 in the aquifer material. If radium-226 dissolved in the ground water were the source of the dissolved radon-222, then the concentration of radon-222 would be approximately equal to that of dissolved radium-226.

Concentrations of radon-222 in the ground water were much higher than those of radium-226 because radon-222, an inert gas, is much more soluble than radium-226, which is chemically reactive. The concentration of radium-226 consequently is controlled to a great degree by the geochemical reactions taking place in the ground water, whereas that of dissolved radon-222 is not. Therefore, the concentration of radon-222 is a better indication of the total radium-226 (and uranium) content of the aquifer material than is the concentration of dissolved radium-226.

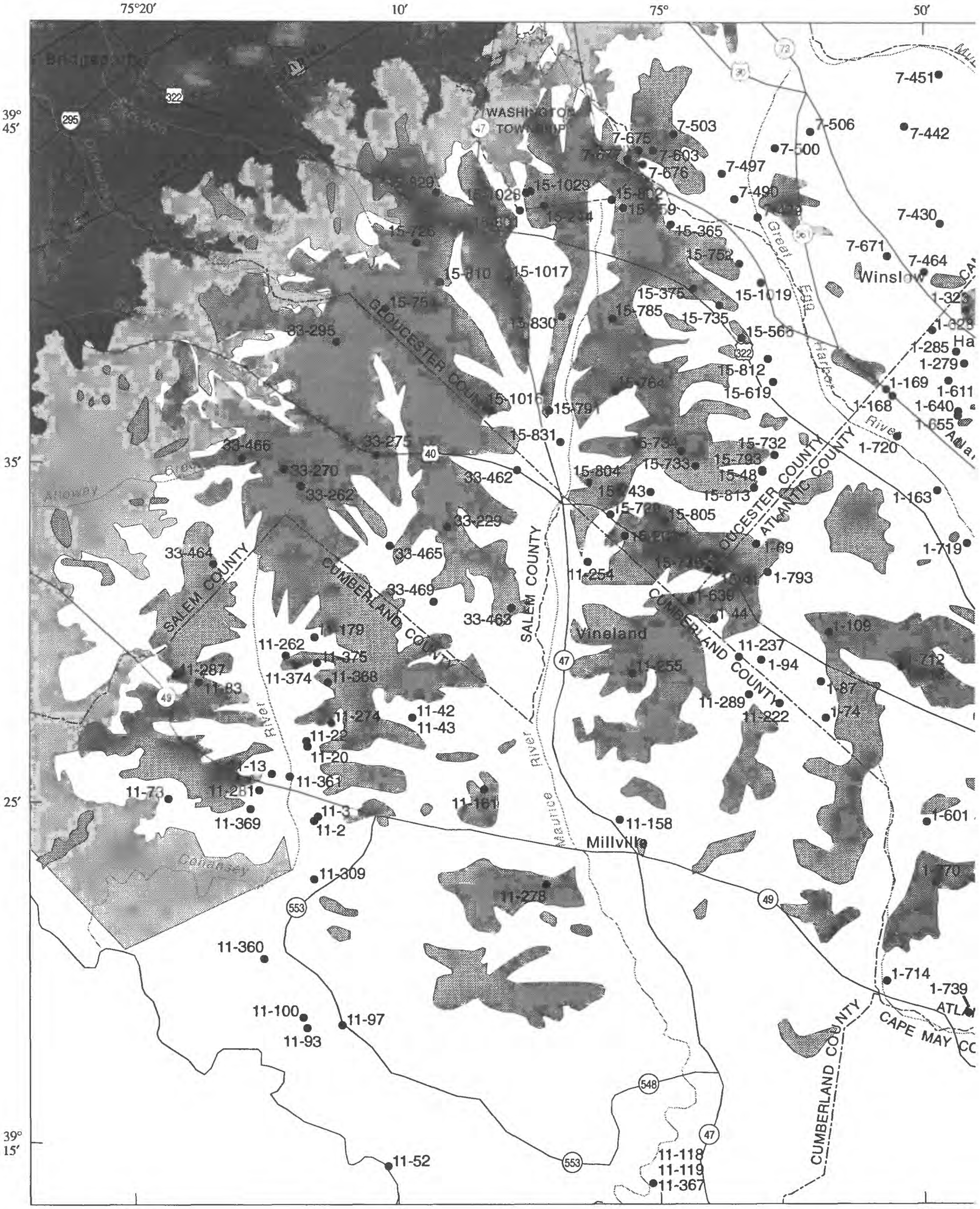
Dissolved radon-222 does not migrate far from its source in the aquifer because of its short half-life (3.82 days), whereas radium-226 and isotopes of uranium can be advected substantial distances from their source by ground-water flow because they have substantially longer half-lives than radon-222. Therefore, the concentrations radon-222 in ground water is more representative of the local concentration of radium-226 (and uranium) in the aquifer matrix than the concentration of either radium-226 or uranium in the ground water.

Spatial Distributions

Ground water from the Kirkwood-Cohansey aquifer system is enriched in uranium, radium-226, and radium-228 in areas where the Bridgeton Formation outcrop overlies the Kirkwood-Cohansey aquifer system and in areas of agricultural land use (figs. 9-13). Concentrations of these radionuclides, and gross alpha-particle and beta-particle activities are highest in these areas.

The spatial distributions of radium-226 and radium-228 in ground water from the Kirkwood-Cohansey aquifer system are shown on figure 12. The largest concentrations of radium were found in north-central Cumberland County, eastern Salem County, north-central Gloucester County, and south-central Camden County. Concentrations of radium-226 and radium-228 tended to be highest in areas where there is Bridgeton Formation outcrop and agricultural land (which tends to coincide with the Bridgeton Formation outcrop area) (figs. 9, 10, and 12).

The spatial distribution of uranium in ground water from the Kirkwood-Cohansey aquifer system is shown on fig. 13. The highest concentrations of uranium were found in north-central Cumberland County, north-central Gloucester County, and south-central Camden County. Concentrations of uranium tended to be highest in areas where there is Bridgeton Formation outcrop and agricultural land (which tends to coincide with the Bridgeton Formation outcrop area).



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-area Conic projection
Standard parallels 29°30′ and 45°30′, central meridian -96°00′

Figure 9. Outcrop areas of the Kirkwood Formation, Cohansey Sand, and Bridgeton Formation, and locations of wells used to interpret ground-water chemistry, 1983-89.

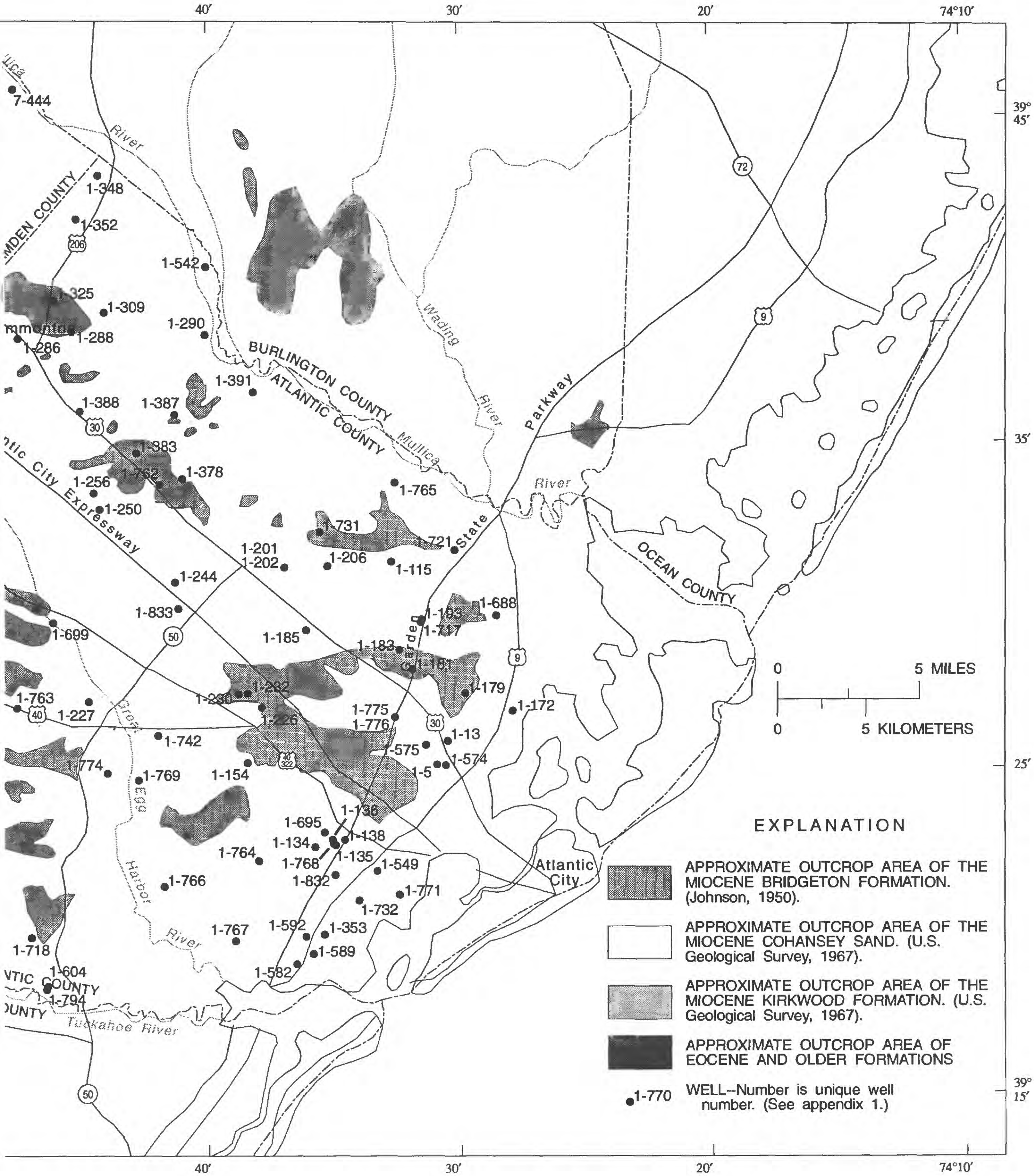


Figure 9. Outcrop areas of the Kirkwood Formation, Cohansey Sand, and Bridgeton Formation, and locations of wells used to interpret ground-water chemistry, 1983-89. --Continued

Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-area Conic projection
Standard parallels 29°30′ and 45°30′, central meridian -96°00′

Figure 10. Area of agricultural land use, and concentration of dissolved soilds in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89.

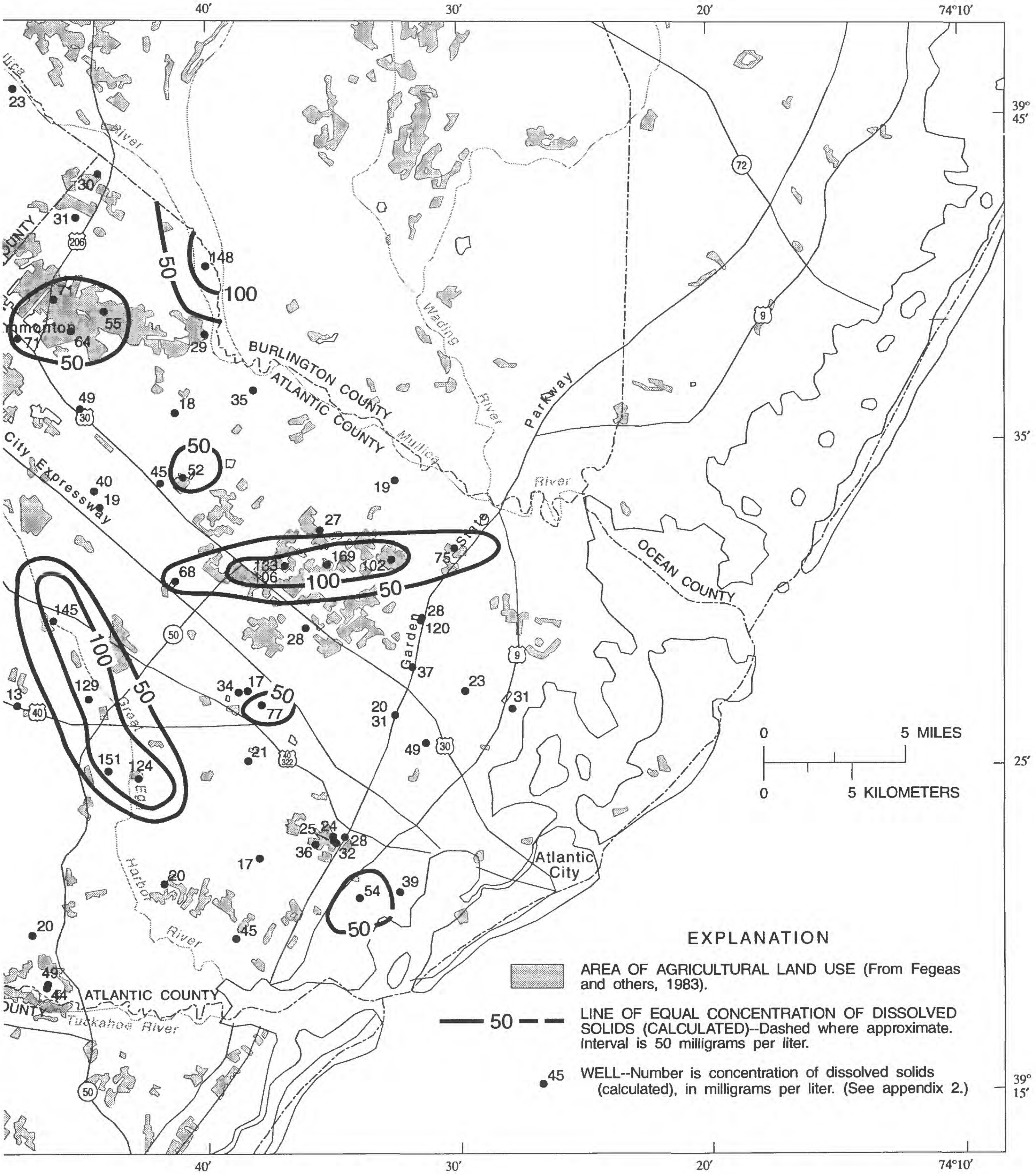
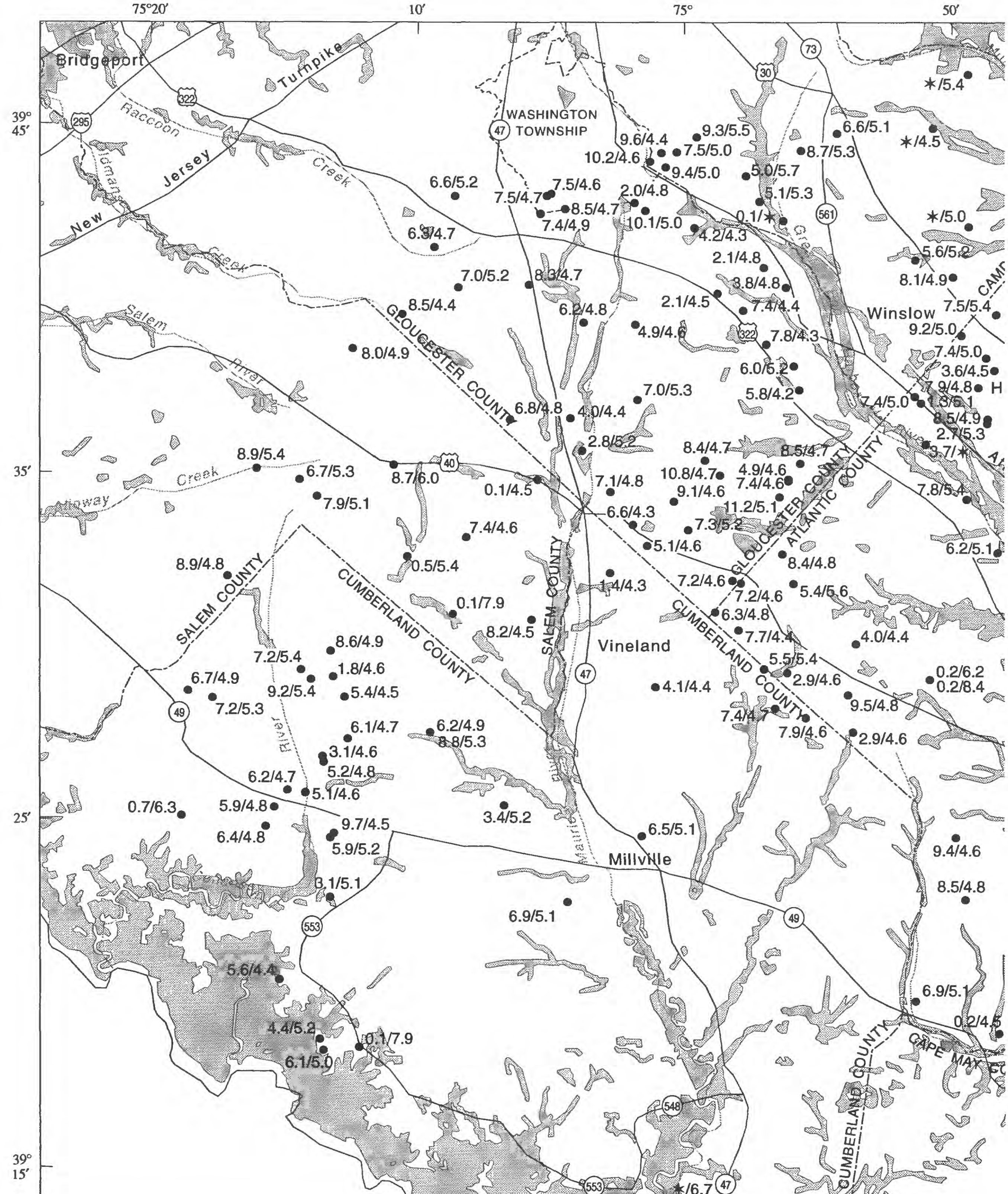


Figure 10. Area of agricultural land use, and concentration of dissolved soilds in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89. --Continued



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-area Conic projection
Standard parallels 29°30' and 45°30', central meridian -96°00'

Figure 11. Area of wetlands, concentration of dissolved oxygen, and pH in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89.

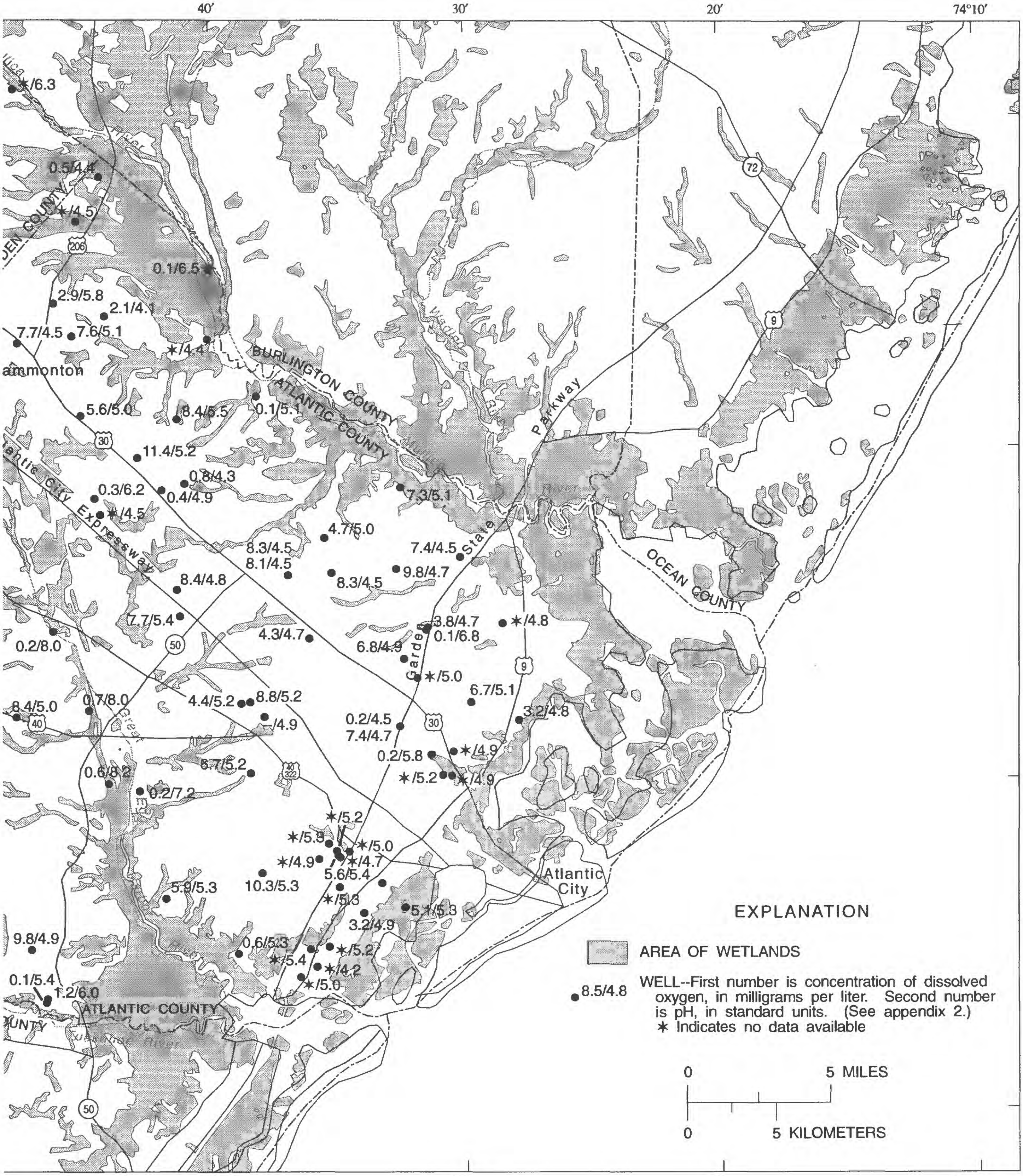
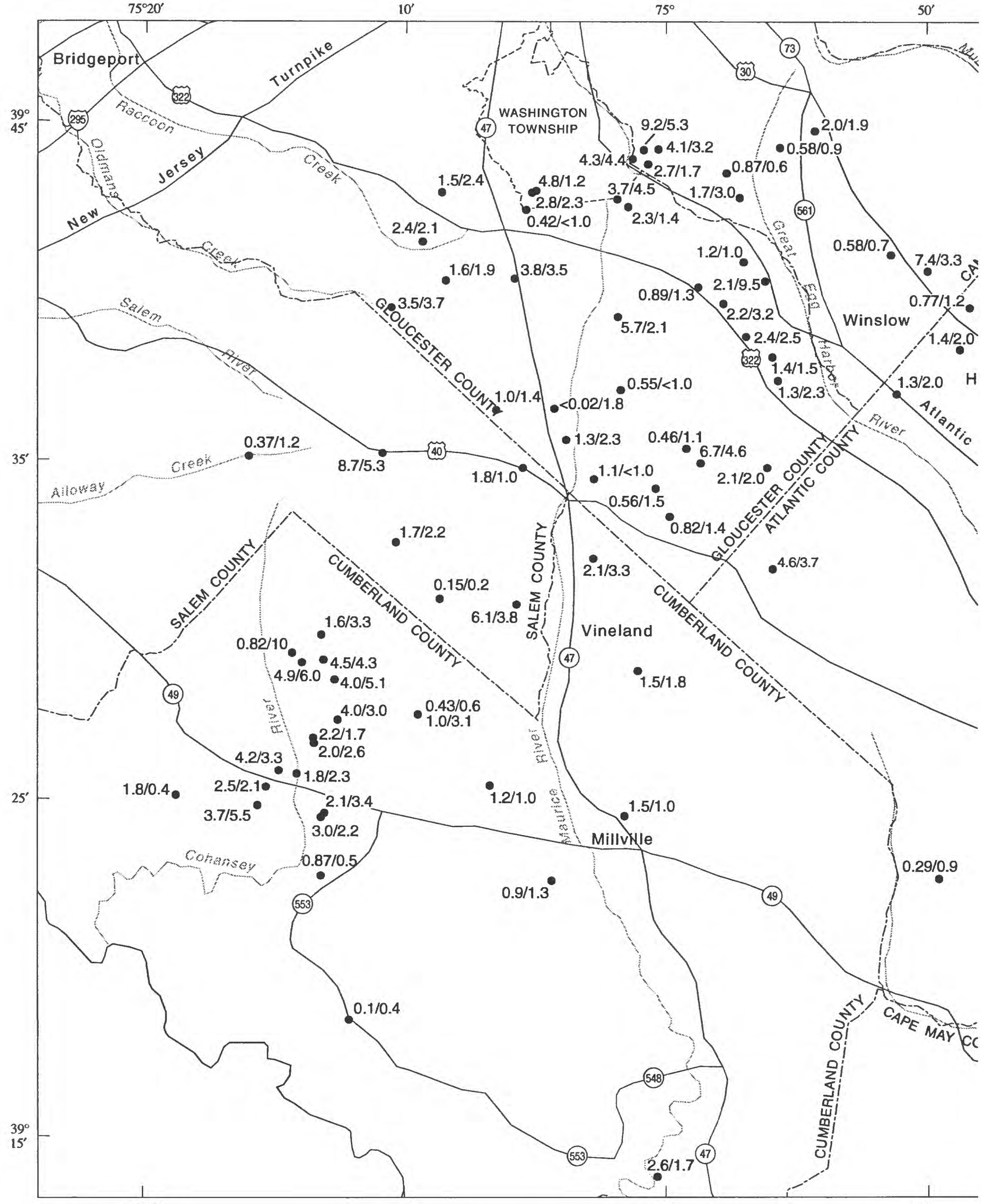


Figure 11. Area of wetlands, concentration of dissolved oxygen, and pH in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89. --Continued



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-area Conic projection
Standard parallels 29°30' and 45°30', central meridian -96°00'

Figure 12. Distribution of radium-226 and radium-228 concentrations in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.

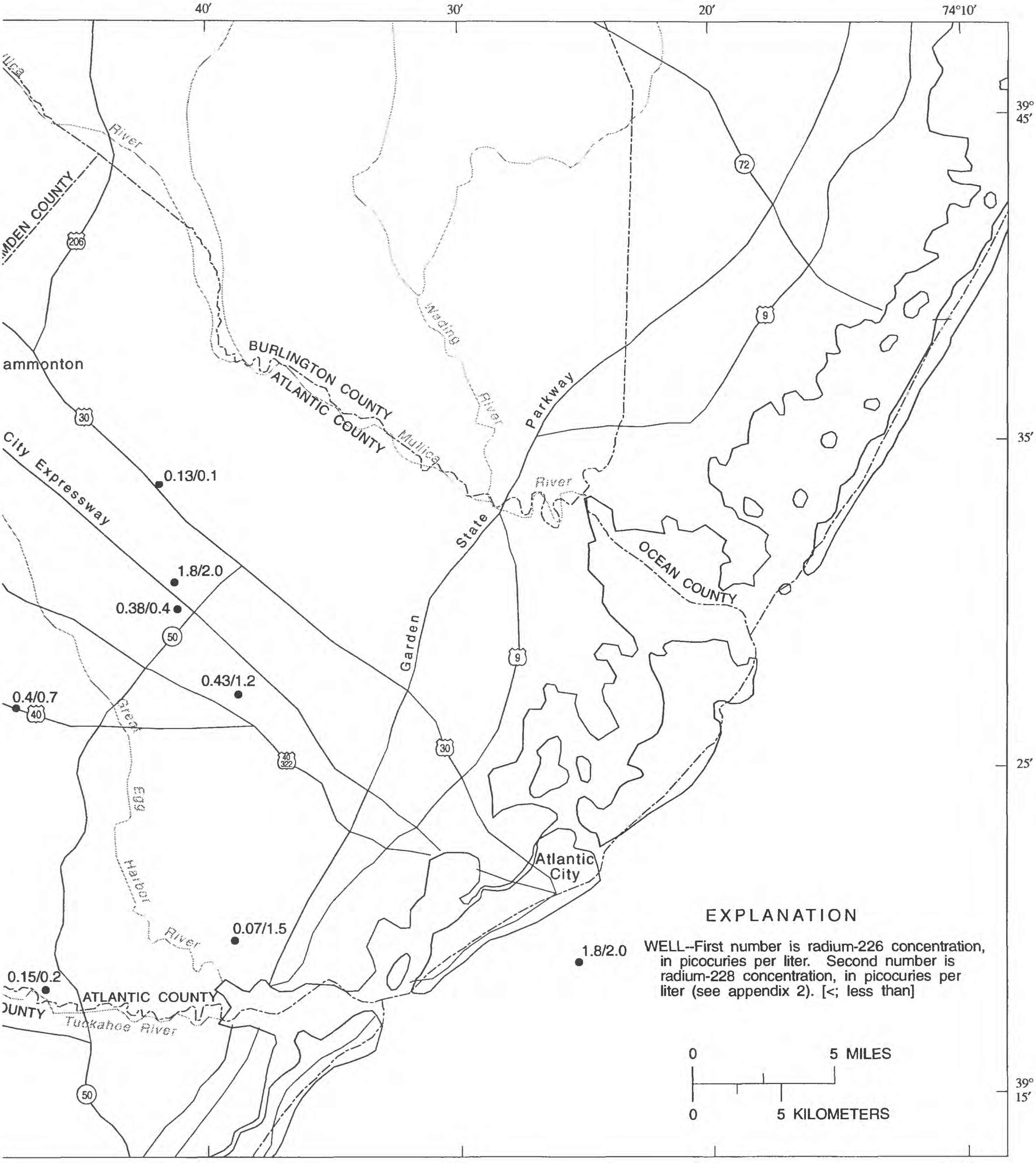
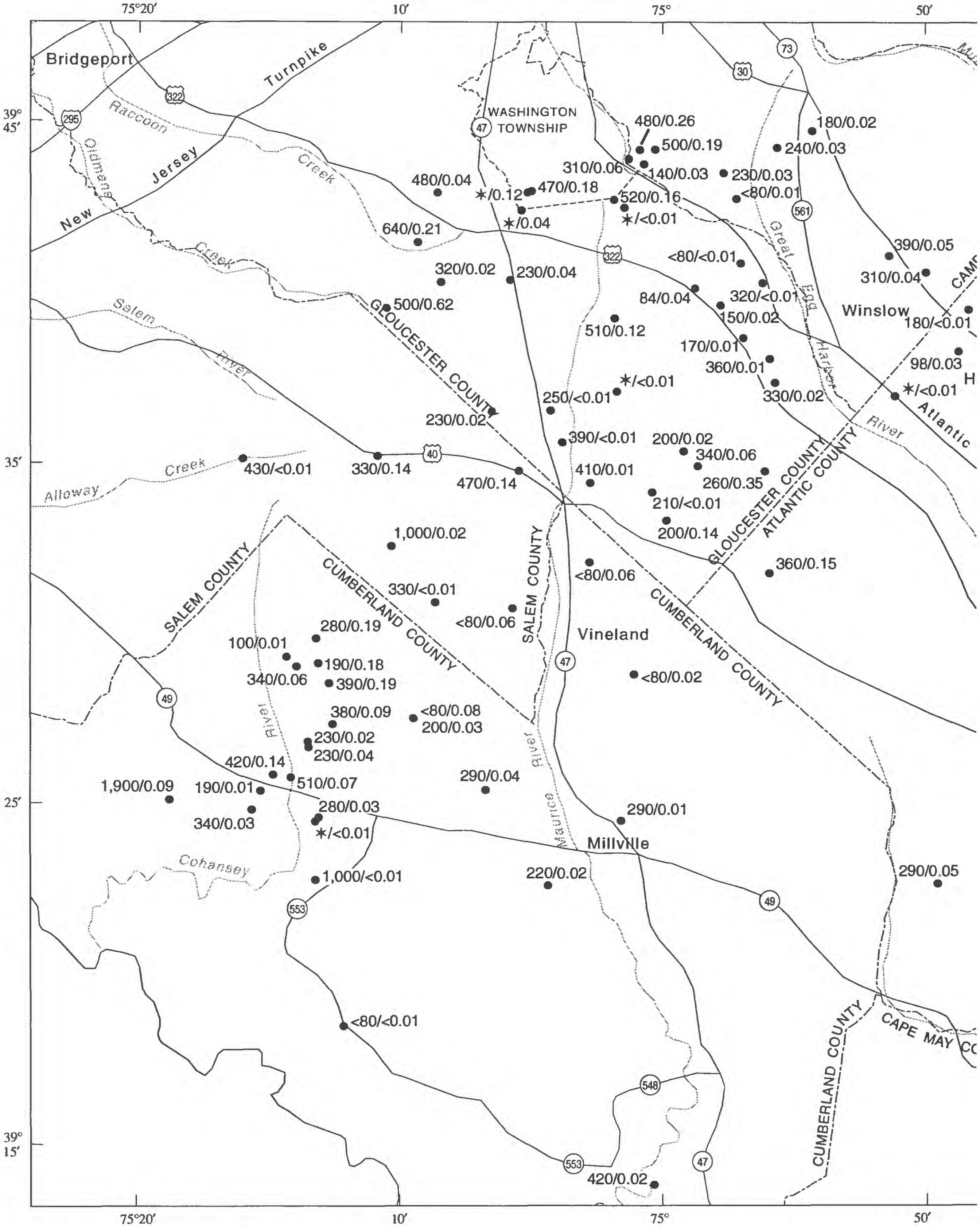


Figure 12. Distribution of radium-226 and radium-228 concentrations in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-area Conic projection
Standard parallels 29°30′ and 45°30′, central meridian -96°00′

Figure 13. Distribution of uranium concentration and radon-222 concentration in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.

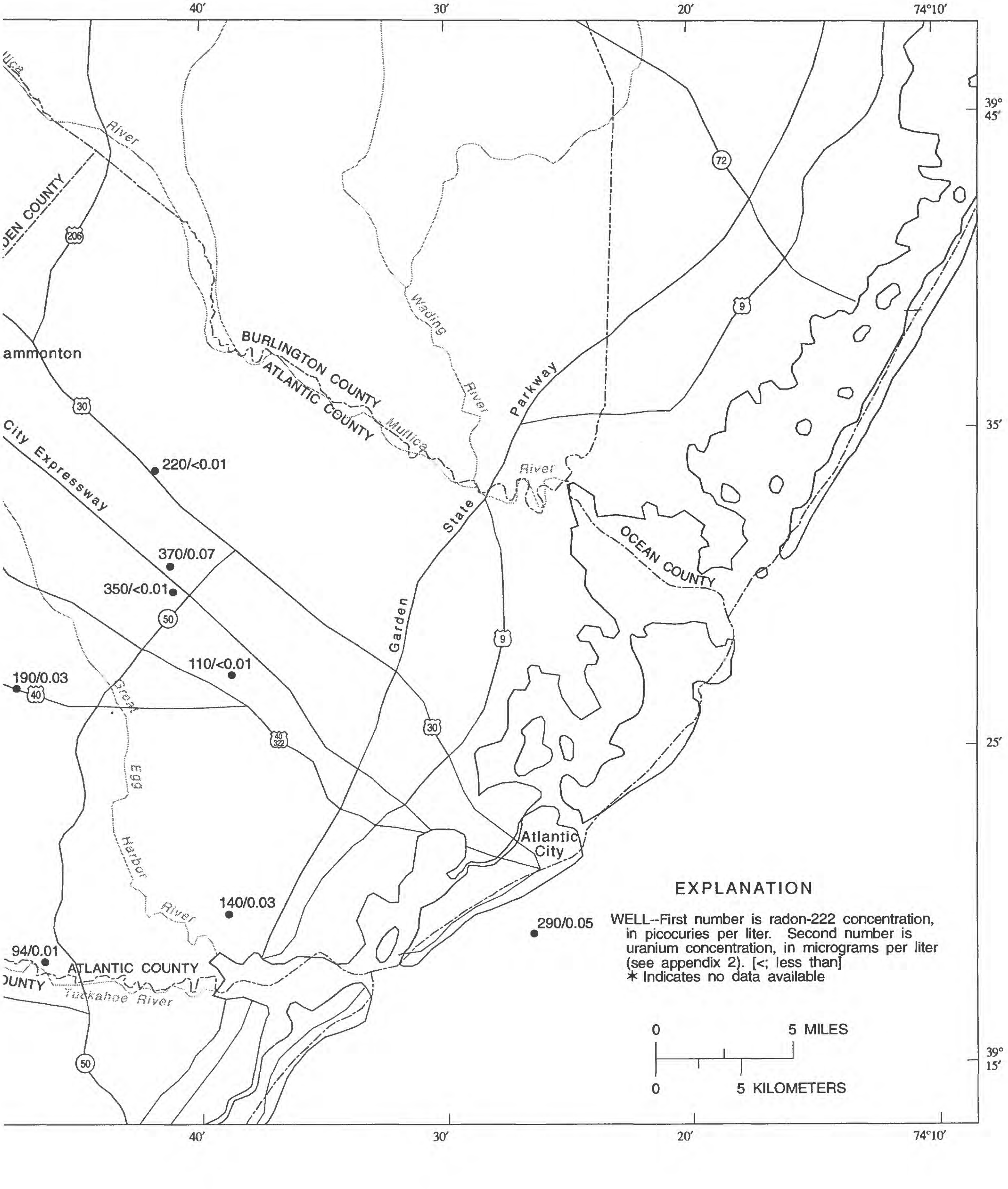


Figure 13. Distribution of uranium concentration and radon-222 concentration in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

The spatial distributions of gross alpha-particle and gross beta-particle activities dissolved in ground water in the Kirkwood-Cohansey aquifer system are similar to those of radium-226 and radium-228. Gross alpha-particle activity and gross beta-particle activity tended to be highest in areas where there is Bridgeton Formation outcrop and agricultural land. The highest gross alpha-particle activities were detected in north-central Cumberland County, eastern Salem County, central Gloucester County, and the southeastern part of Camden County. The spatial distribution of gross beta-particle activity was similar to that of gross alpha-particle activity. The highest gross beta-particle activity was found in north-central Cumberland County.

Concentrations of radon-222 also tended to be higher in samples of ground water collected from wells screened in the Kirkwood-Cohansey aquifer system in the western part of the study area than in samples from wells in the eastern part (fig. 13), but the distribution of radon-222, unlike the distributions of radium and uranium, is not clearly related to the presence of the well in the Bridgeton Formation outcrop area nor to the presence of agricultural land (fig. 8). Concentrations of radon-222 in the ground water were spatially more uniform than concentrations of uranium and radium-226, the radioactive parent of radon-222, indicating that radium-226 may be spatially more uniformly distributed within the aquifer matrix than in the ground water. If this is true, then the relatively higher concentrations of radium-226 in ground water from areas where there is Bridgeton Formation outcrop and agricultural land can be attributed to increased mobilization of radium-226 from the aquifer matrix in these areas relative to areas where the Bridgeton Formation and agricultural land are absent.

Concentrations of uranium, radium-226, and radium-228 do not correlate with well depth. Concentrations of radon-222 in ground water tend to decrease slightly with increasing well depth; the correlation coefficient (r) for the inverse relation between radon-222 concentration and well depth is statistically significant (significance level, $p<0.05$), but is low (-0.28).

One possible cause of the negative correlation between concentration of radon-222 and well depth is that shallow strata in the aquifer contain more radium-226 (and potentially more uranium) than do deep strata. Such a hypothesis is difficult to justify without detailed stratigraphic mapping. Because of the topographic relief of the landscape, a relatively shallow well in a valley may be screened in the same stratum as a relatively deep well at the adjacent hilltop. Furthermore, the Cohansey Sand and the Kirkwood Formation dip to the southeast; therefore, a relatively shallow well may be screened in the same stratum as a relatively deep well located farther east.

An alternative possibility is that a physical or chemical property or process that controls radon emanation to the ground water changes with depth. For example, if grain size increases or if radium-226 concentration in grain coatings decreases with depth, the emanation of radon from sediment to pore water would also decrease with depth. This latter hypothesis cannot be tested without detailed examination of the aquifer material. Because the negative correlation between radon-222 and well depth is weak, little of the variance in the concentration of dissolved radon-222 can be attributed to well depth.

