RELATION OF DISTRIBUTION OF RADIUM, NITRATE, AND PESTICIDES TO AGRICULTURAL LAND USE AND DEPTH, KIRKWOOD-COHANSEY AQUIFER SYSTEM, NEW JERSEY COASTAL PLAIN, 1990-91

By Zoltan Szabo, Donald E. Rice, Cecilia L. MacLeod, and Thomas H. Barringer

---

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 96-4165A

Prepared in cooperation with

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

West Trenton, New Jersey
1997

USGS
science for a changing world

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, ***Secretary***

U.S. GEOLOGICAL SURVEY
Mark Schaefer, ***Acting Director***

For additional information
write to:

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

Copies of this report can be
purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND WATER-QUALITY ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25,400	micron
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
	Volume	
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06308	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Mass	
ounce, avoirdupois (oz)	28.35	gram
pound, avoirdupois (lb)	0.4536	kilogram
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter

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 the United States and Canada, formerly called Sea Level Datum of 1929.

Water-quality abbreviations:

mg/L	- milligrams per liter	BOD	- biological oxygen demand
µg/L	- micrograms per liter	DO	- dissolved oxygen
pCi/L	- picocurie per liter	POC	- purgeable organic compound
pCi/g	- picocurie per gram	TOC	- total organic carbon
µS/cm	- microsiemens per centimeter at 25 degrees Celsius	VOC	- volatile organic compound

RELATION OF DISTRIBUTION OF RADIUM, NITRATE, AND PESTICIDES TO AGRICULTURAL LAND USE AND DEPTH, KIRKWOOD-COHANSEY AQUIFER SYSTEM, NEW JERSEY COASTAL PLAIN, 1990-91

By Zoltan Szabo, Donald E. Rice, Cecilia L. MacLeod, and Thomas H. Barringer

ABSTRACT

Concentrations of radium-226 and radium-228 were determined in 42 water samples collected in 1990 from a targeted regional well network in the Kirkwood-Cohansey aquifer system in southern New Jersey. The network consists of two sets of wells--one completed in agricultural areas and the other completed in areas of mostly forested or sparsely populated residential (non-agricultural) land use. Results of radium analyses indicate that concentrations of both dissolved radium-226 and dissolved radium-228 were significantly higher in agricultural areas than in non-agricultural areas. Concentrations of radium-226 ranged from 0.21 to 8.9 pCi/L (picocuries per liter), with a median value of 2.5 pCi/L, in 29 samples from wells in agricultural areas, but ranged from 0.18 to only 2.4 pCi/L, with a median value of 0.64 pCi/L, in 13 samples from wells in non-agricultural areas. Similarly, concentrations of radium-228 ranged from <1 to 5.0 pCi/L, with a median value of 1.8 pCi/L, in the samples from agricultural areas, but ranged from <1 to only 2.4 pCi/L, with a median value of <1 pCi/L, in the samples from wells in non-agricultural areas. These differences are statistically significant at a 95-percent confidence level for both radionuclides. The sum of the concentrations of radium-226 and radium-228 did not exceed the primary drinking-water standard of 5 pCi/L in any of the 13 ground-water samples collected from non-agricultural areas; however, this value was exceeded in 39 percent of the samples collected from agricultural areas.

Concentrations of dissolved radon-222 in the samples from the targeted regional well network ranged from 80 to 1,300 pCi/L. These concentrations are much greater than those of dissolved radium-226, the radioactive parent of radon-222. This result indicates that the source of the dissolved radon-222 must be radium-226 in the aquifer materials, and that the concentration of radium-226 in the aquifer materials must be much greater than the concentration of radium-226 dissolved in the water.

Concentrations of many of the inorganic chemical constituents determined in the samples were significantly greater (at the 95-percent confidence level) in water from wells in agricultural areas than in water from wells in non-agricultural areas. These constituents include nitrate, magnesium, calcium, barium, strontium, potassium, dissolved oxygen, and chloride. Results of the Spearman's rank correlation test indicate that concentrations of both dissolved radium radionuclides are significantly correlated with the concentrations of these constituents (except dissolved oxygen) all of which are associated with agricultural land use. The correlation coefficients range from about +0.35 to about +0.55 and are significant at the 95-percent confidence level. No difference in pH was noted between samples from agricultural and non-agricultural areas; all the water was acidic, with a median pH of 4.76 for the 42 samples.

Water samples also were collected from a network of nested observation wells located along the surface-water (and assumed ground-water) divide in southwestern New Jersey, where ground-water flow is assumed to be mostly vertical. This network consists of 15 wells at five sites in agricultural or formerly agricultural areas. Each site consists of three wells: a shallow well (screened 5 ft (feet) below the water table), a medium-depth well (screened 20-45 ft below the water table), and a deep well (screened 60 to 90 ft below the water table). Concentrations of

radium-226, radium-228, nitrate, magnesium, calcium, barium, and chloride all were significantly greater (at a 90-percent confidence level) at shallow and medium depths (5-45 ft) than at greater depths in the aquifer. At three of the five sites, the sum of the radium-226 and radium-228 concentrations exceeded 5 pCi/L in samples of water from either the shallow- or the medium-depth well. Additionally, the pH of water from the shallow and medium depths was lower (4.6-5.6) than that of water from greater depths (5.7-6.4). The vertical distributions of radium and of inorganic constituents associated with agricultural activity, such as nitrate (from fertilizer) or calcium and magnesium (from lime, likely in the form of dolomite), are moderately to strongly correlated. The strong correlation of radium, nitrate, calcium, and magnesium with depth indicates that radium is more mobile in shallow ground water, where concentrations of agricultural chemicals are elevated, than in deep ground water, where concentrations of agricultural chemicals are low.

Results of geochemical mass-balance and reaction-path model simulations indicate that nitrification of ammonia-based fertilizer generates approximately enough hydrogen ion to consume the acid-neutralizing capacity of the lime leaching to the ground water. The acidity of the shallow ground water is thereby maintained, despite the presence of more calcium and magnesium in the shallow ground water than the deep ground water. In the relative absence of silicate-mineral weathering (as indicated by the low dissolved-silica concentration), the pH of the ground water in agricultural areas is determined primarily by the material balance of hydrogen ions generated by nitrification and consumed by the dissolution of lime. Because the sorption capacity of the aquifer sediment (quartz, iron hydroxide) for the divalent radium cation is low in acidic water that contains abundant calcium and magnesium, the geochemical environment in the Kirkwood-Cohansey aquifer system in agricultural areas is conducive to the mobility of radium.

The radium-226 content of 15 aquifer-material samples from various depths in the aquifer ranged from 0.05 to 1.1 pCi/g (picocuries per gram), with a median value of 0.35 pCi/g; the radium-228 content ranged from 0.11 to 0.84 pCi/g, with a median value of 0.40 pCi/g. The radium-228/radium-226 ratio of the sediment samples ranged from 0.45 to 2.4, with a median value of 1.0. The median value of the radium-228/radium-226 ratio in associated samples of ground water was 1.1, and the median radium-228/radium-226 ratio in water samples from the regional well network was 1.08. The similarity of the median values of the radium-228/radium-226 ratio in sediment and in ground water indicates that the sediment is the likely source of the dissolved radium in the ground water. The concentration of dissolved radon-222, in contrast to that of dissolved radium-226, is correlated to the radioactivity of the aquifer sediment adjacent to the well screen as determined by gamma-ray logging, rather than to the depth or the chemical composition of the water sample, indicating that the sediment adjacent to the well screen is the source of the dissolved radon-222.

INTRODUCTION

Radium in drinking water is known to increase cancer risk (Mays and others, 1985; Hess and others, 1985). In fact, the U.S. Environmental Protection Agency (USEPA) has indicated that the total risk posed by waterborne radionuclides in drinking-water supplies is greater than that posed by all other toxic chemicals (Cothern, 1987), hence additional MCL's for radionuclides have been proposed (U.S. Environmental Protection Agency, 1991a). Because radium is a known carcinogen, USEPA has established a maximum contaminant level (MCL) of 5 pCi/L for combined radium, defined as the sum of radium-228 and radium-226 (U.S. Environmental Protection Agency, 1988).

Levels of naturally occurring radium greater than 5 pCi/L have commonly been found in shallow water derived from unconsolidated sediments throughout the Atlantic Coastal Plain physiographic province of the United States (Zapecza and Szabo, 1988; King and others, 1982;

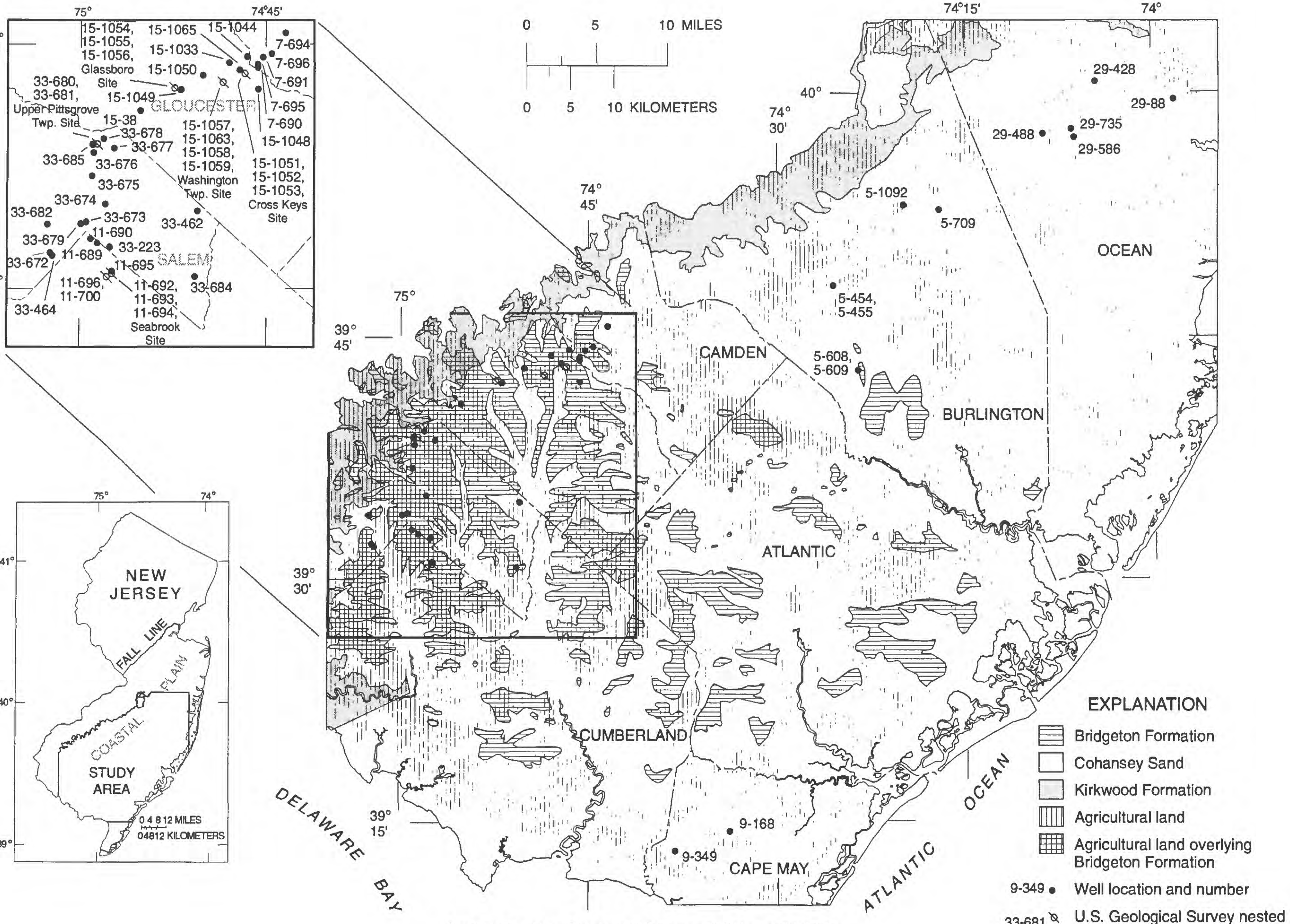
Michel and Moore, 1980). Most communities in this large geographic area, including the southern part of New Jersey, derive their drinking water in large part from these shallow unconfined aquifers. During routine regulatory monitoring conducted by the New Jersey Department of Environmental Protection (NJDEP), levels of radium and gross-alpha particle activity greater than the MCL's established by the USEPA have been detected in water from many public supply systems that withdraw water from the Kirkwood-Cohansey aquifer system, the principal unconfined aquifer in the Coastal Plain of southern New Jersey (fig. 1). The presence of radium at levels greater than the MCL in drinking-water supplies is an issue of major public concern.

Data from 81 (mostly public supply and domestic) wells in a regional reconnaissance sampling network in the Kirkwood-Cohansey aquifer system in southern New Jersey, sampled by the U.S. Geological Survey (USGS) in 1988-89 (Kozinski and others, 1995), indicate a correlation between areas in which radionuclide activities are elevated and areas of intensive agriculture on land overlying the outcrop of the Bridgeton Formation, a local surficial gravel in hydrologic connection with the underlying parts of the aquifer system. Results of chemical analyses of samples from this reconnaissance-well network demonstrate that both general water quality and dissolved-radium concentrations are highly variable in the aquifer system in areas of agricultural land use. The sum of the concentrations of radium-226 and radium-228 exceeded 5 pCi/L in 33 percent of the samples, all of them from agricultural areas. The concentration of nitrate exceeded 10 mg/L in 6 percent of the samples, also all from agricultural areas, and was found to correlate with that of radium. Kozinski and others (1995) concluded that the composition of ground water is affected by agricultural land-use practices, which results in an increase in the mobility of radium in ground water in agricultural areas to that in ground water whose relative composition was not affected by the presence of agricultural chemicals. Kozinski and others (1995) also showed that the radium-228/radium-226 isotope ratio in the ground water differed from published values of this ratio in phosphate fertilizer.

In order to further evaluate the geochemical processes and identify hydrologic processes that control the distribution of radium in water in the Kirkwood-Cohansey aquifer system in the Coastal Plain of southern New Jersey, and to evaluate the radium content of the sediment to determine whether it could be the source of the dissolved radium, the USGS, in cooperation with the NJDEP, began a study in 1990. This report discusses the geochemical processes that control the distribution of radium in the ground water. An understanding of the geochemical processes that favor leaching of radium into solution in the Kirkwood-Cohansey aquifer system of southern New Jersey may help to predict the presence of radium in anomalous concentrations in drinking-water supplies derived from similar quartzose sand aquifers throughout the Coastal Plain of the southeastern United States. A second report (Rice and Szabo, 1997) discusses the effects of the ground-water flow system on the radium distribution.

Purpose and Scope

This report examines the relation of the distributions of dissolved radium, nitrate, and pesticides in the aquifer to the distribution of agricultural land and to depth in agricultural areas in the Coastal Plain of southern New Jersey. The report also discusses the geochemistry of the aquifer system and evaluates possible geochemical processes that result in the leaching of radium into solution. Results of analyses of water samples from (1) 42 wells screened in the Kirkwood-Cohansey aquifer system in agricultural and non-agricultural areas and (2) 15 nested observation wells and two piezometers at five sites in agricultural areas for radium and other radionuclides, nitrate and other nutrients, major inorganic chemical constituents and trace elements, pesticides, dissolved oxygen, and selected physical or chemical properties are presented. The hypotheses that (1) concentrations of dissolved radium differ between the two areas and that (2) water quality and radium concentrations vary with depth in agricultural areas are examined statistically.



Base from New Jersey Department of Environmental Protection digital data, 1: 24,000, 1988, Universal Transverse Mercator projection, Zone 18. Agricultural land-use polygons modified from New Jersey Department of Environmental Protection digital data, 1:24,000, 1986.

Figure 1. Locations of outcrop areas of geologic units comprising the unconfined Kirkwood-Cohansey aquifer system, overlying areas of agricultural land use, and wells and nested observation-well sites in the study area, New Jersey Coastal Plain.

The mineralogical composition and radium content of sediment-core split-spoon samples collected during the installation of nested observation wells at the five sites is presented. The distribution of radium in the sediment is discussed and the radium-228/radium-226 isotope ratio of the sediment and ground water are compared to determine the source of the dissolved radium.

The potential effects of chemical reactions in the soils and the aquifer on the chemical evolution of the water in agricultural areas, as indicated by the water-quality data, are evaluated by using geochemical reaction-path and mass-balance models. The effects of these reactions on radium mobility is discussed.

Radionuclide Decay Series

Radioactive decay is the emission of an alpha particle (the nucleus of a helium atom) or a 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.

Naturally occurring radionuclides are formed principally by the radioactive decay of uranium-238 and thorium-232, which are the long-lived parent elements of the radioactive-decay series that bear their names. 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 including radium-226 and radon-222 to become stable lead-206; thorium-232 decays through 12 radionuclides including radium-228 to become stable lead-208. The half-lives of both uranium-238 and thorium-232 are greater than 1 billion years.

Uranium is highly soluble in oxidizing, bicarbonate-rich ground water (Zapecza and Szabo, 1988). Thorium, however, is not soluble and is rarely detected in ground water (Zapecza and Szabo, 1988). Radium is a divalent cation that behaves chemically in a way similar to calcium, strontium, and barium (Zapecza and Szabo, 1988). Radium-226 has a long half-life (1,622 years) compared to that of radium-228 (5.75 years). 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 water. Because it is inert and soluble, concentrations of radon-222 commonly exceed the concentrations of other radionuclides in ground water (Zapecza and Szabo, 1988).

Gross radioactivity and the radioactivity emitted from individual radionuclides in a water sample are determined by using instruments that count the gross amount of radioactivity emitted by the sample. Some types of analyses can determine the amount of radioactivity emitted by individual radionuclides, respectively. Both gross radioactivity and radioactivity resulting from the presence of 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 of solution (micrograms per liter, for example) are not generally used because the radioactivity, not the chemical mass, is measured. Concentrations of uranium are reported in mass units in this report because the mass retained after sample preconcentration was sufficient to allow chemical measurement of the concentration of uranium by using newly developed laser technology (Brina and Miller, 1992; Bushaw, 1983).

Acknowledgments

The authors thank Karl Muessig, Sonny Saroya. Barker Hamill, and Barbara Litt of the New Jersey Department of Environmental Protection for assistance in developing the sampling plan and for cooperating in the dissemination of information to the public. We thank Rick Westergaard of the Gloucester County Planning Department for assistance in the planning of drilling operations. Gamma spectral analyses of sediment were done by Bahman Parsa and Kirk Nemeth, New Jersey Bureau of Environmental Quality Radiation Protection Laboratory (Ewing, N.J.). The authors also thank the well owners who allowed the USGS to sample their wells, and Washington Township Municipal Utilities Authority, Rowan State University, Rutgers University, and William Coles for allowing the USGS to install wells on their properties.

DESCRIPTION OF STUDY AREA

The study area is located in the Coastal Plain of southern New Jersey (fig. 1). It includes all or parts of eight counties--Atlantic, Burlington, Camden, Cape May, Cumberland, Gloucester, Ocean, and Salem--and is bounded on the north and west by the outcrop of the Kirkwood Formation, on the south and southwest by the Delaware Bay and estuary, and on the east by the Atlantic Ocean. Wells sampled were located in parts of the eight counties listed above. The agricultural area studied is located predominantly in southwestern New Jersey, specifically in south-central Camden, central and eastern Gloucester, eastern Salem, and northern Cumberland Counties (fig. 1). The non-agricultural area studied is in south-central and southeastern New Jersey, specifically in southeastern Ocean, eastern Burlington, and northern Cape May Counties (fig. 1). The study area is characterized by low elevation and relief; land surface ranges from sea level to a few hundred feet above sea level. Both the elevation and the relief of the land surface decrease eastward, toward the Atlantic Ocean.

Geology, Soils, and Land Use

The outcrop of the Kirkwood Formation forms the western boundary of the study area (fig. 1); because the formation dips to the southeast, it is present only in the subsurface in the study area. The Cohansey Sand underlies all of the study area and is the predominant geologic unit at the surface in its northern and eastern part. Uneroded remnants of the Bridgeton Formation, which locally overlies the Cohansey Sand, are present mostly along ridgetops in the western and southwestern parts of the study area (Owens and others, 1983).

The Kirkwood Formation, which is early to middle Miocene in age (Sugarman and others, 1993), is a marine unit that forms the basal part of the Kirkwood-Cohansey aquifer system. Deposits of the Kirkwood Formation typically are micaceous, and calcareous shell material is abundant locally (Owens and Sohl, 1969, p. 252). In coastal areas, thick, diatomaceous clay beds with interbedded zones of sand and gravel are dominant at depth (Zapecza, 1989, p. B19). In the subsurface updip from the coast, the Kirkwood Formation consists of fine- to medium-grained quartz sand and silty sand. Regionally extensive clay beds are present only in the basal part of the Kirkwood Formation (Zapecza, 1989, p. B19); a thick, dark-gray clay member forming the basal part of the formation in southwestern New Jersey is termed the Alloway Clay (Isphording, 1970; Nemickas and Carswell, 1976).

The Cohansey Sand, which is 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. The Cohansey Sand contains 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, which is late Miocene in age, crops out discontinuously throughout the study area, typically at topographic highs (fig. 2). Surficial deposits of the Bridgeton Formation generally are as thick as 30 to 50 ft 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 (Owens and Minard, 1979, p. D-17; Martino, 1981, p. 1), and is composed of a feldspathic, quartz-rich sand and gravel that eroded from bedrock highlands to the north. These source rocks are known to be enriched in uranium and thorium (Bell, 1983) and the radionuclides, such as radium-226 and radium-228, that are derived from the decay of these elements. The eroded source-bedrock debris was deposited across the southern Coastal Plain of New Jersey (fig. 1).

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 soils developed from the Bridgeton Formation are well-drained and are characterized by loamy, sandy, and gravelly texture (Johnson, 1978). These soils generally are medium to low in natural fertility, have low pH (less than 5.0), and are susceptible to leaching of soil nutrients (Johnson, 1978). Soils developed from the Cohansey Sand generally are well-drained to excessively well-drained, are loamy and sandy, are relatively infertile, have low pH (less than 4.4), and are susceptible to leaching (Johnson, 1978). In low-lying, poorly drained areas, loamy, acidic, organic soils have developed from the Cohansey Sand.

Commercial agriculture requires well-drained soils. The somewhat less acidic, well-drained, moderately fertile soils that developed from the Bridgeton Formation generally are more suitable for agriculture, especially commercial vegetable-crop production, than are the low-lying, highly acidic, poorly drained soils that developed from the Cohansey Sand. A large percentage of the study area that is underlain by the Bridgeton Formation is developed for commercial agricultural use (Fegeas and others, 1983). The soils that developed from the Cohansey Sand generally are suitable only for specialized agriculture, such as acid-loving native fruit crops. The presence of abundant wetlands in the southeastern part of the study area, which are poorly drained and are not suitable for commercial vegetable-crop production, is one reason that the area remained forested and was not developed for agriculture.

The soils developed on both the Bridgeton Formation and the Cohansey Sand are strongly acidic because they are composed predominantly of quartz. Acidic precipitation (pH values near 4.5 (Lord and others, 1990)) that falls in the study area infiltrates the quartzose soils and is not neutralized because the Bridgeton Formation and Cohansey Sand contain no carbonate or basic-silicate minerals. Lime is added to cropland in the study area to neutralize the acidity of the soils and to replace the divalent cations (calcium and magnesium) that are leached naturally from the soil. The most commonly used source of lime throughout the United States is dolomite (Severson and Shacklette, 1988), which is a calcium and magnesium carbonate mineral. Barium and strontium, the dominant minor elements in dolomite, also are added to the soil by the application of dolomite. Despite the addition of large quantities of dolomite to the soil (Kozinski and others, 1995), however, the pH of the ground water is low (median 4.90) in agricultural areas overlying the Bridgeton Formation and the Cohansey Sand.

Because soils developed on the Bridgeton Formation are well-drained and naturally low in nutrients, the application of large amounts of fertilizers is required for maximum crop yields. Most manufactured fertilizers contain nitrogen in the form of ammonia (Severson and Shacklette,

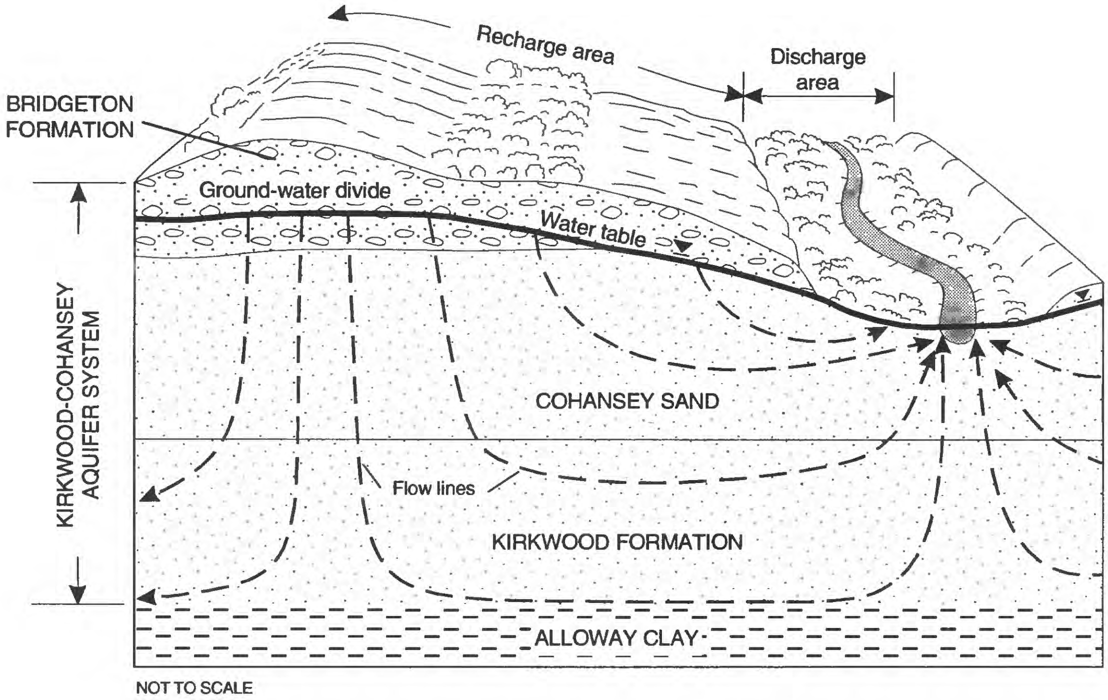


Figure 2. Generalized hydrogeologic section through the unconfined Kirkwood-Cohansey aquifer system and idealized ground-water-flow lines, southern New Jersey (Modified from Kozinski and others, 1995).