Inorganic Constituents and Chemical Characteristics

Results of chemical and radionuclide analyses of the 81 ground-water samples collected during 1988-89 for this study are listed in appendix 2. Results of chemical analyses of ground-water samples from 115 additional wells collected prior to 1988 are stored in U.S. Geological Survey official data systems. No radionuclide analyses are available for water from these wells. Well record information for all 196 wells used in this study is given in appendix 1. Well locations are plotted in figure 9.

Statistical Summary

A descriptive statistical summary listing the 10th, 25th, 50th, 75th, and 90th percentile of field and laboratory measurements and concentrations of inorganic constituents in ground-water samples from the Kirkwood-Cohansey aquifer system collected during 1983-89 is presented in table 5. Descriptive statistical summaries of the water-quality data for the four well-location classes also are given in table 5. Variations in the concentrations of selected chemical constituents among these well-location classes are depicted in boxplots (fig. 14).

Ground water in the Kirkwood-Cohansey aquifer system typically is dilute. Concentrations of dissolved solids in the ground-water samples ranged from 11 to 420 mg/L, but the median was 45 mg/L (table 6), a relatively low concentration for dissolved solids in ground water (Hem, 1985). The ground water was acidic (median pH 4.90; table 6) and had high dissolved oxygen concentrations (median, 6.4 mg/L).

Nitrate concentrations in ground water from the Kirkwood-Cohansey aquifer system exceeded the USEPA MCL of 10 mg/L in 3 of the 81 samples collected during 1988-89 (app. 2), and in 22 of the 159 samples collected from the Kirkwood-Cohansey aquifer system in the study area since 1983 (table 6). The highest nitrate concentration measured in the 81-sample set was 19 mg/L (app. 2), although nitrate concentrations as high as 30 mg/L have been measured in ground water from the Kirkwood-Cohansey aquifer system (Louis and Vowinkel, 1989). Concentrations of sodium, chloride, and sulfate did not exceed the USEPA secondary drinking-water regulations (U.S. Environmental Protection Agency, 1979a) in any of the 81 ground-water samples collected during 1988-89 (app. 2).

The trace elements detected most frequently in the ground water were iron, manganese, aluminum, barium, copper, strontium, and zinc. The concentrations of iron, manganese, aluminum, copper, and zinc in ground water are controlled by pH, temperature, dissolved solids, dissolved oxygen, and oxidation-reduction potential; however, concentrations of these elements also may be limited by the abundance of these elements in the aquifer material. Galvanized-iron well casing and household plumbing, particularly in the presence of acidic water, may also be a source of trace elements (most likely iron, copper, lead, and zinc) to well water (Kish and others, 1987); to avoid household-plumbing sources of these elements, samples were collected as close to the well head as possible. Strontium and barium are divalent cations that behave chemically in a similar way to calcium, magnesium, and radium; concentrations of these elements in ground water are controlled by ion-exchange, precipitation, and adsorption processes.

Table 5.--Statistical summary of concentrations of major ions, silica, and dissolved soilids; concentrations of trace elements; concentrations of organic carbon; and results of field measurements of alkalinity, pH, and specific conductance in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89, grouped by presence or absence of Bridgeton Formation outcrop area and agricultural land within a 500-meter radius of the well head

[All concentrations in milligrams per liter except pH and as noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter]

Chemical constituent or characteristic, and group well-location class	10th percentile	25th percentile	Median	75th percentile	90th percentile	Number of measurements
Alkalinity, as $CaCO_3$						
All wells	<1	<1	2.0	3.0	6.0	177
Bridgeton Formation, agriculture	<1	<1	2.0	3.0	7.0	68
Bridgeton Formation, no agriculture	<1	<1	2.0	3.0	4.0	15
No Bridgeton Formation, agriculture	<1	<1	2.0	3.0	11	58
No Bridgeton Formation, no agriculture	<1	<1	1.5	3.0	5.3	36
pH						
All wells	4.46	4.60	4.90	5.22	5.79	193
Bridgeton Formation, agriculture	4.41	4.60	4.80	5.11	5.42	70
Bridgeton Formation, no agriculture	4.26	4.60	4.93	5.20	5.32	15
No Bridgeton Formation, agriculture	4.48	4.60	4.90	5.25	5.94	61
No Bridgeton Formation, no agriculture	4.50	4.76	5.10	5.40	6.72	47
Dissolved solids						
All wells	17	26	45	102	232	93
Bridgeton Formation, agriculture	33	52	123	215	266	24
Bridgeton Formation, no agriculture	14	18	20	30	65	9
No Bridgeton Formation, agriculture	23	31	45	99	239	33
No Bridgeton Formation, no agriculture	12	19	32	55	105	27
Specific conductance (µS/cm)						
All wells	27	39	73	140	225	194
Bridgeton Formation, agriculture	30	57	126	172	257	70
Bridgeton Formation, no agriculture	22	26	36	62	102	15
No Bridgeton Formation, agriculture	27	36	72	115	212	61
No Bridgeton Formation, no agriculture	25	40	55	122	209	48
Nitrate plus nitrite (as nitrogen)						
All wells	<.10	.20	3.1	6.4	13	159
Bridgeton Formation, agriculture	1.3	3.1	6.0	9.9	17	66
Bridgeton Formation, no agriculture	<.10	<.10	.15	1.1	1.6	10
No Bridgeton Formation, agriculture	<.10	<.10	2.1	5.0	9.6	51
No Bridgeton Formation, no agriculture	<.10	<.10	.25	2.0	4.1	32
Aluminum (µg/L)						
All wells	<10	40	110	300	667	130
Bridgeton Formation, agriculture	<10	40	110	310	630	60
Bridgeton Formation, no agriculture	30	45	100	245	350	9
No Bridgeton Formation, agriculture	18	40	100	300	1,220	47
No Bridgeton Formation, no agriculture	<10	18	100	570	1,230	14
Calcium						
All wells	.40	.90	2.6	8.9	22	180
Bridgeton Formation, agriculture	1.2	2.5	6.1	11	25	69
Bridgeton Formation, no agriculture	.20	.31	.85	1.3	1.9	15
No Bridgeton Formation, agriculture	.47	.91	2.3	9.2	24	59
No Bridgeton Formation, no agriculture	.30	.47	.90	2.8	12.8	37
Chloride						
All wells	3.0	4.4	7.4	14	25	90
Bridgeton Formation, agriculture	3.8	5.9	12	19	33	69
Bridgeton Formation, no agriculture	3.4	4.2	5.1	6.5	27	15
No Bridgeton Formation, agriculture	2.6	4.3	6.3	10	24	61
No Bridgeton Formation, no agriculture	2.8	3.8	5.7	11	18	45
Magnesium						
All wells	.44	.78	1.9	4.6	9.2	180
Bridgeton Formation, agriculture	.90	2.2	4.6	7.0	14	69
Bridgeton Formation, no agriculture	.37	.49	.86	.99	2.5	15
No Bridgeton Formation, agriculture	.44	.73	1.4	3.1	6.3	59
No Bridgeton Formation, no agriculture	.31	.50	.80	2.2	3.2	37
Potassium						
All wells	.50	.90	1.5	2.9	6.0	180
Bridgeton Formation, agriculture	.90	1.3	2.2	3.7	7.6	69
Bridgeton Formation, no agriculture	.30	.40	.70	1.0	1.5	15
No Bridgeton Formation, agriculture	.60	.90	1.5	3.0	8.1	59
No Bridgeton Formation, no agriculture	.30	.60	1.1	1.9	2.8	37
Silica						
All wells	5.4	6.3	7.9	10	14	180
Bridgeton Formation, agriculture	6.2	6.8	7.9	10	13	69
Bridgeton Formation, no agriculture	4.9	5.7	6.2	12	16	15
No Bridgeton Formation, agriculture	5.3	6.2	7.8	11	17	59
No Bridgeton Formation, no agriculture	4.9	5.6	6.9	10	25	37

Table 5.--Statistical summary of concentrations of major ions, silica, and dissolved soilids; concentrations of trace elements; concentrations of organic carbon; and results of field measurements of alkalinity, pH, and specific conductance in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89, grouped by presence or absence of Bridgeton Formation outcrop area and agricultural land within a 500-meter radius of the well head--Continued

Chemical constituent and group well-location class	10th percentile	25th percentile	Median	75th percentile	90th percentile	Number of measurements
Sodium						
All wells	2.0	2.6	3.9	5.9	8.9	180
Bridgeton Formation, agriculture	2.2	3.3	4.3	6.4	9.5	69
Bridgeton Formation, no agriculture	1.9	2.2	3.0	4.0	12.9	15
No Bridgeton Formation, agriculture	1.8	2.5	3.9	5.7	10.0	59
No Bridgeton Formation, no agriculture	1.7	2.4	3.2	4.4	6.9	37
Sulfate						
All wells	<.2	1.0	4.9	13	29	178
Bridgeton Formation, agriculture	<.2	.8	4.9	23	36	69
Bridgeton Formation, no agriculture	.3	.5	2.2	4.1	7.9	15
No Bridgeton Formation, agriculture	<.2	1.6	6.4	15	25	59
No Bridgeton Formation, no agriculture	<.2	1.4	5.2	10	17	35
Barium (μg/L)						
All wells	25	45	72	120	200	127
Bridgeton Formation, agriculture	49	67	120	180	280	60
Bridgeton Formation, no agriculture	19	29	47	110	170	8
No Bridgeton Formation, agriculture	22	37	56	75	110	45
No Bridgeton Formation, no agriculture	17	23	54	66	87	14
Iron (μg/L)						
All wells	8	16	56	200	770	180
Bridgeton Formation, agriculture	8	16	47	120	280	69
Bridgeton Formation, no agriculture	10	20	110	450	1,800	15
No Bridgeton Formation, agriculture	8	11	45	360	770	59
No Bridgeton Formation, no agriculture	6	43	110	450	2,140	37
Manganese (μg/L)						
All wells	4	10	18	36	65	179
Bridgeton Formation, agriculture	9	15	24	42	92	68
Bridgeton Formation, no agriculture	3	5	10	17	32	15
No Bridgeton Formation, agriculture	4	10	17	25	59	59
No Bridgeton Formation, no agriculture	4	6	11	37	64	37
Strontium (μg/L)						
All wells	8	13	27	65	130	127
Bridgeton Formation, agriculture	15	23	54	76	150	60
Bridgeton Formation, no agriculture	5	8	13	19	24	8
No Bridgeton Formation, agriculture	8	11	20	38	130	45
No Bridgeton Formation, no agriculture	5	5	13	28	73	14
Zinc (μg/L)						
All wells	5	10	19	44	120	130
Bridgeton Formation, agriculture	5	9	16	30	84	60
Bridgeton Formation, no agriculture	12	33	55	91	910	9
No Bridgeton Formation, agriculture	4	8	19	41	130	47
No Bridgeton Formation, no agriculture	6	12	31	110	600	14
Dissolved organic carbon						
All wells	.2	.3	.5	.8	1.7	100
Bridgeton Formation, agriculture	.3	.4	.5	.8	1.9	37
Bridgeton Formation, no agriculture	.2	.3	.4	.5	1.6	7
No Bridgeton Formation, agriculture	.2	.3	.5	1.0	1.6	43
No Bridgeton Formation, no agriculture	.1	.3	.3	.7	6.1	13

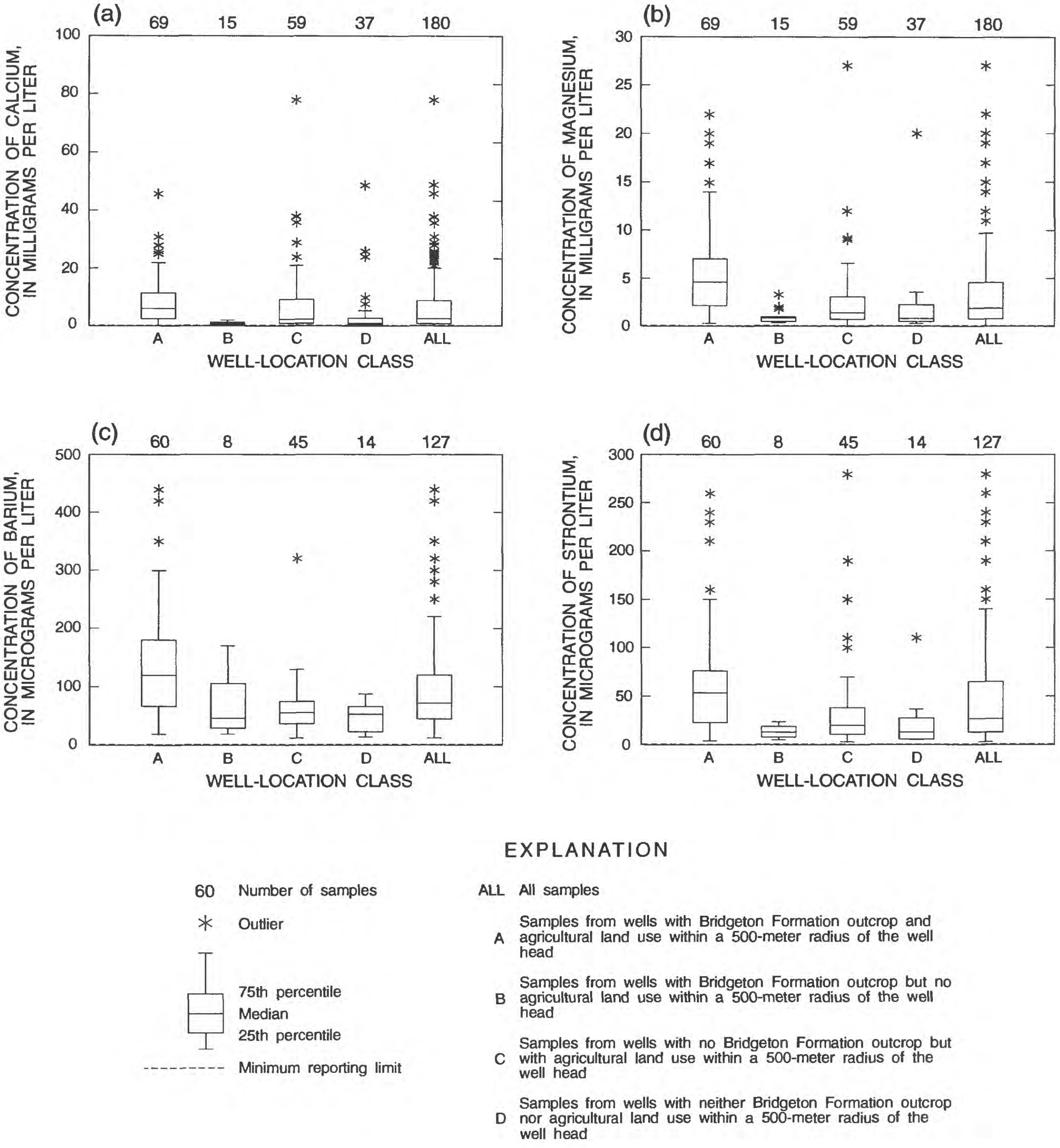


Figure 14. Concentrations of (a) calcium, (b) magnesium, (c) barium, (d) strontium, (e) nitrate plus nitrite (as nitrogen), (f) silica, (g) potassium, (h) chloride, (i) manganese, (j) sulfate, and (k) alkalinity in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89, grouped by presence or absence of Bridgeton Formation outcrop area and agriculutral land within a 500-meter radius of the well head. [Minimum Reporting Limits in milligrams per liter, unless otherwise noted: Calcium, 0.02; Magnesium, 0.01; Barium, 1 microgram per liter; strontium, 1 microgram per liter; nitrate plus nitrite (as nitrogen), 0.10; silica, 0.01; potassium, 0.10; chloride, 0.10; manganese, 1 microgram per liter; sulfate, 0.20; and alkalinity, 1]

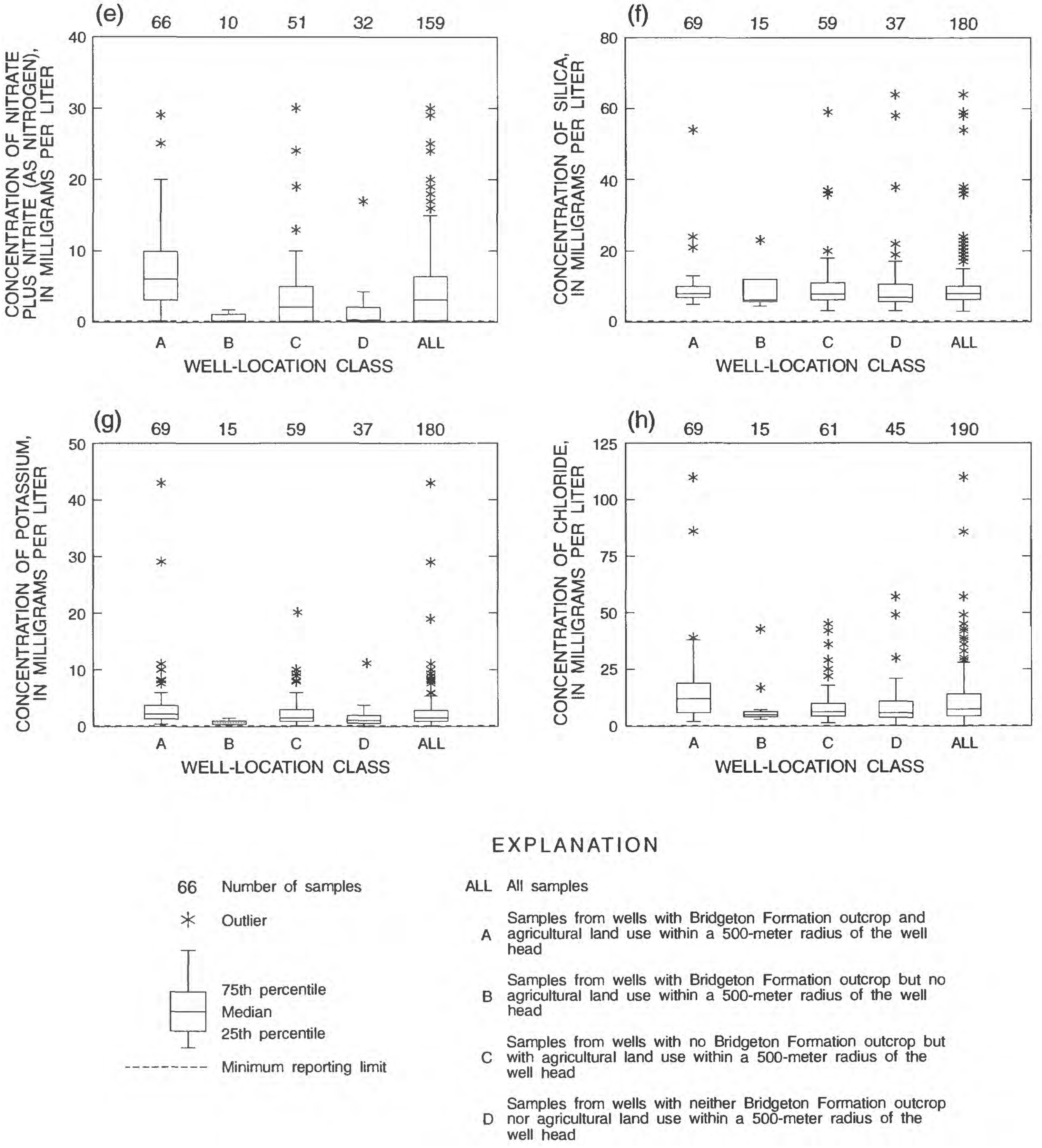


Figure 14. Concentrations of (a) calcium, (b) magnesium, (c) barium, (d) strontium, (e) nitrate plus nitrite (as nitrogen), (f) silica, (g) potassium, (h) chloride, (i) manganese, (j) sulfate, and (k) alkalinity in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89, grouped by presence or absence of Bridgeton Formation outcrop area and agriculutral land within a 500-meter radius of the well head. [Minimum Reporting Limits in milligrams per liter, unless otherwise noted: Calcium, 0.02; Magnesium, 0.01; Barium, 1 microgram per liter; strontium, 1 microgram per liter; nitrate plus nitrite (as nitrogen), 0.10; silica, 0.01; potassium, 0.10; chloride, 0.10; manganese, 1 microgram per liter; sulfate, 0.20; and alkalinity, 1] --Continued

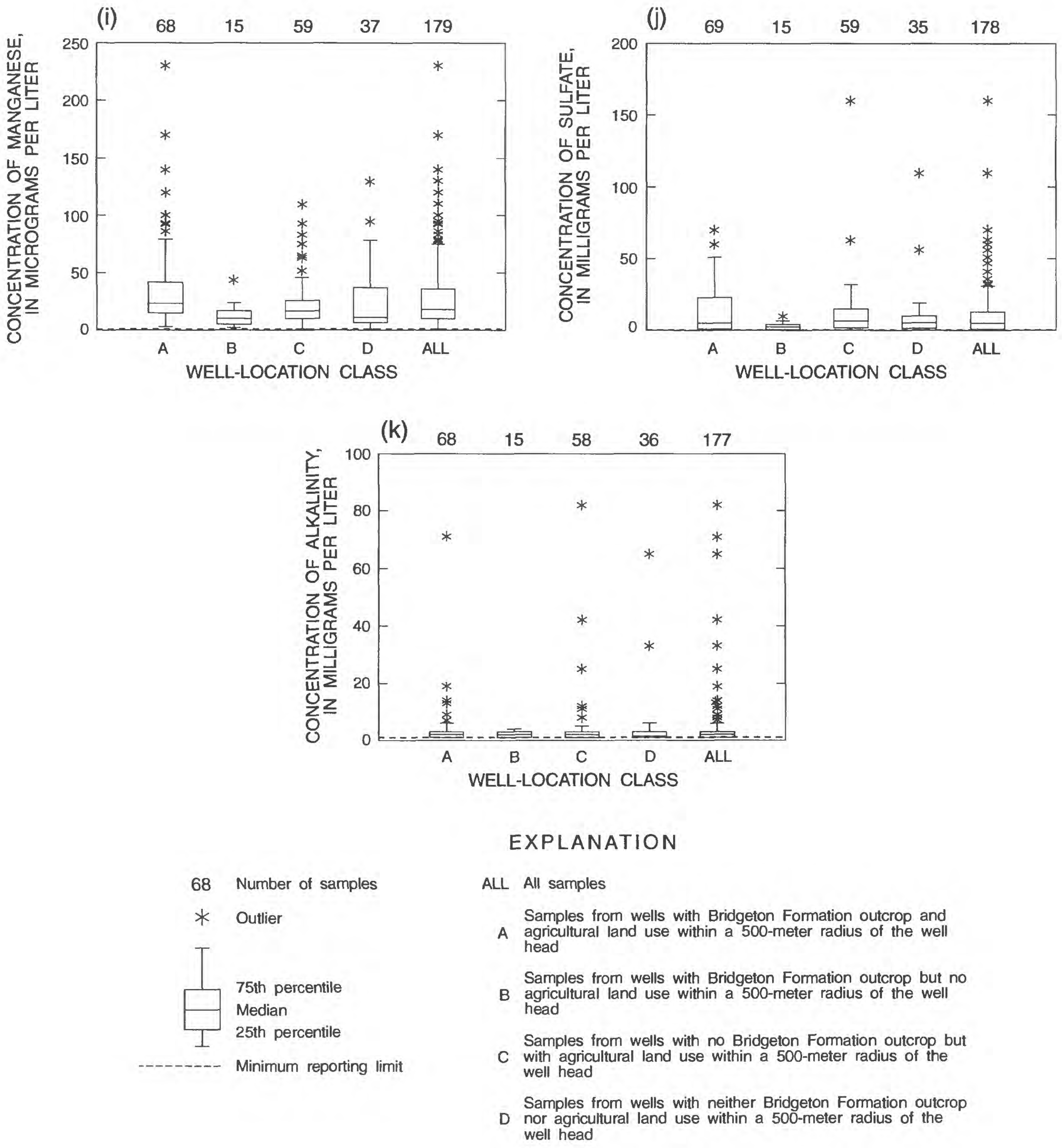


Figure 14. Concentrations of (a) calcium, (b) magnesium, (c) barium, (d) strontium, (e) nitrate plus nitrite (as nitrogen), (f) silica, (g) potassium, (h) chloride, (i) manganese, (j) sulfate, and (k) alkalinity in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89, grouped by presence or absence of Bridgeton Formation outcrop area and agriculutral land within a 500-meter radius of the well head. [Minimum Reporting Limits in milligrams per liter, unless otherwise noted: Calcium, 0.02; Magnesium, 0.01; Barium, 1 microgram per liter; strontium, 1 microgram per liter; nitrate plus nitrite (as nitrogen), 0.10; silica, 0.01; potassium, 0.10; chloride, 0.10; manganese, 1 microgram per liter; sulfate, 0.20; and alkalinity, 1] --Continued

Table 6.--Summary of number of water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89, in which concentrations of inorganic constituents exceeded drinking-water regulations

[mg/L, milligrams per liter; µg/L, micrograms per liter]

Chemical constituent or characteristic	Drinking-water regulations	Number of samples analyzed	Number of samples in which concentration exceeded drinking-water regulation
Nitrate (as N)	10 mg/L (1)	159	22
Iron	300 µg/L (2)	180	36
Manganese	50 µg/L (2)	179	27
Dissolved solids	250 mg/L (2)	93	6

(1) U.S. Primary Drinking-Water Regulation (U.S. Environmental Protection Agency, 1988).

(2) U.S. Secondary Drinking-Water Recommended Limit. (U.S. Environmental Protection Agency, 1979)

Water from the Kirkwood-Cohansey aquifer system generally met the USEPA primary and secondary drinking-water regulations for most of the trace elements. Iron concentrations, however, exceeded the secondary drinking-water regulation of 300 µg/L (U.S. Environmental Protection Agency, 1979a) in 16 of the 81 ground-water samples collected during 1988-89 and in 36 of the 180 samples collected and analyzed for this constituent from the Kirkwood-Cohansey aquifer system in the study area since 1983 (table 6). Manganese concentrations exceeded the secondary drinking-water regulation of 50 µg/L in 8 of the 81 samples and in 27 of the 179 samples collected since 1983 (table 6). The maximum concentrations of iron and manganese measured in the samples collected during 1988-89 were 1,900 and 120 µg/L, respectively. The median concentrations of iron and manganese--56 and 18 µg/L, respectively--are less than the secondary drinking-water regulations (U.S. Environmental Protection Agency, 1979a).

The highest concentration of barium detected in the ground-water samples collected during 1988-89 was 420 µg/L (well 15-0733), with a medium concentration of 71 µg/L, well below the USEPA MCL of 2,000 µg/L (U.S. Environmental Protection Agency, 1991). The median barium concentration in the 127 ground-water samples analyzed for this constituent since 1983 was 72 µg/L. The highest concentration of copper detected in the water samples collected during 1988-89 was 290 µg/L (well 15-0805), also below the USEPA MCL of 1,700 µg/L (U.S. Environmental Protection Agency, 1991). The other frequently detected trace elements, aluminum, strontium, and zinc, are not regulated by Federal drinking-water regulations.

Concentrations of cadmium, lead, molybdenum, and vanadium in the ground-water samples from the Kirkwood-Cohansey aquifer system typically were low (app. 2); more than half the samples contained these constituents in concentrations below their respective reporting limits. Concentrations of cadmium, copper, and mercury did not exceed the USEPA MCLs of 30, 1,700, and 2 µg/L, respectively, in any of the 81 water samples collected from the Kirkwood-Cohansey aquifer system during 1988-89 (U.S. Environmental Protection Agency, 1991). One sample of water exceeded a lead concentration of 50 µg/L (well 15-0754; pH was 4.40), and 9 samples exceeded a concentration of 15 µg/L, the USEPA action level for dissolved lead (U.S. Environmental Protection Agency, 1991). Of these 9 samples, 7 had a pH value below 5.0, and 3 had a pH value below 4.5. Because the solubilities of cadmium, copper, lead, zinc, and mercury increase with decreasing pH, these trace elements were expected to be detected more frequently in ground water with pH less than 5.0. The low pH solubilizes these trace elements in the aquifer, and may also leach them from the well casing or household plumbing (Kish and others, 1987). The expected increased frequency of detection in more acidic water held true only for lead, however. Copper, cadmium, zinc, and mercury were all detected with about equal frequency in water with pH below 5 and pH above 5. Molybdenum and vanadium are relatively insoluble in acidic water. Molybdenum was detected in only one water sample (well 07-0671) collected during 1988-89, whereas vanadium was not detected in any water sample.

Spatial Distributions

The geographic distributions of concentrations of dissolved solids in water from the Kirkwood-Cohansey aquifer system are shown on figure 10; pH and the concentration of dissolved oxygen are shown on figure 11. Generally, water samples from the western part of the study area, where the Bridgeton Formation crops out and agricultural land predominates, were slightly more acidic and more oxygenated, and contained substantially higher concentrations of dissolved solids, than water samples from the eastern part of the study area, where the Bridgeton Formation and agricultural land generally are absent.

Concentrations of dissolved oxygen tended to be low (less than 1.0 mg/L) in samples of water from wells in or near wetland areas. This trend is especially noticable for water samples from wells completed in wetlands along the Egg Harbor River and the Mullica River (fig. 11). Wetlands commonly are zones of ground-water discharge. The ground water in discharge areas tends to be depleted in oxygen compared to ground water from areas of ground-water recharge that receive oxygenated precipitation (Crerar and others, 1979). Low concentrations of dissolved oxygen in ground water from wetland areas may be attributable to oxygen consumption by weathering processes at depth in the aquifer (Crerar and others, 1979) or by the decay of organic material. Organic material is present both near the surface (for example, vegetation), especially in wetlands areas, or in the aquifer in organic-rich layers (Owens and Minard, 1976). Some ground-water samples with low concentrations of dissolved oxygen also may have been from wells screened below local confining clay layers.

The highest concentrations of dissolved oxygen generally were found in water from wells in agricultural areas in the Bridgeton Formation outcrop area. Agricultural land tends to be located in ground-water recharge areas where the soils are well-drained and the ground water is oxygenated.

The highest pH values (greater than 6.00) were measured in water samples from wells 11-0073, 11-0097, and 33-0469 (fig. 11). These wells are located farther south or west than the other wells sampled during 1988-89 in an area where the upper part of the Kirkwood Formation contains carbonate-rich shell layers (Rooney, 1971). The pH of ground water in these wells may be influenced by dissolution of calcium carbonate (calcite or aragonite) in the shell layers. This process produces bicarbonate ions, which neutralize acidity in the ground water, thereby increasing the pH and the alkalinity. Most water samples collected from wells in the Bridgeton Formation outcrop area have a pH less than 5 and are from wells in areas where agricultural land is present (figs. 9-11).

Generally, concentrations of dissolved solids were higher in water samples from wells in and near the outcrop area of the Kirkwood Formation, and in areas where the Bridgeton Formation or agricultural land is present, than in water samples from wells in the outcrop areas of the Cohansey Sand or where agricultural land is absent (figs. 9, 10, and 12). The dissolution of shell material composed of calcium carbonate in the sediments of the Kirkwood Formation could be a natural source of increased dissolved solids concentration in ground water where the Kirkwood Formation crops out (Rooney, 1971). In ground-water samples from the outcrop area of the Bridgeton Formation, the weathering of unstable calcium-, strontium-, barium-, aluminum-, and potassium-bearing minerals in the formation is another possible source of a part of the increase in concentrations of dissolved solids and divalent cations relative to concentrations of these constituents in samples from the area underlain by the Cohansey Sand. The Cohansey Sand has a smaller percentage by weight of unstable (weatherable) minerals such as potassium feldspar and plagioclase than does the Bridgeton Formation (Owens and others, 1983). Finally, in areas of agricultural land, high concentrations of dissolved solids may result from the application of salts, such as sylvite (KCl), as fertilizer.

To determine potential sources of dissolved solids, differences in the major-ion chemistry of water with high concentrations of dissolved solids and water with low concentrations of dissolved solids were examined by comparison of Stiff diagrams (Hem, 1985, p. 175) of ion equivalents for representative ground-water samples from each of the four well-location classes (fig. 15). A representative sample for each of the four classes was defined as the sample with major-ion concentrations that most closely resemble the median concentrations for each of these constituents for each of the four classes (fig. 14; table 5). The ionic composition of water samples from wells 15-1028 and 15-0566 is representative of the ionic composition of ground water from areas where both the Bridgeton Formation outcrop and agricultural land use are present. Two samples were chosen to represent this well-location class because it represents more wells than do the other classes. The ionic composition of the water samples from wells 15-0619, 11-0042, and 01-0794 are, respectively, representative of the ionic composition of ground water from areas where the Bridgeton Formation outcrop is present but agriculture is absent, the Bridgeton Formation outcrop is absent but agriculture is present, and both the Bridgeton Formation outcrop and agriculture are absent.

The ionic composition of precipitation in southern New Jersey is dominated by sodium, chloride, and sulfate (Lord and others, 1990). However, in most water samples from the Kirkwood-Cohansey aquifer system, the predominant cation was either magnesium or calcium, and the predominant anion was either chloride or nitrate (fig. 15). Magnesium and nitrate ions dominated the chemical composition of ground-water samples from wells located in agricultural land-use areas. The major-ion composition of water in the Kirkwood-Cohansey aquifer system is a result of a combination of chemical reactions among precipitation, soil, and aquifer matrix, and leaching of inorganic ions from soil.

The sums of the equivalents of the major ions were much greater in water samples from wells (15-1028 and 15-0566) in the Bridgeton Formation outcrop area where agricultural land is present than in water samples from wells in any of the other three well-location classes (fig. 15). The predominant cations, in order of decreasing relative equivalents, were magnesium, sodium and potassium, and calcium (fig. 15). The predominant anions, in order of decreasing relative equivalents, were nitrate and chloride (fig. 15). The equivalents of magnesium and nitrate ions account for the largest part of the difference in the sum of equivalents between wells in the Bridgeton Formation outcrop area where agricultural land use is present and the other three well-location classes. However, equivalents of chloride, sodium, and potassium, and of calcium were also greater than in the other three well-location classes.

Magnesium and nitrogen are added to soil by the application of liming agents and fertilizer in agricultural areas. The weathering of silicate minerals in the aquifer matrix does not contribute nitrogen to the ground water. In addition, because magnesium-bearing minerals are absent from the

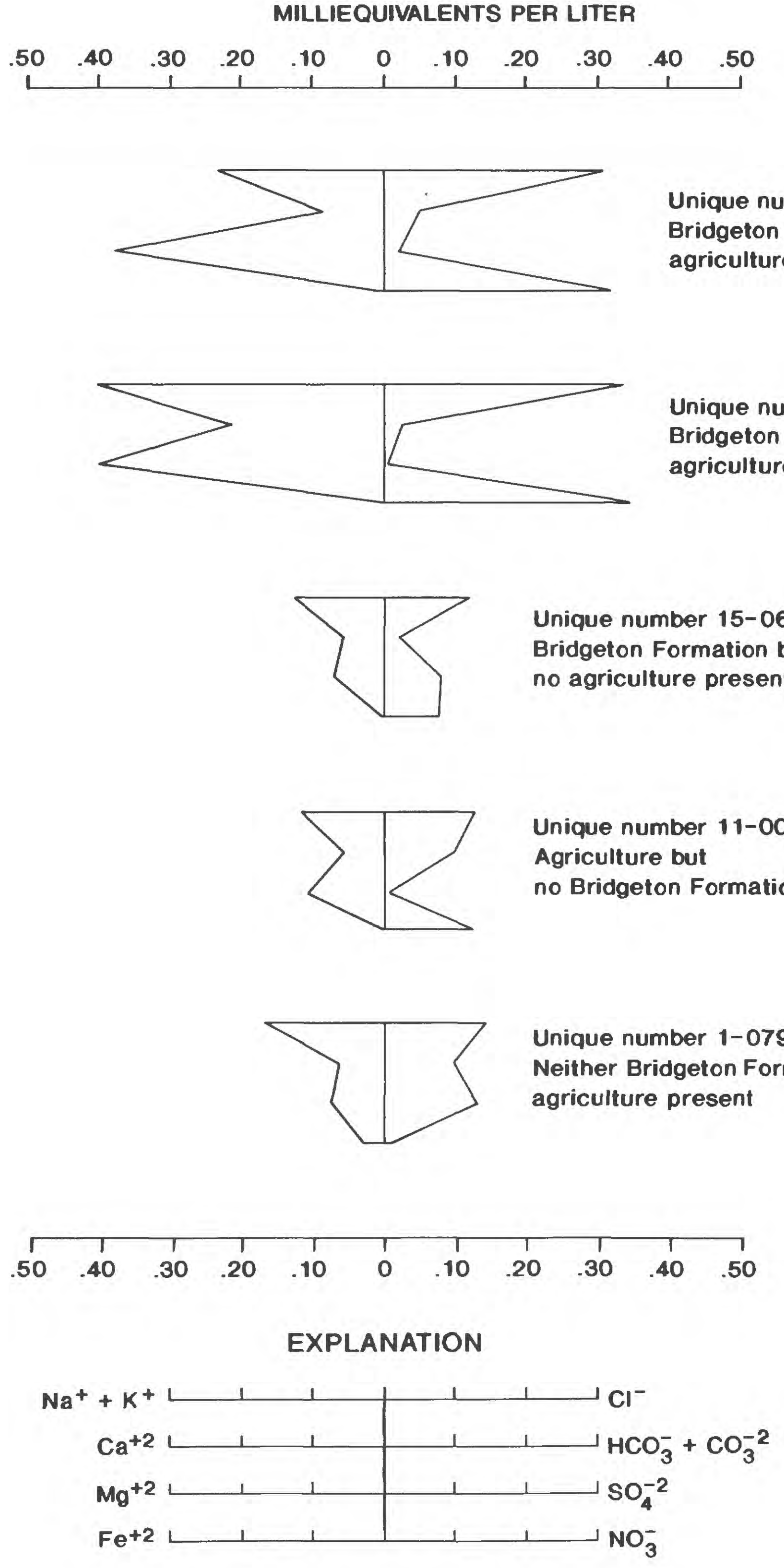


Figure 15. Stiff diagrams showing results of chemical analyses of representative samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89, grouped by presence or absence of Bridgeton Formation outcop area and agricultural land within a 500-meter radius of the well head.

Bridgeton Formation, Cohansey Sand, and generally absent from the Kirkwood Formation (Owens and others, 1983), the relatively elevated concentration of magnesium in areas of agricultural land use strongly indicates leaching of agricultural chemicals from the soil. The Kirkwood Formation contains some carbonate-mineral shell material, which may contain some magnesium. The few wells, however, that may be screened in the Kirkwood Formation are not located in agricultural areas, and the alkalinity of the water withdrawn from these wells is greater than 6 mg/L, in contrast to the low alkalinity of water from wells 15-1028 and 15-0566.

Magnesium and nitrate ions dominated the chemical composition of water samples from wells located in agricultural land-use areas, and the patterns of the relative abundances of equivalents of the major cations and anions are nearly identical regardless of the presence or absence of the Bridgeton Formation. This trend in composition indicates the importance of the effect of agricultural land use on the chemistry of water in the Kirkwood-Cohansey aquifer system. For example, the Stiff diagram for the water sample from well 11-0042 (fig. 15) is representative of the median concentrations of major ions in ground water from areas where agricultural land is present but the Bridgeton Formation is absent. The predominant cations, in order of decreasing relative equivalents per liter, were magnesium, sodium and potassium, and calcium as for wells 15-1028 and 15-0566. The predominant anions, in order of decreasing relative equivalents per liter, were also nitrate, chloride, and bicarbonate. The amount of equivalents is smaller where the Bridgeton Formation is absent (well 11-0042), possibly due to the more intensive application of soil additives where the Bridgeton Formation crops out as opposed to where the Bridgeton Formation is absent, as a result of more intensive agricultural activity.

Sodium and potassium were the dominant cations in this water from well 01-0794, which is located in an area where both agriculture and Bridgeton Formation outcrop are absent (fig. 15), and chloride and sulfate were the dominant anions. The composition of this sample is like the composition of precipitation in southern New Jersey (Lord and others, 1990). The absence of large equivalents of nitrate and magnesium ions in water from well 01-0794 illustrates the large effect that leaching of nitrate and magnesium from the soil has on the composition of ground water from agricultural areas.

The ionic composition of a water sample from well 15-0619 (fig. 15) is representative of the ionic composition of ground water from areas where the Bridgeton Formation crops out but agriculture is absent, and is similar, but not identical, to the ionic composition of samples from areas where neither outcrop of the Bridgeton Formation nor agricultural land is present (well 01-0794) (fig. 15). Sodium and potassium were the dominant cations (although magnesium also was important) and chloride and sulfate were the dominant anions in both samples. However, somewhat more nitrate is present in the water sample from well 15-0619 where the Bridgeton Formation is present than in the water sample from well 01-0794 where the Bridgeton Formation is absent. The overall similarity in ionic composition of ground water from these two well-location classes indicates that in the absence of agricultural practices, weathering of the Bridgeton Formation cannot be the reason for the change in the chemical composition of ground water from a composition approximating that of precipitation (dominated by sodium, potassium, chloride, and sulfate) to being dominated by magnesium and nitrate.

The sums of the equivalents for water samples from wells located in areas where agricultural land is absent (wells 15-0619 and 01-0794) were much lower than the sums of the equivalents for samples from wells located in areas where both agricultural land and the outcrop of the Bridgeton Formation are present (wells 15-1028 and 15-0566). The large difference in the sums of the equivalents between water from wells located in intensively farmed agricultural areas on the Bridgeton Formation outcrop and those located in non-agricultural areas indicates that chemical additives (such as fertilizers, liming agents, and salts) that leach from soils in areas of agricultural land use contribute substantially to the concentrations of inorganic chemical constituents in the water.

The sum of the equivalents of the ions was much lower for the water sample from well 11-0042, which is located in an area in which the Cohansey Sand crops out and agricultural land is present, than for the samples from wells 15-1028 and 15-0566, which are located in areas containing agricultural land and outcrops of the Bridgeton Formation. The relative proportions of nitrate and chloride are not as dominant in the water sample from well 11-0042 as in the water samples from wells 15-1028 and 15-0566 reflecting the fact that the total amounts of nitrate and chloride that leach from the soil to the ground water are less important to the overall water composition in areas of less intense farming where the Cohansey Sand crops out.

The total amount and relative proportion of the bicarbonate anion increased with increasing pH, especially in areas where both the Bridgeton Formation outcrop and agricultural land are absent. Bicarbonate was present in significant amounts in a water sample (well 11-42) that is typical of this well-location class. Bicarbonate was the dominant anion in water from some wells (such as 11-0073, 11-0097, and 33-0469) located in areas where agricultural land is absent.

Statistical Relations Among Concentrations of Radionuclides, Concentrations of Inorganic Chemical Constituents and Chemical Characteristics, Geology, and Agricultural Land Use

Results of the Spearman rank correlation test are presented and indicate strong correlations among radionuclide concentrations, concentrations of inorganic constituents, and chemical characteristics. Results of the Kruskal-Wallis statistical test are presented and confirm that the highest concentrations of these correlated chemical constituents are in water from wells located in areas where the Bridgeton Formation outcrop and agricultural land are present within a 500-m radius of the well head. The correlations indicate that the source of many of the inorganic chemical constituents in the water is most likely agricultural inputs.

Correlations Between Concentrations and Activities of Radionuclides

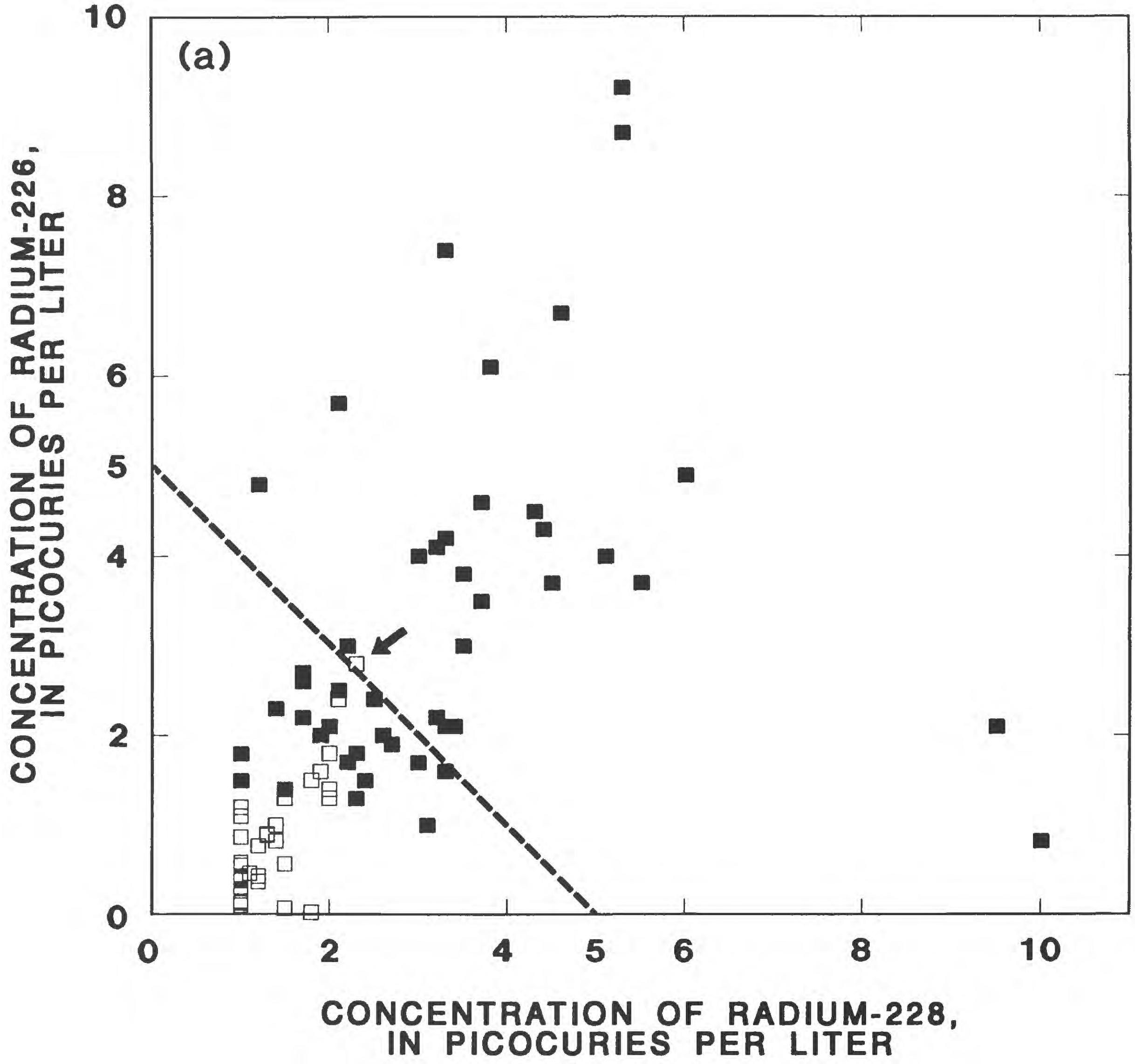
Gross beta-particle activity correlates strongly to gross alpha-particle activity (correlation coefficient, +0.83). This correlation is to be expected, especially when naturally occurring sedimentary materials are the source of the radioactivity, because uranium, thorium, and their progeny are all present in the ground water. The radioactive decay of both uranium and thorium produce numerous progeny, some of which are alpha-particle emitters, and some of which are beta-particle emitters.

Concentrations of radium-226 and radium-228 are strongly correlated (correlation coefficient = +0.75) (fig. 16a, table 7). The median ratio of radium-228 concentration to radium-226 concentration (1.2) indicates that radium-228 concentrations are generally slightly higher than radium-226 concentrations. In half of the ground-water samples, the ratio of radium-228 concentration to radium-226 concentration ranges only from 0.8 to 1.9, indicating that the aquifer material is not enriched in uranium-238 (the radioactive parent of radium-226) relative to thorium-238 (the radioactive parent of radium-228).

The correlation between radium-226 concentration and gross alpha-particle activity is expected to be stronger than that between radium-228 concentration and gross alpha-particle activity because radium-226 is an alpha-emitting radionuclide and radium-228 is a beta-particle emitting radionuclide. However, the strong positive correlation between the concentrations of radium-226 and radium-228 results in nearly identical correlations between radium-226 concentration and gross alpha-particle activity (correlation coefficient = +0.88) and between radium-228 concentration and gross alpha-particle activity (correlation coefficient = +0.84) (table 7). The correlation between the concentrations of radium-226 and radium-228 also results in a strong positive correlation between the sum of radium-226 and radium-228 concentrations and gross alpha-particle activity (fig. 16b, table 7).

The correlation between radium-228 concentration and gross beta-particle activity is expected to be stronger than that between radium-226 and gross beta-particle activity because radium-228 is a beta-emitting radionuclide, whereas radium-226 is an alpha-particle emitter. The correlation coefficients for the relations of radium-226 concentration and radium-228 concentration to gross beta-particle activity are +0.79 and +0.88, respectively (table 7).

The correlation between the dissolved concentrations of radium-226 and radon-222 (fig. 16c; correlation coefficient = +0.36) is statistically significant, but not strong. As an example of the divergence between the dissolved concentrations of these two radionuclides, we note that only one of 18 samples that contained a concentration of radium-226 greater than 3 pCi/L was from the area where the Bridgeton Formation outcrop was absent, whereas 2 of the 3 samples that contained a concentration of radon-222 greater than 1,000 pCi/L were from this area (fig. 16c). The weak, positive correlation, however, does indicate that to some degree the concentration of radium-226 in the ground water increases with the radium-226 (and uranium) content of the aquifer material, which is typically proportional to the concentration of the dissolved radon-222 (Andrews and Wood, 1972). The small correlation coefficient, however, when compared to the coefficient for the correlation between radium-226 and radium-228 indicates that the dissolved concentration of chemically reactive radium-226 has more affinity with the dissolved concentration of chemically similar radium-228 than with the uranium content of the aquifer material. The strong correlation between the dissolved concentrations of radium-226 and radium-228 indicates that these two radionuclides have been mobilized by the geochemical conditions in the aquifer. The correlation of high dissolved concentrations of radium-226 and radium-228 with certain geographical areas, most specifically with the outcrop area of the Bridgeton Formation, indicates relatively high radium mobilization from select strata, possibly in the Bridgeton Formation, that contains uranium and thorium.



EXPLANATION

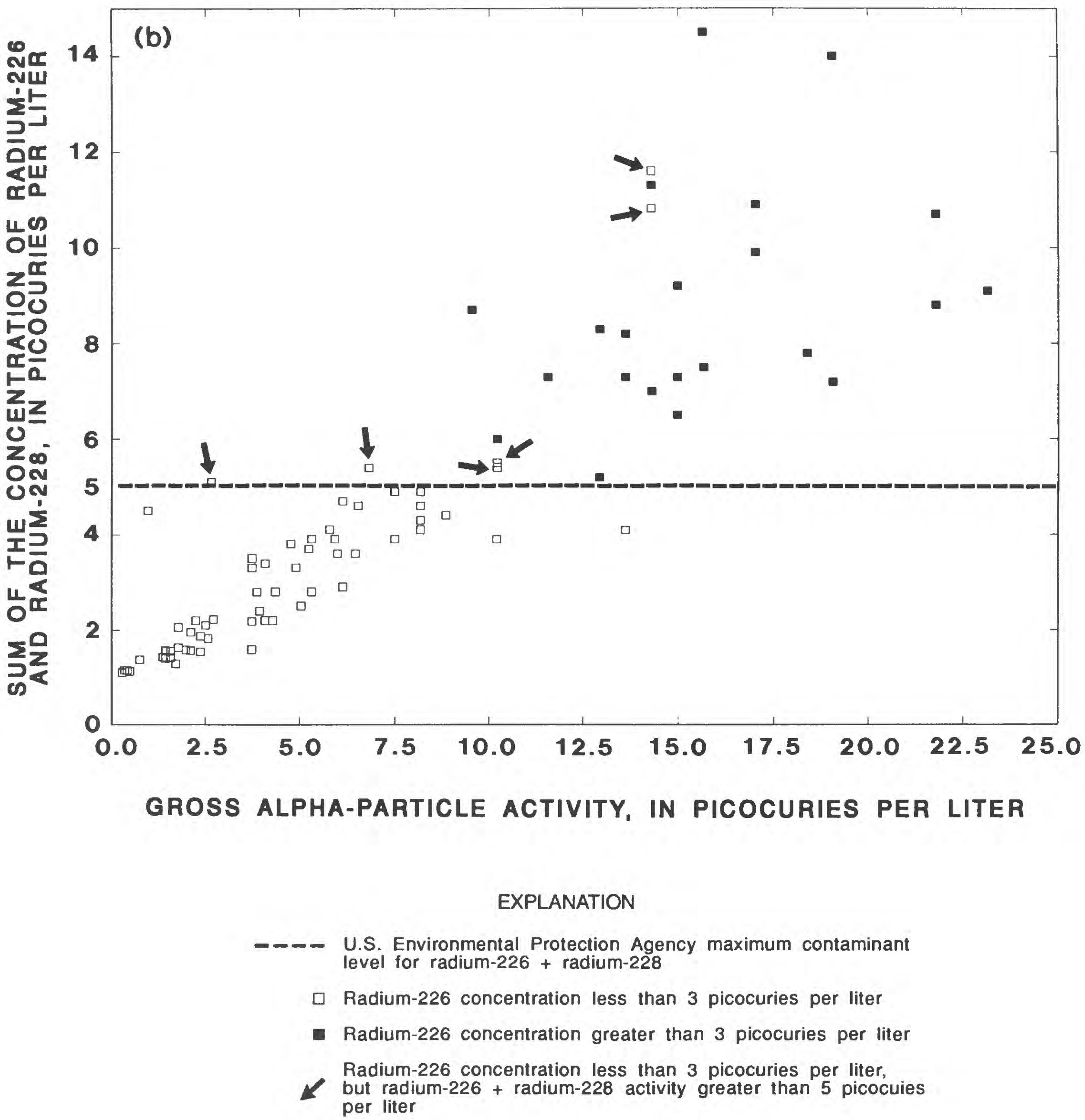
- - - - U.S. Environmental Protection Agency maximum contaminant level for radium-226 + radium-228

☐ Gross alpha-particle activity less than 5 picocuries per liter

■ Gross alpha-particle activity greater than 5 picocuries per liter

↙ Gross alpha-particle activity less than 5 picocuries per liter, but radium-226 + radium-228 concentration greater than 5 picocuies per liter

Figure 16. (a) Concentration of radium-226 as a function of the concentration of radium-228, (b) the sum of the concentrations of radium-226 and radium-228 as a function of gross alpha-particle activity, (c) concentration of radium-226 as a function of the concentration of radon-222, and (d) concentration of radium-226 as a function of the concentration of uranium in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.



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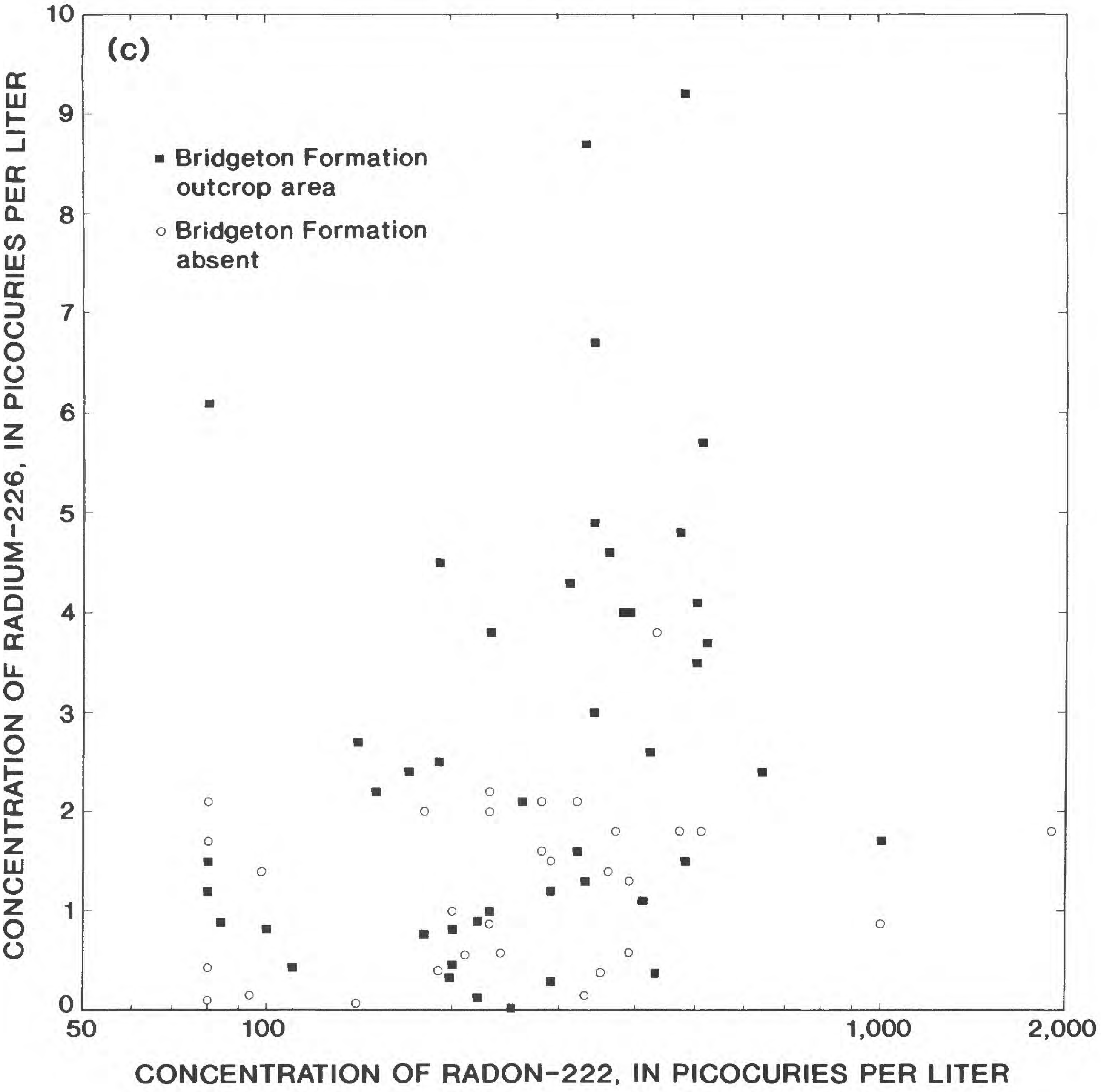

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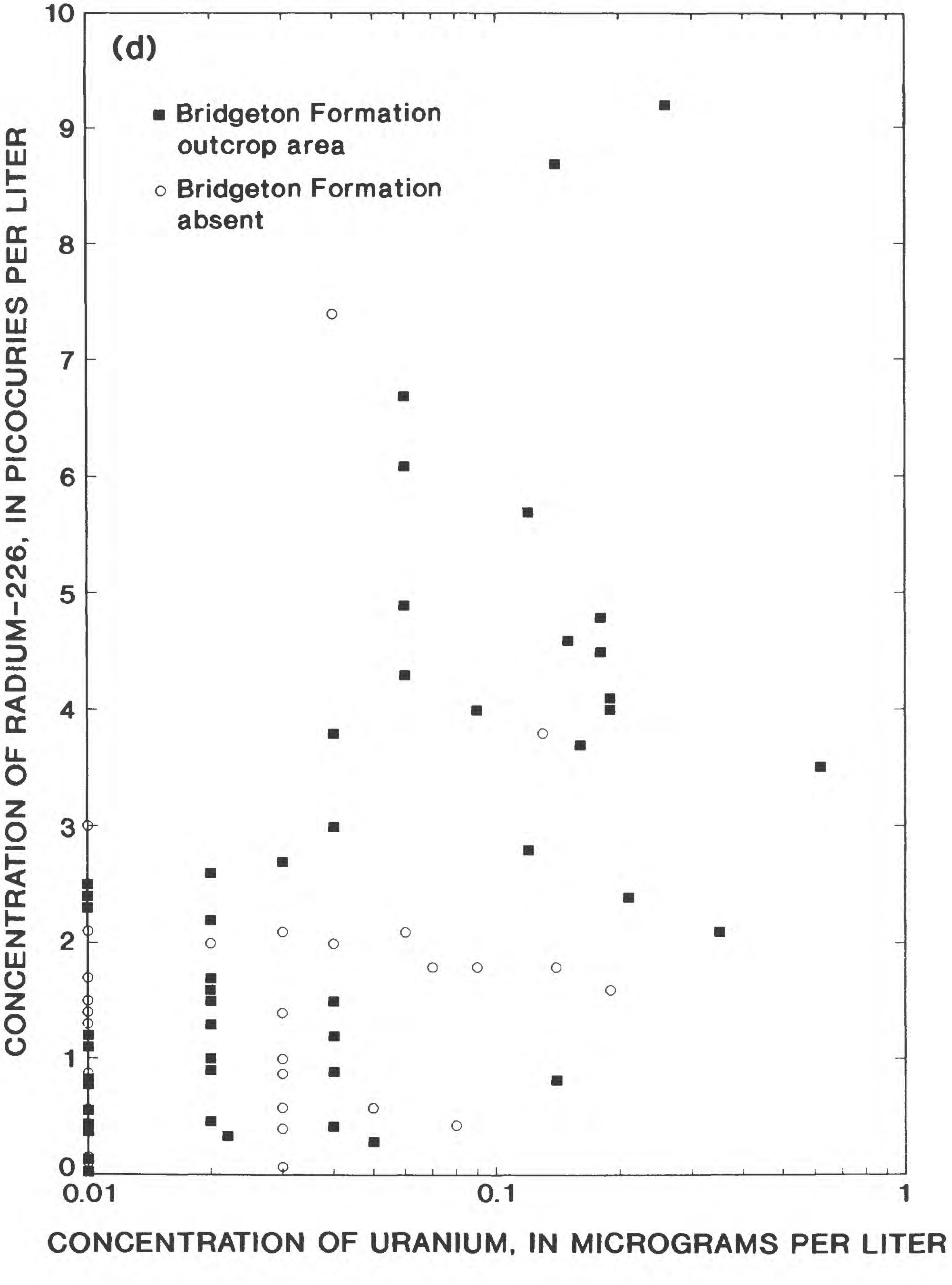


Figure 16. (a) Concentration of radium-226 as a function of the concentration of radium-228, (b) the sum of the concentrations of radium-226 and radium-228 as a function of gross alpha-particle activity, (c) concentration of radium-226 as a function of the concentration of radon-222, and (d) concentration of radium-226 as a function of the concentration of uranium in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

Table 7.--Spearman rank correlation coefficients for relations of concentration of uranium, radium-226, radium-228, sum of radium-226 plus radium-228, nitrate plus nitrite (as nitrogen), barium, magnesium, and dissolved solids to concentrations or activities of other inorganic chemical constituents and radionuclides in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89

[All correlation coefficients listed are significant at the 95-percent conficence level; --, indicates the correlation coefficient is non-significant at the 95-percent confidence level]

Chemical constituent or characteristic	Uranium correlation coefficients	Sum of radium-226 + radium-228 correlation coefficients	Radium-226 correlation coefficients	Radium-228 correlation coefficients	Nitrate + nitrite (as nitrogen) correlation) coefficients	Barium correlation coefficients	Magnesium correlation coefficients	Dissolved solids correlation coefficients
Radionuclides								
Gross alpha-particle activity	+0.46	+0.93	+0.88	+0.84	+0.67	+0.60	+0.60	+0.43
Gross beta-particle activity	+.49	+.90	+.79	+.88	+.75	+.69	+.73	+.66
Radium-226	+.57	+.92	+1.00	+.75	+.65	+.66	+.64	+.45
Radium-228	+.41	+.91	+.75	+1.00	+.69	+.66	+.66	+.54
Radon-222	+.38	+.25	+.36	--	--	--	+.25	--
Uranium	+1.00	+.49	+.57	+.41	+.39	+.43	+.42	+.33
Inorganics chemical constituents and characteristics								
Alkalinity (laboratory)	-.29	-.34	-.38	-.35	--	-.28	--	--
Aluminum	+.58	+.50	+.52	+.48	+.38	+.42	+.39	--
Barium	+.46	+.69	+.64	+.64	+.83	+1.00	+.86	+.53
Calcium	+.27	+.46	+.41	+.46	+.56	+.50	+.75	+.85
Chloride	+.46	+.67	+.60	+.67	+.70	+.73	+.83	+.74
Iron	--	-.25	-.26	--	-.44	-.35	-.29	--
Magnesium	+.42	+.69	+.64	+.65	+.83	+.86	+1.00	+.74
Manganese	+.43	+.49	+.48	+.45	+.52	+.61	+.61	+.65
Nitrate + nitrite (as nitrogen)	+.40	+.73	+.65	+.69	+1.00	+.83	+.83	+.63
Potassium	+.35	+.65	+.54	+.66	+.66	+.64	+.70	+.78
Sodium	+.23	+.48	+.42	+.44	+.47	+.40	+.43	+.49
Strontium	+.26	+.48	+.46	+.45	+.61	+.61	+.82	+.83
Sulfate	+.30	--	--	--	--	--	+.29	+.61
Dissolved solids	+.34	+.54	+.47	+.55	+.63	+.53	+.74	+1.00
pH	-.35	-.40	-.44	-.39	-.31	-.37	-.25	--

The correlation between dissolved concentrations of radium-228 and radon-222 concentration is not significant at the 95-percent confidence level (table 7). If the correlation between dissolved concentrations of radium-226 and radium-228 were solely attributable to possible correlation of the uranium and thorium content of the aquifer matrix, then a weak correlation between dissolved radium-228 and radon-222 concentrations should have been observed, as was the case for the dissolved concentrations of radon-222 and radium-226. In many samples, relatively elevated concentrations of dissolved radium-226 and radium-228 are not accompanied by relatively elevated concentrations of radon-222.

The correlation between the concentrations of radium-226 and uranium in water samples from the Kirkwood-Cohansey aquifer system is stronger (correlation coefficient = +0.57) (fig. 16d) than the correlation between the concentrations of radium-228 and uranium (correlation coefficient = +0.41) (table 7). These relations are expected because radium-226 is a radioactive-decay product of uranium, whereas radium-228 is a decay product of thorium. Because the activity of radium-226 exceeded that of uranium by one to two orders of magnitude, the radium-226 in the ground water must be derived primarily from the radioactive decay of uranium in the aquifer matrix rather than from uranium in solution. Uranium and radium generally, are mobilized under different geochemical conditions (Zapecza and Szabo, 1988), but the correlation between the two indicates that both are being leached simultaneously, albeit in different amounts, from the sediment.

In water from the Kirkwood-Cohansey aquifer system, a gross alpha-particle activity greater than 5 pCi/L appears to be a good indicator that the concentration of total radium exceeds the MCL. As mentioned previously, public-supply wells that yield ground water with gross alpha-particle activity greater than 5 pCi/L must be tested for radium-226 concentration (U.S. Environmental Protection Agency, 1988). Water-quality data for the 81 wells sampled in this study indicate that, for the Kirkwood-Cohansey aquifer system, the gross alpha-particle activity guideline of 5 pCi/L ensured the identification of almost all samples in which the USEPA drinking-water regulation for total radium in ground water was exceeded. In figure 16a, the diagonal line that intercepts both the axes at 5 pCi/L represents the USEPA MCL of 5 pCi/L for total radium; all points to the right of this line represent samples in which the MCL was exceeded. With the exception of one water sample (from well 15-1028), all water samples with concentrations of total radium greater than the MCL of 5 pCi/L also had gross alpha-particle activities greater than 5 pCi/L. The gross alpha-particle activity of the one water sample that did not fit this pattern was 4.9 pCi/L.

Analysis of water samples from the Kirkwood-Cohansey aquifer system for radium-228 would be necessary to determine whether the concentration of total radium exceeded the USEPA drinking-water regulation. Public-supply wells that contain ground water in which the concentration of radium-226 exceeds 3 pCi/L must be tested for radium-228 (U.S. Environmental Protection Agency, 1988). Water-quality data from this study indicate that, for the Kirkwood-Cohansey aquifer system, this guideline did not ensure the identification of all water samples in which the USEPA drinking-water regulation for total radium in ground water was exceeded. In figure 16b, the horizontal line that intercepts the y-axis at a concentration of 5 pCi/L represents the USEPA MCL of 5 pCi/L for total radium; all points above this represent samples in which the MCL was exceeded. Six water samples (from wells 11-0003, 11-0254, 11-0262, 15-0735, 15-1019, and 15-1028) in which the total radium concentration exceeded the drinking-water regulation of 5 pCi/L contained radium-226 in concentrations less than 3 pCi/L (fig. 16b).

Because the USEPA testing protocol for total radium requires analysis for radium-228 only if the radium-226 concentration exceeds 3 pCi/L, the protocol may be inadequate to identify water with a total radium concentration greater than 5 pCi/L in the Kirkwood-Cohansey aquifer system. Data from the Coastal Plain of the southeastern United States indicate that analysis of ground-water samples for radium-228 only when the concentration of radium-226 exceeds 3 pCi/L can result in a failure to detect numerous samples with a total radium concentration greater than the USEPA MCL of 5 pCi/L (Michel and Moore, 1980). In the current study, the six samples from the Kirkwood-Cohansey aquifer system that would not have been recognized as containing total radium in concentrations exceeding the MCL represent 23 percent of the samples in which this regulation was exceeded. Although the ratio of the concentration of radium-226 to the concentration of radium-228 was about 1 for most samples, it deviated from this value in eight samples (nearly 10 percent of the total number of samples collected). Therefore, samples of water from the Kirkwood-Cohansey aquifer system that contain radium-226 in concentrations of less than 3 pCi/L can exceed the USEPA MCL for the concentration of total radium in a significant number of cases.

Correlations Between Concentrations of Inorganic Chemical Constituents and Chemical Characteristics

Results of the Spearman rank correlation test on the results of chemical analyses of samples collected from the Kirkwood-Cohansey aquifer system in 1988-89 indicate that concentrations of most of the inorganic chemical constituents in these samples correlate with each other and with the concentration of dissolved solids. In general, concentrations of nitrate and magnesium tend to correlate with concentrations of most other inorganic constituents.

Concentrations of nitrate correlate strongly with concentrations of many of the inorganic chemical and radioactive constituents determined in the ground-water samples. Increasing nitrate concentrations are highly correlated with increasing concentrations of dissolved solids (fig. 17a). Concentrations of the divalent cations barium, magnesium, calcium, and strontium also positively correlate with concentrations of nitrate (table 7) and dissolved solids.

Nitrate concentrations and pH are inversely related (fig. 17b). The concentration of alkalinity (as $CaCO_3$) correlates positively with pH, as would be expected especially in dilute acidic water undersaturated with carbonate minerals. Therefore, opposing trends can be discerned for nitrate and alkalinity relative to the pH of the water (fig. 17b). Ground-water samples with high nitrate concentrations tended to have pH values below the median of 4.8, and concentrations of alkalinity of 1 or 2 mg/L. Ground-water samples with low nitrate concentrations tended to have pH values above the median of 4.8 and concentrations of alkalinity of 2 mg/L or greater.

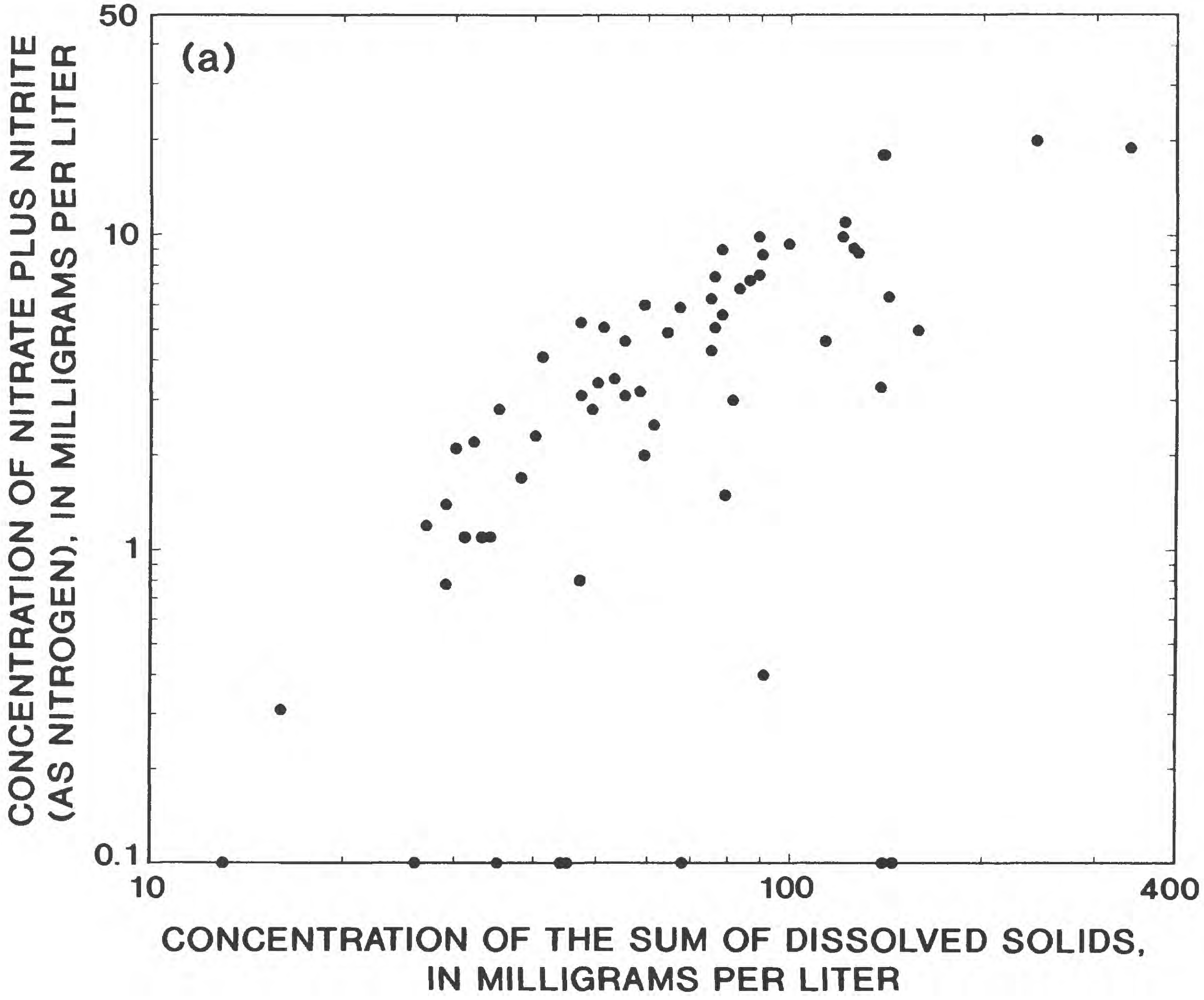


Figure 17. Relation of the concentration of nitrate plus nitrite (as nitrogen) to (a) the concentration of the sum of dissolved solids; (b) the pH, with concentrations of alkalinity (as calcium carbonate) also indicated; and (c) the concentration of potassium in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.

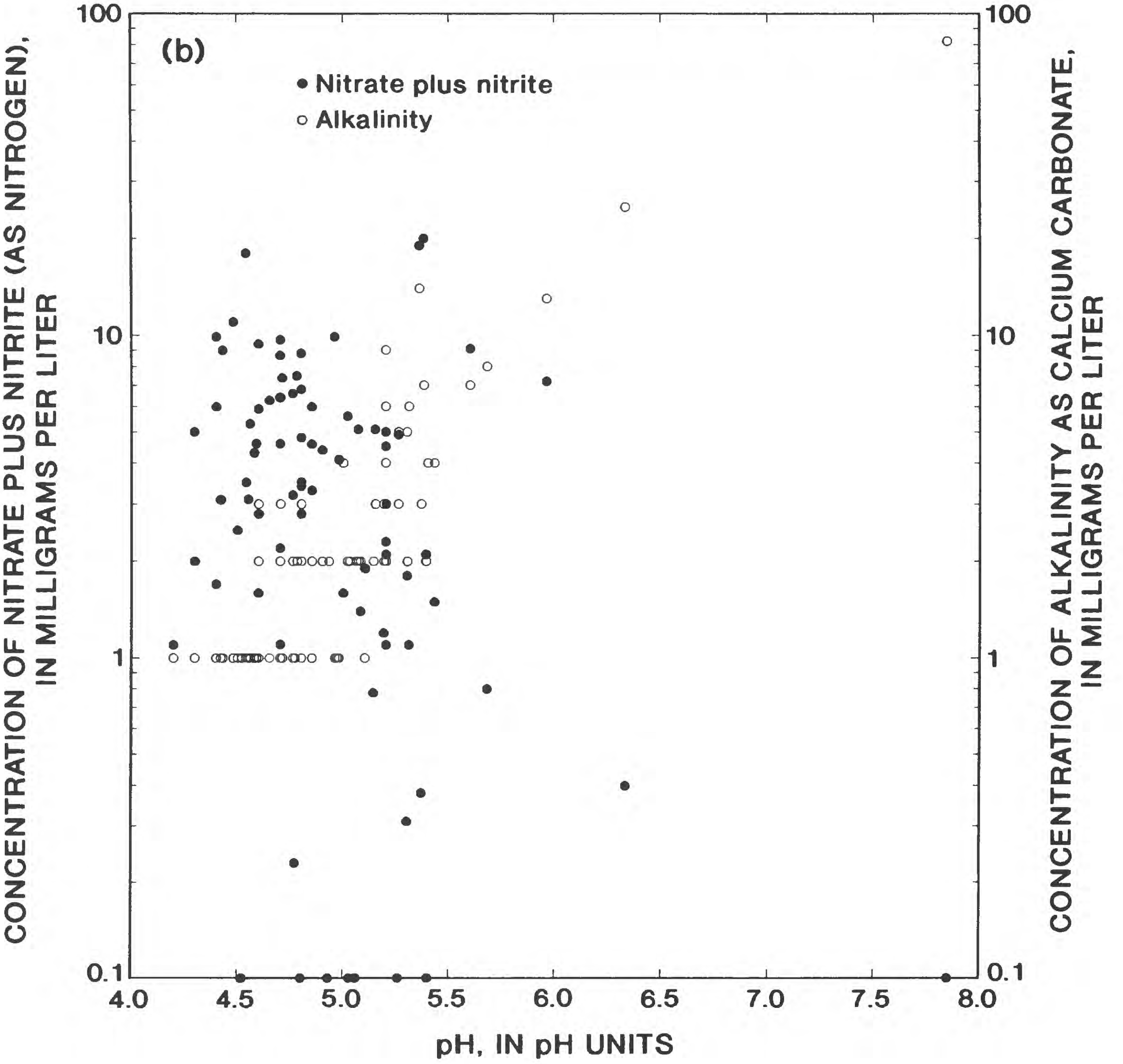


Figure 17. Relation of the concentration of nitrate plus nitrite (as nitrogen) to (a) the concentration of the sum of dissolved solids; (b) the pH, with concentrations of alkalinity (as calcium carbonate) also indicated; and (c) the concentration of potassium in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

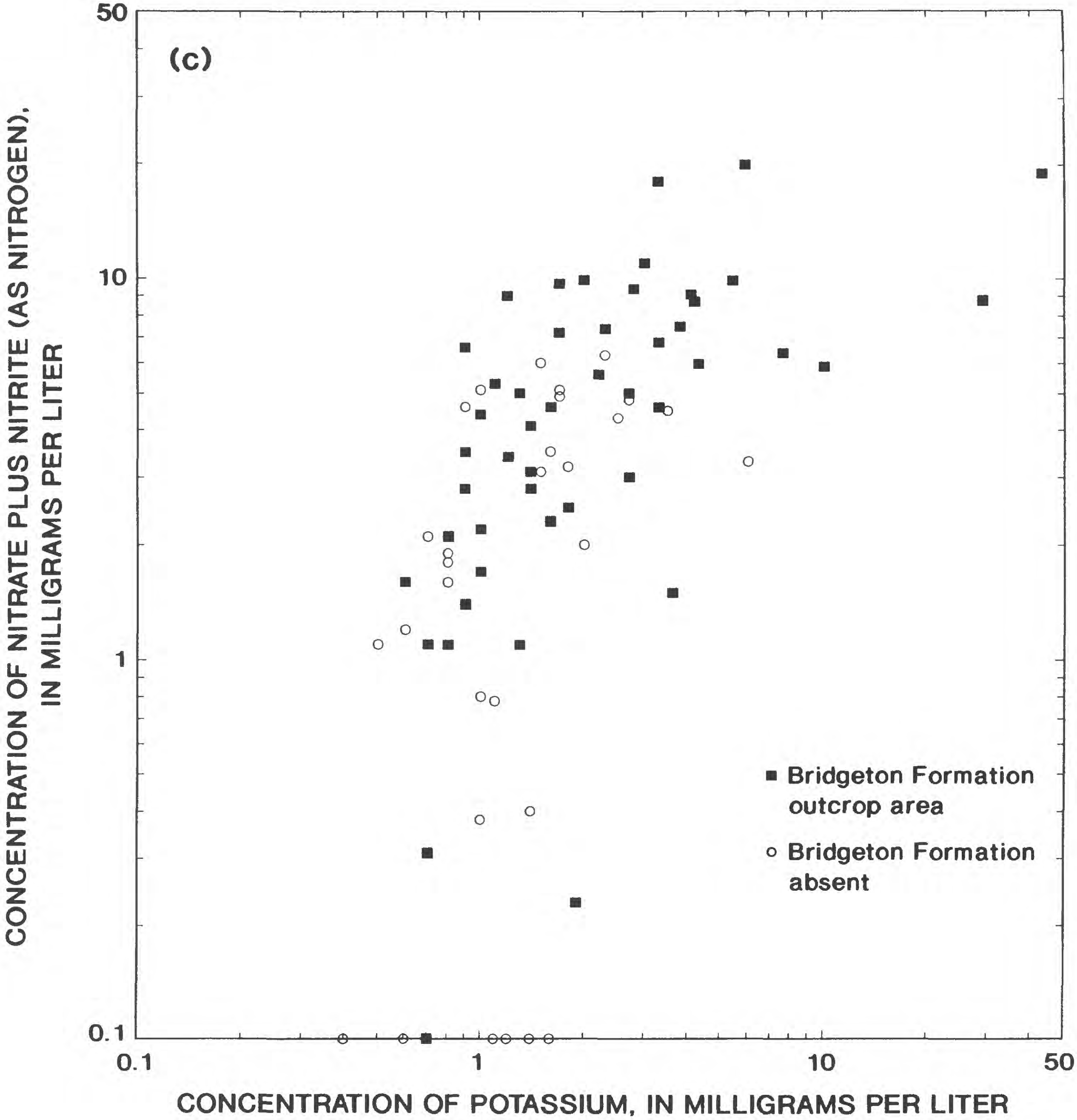


Figure 17. Relation of the concentration of nitrate plus nitrite (as nitrogen) to (a) the concentration of the sum of dissolved solids; (b) the pH, with concentrations of alkalinity (as calcium carbonate) also indicated; and (c) the concentration of potassium in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

Nitrate concentrations correlate positively with concentrations of potassium (fig. 17c) and chloride (table 7), both of which may be derived from agricultural additives. However, aluminum concentration also increases with increasing concentrations of nitrate (table 7). The source of aluminum is likely the aquifer itself, not agricultural additives, as is the likely case for nitrate, potassium, chloride, or magnesium. The inverse correlation of nitrate concentration with pH may explain the positive correlation of nitrate with some constituents, such as aluminum and manganese (table 7), that are probably derived from the aquifer, and are soluble in acidic water. Concentrations of the divalent cations barium, and magnesium also are inversely related to pH (table 7) (as are those of strontium and calcium).