1988). Through the process of nitrification, bacteria in the soil convert (oxidize) ammonia to nitrate (Delwiche, 1970), a nutrient that is very soluble and leaches easily to the ground water. Potassium also is commonly added to cropland because little naturally occurring potassium is available in a form that can be used by plants. Sylvite (KCl), a potassium-bearing salt, is the most common potassium-bearing additive in fertilizer (Severson and Shacklette, 1988). To maintain the high crop yield that the optimum hydrogeologic conditions for intensive agriculture on the Bridgeton Formation allow, pesticides and herbicides are applied liberally to cropland. Soils in low-lying areas of the Cohansey Sand are suitable only for native fruit-crop production; small quantities of soil additives are required for this type of agriculture. Kozinski and others (1995) indicate that some quantities of soil additives may be used, however.

Hydrology

The Kirkwood-Cohansey aquifer system, the principal source of potable water in the study area, is 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 Cohansey Sand and Kirkwood Formation and, depending on location, can include overlying deposits of the Bridgeton Formation. Clay beds in the basal part of the Kirkwood Formation, generally termed the Alloway Clay (Nemickas and Carswell, 1976), form a regional confining unit (Zapecza, 1989, p. B20).

Ground water in the Kirkwood-Cohansey aquifer system flows from areas of high elevation to areas of low elevation, such as streams and swamps. 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 parts of Gloucester and Camden Counties (Rooney, 1971; Farlekas and others, 1976; Lacombe and Rosman, 1995). Perched water tables and semiconfined conditions caused by the presence of local clay beds may exist locally.

Recharge to the aquifer system is through direct percolation of precipitation. Average annual precipitation over the study area ranges from 38 to 45 in. Estimated recharge to the Kirkwood-Cohansey aquifer system in Gloucester County is about 18 in/yr (inches per year) (Lacombe and Rosman, 1995). Rhodehamel's (1973) estimate of 20 in/yr of recharge is for a larger area with fewer measurement points than that studied by Lacombe and Rosman (1995). The rest of the precipitation leaves the study area either as streamflow (about 3 in/yr) (fig. 2) or as evapotranspiration (about 24 in/yr) (Lacombe and Rosman, 1995).

METHODS OF INVESTIGATION

This section describes the standard hydrologic methods used during this study. These methods include site selection, the well-numbering system, installation of nested observation wells, collection and analysis of sediment and ground-water samples, statistical analysis of water-quality data, and geochemical modeling.

Sampling Network

Water samples were collected from 42 wells screened in the Kirkwood-Cohansey aquifer system in agricultural areas and in non-agricultural areas (the regional sampling network) to compare water quality. Eleven public-supply, 16 domestic, 9 observation, 3 irrigation, 2 institutional, and 1 industrial well were included in the regional sampling network. In addition, 15 nested observation wells were installed at five sites to identify changes in ground-water geochemistry as water flows downward through the Bridgeton Formation and the Cohansey Sand. The wells sampled in this study are shown in figure 1. Well-construction information for the wells in the regional sampling network is presented in appendix 1A; well-construction information for the nested observation wells is presented in appendix 2A.

Well-Numbering System

Information on the construction, altitude, owner, and location of wells included in this report is stored in the Ground-Water Site Inventory data base maintained by the USGS. This information is stored under a 6-digit unique well number assigned by the USGS. This well number consists of a 2-digit county code followed by a 4-digit sequence number. County codes used in this report are 01 (Atlantic), 05 (Burlington), 07 (Camden), 09 (Cape May), 11 (Cumberland), 15 (Gloucester), 29 (Ocean), and 33 (Salem). For example, well number 33-0469 is the 469th well inventoried in Salem County. Data in the appendixes in this report are sorted by county and well number.

Selection of Wells for Regional Sampling Network

Twenty-nine of the 42 wells in the regional sampling network are in an area of intensive agriculture, and 13 are in areas of mostly forested or residential, agriculturally undeveloped land (fig. 1). The wells are distributed unevenly because Kozinski and others (1995) demonstrated that general water quality and radium content in water from the Kirkwood-Cohansey aquifer system are far more variable in agricultural areas than in non-agricultural areas.

Special attention was paid to the location of wells selected for sampling in the agricultural area. Agricultural land is scattered, but is concentrated on topographic highs with good drainage. Sampling sites were selected as close as possible to ground-water divides, where ground-water-flow paths are essentially vertical and horizontal ground-water flow from areas of different land use is minimal. All the selected wells were located directly on, or adjacent to, agricultural land. Agricultural land in the area is discontinuous and separated by patches of undeveloped land, thus, a few wells were included in the network that were surrounded by, but were not directly on, agricultural land. Commercial non-native fruit- and vegetable-crop production is common to the agricultural areas selected for the study. Because minimal or no soil additives are applied to native fruit crops, no wells located in these agricultural areas supporting these crops were sampled.

Wells in the non-agricultural areas are located primarily on forested land or, less commonly, on sparsely populated residential land, away from agricultural activity. Because the forested land tends to be continuous, the wells selected did not need to be located precisely at the local ground-water divides; horizontal ground-water flow to individual well sites from areas of different land use was considered unlikely. To maintain consistency with the agricultural sampling network, however, the selection of wells near ground-water divides was given preference, even in forested areas.

The wells selected for inclusion in the regional sampling network were screened at shallow depths to ensure that the sampled water had a short travel time to the well screen. Well depth is important because the chemistry of shallow water is most likely to be affected by recent land-use activity, whereas the chemistry of deep water is most likely controlled by chemical reactions with the aquifer material, thereby making comparisons of the chemistry of water from deep wells unsuitable for the study of the effect of recent land use on radium mobility. The tops of the open intervals are within 150 ft of land surface, with the exception of one well (05-0608) in the non-agricultural area (app. 1A). Screened intervals range from 26 to 173 ft below land surface for sampled wells located in the non-agricultural area and 15 to 141 ft below land surface for sampled wells located in the agricultural areas. Because the aquifer is thicker in the non-agricultural area than in the agricultural area, the percentage of wells in which at least part of the screened interval is below a depth of 100 ft is slightly greater in the non-agricultural area than in the agricultural area.

The concentration of tritium was determined in the samples from the wells and was used as a screening technique to identify water recharged to the aquifer before 1955 (recharge more than 35 years ago as of 1990). A tritium concentration of less than 5 pCi/L is assumed to represent pre-1955 recharge on the basis of the classification system of Hendry (1988). It was intended that any sample falling in this category was to be removed from the data set that was analyzed statistically to characterize the difference in water chemistry between agricultural and non-agricultural areas. Because only one well from each land-use area fit this criterion, however, it was not necessary to remove these two wells from the data set.

Selection of Sites for Installation of Nested Wells in Agricultural Areas

Five sites were selected for installation of nested observation wells to be used for vertical-flow-path analysis and water-quality sampling. These sites are in southwestern New Jersey in known agricultural areas where the Bridgeton Formation crops out. The sites are at or near local surface-water divides, which are assumed to represent ground-water divides, where vertical flow is maximized, ensuring that samples were collected at various distances near the same flow path and that horizontal ground-water flow to the nested wells from areas of different land use is minimal. Placement of the nested wells at locations where flow paths are predominantly vertical allowed for the determination of differences with depth in water quality and radium content resulting from the effects of recent (since 1940) leaching of chemically synthesized agricultural soil additives to shallow ground water.

Active agricultural land use was confirmed at four of the five sites; historical agricultural activity could not be confirmed at the fifth site. Fertilizer or pesticide applications were confirmed at three of the sites.

Observation-Well Installation and Collection of Sediment Samples

Nested observation wells were installed with a hollow-stem-auger drill rig. Consistent procedures were followed with respect to depth of well placement and collection of soil and aquifer cores. All well installations followed NJDEP monitoring-well-installation regulations (Michael Miller, New Jersey Department of Environmental Protection, written commun., 1990). Deep wells were installed before shallow wells.

Two, three, or four observation wells were installed at each site, and were screened at various depths. The number of wells drilled at each site depended on the thickness of the aquifer below the site. All observation wells were 2 in. in diameter with 5-ft screens.

The expected depth to the base of the Kirkwood-Cohansey aquifer system at each site was determined from the map of aquifer thickness prepared by Zapecza (1989). The first test hole at each site was drilled to about the full thickness of the aquifer. Split-spoon samples of aquifer material and continuous cores of unsaturated-zone sediment also were collected. Split-spoon (2-ft-long) samples were collected after every 5 ft of drilling or, if the lithology was uniform, after every 10 ft of drilling.

Drilling was stopped when drill cuttings and split-spoon samples contained dark gray to black clay typical of the Alloway Clay confining unit, which underlies the Kirkwood-Cohansey aquifer system. Drilling was stopped before the Alloway Clay confining unit was reached only at the Seabrook site as a result of drill-rig limitations. When drilling for the deepest well was completed at each site, a gamma-ray log was run in the hole through the augers and used to determine the optimum depth for the screen. After the log was completed, the well was installed. To ensure a good connection with the aquifer, the well screen was placed above any fine-grained material (assumed low-conductance zones) shown on the geophysical logs.

Medium-depth wells were drilled next. Split-spoon samples were collected at 10-ft intervals and at depths where the gamma-ray log from the deepest well indicated changes in lithology. Screens were placed about midway between the deeper well screens and the water table, and at a depth where the gamma-ray log indicated that no fine-grained sediments were present.

The shallow wells were installed last. During drilling, CME[1] continuous split-tube samples were collected from land surface to the water table. Screens were placed 10 to 15 ft below the water table.

Two exceptions were made to these procedures. First, only two wells were installed at the upper Pittsgrove Township site because the Kirkwood-Cohansey aquifer system is thin (base of the aquifer is about 55 ft below land surface) there. These wells correspond to the shallow and deep wells in the described procedure; however, the depth below land surface of the "deep" well at this site corresponds more closely with the depth of the medium-depth wells at the other four sites. The split-spoon samples usually collected during drilling of the medium-depth well were collected instead during drilling of the shallow well.

An additional (fourth) well was installed at the southern Washington Township site. The drill cuttings, split-spoon samples, and gamma-ray log from the deep well at this site revealed the presence of a 20-ft-thick silt layer at the approximate depth of the proposed screened interval where the medium-depth well would have been screened. To investigate the hydrologic effect of this layer on flow in the aquifer, well screens were set immediately above and below it. In this report, these wells are referred to as the "upper medium-depth well" and "lower medium-depth well," respectively. Split-spoon samples were collected only during the drilling of the "lower medium-depth" well.

Determination of Sediment Characteristics

Sediment subsamples collected from the cores were analyzed to characterize lithology, texture, and mineralogy. The mineralogy, color, texture, degree of sorting, and grain size of each subsample were determined in the field on the basis of visual inspection. Descriptions were compared to interpreted lithology based on results of gamma-ray logging. Subsamples also were examined in the laboratory with a binocular microscope to identify trace minerals and were analyzed by x-ray diffraction and gamma spectrometry.

X-Ray Diffraction

In the laboratory, core material was selected for additional mineralogical analysis with X-ray diffraction. Because gamma-ray logs and the gross sedimentological descriptions compiled in the field showed sediment from the southern Washington Township site to be the most heterogeneous, sediment from this site was used. The core was subsampled at intervals of 5 to 6 in. (the shallow continuous core) or 1 ft (the deep split-spoon core).

---

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

Both general mineral and specific clay-mineral identification were performed by using a Scintag PAD V automated X-ray diffractometer. General mineral analyses were performed by grinding each subsample to a fine powder with a mortar and pestle. The powder was then made into a slurry by adding acetone, and the slurry was transferred to a glass disk. The slurry was analyzed on a rotating mechanical sample holder in a beam of Cu-generated X-rays, from a 4-degree to a 60-degree angle of incidence; the amount of rotation was predetermined by mechanical stops adjusted with a goniometer. Minerals were identified by comparing their d-spacings (the distance between parallel crystal lattice planes), as defined by the angle of X-ray incidence, and diffracted X-ray peak intensities to published crystallographic data (Bayliss and others, 1986).

In order to obtain a quartz-free mineral separate for X-ray diffraction analysis, an attempt was made to separate trace-mineral grains from quartz by heavy-liquid and magnetic-separation techniques. This attempt was unsuccessful, however, because the trace-mineral content of the sand was too small.

The sediment subsamples were sieved. Clay-mineral samples were prepared from the smallest sieve-size fraction (40 µ or less). The fraction was suspended in magnesium chloride to flocculate the clays. The clay sample was then centrifuged to remove heavy minerals from suspension and was filtered on 0.22-µ glass-fiber filter paper. After the sample was dried, it was analyzed on the filter disks with the X-ray diffractometer with X-ray incidence angles from 4 to 40 degrees and a scanning speed of 1 degree per minute. Several subsamples from different depths lacked the clay necessary to obtain a clay-mineral separate; therefore, further analysis of these subsamples was not possible.

Gamma Spectrometry

Gamma-ray spectrometry was used on selected subsamples collected from each core to determine the concentrations of radionuclides of radium and the concentrations of potassium in the sediment. The texture of sediment subsamples ranged from clayey silt through silt, silty sand, and sand. A germanium lithium detector was used with a fixed sample configuration and a 200-minute counting time. Density corrections were made for data when possible, according to the method outlined in Nemeth and Parsa (1992). For quality control, a known standard was submitted to the laboratory for gamma-spectral analysis of radium-radionuclide content; analytical results were within 7 percent of the known values.

Determination of Ground-Water Quality

Water samples from the wells (about 2.6 gal total) were collected and analyzed for concentrations of radionuclides, trace elements, major cations and anions, and nutrients. Concentrations of pesticides were determined in water samples from a random subset of 16 wells in the regional well network located in the agricultural areas to determine whether pesticides were present in water that contained elevated concentrations of radium. Water samples were collected from the wells in the regional sampling network during July-September 1990 (with the exception of two water samples that were collected in April 1991). Water samples were collected from all 15 nested observation wells at the five sites during March-May 1991. In addition, at one of the five nested observation-well sites (near Seabrook, N.J.), two additional water samples were collected at varying depths within a single drive-point piezometer in November 1991.

Michel and Moore (1980) noted little seasonal variation in concentrations of radium in samples collected from withdrawal wells in a shallow, unconfined, sandy aquifer that is hydrologically similar to the Kirkwood-Cohansey aquifer system. The concentration of radium in a single sample was assumed, therefore, to be representative of the concentration of radium in water produced from the well. To test the assumption that radium concentrations do not vary seasonally, however, a few randomly selected wells from the regional network were sampled on more than one occasion during this study.

Sampling and analytical reproducibility was monitored by collecting sequential samples from three observation wells chosen at random. Sampling and analytical reproducibility was verified by the close correspondence of results of sequential samples. Ten of the observation wells at three of the sites were resampled at a later date (December 1991) in order to verify that chemical composition of the water from the Kirkwood-Cohansey aquifer system did not exhibit seasonal variation. Little variability through time in concentrations of radium or other constituents was observed from wells sampled on more than one occasion; therefore, it was concluded that the chemical composition of the ground water did not show significant seasonal variation.

Sample Collection and Analysis

Samples were collected after a minimum of three casing volumes of water had been removed from the well, and when the temperature, pH, specific conductance, and DO did not vary by more than 5 percent in three consecutive sets of measurements made at 5-minute intervals, according to methods described by Wood (1976). This procedure ensured the collection of fresh water from the aquifer, rather than standing water from the well casing. Samples from withdrawal wells were collected as close to the well head as possible, before water treatment or filtering systems.

Water samples were collected from the nested observation wells by using a portable variable-pumping-rate 2-in. submersible pump. A pumping rate of about 6 gal/min was generally maintained. The pump was set 10 ft below the static water level. During pumping, temperature, pH, specific conductance, and DO were measured at 5-minute intervals, as described above.

Water samples were collected for analysis for various dissolved chemical constituents by using standard sampling procedures and equipment, as outlined in Claassen (1982), Wood (1976), and Thatcher and others (1977). Sample-collection bottles for radionuclide and trace-element analyses were acid-rinsed polyethylene. Potassium-free glass liquid-scintillation vials containing 10 mL of premeasured mineral oil were used to collect samples for analysis for dissolved gaseous radon-222 (Brutsaert and others, 1981; Pritchard and Gesell, 1977). Glass sample-collection bottles for organic-carbon and pesticide analyses were washed with organic-free distilled water and baked at 350 °C overnight before use. Samples to be analyzed for trace elements and radionuclides were filtered and acidified in the field immediately after sample collection. Samples to be analyzed for nutrients and major anions were filtered through a 0.45-μ filter; mercuric chloride was added to samples collected for nutrient analysis as a preservative. Dissolved-organic-carbon samples were filtered through a 0.10-μ silver filter. Samples to be analyzed for pesticides, nutrients, major anions, and dissolved organic carbon were chilled after collection.

All samples were analyzed at the USGS National Water Quality Laboratory in Arvada, Colo., for nutrients, major ions, trace elements, and radionuclides. Concentrations of major cations (except potassium) and trace elements were determined by use of atomic-emission spectroscopy with an inductively coupled argon radio frequency plasma torch (ICP-AES); concentrations of potassium were determined by means of atomic-absorption spectrometry (Fishman and Friedman, 1985). Concentrations of copper and lead in samples of water from nested observation wells were determined by means of graphite furnace atomic absorption, and concentrations of mercury were determined by means of the USEPA-approved digestion cold-vapor flameless atomic-absorption technique (Fishman and Friedman, 1985). Concentrations of chloride, fluoride, sulfate, and nutrients were measured by means of ion chromatography (Fishman and Friedman, 1985). The method used to determine concentrations of nitrate plus nitrite (as nitrogen) 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 infrared spectroscopy (Wershaw and others, 1987).

Organochlorine pesticide compounds were extracted from the water samples with hexane; the extracts were purified by using adsorption chromatography on an alumina column (Wershaw and others, 1987). Triazine herbicide and carbamate pesticide compounds were extracted from the water samples with methylene chloride. Organochlorine pesticide and triazine herbicide compounds were determined with gas chromatography by using electron-capture detectors and nitrogen-specific detectors, respectively (Wershaw and others, 1987). Carbamate pesticide compounds were determined by high-pressure liquid chromatography with a variable-wavelength ultraviolet detector.

All measurements of radioactivity and radionuclides were made by using procedures approved by the USEPA. Gross alpha-particle activity and gross beta-particle activity were determined by planchet counting (Krieger and Whittaker, 1980). Efficiency corrections for the counter were 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). Concentrations of radium-226 were determined by radon-222-deemanation (Krieger and Whitaker, 1980). Concentrations of radium-228 were determined by beta-counting of ingrown actinium-228 progeny (Krieger and Whittaker, 1980).

Radon-222 concentrations were determined by liquid-scintillation counting of samples within 48 hours of collection (U.S. Environmental Protection Agency, 1978; Prichard and Gesell, 1977). Concentrations of tritium were determined by beta counting by using liquid-scintillation counting after gaseous enrichment in Ostlund-type glass cells (Ostlund and Dorsey, 1977).

Uranium concentrations were determined by means of pulsed-nitrogen-dye laser-induced phosphorescence of the uranium-phosphate complex (Brina and Miller, 1992; Bushaw, 1983). The intensity of the phosphorescence is proportional to the mass of uranium in solution. Uranium concentration is determined by comparing the intensity of the phosphorescence of the sample to that of known uranium standards.

The quality-assurance program included the analysis of duplicate samples in the laboratory. Known standards also were analyzed in the laboratory as part of internal quality assurance. On the basis of results from the known standards, results of chemical analyses for all constituents appeared to be accurate and precise within the limits stated by Fishman and Friedman (1985) and Thatcher and others (1977). Results of analyses of sequential samples collected in the field indicate that analytical results are reproducible (app. 1B and 2C) and that the sampling protocol was adequate to ensure collection of representative samples of ground water.

Data Analysis

Statistical techniques were used to evaluate correlations between concentrations of selected dissolved chemical constituents, differences in concentrations of selected constituents between agricultural and non-agricultural areas, and differences in concentrations of selected constituents among shallow, medium-depth, and deep wells. Geochemical modeling was used to evaluate possible evolution of water chemistry in agricultural areas.

Statistical techniques

Ranked percentiles, including the 10th, 25th, 50th (median), 75th, and 90th, were calculated for concentrations of selected dissolved chemical constituents in water samples from the regional well network. Correlations between the concentrations of inorganic chemical constituents and radionuclides for both the regional well network and the nested-observation-well network were calculated with the non-parametric Spearman-rank correlation technique (Conover, 1980) and are reported, if significant, at the 95-percent confidence level. Because the nested-observation-well network included fewer than 20 wells, correlations significant at the 90-percent confidence level were reported.

To determine whether the chemical composition of ground water differs significantly between agricultural and non-agricultural areas, the Kruskal-Wallis non-parametric statistical test (Conover, 1980) was applied to the water-quality data. Water samples were divided into two groups on the basis of the source of the sample--whether the well sampled was in an agricultural or non-agricultural area. Constituent-concentration data were ranked so that the number 1 was assigned to the lowest concentration, 2 to the second lowest, and so on. Ties were assigned the average rank of the tied values. Concentrations below the analytical reporting limit were tied at rank 1. The mean was computed for the two sample groups. For each constituent, the sample group with the higher mean ranked value was identified. Statistical significance of observed differences in mean ranks was evaluated by means of the chi-square statistic. The observed differences in mean ranks were considered significant if the probability was less than 0.05 that the computed chi-square statistic would occur. An algorithm was used to compute corrections to the chi-square statistic for tied values.

To determine whether the chemical composition of ground water from areas of agricultural land use varies significantly with depth, the Kruskal-Wallis statistical test was applied to the water-quality data from the nested observation wells, as described above. Water samples were divided into three groups on the basis of depth below land surface: shallow (27 to 40 ft), medium (45 to 78 ft), or deep (84 to 115 ft). Constituent-concentration data from the three sample groups were compared; the sample group with the higher mean ranked value from each comparison was recorded.

Geochemical Modeling

The evolution of water chemistry along ground-water flow paths was simulated by using the geochemical computer-modeling programs BALANCE and PHREEQE (Parkhurst and others, 1980; Parkhurst and others, 1982). The models were used to calculate (1) ionic species and ionic complexes on the basis of thermodynamic data, (2) saturation indexes for individual minerals present in the aquifer matrix, (3) the net mass of reactants needed for water of a given composition to evolve from an initial solution of a different composition, and (4) ground-water composition in agricultural areas when proposed geochemical processes were simulated (reaction-path modeling).

The net mass of fertilizer, lime, salt, and solutes from silicate-mineral weathering added to (dissolving in) "typical" soil water in a forested area (average values derived from Lord and others, (1990)) that would result in the composition of water from a well in an agricultural area was calculated. The amount of ammonia and lime added to the initial soil-water solution was fixed by the amount of nitrogen and magnesium in the final ground-water solution because no other source of these elements was known to be present in the aquifer. Variable amounts of silicate-mineral weathering are possible; however, no technique could be used in the simulation to fix the proportion of solutes contributed to solution from one mineral as opposed to another.

More than one combination of the variables can give the same result; therefore, calculated masses of reactants and trends in evolution of ground-water composition are non-unique. The effect on solution pH of adding different amounts of various forms of nitrogen fertilizer also was evaluated. Only one of the possible results is discussed in order to illustrate the general effect of ammonia-based fertilizer on solution pH.

CHARACTERISTICS OF SEDIMENT IN THE KIRKWOOD-COHANSEY AQUIFER SYSTEM

Sediment subsamples from the cores collected from the Kirkwood-Cohansey aquifer system at five sites in southwestern New Jersey (fig. 1) were analyzed for texture, mineralogy, and radium content. Variations in these characteristics were evaluated for possible effects on hydraulic properties and geochemical mass-balance modeling.

Texture and Mineralogy

Gross lithologic descriptions of core samples from each site of nested observation wells are given in appendix 2B. The sediment comprising the Kirkwood-Cohansey aquifer system is predominantly a homogenous, fine- to medium-grained quartz sand that grades into medium to coarse sand or silty sand to silt in places. Grain size is particularly uniform within the Cohansey Sand. In general, grain size, mineralogy, and texture varied little from site to site or with depth (app. 2B), although some minor variations were noted. Therefore, the hydraulic properties of the aquifer are likely to be relatively uniform.

Trends in grain size were noted at the upper (land surface) and lower (base) parts of the aquifer. Grains tend to be largest at shallow depths (medium to coarse sand, with occasional gravel), most likely as a result of the presence of the fluvial Bridgeton Formation, which caps the Cohansey Sand in southwestern New Jersey. Grain size decreases at the base of the Cohansey Sand (very fine to silty sand), which grades into the underlying Kirkwood Formation. Furthermore, layers of silty sand and silt about 10 to 20 ft thick are present in the Cohansey Sand at three of the five sites investigated (fig 3; app. 2B): from 50 to 70 ft at the southern Washington Township site, from 48 to 58 ft at the Glassboro site, and from 78 to 88 ft at the Seabrook site. In general, the sediment appears to be slightly coarser grained and more homogenous at the upper Pittsgrove Township and Cross Keys sites than at the Glassboro and southern Washington Township sites. The sediment at the Seabrook site is generally coarse-grained and homogenous except for the presence of a silt layer.

Like the lithology, the mineralogy of the sediment comprising the Kirkwood-Cohansey aquifer system is generally uniform. Quartz, the dominant mineral, comprises more than 90 percent of the total ground mass. The dominance of quartz varied little with depth or from site to site (app. 2B).

Other minerals that were common in small amounts were small dark minerals (heavy-mineral suite), feldspar, muscovite, iron oxide, and clay (most likely kaolinite). Iron oxide and clay, though not abundant, were present in almost all sediment samples. The heavy-mineral suite also was present throughout the aquifer, but in small amounts (less than 1 percent).

Minor trends in the abundance of feldspar, muscovite, and clay minerals were noted at the upper (land surface) and lower (base) parts of the aquifer. Feldspar is most common at shallow depths. The presence of feldspar is most likely due to the presence of the fluvial arkosic Bridgeton Formation, deposited by the ancestral Hudson River (Martino, 1981; Owens and Minard, 1979), which transported freshly weathered debris from the granitic Appalachian

Highlands across the New Jersey Coastal Plain. Muscovite and clay minerals increase greatly in abundance at the base of the Cohansey Sand as a result of decreasing grain size at the contact with the Kirkwood Formation. Muscovite and clay minerals are also common in silt layers within the Cohansey Sand.

The relatively homogenous quartz-kaolinite-iron hydroxide mineralogy of the sediments comprising the Kirkwood-Cohansey aquifer system provides a nearly uniform, chemically non-reactive quartzose matrix through which ground water percolates. The presence of small amounts of kaolinite and iron hydroxide indicates that percolating ground water degrades weatherable primary minerals to their secondary weathering products. The overwhelming dominance of quartz and the paucity of more easily weatherable minerals indicate, however, that little chemical weathering is taking place. The slight increase in the clay-mineral content at the base of the aquifer is unlikely to affect the quality of the water in the aquifer because most of the water discharges to streams before it reaches this depth (Rice and Szabo, 1997). Hence, little change in water quality due to reactions with the aquifer matrix is expected along ground-water flow paths.