Concentrations of nitrate decrease with increasing concentrations of iron (correlation coefficient = -0.44) (table 7). The likely reason for this inverse correlation is that iron-rich, oxygen-poor water was generally found predominately in areas of wetlands where intensive agricultural land use is generally absent. Water samples with elevated concentrations of iron generally have low concentrations of dissolved oxygen (app. 2). Concentrations of other constituents likely to be derived from soil additives in agricultural areas, such as magnesium, also decrease with increasing concentrations of iron (correlation coefficient = -0.29).

Concentrations of magnesium and barium were highest in ground water that also contained the highest concentrations of dissolved solids (fig. 18a). A similar positive correlation of concentrations of calcium and strontium with concentrations of dissolved solids was also noted (table 7). Concentrations of strontium correlate strongly with those of barium (fig. 18b), calcium (fig. 18b), and magnesium (table 7). Similarly, concentrations of barium correlate strongly with those of calcium and magnesium (table 7).

Concentrations of manganese correlate positively with concentrations of barium (correlation coefficient = +0.61) (fig. 18c), strontium, magnesium (correlation coefficient = +0.61), calcium (correlation coefficient = +0.57), and nitrate (correlation coefficient = +0.52) (table 7). The likely reason for these correlations with manganese is that all these constituents are present in high concentrations in acidic (low pH) waters (table 7), in which manganese concentration is also high because it tends to be highly soluble in acidic environments (Hem, 1985).

Sulfate concentrations in the ground water increase with increasing dissolved-solids concentrations (correlation coefficient = +0.61; table 7); this relation holds whether or not nitrate concentrations increase. Concentrations of sulfate also positively correlate slightly with magnesium (correlation coefficient = +0.29; table 7).

The correlations between concentrations of nitrate and concentrations of dissolved solids, divalent cations (especially barium and magnesium), and potassium and chloride indicate that the elevated concentrations of these divalent cations may be due to a process responsible for producing high concentrations of nitrate in areas of agricultural land use, rather than to weathering of silicate minerals in the aquifer matrix. If weathering of silicate minerals, such as feldspars, were the source of the elevated divalent cation concentrations, pH would be expected to increase with increasing concentrations of these constituents (Krauskopf, 1979, p. 92).

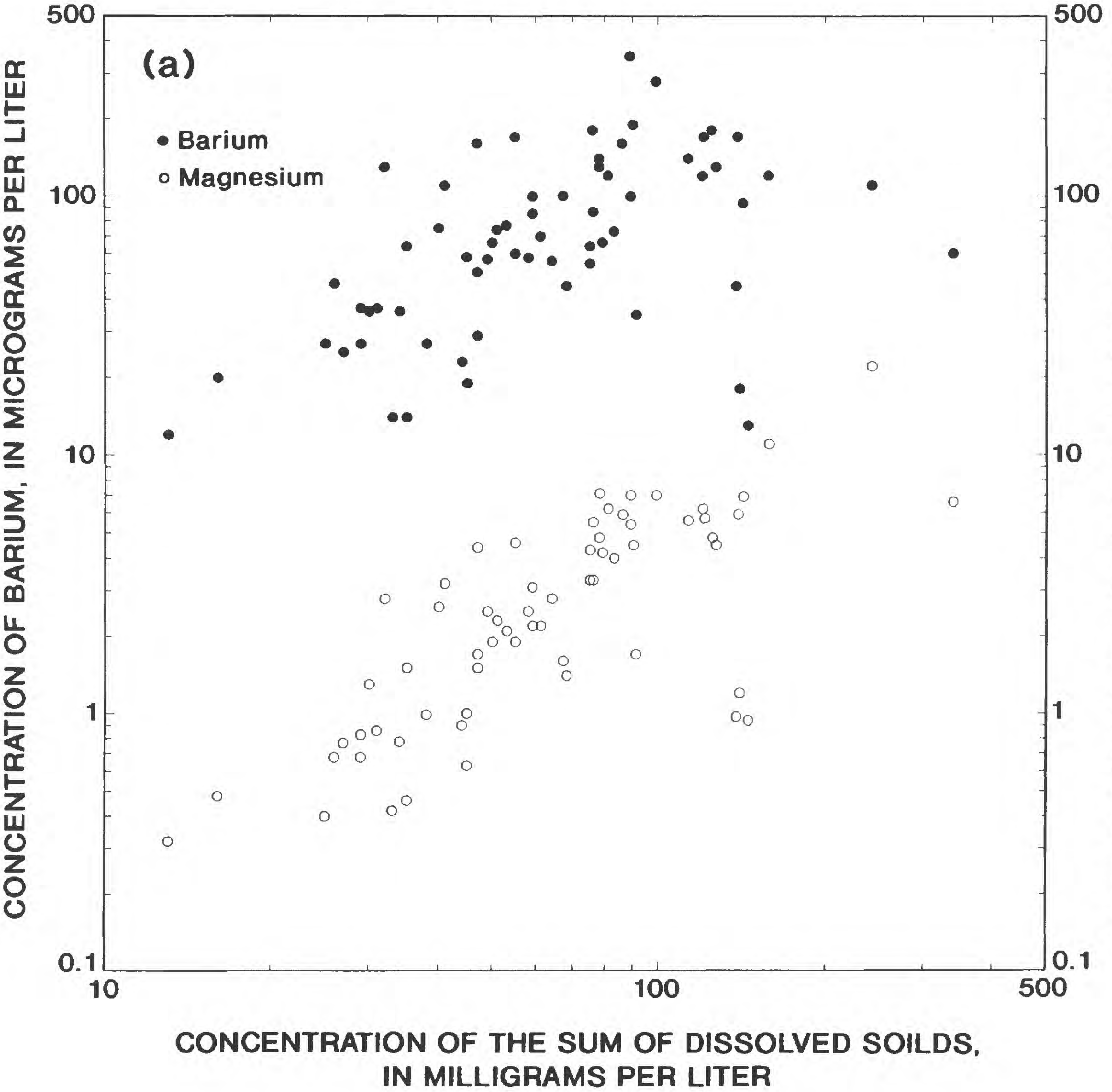


Figure 18. Relation of the concentration of barium to (a) the concentration of the sum of dissolved solids, with concentrations of magnesium also indicated; (b) the concentration of strontium, with concentrations of calcium also indicated; (c) the concentration of manganese; (d) the pH; and (e) the relation of the concentration of aluminum to pH in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.

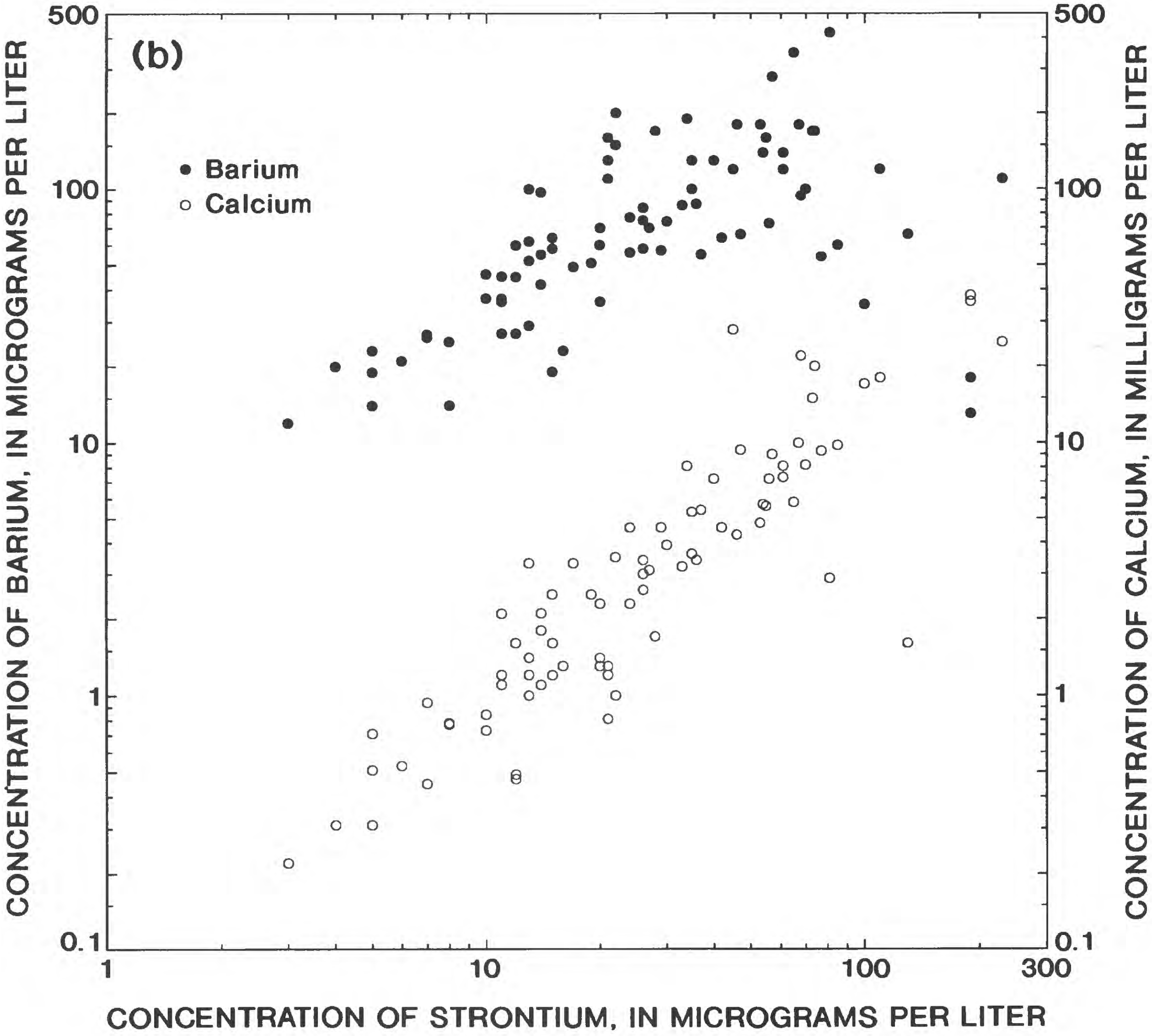


Figure 18. Relation of the concentration of barium to (a) the concentration of the sum of dissolved solids, with concentrations of magnesium also indicated; (b) the concentration of strontium, with concentrations of calcium also indicated; (c) the concentration of manganese; (d) the pH; and (e) the relation of the concentration of aluminum to pH in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

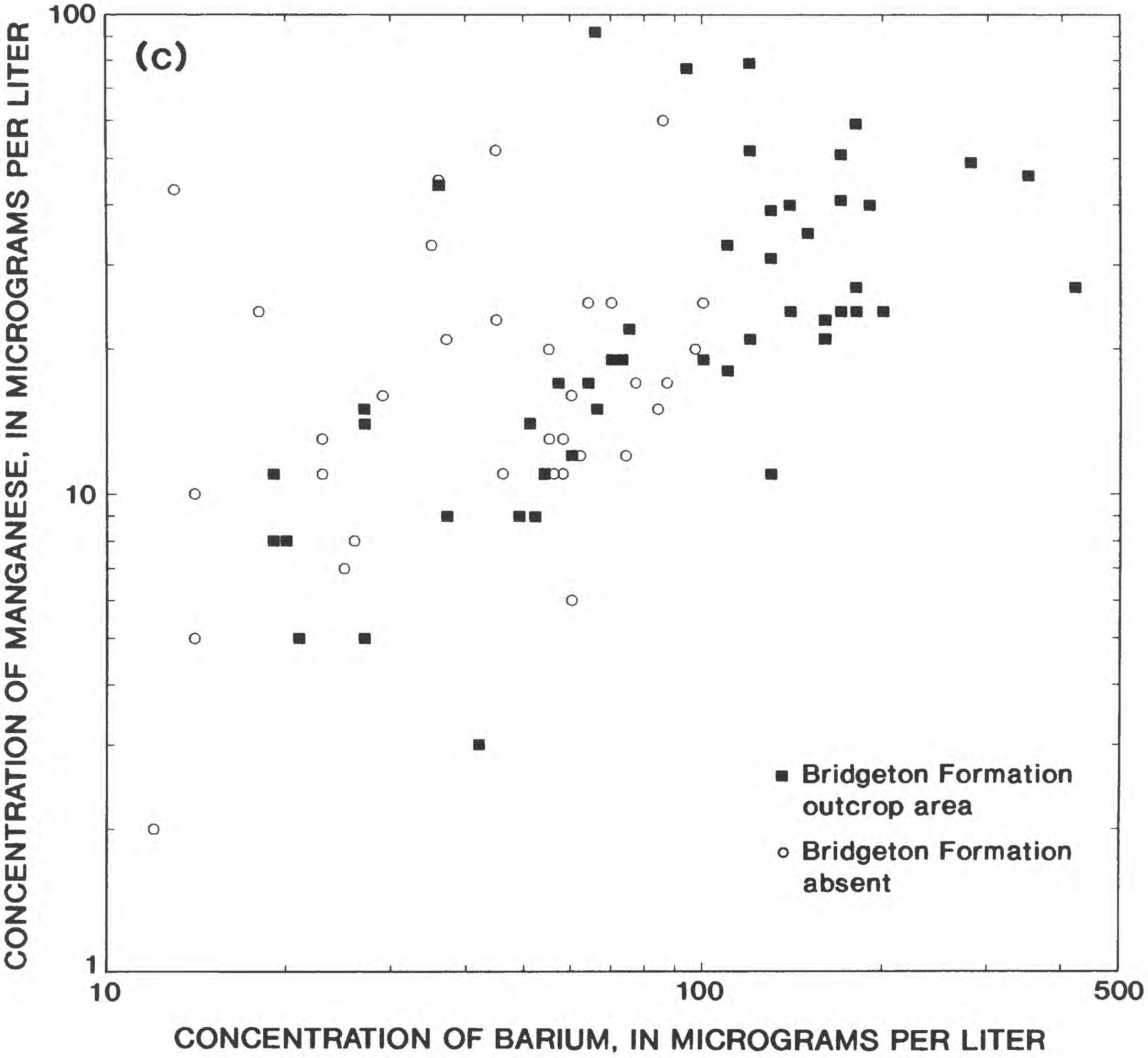
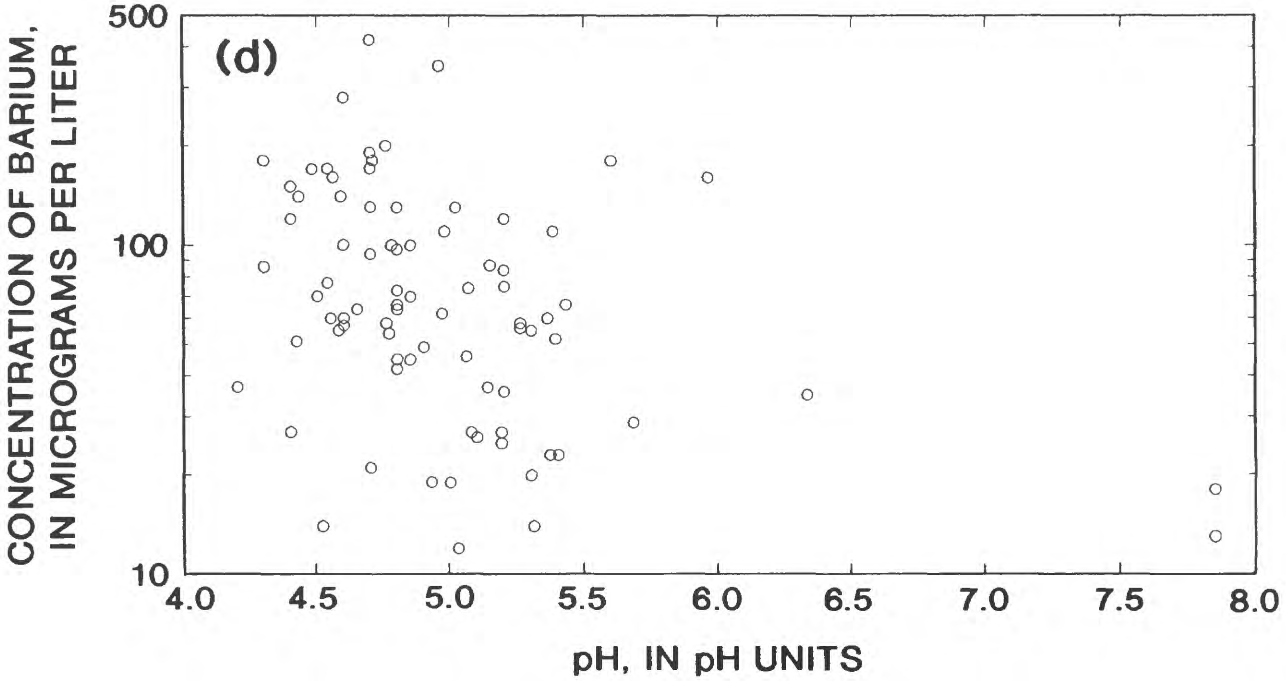


Figure 18. Relation of the concentration of barium to (a) the concentration of the sum of dissolved solids, with concentrations of magnesium also indicated; (b) the concentration of strontium, with concentrations of calcium also indicated; (c) the concentration of manganese; (d) the pH; and (e) the relation of the concentration of aluminum to pH in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued



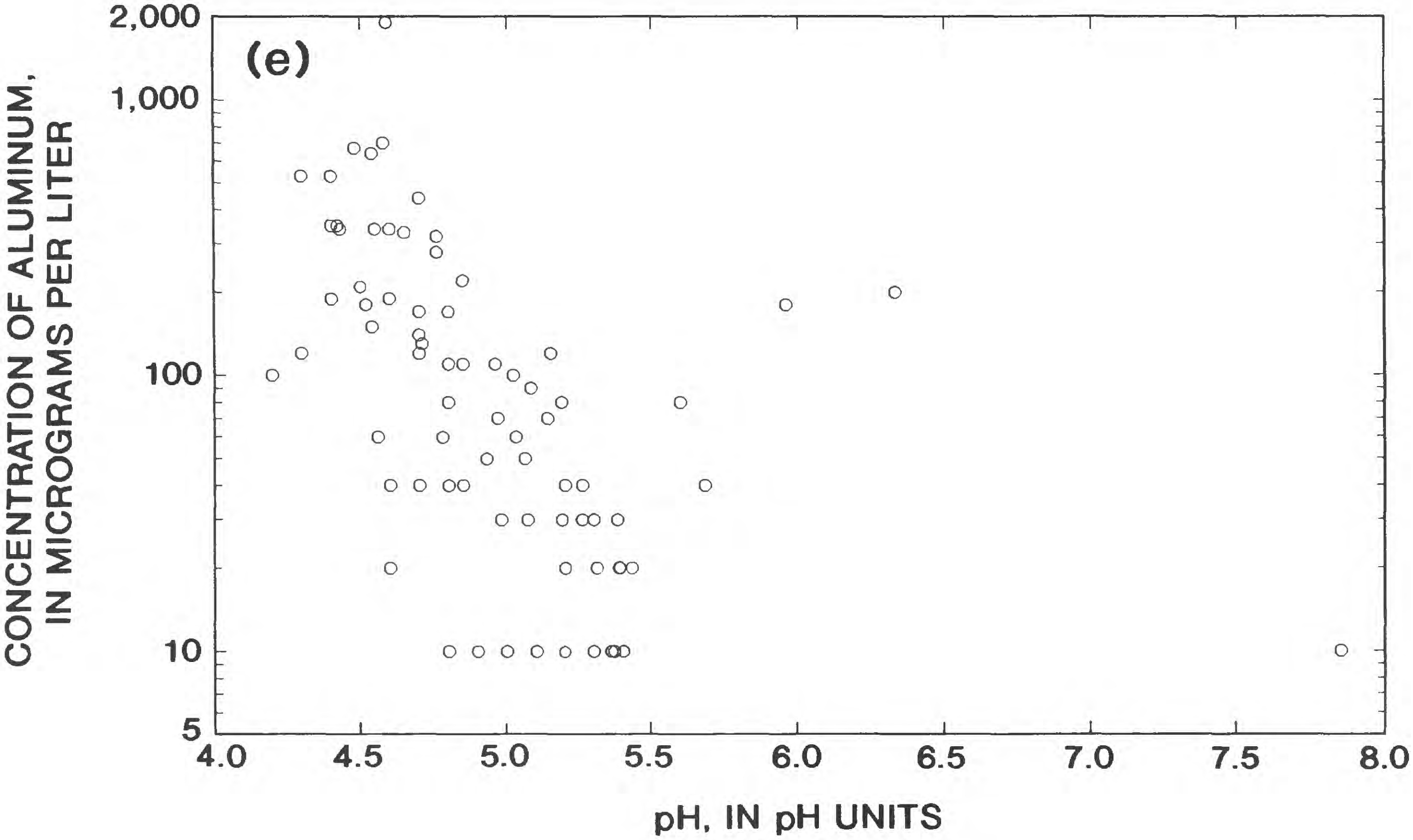


Figure 18. Relation of the concentration of barium to (a) the concentration of the sum of dissolved solids, with concentrations of magnesium also indicated; (b) the concentration of strontium, with concentrations of calcium also indicated; (c) the concentration of manganese; (d) the pH; and (e) the relation of the concentration of aluminum to pH in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

Natural sources of strontium dissolved in ground water from the Kirkwood-Cohansey aquifer system are strontium-bearing plagioclase found in the Bridgeton Formation and shell material found in the Kirkwood Formation composed of calcite, or possibly of aragonite, which is especially strontium-rich (Kinsman, 1969). Strontium cations substitute readily for calcium cations in common minerals such as aragonite, calcite, and plagioclase. The most likely natural source of barium in the ground water is barium-containing potassium feldspars (such as celsian or hyalophane) presumably present in the Bridgeton Formation. Because of its larger ionic radius, barium does not substitute for calcium as readily as does strontium. Barium can substitute more readily for potassium than can strontium, however, because potassium also has a large ionic radius. It is more likely that the source of strontium and barium dissolved in the ground water is related to the source of nitrate and magnesium than to the weathering of silicate minerals.

Strong positive correlations of chloride and potassium concentrations with concentrations of nitrate (fig. 17c, table 7), and with the presence agricultural land (fig. 14) indicate that the predominant source of potassium in the ground water is percolation of leachate from fertilizer application. Chloride-rich precipitation from easterly storms from the Atlantic Ocean also may be source of chloride in the ground water; however, because the ground water also is chloride-enriched in agricultural areas in the western part of the study area, farthest from the Atlantic Ocean, easterly storms are probably not the predominant sources of chloride. Chloride may be derived locally from the application of road salt or the migration of landfill leachate.

Small concentrations of potassium in the ground water may be derived from the weathering of potassium-bearing feldspar grains. Feldspar weathering is a relatively slow process, however, and the short residence time of ground water in the Kirkwood-Cohansey aquifer system most likely precludes the weathering of a large enough mass of potassium-feldspar to yield potassium concentrations as high as 40 mg/L, which were detected in ground-water samples from the Kirkwood-Cohansey aquifer system during this study (app. 2). The likely source of high concentrations of soluble potassium in the ground water is the application to agricultural land of sylvite (KCl) as a component of fertilizer.

Sulfate in water from the Kirkwood-Cohansey aquifer system likely is derived from multiple sources. Sulfate may be added to the ground water through application of chemical fertilizers to the soil; many natural and synthesized chemical fertilizers and fungicides contain sulfate (for example, ammonium sulfate). The positive relation between concentrations of sulfate and dissolved solids coupled with the absence of a strong positive relation between sulfate and nitrate concentrations, however, indicate the presence of sources of sulfate other than agricultural fertilizers or fungicides. These sources may include sulfate-rich precipitation near urban areas derived from burning of fossil fuels. Urban runoff that recharges the aquifer or migration of oxidized landfill leachate may be additional local sources of sulfate. The dissolution of sulfate minerals or oxidation of sulfide minerals in the aquifer at depth may be a natural source of sulfate. In wetland areas near streams (for example, wells 11-0073, 11-0097, and 33-0469), some of the sulfate may be derived from the decomposition of sulfur-bearing organic matter or sulfur-bearing minerals in the aquifer.

Despite the positive correlation of aluminum with nitrate, the primary source of aluminum probably is the dissolution of feldspar minerals in the aquifer matrix, because aluminum is not a common additive in chemical fertilizers. The aluminum concentration increases in strongly acidic water during weathering of silicate minerals (Stumm and Morgan, 1981, p. 549). However, besides acidity, other factors may also control concentrations of dissolved aluminum, such as the rate of silicate-mineral weathering; high aluminum concentration in dilute acidic water is possible in the presence of easily weatherable silicate minerals, such as plagioclase. The slow rate of precipitation of aluminum-bearing secondary minerals, such as kaolinite, may result in elevated aluminum concentrations in water supersaturated with respect to kaolinite. (Elevated concentrations of fluoride or fulvic acid in the water also result in an increase in aluminum concentration because these ions form soluble complexes with aluminum; however, the concentration of these constituents in the water was generally low).

The concentration of dissolved oxygen and the pH control the concentrations of iron and manganese in ground water from the Kirkwood-Cohansey aquifer system. The dissolution of minor amounts of iron- and manganese-bearing minerals such as ilmenite, magnetite, hornblende, and pyrite found in the aquifer material (Owens and others, 1983) is a source of available iron. These minerals weather in oxidizing water to form coatings of iron oxides or hydroxides and manganese oxides or hydroxides on mineral grains in the Kirkwood-Cohansey aquifer system. In water having a low pH, however, even iron oxides and hydroxides are soluble, resulting in a readily available source of iron or manganese.

Crerar and others (1979, p. 127) suggest that elevated concentrations of iron in the ground and surface water of the New Jersey Pine Barrens are derived from upward-migrating ground water from iron-enriched glauconitic sand layers of deeply buried geologic formations of the New Jersey Coastal Plain. Wetlands may serve as discharge zones for these deep regional ground-water systems (Rhodehamel, 1973). During the current study, oxygen-poor, iron-rich ground water was generally found in wetland areas, whereas the concentrations of iron were generally low in the more oxidizing waters associated with recharge areas in upland sites, where agricultural land use prevailed (figs. 10 and 11). Manganese was commonly detected in both oxygen-rich ground water in recharge areas associated with agricultural land and oxygen-poor ground water in discharge areas associated with wetlands. Manganese is more soluble than iron in acidic water, even in the presence of oxygen (Hem, 1985), hence, elevated concentrations of manganese were often found in iron-poor and oxygenated, but acidic water samples.

A likely reason that increasing concentrations of manganese correlate with increasing concentrations of barium (fig. 18c), strontium, magnesium, and calcium in samples of water from the Kirkwood-Cohansey aquifer system is because manganese, like barium and strontium, is a common trace element in calcite and dolomite, liming agents added to soil in agricultural areas. Manganese is soluble in acidic water, and can enter into solution in the acidic leachate recharging ground water in agricultural areas.

Correlations Between Concentrations of Radionuclides, and Concentrations of Inorganic Chemical Constituents and Chemical Characteristics

Concentrations of both radium-226 and radium-228 in water samples from the Kirkwood-Cohansey aquifer system are inversely correlated with pH (correlation coefficient, $r = -0.44$ and -0.39, respectively; table 7). The percentage of water samples having a sum of the concentrations of radium-226 and radium-228 greater than 5 pCi/L increases as the pH decreases; this trend is especially noticeable when the pH is less than 5.0 (fig. 19). Of 26 samples that contained concentrations of radium-226 plus radium-228 greater than the MCL of 5 pCi/L (U.S. Environmental Protection Agency, 1988), 81 percent (21 samples) had a pH less than 5.0 (fig. 19). The large majority of samples that contained low concentrations of radium also had pH values above 5.0. Concentrations of uranium do not show as strong a negative correlation with pH as do the radium isotopes.

Uranium concentrations correlate positively with concentrations of the sum of dissolved solids (fig. 20a), nitrate (fig. (21a), chloride (fig. 22a), and sulfate (table 7), and divalent cations, such as magnesium (fig. 23a), and barium (fig. 24a). Concentrations of radium-226, and radium-228, and the sum of the concentrations of the two radium radionuclides increase with increasing concentrations of numerous inorganic chemical constituents, including the sum of dissolved solids (fig. 20b), nitrate (fig. 21b), chloride (fig. 22b), magnesium (fig. 23b), calcium (table 7), strontium (table 7), barium (fig. 24b), potassium (table 7), and aluminum (table 7). Results of Spearman's rank correlation test indicate significant positive correlation between radium radionuclides and these inorganic constituents (most correlation coefficients are between +0.5 and +0.7; table 7), and between uranium and these inorganic constituents (most correlation coefficients are between +0.3 and +0.5; table 7).

Relations Among Geology, Agricultural Land Use, Concentrations of Inorganic Chemical Constituents and Chemical Characteristics, and Concentrations of Radionuclides

The presence of the Bridgeton Formation outcrop or agricultural land may be among the variables that control spatial correlations among concentrations of the sum of dissolved solids (fig.10), pH (fig. 11), and concentrations of radioactive constituents (especially radium-226 and radium-228) (fig. 12) and inorganic chemical constituents (table 7). To test these two hypotheses, the results of chemical analyses of water samples collected from the Kirkwood-Cohansey aquifer system during 1988-89 were analyzed statistically with the Kruskal-Wallis test (tables 8 and 9).

The Kruskal-Wallis test determines the probability, based on the chi-square statistic, that the mean concentrations of the ranked values of a constituent from two or more groups are different from one and other. The Kruskal-Wallis test was used to determine whether the probability was greater than 95-percent, that the mean concentration of the ranked values of radioactive or inorganic constituents from water samples from areas where agricultural land or the Bridgeton Formation is present within a 500-meter radius of the well head is different (either larger or smaller) from the mean concentration of the ranked values of these constituents where agricultural land and the Bridgeton Formation are absent within a 500-meter radius of the well head.

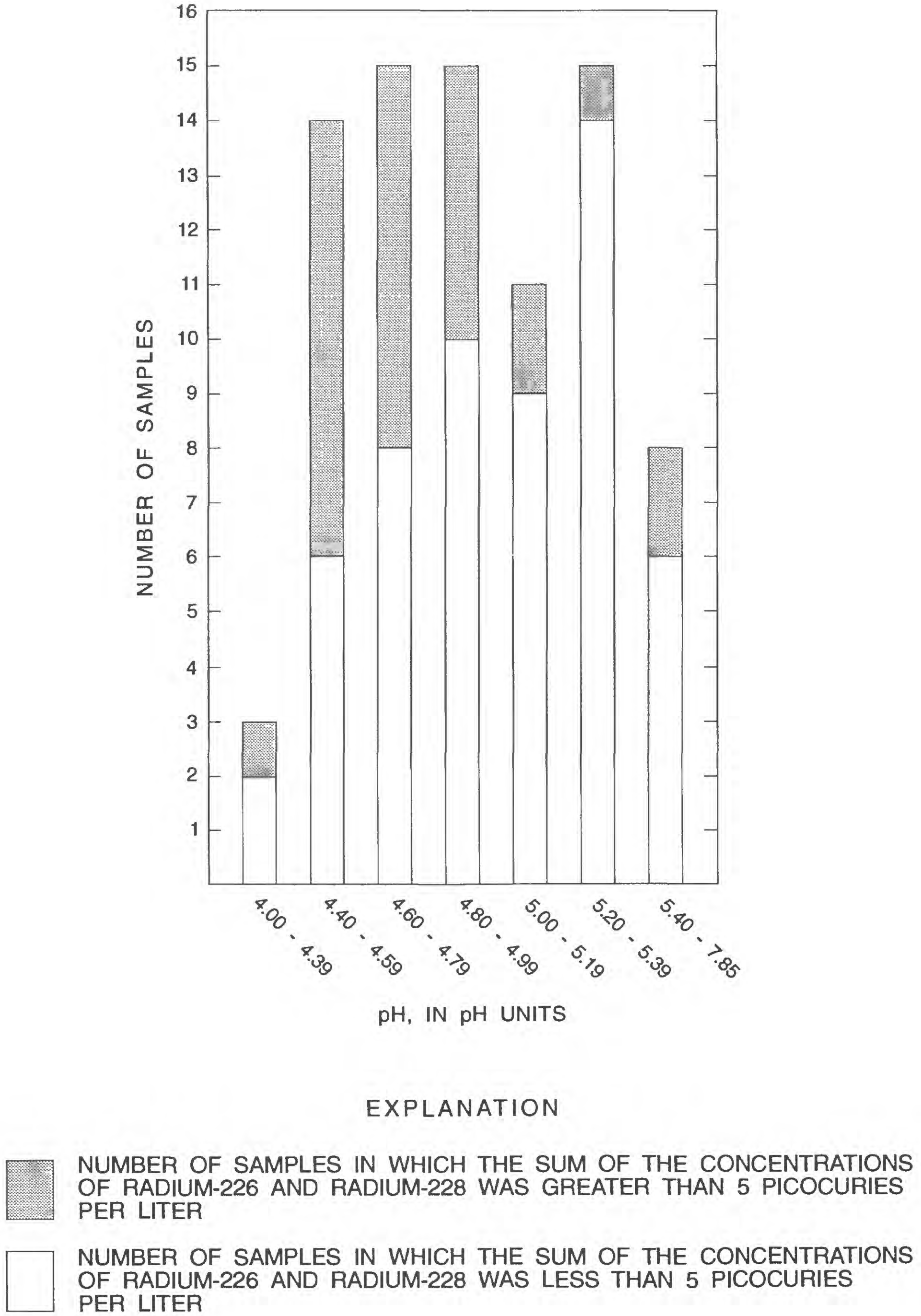


Figure 19.--Histogram of pH and the number of samples in each range of pH for which the sum of concentrations of radium-226 and radium-228 exceeded 5 picocuries per liter in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.

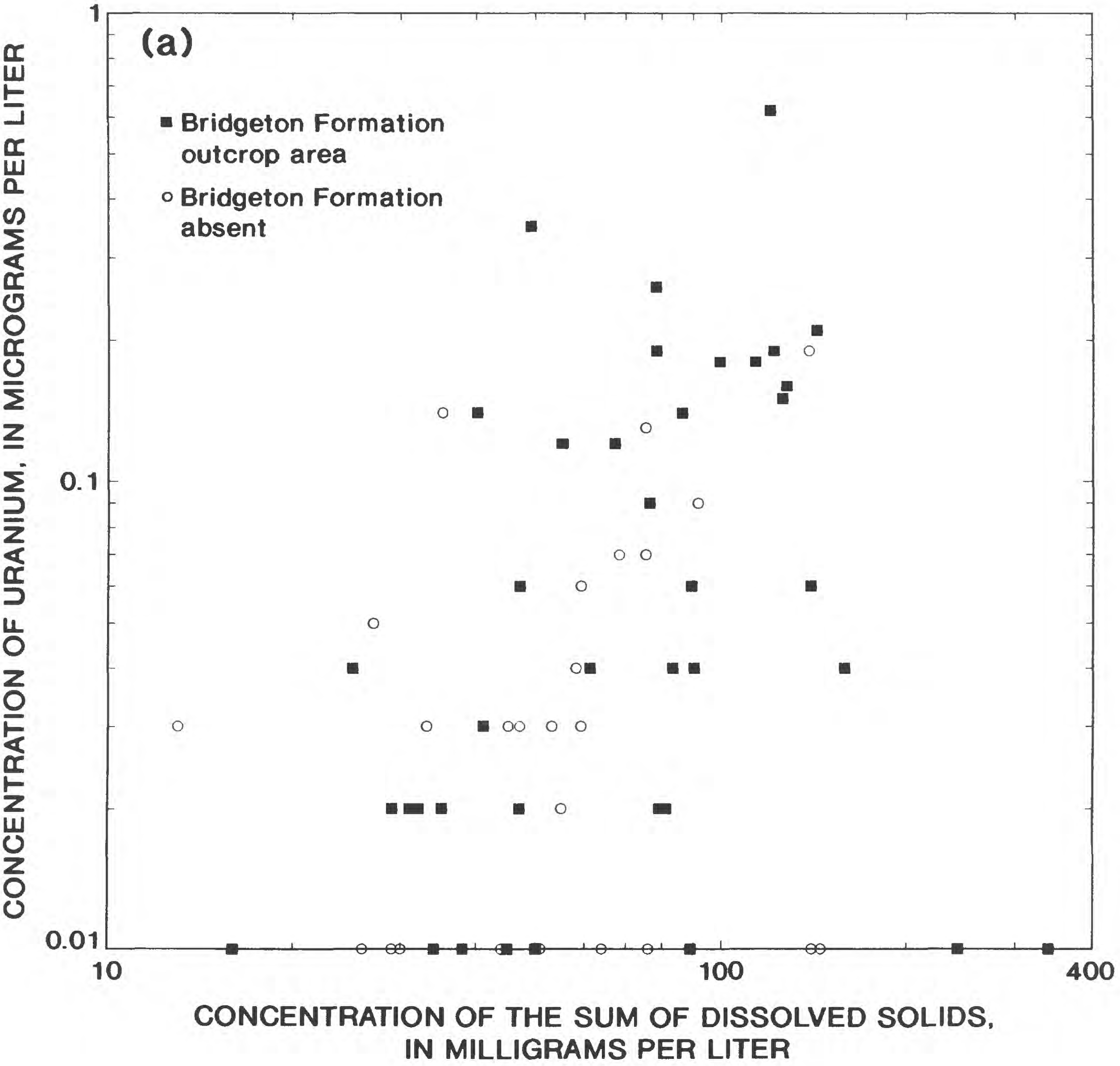


Figure 20. Relation of the concentration of the sum of dissolved solids to the (a) concentration of uranium, and (b) the sum of the concentrations of radium-226 and radium-228 in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.

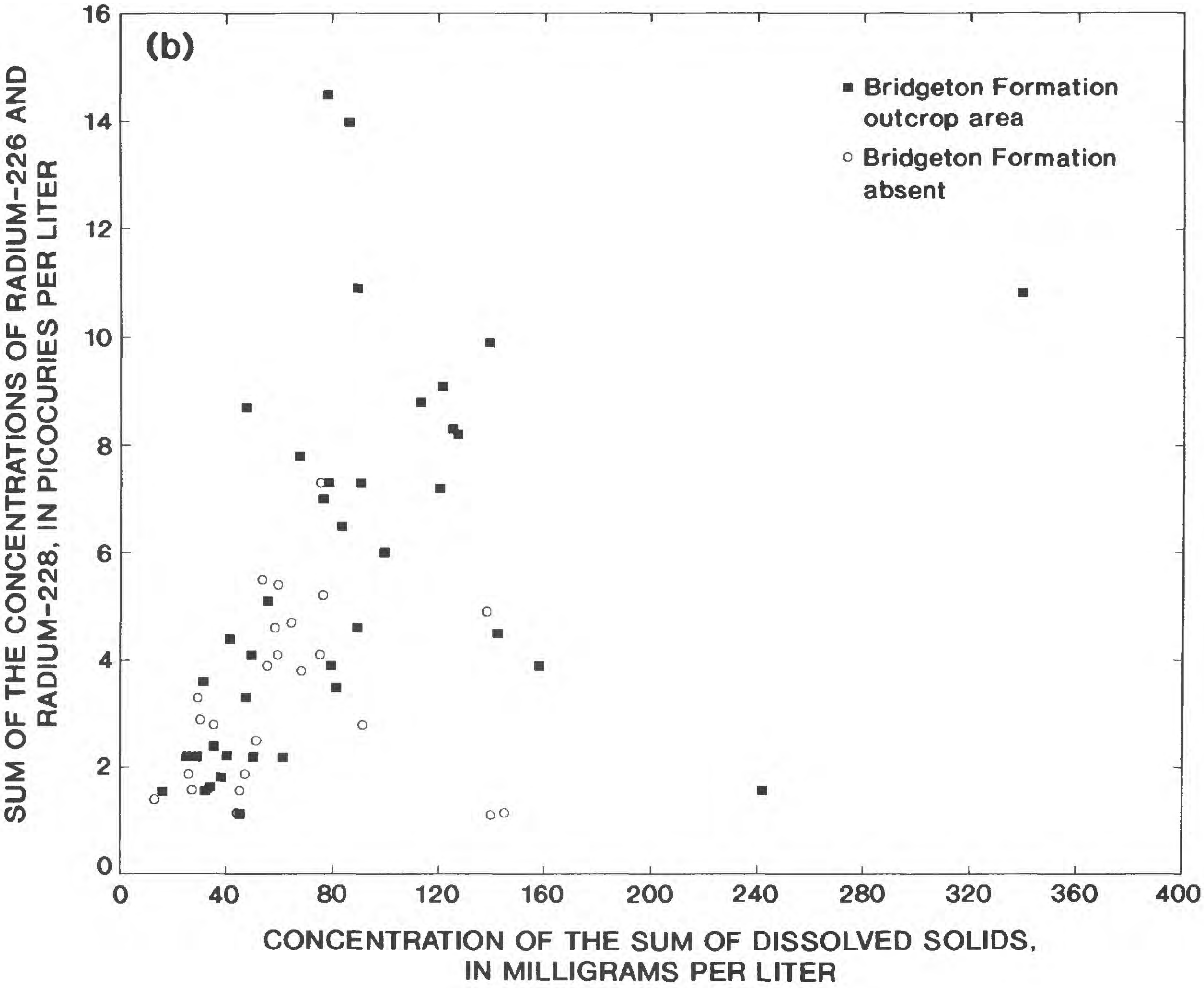


Figure 20. Relation of the concentration of the sum of dissolved solids to the (a) concentration of uranium, and (b) the sum of the concentrations of radium-226 and radium-228 in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

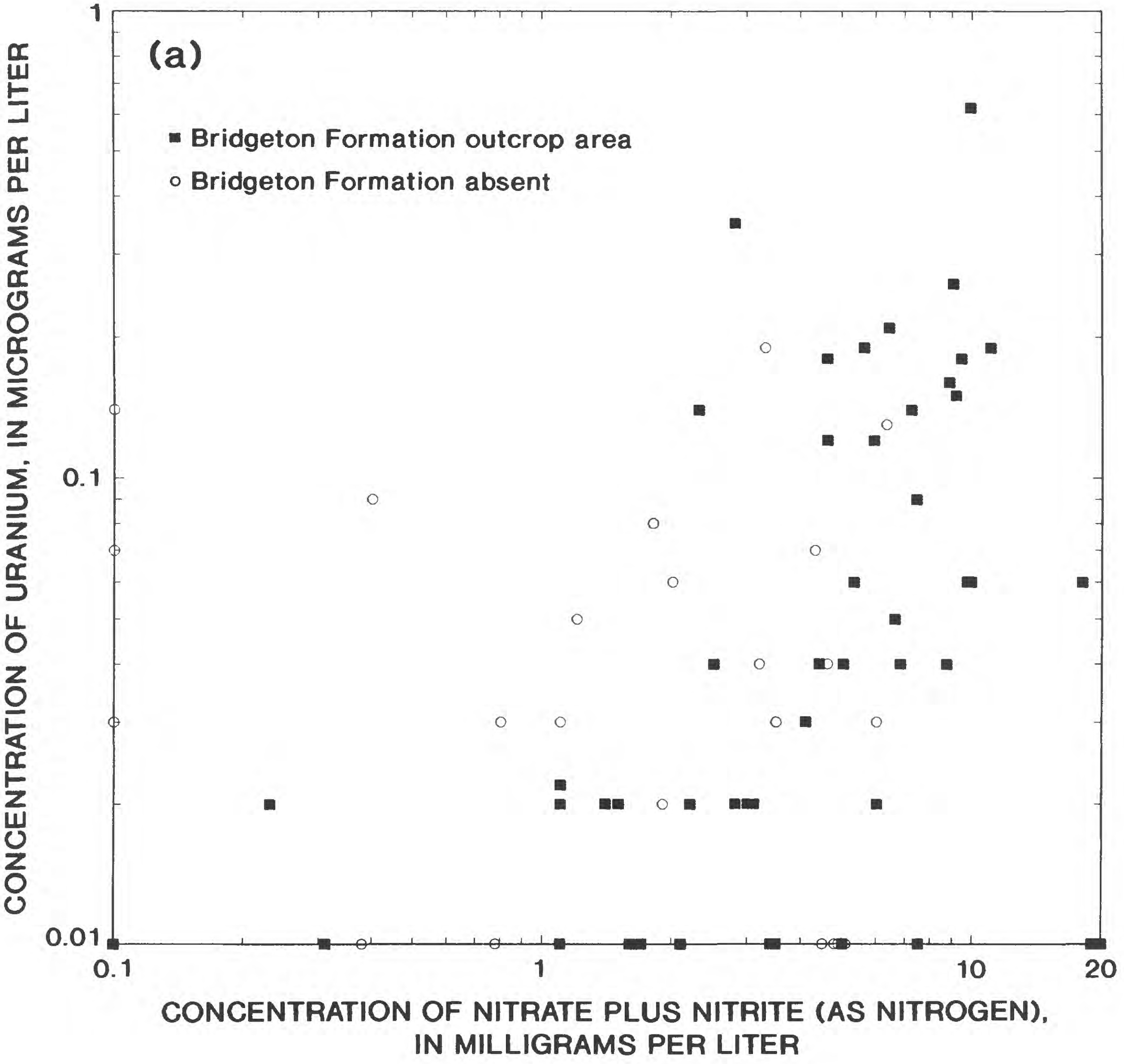


Figure 21. Relation of the concentration of nitrate plus nitrite (as nitrogen) to (a) the concentration of uranium, and (b) the sum of the concentrations of radium-226 and radium-228 in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.

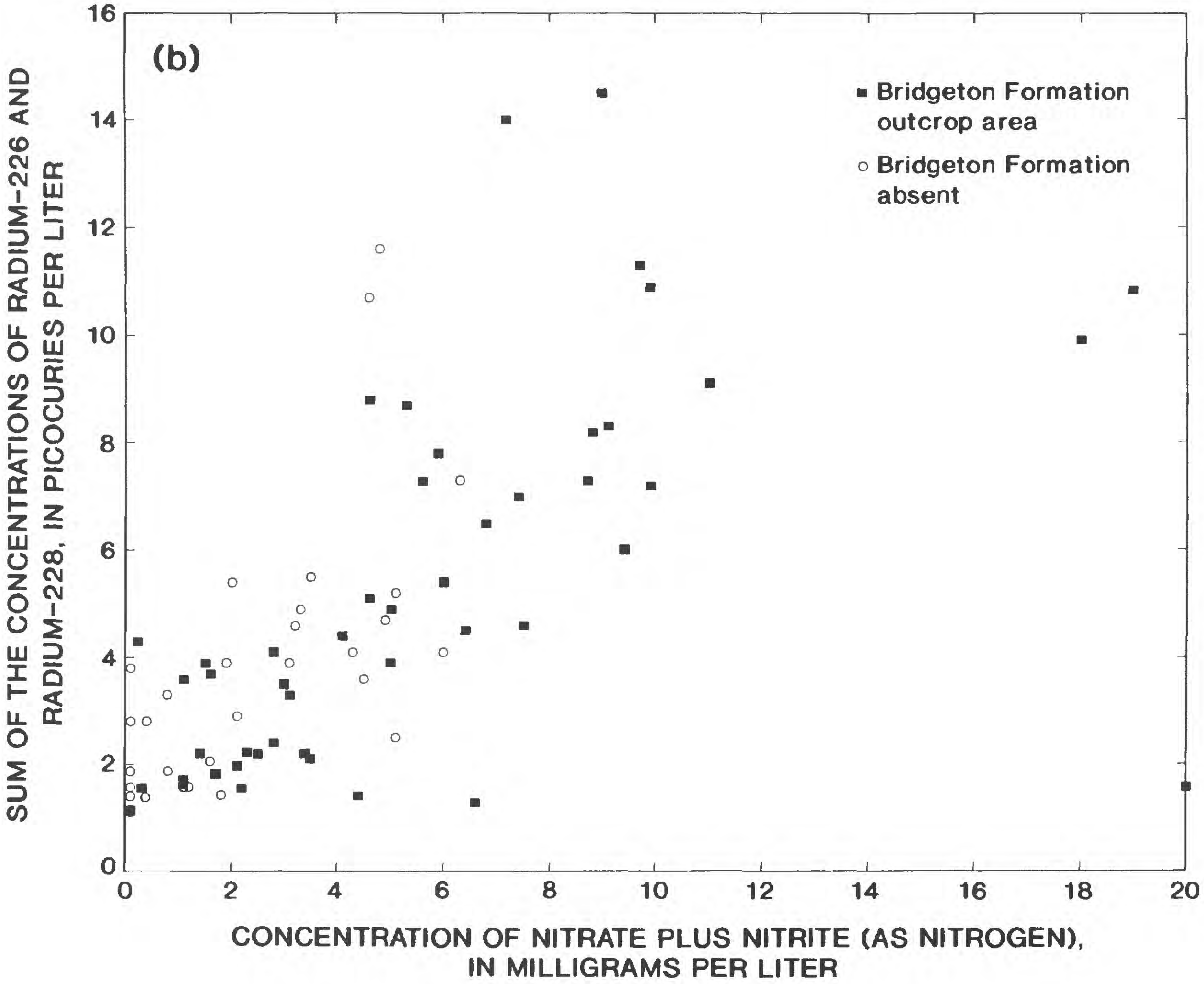


Figure 21. Relation of the concentration of nitrate plus nitrite (as nitrogen) to (a) the concentration of uranium, and (b) the sum of the concentrations of radium-226 and radium-228 in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

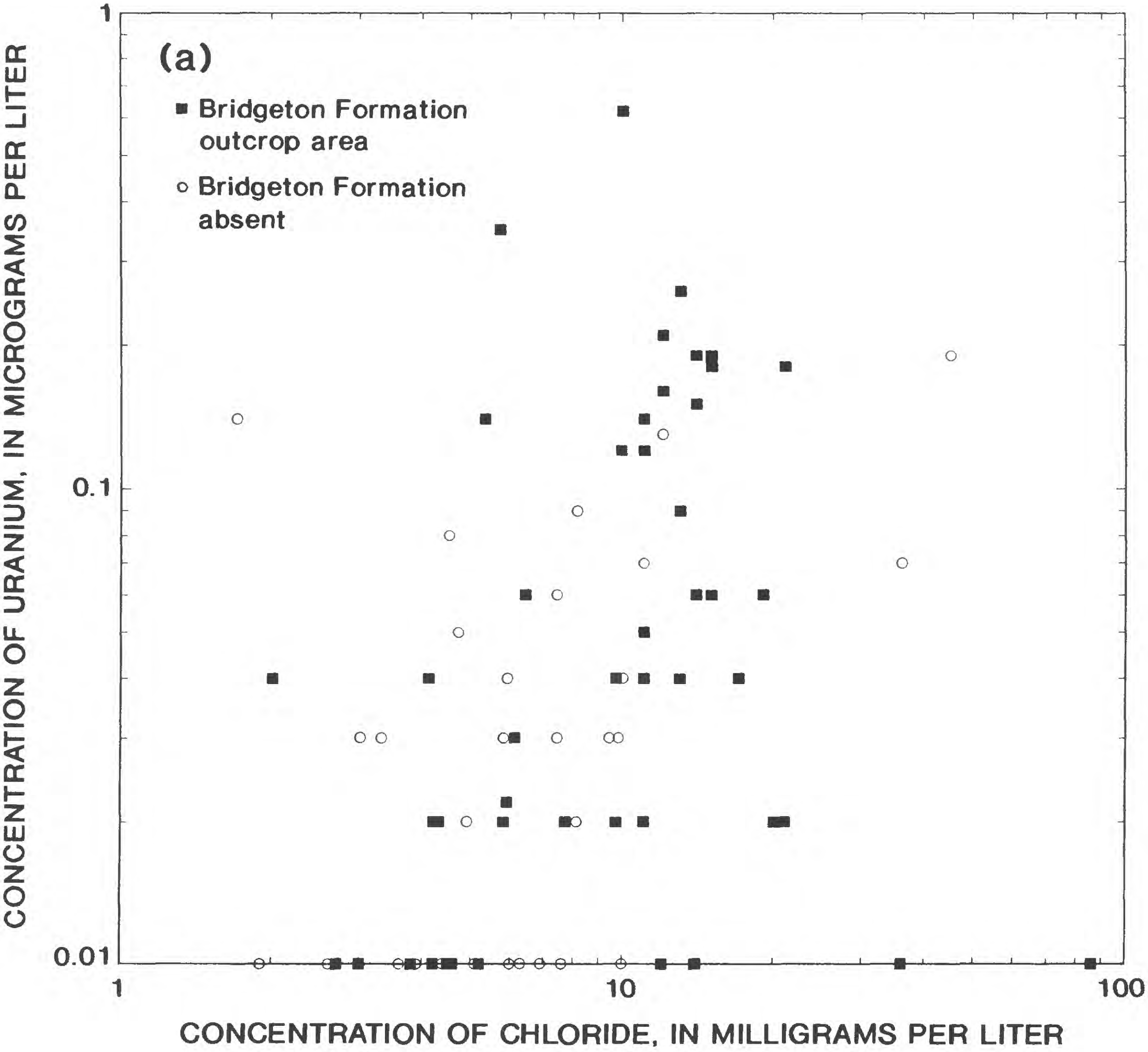


Figure 22. Relation of the concentration of chloride to (a) the concentration of uranium, and (b) the sum of the concentrations of radium-226 and radium-228 in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.

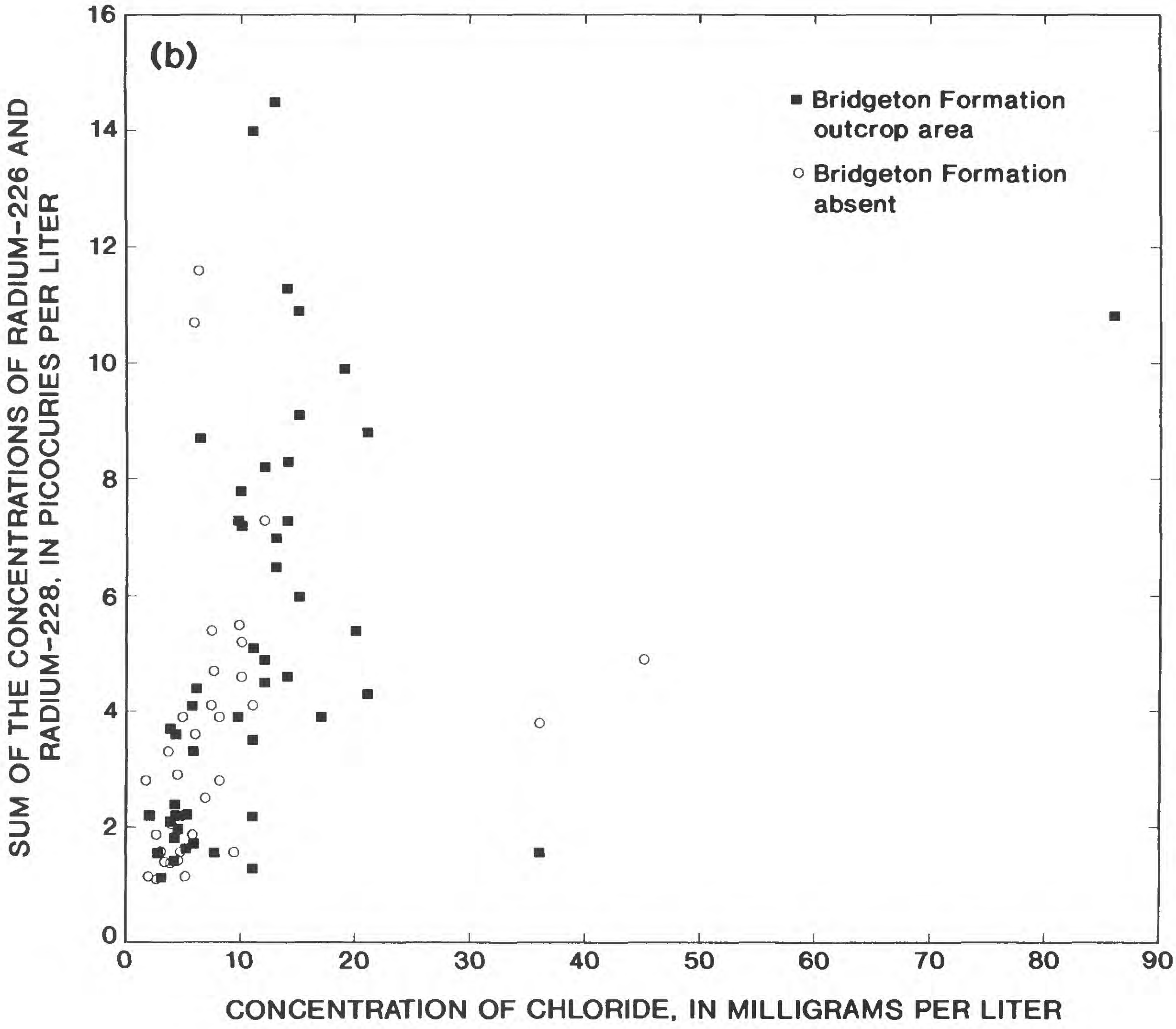


Figure 22. Relation of the concentration of chloride to (a) the concentration of uranium, and (b) the sum of the concentrations of radium-226 and radium-228 in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

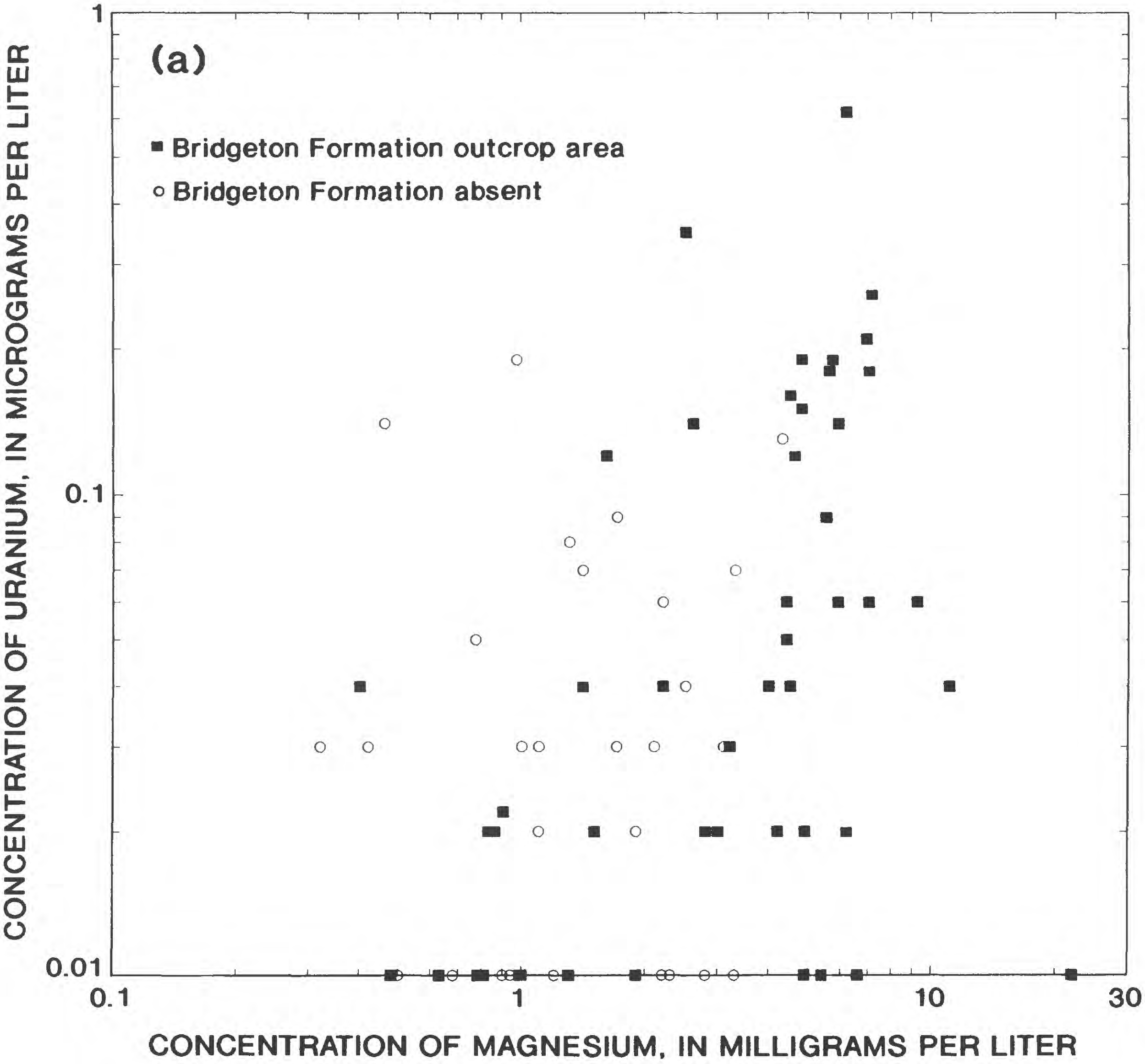


Figure 23. Relation of the concentration of magnesium to (a) concentration of uranium, and (b) the sum of the concentrations of radium-226 and radium-228 in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.

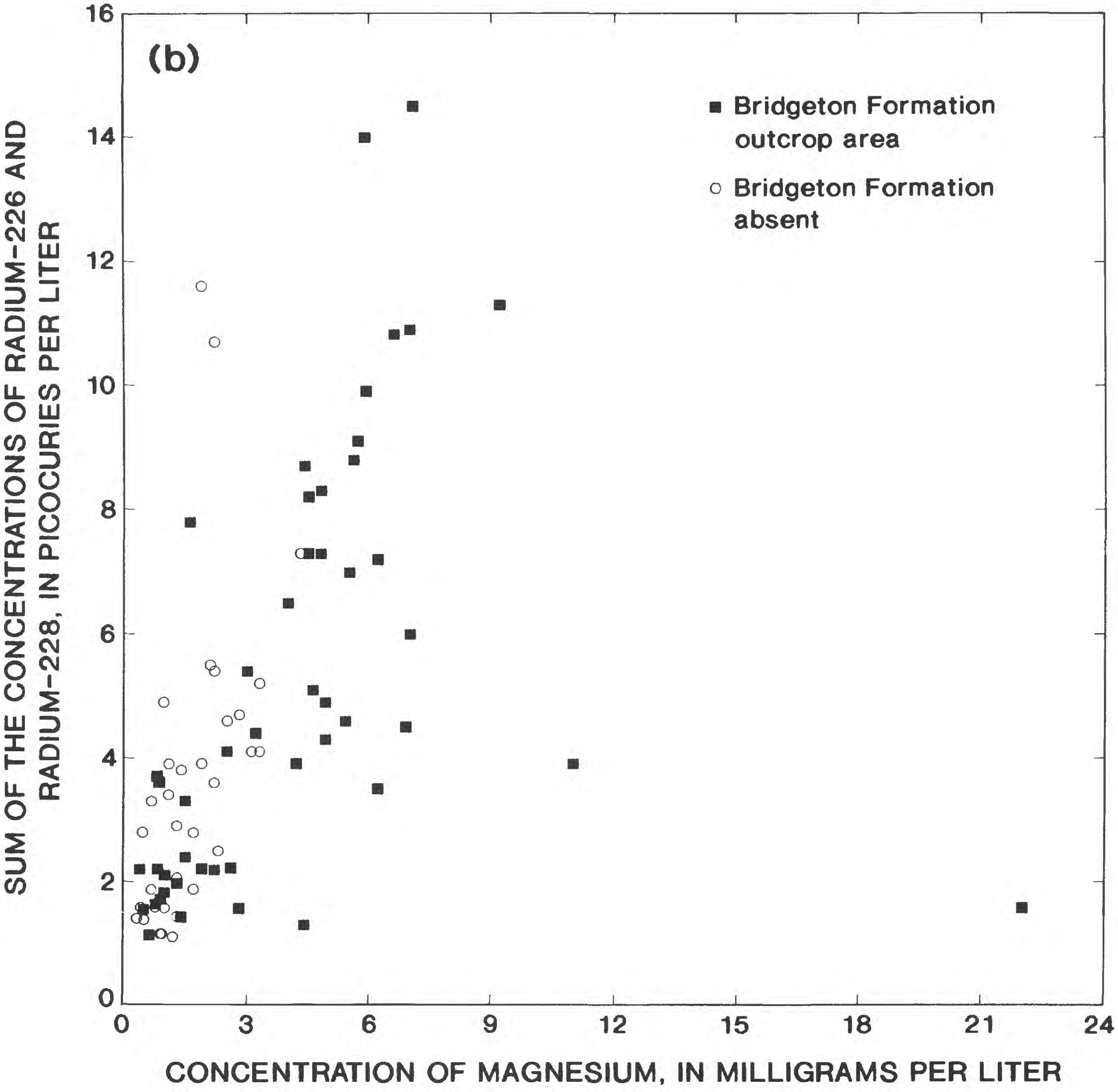


Figure 23. Relation of the concentration of magnesium to (a) concentration of uranium, and (b) the sum of the concentrations of radium-226 and radium-228 in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

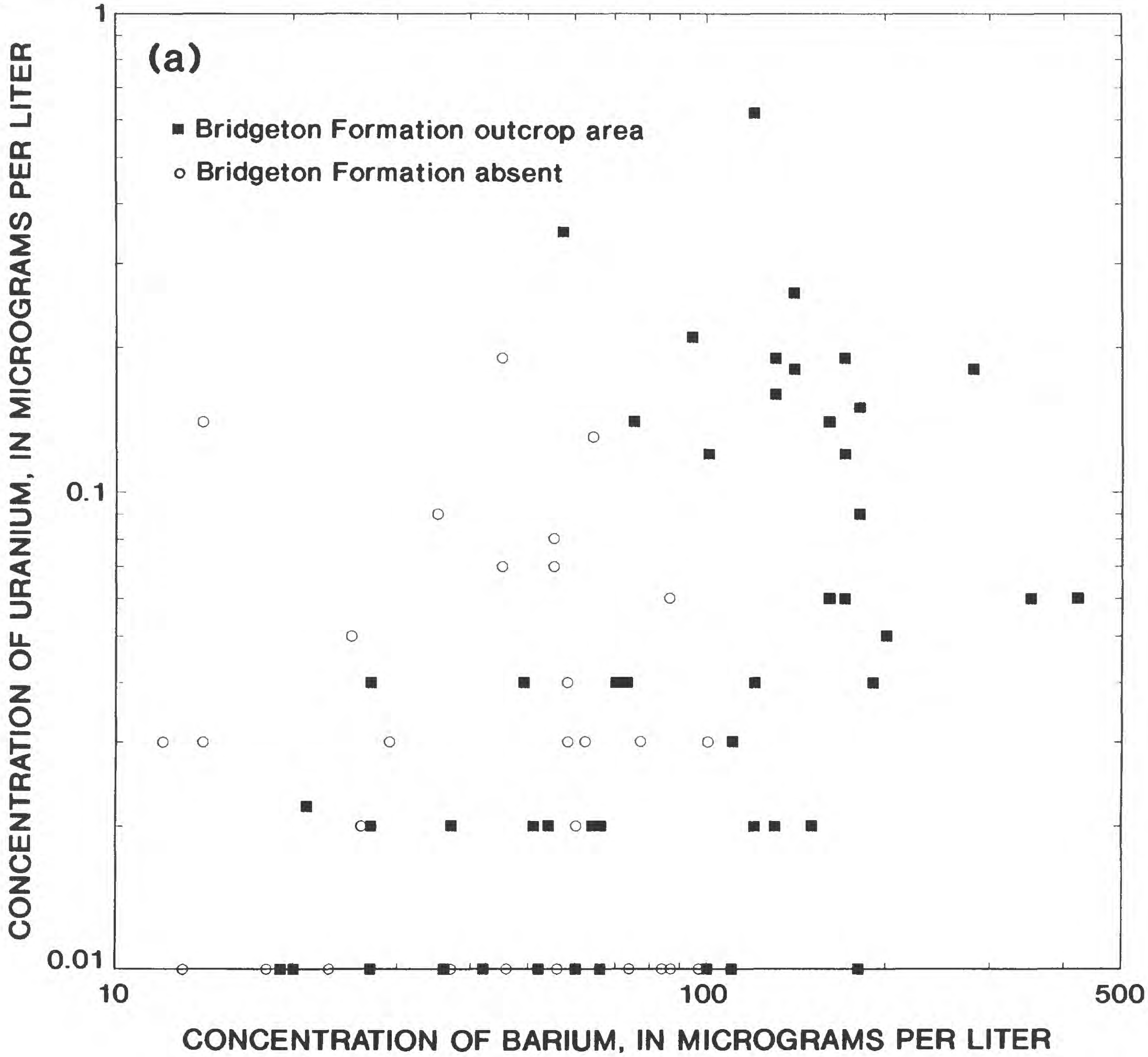


Figure 24. Relation of the concentration of barium to (a) the concentration of uranium, and (b) the sum of the concentrations of radium-226 and radium-228 in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.

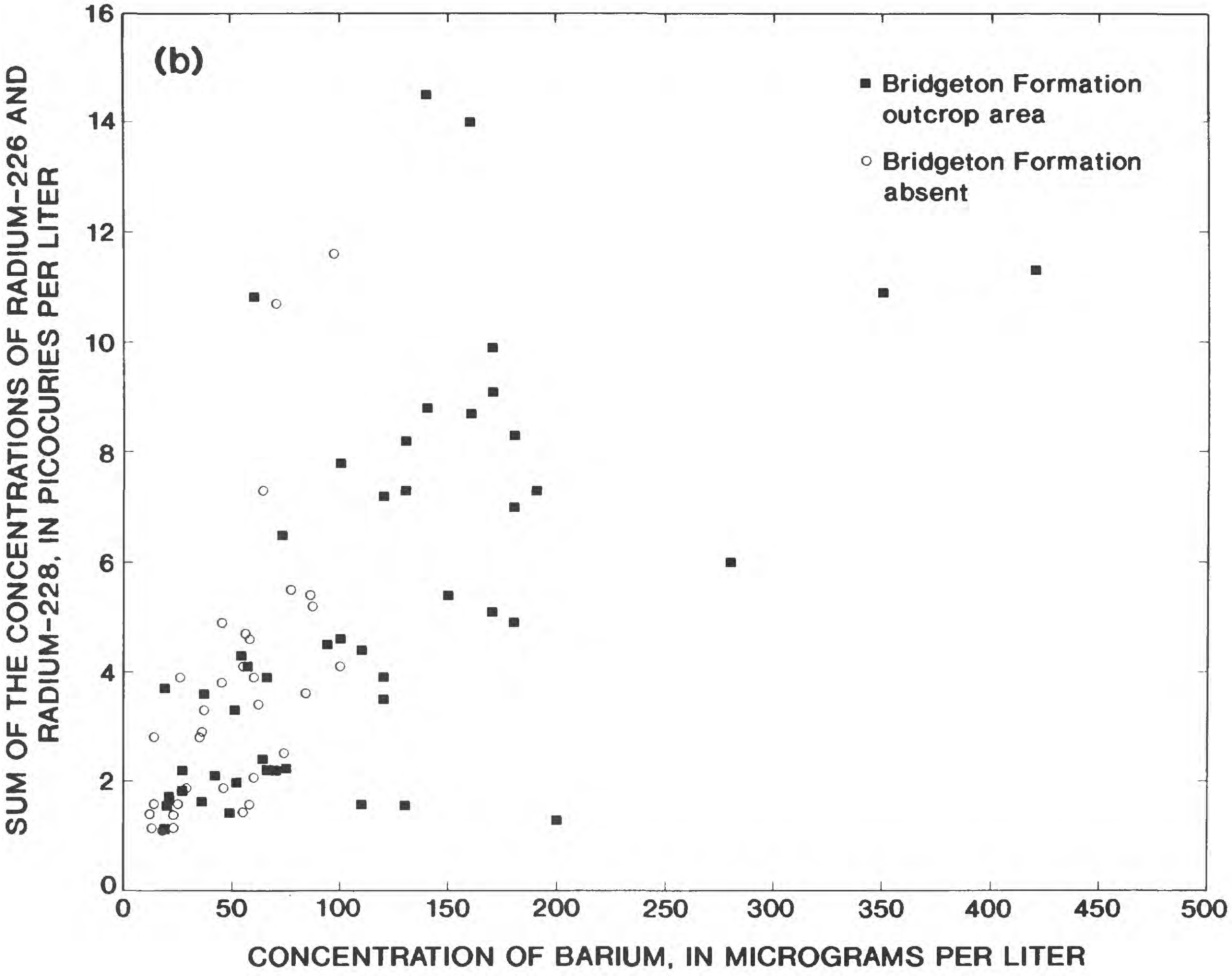


Figure 24. Relation of the concentration of barium to (a) the concentration of uranium, and (b) the sum of the concentrations of radium-226 and radium-228 in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

Table 8.--Results of Kruskal-Wallis statistical test for concentrations of radionuclides; concentrations of inorganic chemical constituents; and chemical characteristics for samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89, grouped by presence or absence of the Bridgeton Formation outcrop area within a 500-meter radius of the well head

Chemical constituent or characteristic	Mean of ranked values		Chi-square corrected for ties	Significance of chi-square corrected for ties
	Bridgeton Formation present	Bridgeton Formation absent		
		Radionuclides		
Gross alpha-particle activity	44.4	37.2	1.817	0.178
Gross beta-particle activity	46.2	34.6	4.712	.030
Radium-226	46.3	34.4	4.877	.027
Radium-228	45.4	35.7	3.277	.070
Ra-226 + Ra-228	45.9	34.9	4.192	.041
Radon-222	39.3	36.1	.394	.530
Uranium	45.0	36.3	2.703	.100
		Chemical constituents and characteristics		
Aluminum	43.0	38.1	.831	.362
Barium	50.1	28.7	15.892	<.001
Calcium	47.1	33.3	6.618	.010
Chloride	46.8	32.1	7.508	.006
Iron	37.0	48.1	4.329	.038
Magnesium	50.0	28.8	15.779	<.001
Manganese	45.3	35.9	3.098	.078
Nitrate	48.7	28.2	15.000	<.001
Potassium	46.4	34.2	5.160	.023
Silica	41.0	42.2	.049	.824
Strontium	47.6	32.4	8.079	.005
Dissolved solids	35.5	27.8	2.637	.100
pH	36.4	49.2	5.710	.017

Table 9.--Results of Kruskal-Wallis statistical test for concentrations or activities of radionuclides; concentrations of inorganic chemical constituents; and chemical characteristics for samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89, grouped by presence or absence of agricultural land within a 500-meter radius of the well head

Chemical constituent or characteristic	Mean of ranked values		Chi-square corrected for ties	Significance of chi-square corrected for ties
	Agriculture Present	Agriculture Absent		
Radionuclides				
Gross alpha-particle activity	43.8	29.1	4.181	0.041
Gross beta-particle activity	44.0	28.3	4.771	.029
Radium-226	44.6	24.9	7.559	.006
Radium-228	42.9	34.0	1.556	.212
Ra-226 + Ra-228	44.2	27.2	5.548	.019
Radon-222	40.0	28.4	3.090	.078
Uranium	43.3	32.0	2.542	.111
Chemical constituents and characteristics				
Aluminum	41.2	39.8	.043	.836
Barium	45.4	20.6	11.886	.009
Calcium	44.7	24.5	7.911	.005
Chloride	43.5	26.5	5.325	.021
Iron	39.0	54.5	4.632	.031
Magnesium	45.3	21.3	11.154	.001
Manganese	44.2	27.3	5.495	.019
Nitrate	43.9	21.3	9.620	.002
Potassium	44.1	27.5	5.379	.020
Silica	40.3	47.8	1.085	.298
Strontium	45.1	22.2	10.120	.002
Dissolved solids	34.5	20.4	4.433	.035
pH	42.0	39.0	.171	.680

Results of the Kruskal-Wallis test indicate that the significance of the chi-square statistic (corrected for ties) for the randomness of the distributions of the data for the sum of the concentrations of radium-226 and radium-228, for concentrations of radium-226, and for gross beta-particle activities is below the 0.05-significance level (tables 8 and 9). This result indicates that the areal distributions of these constituents are not random at this level of significance. Two distinct populations exist for these three radioactive constituents among each of the two sets of well-location classes. The means of the ranked values for these constituents are significantly higher for water samples collected from areas where the Bridgeton Formation is present within a 500-meter radius of the well head than for water samples collected from areas where the Bridgeton Formation is absent within a 500-meter radius of the well head (table 8), and also are higher for samples collected from wells in areas of agricultural land than for samples collected from wells in areas where agricultural land is absent within a 500-meter radius of the well head (table 9).