The relatively heterogeneous core from the southern Washington Township site is composed primarily of unconsolidated quartz sand that is heavily coated within iron oxides (app. 2B). The virtually uncemented sand is friable and disintegrates readily. The sand grains are primarily subangular to subrounded with some well-rounded, frosted or polished grains.

Primary minerals identified in the core are, in order of abundance: quartz, ilmenite, muscovite, plagioclase and(or) K-feldspar, biotite, zircon, and possibly garnet. Quartz grains are the largest particles within the sediment, and dark minerals, possibly ilmenite grains, are the smallest. No fossils were present.

The upper 25 ft of this core may represent the Bridgeton Formation. The sediment is highly weathered, very coarse to gravelly sand that is poorly sorted and stained with hematite. Little clay or silt is present except as coatings on mineral grains. Mineralogically, this interval is composed of quartz with some clay nodules that may be the highly weathered remains of plagioclase or K-feldspar. Scattered ilmenite-rich bands are present throughout the section, particularly at a depth of 25 ft in a zone that is also enriched in clay- and silt-sized sediment. Weathering of these iron and titanium oxides could provide mobile iron to the ground-water solution, resulting in the abundant iron staining of quartz pebbles. Some sequences of sediment appear to fine upward, possibly indicating fluvial deposition, which is consistent with the hypothesized origin of the Bridgeton Formation (Martino, 1981; Owens and Minard, 1979).

The Cohansey Sand is tentatively identified in this core as comprising the interval from 25 to 95 ft. The sand is fine- to medium-grained, with silty matrix material in places, and is unconsolidated. Mineralogically, the sand is composed predominantly of quartz, with minor amounts of dark minerals, most likely biotite and ilmenite, and trace amounts of feldspars, zircon, and possibly garnet. Quartz grains are subangular to subrounded to rounded with a polished or frosted texture. Coatings of clay (kaolinite) cling to the quartz grains. The sand is marked by zones of intense weathering, where the sediment is entirely stained with iron oxide. The grain size of the sediment that makes up the Cohansey Sand is fairly uniform within individual zones but varies from zone to zone within the section. Most of the section is massive fine sand that is consistent with its hypothesized deposition on or near a beach (Owens and Sohl, 1969).

The lowermost section of the core (from 95 to 115 ft) is tentatively identified as the Kirkwood Formation. The sediment is dark green to black and is composed primarily of quartz with some ilmenite, rare biotite, and some glauconitic clay. The quartz grains are angular to subrounded and do not exhibit the frosted surface texture commonly seen in the Cohansey Sand. The quartz grains at this depth are much smaller than those in the Cohansey Sand or the Bridgeton

The quartz grains at this depth are much smaller than those in the Cohansey Sand or the Bridgeton Formation. The dark minerals, such as ilmenite, also are much finer grained than those in the Cohansey Sand. No bedding is visible. The Kirkwood Formation sediments have a distinct hydrogen sulfide odor, indicating the possible decomposition of organic matter. These characteristics are consistent with deposition at moderate depths on the continental shelf, as hypothesized by Owens and Sohl (1969).

Quartz, the most abundant mineral by far in the whole-sediment samples from the southern Washington Township site, produced the most intense peaks of all the mineral patterns identified on the X-ray diffractograms. Biotite also was identified in some samples, although in small amounts.

X-ray diffractograms of clay-mineral samples collected from the southern Washington Township site indicated that kaolinite is the only clay mineral in the Bridgeton Formation and Cohansey Sand. Smectite or chloritoid clays were tentatively identified in the Kirkwood Formation sediments at the base of the aquifer (at about 115 ft). These clay minerals may compose the greenish grains noted above, and may account for the greenish color of the sediment at this depth (app. 2B). These mineralogic characteristics are consistent with those observed by Owens and others (1988), who report the presence of illite-smectite only at the base of the Cohansey Sand and in the Kirkwood Formation, and with those of Isphording (1970), who reports the presence of illite-smectite in the Kirkwood Formation.

Radium Content

The radium-226, radium-228, and potassium-40 concentrations in 15 samples of sediment collected at various depths at the nested-observation-well sites was determined. The measured concentrations of these three radionuclides in each sediment sample are given in table 1. The depth of the analyzed sediment sample, the natural gamma-ray log of the borehole, and the dissolved radon-222 concentration in the ground water collected at various depths at each site are shown in figure 3.

The radium-226 concentration in the sediment ranged from 0.05 to 1.1 pCi/g, with a median value of 0.35 pCi/g; the radium-228 concentration ranged from 0.11 to 0.84 pCi/g, with a median value of 0.40 pCi/g; and the potassium-40 concentration ranged from 0.80 to 8.5 pCi/g, with a median value of 4.5 pCi/g. The ratio of radium-228/radium-226 in the sediment samples ranged from 0.43 to 1.7 (table 1), with a median value of 1.0.

The sediment samples were divided into two major groups: sand or gravelly sand (nine samples) and silty sand or silt (six samples). Substantial differences in radionuclide content and radium-isotope ratios were noted between the groups. The concentrations of all three measured radionuclides were higher in the silty sand than in the sand. The absolute difference was greatest for potassium-40, which was generally more abundant in the silty sand than in the sand by 2 to 3 pCi/g and, in some samples, by more than 5 pCi/g. The greatest relative difference was in the concentration of radium-226, which was generally 3 to 5 times that in the silty sand than in the sand. The median potassium-40 concentrations in sand and silty sand were 1.1 and 3.8 pCi/g, respectively; the median radium-228 concentrations were 0.19 and 0.56, respectively; and the median radium-226 concentrations were 0.13 and 0.71, respectively. Concentrations of radium-226 appear to be slightly more sensitive to grain size than those of potassium-40 and radium-228.

These results are consistent with borehole geophysical data. Gamma logs indicate the presence of substantially greater gamma radiation in silty sand than in sand (figs. 3 and 4).

Table 1. Concentration of potassium-40, equivalent radium-228, and equivalent radium-226, and radium-228/radium-226 ratio in sediment samples from various depths at five sites, Kirkwood-Cohansey aquifer system, southwestern New Jersey

[Stratigraphy of each core and location of sediment samples are shown in figure 3, and are described in appendix 2B; ft, feet; pCi/g, picocuries per gram; <, less than]

Sample number	Sample depth below land surface (ft)	Gross lithologic description	Potassium-40 (pCi/g as potassium-40)	Equivalent radium-228 (pCi/g as actinium-228)[1]	Equivalent radium-228 (pCi/g as lead-212)[1]	Equivalent radium-226 (pCi/g as bismuth-214)[1]	Equivalent radium-226 (pCi/g as lead-214)[1]	Radium-228/ radium-226 ratio (as actinium-228/ bismuth-214)[2]
				<u>Cross Keys site</u>				
G-1	27	Well-sorted medium sand	0.59 ± .51	<.2	0.074 ± .024	0.12 ± .04	0.11 ± .03	[2]0.61
				<u>Glassboro site</u>				
[3]G-2	15	Moderately sorted fine, medium, and coarse sand	3.7 ± 1.5	.45 ± 0.13	.50 ± .07	.64 ± .11	.60 ± .08	.70
G-3	25	Moderately sorted medium sand	2.6 ± .7	.55 ± .06	.54 ± .05	.52 ± .06	.51 ± .05	1.06
G-4	37	Moderately poorly sorted clayey medium sand	1.6 ± .9	.47 ± .10	.50 ± .06	.70 ± .09	.69 ± .07	.67
G-5	57	Moderately sorted clayey very fine sand	5.3 ± 1.1	.84 ± .09	.74 ± .06	1.3 ± .1	1.4 ± .1	.65
G-6	67	Moderately sorted clayey coarse sand	3.9 ± 1.2	.24 ± .12	.21 ± .05	.38 ± .09	.41 ± .06	.63
				<u>Southern Washington Township site</u>				
G-7	5	Poorly sorted coarse sand and gravel	1.1 ± .8	.35 ± .08	.36 ± .04	.26 ± .07	.25 ± .05	1.35
G-8	27	Well-sorted coarse sand	<.88	.19 ± .05	.11 ± .03	.11 ± .05	.13 ± .03	1.73
G-9	60	Moderately sorted clayey fine to medium sand	2.5 ± 1.0	.64 ± .09	.48 ± .06	.75 ± .07	.80 ± .06	.85
G-10	67	Moderately sorted clayey fine sand	3.7 ± .4	.31 ± .03	.29 ± .02	.72 ±.04	.71 ± .03	.43

Table 1. Concentration of potassium-40, equivalent radium-228, and equivalent radium-226, and radium-228/radium-226 ratio in sediment samples from various depths at five sites, Kirkwood-Cohansey aquifer system, southwestern New Jersey--Continued

Sample number	Sample depth below land surface (ft)	Gross lithologic description	Potassium-40 (pCi/g as potassium-40)	Equivalent radium-228 (pCi/g as actinium-228)[1]	Equivalent radium-228 (pCi/g as lead-212)[1]	Equivalent radium-226 (pCi/g as bismuth-214)[1]	Equivalent radium-226 (pCi/g as lead-214)[1]	Radium-228/ radium-226 ratio (as actinium-228/ bismuth-214)[2]
				Southern Washington Township site--Continued				
G-11	97	Well-sorted fine sand	6.7 ± .9	0.27 ± .07	0.21 ± .04	0.25 + .06	0.24 ± .04	1.08
G-12	117	Well-sorted silty sand and clay	9.0 ± .7	.80 ± .06	.69 ± .04	.51 ± .05	.59 ± .04	1.57
				Seabrook site				
G-13	32	Moderately sorted coarse sand with gravel	.88 ± .59	.17 ± .06	.11 ± .03	.11 ± .04	.11 ± .03	1.55
G-14	72	Well-sorted medium sand	<.97	<.19	.056 ± .029	.12 ± .05	.13 ± .04	[2].47
				Upper Pittsgrove Township site				
G-15	19	Moderately sorted medium to coarse sand	4.6 ± .8	<.27	.13 ± .04	.13 ± .05	.13 ± .04	1.00

---

[1] Equivalent radionuclide concentration is reported in terms of the radionuclide or radioactive progeny used to determine concentration from gamma-ray measurements made by using the gamma-spectral method.

[2] Where equivalent radium-228 could not be detected as actinium-228, equivalent concentrations as lead-212 were used.

[3] Laboratory duplicate analyses match within standard two-sigma errors.

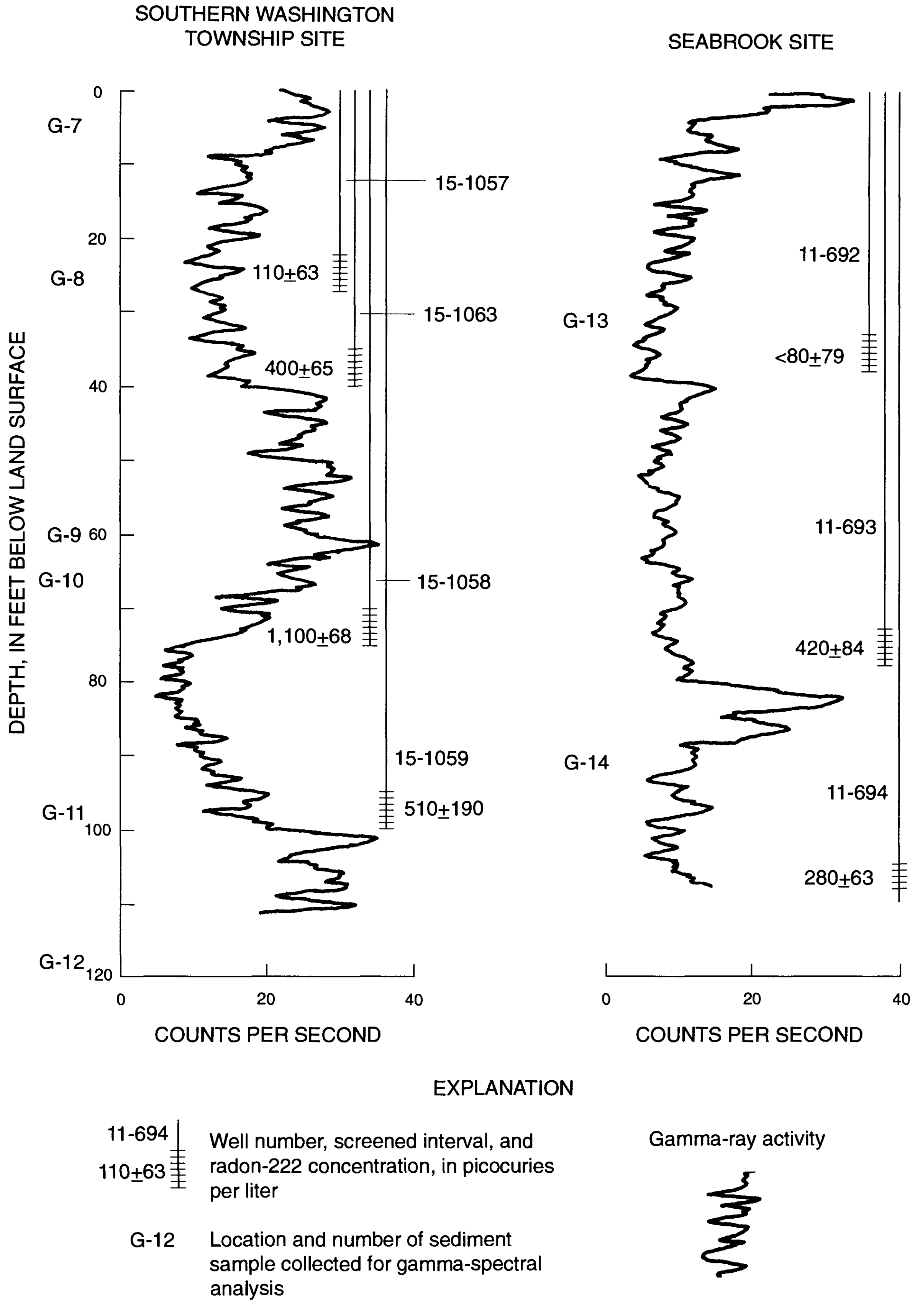


Figure 3. Gamma logs of the Kirkwood-Cohansey aquifer system at five nested-observation-well sites in southwestern New Jersey, screened intervals, location of sediment samples collected for gamma-spectral analysis, and dissolved radon-222 concentrations, 1991.

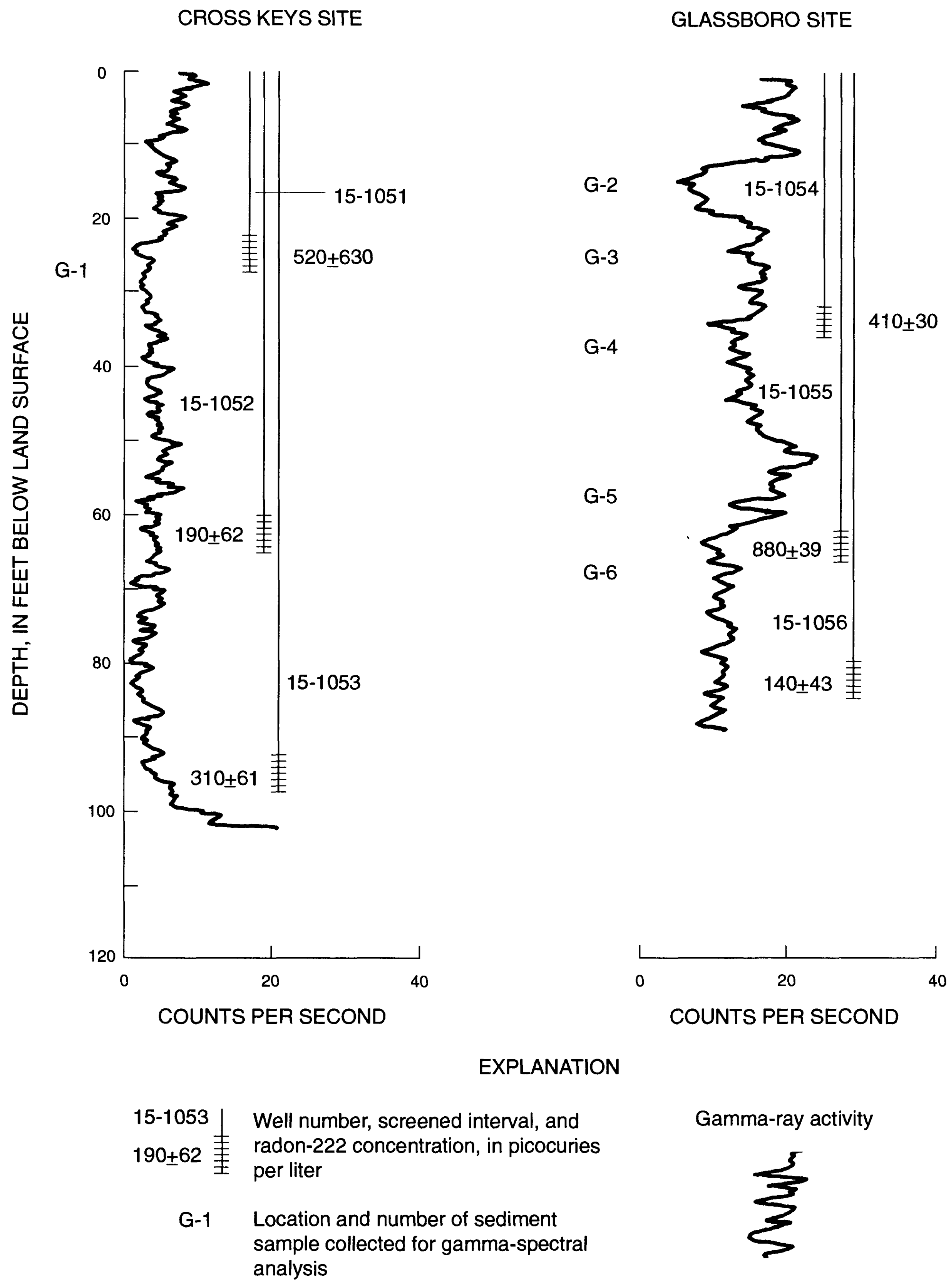


Figure 3. Gamma logs of the Kirkwood-Cohansey aquifer system at five nested-observation-well sites in southwestern New Jersey, screened intervals, location of sediment samples collected for gamma-spectral analysis, and dissolved radon-222 concentrations, 1991--Continued.

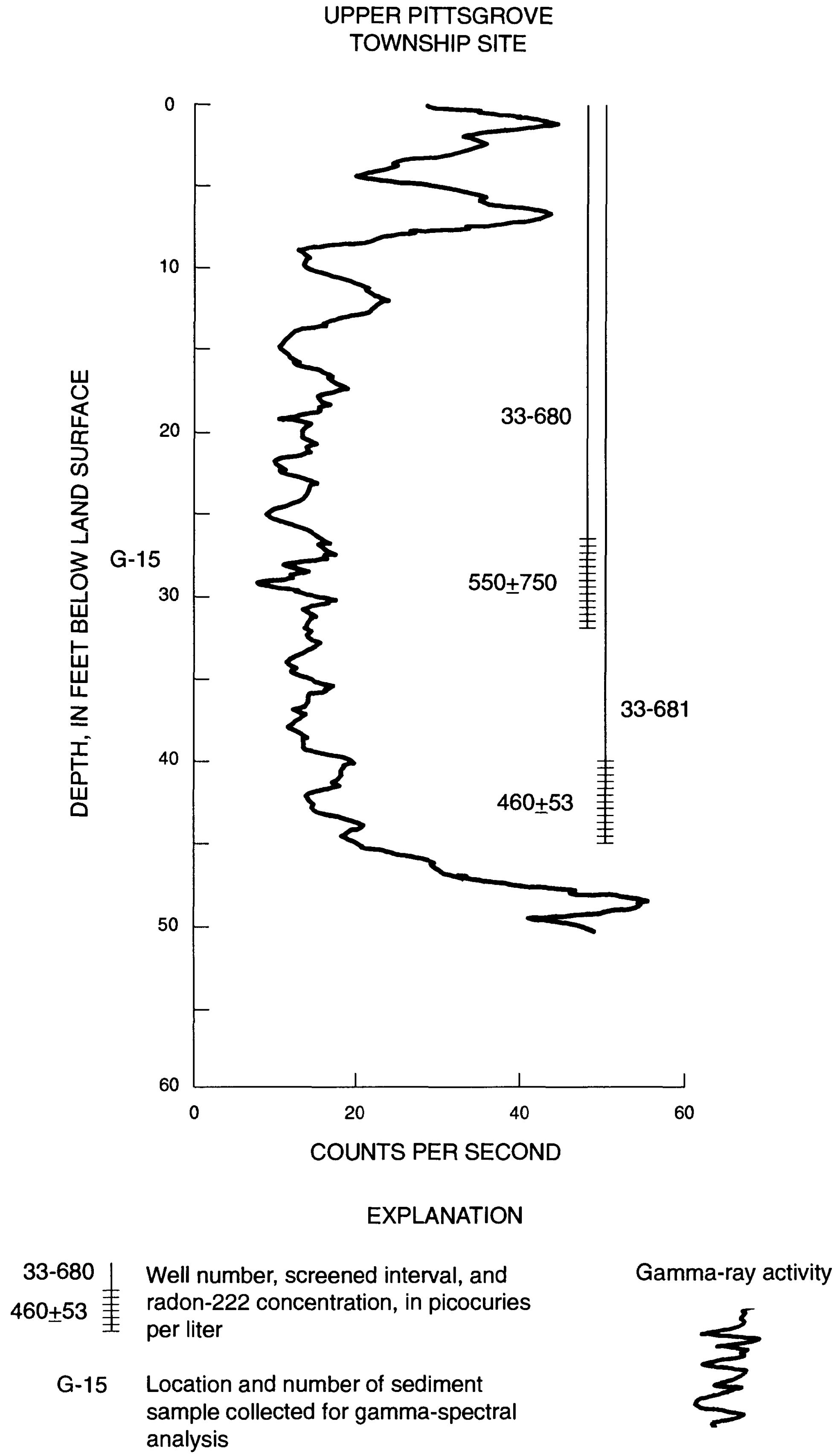


Figure 3. Gamma logs of the Kirkwood-Cohansey aquifer system at five nested-observation-well sites in southwestern New Jersey, screened intervals, location of sediment samples collected for gamma-spectral analysis, and dissolved radon-222 concentrations, 1991--Continued.

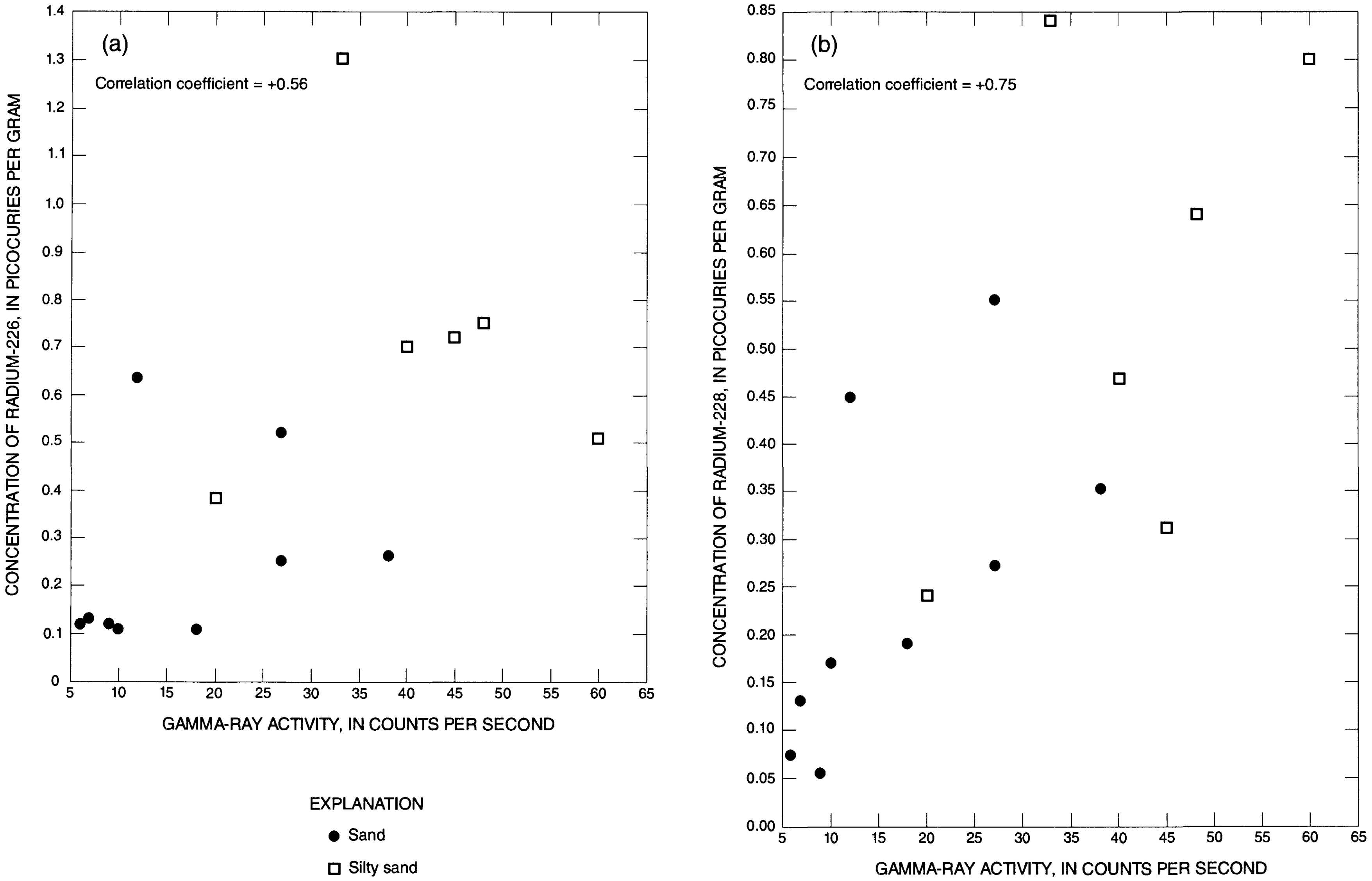


Figure 4. Concentrations of (a) radium-226 and (b) radium-228 in samples of silty sand and sand as a function of gamma-ray activity of the sediment, Kirkwood-Cohansey aquifer system, southwestern New Jersey.