Results of the Kruskal-Wallis test also indicate that the significance of the chi-square statistic (corrected for ties) for the randomness of the distributions of the data for concentrations of radium-228, radon-222, and uranium is slightly above the 0.05-significance level (tables 8 and 9) indicating that the areal distributions for these constituents are random at this level of significance. The populations among each of the two sets of well-location classes are not distinct. The mean of the ranked values for these three radioactive constituents is higher, but not to a statistically significant degree, for samples collected from areas where the Bridgeton Formation is present than for samples collected from areas where the Bridgeton Formation is absent within a 500-meter radius of the well head (table 8), nor for water samples collected from wells in areas where agricultural land is present than for water samples collected from wells in areas where agricultural land is absent within a 500-meter radius of the well head (table 9).

The technique for the determination of radium-228 concentrations has a higher minimum reporting limit (1 pCi/L) than does the technique for the determination of radium-226 concentrations (0.02 pCi/L). A greater number of radium-228 concentrations than radium-226 concentrations were, therefore, reported as being below the minimum reporting limit (MRL). The larger number of samples that had radium-228 concentrations below the MRL may skew the calculation of the mean value of the rank of radium-228 concentrations sufficiently to introduce bias in the calculation of the chi-square statistic in the Kruskal-Wallis test (tables 8 and 9). All the samples with radium-228 concentrations below the MRL were assigned the same value. In fact, it is possible to infer, however, based on observation of the distribution of measureable concentrations of radium-226 between the concentration range of 0.02 to 1 pCi/L, that radium-228 concentrations also are highly variable in the concentration range of 0.02 to 1 pCi/L.

Results of the Kruskal-Wallis test also indicate that the distribution of data for many inorganic constituents is not random among each of the two sets of well-location classes. These inorganic constituents include barium, calcium, chloride, magnesium, nitrate, and strontium (tables 8 and 9). The mean ranked value of the concentrations of these inorganic constituents in water samples from areas where agricultural land or the Bridgeton Formation is present, will exceed the mean of the ranked value of concentrations of constituents in water samples from areas where agricultural land or the Bridgeton Formation outcrop is absent within a 500-meter radius of the well head with greater than 95-percent probability (based on chi-square statistic corrected for ties). The most highly significant chi-square value, indicating the greatest difference in the mean of ranked values for concentrations of a constituent in the ground water among each of the two sets of well-location classes, is that for nitrate (chi-square significance of <0.001 and 0.002, respectively, in tables 8 and 9). Chi-square values also are highly significant for barium (chi-square significance of <0.001 and 0.009, respectively, in tables 8 and 9) and magnesium (chi-square significance of <0.001 and 0.001, respectively, in tables 8 and 9).

Neither the mean of the ranked values for the sum of dissolved-solids concentration nor for that of the manganese concentration is higher at the 95-percent significance level in the group of samples from where the Bridgeton Formation is present than in the group of samples from areas where the Bridgeton Formation is absent within a 500-meter radius of the well head (table 8). The probability, however, that concentrations of the sum of dissolved solids are higher in samples collected from wells in areas of agricultural land use than in non-agricultural areas within a 500-meter radius of the well head is significant at the 95-percent level (significance level of 0.035 in table 9); this result is consistent with the observed positive correlation between the sum of dissolved-solids concentrations and the presence of agricultural land (fig. 10). A similar relation is also noted for concentrations of manganese and the presence of agricultural land (table 9).

The mean of the ranked values for pH is lower at the 95-percent significance level in water samples from wells in areas where the Bridgeton Formation is present than in areas where the Bridgeton Formation is absent within a 500-meter radius of the well head (significance level of 0.017 in table 8). This result contrasts with that obtained when the pH values are grouped according to the presence or absence of agricultural land. The mean of the ranked values of pH is lower, but not at the 95-percent significance level (table 9) for the group of water samples from wells with agricultural land within a 500-m radius of the well head relative to the group of water samples from wells with no agricultural land within this radius.

The relation of dissolved iron concentration to the presence or absence of the Bridgeton Formation and agricultural land is controlled by the concentration of dissolved oxygen in the ground water. The mean of the ranked values for iron concentrations in samples of water from wells in either the Bridgeton Formation outcrop area or in areas of agricultural land within a 500-m radius of the well head tends to be less than the mean of the ranked values for iron concentrations in samples of water from areas where the Bridgeton Formation or agricultural land are absent within a 500-m radius of the well head. The chi-square statistic indicates that this difference is significant at the 95-percent confidence level (tables 8 and 9). Of the inorganic constituents determined, only iron tends to be present in lower concentrations in water samples from areas where the Bridgeton Formation is present than in samples from areas where the Bridgeton Formation is absent within a 500-m radius of the well head, and at the same time, tends to be present in lower concentrations in areas of agricultural land use than in areas where agricultural land use is absent within a 500-m radius of the well head.

Because iron is soluble in acidic water, iron concentrations were expected to be high in the strongly acidic water found in areas of agricultural land use on the intensively farmed Bridgeton Formation outcrop area where the median pH (4.80) was lower than in the other well-location classes (table 5). The concentration of iron in solution, however, appears to be most enhanced by the lack of oxygen in water, as indicated by samples from wells in low-lying, poorly-drained wetlands areas. In these areas, agricultural-land use and the Bridgeton Formation is generally absent within a 500-m radius of the well head (figs. 10 and 11). Acidity of the water does not appear to strongly enhance the dissolved iron concentration.

The converse association with land-use holds for the concentration of the sum of radium-226 and radium-228 than for concentration of iron (tables 8 and 9). Either the source material or the mechanism by which iron is mobilized in the ground water is different than that for radium, or both these possibilities are true. The predominant association of radium with the presence of the Bridgeton Formation outcrop along ridges and with agricultural land indicates that the source of the radium is not that of iron. The geographic distribution of elevated radium concentrations indicates the source of the radium cannot be the glauconitic strata reported near the base of the Kirkwood Formation from which oxygen-poor iron-rich ground water discharges to the wetlands (Crerar and others, 1979).

The mean of the ranked values of chemically inert radon-222 is greater, but not at the 95-percent significance level, in water samples from wells in areas where the Bridgeton Formation or agricultural land is present within a 500-m radius of the well head than in water samples from wells in areas where the Bridgeton Formation or agricultural land is absent within a 500-m radius of the well head (tables 8 and 9). This statistical result indicates that while it is possible that greater amounts of uranium-decay-series radionuclides are present in the aquifer matrix where the Bridgeton Formation or agricultural land is present than where the Bridgeton Formation or agricultural land is absent, this difference in concentration of these radionuclides may not be statistically significant at the 95-percent confidence level (assuming other variables that may affect dissolved radon-222 concentrations, such as porosity, are uniformly distributed in the aquifer).

Relation Between Concentrations of Radium and Concentrations of Nitrate

A linear regression relation between radium and nitrate was estimated by using the ranked total radium (the sum of the concentrations of radium-226 and radium-228) concentration (RTRA) and ranked nitrogen (as the sum of nitrate plus nitrite) concentration (RNO3). This regression model can be used to identify ground water that has a high statistical probability that it may contain elevated concentrations of radium.

The number of the samples used in this statistical analysis is N = 76. Samples from three wells (11-0097, 33-0466, and 33-0469) were deleted from the original sample set of 81, because they are located near the border of the study area (fig. 9). These wells are assumed to be screened in the upper part of the Kirkwood Formation near the base of the aquifer system; therefore, samples from these three wells are not chemically representative of water from the rest of the wells, most of which are screened in the Cohansey Sand in the upper part of the aquifer system. Wells 15-0748 and 11-0367 were excluded because the depths of their screened zone are uncertain. One additional sample from a well (01-0285) of the remaining 77 samples was omitted from the statistical analysis because of a missing nitrate value. Of the 76 samples, 21 had concentrations less than the analytical reporting limit for one or both of the constituents of interest. Concentrations of either constituent that was less than the reporting limit was set to a concentration value of zero for purposes of the statistical analysis.

Regression on the unranked data yielded poorly distributed residuals having several high leverage points (points that exert an unduly large influence on the regression line). Rank-order regression, which provides robust estimators in such situations (Iman and Conover, 1979; Conover, 1980), was used to correct this problem. Because rank-order regression was used, the regression formulas developed below cannot be used to directly predict dissolved radium concentrations from dissolved nitrate concentrations. Only the rank-order concentration of radium can be determined. Nevertheless, the rank-order concentration of radium can be used to assess whether or not it is likely that the true radium concentration of a water sample exceeds the 5 pCi/L MCL.

For the number of samples of N = 76, the estimated relation is

$$\begin{aligned} \mathrm{RTRA} &= 8.78 + 0.790\ \mathrm{RNO3} \\ \mathrm{s.e.} &= (3.301)\ \ (0.075) \\ t &= (2.66)\ \ (10.60) \\ \mathrm{df} &= 74,\ \mathrm{Rsq} = 0.603 \end{aligned}$$

where s.e. is the standard error of the coefficient, t is the t-ratio, df is the degrees of freedom, and Rsq is the regression coefficient (the part of variability of the dependent variable explained by the variability of the independent variables in the regression model); the numbers in parentheses are standard errors of the coefficients, and the numbers below them are the respective t-statistics. The greater the value of the t-statistic, the more significant is the regression. The relation reported is intended to represent a predictive, rather than a causal, relation. It was chosen for the high t-statistics of the predictor and for the ability of the model to explain a large part of sample variance.

Results obtained by using this regression model indicate that relatively high concentrations of total radium are significantly related to relatively high concentrations of nitrate anions in the ground water of the Kirkwood-Cohansey aquifer system. Residuals from the regression are well-distributed and show no correlation with the independent variable, indicating that the value of one point did not exert undue influence on the slope of the regression line. The t-ratio for the regression coefficient is significant at the 99.9-percent confidence level, and the coefficient of determination is substantial. This high degree of confidence suggests that, if the sampling experiment were repeated 1,000 times, the concentration of radium would show a significant relation to the concentration of nitrate in 999 of them.

To test the robustness of this regression model, all observations for which concentrations of radium or nitrate were set to zero were deleted from the data set. The regression was reestimated by using the sample of 59 reranked observations. The resulting model is

$$\begin{aligned} \mathrm{RTRA} &= 6.33 + 0.815\ \mathrm{RNO3} \\ \mathrm{s.e.} &= (2.708)\quad (0.080) \\ t &= (2.34)\quad (10.21) \\ \mathrm{df} &= 57,\ \mathrm{Rsq} = 0.651 \end{aligned}$$

which is nearly identical to the previous model. The t-ratio of the slope coefficient for this model is slightly smaller than its counterpart in the previous model, and the coefficient of determination is only 5 percent larger. The model results are significant at the 99.9-percent confidence level, as before. The residual distribution of this model is similar to that of the first model. Thus, the conclusions are the same and are not affected by the large number of ground-water samples in which either radium or nitrate was not detected.

All 76 water-sample analyses were used with the regression relation to estimate the rank-order nitrate concentration that corresponds to the rank-order value of 5 pCi/L (the USEPA MCL) for radium-226 plus radium-228 in water from the Kirkwood-Cohansey aquifer system. The method of Iman and Conover (1979) was applied. A ranked value of about 51 for nitrate concentration, which is approximately equivalent to 5 mg/L of nitrate, corresponds approximately to the 67th-percentile concentration for the 76 samples included in this statistical analysis. Above the 67th-percentile of nitrate concentrations, corresponding concentrations of total radium are generally above 5 pCi/L. Water pumped from wells screened in the Kirkwood-Cohansey aquifer system in the study area that are found to contain nitrate in concentrations greater than 5 mg/L may be expected to contain total radium concentrations greater than the USEPA MCL of 5 pCi/L (U.S. Environmental Protection Agency, 1988), with a 99-percent level of confidence.

CHEMICAL CONTROLS ON RADIONUCLIDE MOBILITY AND SOURCES OF RADIONUCLIDES

Results of the Kruskal-Wallis test indicate that water samples from wells in areas where the Bridgeton Formation is present within a 500-m radius of the well head and from areas of agricultural land use within a 500-m radius of the well head have similar chemistry. In this way, the Kruskal-Wallis test results are consistent with the inferences about water chemistry, geology, and land use drawn from the Stiff diagrams, boxplots, summary statistics, and from results of the Spearman rank correlation test. Because virtually all of the Bridgeton Formation outcrop area is agriculturally developed, it is unclear whether geology or land use is more important in determining the chemistry of the ground water. The boxplots discussed previously (figs. 8 and 14) are evaluated to determine whether agricultural land use might have a greater effect on ground-water chemistry than dissolution of minerals from the Bridgeton Formation. The ground-water chemistry is examined in terms of potential impact on radium mobility due to limited capacity of processes that may reduce mobility of radium.

Boxplots and summary statistics of concentrations of inorganic constituents grouped according to the four well-location classes support the notion that agricultural land use has a greater effect on the chemistry of the water in the Kirkwood-Cohansey aquifer system than does dissolution of the weatherable minerals in the Bridgeton Formation. Median concentrations of calcium, magnesium, nitrate, manganese, sodium, potassium, and dissolved solids, are substantially higher, and the median concentration of chloride, barium, and strontium are slightly higher in ground-water samples from areas of agricultural land use than in samples from areas with no agricultural land use (table 5; figs. 14 and 15). These relations persist regardless of the presence or absence of the Bridgeton Formation outcrop area. For example, the median concentrations of magnesium in ground-water samples from areas of agricultural land use, with and without outcrop of the Bridgeton Formation, are 4.6 and 1.4 mg/L, respectively. The median concentrations of magnesium in samples from areas with no agricultural land, with and without outcrops of the Bridgeton Formation are 0.86 and 0.80 mg/L, respectively (table 5 and fig. 14b). The median concentration of magnesium in samples from areas where outcrops of the Bridgeton Formation are absent but agricultural land is present (1.4 mg/L) is greater than the 75th-percentile concentration of magnesium in water samples from areas where outcrops of the Bridgeton Formation is present but agricultural land is absent (0.99 mg/L).

As another example, we consider the median concentrations of both barium and strontium, which are higher in water samples from wells in areas of agricultural land use than in samples from wells in areas with no agriculture, regardless of whether or not the Bridgeton Formation is present (fig. 14c and d). The median concentration of barium and strontium in water samples from wells in areas where the Bridgeton Formation crops out and agricultural land is present is 120 and 54 μg/L, respectively, whereas the median concentration is substantially lower (47 and 13 μg/L, respectively) in water samples from wells in areas where the Bridgeton Formation crops out but there is no agricultural land (table 5). Conversely, the median concentration of barium and strontium in water samples from wells in areas where agricultural land is absent but the Bridgeton Formation crops out (47 and 13 μg/L, respectively) is almost identical or is identical, respectively, to the median concentration of these constituents in samples from wells in areas where neither agricultural land nor outcrops of the Bridgeton Formation is present (54 and 13 μg/L, respectively).

A similar examination of other boxplots in figures 8 and 14 show that the upper quartile (75th percentile and above) of concentration distributions of several constituents (including sulfate, radium-228, radium-226, uranium, and radon-222) are substantially higher in water samples from wells in areas of agricultural land use than in nonagricultural areas, regardless of whether or not the Bridgeton Formation crops out.

Aluminum, alkalinity, and silica (fig. 14) are not preferentially distributed either in areas of the outcrop of the Bridgeton Formation or in areas of agricultural land use. For example, the median concentration of aluminum in water samples from wells in the four well-location classes is nearly identical (range from 100 to 110 μg/L) (table 5). Iron and zinc (table 5) are preferentially distributed in areas where agricultural land use is absent.

These results, in addition to results of the Spearman rank correlation test, the Kruskal-Wallis test, and observations made from the Stiff diagrams and chemical constituent distribution maps, support the hypothesis that intensive agricultural land use, especially in the area where the geology is favorable for such land use, and where soils are well-drained allowing for rapid leaching of agricultural chemicals applied to the soil, exerts significant influence on ground-water chemistry. The higher concentration of dissolved solids observed in water from wells in areas where the Bridgeton Formation or agricultural land are present within a 500-m radius of the well head (fig. 14) relative to water from wells in areas where the Bridgeton Formation or agricultural land within a 500-m radius of the well head is predominantly a consequence of applications of fertilizers and liming materials.

The addition of dolomite, used as a liming agent, to soils accounts for the nearly tenfold increase in divalent cation concentrations in ground water from agricultural areas relative to those areas where agriculture is absent. The application of nitrogen fertilizer to soil in agricultural areas on the Bridgeton Formation outcrop area is the only plausible source of the large concentrations of nitrogen in the ground water in these areas. The oxidation of ammonia-based (nitrification) fertilizer in the unsaturated and saturated zones of the aquifer system is the likely source of the nitrate in ground water (and could generate large amounts of the observed acidity in agricultural areas).

Summary statistics, chemical constituent distribution maps, and boxplots (fig. 8) indicate that agricultural land use also has a more significant effect on the occurrence of elevated concentrations of radium-226 and uranium in water of the Kirkwood-Cohansey aquifer system than does geology. The range of radium-226 concentrations is far greater, and the median and maximum radium-226 concentration is much higher, in samples from wells in areas where agricultural land is present than in samples from wells in areas where it is absent, regardless of the geologic formation that crops out adjacent to the well (fig. 8b). This result indicates that land use has a more significant effect on the presence of elevated concentrations of radium-226 than does geology. In addition, the ranges of the concentrations and the maximum concentrations of uranium, and to a lesser extent of radium-228, are greater in samples from wells in areas where agricultural land is present than in samples from wells in areas where it is absent (fig. 8c and 8d), regardless of the geologic formation that crops out adjacent to the well.

In the absence of agriculture, the presence of the sediments of the Bridgeton Formation alone does not result in relatively elevated concentrations of radon-222, radium-226, radium-228, and uranium in the water of the Kirkwood-Cohansey aquifer system, as illustrated by the median and maximum concentrations of radium-226, radium-228, and uranium, which are lower in the absence of agricultural land within a 500-m radius of the well head when the Bridgeton Formation is present than when it is absent (fig. 8). In the presence of the Bridgeton Formation outcrop within a 500-m radius of the well head, the median and maximum concentrations of radium-226, radium-228, radon-222, and uranium are all higher when agricultural land use is present than when it is absent.

Agricultural land use overlying the Bridgeton Formation is far more intensive (larger in the percent of the area farmed) and produces crops that require more soil additives than the native-fruit crop grown where the Bridgeton Formation is absent. It appears that the enhanced concentration of radium-226, radium-228, and uranium in solution strongly correlates with the intensive application and leaching of agricultural soil additives, a condition most commonly found on the outcrops of the Bridgeton Formation, and are likely not the result of compositional, mineralogical, textural, or other physical properties of the Bridgeton Formation.

The composition and texture of the geologic deposits of the Kirkwood-Cohansey aquifer system vary only slightly on both a local and a regional scale (Owens and others, 1983; Owens and Sohl, 1969). Because the texture of the Kirkwood-Cohansey aquifer system material is fairly uniform, it can be assumed that radon-222 will emanate into ground water in an amount nearly proportionate to the total amount of radon-222 produced from radium-226 in the aquifer material (Andrews and Wood, 1972). The small relative difference of radon-222 concentrations in water from the four well-location classes, therefore, indicates that variations in the radium-226 contents of the aquifer material are not sufficiently large to explain the statistically significant large enhancement of radium-226 in water from wells in areas containing both agricultural land and the Bridgeton Formation outcrop within a 500-m radius of the well head.

If the chemical mobility of radium-226 were uniform throughout the Kirkwood-Cohansey aquifer system, the ratio of the concentration of radon-222 to the concentration of radium-226 would depend only on the distribution of radium-226 in the aquifer matrix. Because of the relative uniformity of the aquifer material, the radon-222 to radium-226 concentration ratio of the water samples would be expected to be relatively uniform. The ratios of the concentrations of radon-222 to the concentrations of radium-226 in most of the water samples from the aquifer from areas where the Bridgeton Formation is present within a 500-m radius of the well head range approximately from 30:1 to 300:1. For water samples from wells where the Bridgeton Formation is absent within a 500-m radius of the well head, however, the ratios of the concentrations of radon-222 to the concentrations of radium-226 range approximately from 200:1 to 2,000:1. Differences in these ratios are a result of increasing radium-226 concentrations in ground water from where the Bridgeton Formation outcrop (and associated intensive agricultural land use) is present. This result indicates relative differences in the mobility of chemically active radium-226, depending upon the chemical composition of the water, between areas where the Bridgeton Formation (and associated intensive agricultural land use) is present and where it is absent.

The ratio of the concentration of radon-222 to the concentrations of radium-226 in ground water decreases by a factor of about 100 (from approximately 2,000 to 20) with increasing concentrations of nitrate (fig. 25a) and barium (fig. 25b). This inverse relation between the ratio of the concentrations of radon-222 to radium-226 and the concentrations of barium and nitrate is most pronounced for samples collected from wells in the Bridgeton Formation outcrop area (fig. 25), where agricultural land use is more prevalent than in other parts of the study area. The strong positive correlations among the concentrations of barium, nitrate, and radium-226 (table 7) indicate that concentrations of nitrate, barium, and other divalent cations are associated with increasing mobility of radium-226. Concentrations of nitrate and barium (and other divalent cations) dissolved in ground water show no correlation with the concentration of dissolved chemically inert radon-222.

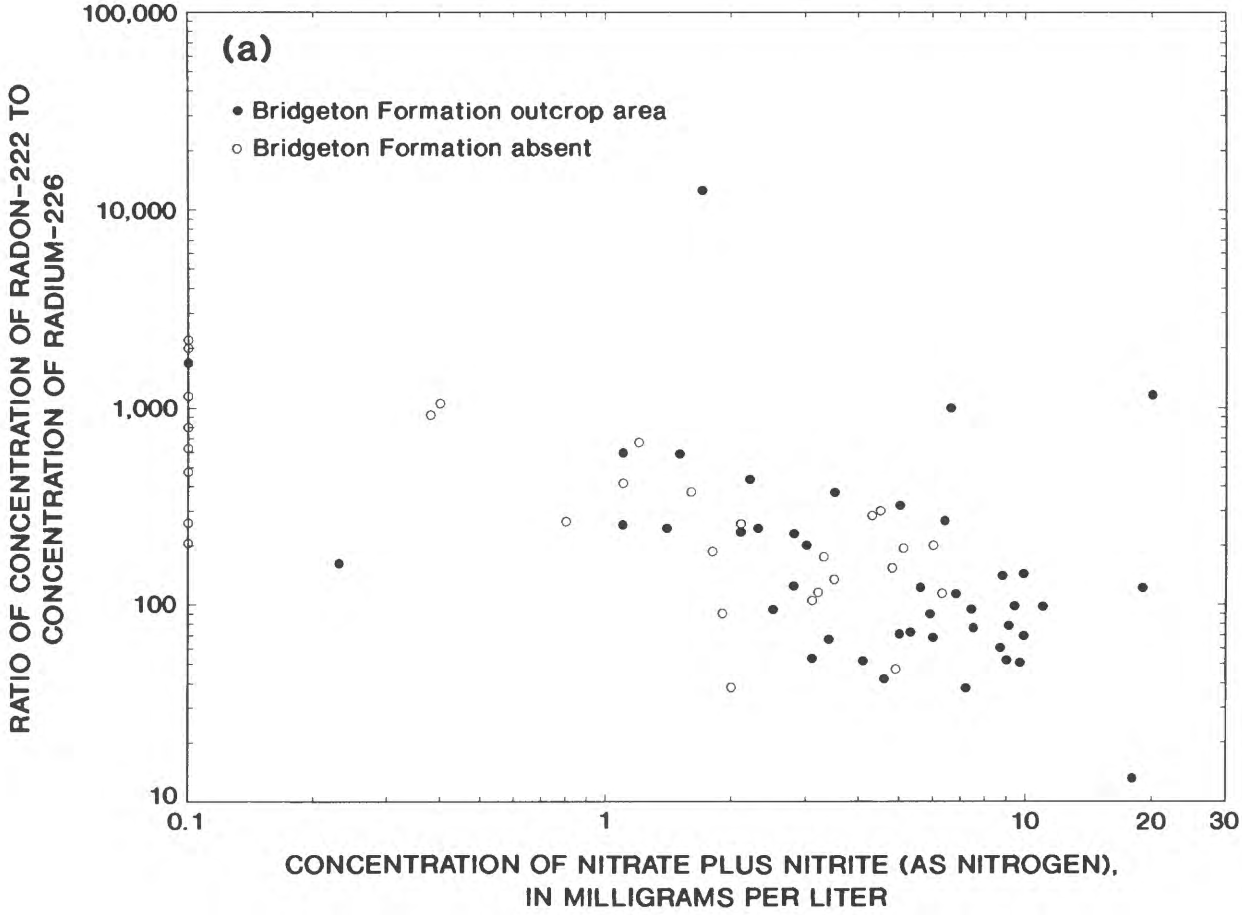


Figure 25. Relation of the ratio of the concentration of radon-222 to the concentration of radium-226 to (a) the concentration of nitrate plus nitrite (as nitrogen); and (b) the concentration of barium in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89.

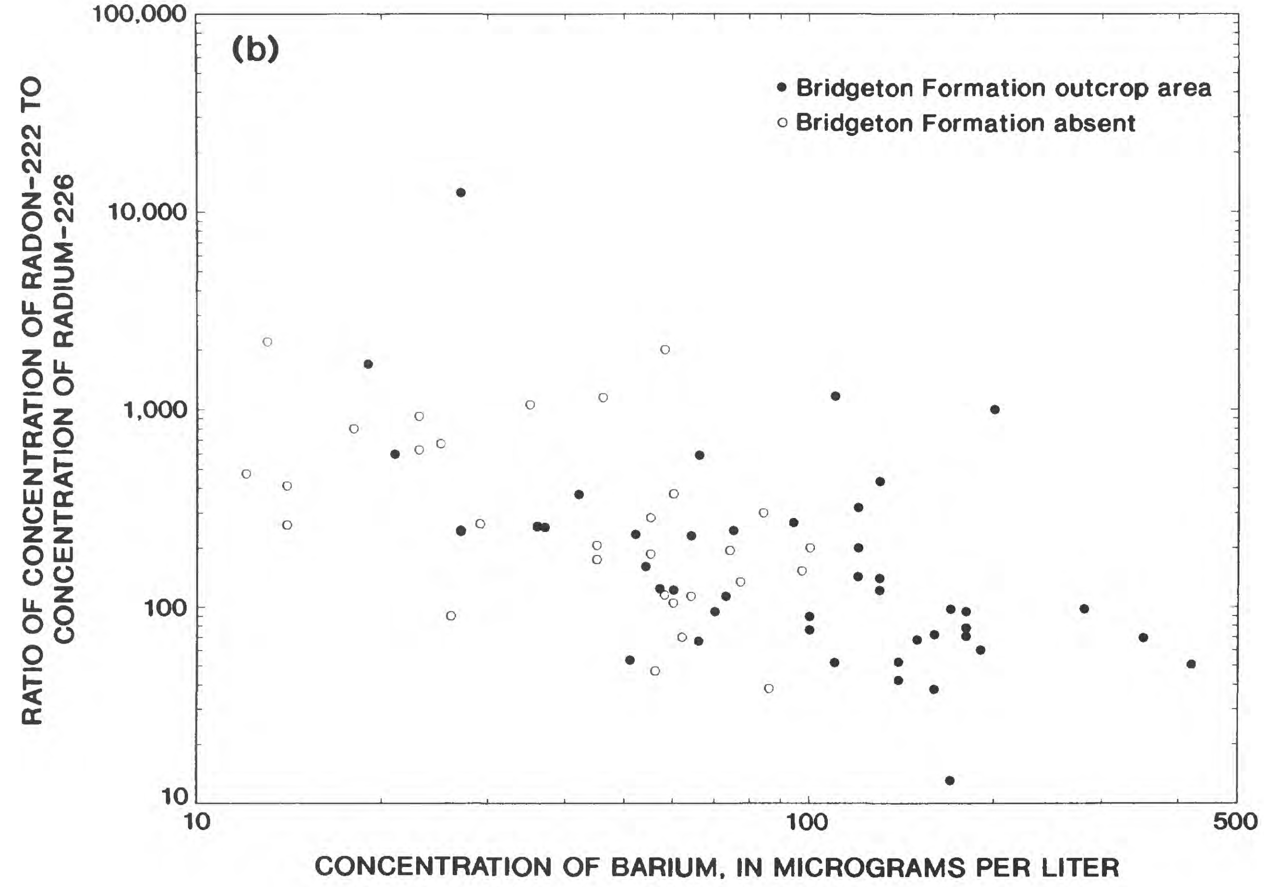


Figure 25. Relation of the ratio of the concentration of radon-222 to the concentration of radium-226 to (a) the concentration of nitrate plus nitrite (as nitrogen); and (b) the concentration of barium in samples of water from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89. --Continued

Chemical Mechanisms

Chemical controls on the mobility of radium are potentially numerous, and include: sorption, cation exchange, and coprecipitation. These controls do not appear to limit radium concentrations in water of the Kirkwood-Cohansey aquifer system in the presence of agricultural land use. The sorption capacity of the aquifer is low due to the low pH of the ground water. Cation exchange is not effective because of the high concentration of divalent cations in agricultural areas, with the high corresponding competition for exchange sites resulting in radium mobility. The absence of coprecipitation of radium with barium in the mineral barite is due to the relatively low concentration of sulfate in the water. In addition, formation of soluble uranium-chloride complexes in areas of agricultural land use may explain increased concentration of uranium in the ground water in such areas. The addition of agricultural chemicals containing uranium and radium-226 cannot, however, be completely ruled out as a minor source of these radionuclides; although, it may be argued that uranium and radium-226 from this source could be immobilized under different geochemical conditions than are present in this aquifer.

Adsorption of Radium

Adsorption onto the aquifer matrix limits the concentrations of most trace elements in ground water (Jenne, 1968). Radium is strongly sorbed from solution by numerous secondary and detrital minerals common in sediments (Ames and others, 1983). Sorption capacity differs with the type of aquifer material. Iron- and manganese-oxide and -hydroxide coatings on mineral grains of the aquifer material are stable in ground water where pH and Eh are above critical minimum values and strongly adsorb radium (Ames and others, 1983);therefore, they are potential sorbents of radium in the Kirkwood-Cohansey aquifer system. Experimental studies show kaolinite, illite, and even silica can adsorb radium, but only in limited quantities (Benes and others, 1984); these minerals may adsorb some small quantities of radium from water in the Kirkwood-Cohansey aquifer system.

The capacity of the sorption process to remove positively charged ions from solution decreases with decreasing pH. The pH at which the surface charge of a particle in an aquifer is zero is termed the "zero point of charge" (Stumm and Morgan, 1981, p. 628). As pH falls below the zero point of charge, the surface charge of a particle becomes increasingly positive, and the ability of the particle to attract cations (the adsorption capacity) decreases (Stumm and Morgan, 1981, p. 630). The sorption capacity of mineral-grain surfaces in the aquifer matrix for trace cations, such as radium, therefore, decreases with decreasing pH.

Iron oxides and hydroxides in the Kirkwood-Cohansey aquifer system may have negligible cation-sorption capacities because the pH of the ground water is below the typical zero point of charge (6 to 8) for these sorbents (Stumm and Morgan, 1981, p. 631). Manganese-oxide and -hydroxide grain coatings may be effective adsorbents of trace cations even in the Kirkwood-Cohansey aquifer system, because some manganese-oxide phases do not reach the zero point of charge until the pH is approximately 4 (Stumm and Morgan, 1981, p. 631).

Manganese oxides and hydroxides are less abundant in the aquifer matrix than are iron oxides and hydroxides (Owens and others, 1983); therefore, manganese oxides and hydroxides can adsorb only small quantities of trace elements (such as radium).

The low pH of the ground water in the Kirkwood-Cohansey aquifer system not only results in poor cation-sorption capacity for iron and manganese hydroxides and oxides, but reduce sorption capacity of the aquifer because iron and manganese oxides and hydroxides are soluble in the strongly acidic ground water. Even in samples of oxygenated ground water, substantial concentrations of iron and manganese were noted (app. 2). Corrosion or dissolution of the iron and manganese oxides and hydroxides decreases their effectiveness as adsorbents of trace cations, such as radium. Concentrations of dissolved radium generally are highest where pH is low in the Kirkwood-Cohansey aquifer system (fig. 19). Dissolved radium concentrations, however, increase only gradually with decreasing pH indicating some capacity for the aquifer to adsorb radium even at pH values as low as 4.5.

The degree of competition for sorption sites on mineral-grain surfaces from other similarly charged ions, in addition to pH, also controls the sorption capacity of the Kirkwood-Cohansey aquifer system for radium. Such competition may be especially important for sorption sites on the surfaces of clay minerals. Competition with the divalent radium cation for adsorption sites in the aquifer system is provided by divalent cations such as barium, calcium, magnesium, and strontium, the concentrations of which increase greatly with the increasing concentration of dissolved solids. With increasing amounts of barium, calcium, magnesium, and strontium, mineral-grain surfaces sorb greater amounts of these divalent cations, thereby replacing or excluding radium from sorption sites on the aquifer matrix (Miller and Sutcliffe, 1985; Langmuir and Melchoir, 1985). Competing divalent cations replace adsorbed radium or prevent the adsorption of newly formed radium that is continuously being generated by radioactive decay in the aquifer. Hence, in the Kirkwood-Cohansey aquifer system, concentrations of radium are observed to increase with increasing concentrations of dissolved solids (fig. 20b) and dissolved divalent cations such as magnesium (fig. 23b) or barium (fig. 24b).

The correlations of radium concentration with dissolved-solids concentration, divalent-cation concentration, and acidity (negative correlation with pH) indicate that the sorption process is not effective in limiting concentrations of radium in the ground water of the Kirkwood-Cohansey aquifer system. The naturally low sorption capacity of the aquifer matrix is decreased further where the divalent-cation concentration and acidity are high. These conditions are most prevalent in ground water in areas of agricultural land use in the Bridgeton Formation outcrop area.

The concentrations of nitrate and chloride correlate positively with concentrations of radium and other divalent cations; but these dissolved constituents are anionic and hence do not directly increase radium mobility through competition for sorption sites. The correlation of radium concentrations with the concentrations of the anions nitrate and chloride is possibly fortuitous and results from the leaching of the nitrogen and chloride from fertilizer and salts added to the soil in agricultural areas, along with similar leaching of divalent cations that are added to soil as liming agents.

Nitrification of ammonia-based fertilizers generates large quantities of hydrogen ions (Denver, 1986); as such, it is likely the mechanism directly responsible for both the increased nitrate concentration and generally high acidity of ground water in areas where agricultural land use is present. The carbonate ion resulting from the dissolution of dolomite added to soil as lime, combines with the hydrogen ions that are generated by the nitrification process to produce carbonic acid (Denver, 1986), maintaining a large reservoir of acidity in solution. Nitrification of ammonia-based fertilizer and leaching of lime appear indirectly responsible for the low capability of the Kirkwood-Cohansey aquifer system to adsorb radium in agricultural areas.

Coprecipitation of Radium With Barite

Coprecipitation of radium with barite (barium sulfate) in barium- or sulfate-rich water is a process that can control the concentration of dissolved radium in some aquifers (Langmuir and Riese, 1985). This process is not a significant factor in the Kirkwood-Cohansey aquifer system. Concentrations of both dissolved radium-226 and radium-228 increase with increasing concentrations of dissolved barium in the Kirkwood-Cohansey aquifer system (fig. 24b), but show no relation to concentrations of sulfate (table 7). The concentrations of both sulfate (median 4.6 mg/L; range 0.2-60 mg/L) and barium (median 64 µg/L; range 12-420 µg/L) are relatively low when compared to typical ground water (Hem, 1985). Calculations made with the geochemical-speciation computer model SOLMINEQ.88 (Kharakha and others, 1989) indicate that the water is undersaturated with respect to barite in nearly all of the 81 wells sampled in 1988-89. Therefore, neither the concentration of barium nor the concentration of radium in solution is limited by barite precipitation.

Complexation of Uranium

In acidic water, uranium tends to form soluble complexes with sulfate (Langmuir, 1978) and, to a lesser extent, fluoride (Langmuir, 1978) and chloride (Herczeg and others, 1988). As concentrations of sulfate and chloride in the ground water in the Kirkwood-Cohansey aquifer system increase, concentrations of uranium increase slightly (fig. 22a, table 7), indicating complexation of uranium with these anions. Results of calculations made with the geochemical-speciation computer model SOLMINEQ.88 (Kharaka and others, 1988) indicate that the uncomplexed UO_2+^2 ion is an important and, in many cases, the dominant uranium species in solution. Other important uranium species include UO_2SO_4, UO_2F^+, $UH_3SiO_6^+$, and UO_2Cl^+, and, in samples that contain detectable alkalinity, the UO_2CO_3 species also is present in solution. Because many of these complexes are cationic, the concentration of dissolved solids in the ground water is directly related to the solubility of uranium as a result of competition for cationic sorption sites in the aquifer matrix, and correlation of uranium concentrations is noted with those of magnesium and barium (table 7). Correlations of the concentration of uranium with concentrations of chloride, nitrate, barium, and magnesium, which are representative of leachate from chemically fertilized soils, are significant. These correlations may result from enhanced chemical mobility of uranium from the aquifer matrix in the presence of these constituents, as is the case for radium-226, rather than from the fact that uranium is derived from the fertilizer itself.

Sources of Radionuclides

Phosphate-bearing fertilizers can contain substantial concentrations of uranium and radium-226 (Roessler and others, 1979) but generally contain little thorium or radium-228. The ratio of uranium to thorium in phosphate rocks used in the manufacture of phosphate fertilizers generally ranges from 3 to 20 (Menzel, 1968). The sandy sediments that comprise the Kirkwood-Cohansey aquifer system are not known to be enriched in either thorium- or uranium-bearing minerals (Owens and others, 1983). Sandy sediments generally contain greater concentrations of thorium than uranium (Hem, 1985) indicating that radium-228:radium-226 ratios should be 1 or greater. Chemical data from the 81 well-water samples were examined to see if they support the hypothesis that the primary source of dissolved radium and uranium in the Kirkwood-Cohansey aquifer system is the aquifer material, and not phosphate-bearing fertilizers.

Aquifer Materials as a Source of Radium

The ratios of the concentration of radium-228 to the concentration of radium-226 in water samples from the Kirkwood-Cohansey aquifer system would generally be greater than 1, if the predominant source of the dissolved radium were the sedimentary material that comprises the aquifer. The median value of this ratio for 81 well-water samples is, in fact, slightly greater than 1, and most samples have a ratio that falls close to this value (fig. 16b). If phosphate fertilizers were the dominant source of radium in the ground water, sharply decreasing ratios of the concentration of radium-228 (derived from thorium) to the concentration of radium-226 (derived from uranium) would be expected to accompany increasing radium concentrations. The ratios of the concentration of radium-228 to the concentration of radium-226 would also be expected to show a strong inverse correlation with amounts of fertilizer leachate (indicated by high concentrations of nitrate and barium) in the ground water. These concentration ratios (calculated for samples in which both radium-226 and radium-228 were detected) show no correlation with nitrate or barium concentrations. The result indicates that the dominant source of radium in the ground water is most likely not uranium-enriched phosphate fertilizer.

Radon-222 in ground water generally ranges in concentration from 100 to 400 pCi/L (fig 8a) in areas where agricultural land (and, therefore, fertilizer application) is absent. The aquifer material must, therefore, contain radium-226 at a concentration high enough to decay to radon-222 concentrations of at least this magnitude, because this amount of radium-226 is not observed in the ground water. The aquifer matrix is, therefore, more than sufficiently rich in radium-226 to supply the concentrations of dissolved radium-226 (and, by inference, the concentrations of radium-228).