The concentrations of both radium-226 and radium-228 were more uniform in sand than in silty sand. The range of concentrations of radium-226 was greater, particularly in silty sand, than that of radium-228. Concentrations of radium-226 in silty sand generally were greater than those of radium-228. The radium-228/radium-226 ratio for silty sand was lower than that for sand. Only one of the six silty sand samples had a radium-228/radium-226 ratio greater than 1.0; three of the samples had ratios of about 0.6. In contrast, six of nine sand or gravel samples had a radium-228/radium-226 ratio greater than 1.0; the maximum ratio of 1.73 was determined for a sample of coarse sand (sample G-8, table 1).

Because the aquifer sediment tends to be coarser near the land surface and finer near the base of the aquifer, radium-228/radium-226 ratios in the sediment might be expected to be higher near the land surface than near the base of the aquifer. In general, in the medium- and coarse-sand samples recovered from depths less than 35 ft, the radium-228/radium-226 ratio slightly exceeded 1.0; the exception is sample G-1 from the Cross Keys site (0.61). Three of five samples collected from depths greater than 65 ft had radium-228/radium-226 ratios that were slightly less than 1.0, though sample G-12 (sandy silt) had a radium-228/radium-226 ratio of 1.6. The number of samples is insufficient, however, to statistically test the validity of this hypothesis.

RELATION OF DISTRIBUTION OF RADIUM, NITRATE, AND PESTICIDES TO AGRICULTURAL LAND USE AND DEPTH

In this section, differences in concentrations of dissolved radium, nitrate, pesticides, and other chemical constituents (1) between agricultural and non-agricultural areas and (2) with depth in agricultural areas are evaluated statistically. Correlations between the concentrations of dissolved radium and other inorganic chemical constituents also are discussed. Concentrations of dissolved radium, nitrate, pesticides, and other inorganic chemical constituents were found to be higher in agricultural areas than in non-agricultural areas, and in shallow- and medium-depth wells in agricultural areas than in deep wells in agricultural areas.

Relation to Agricultural Land

A statistical summary of concentrations of dissolved inorganic chemicals and radionuclides in samples from the regional well network is presented in table 2. Water-quality data for wells in agricultural and non-agricultural areas are compared.

Radium and Other Radionuclides

The concentration of tritium, determined in samples from 39 of the 42 wells in the regional sampling network, was used to identify the presence of pre-1955 (more than 35-year-old) ground water (Hendry, 1988). Only two samples contained less than 6 pCi/L of tritium--one (well 5-0454) from a non-agricultural area and one (well 33-0462) from an agricultural area. The results of chemical analysis of these two samples were not removed from the data base prior to statistical analyses because they were not expected to bias the overall data set. The minimum and maximum tritium concentrations were 2 and 120 pCi/L, respectively, in water samples from agricultural areas and <5.7 and 88 pCi/L, respectively, in water samples from non-agricultural areas. Excluding these extremes tritium concentrations ranged from 34 to 92 pCi/L in samples from agricultural areas and from 20 to 75 pCi/L in samples from non-agricultural areas. These results indicate that the general range of travel time from the water table to the well screen for the samples is less than 30 years, and cannot be differentiated by land use. Therefore, any difference in water quality between the two areas cannot be attributed to a difference in residence time.

The highest concentrations of radium-226 and radium-228 were detected in water from the southwestern part of the study area in agricultural areas of northern Cumberland County, eastern Salem County, eastern and central Gloucester County, and south-central Camden County. The maximum concentration of radium-226, 8.9 pCi/L, was determined in a sample from well 11-689 in north-central Cumberland County; the maximum concentration of radium-228, 5.0 pCi/L, was in a sample from well 7-695 in central Gloucester County. Median concentrations of radium-226 and radium-228 in ground water in agricultural areas were 2.2 and 1.7 pCi/L, respectively. Median concentrations of radium-226 and radium-228 in ground water in non-agricultural areas were 0.73 and <1 pCi/L, respectively.

None of the 13 samples from wells in non-agricultural areas contained radium in concentrations that exceed the U. S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) for total radium (radium-226 plus radium-228) of 5 pCi/L (U.S. Environmental Protection Agency, 1988). In contrast, 11 of the 29 samples (38 percent) from wells in agricultural areas contained radium in concentrations that exceed the USEPA MCL for total radium. These findings are almost identical to those of Kozinski and others (1995), in which radium concentrations in 26 of the 81 samples (33 percent)--all of them from agricultural areas--exceeded the USEPA MCL for total radium.

The distribution of dissolved uranium was similar to that of radium-226 and radium-228; the highest concentrations were detected in agricultural areas in southwestern New Jersey. The highest concentration of dissolved uranium, 0.36 μg/L, was present in a sample from well 33-674 in eastern Salem County. The median concentrations of uranium in ground-water samples from agricultural and non-agricultural areas were 0.07 μg/L and 0.02 μg/L, respectively. The maximum concentration of dissolved uranium in samples from non-agricultural areas was 0.07 μg/L (well 29-596) (table 2).

The radioactivity in the ground water resulting from the presence of uranium (0.67 pCi μg of uranium in isotopic equilibrium) is more than an order of magnitude less and, in most cases, two orders of magnitude less than the radioactivity resulting from the presence of either radium-226 or radium-228. Radium, therefore, appears to be more mobile in the ground water than uranium. This result is unexpected because uranium is expected to be highly mobile in the oxic environment of the Kirkwood-Cohansey aquifer system.

Concentrations of dissolved radon-222 were slightly higher in samples from the agricultural areas in the southwestern part of the study area than in samples from the non-agricultural areas in the southeastern part of the study area. The highest dissolved-radon-222 concentration, 1,300 pCi/L, was present in a sample from well 33-674 in an agricultural area in eastern Salem County. The highest concentration of dissolved radon-222 found in the samples from non-agricultural areas was 880 pCi/L (well 5-709). The median concentration of radon-222 in the samples from wells in agricultural areas was 380 pCi/L; the median concentration of radon-222 in the samples from wells in non-agricultural areas was 220 pCi/L (table 2). However, concentrations of dissolved radon-222 were only about 1.5 times as high in agricultural areas as in non-agricultural areas, whereas concentrations of uranium, radium-226, and radium-228 generally were about 3 to 5 times as high in agricultural areas as in non-agricultural areas.

The difference between concentrations of dissolved radon-222 in agricultural and non-agricultural areas may result from the fact that agricultural land in southern New Jersey is located primarily on soils developed from the Bridgeton Formation. Gunderson and Peake (1992) observed higher radon-222 concentrations in soil gas from the Bridgeton Formation in the southwestern part of the study area than in soil gas from the Cohansey Sand in the southeastern part of the study area. Furthermore, the Cohansey Sand becomes more quartzose to the east (Owens and Sohl, 1969); it is likely that uranium concentration decreases as the abundance of quartz increases.

The radioactivity in the ground water attributable to radon-222 is two to four orders of magnitude greater than that attributable to radium-226. This result is consistent with results of previous studies in which the solubilities of these radionuclides in southern New Jersey (Szabo, 1990) and in other geologic terrains (Earle and Drever, 1983; Szabo and others, 1991) were compared. Further, even though radium is more mobile than uranium, most of the radium (the radioactive parent of radon) in the Kirkwood-Cohansey aquifer system appears to be bound up in the solids that comprise the aquifer matrix rather than in solution.

Concentrations of uranium, radium-226, radium-228, and radon-222 measured in 1990 in samples from the regional well network were nearly identical to the concentrations of these constituents measured in samples collected during 1988-89 by Kozinski and others (1995). This similarity indicates that the radionuclide-concentration data obtained during this study are typical of concentrations of dissolved radionuclides in the Kirkwood-Cohansey aquifer system.

Nitrate and Inorganic Chemical Constituents

Water in the Kirkwood-Cohansey aquifer system typically is low in dissolved solids. Specific conductance of water samples from the 42 wells ranged from 18 to 415 μS/cm (table 2), with a median of 123 μS/cm. These values are relatively low when compared to those for most ground water (Hem, 1985). Specific conductance was much greater in agricultural areas (median 158 μS/cm) than in non-agricultural areas (median 57 μS/cm).

The ground water was strongly acidic; more than half the samples had a pH of less than 5.0. The pH did not differ significantly between ground-water samples from agricultural areas and those from non-agricultural areas.

Dissolved-oxygen concentrations, however, typically were lower in water from non-agricultural areas (median 3.26 mg/L; moderately well-oxygenated) than in water from agricultural areas (median 8.02 mg/L; well-oxygenated). Agricultural land tends to be located in well-drained ground-water-recharge areas on ridges underlain by the Bridgeton Formation. Concentrations of DO tended to be lowest (typically less than 1.0 mg/L) in samples of water from wells in or near wetland areas, probably because wetlands are zones of ground-water discharge. Ground water in wetlands tends to be depleted in oxygen as a result of oxygen consumption by mineral-weathering processes at depth in the aquifer or by the decay of organic material beneath the land surface. Additional organic material is present at depth in the aquifer (Owens and Minard, 1979).

Concentrations of nitrate in water from the Kirkwood-Cohansey aquifer system exceeded the USEPA MCL of 10 mg/L in 12 of the 42 samples from the regional well network (app. 1B). All the water samples from the regional well network in which the USEPA MCL for nitrate was exceeded were collected from the 29 wells in agricultural areas. The highest nitrate concentration (27 mg/L) was measured in the sample from well 11-689, in an agricultural area in northern Cumberland County; the median concentration in agricultural areas was 8.2 mg/L. The USEPA MCL for nitrate was exceeded in 5 of the 81 samples from the well network sampled by Kozinski and others (1995). The highest nitrate concentration measured by Kozinski and others (1995) was 20 mg/L; this sample also was collected from a well in an agricultural area. A nitrate concentration of 30 mg/L was measured in water from the Kirkwood-Cohansey aquifer system in an agricultural area by Louis and Vowinkel (1989).

Concentrations of nitrate generally were low in samples from the 13 wells in the regional well network in non-agricultural areas . The maximum concentration was 3 mg/L in water from well 29-88 in northeastern Ocean County, near the city of Toms River, where residential development has occurred (app. 1B). The median nitrate concentration in non-agricultural areas was 0.3 mg/L, and nearly one-half of the water samples contained no detectable nitrate (table 2).

The isotopic ratios of nitrogen in nitrate were determined for water samples from 13 production wells in agricultural areas and are reported in standard delta-15N notation (Heaton, 1986). Concentrations of nitrate in these wells ranged from 0.80 to 27 mg/L and were greater than 1 mg/L in samples from 12 of the 13 wells. Nitrate is not likely to be chemically reduced to ammonia within this oxygenated aquifer; dissolved-oxygen concentrations exceeded 4 mg/L in water from all 13 wells. Delta-15N values ranged from -1.4 to +10.4 per mil and exceeded 5 per mil in only 1 sample; in 10 of 13 samples, values ranged from 2.5 to 4.6 per mil (app. 1B). Similar delta-15N results were observed in Nebraska by Exner and Spalding (1994). These values indicate a fairly homogeneous regional source of nitrate--either commercial fertilizer or enhanced leaching of soil nitrogen from cultivated land (Heaton, 1986). The notable exception is the sample from an area of dairy farms (well 33-676; app. 1B) with an associated delta-15N value of 10.4 per mil, which is typical for animal wastes (Heaton, 1986).

Concentrations of magnesium as high as 23 mg/L (well 33-679) and calcium as high as 39 mg/L (well 33-685) were measured in water samples collected from the regional well network. All of the water samples from the regional well network that contained more than 2.5 mg/L of magnesium and all but one of the samples that contained more than 5 mg/L of calcium were from agricultural areas. The median concentrations of magnesium and calcium in the agricultural areas were 4.9 and 6.2 mg/L, respectively; in contrast, the median concentrations of magnesium and calcium in the non-agricultural areas were 1.0 and 1.3 mg/L, respectively (table 2). Four of the water samples from non-agricultural areas contained less than 1 mg/L of each of these two constituents. Concentrations of magnesium greater than 2.5 mg/L also were found only in agricultural areas by Kozinski and others (1995); however, concentrations of calcium greater than 5 mg/L were reported for a few wells in non-agricultural areas.

Potassium concentrations as high as 5.5 mg/L (well 33-0233) were measured in water samples collected from the regional well network (app. 1B). All potassium concentrations greater than 2.8 mg/L were in samples from agricultural areas (median 2.3 mg/L); more than one-half of the samples from non-agricultural areas contained potassium in concentrations less than 1 mg/L (median 0.80 mg/L (table 2)). Kozinski and others (1995) reported a maximum potassium concentration of 40 mg/L in water from an agricultural area.

Concentrations of sodium (1.2-46 mg/L), chloride (<0.1-44 mg/L), and sulfate (<0.5-77mg/L) did not exceed the USEPA secondary drinking-water standards (U.S. Environmental Protection Agency, 1979a) in any of the samples collected from the regional well network. Concentrations of chloride were significantly higher in agricultural areas than in non-agricultural areas (table 2). Concentrations of sodium and sulfate were about the same in both areas.

The major-ion composition of ground water in the agricultural areas generally is dominated by the cations (in decreasing order of abundance) magnesium, sodium and potassium, and calcium, and by the anions (in decreasing order of abundance) nitrate and chloride. In general, the concentrations of all the cations were elevated relative to those in water from non-agricultural areas. Sulfate concentrations generally were low (median 7.1 mg/L) (table 2A). Alkalinity (bicarbonate concentration) also was low (<1-12 mg/L) (table 2A). In contrast, the major-ion composition of ground water in the non-agricultural areas is dominated by the cations sodium and potassium, and by the anions chloride and, to a lesser degree, sulfate. Concentrations of magnesium were low (maximum 2.5 mg/L), and concentrations of nitrate (<0.1-3.0 mg/L)

Table 2. Statistical summary of concentrations of major ions and silica, trace elements, radionuclides, and nutrients, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in samples of water from the Kirkwood-Cohansey aquifer system in southern and east-central New Jersey, 1990, in (A) agricultural areas and (B) non-agricultural areas

[All concentrations in milligrams per liter, unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; pCi/L, picocuries per liter]

A. Agricultural Areas

Constituent or characteristic	Minimum	25th percentile	Median	75th percentile	Maximum	Number of samples
Field characteristics						
Dissolved oxygen	0.27	4.94	8.02	9.28	9.79	27
pH, in standard units	4.18	4.56	4.78	5.02	5.50	29
Specific conductance, in µS/cm	18	85	158	242	415	29
Major ions and silica						
Alkalinity, as $CaCO_3$	<1	2	2.7	4.8	12	29
Calcium	.09	2.95	6.2	16.5	39	29
Chloride	<.1	8.9	20	25.5	44	29
Fluoride	<.1	<.1	<.1	.2	.3	29
Magnesium	.18	2.6	4.9	10.2	23	29
Potassium	.3	1.5	2.3	3.0	5.5	29
Silica, as SiO_2	5	7.7	9.5	10.5	18	29
Sodium	1.2	2.8	4.0	7.7	46	29
Sulfate	<.5	1.0	7.1	20.5	77	29
Trace elements						
Aluminum	.02	.03	.085	.20	.91	26
Barium	.011	.053	.084	.17	.27	29
Cobalt	<.003	<.003	<.003	.003	.007	29
Copper	<.01	<.01	<.01	.02	.41	29
Iron	.005	.008	.015	.095	3.8	29
Lead	<.01	<.01	<.01	<.01	.03	29
Lithium	<.004	<.004	<.004	<.004	.005	29
Manganese	<.001	.009	.022	.039	.094	29
Strontium	<.001	.025	.053	.145	.30	29
Zinc	<.003	.008	.013	.028	.16	29
Nutrients and dissolved organic carbon						
Ammonia, as N	<.01	<.01	<.01	.02	.15	29
Nitrate, as N	.097	3.55	8.2	13.5	27	29
Phosphate (ortho), as P	<.01	<.01	<.01	<.01	<.01	29
Carbon, organic	.3	.4	.6	.98	2.4	29
Radionuclides						
Uranium	<.00001	.00004	.00007	.00009	.00036	29
Radium-226, in pCi/L	.21	1.1	2.2	3.6	8.9	29
Radium-228, in pCi/L	<1	<1	1.7	3.4	5.0	25
Radon-222, in pCi/L	110	245	380	505	1,300	29
Gross beta particle activity, in pCi/L	.9	3.5	4.6	9.0	12	29

Table 2. Statistical summary of concentrations of major ions and silica, trace elements, radionuclides, and nutrients, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in samples of water from the Kirkwood-Cohansey aquifer system in southern and east-central New Jersey, 1990, in (A) agricultural areas and (B) non-agricultural areas--Continued

B. Non-Agricultural Areas

Constituent or characteristic	Minimum	25th percentile	Median	75th percentile	Maximum	Number of samples
Field characteristics						
Dissolved oxygen	<0.1	0.20	3.26	6.2	6.8	11
pH, is standard units	4.51	4.70	4.72	5.04	6.40	13
Specific conductance, in µS/cm	20	35	57	123	129	13
Major ions and silica						
Alkalinity, as $CaCO_3$	<1	1.2	1.9	4.7	15	13
Calcium	.15	.39	1.3	3.1	8.5	13
Chloride	2.2	3.6	5.8	21	31	13
Fluoride	<.1	<.1	<.1	.2	.2	13
Magnesium	.2	.31	1.0	1.7	2.5	13
Potassium	.2	.50	.80	2.0	2.8	13
Silica, as SiO_2	3.8	4.6	6.6	8.7	32	13
Sodium	1.6	2.0	4.0	10.4	15	13
Sulfate	<1	3.5	4.0	8.6	22	13
Trace elements						
Aluminum	<.01	.03	.11	.20	.40	11
Barium	.01	.019	.030	.055	.074	13
Cobalt	<.003	<.003	<.003	<.003	.006	13
Copper	<.01	<.01	<.01	.025	.08	13
Iron	<.003	.012	.047	1.21	5.0	13
Lead	<.01	<.01	<.01	<.01	.02	13
Lithium	<.004	<.004	<.004	<.004	<.004	13
Manganese	<.001	.010	.018	.040	.130	13
Strontium	.003	.007	.016	.025	.041	13
Zinc	<.003	.006	.011	.027	.075	13
Nutrients and dissolved organic carbon						
Ammonia, as N	<.01	<.01	<.02	.025	.12	13
Nitrate, as N	<.1	<.1	.3	1.25	3.0	13
Phosphate (ortho), as P	<.01	<.01	<.01	<.01	.09	13
Carbon, organic	<.2	.3	.45	.7	1.0	12
Radionuclides						
Uranium	<.00001	<.00001	.00002	.00005	.00007	13
Radium-226, in pCi/L	.18	.35	.73	1.2	2.4	13
Radium-228, in pCi/L	<1	<1	<1	1.8	2.4	13
Radon-222, in pCi/L	80	104	220	490	880	13
Gross beta particle activity, in pCi/L	.7	1.95	3.3	4.4	7.7	13

(table 2B) and alkalinity (bicarbonate anion) (<1-15 mg/L) (table 2B) were minute, typically less than the minimum reporting level (MRL). According to Lord and others (1990), the composition of precipitation in the New Jersey Coastal Plain is dominated by the cations sodium and potassium and the anion chloride. The composition of ground water in the non-agricultural areas resembles that of precipitation, indicating that ground-water chemistry has changed little with infiltration. In contrast, the composition of ground water in the agricultural areas is significantly different from that of precipitation, indicating that ground-water chemistry is altered substantially with infiltration to the aquifer.

The trace elements detected most frequently in the water samples from the Kirkwood-Cohansey aquifer system are aluminum, barium, iron, manganese, strontium, and zinc. Most water samples met the USEPA primary and secondary drinking-water standards for trace elements.

Concentrations of iron exceeded the secondary drinking-water standard of 300 μg/L (U.S. Environmental Protection Agency, 1979a) in 9 of the 42 samples from the regional well network (app. 1B). Only four of the nine water samples from the regional well network in which iron concentrations exceeded 300 mg/L were from the agricultural areas. Concentrations of manganese exceeded the secondary drinking-water standard of 50 μg/L (U.S. Environmental Protection Agency, 1979a) in 7 of the 42 samples from the regional well network. Six of the seven water samples from the regional well network in which manganese concentrations exceeded 50 μg/L were from the agricultural areas. The maximum concentrations of iron and manganese measured in the water samples from the regional well network were 5,000 and 130 μg/L, respectively. All four water samples in which dissolved-iron concentrations exceeded 1,000 μg/L were anoxic (dissolved-oxygen concentrations were less than 1 mg/L). Three of these four samples were from non-agricultural (forested) areas. The median concentration of iron in samples from wells in the agricultural areas was 15 μg/L; in contrast, the median concentration of iron in samples from the non-agricultural areas was 47 μg/L (table 2). The median concentration of manganese was about the same in samples from wells in both areas (table 2).

The maximum concentration of barium measured in water samples collected from the regional well network was 270 μg/L, a concentration substantially below the USEPA MCL of 2,000 μg/L (U.S. Environmental Protection Agency, 1988). This sample was collected from well 7-690, located in an agricultural area in southeastern Camden County. The median barium concentration in the water samples from the agricultural areas was 84 μg/L. The maximum concentration of barium in water samples from the non-agricultural areas was 74 μg/L (table 2B).

The concentration of strontium, a divalent alkaline-earth metal like barium, also was substantially greater in ground water from agricultural areas than in ground water from non-agricultural areas. The median strontium concentration in the samples from the regional well network in agricultural areas was 53 μg/L, which was greater than the maximum concentration of 41 μg/L in the samples from non-agricultural areas (table 2).

Concentrations of cadmium, copper, lead, mercury, molybdenum, and vanadium in the samples from the regional well network were low (app. 1B). In most of the samples in which these constituents were detected, the concentrations only slightly exceeded the MRL for the constituent and, in more than one-half of the samples, the concentrations of these constituents were less than the MRL. The maximum concentrations of copper, cadmium, and mercury were 410, 1.0, and 0.2 μg/L, respectively, and did not exceed the USEPA MCL's for these constituents (U.S. Environmental Protection Agency, 1988; 1991b). The maximum concentration of lead was 30 μg/L (well 15-1033). Six of the 42 samples contained lead in concentrations of 10 μg/L or more, the maximum allowable source-water (in this case, ground water collected before a tap) concentration of lead (U.S. Environmental Protection Agency, 1991b). Four of the six samples in which lead concentrations were 10 µg/L or more were collected from wells in agricultural areas. The pH of these six samples ranged from 4.3 to 4.9; these values are approximately at or are below the median pH (4.78) of the water samples collected from wells in the regional well network in agricultural areas. Cadmium, copper, and mercury also were detected more frequently in ground water in which the pH was less than 5.0 than in ground water in which the pH was greater than 5.0. Because the solubilities of these trace elements increase with decreasing pH, they are likely to be present in measurable concentrations in acidic water. Molybdenum and vanadium were not detected in any water sample collected from the regional well network. Molybdenum and vanadium are relatively insoluble in acidic water and, hence, are unlikely to be present in measurable concentrations in the Kirkwood-Cohansey aquifer system.

For almost all inorganic constituents whose concentrations were determined in this study, similar concentrations were reported for water from a reconnaissance-well network sampled by Kozinski and others (1995). The close correspondence of the results of these two studies for constituents whose concentrations typically vary considerably (especially nitrate, calcium, iron, and manganese) confirms that the concentrations measured in the current study are representative of geochemical conditions in the aquifer.

Pesticides

Only 16 of the wells in agricultural areas were sampled for pesticides. Water from only two of these wells (33-679 and 33-685 in Salem County) contained detectable concentrations of pesticides. The following pesticides were detected--alachlor, atrazine, carbofuran, cyanazine, heptachlor epoxide, and metolachlor. The maximum concentration of any of the detected pesticides was 7.5 µg/L of alachlor in the sample from well 33-685 (app. 1B). Of the remaining detected pesticides, only carbofuran was present in a concentration (maximum 2.6 µg/L) that exceeded 1 µg/L.

The same pesticides were commonly detected by Louis and Vowinkel (1989) in their large-scale survey of water quality in the Kirkwood-Cohansey aquifer system. Furthermore, Louis and Vowinkel (1989) found that a greater percentage of samples from wells in the Kirkwood-Cohansey aquifer system contained pesticides when nitrate concentrations exceeded 10 mg/L than when nitrate concentrations were less than 10 mg/L. The concentration of nitrate did, indeed, exceed 10 mg/L in water from both wells in Salem County in which the pesticides were detected; however, it also exceeded 10 mg/L in water from many sampled wells in which no pesticides were detected.

The presence of dissolved pesticides is uncommon even in nitrate-rich ground water in the agricultural areas for several reasons. Unlike nitrogen, pesticides are not applied evenly either spatially or temporally at the land surface. Furthermore, many pesticides are not persistent in the environment.

Statistical Relation of Water Quality to Land Use

Statistically significant differences in the concentrations of radium-226, radium-228, radon-222, and uranium, and the activities of gross beta particles were found between water samples from wells in agricultural areas and those from wells in non-agricultural areas. Results of the Kruskal-Wallis test indicate that the mean of the ranked values for each of these constituents was significantly higher at the 95-percent confidence level in water from wells in agricultural areas than in water from wells in non-agricultural areas (table 3).

Table 3. Results of Kruskal-Wallis statistical test for differences between agricultural areas and non-agricultural areas in concentrations of major ions and silica, trace elements, nutrients, and radionuclides, and for results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in 42 samples of water from the Kirkwood-Cohansey aquifer system in southern and east-central New Jersey, 1990

[Constituent concentrations are considered significantly different in water samples from the two land-use groups if the significance of the chi-square statistic is less than 0.05 (shown in boxes in bold print); <, less than]

Dissolved constituent	Land use (agricultural or non-agricultural) for which mean rank of constituent concentrations in water samples is higher	Chi-square statistic corrected for ties	Significance of chi-square statistic
	Field characteristics		
Dissolved oxygen	**Agricultural**	**11.61**	**<0.001**
pH	No difference	.34	.558
Specific conductance	**Agricultural**	**9.88**	**.002**
	Major ions and silica		
Alkalinity, as $CaCO_3$	Agricultural	1.05	.305
Calcium	**Agricultural**	**10.66**	**.001**
Chloride	Agricultural	3.68	.055
Magnesium	**Agricultural**	**14.41**	**<.001**
Potassium	**Agricultural**	**7.94**	**.005**
Silica, as SiO_2	**Agricultural**	**5.67**	**.017**
Sodium	No difference	.01	.924
Sulfate	No difference	.34	.557
	Trace elements		
Aluminum	No difference	.10	.752
Barium	**Agricultural**	**12.33**	**<.001**
Cobalt	Agricultural	1.47	.226
Copper	No difference	.01	.907
Iron	Non-agricultural	1.74	.187
Lead	Non-agricultural	1.52	.217
Manganese	No difference	<.01	.978
Strontium	**Agricultural**	**9.80**	**.002**
Zinc	No difference	.78	.376
	Nutrients		
Ammonia, as N	No difference	.03	.579
Nitrate, as N	**Agricultural**	**17.64**	**<.001**
Carbon, organic	Agricultural	2.50	.114
	Radionuclides		
Uranium	**Agricultural**	**8.29**	**.004**
Radium-226	**Agricultural**	**10.23**	**.001**
Radium-228	**Agricultural**	**3.87**	**.049**
Radon-222	**Agricultural**	**4.06**	**.044**
Gross beta particle activity	**Agricultural**	**6.07**	**.014**

In addition to their statistical significance, the differences in the quality of ground water between the agricultural and non-agricultural areas also are significant in terms of the potability of the water. The median concentrations of radium-226 and radium-228 in the agricultural areas were 2.2 pCi/L and 1.7 pCi/L, respectively, totaling 3.9 pCi/L, which is only slightly less than the USEPA MCL of 5.0 pCi/L for total radium in drinking water (U.S. Environmental Protection Agency, 1988). Furthermore, the maximum concentrations of both radium-226 and radium-228 (8.9 and 5.0 pCi/L, respectively) in agricultural areas equaled or exceeded the USEPA MCL for total radium. In contrast, the median concentrations of both radium-226 and radium-228 in non-agricultural areas were less than 1 pCi/L. Therefore, in individual samples, even though one or both of these constituents generally were present in detectable quantities, the sum of their concentrations was well below the USEPA MCL for total radium. Even the sum of the maximum concentrations of radium-226 and radium-228 in non-agricultural areas (2.4 and 2.4 pCi/L, respectively) was slightly less than the USEPA MCL.

The relative difference between the median concentrations of radon-222 in the water samples from agricultural and non-agricultural areas is smaller than the relative differences for both radium-226 and radium-228, but is also significant in terms of the potability of the water. The median concentration of radon-222 in samples from the agricultural areas (380 pCi/L) (table 2A) exceeded the proposed USEPA MCL of 300 pCi/L (U.S. Environmental Protection Agency, 1991a) for this radionuclide, whereas the median concentration of radon-222 in samples from non-agricultural areas was 220 pCi/L, slightly less than the proposed MCL. Neither uranium concentrations nor gross beta-particle activities exceeded proposed or final USEPA MCL's in samples from either agricultural or non-agricultural areas.

Median and maximum concentrations of nitrate and the inorganic constituents calcium, magnesium, barium, strontium, silica, and potassium, and those of DO, like those of the radioactive constituents, were greater in water samples from wells in agricultural areas than in those from wells in non-agricultural areas (table 2). Results of the Kruskal-Wallis test indicate that the means of the ranked values for all these constituents were significantly higher for samples from wells in agricultural areas than for samples from wells in non-agricultural areas (table 3). Concentrations of alkalinity, aluminum, ammonia, chloride, iron, lead, manganese, sodium, and sulfate did not show statistically significant differences between agricultural and non-agricultural areas (although the concentrations of iron and lead generally were greater in non-agricultural areas than in agricultural areas and that of chloride generally was greater in agricultural areas than in non-agricultural areas). According to statistical measures, therefore, these constituents are not preferentially distributed in the ground water with respect to agricultural land use.

A similar statistical result was found by Kozinski and others (1995) for these same radionuclides and inorganic constituents, with the exception of iron, silica, and chloride. The close correspondence of statistical results of the two studies confirms that the observed differences in the quality of water between agricultural and non-agricultural areas are representative of conditions in the aquifer. The differences in chloride concentrations (higher in water from wells in agricultural areas than in non-agricultural areas) and iron concentrations (higher in water from wells in non-agricultural areas than in agricultural areas) were found to be statistically significant in the data from the reconnaissance well network sampled by Kozinski and others (1995), but concentrations of silica were found not to be statistically different between agricultural and non-agricultural areas. Kozinski and others (1995) reported values of statistical significance that were lower than those reported in this study, most likely because their well network was designed as a reconnaissance network.

Relation to Depth in Agricultural Areas

The results of chemical analyses of water samples from the 15 nested observation wells and 2 nested piezometers located in agricultural areas are presented in appendix 2C. The relation of concentrations of radium and radionuclides, nitrate, dissolved inorganic chemical constituents, and pesticides to depth is illustrated in figure 5.

Radium and Other Radionuclides

Concentrations of uranium, radium-226, and radium-228 were substantially higher in water from shallow and medium-depth wells than in water from deep wells (fig. 5a-d), where they were barely detectable or undetectable. At three of the five sites, the sum of the concentrations of radium-226 and radium-228 exceeded 5 pCi/L in samples of water from either shallow or medium depths in the aquifer. The maximum radium-226 and radium-228 concentrations measured in water from the nested observation wells, the production wells sampled during this study, and the wells sampled by Kozinski and others (1995) were 14 pCi/L in the medium-depth well at the Seabrook site (well 11-693) and 26 pCi/L in the medium-depth drive-point piezometer (well 11-700) at the same site, respectively (app. 2C). Maximum concentrations of uranium (0.19 µg/L in the shallow well 15-1057) and radon-222 (1,100 pCi/L in the lower medium-depth well 15-1058) in the nested observation wells were typical of, but did not exceed, the maximum concentrations of these constituents measured in water samples from the regional well network of this study or the reconnaissance well network sampled by Kozinski and others (1995).

Concentrations of radon-222 (the soluble progeny of radium-226) and radium-226 in the ground water at the five sites varied by slightly more than one and two orders of magnitude, respectively. The concentration of radium-226 in the sediment at the sites varied by about one order of magnitude (table 1), and was highest in the finest sediment. The concentration of radon-222 was highest in water from wells screened in the finest sediment (fig. 3), as determined from gamma logs.

Concentrations of tritium varied greatly with depth and were highest in samples from the medium-depth wells (fig. 5m). Concentrations as high as 130 pCi/L and 160 pCi/L were measured in wells 11-693 (78 ft) and 15-1058 (75 ft), respectively. Tritium concentrations in water samples from the medium-depth wells at the other three sites ranged from 50 to 56 pCi/L; these concentrations were generally higher than those in water from the shallowest wells and were significantly higher than those in water from the deepest wells. At shallow depths, concentrations of tritium ranged from 37 to 55 pCi/L. In three of the four deep wells (11-694 (110 ft), 15-1059 (100 ft), and 15-1053 (97 ft)), concentrations of tritium were less than or equal to 3 pCi/L; the exception was well 15-1056 (84 ft), which contained water with a tritium concentration of 53 pCi/L.

Nitrate and Inorganic Chemical Constituents

Concentrations of nitrate were low in the deep wells (0.14-5.1 mg/L, and less than 1 mg/L in water from 2 of the 4 wells) but were as high as 23 mg/L (well 11-693; see fig. 5e) in the shallow and medium-depth wells. Trends in concentrations of magnesium with depth were similar to those of nitrate. Concentrations of magnesium were low in the deep wells (0.33-1.8 mg/L, and less than 1 mg/L in water from 2 of the 4 wells) but were at least five times greater in the shallow and medium-depth wells (maximum 17 mg/L in water from the shallow well 15-1057; see fig. 5f). Nitrogen- and magnesium-bearing minerals and compounds are not present in the aquifer itself;

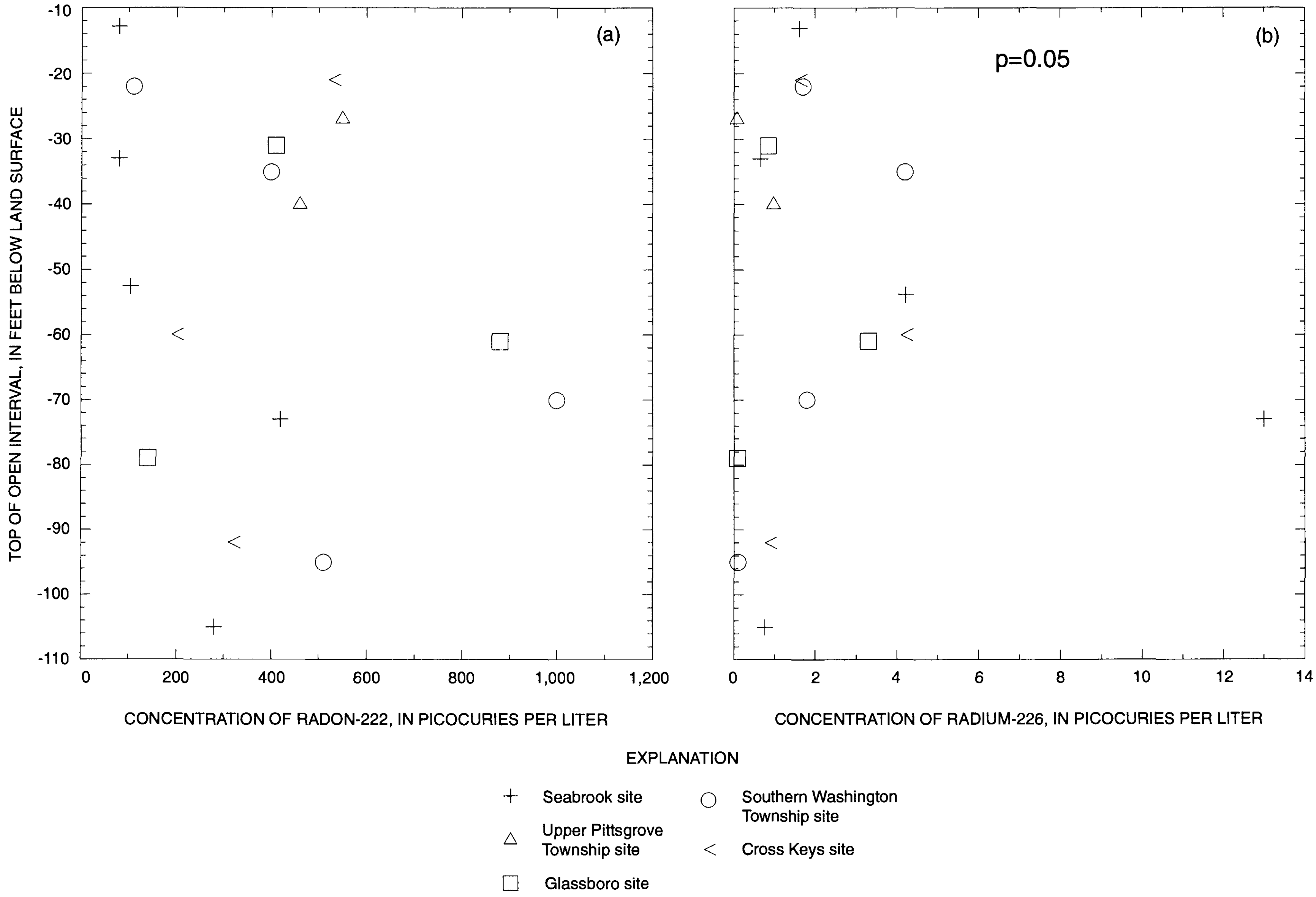


Figure 5. Graphs showing concentration or value in water of (a) radon-222, (b) radium-226, (c) radium-228, (d) uranium, (e) nitrate (as nitrogen), (f) magnesium, (g) barium, (h) dissolved oxygen, (i) lead, (j) atrazine, (k) silica, (l) pH, and (m) tritium as a function of depth in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991 (A p-value is shown for those constituents that varied significantly with depth according to the results of the Kruskal-Wallis statistical test; see table 4).

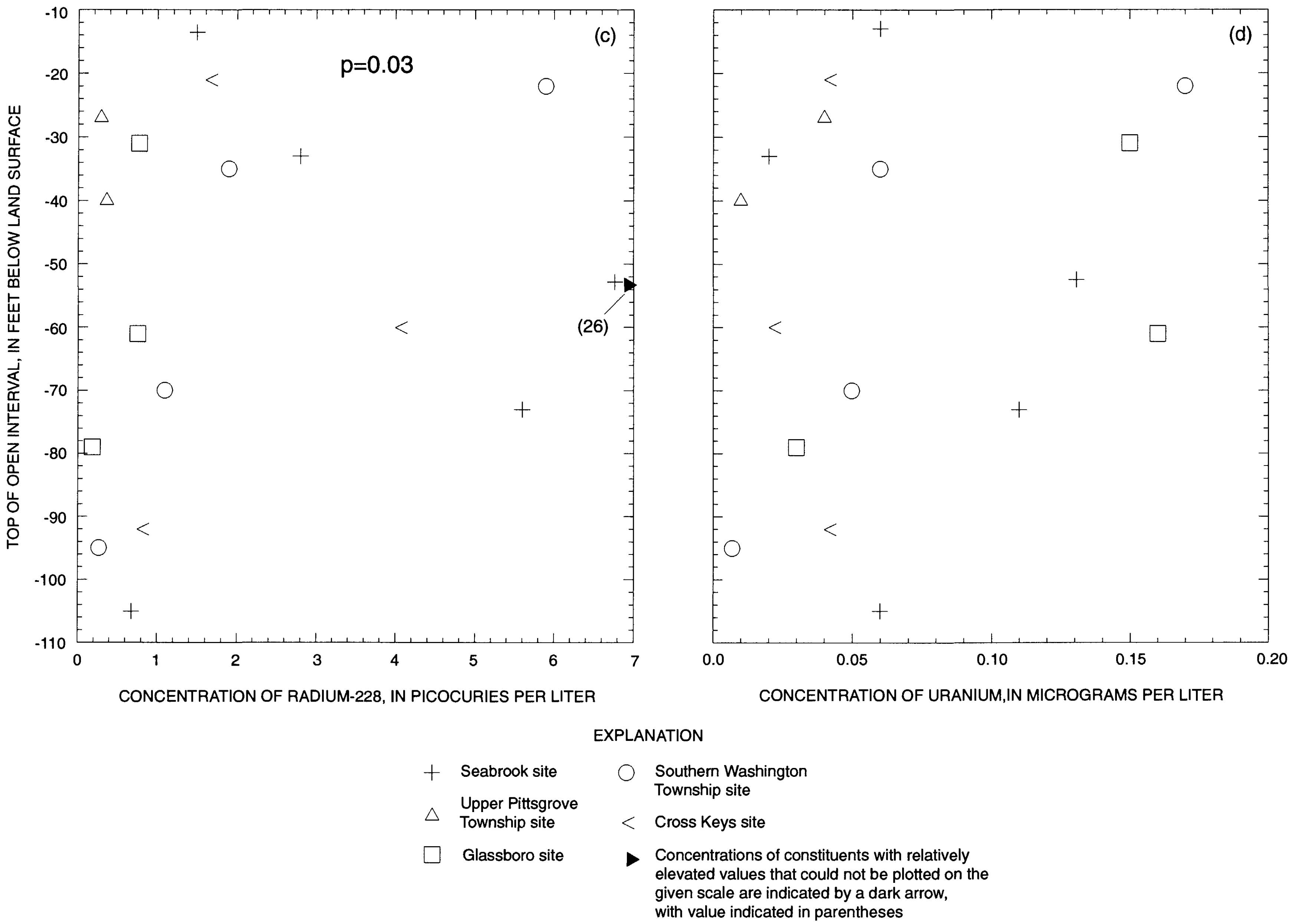


Figure 5. Graphs showing concentration or value in water of (a) radon-222, (b) radium-226, (c) radium-228, (d) uranium, (e) nitrate (as nitrogen), (f) magnesium, (g) barium, (h) dissolved oxygen, (i) lead, (j) atrazine, (k) silica, (l) pH, and (m) tritium as a function of depth in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991 (A p-value is shown for those constituents that varied significantly with depth according to the results of the Kruskal-Wallis statistical test; see table 4)--Continued.

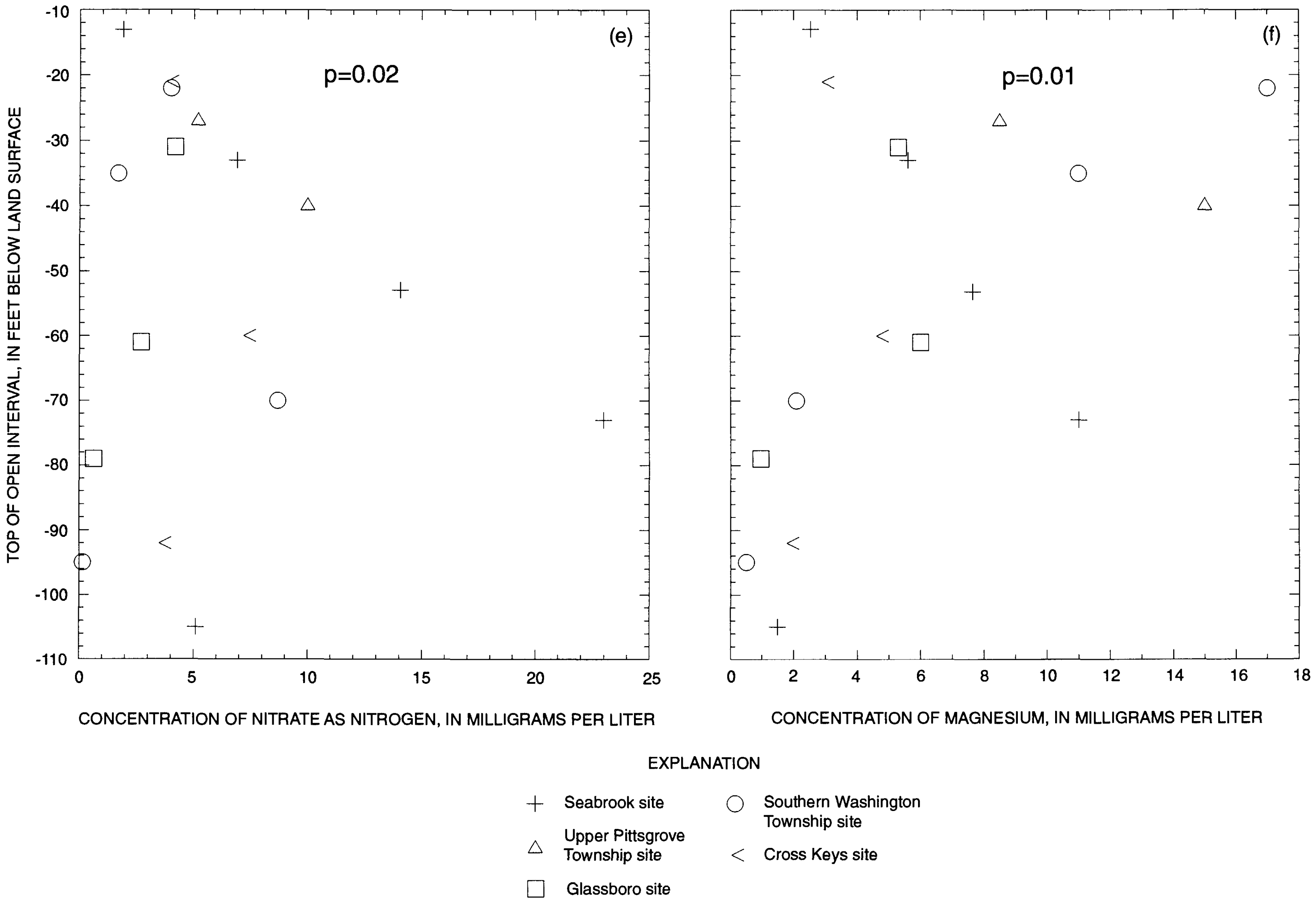


Figure 5. Graphs showing concentration or value in water of (a) radon-222, (b) radium-226, (c) radium-228, (d) uranium, (e) nitrate (as nitrogen), (f) magnesium, (g) barium, (h) dissolved oxygen, (i) lead, (j) atrazine, (k) silica, (l) pH, and (m) tritium as a function of depth in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991 (A p-value is shown for those constituents that varied significantly with depth according to the results of the Kruskal-Wallis statistical test; see table 4)--Continued.

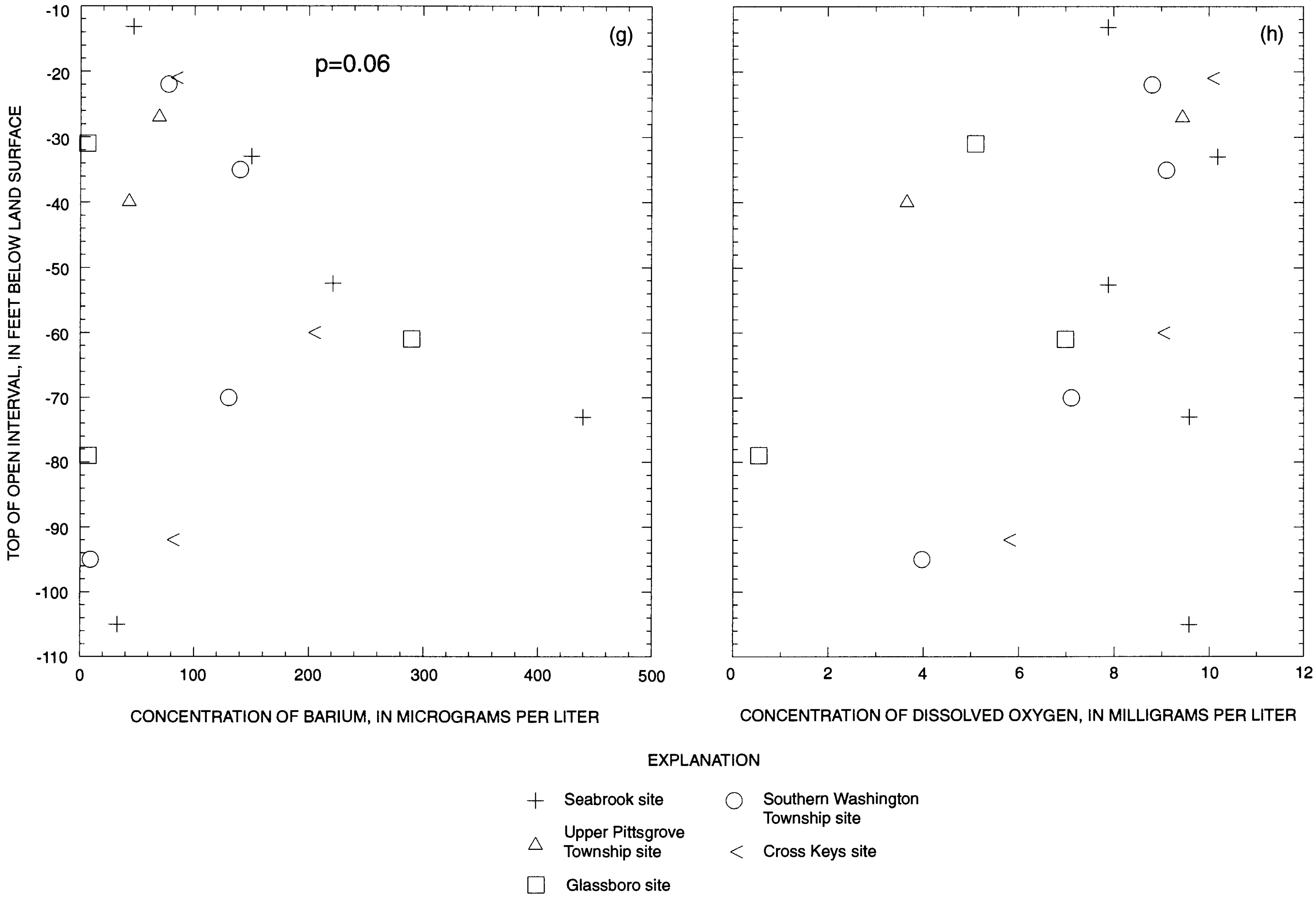


Figure 5. Graphs showing concentration or value in water of (a) radon-222, (b) radium-226, (c) radium-228, (d) uranium, (e) nitrate (as nitrogen), (f) magnesium, (g) barium, (h) dissolved oxygen, (i) lead, (j) atrazine, (k) silica, (l) pH, and (m) tritium as a function of depth in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991 (A p-value is shown for those constituents that varied significantly with depth according to the results of the Kruskal-Wallis statistical test; see table 4)--Continued.

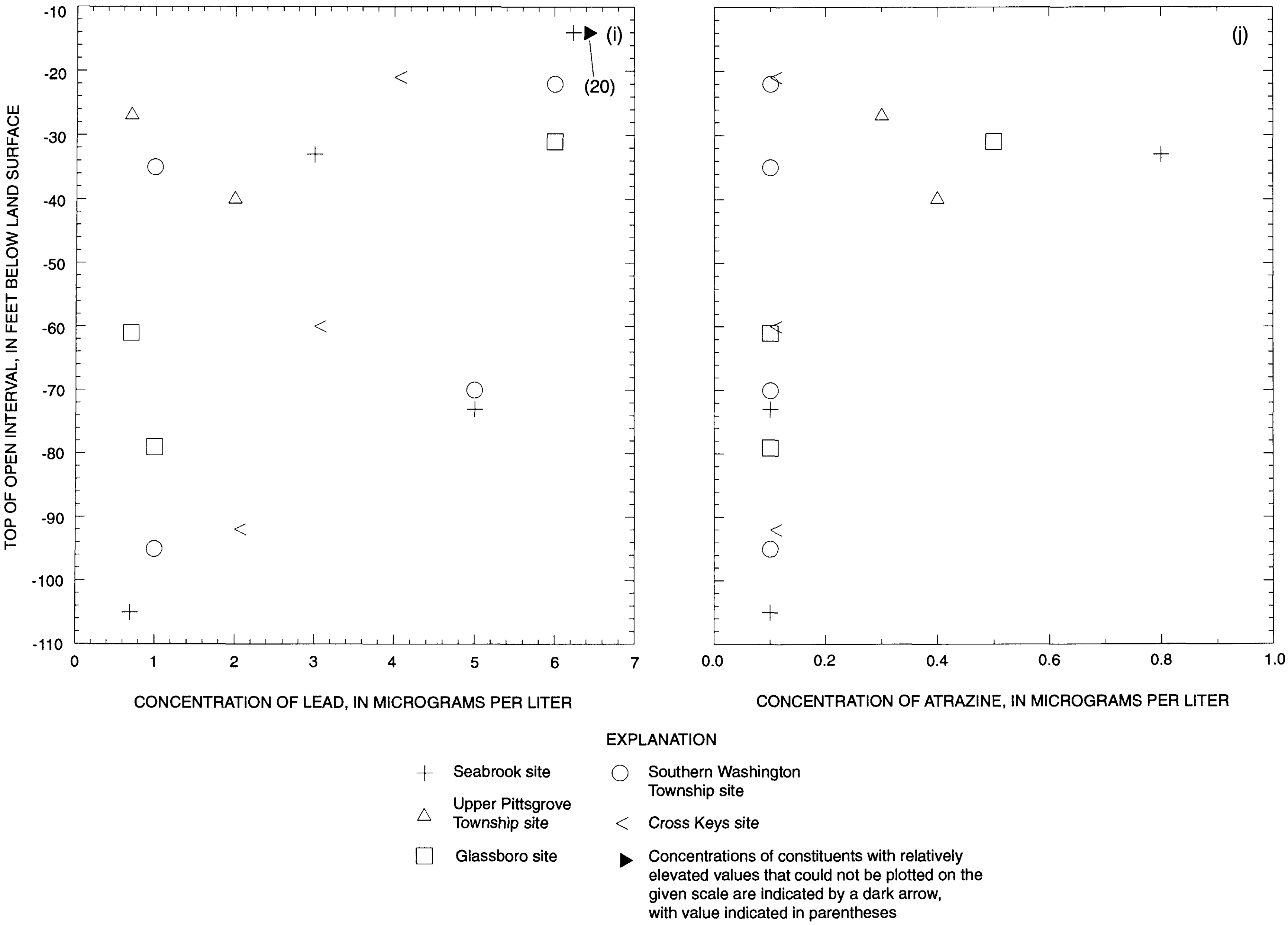


Figure 5. Graphs showing concentration or value in water of (a) radon-222, (b) radium-226, (c) radium-228, (d) uranium, (e) nitrate (as nitrogen), (f) magnesium, (g) barium, (h) dissolved oxygen, (i) lead, (j) atrazine, (k) silica, (l) pH, and (m) tritium as a function of depth in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991--Continued.