The ratio of the concentrations of uranium to radium-226 in processed phosphate fertilizers generally range from 3 to 20 (Roessler and others, 1979). Therefore, the value of this ratio for the water in the Kirkwood-Cohansey aquifer system should exceed 1 if processed phosphate-bearing fertilizers were the dominant source of these radionuclides (and the solubilities of the uranium and radium were similar). Instead, the observed ratio of the concentration of uranium (considered in terms of activity of 0.34 pCi/L per μg/L) to the concentration of radium-226 generally are low (less than 0.1). The ratio of the concentrations of uranium to radium-228 in phosphate fertilizers can be calculated to be even higher than the ratio of the concentrations of uranium to radium-226. Nevertheless, the ratios of concentrations of uranium to radium-228 in the ground water are also low.

Phosphate Fertilizer

The slightly greater significance of the association of elevated uranium and radium-226 concentrations with the presence of agricultural land use relative to that of elevated radium-228 concentrations with the presence of agricultural land use (table 9) indicates that the possibility exists that a small portion of the uranium and the radium-226 in the ground water in agricultural areas may be derived from phosphate fertilizer rather than from the aquifer material. Chemical testing of aquifer materials and phosphate fertilizers is necessary to determine their uranium, radium-226, and radium-228 contents in order to verify their relative importance as sources of the uranium and radium in the ground water.

SUMMARY AND CONCLUSIONS

A study of the effects of geology, geochemistry, and land use on the distribution of naturally occurring radionuclides dissolved in ground water in the Kirkwood-Cohansey aquifer system in the Coastal Plain of New Jersey was conducted during 1988-89 in all or parts of Atlantic, Camden, Cumberland, Gloucester, and Salem Counties. The Kirkwood-Cohansey aquifer system is composed predominantly of quartz-sand and gravel of the Kirkwood Formation, the Cohansey Sand, and, in some places, the Bridgeton Formation and the Cape May Formation. The Cape May and Bridgeton Formations are predominantly gravel.

A large percentage of the study area underlain by the Bridgeton Formation is developed for agricultural use (Fegeas and others, 1983). Irrigation of agricultural land commonly is necessary because of the low moisture capacity of the well-drained soils developed on the Bridgeton Formation. Irrigation tends to increase the leaching of nutrients (such as calcium, magnesium, and nitrate) from the soil. Because soils developed on the Bridgeton Formation are well-drained and naturally low in nutrients, these soils require the application of large amounts of fertilizers and lime for optimal crop production. The amount of fertilizer and lime added to the soil varies depending on the crop.

Results of routine monitoring of radioactivity in public supply wells that tap the Kirkwood-Cohansey aquifer system in southern New Jersey indicated the presence of elevated gross-alpha particle activities and concentrations of radium in the ground water. These findings prompted an investigation of the presence and distribution of naturally occurring radionuclides in ground water in the Kirkwood-Cohansey aquifer system in southern New Jersey.

In 26 of 81 wells screened in the Kirkwood-Cohansey aquifer system from which water samples were collected during 1988-89, the sum of the concentrations of radium-226 and radium-228 was greater than the MCL of 5 pCi/L. In 12 of 81 well-water samples, gross alpha-particle activity was greater than the MCL of 15 pCi/L. The sum of the concentrations of radium-226 and radium-228 ranged from less than 1.1 to 14.5 pCi/L with a median value of 3.85 pCi/L. Ratios of the concentration of radium-226 to the concentration of radium-228 were approximately 1 in most samples, indicating that the source of the radium is not enriched in uranium relative to thorium. The median uranium concentration was 0.30 μg/L (maximum concentration 0.62 μg/L), and the median radon-222 concentration was 280 pCi/L (maximum concentration 1,900 pCi/L), indicating the aquifer material contains relatively little soluble uranium or its daughter products.

Concentrations of radium-226 and radium-228 tended to be higher in water samples from wells in areas where Bridgeton Formation outcrop and agricultural land are present within a 500-m radius of the well head than in water samples from wells in areas where the Bridgeton Formation and agricultural land use are absent within a 500-m radius of the well head. Leaching of uranium and radium from the minerals of the Bridgeton Formation is suspected to be a source of the uranium and radium in the ground water. Concentrations of uranium and radon-222 appeared to increase in areas where Bridgeton Formation and areas of agricultural land are present within a 500-m radius of the well head, but results of statistical tests indicate that the geographic distribution is not statistically significant.

Samples of water from the Kirkwood-Cohansey aquifer system contained low concentrations of dissolved solids (median concentration 45 mg/L) and were acidic (median pH 4.90). The predominant ions in the water samples were calcium, chloride, magnesium, nitrate, potassium, and sodium. Concentrations of the inorganic constituents in the water were higher if the well from which the sample was collected was located in an area where the Bridgeton Formation or agricultural land use was present within a 500-m radius of the well head rather than areas where the Bridgeton Formation or agricultural land were absent within a 500-m radius of the well head. Values of pH, however, tended to decrease especially where the Bridgeton Formation was present within a 500-m radius of the well head. Results of the Kruskal-Wallis statistical test indicate that the geographic relation between constituent concentration and the presence or absence of the Bridgeton Formation or agricultural land within a 500-m radius of the well head is not random. Oxidation of ammonia-based fertilizer and dissolution of dolomite applied to soils in agricultural areas as crop nutrients are, respectively, sources of increased concentrations of nitrate and divalent cations such as calcium, magnesium, strontium, and barium in ground water from areas of agricultural land use.

The sum of the concentrations of radium-226 and radium-228 are positively correlated with concentrations of aluminum, barium, calcium, chloride, magnesium, nitrate, potassium, sodium, strontium, and dissolved solids. The sum of the concentrations of radium-226 and radium-228 increased with decreasing pH. Of 26 ground-water samples in which the sum of the concentrations of radium-226 and radium-228 exceeded the USEPA MCL of 5 pCi/L, 81 percent (21 samples) had a pH less than 4.8. The correlation of radium concentrations with the concentrations of chemical constituents added to soil in agricultural areas indicates that leaching of radium may be enhanced by the chemical processes in ground water that are associated with the addition of agricultural chemicals to the geochemical system.

Because the pH of the water samples from the Kirkwood-Cohansey aquifer system was low, we assume the aquifer matrix has little or no sorption capacity. Furthermore, in areas where the Bridgeton Formation or where agricultural land is present within a 500-m radius of the well head, the dissolved concentration of divalent cations was as much as an order of magnitude greater than that from areas where the Bridgeton Formation or agricultural land use are absent within a 500-m radius of the well head. Increased competition of divalent cations, such as calcium, magnesium, strontium, and barium, with radium for the limited number of adsorption sites is a result of the increase in divalent cation concentration. Both the low pH of the ground water and the elevated concentrations of these divalent cations are likely causes of increased dissolved radium concentrations in areas of agricultural land use relative to where agricultural land use is absent.

The sum of the concentrations of radium-226 and radium-228 in ground water correlates positively with nitrate concentration. Results of a rank order regression model indicate that this relation is significant at a 99.9-percent confidence level. In ground-water samples containing nitrate in a concentration of approximately 5 mg/L, the sum of the concentrations of radium-226 and radium-228 is expected to be 5 pCi/L, with 99 percent confidence.

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GLOSSARY

Alpha-particle emission: Radioactive decay resulting in the ejection of the nucleus of a helium atom from the nucleus of the radionuclide undergoing the decay.

Alpha-recoil: Energy imparted to the product radionuclide formed from radioactive emission of an alpha particle causing the product radionuclide to move a slight distance resulting in structural damage to the surrounding crystal lattice.

Altitude: As used in this report, "altitude" refers to the distance above or below sea level.

Aquifer: A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Beta-particle emission: Radioactive decay resulting in the ejection of an electron particle from the nucleus of the radionluclide undergoing the decay.

Confining unit: A body of less permeable material stratigraphically adjacent to one or more aquifers. The hydraulic conductivity of a confining unit may range from nearly zero to some value significantly lower than that of the aquifer.

Delaware River estuary: That segment of the Delaware River, excluding the bay, from river mile 48.23 at the mouth of the Delaware River to river mile 133 at the head of tide at Trenton, N.J.

Dissolved: Chemical constituents in a water sample that pass through a 0.45-micrometer membrane filter. This is a convenient operational definition used by Federal agencies that collect water data. Determinations of "dissolved" constituents are made on subsamples of the filtrate.

Element: Any substance identified by a specific number of protons in its nucleus (known as the atomic number) that cannot be separated into smaller component substances except by nuclear disintegration (radioactivity).

Field-measured characteristics: A phrase used to identify characteristics determined in the field when the water sample is collected. Water temperature, specific conductance, pH, and dissolved oxygen are considered field-measured characteristics in this study.

Ground water: Water that saturates soil, unconsolidated deposits, and (or) bedrock beneath the land surface.

Isotope: Any of two or more forms of an element that have different atomic weights due to different numbers of neutrons found in the nucleus. The chemical properties of isotopes are identical.

Isotropy: The condition in which all significant properties are independent of direction.

Maximum contaminant level: Maximum permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system.

Micrograms per liter (μg/L): A unit expressing the concentration of chemical constituents in solution as the mass (microgram = 1×10^{-6} gram) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. One microgram per liter is approximately equal to 1 part per billion (ppb) in aqueous solutions of low dissolved-solids concentration.

Milliequivalent: A number computed by multiplying the reported concentration of an individual ion, in milligrams per liter, by the valence charge of the ion and then dividing the result by the formula weight of the ion in grams.

Milligrams per liter (mg/L): A unit expressing the concentration of chemical constituents in solution as the mass (milligram) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For water containing less than 7,000 mg/L dissolved solids, the numerical value for milligrams per liter of a constituent is the same as for concentrations in parts per million (ppm).

Minimum reporting limit: For a given type of sample and analytical procedure, the concentration value below which the presence of the constituent being analyzed can be neither verified nor denied. Minimum detection limits can be identified in the tables of this report by a "less-than" (<) symbol preceding a numerical value. The reported minimum detection limit can vary from analysis to analysis for any single constituent.

Outcrop: As used in this report, outcrop areas are defined as areas where a geologic or hydrogeologic unit is exposed at land surface.

Picocuries per liter (pCi/L): A unit expressing the concentration of radioactive constituents in solution as the radioactivity (picocuries) of the solute per unit volume (liter) of water. One picocurie is equal to 1×10^{-12} Curies, where one Curie is the amount of radiation emitted by one gram of radium. One picocurie represents 2.2 radioactive decays per second.

Radioactivity: The disintegration of the nucleus of an atom of an element giving off energy in the forms of alpha (a nucleus of a helium atom) and beta (an electron) particles and in gamma rays. A different element is produced by the radioactive decay.

Radioactive-decay series: The series of radionuclides successively formed by the radioactive decay of a long-lived parent radionuclide before a stable isotope of a product element is formed.

Radionuclide: A specific isotope of an element that is radioactive (will undergo a form of radioactive decay).

Specific conductance: A measure of the capacity of a water to conduct an electrical current, expressed in microsiemens per centimeter at 25 degrees Celsius.

Appendix 1.--Selected well-record information for wells used to assess chemistry of water in the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89

[--, data unavailable]

New Jersey well number	New Jersey permit number	Latitude	Longitude	Altitude of land surface (feet)	Top of open interval (feet below land surface)	Bottom of open interval (feet below land surface)	Diameter of open interval (inches)	Primary use of site[1]	Primary use of water[2]
Atlantic County									
1-0005	--	392511	743052	10	180	210	--	W	P
1-0013	36-00299	392554	743027	20	178	205	10.0	W	P
1-0044	--	393027	745757	110	--	--	--	W	I
1-0069	--	393240	745619	125	--	--	--	W	I
1-0074	--	392732	745342	80	--	--	--	W	I
1-0087	35-00873	392836	745353	100	41	85	17.0	W	I
1-0094	35-00998	392914	745609	85	100	120	4.0	W	I
1-0109	--	393004	745335	100	42	47	2.0	W	S
1-0115	--	393124	743240	50	--	--	--	W	I
1-0134	--	392241	743544	35	105	135	5.0	W	I
1-0135	36-00429	392244	743455	20	92	127	12.0	W	P
1-0136	--	392255	743503	20	64	70	2.0	Z	U
1-0138	36-00404	392254	743434	15	99.7	123	16.0	W	P
1-0154	--	392515	743824	55	127	157	8.0	W	F
1-0163	--	393414	744927	60	48	53	2.0	W	H
1-0168*	--	393700	745110	80	153	168	6.0	W	N
1-0169	--	393711	745124	90	96	104	3.0	W	H
1-0172	36-00426	392650	742752	10	161	201	12.0	W	I
1-0179	36-00265	392723	742945	70	58	64	1.5	W	H
1-0181	--	392807	743151	60	80	110	8.0	W	H
1-0183	36-00443	392842	743222	45	172	192	8.0	W	P
1-0185	36-00392	392919	743605	70	140	173	8.0	W	N
1-0193	36-00425	392938	743127	40	130	150	8.0	W	T
1-0201	--	393114	743654	55	-	--	--	W	I
1-0202	--	393114	743654	55	-	--	--	W	I
1-0206	36-00393	393116	743513	55	20	100	8.0	W	I
1-0226	36-00353	392658	743751	70	53	64	6.0	W	H
1-0227	36-00391	392710	744440	10	316	347	12.0	W	P
1-0230*	36-00441	392722	743845	70	65.7	85.7	8.0	C	P
1-0232	36-00399	392724	743824	70	129	151	11.7	W	C
1-0244*	36-00352	393047	744114	65	45	55	6.0	W	H
1-0250	32-00474	393303	744413	75	142	157	8.0	Z	U
1-0256	32-00173	393333	744426	93.19	254	275	8	O	U
1-0279	51-00039	393757	744825	110	268	320	10.0	W	P
1-0285*	51-00001	393818	744843	105	--	--	--	W	N
1-0286	31-05052	393815	744728	85	45	100	4.0	W	I
1-0288	--	393828	744519	45	--	--	--	W	I
1-0290	--	393822	744002	15	--	--	--	W	I
1-0309	--	393904	744402	65	--	--	--	U	U
1-0323*	--	393932	744820	100	153	165	6.0	W	A
1-0325	--	393927	744602	65	--	--	--	W	I
1-0348	--	394316	744415	50.1	10	15	2.0	U	U
1-0352	--	394156	744508	54	20	25	2.0	U	U
1-0353	36-00315	392001	743522	10	56	71	12.0	W	P

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[1] C, standby or emergency; O, observation; T, test; U, unused; W, withdrawal; Z, destroyed.

[2] A, air conditioning; F, fire; C, commercial; H, domestic; I, irrigation; J, industrial, cooling; N, industrial; P, public-supply; S, stock; T, institutional; U, unused.

* Indicates these wells were sampled for this study (see app. 2). Results of chemical analyses of samples from all other wells listed are stored in the WATSTORE data base maintained by the U.S. Geological Survey.

Appendix 1.--Selected well-record information for wells used to assess chemistry of water in the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89--Continued

New Jersey well number	New Jersey permit number	Latitude	Longitude	Altitude of land surface (feet)	Top of open interval (feet below land surface)	Bottom of open interval (feet below land surface)	Diameter of open interval (inches)	Primary use of site[1]	Primary use of water[2]
				Atlantic County--continued					
1-0378	32-00529	393359	744056	75	36	48	17.0	W	I
					70	93	17.0		
					163	176	17.0		
1-0383	--	393447	744245	95	72	80	5.0	W	T
1-0387	--	393557	744114	60	--	--	--	U	U
1-0388	--	393604	744459	95	97	108	6.0	W	H
1-0391	--	393638	743808	35	84	91	3.0	W	H
1-0542	--	394028	744000	20	66	76	8.0	O	U
1-0549	36-00008	392157	743317	25	117	152	10.0	W	P
1-0574	56-00029	392510	743031	7	160	195	--	W	P
1-0575	56-00033	392548	743119	5	145	195	12.0	W	P
1-0582	36-00021	391906	743629	15	79	99	10.0	W	P
1-0589	36-00388	391924	743550	19	129	159	12.0	W	P
1-0592	--	391957	743606	10	80	110	--	U	U
1-0601	--	392428	744953	80	--	--	--	W	H
1-0604	36-02064	391826	744620	20	101	111	6.0	W	P
1-0611	--	393727	744901	100	--	--	--	W	I
1-0628	31-04487	393856	744939	120	--	--	--	W	H
1-0639	35-01187	393059	745850	100	100	160	6.0	W	I
1-0640	31-14272	393632	744839	75	80	100	8.0	W	I
1-0655	31-18310	393625	744840	75	58	98	4.0	W	I
1-0688	36-02432	392945	742830	30	130	180	12.0	W	P
1-0695	36-02463	392308	743521	25	100	130	10.0	W	P
1-0699	35-04370	392933	744604	40	130	160	2.0	O	U
1-0712	35-04796	392902	745051	90	377	387	4.0	O	U
1-0713	35-04656	392902	745051	90	525	535	4.0	O	U
1-0714	35-04904	391946	745125	40	63	73	4.0	O	U
1-0717	35-0655514	392933	743130	40	320	330	4.0	O	U
1-0718	35-05166	391957	744657	35	23.2	26.2	2.0	O	U
1-0719	31-23946	393241	744818	70	35	38	2	O	U
1-0720	31-23945	393549	745059	65	19	22	2.0	O	U
1-0721	36-06133	393145	743009	30	22.9	25.9	2.0	O	U
1-0731	32-06391	393220	743530	45	100	105	2.4	W	H
1-0732	32-06391	392102	743400	25	89.5	95	2.0	W	H
1-0739	36-03596	391850	744818	10	92	102	4.0	W	I
1-0742	36-05648	392606	744156	60	32	52	4.0	O	U
1-0762*	36-02642	393348	744150	80	76	81	2.0	W	H
1-0763*	--	392658	744731	70	57	60	2.0	W	H
1-0764	36-00409	392216	73758	50	94	114	8.0	W	T
1-0765	32-05988	393351	743230	10	76	81	2.0	W	H
1-0766	36-04862	392130	744142	20	132	140	3.8	W	H
1-0767*	36-03305	391949	743854	10	120	126	2.4	W	H
1-0768	36-04205	392247	743500	20	107	112	2.0	W	H
1-0769	36-04980	392444	744243	10	132	139	2	W	H
1-0770*	36-03612	392241	744933	80	60	70	4.0	W	T

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[1] C, standby or emergency; O, observation; T, test; U, unused; W, withdrawal; Z, destroyed.

[2] A, air conditioning; F, fire; C, commercial; H, domestic; I, irrigation; J, industrial, cooling; N, industrial; P, public-supply; S, stock; T, institutional; U, unused.

* Indicates these wells were sampled for this study (see app. 2). Results of chemical analyses of samples from all other wells listed are stored in the WATSTORE data base maintained by the U.S. Geological Survey.

Appendix 1.--Selected well-record information for wells used to assess chemistry of water in the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89--Continued

New Jersey well number	New Jersey permit number	Latitude	Longitude	Altitude of land surface (feet)	Top of open interval (feet below land surface)	Bottom of open interval (feet below land surface)	Diameter of open interval (inches)	Primary use of site[1]	Primary use of water[2]
Atlantic County--continued									
1-0771	--	392113	743223	5	117	120	--	W	H
1-0774	--	392457	744355	10	160	180	8.0	W	U
1-0775	--	392639	743232	38.1	132	182	4.0	O	U
1-0776	--	392639	743232	38.1	73	93	4.0	O	U
1-0793*	--	393149	745554	105	74	106	8	W	N
1-0794*	35-0600	391820	744622	20	110	120	6	W	T
1-0832	36-02955	392150	743457	20	77	83	2	W	I
1-0833*	36-00461	392959	744107	55	50	80	6	W	F
Camden County									
7-0430	--	394204	744921	93.8	115	120	--	O	U
7-0442	--	394455	745043	101.0	19	24	--	O	U
7-0444	--	394553	744739	78.3	21	26	--	O	U
7-0451	--	394628	744923	122.4	161	166	--	O	U
7-0464*	--	394038	744958	90	144	151	3.0	W	P
7-0479	--	394215	745617	110	200	210	--	O	U
7-0490*	31-05542	394248	745710	115	73	103	16.0	W	P
7-0497*	31-05543	394332	745740	120	64	90	16.0	W	P
7-0500*	51-00034	394417	745538	160	113	138	8.0	W	N
7-0503	31-05926	394440	745931	173.3	71	76	6.0	O	U
7-0506*	31-05342	394446	745418	180	115	125	6.0	W	T
7-0603*	31-16697	394414	750016	140	100	120	12.0	W	P
7-0671*	--	394107	745123	105	116	141	12	W	T
7-0675*	31-26723	394413	750050	165	80	120	4.0	O	U
7-0676*	31-27652	394348	750041	165	79	99	4.0	O	U
7-0677*	31-27549	394357	750116	150	40	60	4.0	O	U
Cumberland County									
11-0002*	34-00561	392430	751313	20	72	98	18.0	W	P
11-0003*	54-00003	392437	751305	40	84	104	18.0	W	P
11-0013*	34-00598	392552	751450	70	76	117	12.0	W	P
11-0020*	54-00001	392641	751329	80	91	111	--	W	P
11-0022*	34-00712	392650	751331	60	99	129	12.0	W	P
11-0042*	35-01145	392732	750929	80	42	47	4.0	O	V
11-0043*	35-01146	392732	750929	80	133	138	4.0	O	V
11-0052	35-01299	391420	751023	10	283	303	8.0	W	P
11-0073*	--	392508	751846	37.3	35	40	4.0	O	U
11-0083	34-00618	392832	751738	100	37	69	17.0	W	I
11-0093	34-00041	391824	751329	20	37	62	5.0	W	I
11-0097*	--	391829	751208	10	166	171	4.0	O	U
11-0100	34-00460	391842	751337	20	48	74	17.0	W	I
11-0118	--	391350	750018	5	36	41	4.0	O	U
11-0119	--	391350	750018	5	125	135	4.0	O	U
11-0158*	35-00986	392432	750133	40	92	147	6.0	W	N
11-0161*	35-01144	392526	750643	80	171	176	4.0	O	U
11-0179*	34-00589	392953	751313	90	--	--	--	W	I
11-0222	--	392757	745528	95	--	--	--	W	I
11-0237	35-01165	392920	745700	90	76	81	4.0	O	U

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[1] C, standby or emergency; O, observation; T, test; U, unused; W, withdrawal; Z, destroyed.

[2] A, air conditioning; F, fire; C, commercial; H, domestic; I, irrigation; J, industrial, cooling; N, industrial; P, public-supply; S, stock; T, institutional; U, unused.

* Indicates these wells were sampled for this study (see app. 2). Results of chemical analyses of samples from all other wells listed are stored in the WATSTORE data base maintained by the U.S. Geological Survey.

Appendix 1.--Selected well-record information for wells used to assess chemistry of water in the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89--Continued

New Jersey well number	New Jersey permit number	Latitude	Longitude	Altitude of land surface (feet)	Top of open interval (feet below land surface)	Bottom of open interval (feet below land surface)	Diameter of open interval (inches)	Primary use of site[1]	Primary use of water[2]
				Cumberland County--continued					
11-0254*	35-05227	393208	750245	90	130	160	16.0	W	P
11-0255*	35-00869	392850	750103	90	140	170	16.0	W	P
11-0262*	34-01360	392921	751420	100	20	50	4.0	O	U
11-0274*	34-01195	392724	751236	100	70	110	12.0	W	P
11-0278*	35-00862	392238	750420	70	161	191	12.0	W	P
11-0281*	34-01194	392523	751519	75	86	146	12.0	W	P
11-0287	34-01468	392845	751832	105	40	90	30.0	W	I
11-0289	35-01853	392813	745636	75	30	60	16.0	W	I
11-0309*	--	392247	751313	30	120	130	6.0	W	T
11-0360	34-02047	392026	751507	10	20	60	8.0	W	I
11-0361*	34-01945	392547	751409	10	75	90	12.0	W	P
11-0367*	34-00438	392933	751708	105	--	--	--	W	I
11-0368*	--	392834	751242	120	71	101	8	W	T
11-0369*	--	392450	751539	90	--	--	--	W	T
11-0374*	34-03077-8	392904	751357	115	40	60	4.0	O	U
11-0375*	--	392909	751308	110	175	205	15	W	N
				Gloucester County					
15-0041	--	393149	745752	--	--	--	--	W	I
15-0048	31-04954	393446	745606	110	20	120	4.0	W	I
15-0209	31-04599	393254	750121	130	132	162	8.0	W	P
15-0244	31-04779	394235	750427	150	20	100	12.0	W	I
15-0365	31-05375	394203	745936	140	109	143	--	W	P
15-0375*	31-14080	394010	745845	150	118	147	12.0	W	P
15-0566*	31-19549	393842	745655	110	108	128	6.0	W	F
15-0619*	31-12099	393724	745542	105	38	98	6.0	W	I
15-0726*	--	394130	750921	140	52	62	3	W	H
15-0729	--	393331	750154	105	70	80	6	W	C
15-0730	--	393154	745811	110	38	98	--	W	I
15-0732	31-19570	393517	745539	110	84	89	2	W	H
15-0733*	31-18493	393457	745839	135	84	110	--	W	H
15-0734*	--	393523	745912	140	100	110	--	W	H
15-0735*	--	393940	745746	140	75	80	4	W	H
15-0743*	31-05162	393411	750022	110	83	98	6	W	T
15-0752*	31-07471	394054	745700	130	105	120	8	W	J
15-0754*	--	393934	751033	145	48	58	4	W	H
15-0759*	--	394232	750126	160	130	135	4	W	H
15-0764*	--	393708	750143	130	44	49	2	W	U
15-0785*	31-20754	393917	750149	145	52	56	2	W	H
15-0791*	31-00470	393634	750415	110	70	90	6	W	T
15-0793*	--	393448	745606	110	100	150	6	W	I
15-0801*	--	394227	750522	145	80	85	4	W	H
15-0802*	--	394246	750151	150	60	65	4	W	C
15-0804*	--	393428	750244	110	95	100	4	W	C
15-0805*	--	393322	745950	120	95	100	4	W	C
15-0810*	--	394021	750827	145	58	63	4	W	C
15-0812*	--	393805	745554	125	90	100	4	W	C
15-0813	--	393419	745626	110	60	70	4	W	I

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[1] C, standby or emergency; O, observation; T, test; U, unused; W, withdrawal; Z, destroyed.

[2] A, air conditioning; F, fire; C, commercial; H, domestic; I, irrigation; J, industrial, cooling; N, industrial; P, public-supply; S, stock; T, institutional; U, unused.

* Indicates these wells were sampled for this study (see app. 2). Results of chemical analyses of samples from all other wells listed are stored in the WATSTORE data base maintained by the U.S. Geological Survey.

Appendix 1.--Selected well-record information for wells used to assess chemistry of water in the Kirkwood-Cohansey aquifer system in southern New Jersey, 1983-89--Continued

New Jersey well number	New Jersey permit number	Latitude	Longitude	Altitude of land surface (feet)	Top of open interval (feet below land surface)	Bottom of open interval (feet below land surface)	Diameter of open interval (inches)	Primary use of site[1]	Primary use of water[2]
Gloucester County--continued									
15-0829*	--	394258	750836	140	25	29	2	W	H
15-0830	--	393920	750345	120	70	90	4	W	H
15-0831*	--	393539	750348	105	80	85	4	W	H
15-1016*	--	393633	750630	130	50	60	6	W	H
15-1017*	--	394025	750548	135	60	80	6	W	I
15-1019*	--	394020	745611	115	40	45	2	W	I
15-1028*	--	394258	750508	135	42	62	10	T	U
15-1029*	--	394301	750459	145	45	65	12	T	U
Salem County									
33-0229	31-01065	393310	750808	120	36	56	6.0	W	I
33-0262	30-01292	393420	751345	130	63	93	17.0	W	I
33-0270	30-01120	393450	751424	140	48	88	17.0	W	I
33-0275*	--	393515	751053	140	38	58	8.0	W	T
33-0295	30-01064	393835	751225	160	24	84	17.0	W	I
33-0462*	31-22844	393449	750528	95	60	70	3	W	H
33-0463*	35-02150	393047	750542	105	67	74	2	W	H
33-0464	31-01428	393203	751705	115	48	58	4	W	H
33-0465*	--	393236	751021	90	94	104	4	W	H
33-0466*	--	393509	751601	140	55	65	4	W	H
33-0469*	--	393057	750839	75	104	114	4	W	P

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[1] C, standby or emergency; O, observation; T, test; U, unused; W, withdrawal; Z, destroyed.

[2] A, air conditioning; F, fire; C, commercial; H, domestic; I, irrigation; J, industrial, cooling; N, industrial; P, public-supply; S, stock; T, institutional; U, unused.

* Indicates these wells were sampled for this study (see app. 2). Results of chemical analyses of samples from all other wells listed are stored in the WATSTORE data base maintained by the U.S. Geological Survey.

Appendix 2.--Results of field measurements of selected physical and chemical characteristics of, and results of analyses for dissolved inorganic chemical constituents, radionuclides, and organic carbon in, water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; pCi/L, picoCuries per liter; µg/L, micrograms per liter; --, data unavailabale; deg C, degrees Celsius; <, less than]

New Jersey well number	Sample-collection date	Alkalinity water whole, total field, (mg/L as $CaCO_3$)	Oxygen, dissolved (mg/L)	Hardness, (mg/L as $CaCO_3$)	pH (standard units)	Specific conductance (µS/cm)	Temperature, water (deg C)	Solids, sum of constituents, dissolved (mg/L)	Carbon, organic dissolved (mg/L as C)	Gross alpha, dissolved (pCi/L as Th-230)	Gross beta, dissolved (pCi/L as Cs-137)
					Atlantic County						
1-0168	12-01-88	--	--	5	--	--	--	28	--	5.2 ± 1.2	2.6 ± 0.8
1-0168*	12-01-88	3	1.3	5	5.14	35	13.5	29	0.2	4.7 ± 1.1	2.3 ± .8
1-0230	12-06-88	6	4.4	7	5.20	49	14.0	34	.3	1.7 ± 0.7	2.3 ± .8
1-0244	12-07-88	1	8.0	7	4.80	143	15.5	68	.5	4.4 ± 1.3	3.9 ± 1.2
1-0285	11-22-88	1	7.4	8	4.97	44	12.5	--	--	10 ± 1.0	4.2 ± 1.0
1-0285*	11-22-88	1	7.4	8	4.97	44	12.5	30	1.0	3.7 ± 1.0	4.2 ± 1.0
1-0323	11-22-88	4	7.5	8	5.39	41	13.0	--	.2	1.8 ± .7	1.9 ± .7
1-0762	12-07-88	3	.5	4	5.02	41	13.5	--	--	--	--
1-0762	03-30-89	--	.4	4	4.93	39	13.5	45	.2	.5 ± .4	.6 ± .5
1-0763	12-05-88	--	8.4	2	5.03	19	11.5	13	.5	1.3 ± .5	1.2 ± .5
1-0767	12-01-88	3	.6	8	5.26	59	13.0	45	.2	1.4 ± .6	2.5 ± .9
1-0770	12-02-88	2	8.5	21	4.76	101	14.0	--	.4	1.7 ± .7	1.4 ± .7
1-0793	12-13-88	29	5.4	45	5.60	178	13.5	125	.4	14.4 ± 2.6	8.8 ± 2.1
1-0794	12-05-88	4	.1	7	5.40	40	13.5	44	.3	.4 ± .4	1.4 ± .6
1-0833	12-06-88	5	7.7	3	5.37	25	13.0	--	.3	.6 ± .4	1.2 ± .6
					Camden County						
7-0464	12-21-88	--	8.1	13	4.85	73	12.5	--	.4	21.2 ± 3.2	6.6 ± 1.6
7-0490	12-16-88	9	5.1	23	5.26	92	11.5	64	.4	5.5 ± 1.5	7.6 ± 1.4
7-0497	12-16-88	25	5.0	15	5.68	54	12.5	47	.7	2.3 ± .7	2.6 ± .7
7-0500	12-09-88	7	8.7	3	5.31	45	12.0	33	.3	2.0 ± .7	1.6 ± .6
7-0506	12-12-88	--	6.6	6	5.10	39	12.0	--	.5	6.0 ± 1.5	2.7 ± .9
7-0603	12-02-88	3	7.5	38	5.02	127	13.0	70	.4	12.7 ± 2.3	7.4 ± 1.8
7-0671	12-21-88	--	5.6	5	5.19	37	13.0	27	.4	3.5 ± .9	1.6 ± .7
7-0675	03-29-89	1	9.6	44	4.43	--	13.2	--	.2	16.1 ± 2.6	9.2 ± 2.2
7-0676	03-29-89	1	9.4	16	4.98	66	13.3	23	.2	8.0 ± 1.8	4.6 ± 1.3
7-0677	03-29-89	<1	10.2	22	4.56	75	13.4	--	.2	9.5 ± 1.7	7.8 ± 2.0
					Cumberland County						
11-0002	12-08-88	--	5.9	22	5.15	109	13.0	76	.4	13.7 ± 2.4	6.5 ± 1.6
11-0003	12-07-88	--	9.7	14	4.54	81	12.5	53	.3	--	6.9
11-0003*	12-07-88	--	9.7	15	4.54	81	12.5	53	.5	9.6 ± 1.8	9.9 ± 1.6
11-0013	12-06-88	--	6.2	29	4.65	121	12.5	75	.3	15.8 ± 2.6	8.9 ± 2.2
11-0013*	12-06-88	--	6.2	29	4.65	121	12.5	74	.4	15.7 ± 2.5	10.3 ± 1.7
11-0020	12-06-88	--	5.2	19	4.76	93	14.0	58	.3	8.3 ± 1.7	8.6 ± 1.5
11-0020*	12-06-88	--	5.2	19	4.76	93	14.0	58	.4	8.0 ± 1.7	8.4 ± 1.5
11-0022	12-06-88	--	3.1	14	4.55	83	13.0	55	.3	9.1 ± 2.0	6.9 ± 1.3
11-0042	03-30-89	4	8.8	8	5.30	36	13.5	--	.2	1.3 ± .5	1.5 ± .7
11-0043	03-31-89	3	6.2	22	4.85	86	13.0	59	.2	5.8 ± 1.3	4.1 ± 1.1
11-0073	03-31-89	29	.7	50	6.33	142	13.0	91	.3	4.8 ± 1.5	2.6 ± .9
11-0097	11-16-88	81	.1	95	7.85	183	13.5	140	--	.1 ± .5	1.4 ± .8
11-0158	11-30-88	--	6.5	19	5.07	73	12.5	51	.3	5.0 ± 1.2	3.4 ± .9
11-0161	11-15-88	--	3.4	4	5.19	24	12.5	25	--	1.9 ± .7	2.4 ± .8
11-0179	12-03-88	--	8.6	--	4.85	246	15.5	123	--	9.0 ± 2.5	14.2 ± 2.2
11-0254	11-30-88	--	1.4	17	4.30	97	12.0	59	.6	10.1 ± 2.0	9.5 ± 1.6
11-0255	11-30-88	--	4.1	12	4.42	73	12.5	47	.3	3.7 ± 1.0	3.9 ± 1.1
11-0262	12-02-88	--	7.2	52	5.36	561	13.6	256	1.0	13.2 ± 4.6	74.0 ± 8.7
11-0274	12-08-88	--	6.1	35	4.71	125	12.5	76	.4	14.2 ± 2.5	9.2 ± 2.2
11-0278	12-09-88	--	6.9	7	5.08	38	11.5	29	.3	3.9 ± 1.0	2.6 ± .9
11-0281	12-07-88	--	5.9	43	4.78	142	12.5	89	.5	6.0 ± 1.6	6.9 ± 1.7
11-0309	12-13-88	3	3.1	5	5.06	26	13.0	26	.5	2.3 ± .7	2.2 ± .7
11-0361	12-07-88	--	5.1	27	4.58	120	13.5	75	.5	12.3 ± 2.6	8.6 ± 1.5
11-0367	12-09-88		7.2	44	4.77	148	12.4	60	.4	8.1 ± 1.8	6.0 ± 1.2
11-0368	12-15-88	--	5.4	61	4.48	201	12.5	121	.7	24.6 ± 3.7	16.0 ± 2.4

Footnotes at end of table.