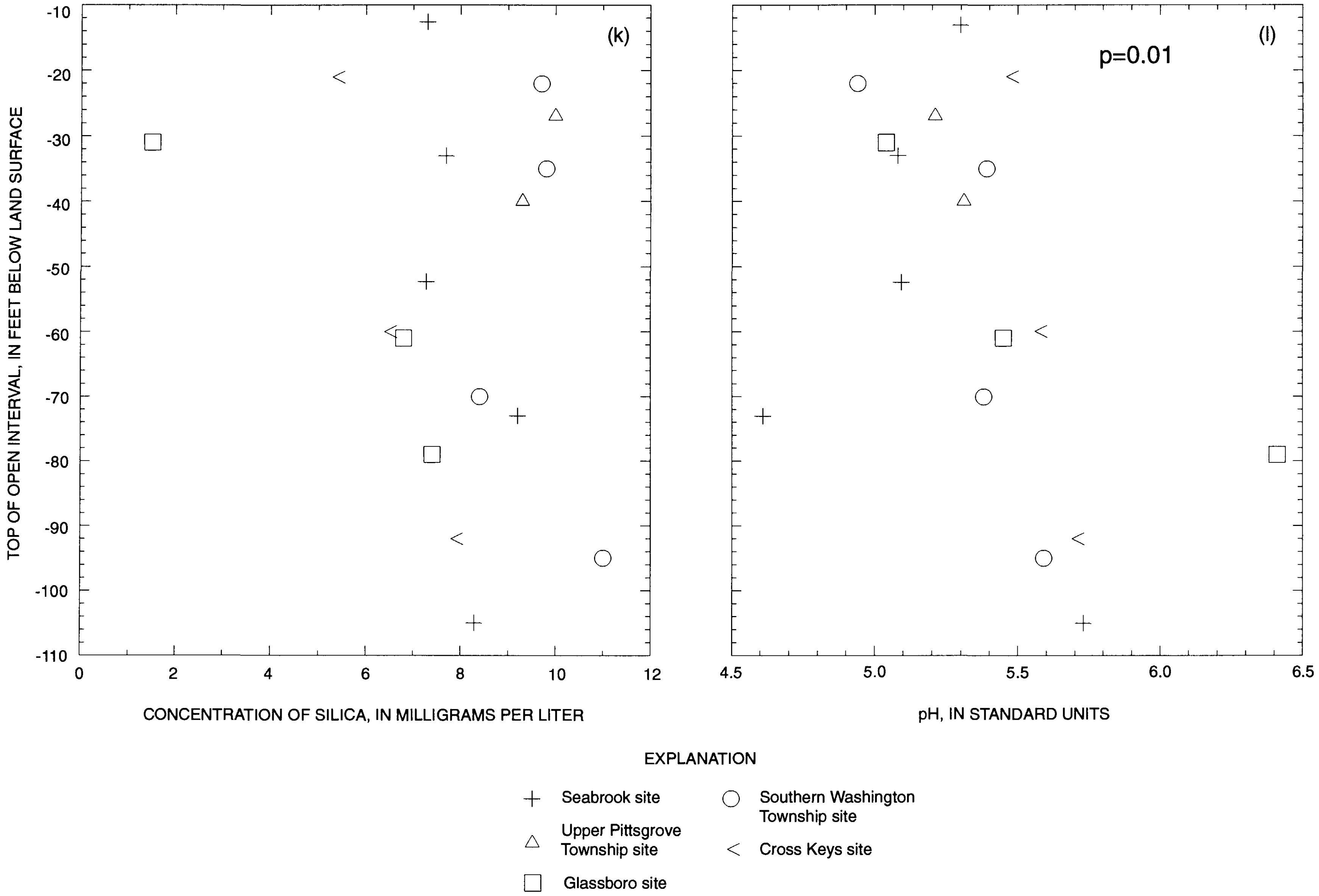


Figure 5. Graphs showing concentration or value in water of (a) radon-222, (b) radium-226, (c) radium-228, (d) uranium, (e) nitrate (as nitrogen), (f) magnesium, (g) barium, (h) dissolved oxygen, (i) lead, (j) atrazine, (k) silica, (l) pH, and (m) tritium as a function of depth in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991 (A p-value is shown for those constituents that varied significantly with depth according to the results of the Kruskal-Wallis statistical test; see table 4)--Continued.

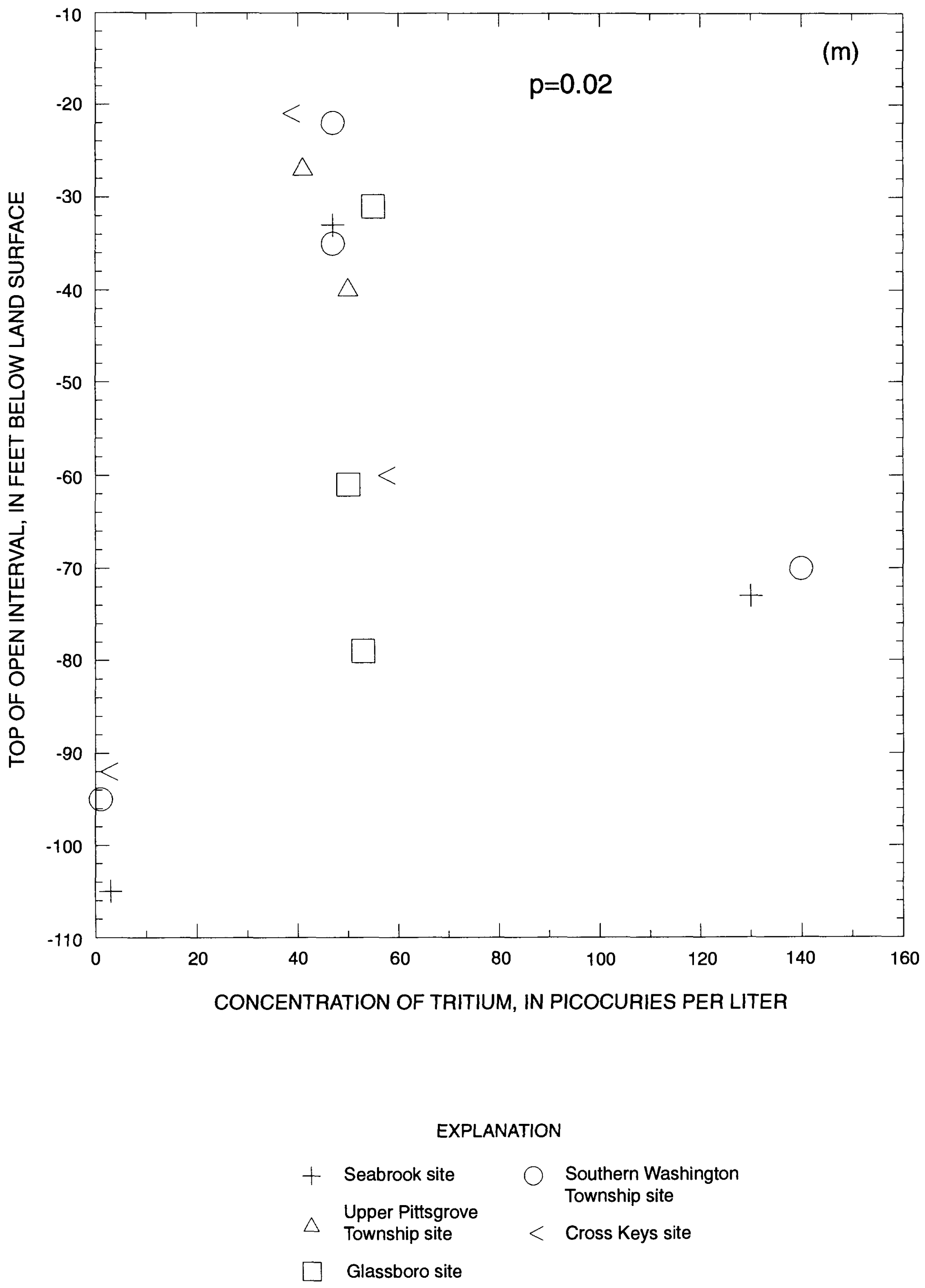


Figure 5. Graphs showing concentration or value in water of (a) radon-222, (b) radium-226, (c) radium-228, (d) uranium, (e) nitrate (as nitrogen), (f) magnesium, (g) barium, (h) dissolved oxygen, (i) lead, (j) atrazine, (k) silica, (l) pH, and (m) tritium as a function of depth in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991 (A p-value is shown for those constituents that varied significantly with depth according to the results of the Kruskal-Wallis statistical test; see table 4)--Continued.

rather, they are applied extensively as agricultural soil amendments. Therefore, the presence of high concentrations of nitrate and magnesium in the shallow ground water in agricultural areas likely results from the use of agricultural chemicals.

Although nitrate concentrations varied significantly with depth, delta-15N values of the nitrate varied only slightly. Delta-15N values of nitrate in the samples ranged from +0.70 to +7.90 per mil. At one site, water from the medium-depth well (15-1058) had a nitrate concentration of 8.7 mg/L and a delta-15N value of 6.3 per mil, whereas water from the shallow well (15-1057) had a nitrate concentration of 4.0 mg/L and a delta-15N value of 4.6 per mil (app. 2C). At another site, water from the medium-depth well (11-693) had a nitrate concentration of 23 mg/L and delta-15N value of 3.0 per mil, whereas water from the shallow well (11-692) had a nitrate concentration of 6.9 mg/L and a delta-15N value of 3.9 per mil. The site owner noted that fertilizer use at the site had decreased over the last 20 years, which likely accounts for the lower concentration of nitrate in the water from the shallow than the medium-depth well, and may account for the difference in delta-15N values (the samples contained different proportions of nitrate from fertilizer and from soil nitrogen). Dissolved-oxygen concentrations were greater than 4 mg/L (app. 2C) in water from all wells except 33-681 and 15-1056 screened near the base of the aquifer (app. 2A). Therefore, except near the base of the aquifer, nitrate is not likely to be chemically reduced. The presence of nitrate in highly variable concentrations together with only moderately variable delta-15N values and abundant dissolved oxygen barring denitrification (chemical reduction of nitrate) indicates a fairly homogeneous source of nitrate. This source could be commercial fertilizer, enhanced leaching of soil nitrogen from cultivated land, or both (Heaton, 1986; Exner and Spalding, 1994), with a variable rate of input through time.

Stiff diagrams of major-ion concentrations (fig. 6) indicate that, in general, concentrations of nitrate, chloride, magnesium, and calcium were much greater in water from the shallow and medium-depth wells than in water from the deep wells. Concentrations of nitrate and calcium typically were more than 10 times greater in water from the shallow and medium-depth wells than in water from the deep wells; concentrations of magnesium, sodium, and chloride commonly were 10 times greater. Water from shallow wells was strongly enriched in sulfate relative to water from the medium-depth and deep wells (table 4). Of the major ions, only potassium showed no relation to depth (table 4). Two water samples (from piezometer 11-696 and well 33-681), both from depths of 45 ft or less below land surface, contained potassium concentrations of 12 mg/L or more; however, a sample from 84 ft below land surface (well 15-1056) also contained 7.7 mg/L of potassium. In water from the other 14 wells or piezometer, the concentrations of potassium ranged from 0.7 to 4.6 mg/L with no apparent relation to depth.

If weathering of aquifer material were the predominant source of dissolved solids, water from the deep wells (with the longest residence time and, hence, the most contact with the sediments) would contain the highest concentrations of dissolved solids. The water-quality data indicated the opposite: that dissolved-solids concentrations were highest in water from the shallow wells and lowest in water from the deep wells, indicating a large surficial input of dissolved solids. The presence of high concentrations of dissolved nitrate, chloride, calcium, and magnesium in water from the shallow wells indicates that the input of dissolved-solids species is related to agriculture because these constituents are contained in soil additives applied to agricultural land.

Like the divalent alkali-earth major ions calcium and magnesium, the divalent alkali-earth trace elements barium and strontium also were enriched in water from the shallow and medium-depth wells (figs. 5 and 6). Maximum concentrations of barium and strontium were 490 and 190 µg/L, respectively, in water from well 11-693. The difference between concentrations of

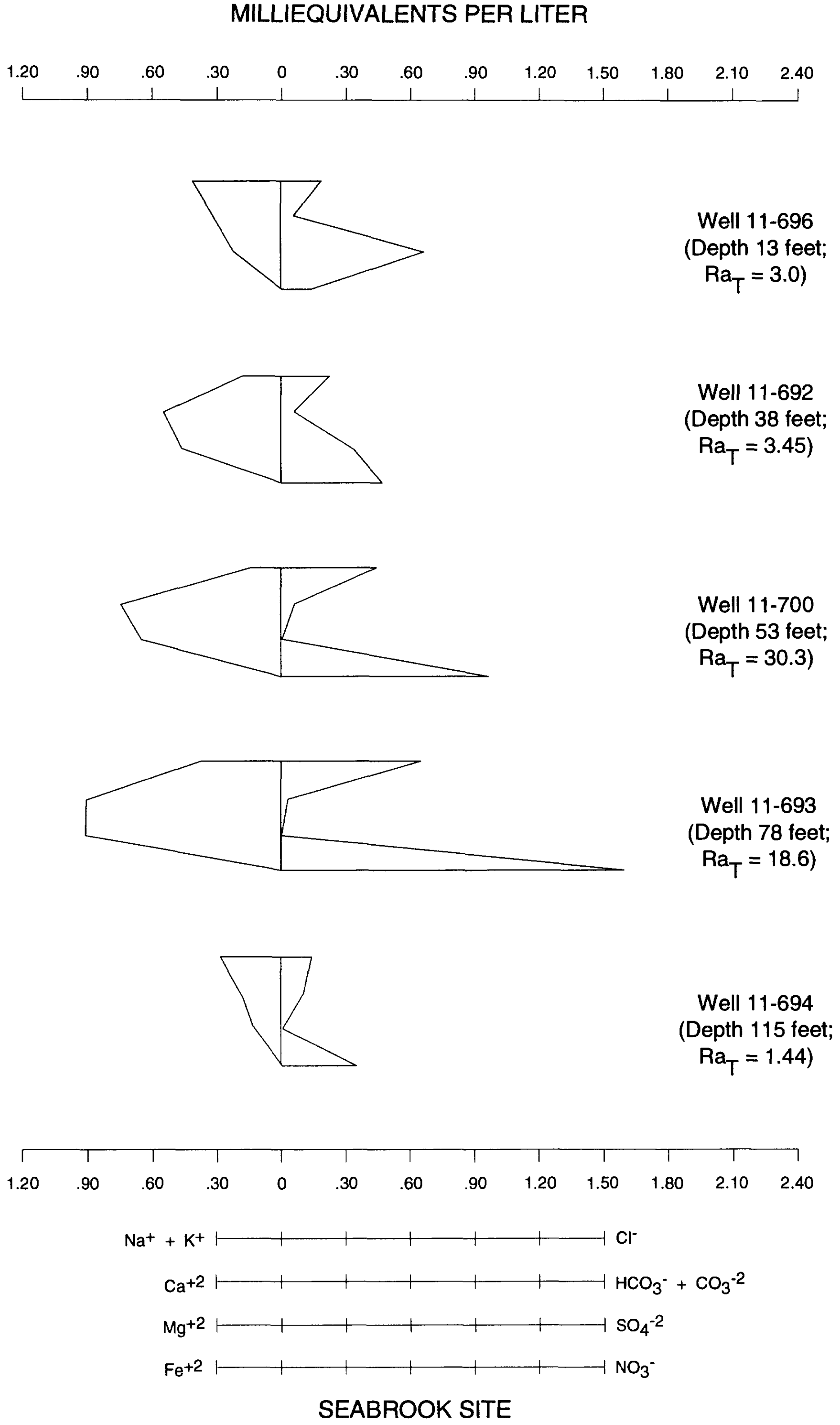


Figure 6. Stiff diagrams illustrating variations in concentrations of major ions in water with depth at five sites in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991, and radium concentration (Depth is depth below land surface; Ra_T is the sum of the concentration of radium-228 + radium-226 in picocuries per liter).

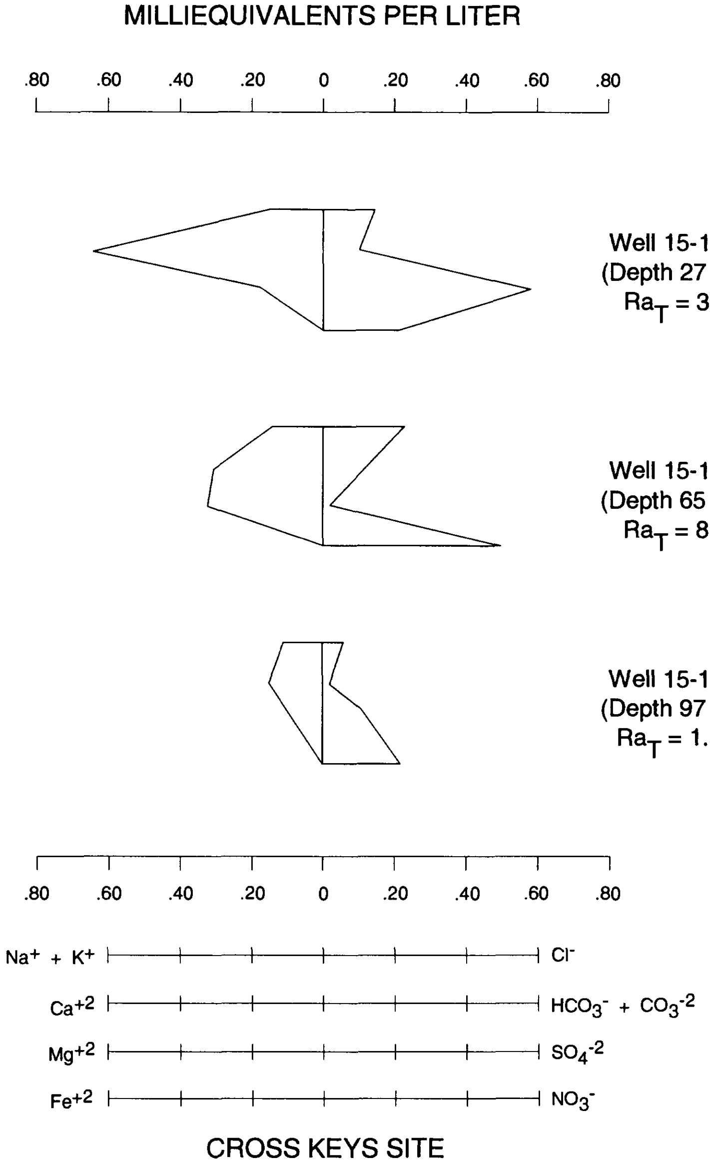


Figure 6. Stiff diagrams illustrating variations in concentrations of major ions in water with depth at five sites in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991, and radium concentration (Depth is depth below land surface; Ra_T is the sum of the concentration of radium-228 + radium-226 in picocuries per liter)--Continued.

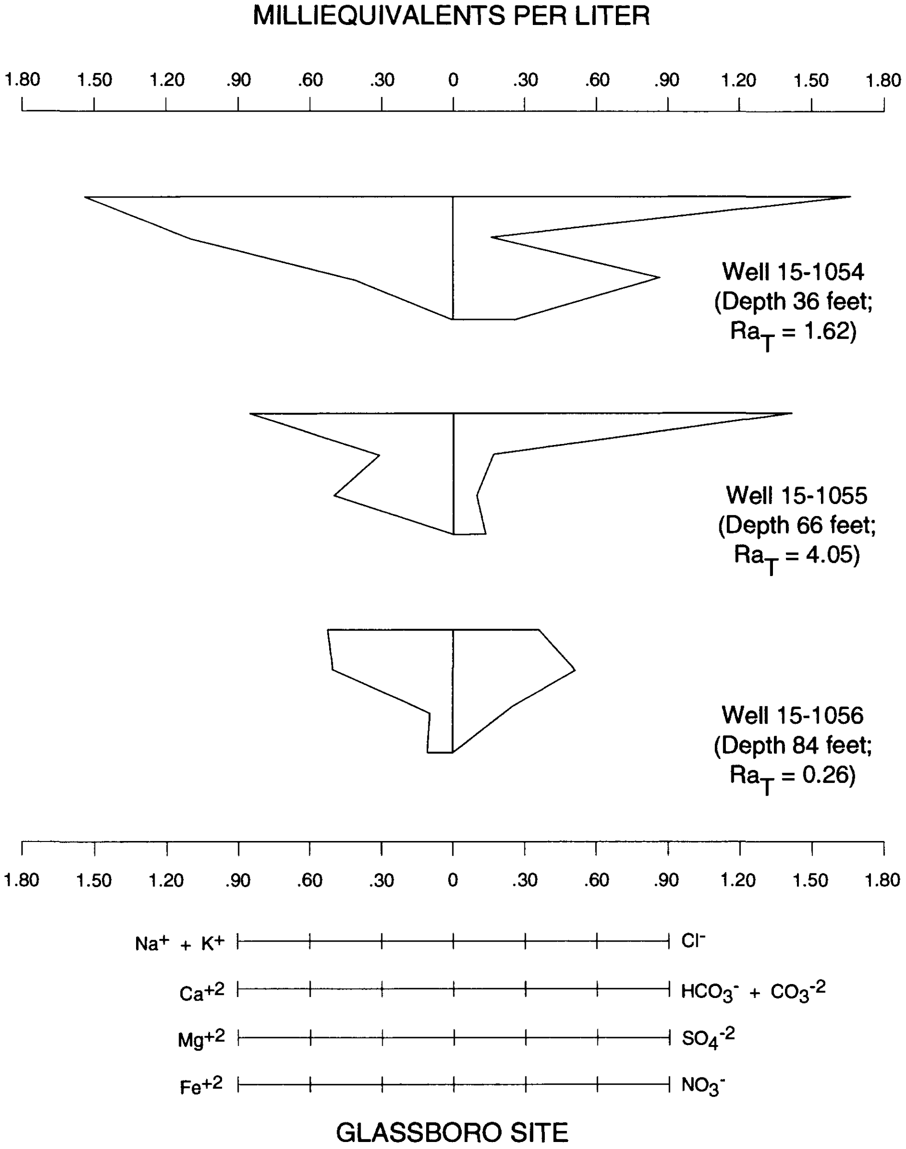


Figure 6. Stiff diagrams illustrating variations in concentrations of major ions in water with depth at five sites in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991, and radium concentration (Depth is depth below land surface; Ra_T is the sum of the concentration of radium-228 + radium-226 in picocuries per liter)--Continued.

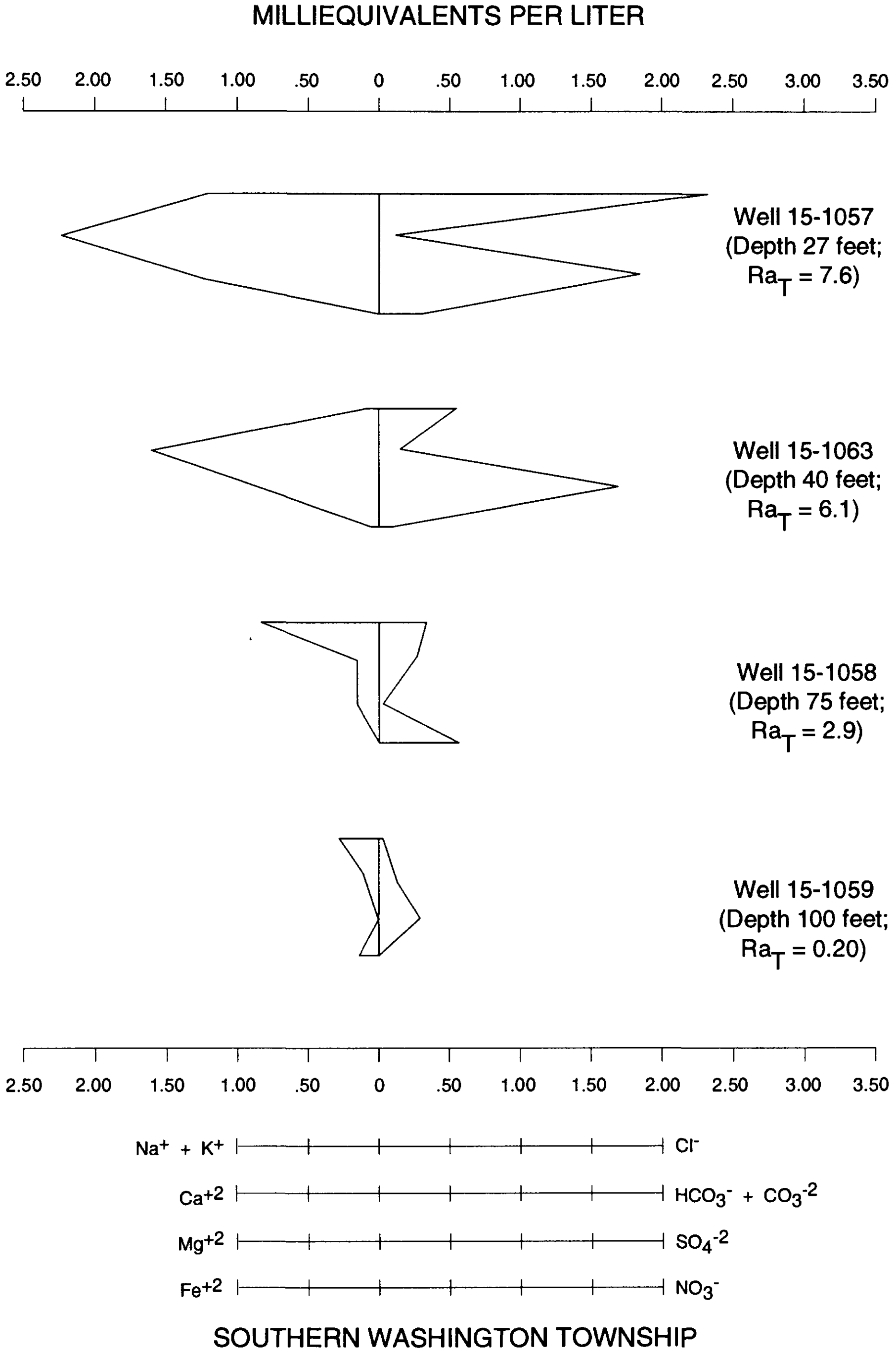


Figure 6. Stiff diagrams illustrating variations in concentrations of major ions in water with depth at five sites in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991, and radium concentration (Depth is depth below land surface; Ra_T is the sum of the concentration of radium-228 + radium-226 in picocuries per liter)--Continued.

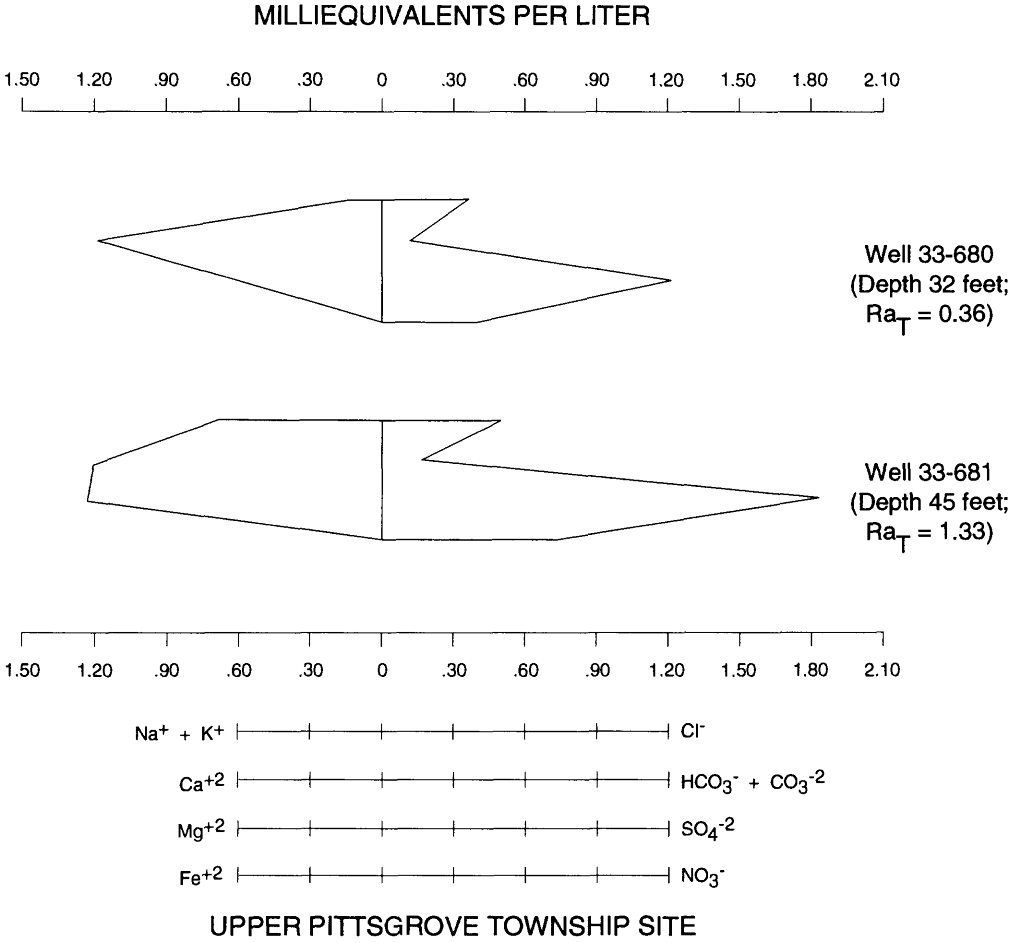


Figure 6. Stiff diagrams illustrating variations in concentrations of major ions in water with depth at five sites in agricultural areas, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991, and radium concentration (Depth is depth below land surface; Ra_T is the sum of the concentration of radium-228 + radium-226 in picocuries per liter)--Continued.

barium in water from shallow and medium-depth wells and those in water from deep wells (more than a factor of 10 at three sites) was greater than the difference between strontium concentrations (about a factor of five at four of the sites) (app. 2C; fig. 5g).

Concentrations of other trace elements--for example, aluminum, lead, and mercury--also appeared to be higher in water from the shallow and medium-depth wells than in water from the deep wells. Because the concentrations of lead and mercury generally were near or below the MRL's of 1.0 and 0.2 µg/L, respectively, the relative enrichment of these elements in the shallow relative to deep ground water is less evident than the relation between major-ion concentrations and depth. Concentrations of lead and mercury did not exceed the USEPA MCL's (U.S. Environmental Protection Agency, 1991b), but concentrations of lead in water from two shallow wells 15-1057 (7 µg/L) and 15-1054 (6 µg/L) located in Gloucester County approached limits imposed by the USEPA for lead in source water (U.S. Environmental Protection Agency, 1991b). Concentrations of aluminum in water from the shallow wells were much higher than those of lead and mercury (for example, 540 and 490 µg/L in water from wells 15-1057 and 15-1054, respectively) and generally exceeded the proposed secondary standard (U.S. Environmental Protection Agency, 1989). The solubility of aluminum and lead is highly enhanced in acidic water (Hem, 1985). Aluminum generally is much more abundant in sediments than is lead; therefore, the concentrations of aluminum in the acidic water are greater than those of lead.

Many trace elements, including cobalt, copper, iron, manganese, and zinc, although present in detectable concentrations in several of the samples, did not appear to be enriched in water from either the shallow or the deep wells (app. 2C). Concentrations of cobalt and copper were at or near the MRL's; therefore, any trend in the concentrations of these elements is difficult to detect. Concentrations of zinc appeared to be elevated (greater than 40 µg/L) in shallow ground water at two of the five sites (Seabrook and Glassboro), but was low (less than 10 µg/L) at two of the remaining sites (upper Pittsgrove and Cross Keys) (app. 2C). Concentrations of zinc determined in shallow ground water at the southern Washington Township site were inconsistent over time.

Concentrations of iron generally were highest in water from the deep wells (maximum 900 µg/L), whereas concentrations of manganese were higher in the shallow and medium-depth wells than in the deep wells. (The extremely high concentrations of iron in water from the shallow and medium-depth piezometers (maximum 3,100 µg/L) are likely due to iron colloids and fine iron-bearing particles mobilized from the sediment and the cast iron AW-design drill rods used during installation of the piezometers.) Concentrations of manganese ranged from 8 to 96 µg/L in the shallow wells, and from 8 to 21 µg/L in the deep wells. The solubility of iron and manganese increases with increasing acidity (decreasing pH) and decreasing oxidation-reduction potential (Eh). Alkalinity and pH were highest at the greatest depths at all of the sites. Concentrations of iron and manganese were high, therefore, in water from the shallow wells as a result of high acidity (low pH). Concentrations of DO, however, were lowest in water from the deepest wells at four of the five sites. At the Seabrook site, the concentration of DO in water from well 11-694 at a depth of 80 ft below the water table was 9.6 mg/L or greater (fig. 5h). When the concentration of DO decreases to low values (0.5 mg/L in water from well 15-1056, for example), the Eh of the solution generally decreases sharply and the solubility of manganese and iron is thus enhanced. The concentration of dissolved iron in water from the deep well 15-1056 was 900 µg/L, and also exceeded 100 µg/L in water from deep well 15-1059. Orange or red iron hydroxide and black iron oxide minerals are common throughout the Kirkwood-Cohansey aquifer system (app. 2B). The presence of iron-bearing minerals in the aquifer matrix at depth coupled with chemical conditions that enhance iron solubility in the deepest part of the aquifer most likely are responsible for the abundance of dissolved iron in water samples from the deep wells.

Pesticides

Pesticides were detected in water from wells--mainly the shallowest wells--at four of the five sites investigated (app. 2C). At least one pesticide compound was detected in three of the medium-depth wells (15-1055, 15-1063, and 33-681), however. No pesticides were detected in water from any of the four deep wells that were completed more than 40 ft below the water table. The presence of both nitrate and of pesticides in the shallow ground water indicates that agricultural soil additives have a widespread effect on the quality of water in the Kirkwood-Cohansey aquifer system. The concentrations of all detected pesticides were relatively low (maximum, 2.8 μg/L of metolachlor and 1.1 μg/L of alachlor in shallow well 11-692) and did not exceed USEPA drinking-water standards (U.S. Environmental Protection Agency, 1991). Atrazine (maximum concentration, 0.9 μg/L) was the pesticide detected most frequently (in four wells at three sites). The distribution of atrazine with depth (figure 5j) is typical of that of the pesticide compounds. The metabolite of atrazine, desethyl atrazine, was detected in low concentrations (maximum, 0.8 μg/L) in all four of the wells in which atrazine was detected. In two of the four wells, the concentration of this metabolite exceeded the concentration of atrazine.

Other pesticides detected in the shallow ground water include bromacil, carbofuran, metribuzin, propachlor, simazine, terbacil, and trifluralin (app. 2C). Bromacil, the pesticide detected at the greatest depth (40 ft below the water table), is known to be particularly persistent in the environment. Terbacil and atrazine, detected in water from medium-depth as well as shallow wells, also are relatively persistent.

Louis and Vowinkel (1989) found that the distributions of nitrate and pesticides in the Kirkwood-Cohansey aquifer system in agricultural areas were similar, as would be expected from the application of pesticides and nitrogen-bearing fertilizer to agricultural land. In this study, the presence of pesticides at four of the five nested-well sites, as illustrated by atrazine, corresponded more strongly with shallow depth than with elevated concentrations of nitrate (fig. 5j). Nitrate has penetrated further than pesticides into the aquifer probably because the application history of nitrogen-based fertilizer is longer than that of pesticides. (See Szabo and others (1994) for additional discussion.) Also, nitrate is more persistent than pesticides in oxygenated ground water.

Statistical Relation of Water Quality to Depth in Agricultural Areas

Results of the Kruskal-Wallis test indicate that the means of the ranked values of concentrations of radium-226 and radium-228 are significantly higher at the 90-percent confidence level in water from shallow and medium-depth wells and piezometers than in water from deep wells in the agricultural areas. A similar statistically significant difference with depth is indicated for concentrations of dissolved nitrate, calcium, magnesium, barium, strontium, chloride, and tritium (table 4). Concentrations of lead and manganese were greater in water from shallow and medium-depth wells and piezometers than in water from deep wells, but the computed chi-square statistic was not significant at the 90-percent confidence level. Concentrations of dissolved sulfate were significantly greater in water from shallow wells and piezometer than in water from medium-depth and deep wells and the medium-depth piezometer. Concentrations of dissolved oxygen, atrazine, and aluminum were greater in water from shallow wells and the shallow piezometer than in water from medium-depth and deep wells and the medium-depth piezometer, but the computed chi-square statistic was not significant at the 90-percent confidence level. Concentrations of iron and values of pH were significantly higher at the 90-percent confidence level in water from deep wells than in water from shallow and medium-depth wells (table 4). No difference with depth was found in concentrations of dissolved silica, sodium, copper, zinc, or uranium (table 4).

Table 4. Results of Kruskal-Wallis statistical test for differences with depth in concentrations of major ions and silica, trace elements, nutrients, and radionuclides, and for results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in 17 samples of water from the Kirkwood-Cohansey aquifer system in an agricultural area, southwestern New Jersey, spring 1991

[Constituent concentrations are considered significantly different in water samples from wells in different well-depth groups if the significance of the chi-square statistic is equal to or less than 0.10 (shown in boxes in bold print); well depths: S, 27 to 40 feet below land surface; M, 45 to 78 feet; and D, 84 to 115 feet; >, greater than; <<, much less than; >>, much greater than; =, equals; ≈, no apparent difference]

Dissolved constituent	Depth for which mean rank of constituent concentrations in water samples is notably higher than that for other depths	Chi-square statistic corrected for ties, with significance of chi-square statistic in parentheses	
	Field characteristics		
Dissolved oxygen	S>M≈D	1.85(0.17);	0.93(0.34)
pH	D>>M≈S	**6.55(.01);**	0.51(.48)
Specific conductance	S≈M>>D	0.33(.57);	**5.50(.02)**
	Major ions and silica		
Alkalinity, as $CaCO_3$	M≈D≈S	0.05(.83);	0.23(.64)
Calcium	S>M>>D	1.85(.17);	**3.68(.06)**
Chloride	M≈S>>D	0.08(.78);	**4.55(.03)**
Magnesium	M≈S>>D	0.01(.94);	**6.55(.01)**
Potassium	M≈S≈D	0.25(.62);	0.14(.70)
Silica, as SiO_2	D≈S≈M	0.57(.45);	0.18(.67)
Sodium	D≈M≈S	0.01(.91);	0.02(.89)
Sulfate	S>>D≈M	**7.00(.01);**	0.73(.39)
	Trace elements		
Aluminum	S>M≈D	1.22(.27);	0.24(.62)
Barium	M>>S>D	**3.45(.06);**	2.02(.16)
Mercury	M>S≈D	1.10(.29);	0.67(.41)
Copper	S≈M≈D	0.13(.72);	0.01(.91)
Iron	D>M≈S	2.23(.14);	0.13(.72)
Iron[1]	D>>M≈S	**4.86(.03);**	0.08(.78)
Lead	S≈M>D	0.89(.34);	2.22(.14)
Manganese	M≈S>D	0.18(.67);	1.09(.30)
Strontium	M≈S>>D	0.08(.77);	**3.57(.06)**
Zinc	S≈M≈D	0.05(.83);	0.01(.91)
	Nutrients and pesticides		
Ammonia, as N	D=M>S	0.0(1.00);	2.53(.11)
Nitrate, as N	M>>S>D	**5.22(.02);**	1.75(.19)
Carbon, organic	S>M≈D	2.16(.14);	0.59(.44)
Atrazine	S>M≈D	1.12(.29);	0.80(.37)
	Radionuclides		
Uranium	S≈M≈D	0.05(.83);	0.93(.34)
Radium-226	M>>S>D	**4.01(.05);**	2.31(.13)
Radium-228	M≈S>>D	0.08(.77);	**4.75(.03)**
Radon-222	M>S=D	1.31(.25);	0 (1.0)
Gross beta particle activity	M>S≈D	1.20(.27);	0.73(.39)
Tritium	M>>S>D	**5.76(.02);**	2.30(.13)

[1] High iron concentrations in shallow and medium-depth piezometers may be caused by colloidal iron mobilized during installation; therefore, statistical results are for observation-well data only.

Concentrations of nitrate, calcium, magnesium, radium-226, radium-228, barium, strontium, and dissolved solids, all of which were significantly higher in water from shallow and medium-depth wells and piezometers than in water from deep wells in agricultural areas, also were significantly higher in water from agricultural than in non-agricultural areas (tables 3 and 4). These results indicate that the difference in the quality of water in the aquifer between agricultural and non-agricultural areas likely is due to the effect of land-management practices in agricultural areas on shallow and medium-depth water--water that has been recharged in approximately the last 30 years (as of 1990), as evidenced by the high tritium concentrations (table 4) (Hendry, 1988).

Relations Among Radium, Nitrate, and Inorganic Chemical Constituents in Water

The non-parametric Spearman rank correlation test was used to evaluate correlations among concentrations of dissolved radium, nitrate, and inorganic constituents related to agricultural land use. For the samples from the 42 wells in the regional well network, correlations were considered statistically significant at the 95-percent confidence level. Because of the small number of samples (17) collected from the nested observation wells and piezometers, correlations for this data set were considered statistically significant at the 90-percent confidence level.

Results of the Spearman rank correlation test indicate that concentrations of radium-226 and radium-228 were correlated with concentrations of nitrate and many inorganic constituents, including calcium, magnesium, strontium, barium, chloride, and potassium, in the water samples from the 42 wells in the regional well network. Correlation coefficients ranged from about +0.3 to about +0.5; they were highest for the correlations of barium, nitrate, and magnesium with both radium-226 and radium-228 (table 5). The correlation of concentrations of these inorganic constituents likely is related to agricultural land use. Concentrations of radium-228 in several samples were less than the MRL (1 pCi/L), which may have obscured correlations. Concentrations of uranium were correlated with concentrations of nitrate, aluminum, chloride, magnesium, calcium, and strontium, but not barium. Most correlation coefficients ranged from about +0.3 to about +0.5 (table 5).

Concentrations of radium-226 in the ground-water samples were correlated strongly (correlation coefficient, $r = +0.82$) with concentrations of radium-228, but were less strongly correlated ($r = +0.48$) with concentrations of uranium. These results were unexpected because radium-226 is a decay product of insoluble, short-lived thorium-230, which is a decay product of uranium-234. Radium-228 is derived from decay of thorium-232 and is not a part of the uranium-decay series.

The concentration of radium did not exceed 5 pCi/L in water from either of the two wells in which pesticides were detected. Pesticides were not detected in samples in which the concentration of total radium exceeded 5 pCi/L. The presence of pesticides in the ground water, therefore, is most likely not a consistent indicator of elevated concentrations of radium.

Concentrations of dissolved nitrate correlated strongly with concentrations of dissolved radium-226, radium-228, and uranium (table 5). Dissolved-nitrate concentrations also were highly correlated with concentrations of most of the major inorganic chemical constituents, especially barium, calcium, magnesium, and strontium (correlation coefficients ranged from about +0.7 to about +0.9; table 5) and, to a lesser degree, dissolved oxygen, potassium, and chloride. Concentrations of dissolved strontium and barium correlated positively with concentrations of both nitrate and magnesium (table 5), but not with concentrations of aluminum and silica.

Table 5. Spearman rank correlation coefficients for relations of concentrations of radium-226, radium-228, uranium, nitrate, magnesium, and barium with concentrations of selected inorganic constituents in, and characteristics of, 42 samples of water from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990

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

Dissolved constituent or characteristic	Correlation coefficient with radium-226	Correlation coefficient with radium-228	Correlation coefficient with uranium	Correlation coefficient with nitrate	Correlation coefficient with magnesium	Correlation coefficient with barium
Field characteristics						
Dissolved oxygen	+0.43	--	--	+0.68	+0.64	+0.44
pH	--	--	-.55	--	--	--
Specific conductance	+.36	+0.39	+.45	+.88	+.86	+.53
Major ions and silica						
Alkalinity, as $CaCO_3$	--	--	--	+.32	--	--
Calcium	+.32	+.36	+.34	+.82	+.88	+.58
Chloride	+.31	+.37	+.48	+.70	+.63	--
Magnesium	+.48	+.45	+.43	+.89	+1.00	+.73
Potassium	+.38	+.38	--	+.64	+.74	+.64
Silica, as SiO_2	--	--	--	--	+.36	--
Sulfate	--	--	--	--	+.31	--
Trace elements						
Aluminum	--	--	+.52	--	--	--
Barium	+.52	+.50	--	+.72	+.73	+1.00
Cobalt	--	--	--	--	--	+.46
Manganese	--	--	--	--	--	+.30
Strontium	+.38	+.40	+.33	+.79	+.91	+.65
Nutrients						
Nitrate, as N	+.51	+.48	+.42	+1.00	+.89	+.72
Radionuclides						
Uranium	+.48	+.37	+1.00	+.42	+.43	--
Radium-226	+1.00	+.82	+.48	+.51	+.48	+.52
Radium-228	+.82	+1.00	+.37	+.48	+.45	+.50
Gross beta particle activity	+.77	+.84	+.41	+.61	+.63	+.59

Concentrations of dissolved potassium correlated positively with concentrations of dissolved barium and other divalent cations, especially magnesium (table 5). Positive correlations of dissolved-potassium and -chloride concentrations with concentrations of dissolved nitrate (table 5) also were noted.

Results of the Spearman non-parametric statistical test indicate (table 6) that concentrations of dissolved radium-226 and radium-228 in water from the nested wells and piezometers were positively correlated at the 90-percent confidence level with concentrations of dissolved divalent cations--especially magnesium, barium, and manganese. Concentrations of radium-226 were correlated with those of uranium, chloride, and tritium, whereas concentrations of radium-228 were correlated with those of calcium, nitrate, and dissolved oxygen (table 6). Concentrations of uranium were positively correlated with those of chloride and aluminum. Concentrations of radium-228 were negatively correlated with pH and with the concentration of dissolved radon-222 (table 6). These correlations are nearly identical to those observed for the samples from the regional well network.

Possible Sources of Radium

In all samples of water from the nested wells and the regional well network, activities of dissolved radium-226 were substantially higher than those of dissolved uranium (calculated by assuming natural isotopic ratios). Therefore, dissolved radium-226 could not have been derived from the decay of uranium isotopes in solution and another source of radium must exist. Possible sources of radium are the aquifer matrix and additives to the soil (primarily phosphate fertilizer, and possibly lime).

Agricultural Additives

Uranium-rich runoff to surface-water bodies from agricultural fields after the application of phosphate-bearing fertilizer has been documented in the midwestern United States (Spalding and Sackett, 1972). Phosphate fertilizers, unlike the sedimentary materials of the Kirkwood-Cohansey aquifer system, are strongly enriched in uranium relative to thorium (Roessler and others, 1979) and in radium-226 relative to radium-228. In general, the radium-228/radium-226 ratio of phosphate fertilizer is less than 0.1 (Roessler and others, 1979).

If phosphate fertilizer were the predominant source of dissolved radium in the ground water, the water samples would have been highly enriched in radium-226 relative to radium-228. The radium-228/radium-226 activity ratios in water samples from the wells in the regional well network varied moderately (from 0.27 to 2.74), with a median of 1.08. The median radium-228/radium-226 activity ratio in samples of water from all 17 observation wells and piezometers was 0.99. Values of this ratio ranged from 0.23 to 6.05, with an inter-quartile range from 0.53 to 3.24. The median of the ratio in samples of water from the nine observation wells for which associated sediment samples were available was 1.07. Values ranged from 0.23 to 4.31, with an inter-quartile range from 0.52 to 3.81. The median radium-228/radium-226 activity ratio calculated by Kozinski and others (1995) for water samples from their reconnaissance well network was 1.25. These results indicate that phosphate fertilizer is not the predominant source of the radium. Some input of radium-226 directly from fertilizer into the ground water in agricultural areas cannot be completely ruled out, however. The radium-228/radium-226 isotope ratio is 0.23 in the medium-depth well 15-1055 and is 0.43 in the medium-depth well 11-693, and water from these wells contains abundant nitrate as well as radium, indicating the possible presence of radium from phosphate fertilizer. This possibility can only be fully evaluated by determining the exact radium-isotope ratio in the fertilizer applied in southern New Jersey and the actual amount of fertilizer applied; such an evaluation is beyond the scope of this study.

Table 6. Spearman rank correlation coefficients for relations of concentrations of radium-226, radium-228, uranium, nitrate, magnesium, and barium with concentrations of selected inorganic constituents in, and characteristics of, 17 samples of water from various depths in the Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991

[All correlation coefficients listed are significant at the 90-percent confidence level; a dash (--) indicates the correlation coefficient is non-significant at the 90-percent confidence level]

Dissolved constituent or characteristic	Correlation coefficient with radium-226	Correlation coefficient with radium-228	Correlation coefficient with uranium	Correlation coefficient with nitrate	Correlation coefficient with magnesium	Correlation coefficient with barium
			Field characteristics			
Dissolved oxygen	--	+0.54	-0.46	--	+0.64	+0.49
pH	--	-.55	--	-.52	-.73	--
Specific conductance	--	--	+.51	--	+.88	--
			Major cations and chloride			
Calcium	--	+.44	--	--	+.86	--
Magnesium	+.48	+.49	--	+.46	+1.00	+.44
Chloride	+.43	--	+.62	--	+.77	--
Sulfate	--	--	--	--	--	-.41
			Trace elements			
Aluminum	--	--	+.57	--	--	--
Barium	+.74	+.62	--	+.44	+.44	+1.00
Manganese	+.45	+.64	--	--	--	+.62
Strontium	--	--	--	--	+.73	--
			Nutrients			
Nitrate, as N	--	+.42	--	+1.00	+.46	+.44
			Radionuclides			
Uranium	+.51	--	+1.00	--	--	--
Radium-226	+1.00	+.67	+.51	--	+.48	+.74
Radium-228	+.67	+1.00	--	+.42	+.49	+.62
Radon-222	--	-.42	--	--	--	--
Gross beta particle activity	--	+.46	--	--	+.50	--
Tritium	+.54	--	--	+.52	--	--

The primary source of lime is dolomite. Sedimentary carbonate minerals (such as dolomite) are enriched in uranium relative to thorium (thorium/uranium ratio, 0.77; see Turekian and Wedopohl (1961)) because carbonate minerals readily incorporate uranium, but not thorium, as they precipitate. Uranium enrichment relative to thorium is less in phosphate rocks than in carbonate rocks. The radium-228/radium-226 isotopic ratio of the water samples nevertheless indicates that sedimentary carbonates are not likely to be the dominant source of the dissolved radium. The thorium/uranium ratio is highly variable in the sedimentary carbonates, however. As with the phosphate fertilizers, a liming agent with an unusual radium-228/radium-226 ratio as a source of the dissolved radium cannot be ruled out unless the liming additives used are analyzed to determine this ratio.

Aquifer Sediment

If aquifer materials were the source of the dissolved radium, the radium content of the sediment would be measurable and the ratios of the activities of radium-228 to those of radium-226 in solution would be similar to those observed in the aquifer sediment. Radium is measurable in the aquifer sediment, and the content of radium-228 and radium-226 in the sediment is more than sufficient to account for the concentrations of these radionuclides measured in water samples (table 1). Amounts of both radium-228 and radium-226 increase with decreasing grain size and increasing gamma activity (fig. 4). The radium-228/radium-226 activity ratios of the nine sediment samples collected from the screened intervals of the observation wells (table 1) varied little (from 0.43 to 1.73, with an inter-quartile range from 0.55 to 1.32), with a median of 0.67. The median ratio in all 15 sediment samples was 0.85, with an inter-quartile range of 0.63 to 1.35. The strong correlation between the concentrations of radium-228 and those of radium-226 in the water also supports the hypothesis that the aquifer sediment is the major source of dissolved radium. Small variations in the proportion of silt (enriched slightly in radium-226 relative to radium-228) in the aquifer sediment could be the cause of the observed local variations in the ratio of the activites of radium-228 and radium-226 in the water. The presence of measurable amounts of radium in the sediment together with the similarity among the radium-228/radium-226 ratios in water samples from the regional well network, the nested observation wells, and the sediment samples indicates that the dissolved radium probably is derived from the sediment.