Appendix 2.--Results of field measurements of selected physical and chemical characteristics of, and results of analyses for dissolved inorganic chemical constituents, radionuclides, and organic carbon in, water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89--Continued

New Jersey well number	Radium-226, dissolved by radon-222 emanation (pCi/L)	Radium-228, dissolved by beta counting[a] (pCi/L)	Radon-222, total, liquid scintillation (pCi/L)	Uranium, dissolved (µg/L as U)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, ammonia + organic dissolved (mg/L as N)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorous, ortho, dissolved (mg/L as P)
Atlantic County									
1-0168	1.2 ± 0.2	2.6 ± 1.2	--	0.04 ± 0.01	<0.010	0.20	<0.010	0.81	<0.010
1-0168*	1.3 ± .2	2.0 ± 1.3	--	<.01 ± .01	<.010	<.20	<.010	.78	<.010
1-0230	.4 ± .1	1.2 ± .6	110 ± 55[a]	<.01 ± .01	<.010	.20	.010	1.10	<.010
1-0244	1.8 ± .3	2.0 ± .7	370 ± 100	.07 ± .01	<.010	.20	.010	<.10	<.010
1-0285	1.4 ± .2	2.0 ± .7	98 ± 70	.03 ± .01	--	--	--	--	--
1-0285*	1.3 ± .2	1.5 ± .6	--	.03 ± .01	.030	.20	<.010	2.00	<.010
1-0323	.8 ± .1	1.2 ± .6	180 ± 65	<.01 ± .01	.020	<.20	<.010	2.10	<.010
1-0762	--	--	180	--	--	--	--	--	--
1-0762	.1 ± .03	.1 ± .6[a]	220 ± 50	<.01 ± .01	.010	<.20	<.010	<.10	<.010
1-0763	.4 ± .1	.7 ± .5[a]	190 ± 65	.03 ± .01	<.010	<.20	<.010	<.10	<.010
1-0767	.1 ± .01	1.5 ± 1.0	140 ± 80	.03 ± .01	<.010	<.20	<.010	<.10	<.010
1-0770	.3 ± .05	.9 ± 1.0[a]	290	.05 ± .01	<.010	.40	<.010	6.60	<.010
1-0793	4.6 ± .8	3.7 ± 1.0	360 ± 80[b]	.15 ± .01	.020	.30	<.010	9.10	.010
1-0794	.1 ± .03	.2 ± .3[a]	94 ± 50	<.01 ± .01	.010	<.20	.010	<.10	<.010
1-0833	.4 ± .07	.4 ± .6[a]	350 ± 40	<.01 ± .01	<.010	.20	.020	.38	<.010
Camden County									
7-0464	7.4 ± 1.3	3.3 ± 0.9	310 ± 100[b]	.04 ± .01	<.010	.40	<.010	4.60	<.010
7-0490	1.7 ± .3	3.0 ± .9	<80 ± 80	.01 ± .01	<.010	.60	<.010	4.90	<.010
7-0497	.9 ± .1	.6 ± .5[a]	230 ± 50	.03 ± .01	.040	.20	<.010	.80	<.010
7-0500	.6 ± .1	.9 ± .6[a]	240 ± 80	.03 ± .01	.010	.30	<.010	1.10	<.010
7-0506	2.0 ± .3	1.9 ± .8	180 ± 70	.02 ± .01	<.010	.20	<.010	1.90	<.010
7-0603	4.1 ± .7	3.2 ± 1.2	500 ± 40	.19 ± .03	<.010	.50	<.010	5.60	<.010
7-0671	.6 ± .1	.7 ± .5[a]	390 ± 80	.05 ± .01	<.010	.30	<.010	1.20	<.010
7-0675	9.2 ± 1.6	5.3 ± 1.3	480 ± 65[c]	.26 ± .01	<.010	.30	<.010	9.00	<.010
7-0676	2.7 ± .5	1.7 ± .8	140 ± 60	.03 ± .01	<.010	.30	<.010	4.10	<.010
7-0677	4.3 ± .7	4.4 ± 1.2	310 ± 90[b]	.06 ± .01	<.010	.50	<.010	5.30	<.010
Cumberland County									
11-0002	3.0 ± 0.5	2.2 ± 0.7	--	<.01 ± .01	<.010	.30	<.010	5.10	.010
11-0003	2.1	3.4	280 ± 60	.03 ± .01	<.010	.60	<.010	3.50	.010
11-0003*	1.8 ± .3	3.6 ± 1.0	--	.02 ± .01	<.010	.20	<.010	3.50	.010
11-0013	3.8 ± .7	3.5 ± 1.0	420 ± 55	.13 ± .02	<.010	.50	<.010	6.30	<.010
11-0013*	4.2 ± .7	3.3 ± .9	--	.14 ± .02	<.010	.60	<.010	6.20	<.010
11-0020	2.0 ± .4	2.6 ± .7	230 ± 55	.04 ± .01	.050	.50	<.010	3.20	<.010
11-0020*	1.9 ± .3	2.7 ± .9	230 ± 70	.04 ± .01	.110	.30	<.010	3.20	.020
11-0022	2.2 ± .4	1.7 ± .6	230 ± 40	.02 ± .01	<.010	.40	<.010	3.10	<.010
11-0042	.4 ± .1	.6 ± .5[a]	<80 ± 70[b]	.08 ± .01	<.010	.20	<.010	1.80	<.010
11-0043	1.0 ± .2	3.1 ± 1.0	200 ± 60	.03 ± .01	.020	.30	<.010	6.00	<.010
11-0073	1.8 ± .3	.4 ± .4[a]	1,900 ± 70	.09 ± .01	.030	<.20	<.010	.40	.100
11-0097	.1 ± .02	.4 ± .4[a]	<80 ± 70	<.01 ± .01	--	--	--	--	--
11-0158	1.5 ± .3	1.0 ± 1.0	290 ± 60	.01 ± .01	<.010	.50	<.010	5.10	<.010
11-0161	1.2 ± .2	1.0 ± .5	290	.04 ± .01	<.010	<.20	<.010	<.10	.010
11-0179	1.6 ± .3	3.3 ± 1.4	280 ± 70	.19 ± .01	<.010	.70	<.010	3.30	<.010
11-0254	2.1 ± .3	3.3 ± .9	<80 ± 70	.06 ± .01	<.010	.20	<.010	2.00	<.010
11-0255	1.5 ± .2	1.8 ± .6	<80 ± 60	.02 ± .01	<.010	.20	<.010	3.10	<.010
11-0262	.8 ± .1	10.2 ± 2.5	100 ± 70	.01 ± .01	<.010	1.3	<.010	19	<.010
11-0274	4.0 ± .6	3.0 ± .8	380	.09 ± .01	<.010	1.1	<.010	7.40	<.010
11-0278	.9 ± .1	1.3 ± .6	220 ± 40	.02 ± .01	<.010	.20	.010	1.40	<.010
11-0281	2.5 ± .4	2.1 ± .8	190 ± 65	.01 ± .01	<.010	1.5	<.010	7.50	<.010
11-0309	.9 ± .1	.5 ± .5[a]	1,000 ± 60	<.01 ± .01	<.010	<.20	<.010	<.10	<.010
11-0361	1.8 ± .3	2.3 ± .7	510 ± 60	.07 ± .01	<.010	.30	<.010	4.30	<.010
11-0367	2.6 ± .5	1.7 ± .7	420	.02 ± .01	.041	.40	.010	.23	.030
11-0368	4.0 ± .7	5.1 ± 1.2	390 ± 50	.19 ± .01	<.010	.90	<.010	11.0	<.010

Appendix 2.--Results of field measurements of selected physical and chemical characteristics of, and results of analyses for dissolved inorganic chemical constituents, radionuclides, and organic carbon in, water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89--Continued

New Jersey well number	Calcium, dissolved (mg/L as Ca)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Magnesium, dissolved (mg/L as Mg)	Potassium, dissolved (mg/L as K)	Silica, dissolved (mg/L as SiO_2)	Sodium, dissolved (mg/L as Na)	Sulfate, dissolved (mg/L as SO_4)	Aluminum, dissolved (μg/L as Al)	Arsenic, dissolved (μg/L as As)	Barium, dissolved (μg/L as Ba)	Beryllium, dissolved (μg/L as Be)
Atlantic County												
1-0168	0.73	3.6	0.10	0.67	1.1	9.6	2.4	3.4	70	<1	36	<0.5
1-0168*	.73	3.6	<.10	.68	1.1	9.8	2.6	3.7	70	<1	37	<.5
1-0230	1.3	5.2	<.10	.78	.80	9.5	4.0	2.5	40	<1	36	<.5
1-0244	.49	36	<.10	1.4	.60	5.7	22	.50	170	<1	45	<.5
1-0285	1.4	--	--	1.1	1.2	8.7	2.5	--	70	<1	62	<.5
1-0285*	1.4	3.6	<.10	1.0	1.2	8.6	2.5	1.9	80	<1	68	<.5
1-0323	1.2	4.5	<.10	1.3	.80	6.1	2.7	<.20	20	<1	52	<.5
1-0762	.69	--	--	.60	--	23	2.0	--	--	--	19	<.5
1-0762	.71	3.0	<.10	.63	.70	23	2.1	9.8	50	<1	19	<.5
1-0763	.22	3.3	.10	.32	.40	4.6	1.9	.80	60	<1	12	<.5
1-0767	1.6	9.4	<.10	1.0	1.6	15	6.1	7.4	30	<1	58	<.5
1-0770	1.0	11	.10	4.4	.90	6.2	9.4	<.20	320	<1	200	<.5
1-0793	10	14	<.10	4.8	4.1	7.0	12	15	80	<1	180	<.5
1-0794	1.3	5.1	.10	.90	1.1	22	3.2	6.3	<10	<1	23	<.5
1-0833	.31	3.8	<.10	.50	1.0	5.1	2.3	<.20	<10	<1	23	<.5
Camden County												
7-0464	1.4	5.9	<.10	2.2	.90	6.6	5.7	<.20	40	<1	70	<.5
7-0490	4.6	7.6	<.10	2.8	1.7	7.4	6.8	5.5	40	<1	56	<.5
7-0497	3.3	5.8	<.10	1.7	1.0	7.7	3.5	5.4	40	<1	29	<.5
7-0500	.51	3.0	<.10	.42	.50	6.7	7.1	5.0	20	<1	14	<.5
7-0506	.45	4.9	<.10	1.1	.80	5.7	3.5	<.20	<10	<1	26	<.5
7-0603	7.2	14	.10	4.8	2.2	8.7	5.6	8.9	100	<1	130	<.5
7-0671	.77	4.7	<.10	.77	.60	7.8	4.2	2.0	80	<1	25	<.5
7-0675	5.7	13	<.10	7.1	1.2	7.0	3.1	.90	340	<1	140	<.5
7-0676	1.2	6.1	<.10	3.2	1.4	6.3	3.4	1.0	30	<1	110	<.5
7-0677	1.3	6.4	<.10	4.4	1.1	7.0	2.3	.40	60	<1	160	<.5
Cumberland County												
11-0002	3.4	10	<.10	3.3	1.7	11	10	12	120	<1	87	<.5
11-0003	2.3	9.8	<.10	2.1	1.6	11	5.7	4.0	150	<1	77	<.5
11-0003*	2.3	9.7	<.10	2.2	1.6	11	5.7	4.1	150	<1	77	<.5
11-0013	4.6	12	.10	4.3	2.3	9.4	5.7	7.6	330	<1	64	<.5
11-0013*	4.6	12	.10	4.3	2.3	9.4	6.0	7.1	310	<1	63	<.5
11-0020	3.4	10	.10	2.5	1.8	9.9	6.1	9.3	280	<1	58	<.5
11-0020*	3.4	10	<.10	2.5	1.8	10	6.0	9.3	280	<1	58	<.5
11-0022	2.3	8.1	.10	1.9	1.5	14	5.2	7.6	340	<1	60	<.5
11-0042	1.1	4.5	.10	1.3	.80	6.2	2.2	<.20	30	<1	55	<.5
11-0043	3.6	7.4	<.10	3.1	1.5	8.8	4.1	1.4	220	<1	100	<.5
11-0073	17	8.1	<.10	1.7	1.4	17	4.9	20	200	<1	35	<.5
11-0097	36	2.6	.10	1.2	1.4	37	2.4	9.8	<10	<1	18	<.5
11-0158	3.9	6.9	<.10	2.3	1.0	7.4	5.3	.80	30	<1	74	<.5
11-0161	.94	2.0	<.10	.40	.90	12	1.5	4.6	30	<1	27	<.5
11-0179	1.1	45	.10	.97	6.0	5.4	42	21	110	<1	45	<.5
11-0254	3.2	7.4	<.10	2.2	2.0	13	5.3	16	530	<1	86	<.5
11-0255	2.5	5.8	.10	1.5	1.4	11	4.2	6.5	350	<1	51	<.5
11-0262	9.8	86	<.10	6.6	43	9.6	59	33	<10	<1	60	<.5
11-0274	4.8	13	.10	5.5	2.3	8.5	6.1	2.1	130	<1	180	<.5
11-0278	1.6	4.3	<.10	.83	.90	8.2	2.7	2.5	90	<1	27	<.5
11-0281	8.2	14	<.10	5.4	3.8	11	5.2	6.6	60	<1	100	<.5
11-0309	.84	2.6	<.10	.68	1.1	12	1.6	4.8	50	<1	46	<.5
11-0361	5.4	11	.10	3.3	2.5	9.7	6.9	16	700	<1	55	<.5
11-0367	9.3	21	<.10	4.9	1.9	9.8	5.9	6.5	310	<1	54	<.5
11-0368	15	15	.10	5.7	3.0	11	6.2	15	670	<1	170	<.5

Footnotes at end of table.

Appendix 2.--Results of field measurements of selected physical and chemical characteristics of, and results of analyses for dissolved inorganic chemical constituents, radionuclides, and organic carbon in, water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89--Continued

New Jersey well number	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)
Atlantic County											
1-0168	<1	<5	<3	30	770	<10	<4	20	--	<10	<10
1-0168*	<1	<5	<3	30	770	<10	<4	21	<0.1	<10	<10
1-0230	<1	<5	<3	30	1,300	<10	<4	44	<.1	<10	<10
1-0244	<1	<5	<3	170	45	<10	<4	52	<.1	<10	<10
1-0285	<1	<5	<3	20	41	10	<4	12	--	<10	<10
1-0285*	<1	<5	<3	20	25	<10	<4	11	<.1	<10	<10
1-0323	<1	<5	<3	210	32	10	<4	9	.2	<10	<10
1-0762	<1	<5	<3	<10	2,400	<10	<4	10	--	<10	<10
1-0762	<1	<5	<3	<10	2,500	<10	<4	11	--	<10	<10
1-0763	<1	<5	<3	40	95	<10	<4	2	<.1	<10	<10
1-0767	<1	<5	<3	<10	770	<10	4	13	<.1	<10	<10
1-0770	<1	<5	4	10	6	<10	<4	24	.3	<10	<10
1-0793	<1	<5	<3	<10	15	<10	<4	59	1.0	<10	<10
1-0794	<1	<5	<3	<10	870	<10	<4	11	<.1	<10	<10
1-0833	<1	<5	<3	<10	44	<10	<4	13	<.1	<10	<10
Camden County											
7-0464	<1	<5	3	30	4	<10	<4	25	--	<10	<10
7-0490	<1	<5	<3	<10	30	<10	<4	11	<.1	<10	<10
7-0497	<1	<5	<3	<10	200	<10	<4	16	<.1	<10	<10
7-0500	2	<5	<3	80	57	<10	<4	5	<.1	<10	<10
7-0506	<1	<5	<3	<10	12	<10	<4	8	--	<10	<10
7-0603	<1	<5	<3	<10	91	<10	<4	31	.2	<10	<10
7-0671	<1	<5	<3	<10	17	<10	<4	7	--	10	<10
7-0675	<1	<5	4	40	20	40	<4	24	--	<10	10
7-0676	<1	<5	<3	20	8	<10	<4	18	--	<10	<10
7-0677	<1	<5	3	20	34	<10	<4	21	--	<10	<10
Cumberland County											
11-0002	<1	<5	<3	<10	50	10	<4	17	--	<10	<10
11-0003	<1	<5	<3	40	230	10	<4	17	--	<10	<10
11-0003*	<1	<5	<3	40	230	<10	<4	17	--	<10	<10
11-0013	<1	<5	<3	10	39	<10	<4	25	--	<10	<10
11-0013*	<1	<5	<3	10	36	<10	<4	26	--	<10	<10
11-0020	<1	<5	<3	30	130	<10	<4	11	--	<10	<10
11-0020*	<1	<5	<3	40	130	<10	<4	11	--	<10	<10
11-0022	<1	<5	<3	70	380	<10	<4	16	--	<10	<10
11-0042	<1	<5	<3	10	160	<10	<4	13	--	<10	<10
11-0043	<1	<5	<3	10	350	<10	<4	25	--	<10	<10
11-0073	<1	<5	<3	<10	1,200	<10	<4	33	--	<10	<10
11-0097	<1	<5	<3	<10	260	<10	5	24	--	<10	<10
11-0158	<1	<5	4	<10	10	10	<4	12	--	<10	<10
11-0161	<1	<5	<3	<10	810	10	<4	15	--	<10	<10
11-0179	<1	<5	<3	100	77	30	<4	23	--	<10	10
11-0254	<1	<5	6	40	750	<10	<4	60	--	<10	<10
11-0255	<1	<5	<3	20	23	<10	<4	14	--	<10	<10
11-0262	<1	<5	<3	10	16	<10	<4	12	--	<10	10
11-0274	<1	<5	<3	40	130	<10	<4	27	--	<10	<10
11-0278	<1	<5	<3	<10	7	<10	<4	5	--	<10	<10
11-0281	<1	<5	<3	40	35	10	<4	19	--	<10	<10
11-0309	<1	<5	<3	110	28	<10	<4	11	--	<10	<10
11-0361	<1	<5	<3	20	270	<10	<4	20	--	<10	<10
11-0367	<1	<5	<3	10	64	<10	<4	11	--	<10	<10
11-0368	<1	<5	<3	50	96	<10	<4	41	--	<10	<10

Footnotes at end of table.

Appendix 2.--Results of field measurements of selected physical and chemical characteristics of, and results of analyses for dissolved inorganic chemical constituents, radionuclides, and organic carbon in, water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89--Continued

New Jersey well number	Silver, dis-solved (μg/L as Ag)	Stron-tium, dis-solved (μg/L as Sr)	Vana-dium, dis-solved (μg/L as V)	Zinc, dis-solved (μg/L as Zn)
Atlantic County				
1-0168	<1	11	<6	12
1-0168*	<1	10	<6	13
1-0230	<1	20	<6	81
1-0244	<1	12	<6	3
1-0285	<1	13	<6	10
1-0285*	<1	13	<6	11
1-0323	<1	13	<6	240
1-0762	<1	4	<6	730
1-0762	<1	5	<6	910
1-0763	<1	3	<6	27
1-0767	<1	15	<6	29
1-0770	<1	22	<6	28
1-0793	<1	67	<6	23
1-0794	2	16	<6	400
1-0833	<1	5	<6	810
Camden County				
7-0464	<1	20	<6	110
7-0490	<1	24	<6	10
7-0497	<1	13	<6	4
7-0500	<1	5	<6	3
7-0506	<1	7	<6	44
7-0603	<1	40	<6	10
7-0671	1	8	<6	<3
7-0675	<1	54	<6	120
7-0676	2	21	<6	12
7-0677	2	21	<6	9
Cumberland County				
11-0002	<1	36	<6	32
11-0003	<1	24	<6	120
11-0003*	<1	24	<6	120
11-0013	<1	42	<6	9
11-0013*	<1	41	<6	6
11-0020	<1	26	<6	29
11-0020*	1	26	<6	31
11-0022	<1	20	<6	55
11-0042	<1	14	<6	9
11-0043	<1	35	<6	19
11-0073	<1	100	<6	41
11-0097	<1	190	<6	<3
11-0158	<1	30	<6	19
11-0161	<1	7	<6	12
11-0179	<1	11	<6	78
11-0254	<1	33	<6	72
11-0255	<1	19	<6	21
11-0262	<1	85	<6	18
11-0274	<1	53	<6	<3
11-0278	<1	12	<6	24
11-0281	<1	70	<6	26
11-0309	<1	10	<6	10
11-0361	<1	37	<6	15
11-0367	<1	77	<6	63
11-0368	<1	73	<6	17

Footnotes at end of table.

Appendix 2.--Results of field measurements of selected physical and chemical characteristics of, and results of analyses for dissolved inorganic chemical constituents, radionuclides, and organic carbon in, water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89--Continued

New Jersey well number	Sample-collection date	Alkalinity water whole, total field, (mg/L as $CaCO_3$)	Oxygen, dissolved (mg/L)	Hardness, (mg/L as $CaCO_3$)	pH (standard units)	Specific conductance (µS/cm)	Temperature, water (deg C)	Solids, sum of constituents, dissolved (mg/L)	Carbon, organic dissolved (mg/L as C)	Gross alpha, dissolved (pCi/L as Th-230)	Gross beta, dissolved (pCi/L as Cs-137)
Cumberland County--Continued											
11-0369	12-08-88	3	6.4	35	4.80	128	12.5	83	1.1	15.7 ± 2.6	10.8 ± 0.8
11-0369*	12-08-88	3	6.4	35	4.80	128	12.5	82	.4	16.2 ± 2.6	10.0 ± 2.4
11-0374	12-20-88	--	9.2	44	4.96	143	13.5	89	.5	17.1 ± 2.6	12.8 ± 2.8
11-0375	12-20-88	--	1.8	41	4.59	202	12.5	113	.5	23.3 ± 3.6	12.4 ± 2.9
Gloucester County											
15-0375	09-28-88	<1	2.1	17	4.5	101	13.0	61	--	3.8 ± 1.1	3.4 ± 1.1
15-0566	09-26-88	--	7.8	31	4.3	135	14.0	--	--	7.7 ± 1.6	9.4 ± 1.6
15-0619	09-15-88	<1	5.8	6	4.2	36	14.0	31	--	5.9 ± 1.3	4.2 ± 1.1
15-0726	09-20-88	2	6.3	83	4.7	246	13.5	142	--	1.0 ± .6	11.7 ± 1.9
15-0733	09-29-88	<1	10.8	46	4.7	145	13.5	--	--	14.2 ± 2.5	11.0 ± 3.0
15-0734	08-26-88	<1	8.4	14	4.7	51	15.5	32	--	1.4 ± .6	2.2 ± .8
15-0735	09-23-88	<1	7.4	21	4.4	125	17.5	--	--	7.1 ± 1.6	9.8 ± 1.6
15-0743	09-26-88	--	9.1	7	4.6	37	16.0	--	--	1.6 ± .6	2.2 ± .7
15-0752	09-29-88	1	--	12	4.8	52	14.0	50	--	4.1 ± 1.0	2.6 ± .9
15-0754	09-19-88	<1	8.5	71	4.4	190	14.0	120	--	19.9 ± 3.3	13 ± 2
15-0759	09-07-88	2	10.1	6	5.0	30	13.5	--	--	5.0 ± 1.1	2.5 ± .9
15-0764	09-27-88	6	7.0	3	5.3	21	12.5	16	--	2.0 ± .7	1.0 ± .5
15-0785	09-19-88	<1	4.9	9	4.6	73	15.0	67	--	18.6 ± 3.0	18 ± 3
15-0791	09-15-88	<1	4.0	9	4.4	28	15.0	38	--	2.3 ± .8	3.0 ± 1.0
15-0793	09-09-88	<1	4.9	22	4.6	79	14.0	49	--	7.3 ± 1.7	4.4 ± 1.0
15-0801	08-25-88	2	7.4	14	4.9	57	15.5	--	--	1.5 ± .6	2.2 ± .7
15-0802	09-30-88	3	2.0	32	4.8	203	14.0	127	--	14 ± 2.7	38 ± 5
15-0804	09-09-88	1	7.1	9	4.8	45	14.0	--	--	2.4 ± .8	1.9 ± .8
15-0805	09-20-88	5	7.3	17	5.2	58	14.5	40	--	2.7 ± .9	3.8 ± .9
15-0810	09-08-88	4	7.0	46	5.2	140	19.0	81	--	4.0 ± 1.2	7.3 ± 1.4
15-0812	08-24-88	4	6.0	8	5.2	38	17.5	30	--	5.7 ± 1.2	3.4 ± .8
15-0829	09-22-88	8	6.6	120	5.2	256	15.5	158	--	5.0 ± 1.9	4.9 ± 1.4
15-0831	09-14-88	4	2.8	17	5.2	74	15.0	--	--	5.7 ± 1.5	6.5 ± 1.3
15-1016	09-20-88	2	6.8	12	4.8	47	14.0	35	--	2.7 ± .9	2.7 ± .9
15-1017	09-22-88	1	8.3	39	4.7	146	15.0	90	--	12.3 ± 2.6	9.0 ± 2.1
15-1019	09-28-88	2	3.8	12	4.8	74	12.5	--	--	14.2 ± 2.3	20 ± 3
15-1028	06-02-88	--	7.5	23	4.7	99	12.5	55	--	4.4 ± 1.2	9.3 ± 1.6
15-1029	06-02-88	<1	7.5	52	4.6	170	13.5	99	--	15 ± 3	5.8 ± 1.2
Salem County											
33-0275	11-23-88	15	8.7	38	5.96	140	15.5	86	.3	21.0 ± 3.2	10.6 ± 2.5
33-0462	12-14-88	--	.1	4	4.52	43	12.0	35	.4	5.3 ± 1.3	5.0 ± 1.0
33-0463	12-14-88	--	8.2	74	4.54	226	11.0	139	.4	18.3 ± 3.0	10.6 ± 2.4
33-0465	11-23-88	7	.5	41	5.43	127	14.0	79	.5	6.2 ± 1.5	7.6 ± 1.8
33-0466	12-08-88	10	8.9	150	5.38	382	13.0	242	.4	2.2 ± 1.2	7.6 ± 1.5
33-0469	12-01-88	81	.1	99	7.85	18	12.5	145	.3	.4 ± .5	1.6 ± .7

Footnotes at end of table.

Appendix 2.--Results of field measurements of selected physical and chemical characteristics of, and results of analyses for dissolved inorganic chemical constituents, radionuclides, and organic carbon in, water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89--Continued

New Jersey well number	Radium -226, dissolved by radon-222 emanation (pCi/L)	Radium -228, dis- solved by beta counting[a] (pCi/L)	Radon -222, total, liquid scintil- lation (pCi/L)	Uranium, dis- solved (µg/L as U)	Uranium -234, dis- solved (pCi/L)	Uranium -238, dis- solved (pCi/L)	Nitro- gen, ammo- nia dis- solved (mg/L as N)	Nitro- gen ammo- nia + organ- ic dis- solved (mg/L as N)	Nitro- gen, ni- trite dis- solved (mg/L as N)	Nitro- gen, NO_2+NO_3 dis- solved (mg/L as N)	Phos- phorous ortho, dis- solved (mg/L as P)
Cumberland County--Continued											
11-0369	3.0 ± .5	3.5 ± 1.0	340 ± 60	0.04 ± 0.01	--	--	<0.010	0.70	<0.010	6.80	0.020
11-0369*	3.7 ± .6	5.5 ± 1.7	340	.03 ± .01	--	--	<.010	.60	<.010	6.00	.020
11-0374	4.9 ± .8	6.0 ± 1.4	340 ± 80	.06 ± .01	--	--	<.010	.70	<.010	9.90	<.010
11-0375	4.5 ± .8	4.3 ± 1.1	190 ± 80	.18 ± .01	--	--	.550	.90	<.010	4.60	<.010
Gloucester County											
15-0375	.9 ± .1	1.3 ± .7	84 ± 30	.04 ± .01	<.10 ± .02	<.10	<.010	.20	<.010	2.50	<.010
15-0566	2.4 ± .4	2.5 ± .8	170 ± 30	.01 ± .01	<.10 ± .02	<..0	<.010	.70	<.010	5.00	<.010
15-0619	1.3 ± .2	2.3 ± .7	330 ± 70	.02 ± .01	<.10 ± .02	<.10	<.010	.20	<.010	1.10	<.010
15-0726	2.4 ± .4	2.1 ± .8	640 ± 40	.21 ± .01	<.10 ±	<.10	<.010	.30	<.010	6.40	<.010
15-0733	6.7 ± 1.1	4.6 ± 1.1	340 ± 40	.06 ± .01	<.10 ± .02	<.10	.010	.30	<.010	9.70	.010
15-0734	.5 ± .1	1.1 ± .8	200 ± 40	.02 ± .01	<.10 ± .02	<.10	<.010	.30	<.010	2.20	<.010
15-0735	2.2 ± .4	3.2 ± 1.0	150 ± 40	.02 ±	<.10 ±	<.10	<.010	.30	<.010	6.00	<.010
15-0743	.6 ± .1	1.5 ± .8	210 ± 30	<.01 ± .01	<.10 ± .01	<.10	<.010	.20	<.010	1.60	<.010
15-0752	1.2 ±-1.0	1.0 ± .6	<80 ± 40	<.01 ± .01	--	--	.020	.50	<.010	3.40	.010
15-0754	3.5 ± .6	3.7 ± 1.0	500 ± 40	.62 ± .08	.20 ± .05	.30	<.010	.40	<.010	9.90	<.010
15-0759	2.3 ± .4	1.4 ± .8	--	<.01 ± .01	<.10 ± .02	<.10	<.010	<.20	<.010	1.60	.020
15-0764	.6 ± .01	<1.0 ± .7	--	<.01 ± .01	.30 ± .08	.30	<.010	<.20	<.010	.31	.010
15-0785	5.7 ± 1.0	2.1 ± .7	510 ± 50	.12 ± .02	<.10 ± .01	<.10	.440	.90	<.010	5.90	<.010
15-0791	<.02± .01	1.8 ± .6	250 ± 70	<.01 ± .01	<.10 ± .01	<.10	<.010	<.20	<.010	1.70	<.010
15-0793	2.1 ± .3	2.0 ± .9	260 ± 40	.35 ± .05	<.10 ± .03	.10	.020	<.20	<.010	2.80	<.010
15-0801	.4 ± .1	<1.0 ± .6	--	.04 ± .01	<.10 ± .01	<.10	<.010	.40	<.010	4.40	<.010
15-0802	3.7 ± .6	4.5 ± 1.1	520 ± 40	.16 ± .02	<.10 ± .01	<.10	.010	<.20	<.010	8.80	<.010
15-0804	1.1 ± .2	<1.0 ± .6	410 ± 40	.01 ± .01	<.10 ± .02	<.10	.020	<.20	<.010	3.50	<.010
15-0805	.8 ± .1	1.4 ± .5	200 ± 40	.14 ± .02	<.10 ± .04	<.10	<.010	.30	<.010	2.30	<.010
15-0810	1.6 ± .3	1.9 ± .7	320 ± 50	.02 ± .01	.10 ± .02	<.10	<.010	<.20	<.010	3.00	<.010
15-0812	1.4 ± .2	1.5 ± .8	360 ± 30	.01 ±	<.10 ±	<.10	.060	.30	.010	2.10	.010
15-0829	1.5 ± .3	2.4 ± .8	480 ± 50	.04 ± .01	<.10 ± .01	<.10	<.010	<.20	<.010	5.00	.020
15-0831	1.3 ± .2	2.3 ± 1.0	390 ± 30	<.01 ± .01	<.10 ± .03	<.10	<.010	<.20	<.010	4.50	<.010
15-1016	1.0 ± .2	1.4 ± .4	230 ± 40	.02 ± .01	<.10 ± .01	<.10	<.010	<.20	<.010	2.80	<.010
15-1017	3.8 ± .6	3.5 ± 1.0	230 ± 70	.04 ± .01	<.10 ± .01	<.10	<.010	.50	<.010	8.70	<.010
15-1019	2.1 ± .4	9.5 ± 2.2	320 ± 40	<.01 ± .01	<.10 ± .01	<.10	<.010	.30	<.010	4.80	.010
15-1028	2.8 ± .5	2.3 ± .9	470 ± 40	.12 ± .02	<.10 ± .02	<.10	<.010	.30	<.010	4.60	<.010
15-1029	4.8 ± .8	1.2 ± .8	--	.18 ± .03	<.10 ± .03	<.10	<.010	.60	<.010	9.40	<.010
Salem County											
33-0275	8.7 ± 1.4	5.3 ± 1.3	330 ± 60	.14 ± .01	--	--	.010	.70	<.010	7.20	<.010
33-0462	1.8 ± .3	1.0 ± .5	470 ± 50	.14 ± .01	--	--	<.010	<.20	<.010	<.10	.010
33-0463	6.1 ± 1.1	3.8 ± 1.0	<80 ± 45	.06 ± .01	--	--	<.010	2.5	<.010	18.0	<.010
33-0465	1.7 ± .3	2.2 ± .7	1,000 ± 60	.02 ± .01	--	--	.040	.40	<.010	1.50	<.010
33-0466	.4 ± .1	1.2 ± .5	430 ± 65	<.01 ± .01	--	--	<.010	2.6	<.010	2.0	.010
33-0469	.1 ± .03	.2 ± ^{1}.8	330 ± 60	<.01 ± .01	--	--	.010	.20	<.010	<.10	.200

Footnotes at end of table.

Appendix 2.--Results of field measurements of selected physical and chemical characteristics of, and results of analyses for dissolved inorganic chemical constituents, radionuclides, and organic carbon in, water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89--Continued

New Jersey well number	Calcium, dissolved (mg/L as Ca)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Magnesium, dissolved (mg/L as Mg)	Potassium, dissolved (mg/L as K)	Silica, dissolved (mg/L as SiO_2)	Sodium, dissolved (mg/L as Na)	Sulfate, dissolved (mg/L as SO_4)	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved as Be)
Cumberland County--Continued												
11-0369	7.2	13	0.10	4.0	3.3	12	5.7	5.9	170	<1	73	<0.5
11-0369*	7.3	14	<.10	4.1	3.3	13	5.7	5.7	170	<1	74	<.5
11-0374	5.8	15	.10	7.0	2.0	7.9	5.9	.30	110	<1	350	<.5
11-0375	7.3	21	.10	5.6	3.3	13	9.5	29	1,900	<1	140	<.5
Gloucester County												
15-0375	3.1	11	<.10	2.2	1.8	11	8.6	11	210	2	70	<.5
15-0566	4.3	12	<.10	4.9	2.7	7.5	7.7	<.20	120	<1	180	<.5
15-0619	1.1	4.3	<.10	.86	1.3	12	2.2	3.9	100	<1	37	<.5
15-0726	22	12	.10	6.9	7.6	7.7	3.9	51	440	<1	94	<.5
15-0733	2.9	14	<.10	9.2	1.7	6.2	5.1	<.20	140	<1	420	<.5
15-0734	.81	7.7	.10	2.8	1.0	6.4	2.1	.50	40	<1	130	<.5
15-0735	3.5	20	.10	3.0	4.3	6.2	12	<.20	190	<1	150	<.5
15-0743	.47	3.9	<.10	1.3	.80	6.2	2.2	<.20	20	<1	60	<.5
15-0752	1.6	4.6	<.10	1.9	1.2	21	3.0	.30	40	<1	66	<.5
15-0754	18	10	.10	6.2	5.4	7.9	2.2	26	530	<1	120	<.5
15-0759	1.2	3.8	<.10	.81	.60	6.5	3.4	<.20	<10	<1	19	.5
15-0764	.31	2.7	.10	.48	.70	5.1	1.6	.30	<10	<1	20	<.5
15-0785	1.0	9.9	<.10	1.6	10	6.9	7.9	.80	40	<1	100	<.5
15-0791	2.1	4.2	<.10	.99	1.0	12	2.9	6.6	350	<1	27	<.5
15-0793	4.6	5.7	.10	2.5	1.4	8.1	2.1	11	340	<1	57	<.5
15-0801	3.3	4.1	.10	1.4	1.0	7.9	3.3	<.20	<10	<1	49	<.5
15-0802	5.3	12	<.10	4.5	29	7.5	3.9	24	110	<1	130	<.5
15-0804	2.1	3.8	<.10	1.0	.90	7.1	4.0	<.20	<10	<1	42	<.5
15-0805	2.6	5.3	<.10	2.6	1.6	8.2	2.0	4.8	<10	<1	75	<.5
15-0810	8.1	11	<.10	6.2	2.7	9.8	2.5	25	20	<1	120	<.5
15-0812	1.2	4.4	<.10	1.3	.70	6.2	3.1	.90	<10	1	36	<.5
15-0829	28	17	<.10	11	1.3	10	2.4	60	<10	<1	120	<.5
15-0831	3.0	6.0	<.10	2.2	3.5	6.5	2.5	<.20	20	<1	84	<.5
15-1016	2.5	4.2	<.10	1.5	.90	7.7	2.8	.50	40	<1	64	<.5
15-1017	8.1	9.7	.10	4.5	4.2	7.3	7.7	8.7	120	<1	190	<.5
15-1019	1.8	6.3	<.10	1.9	2.7	5.2	4.8	<.20	80	<1	97	<.5
15-1028	1.7	11	.30	4.6	1.6	8.4	4.4	1.0	170	--	170	<.5
15-1029	9.0	15	.30	7.0	2.8	7.9	6.1	7.9	190	<1	280	<.5
Salem County												
33-0275	5.6	11	.10	5.9	1.7	6.8	9.3	4.1	180	<1	160	<.5
33-0462	.78	1.7	<.10	.46	1.2	18	2.3	10	180	<1	14	<.5
33-0463	20	19	<.10	5.9	3.3	6.4	3.3	1.0	640	<1	170	.6
33-0465	9.4	9.7	<.10	4.2	3.6	7.1	3.2	30	20	<1	66	<.5
33-0466	25	36	<.10	22	5.9	9.9	8.2	41	30	<1	110	<.5
33-0469	38	1.9	.10	.94	1.2	36	2.5	13	<10	<1	13	<.5

Footnotes at end of table.

Appendix 2.--Results of field measurements of selected physical and chemical characteristics of, and results of analyses for dissolved inorganic chemical constituents, radionuclides, and organic carbon in, water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89--Continued

New Jersey well number	Cadmium, dis-solved (μg/L as Cd)	Chromium, dis-solved (μg/L as Cr)	Cobalt, dis-solved (μg/L as Co)	Copper, dis-solved (μg/L as Cu)	Iron, dis-solved (μg/L as Fe)	Lead, dis-solved (μg/L as Pb)	Lithium, dis-solved (μg/L as Li)	Manganese, dis-solved (μg/L as Mn)	Mercury, dis-solved (μg/L as Hg)	Molybdenum, dis-solved (μg/L as Mo)	Nickel, dis-solved (μg/L as Ni)
Cumberland County--Continued											
11-0369	<1	<5	4	10	37	<10	<4	19	--	<10	<10
11-0369*	<1	<5	4	10	41	10	<4	19	--	<10	<10
11-0374	<1	<5	6	30	15	30	<4	46	--	<10	<10
11-0375	<1	<5	10	<10	740	<10	<4	40	--	<10	30
Gloucester County											
15-0375	<1	<5	<3	<10	160	10	<4	19	<0.1	<10	<10
15-0566	<1	<5	<3	210	16	<10	<4	24	<.1	<10	<10
15-0619	<1	<5	<3	20	120	<10	<4	9	<.1	<10	<10
15-0726	<1	<5	5	<10	30	<10	<4	77	<.1	<10	<10
15-0733	<1	<5	5	20	4	<10	<4	27	<.1	<10	<10
15-0734	<1	<5	<3	160	10	<10	<4	11	<.1	<10	<10
15-0735	<1	<5	5	70	19	20	<4	35	<.1	<10	<10
15-0743	<1	<5	<3	--	10	--	<4	6	<.1	<10	<10
15-0752	<1	<5	<3	<10	95	<10	10	92	<.1	<10	<10
15-0754	<1	<5	4	20	52	60	<4	79	<.1	<10	<10
15-0759	<1	<5	<3	40	42	<10	<4	8	<.1	<10	20
15-0764	1	<5	<3	<10	280	40	<4	8	<.1	<10	<10
15-0785	<1	<5	<3	270	8	<10	<4	19	.2	<10	<10
15-0791	<1	<5	<3	60	450	<10	<4	14	<.1	<10	<10
15-0793	<1	<5	<3	10	72	<10	<4	17	<.1	<10	<10
15-0801	<1	<5	<3	80	13	<10	<4	9	<.1	<10	<10
15-0802	<1	<5	<3	<10	250	<10	<4	39	<.1	<10	<10
15-0804	<1	<5	<3	20	12	30	<4	3	<.1	<10	<10
15-0805	<1	<5	<3	290	250	<10	<4	22	<.1	<10	<10
15-0810	<1	<5	<3	40	33	<10	<4	21	<.1	<10	<10
15-0812	<1	<5	<3	<10	620	<10	<4	45	.1	<10	<10
15-0829	<1	<5	<3	230	450	20	<4	52	<.1	<10	<10
15-0831	<1	<5	<3	270	120	<10	<4	15	.3	<10	<10
15-1016	<1	<5	<3	20	190	20	<4	17	<.1	<10	<10
15-1017	<1	<5	<3	<10	40	<10	<4	40	<.1	<10	<10
15-1019	1	<5	<3	10	15	20	<4	20	.2	<10	<10
15-1028	<1	<5	4	<10	120	<10	<4	24	--	<10	<10
15-1029	<1	<5	5	<10	53	<10	<4	49	--	<10	<10
Salem County											
33-0275	<1	<5	<3	130	29	<10	<4	23	--	<10	<10
33-0462	<1	<5	<3	<10	740	<10	<4	10	--	<10	<10
33-0463	<1	<5	8	<10	50	<10	<4	51	--	<10	<10
33-0465	<1	<5	<3	<10	130	<10	<4	15	--	<10	<10
33-0466	<1	<5	<3	<10	5	<10	<4	33	--	<10	<10
33-0469	<1	<5	<3	<10	1,900	<10	8	43	--	<10	<10

Footnotes at end of table.

Appendix 2.--Results of field measurements of selected physical and chemical characteristics of, and results of analyses for dissolved inorganic chemical constituents, radionuclides, and organic carbon in, water samples from the Kirkwood-Cohansey aquifer system in southern New Jersey, 1988-89--Continued

New Jersey well number	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)
Cumberland County--Continued				
11-0369	<1	56	<6	130
11-0369*	<1	57	<6	140
11-0374	<1	65	<6	23
11-0375	<1	61	<6	46
Gloucester County				
15-0375	<1	27	<6	11
15-0566	<1	46	<6	16
15-0619	<1	11	<6	98
15-0726	<1	68	<6	16
15-0733	<1	81	<6	5
15-0734	<1	21	<6	10
15-0735	<1	22	<6	32
15-0743	<1	12	<6	14
15-0752	<1	130	<6	7
15-0754	<1	110	<6	85
15-0759	<1	15	<6	14
15-0764	<1	4	<6	--
15-0785	<1	13	<6	19
15-0791	<1	11	<6	38
15-0793	<1	29	<6	22
15-0801	<1	17	<6	12
15-0802	<1	35	<6	58
15-0804	<1	14	<6	7
15-0805	<1	26	<6	6
15-0810	<1	61	<6	390
15-0812	<1	11	<6	52
15-0829	<1	45	<6	7
15-0831	<1	26	<6	45
15-1016	<1	15	<6	25
15-1017	<1	34	<6	5
15-1019	<1	14	<6	870
15-1028	2	28	<6	30
15-1029	2	57	<6	7
Salem County				
33-0275	<1	55	<6	15
33-0462	<1	8	<6	10
33-0463	<1	74	<6	25
33-0465	<1	47	<6	370
33-0466	<1	230	<6	4
33-0469	<1	190	<6	340

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[a] Minimum reporting limit is 1 pCi/L.

[b] Single analysis, not average of two individual analyses.

[c] Results and the two standard-deviation counting error do not overlap for the two individual analyses used to compute the average value individual analysis.

* Sequentially collected duplicate sample.