The median activity ratios of radium-228 to radium-226 in both the sediment and the associated water samples indicates the general behavior of radium in the aquifer system but obscure the details of trends in these ratios at individual sites. The radium-228/radium-226 isotope ratio in the sediment was, in general, highest at shallow depths (less than 30 ft) at most of the nested-observation-well sites. A trend in the radium-228/radium-226 isotope ratios in the water also was noted despite the fact that radium-228 concentrations in the deep wells at all of the nested-observation-well sites were below the MRL, and thus only limited conclusions can be drawn: the ratio was higher in radium-rich water from shallow wells than in radium-rich water from medium-depth wells.

In the current study, the pattern of decreasing radium-228/radium-226 isotope ratios with depth for both sediment and water was most pronounced at the Seabrook and southern Washington Township sites. Radium-228/radium-226 isotope ratios in water from shallow wells at these two sites were much greater than 1. At the Seabrook site, the ratios in water from the shallowest well and the two shallow piezometers (11-0692, 11-0700, and 11-0696) were 1.0, 6.0, and 4.3, respectively; at the southern Washington Township site, the ratio in water from shallow well 15-1057 was 3.5. The radium isotope ratios in water from the medium-depth wells at these two sites were less than 1, however. At the Seabrook site, the ratio was about 0.4 in water from the medium-depth well 11-0693; at the southern Washington Township site, the ratios were about 0.45 and 0.6 in water from the medium-depth wells 15-1063 and 15-1058, respectively (table 1). Similarly, the radium-228/radium-226 isotope ratios were slightly greater than 1 in samples of shallow sediment at the two sites and less than 1 in samples from medium depths. At the Seabrook site, the ratio was 1.55 in the sediment sample from 32 ft and about 0.4 in that from 72 ft. At the southern Washington Township site, the ratios were 1.35 and 1.73 in sediment from shallow depths (5 and 27 ft, respectively) and 0.85 and about 0.43 in sediment from medium depths (60 and 67 ft, respectively).

The radium-228/radium-226 isotope ratios in near-surface sediment are greater than those in deeper sediments probably as a result of the decrease in grain size with depth. The median ratio was higher in coarse-grained than in fine-grained sediment (coarse sands, 1.6; silts, 0.6). Additional analyses to determine the ratio of radium-228 to radium-226 in the sediment are needed to confirm these patterns.

In contrast to the ratio of radium-228 to radium-226, the actual concentrations of radium-228 and radium-226 in ground-water samples were unrelated to the actual radium concentrations in the adjacent sediment samples. For example, the concentrations of radium-228 and radium-226 were high (5.6 and 13 pCi/L, respectively (app. 2C)) in the water sample collected on May 1, 1991, from the medium-depth well (11-0693) at the Seabrook site, whereas both radium-228 and radium-226 were barely detectable in sediment sample G-14 collected from about the same depth at the same site (table 1). The highest concentrations of radium in water were associated with the lowest concentrations of radium in adjacent sediment at other sites as well (for example, southern Washington Township well 15-1057 and sediment sample G-8; app. 2C; table 1). At the southern Washington Township site, however, at 97 and 117 ft (sediment samples G-11 and G-12, respectively; table 1), radium-228 and radium-226 concentrations (0.25 and 0.51 pCi/L, respectively) were near or greater than the median values determined for all the sediment samples, whereas radium-228 and radium-226 concentrations in the water sample (well 15-1059; app. 2C) were among the lowest measured in samples from observation wells (0.27 and 0.09 pCi/L, respectively, in the water sample collected on March 20, 1991).

The relation between the concentration of radon-222 in the water and the radioactivity of the sediment also indicates that the sediment is a source of radionuclides to the water. Concentrations of dissolved radon-222 were highest in water from wells that are completed in silty zones in which gamma counts in or near the screened interval were highest (fig. 3). The correlations between concentrations of dissolved radon-222 and overall (gamma) radiation in the adjacent sediment (r = +0.48, fig. 7) and concentrations of dissolved radon-222 in ground water and the radium-226 content of the adjacent sediment (r = +0.56 for the nine intervals for which both values were determined) indicates that the concentration of dissolved radon-222 is controlled primarily by the radioactivity (radium-226 content) of the immediately adjacent strata. The correlations could be moderate because concentrations of dissolved radon-222 are also affected by porosity and the radon-222 emanation coefficient (Wanty and others, 1992) of the sediment. No correlation was found between the concentration of dissolved radon-222 and depth. Water samples from both shallow and deep parts of the aquifer contained radon-222 in elevated concentrations at some sites, but not others. The 3.8-day half-life of radon-222 precludes migration of radon-222 to the well screen from any distant source strata in the aquifer; the concentration of dissolved radon-222, thus, is primarily a result of the radium-226 concentration of the sediment directly adjacent to the well screen.

The radium-226 content of the aquifer materials is sufficiently high to be the source of the dissolved radon-222 in the ground water. An expected concentration of dissolved radon-222 of about 130 pCi/L can be calculated by using the formula given by Wanty and others (1992) with a median radium-226 content of the sediment of 0.35 pCi/g, a porosity of 35 percent, a density of 2 grams per cubic centimeter, and a radon-222 emanation coefficient for sediment of 0.2. This calculated concentration of dissolved radon-222 is within the range of observed concentrations (<80-1,100 pCi/L with a median of 400 pCi/L) at the five sites.

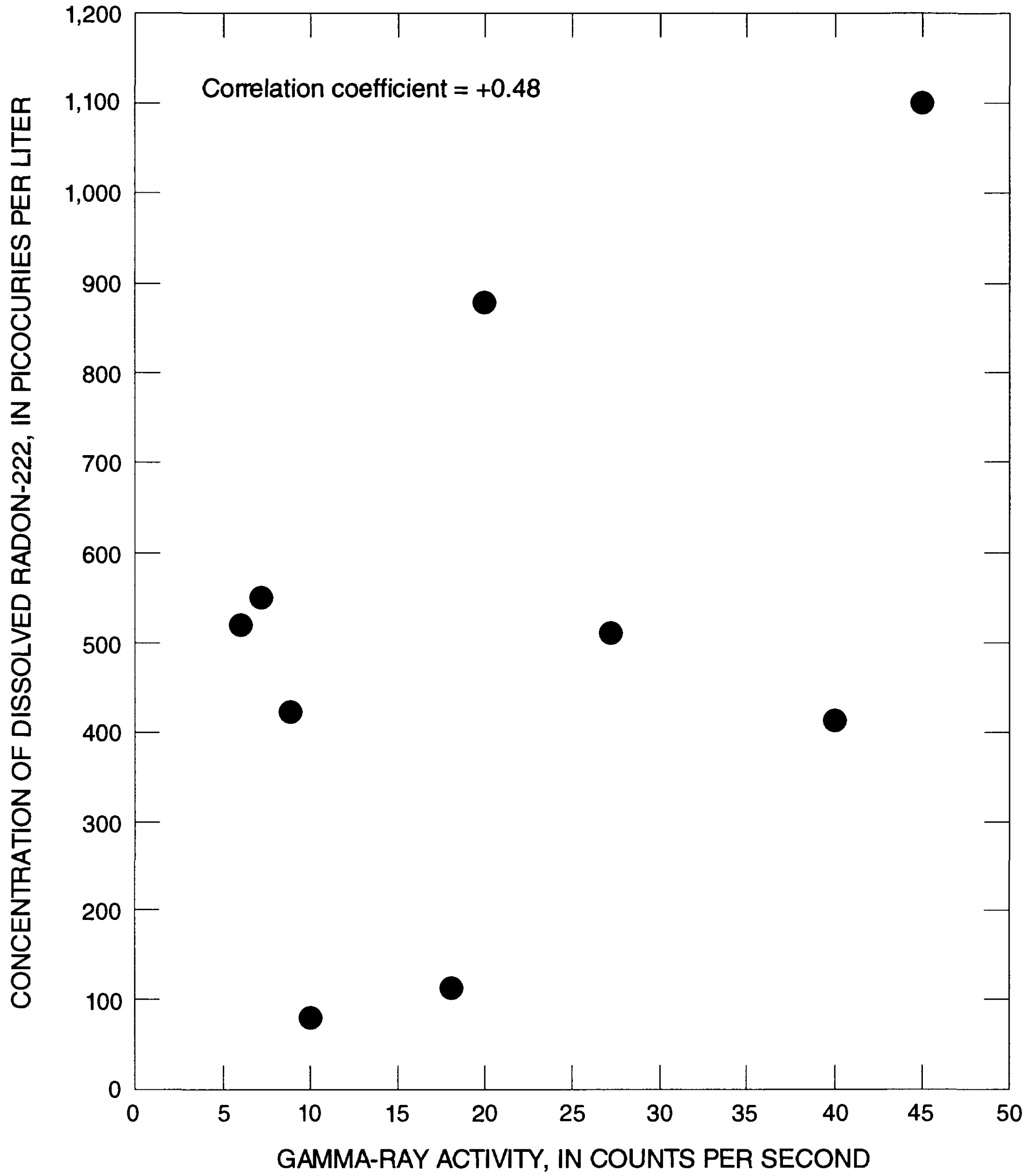


Figure 7. Concentration of radon-222 in water from nine observation wells as a function of gamma activity of the sediment adjacent to the well screen, Kirkwood-Cohansey aquifer system, southwestern New Jersey, spring 1991.

The difference in the vertical distributions of radon-222 and radium-226 in the Kirkwood-Cohansey aquifer system indicates that the mobilities of these radionuclides are controlled by different processes. The concentration of radon-222 in water from a well is proportional to the radioactivity of the aquifer matrix adjacent to the screen. The concentration of radium-226, however, appears to be controlled more by the geochemistry of the water in the part of the aquifer in which the well is screened than by the radioactivity of the aquifer material. The geochemistry of water in the Kirkwood-Cohansey aquifer system is, in turn, affected to a large degree by the presence or absence of agricultural land use at the time the water infiltrated the aquifer.

Possible Mechanisms of Radium Mobilization in Agricultural Areas

Factors that decrease the effectiveness of the chemical processes likely to limit the mobility of radium in the Kirkwood-Cohansey aquifer system in general and especially in agricultural areas are discussed in this section. Water-quality data obtained in this study confirm the results of Kozinski and others (1995) that radium is mobile even in non-agricultural areas. The median concentration of dissolved radium-226 in samples from wells in the regional well network in non-agricultural areas was 0.64 pCi/L; Kozinski and others (1995) reported the median value to be 0.58 pCi/L for samples from their reconnaissance well network in non-agricultural areas. Concentrations of dissolved radium-226, therefore, are naturally higher in water from the uranium-poor Kirkwood-Cohansey aquifer system, even in non-agricultural areas, than in water from the uraniferous rock aquifers of the Newark Basin, where concentrations of dissolved radium-226 typically are less than 0.6 pCi/L (Szabo, 1990). Radium-228 is rarely detected in ground water in the Newark Basin (Szabo, 1990), whereas it is frequently detected even in non-agricultural areas in the Kirkwood-Cohansey aquifer system. The quartzose soils overlying the Kirkwood-Cohansey aquifer system are strongly acidic. The aquifer matrix itself is also quartzose and does not neutralize acidic recharge. Because trace-element mobility is enhanced in acidic systems, the natural capacity of the aquifer to limit the mobility of radium through sorption is, in general, low (Demir, 1989).

All measured concentrations of total radium greater than 5 pCi/L in water from the Kirkwood-Cohansey aquifer system both in this study and in the study of Kozinski and others (1995) were in samples from agricultural areas. The strong positive correlation among the concentrations of radium and other divalent alkali-earth cations (tables 5 and 6) and their predominance in shallow ground water in agricultural areas (table 4) indicates that the presence of the highest concentrations of these constituents is related to the large-scale changes in the quality of the water from the aquifer due to agricultural activity. Either these constituents could all be derived from the same source, such as agricultural additives, or the mobility of the divalent alkali-earth cations could be enhanced in the acidic geochemical environment in the shallow part of the aquifer, or both.

The correlation of potassium and chloride with nitrate indicates that the major source of dissolved potassium and chloride is fertilizer. Although the weathering of potassium-bearing feldspar grains could be an additional source of potassium in the ground water, feldspar weathers relatively slowly, and feldspar minerals are uncommon in the aquifer matrix; therefore, weathering is unlikely to be an important source of potassium, especially in shallow, young ground water. Percolation of leachate from fertilizer (such as sylvite (KCl)) is, therefore, the most likely explanation for the presence of potassium (and chloride) in elevated concentrations in ground water in agricultural areas.

Correlations were noted among concentrations of magnesium, strontium, barium, radium, and nitrate; correlations were not noted for the concentrations of these constituents with those of silica or aluminum. These results indicate that the concentrations of dissolved strontium and barium are related to the presence of agricultural additives that have leached to the ground water;

these additives also are the origin of the highest concentrations of dissolved nitrate and magnesium. Strontium and barium are common trace components of many silicate (especially feldspar) minerals, but silica and aluminum are also derived from the weathering of silicate minerals. In the dilute waters of the Kirkwood-Cohansey aquifer system, a general correlation would be expected among the concentrations of barium, strontium, and at least silica, if silicate-mineral weathering were the dominant source of these dissolved constituents. Calcite and dolomite applied to agricultural land as liming agents also contain trace amounts of strontium and barium which, along with calcium and magnesium, probably are leached from the soil to the ground water. Alternatively, some of the strontium and barium may be released from the aquifer matrix by a geochemical mechanism similar to that which accounts for the mobility of radium. The hypothesis that radium and barium are mobilized concurrently by similar geochemical mechanisms is especially likely because both are divalent alkali-earth-element cations. The isotope ratios of radium demonstrate that the aquifer sediment is the dominant source of radium in solution; hence, it is likely that some barium in solution may also be derived from the sediment.

If volumetric leaching from sediment (leaching by percolating water of small amounts of constitiuents from sediment in proportion to their abundance) were the sole mechanism responsible for the mobility of uranium and radium-226 in the water of the Kirkwood-Cohansey aquifer system, the concentrations of uranium and radium-226 would be closely correlated because radium-226 is a member of the uranium-238 decay series and the two radionuclides have approximately the same activity in sediment. Radium-228, on the other hand, is not a part of the uranium-238 decay series, but rather is derived from the radioactive decay of long-lived thorium-232. The stronger correlation of radium-226 with radium-228 and with inorganic constituents associated with agricultural soil additives (such as nitrate, magnesium, and barium) than with uranium indicates that radium-226, radium-228, and the correlated inorganic trace-element constituents, such as barium, are likely mobilized primarily by a geochemical process operating in agricultural areas. The chemical characteristics of the water (large concentrations of dissolved calcium, magnesium, and nitrate; see figs. 5 and 6) of the aquifer in agricultural areas hinder, to a greater degree than in non-agricultural areas, the effectiveness of chemical mechanisms that may limit radium mobility. Discussed below are acidification and ion exchange, possible mechanisms that likely enhance the mobility of radium in agricultural areas.

Nitrification and Hydrogen-Ion Generation (Acidification)

Despite the extensive liming of soils and the abundance of calcium and magnesium in water in the Kirkwood-Cohansey aquifer system in agricultural areas, the pH of the water in these areas is no higher than it is in non-agricultural areas. Median pH values were 4.78 and 4.72 in samples of water collected from wells in the regional well network in agricultural and non-agricultural areas, respectively. (Kozinski and others (1995) obtained a similar result using a larger data set.) Therefore, in the acidic waters found in both agricultural and non-agricultural areas, trace elements (including radium) are mobile because of the low sorption capacity of the sediment in an acidic environment (Demir, 1989). It is unclear why ground water is just as acidic in agricultural as in non-agricultural areas despite liming. Mass-balance calculations of hydrogen-ion-forming and -consuming reactions were performed in an effort to answer this question.

The net change in the mass of chemical constituents per liter of water in agricultural areas that results from agricultural inputs can be evaluated through mass-balance calculations. Hypothetical chemical reactions that produce or consume hydrogen ions (table 7) in the ground water were simulated in mass-balance and reaction-path modeling of the evolution of ground-water chemistry in agricultural areas in order to determine the effect of various reactions on pH. The net mass of solid-phase reactants that would have to be added to (dissolution reactions) or subtracted from (precipitation reactions) "median-composition" soil water from a non-agricultural (forested) area (initial solution) to account for the amount of nitrate (as nitrogen), magnesium, and other constituents, and the pH, in the ground water in an agricultural area (final solution) was calculated. The composition of the initial solution was calculated from water-quality data reported by Lord and others (1990) for uplands-type Evesham and Woodbury soils, which are assumed to be reasonably similar to soils developed on the Bridgeton Formation. The composition of the final solution was represented by the composition of the first sample collected from observation well 11-693 (app. 2C).

Because the soils used for agriculture in southern New Jersey are low in nutrients, large amounts of ammonia-based fertilizer are applied. Nitrification of ammonia-based fertilizers added to agricultural soils is the most plausible source of the elevated nitrate concentrations in the ground water in agricultural areas relative to non-agricultural areas, as demonstrated by the mass-balance calculation (table 8). A total of 1.63 millimoles of nitrogen as ammonia per liter of water would need to nitrify and dissolve to produce water with the composition of that from well 11-693 (1.645 millimoles per liter) from the assumed initial soil-water solution (0.015 millimoles per liter).

Ammonia-based fertilizer is oxidized rapidly to nitrate (nitrification) in the soil and shallow ground water (Denver, 1986; Delwiche, 1970; Brown, 1970). This process requires an oxygen-to-ammonia ratio of 2:1. To oxidize the calculated mass of ammonia per liter of water added to the initial solution to account for the measured nitrate concentration, 3.26 millimoles of oxygen gas per liter of water would need to be consumed (table 8). The vadose zone and the capillary fringe of the water table in the highly permeable and porous soils formed on the Bridgeton Formation are open to atmospheric gases, enabling large quantities of oxygen gas to be consumed in chemical reactions.

The addition of 0.432 millimoles of magnesium per liter of water from the dissolution of dolomite and of magnesium oxide (lime) added to the soil as a liming agent and from the dissolution of magnesium chloride (used as road salt) to the initial soil water with a magnesium content of 0.021 millimoles per liter accounted in the simulation for the amount of magnesium (0.453 millimoles per liter) in the water from well 11-693. The dissolution of dolomite adds twice as much carbonate as magnesium to the ground-water solution. Because one carbonate ion consumes two hydrogen ions as it is converted to carbonic acid, every magnesium ion from dolomite added to the solution is coupled with the consumption of four hydrogen ions (table 7). (Magnesium chloride, a possible component of road salt, was not considered in the acid-neutralization mass balance. No information is available to help determine the proportion of magnesium contributed from each source.)

Hydrogen-ion generation due to nitrification was simulated by reaction-path modeling of the evolution of water composition from that of the water sample from well 11-693 by adding nitrogen (as ammonia and sodium nitrate) to the initial soil water. The calculated pH was 3.7 when ammonia, in conjunction with dolomite, was added to the initial solution and then oxidized to nitrate. The calculated pH rose to 6.6 when sodium nitrate was added in conjunction with the dolomite and no ammonia oxidation occurred. These simulations indicate that it is the nitrification of ammonia that is the chemical process generating hydrogen ions in agricultural areas. The strongly acidifying nature of ammonia has been suggested as a major factor in the acidity of ground water in similar agricultural areas of the Atlantic Coastal Plain (Denver, 1986).

The final pH (free hydrogen-ion content) of the solution, therefore, depends on the ratio of the amount of ammonia converted to nitrate to the amount of dolomite dissolved. A high ratio of ammonia to dolomite (indicated by a high ratio of nitrate to magnesium in solution) results in a low ground-water pH; this is most likely the case for water from well 11-693 (table 8).

Table 7. Hypothetical chemical reactions that produce or consume hydrogen ions in water in the Kirkwood-Cohansey aquifer system, southwestern Coastal Plain, New Jersey

HYDROGEN-ION-PRODUCING REACTIONS

Redox reactions:

Nitrification:

$$NH_3 + 2O_2 \rightarrow NO_3^- + H_20 + H^+$$

Aluminum precipitation as a clay mineral:

Kaolinite precipitation:

$$2Al^{+3} + 2\ H_4SiO_4 + H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 6H^+$$

HYDROGEN-ION-CONSUMING REACTIONS

Carbonate reactions:

Dolomite dissolution:

$$2H^+ + CaMg(CO_3)_2 \rightarrow Ca^{+2} + Mg^{+2} + 2HCO_3^-$$

Bicarbonate consumption:

$$H^+ + HCO_3^- \rightarrow H_2CO_3$$

Incongruent silicate-mineral weathering reactions:

K-feldspar weathering to kaolinite:

$$2H^+ + 2KAlSi_3O_8 + 9H_2O \rightarrow 2K^+ + 4H_4SiO_4 + Al_2Si_2O_5(OH)_4$$

Table 8. **Net amount of constituents added to, or removed from, an initial solution of soil water of median composition from well-drained Evesham and Lakewood soils in a non-agricultural area to obtain the composition of ground water from well 11-693 located in an agricultural area, Kirkwood-Cohansey aquifer system, southwestern Coastal Plain, New Jersey; actual pH and calculated pH when nitrogen is added in various forms; and mass balance of hydrogen ions when nitrogen is added as ammonia**

[mmol/L, millimoles per liter; +, constituent dissolved; -, constituent precipitated]

Constituent	Initial solution (median composition of water from well-drained Lakewood and Evesham soils in non-agricultural area) (mmol/L)	Final solution (composition of water from well 11-693 in the Kirkwood-Cohansey aquifer system in an agricultural area) (mmol/L)	Net amount of constituent added to, or removed from, the initial solution to derive the composition of the final solution, and probable source (mmol/L)
Ca	0.018	0.449	+ 3.2600, O_2 gas (soil gas)
Mg	.021	.453	+ 1.6300, NH_3 (fertilizer)
C	1.353	2.144	+ .0785, CO_2 gas (soil gas)
N	.015	1.645	+ .1495, calcite (lime)
Na	.057	.287	+ .2815, dolomite (lime)
K	.010	.084	+ .0640, K-feldspar (weathering)
Cl	.108	.649	+ .1505, $MgCl_2$ (salt)
Si	.031	.153	+ .0100, KCl (potash salt)
Al	.020	.014	+ .2300, NaCl (salt)
			- .0350, kaolinite (weathering)

Actual and calculated pH

Actual pH of initial solution is 4.1.
Calculated pH of final solution when no N is added with lime is 6.6.
Calculated pH of final solution when N is added as $NaNO_3$ with lime is 6.6.
Calculated pH of final solution when N is added as NH_3 with lime is 3.7.
Actual pH of final solution is 4.5.

Mass balance of hydrogen ions per liter, well 11-693

Hydrogen-ion production		Hydrogen-ion consumption	
Nitrification	1.630 mmol/L x $1H^+$ = + 1.630	Calcite dissolution	0.1495 mmol/L x $1H^+$ = -.1495
Kaolinite precipitation	.003 mmol/L x $6H^+$ = + .018	Dolomite dissolution	.2815 mmol/L x $2H^+$ = -.5630
		Bicarbonate consumption	.7125 mmol/L x $1H^+$ = -.7125
		K-feldspar weathering to kaolinite	.064 mmol/L x $2H^+$ = -.1280
Total hydrogen-ion production	+1.648	Total hydrogen-ion consumption	-1.5530

Net balance for solution +0.095 mmol H^+/L

The consumption of silicate minerals (weathering) also consumes hydrogen ions (table 7). Because the net amount of silicate weathering in the aquifer is small (0.064 millimoles per liter), the amount of solute derived from this source is small relative to the net amount of solute added to the solution in agricultural areas by nitrification and dolomite dissolution (table 8). Therefore, silicate-mineral weathering is not an important determinant of ground-water pH in agricultural areas. In non-agricultural areas, however, reactions involving agricultural chemicals are of little importance; therefore, silicate-mineral weathering could be responsible for the presence of a large percent of the dissolved solutes and could be a major determinant of ground-water pH.

Concentrations of dissolved radium in water in the Kirkwood-Cohansey aquifer system increase sharply as pH values decrease below 5. Despite extensive liming of soils in agricultural areas, ground-water pH generally is low (typically less than 5), most likely as a result of nitrification of added ammonia-based fertilizer. The low solution pH, in turn, causes the sorption capacity of the quartzose aquifer material to be minimal. Sorption of radium onto quartz decreases very sharply at a pH of about 6 and becomes negligible at pH values between 4 and 5 (Benes and others, 1984) as sorption sites are occupied by hydrogen ions. Laboratory experiments of Lyle and others (1984) also showed that an acetic-acid-leach solution (pH 5) strongly mobilizes divalent alkali-earth cations from sediment. The radium is mobilized just as easily in ground water from agricultural areas as in ground water from non-agricultural areas because the water is just as acidic in the former as in the latter as a result of the nitrification process.

Competition With Other Divalent Ions (Ion Exchange)

In low-pH water in the Kirkwood-Cohansey aquifer system, abundant hydrogen ions compete for and thus limit the number of available adsorption and exchange sites. Furthermore, in ground water in agricultural areas, because of liming of soil, concentrations of the divalent cations barium, calcium, magnesium, and strontium are higher by a factor of 10 or more than those in ground water in non-agricultural areas (table 8). The concentration of radium increases with increasing concentrations of these other divalent cations (tables 5 and 6). Competition from these other similarly charged ions derived from liming for adsorption and exchange sites on mineral-grain surfaces controls the overall sorption and exchange capacity of the aquifer matrix for any cationic species, including divalent radium cations (Miller and Sutcliffe, 1985). Competing divalent cations displace adsorbed radium or prevent the adsorption of newly formed radium, which is continuously generated by radioactive decay in the aquifer.

In a previous field study, competition with elevated concentrations of the divalent cations calcium and magnesium was cited as the reason for elevated concentrations of radium in the neutral-pH water in the Athabasca Sandstone in western Canada (Earle and Drever, 1983). In a related laboratory study, radium sorption from solution in soils was limited by the addition of calcium to the solution; competition for sorption sites was most pronounced in soil material with low sorption capacities (Nathwani and Phillips, 1979). In another laboratory study, high concentrations of dissolved (monovalent) potassium (commonly added to the sandy quartzose soils in agricultural areas in southern New Jersey) also were shown to limit radium sorption onto soil, possibly as a result of an increase in the ionic strength of the solution (Nirdosh and others, 1987).

The flow diagram in figure 8 illustrates the effects of agricultural chemicals on water quality in the Kirkwood-Cohansey aquifer system and the possible mechanisms by which chemical processes may enhance radium mobility. High ground-water acidity is the cause of the low sorption capacity of the aquifer matrix, in general. In agricultural areas, fertilization and liming of the soil results in nitrate- and divalent-cation-laden recharge that is acidic because of hydrogen-ion generation during nitrification of ammonia-based fertilizer; therefore, radium is

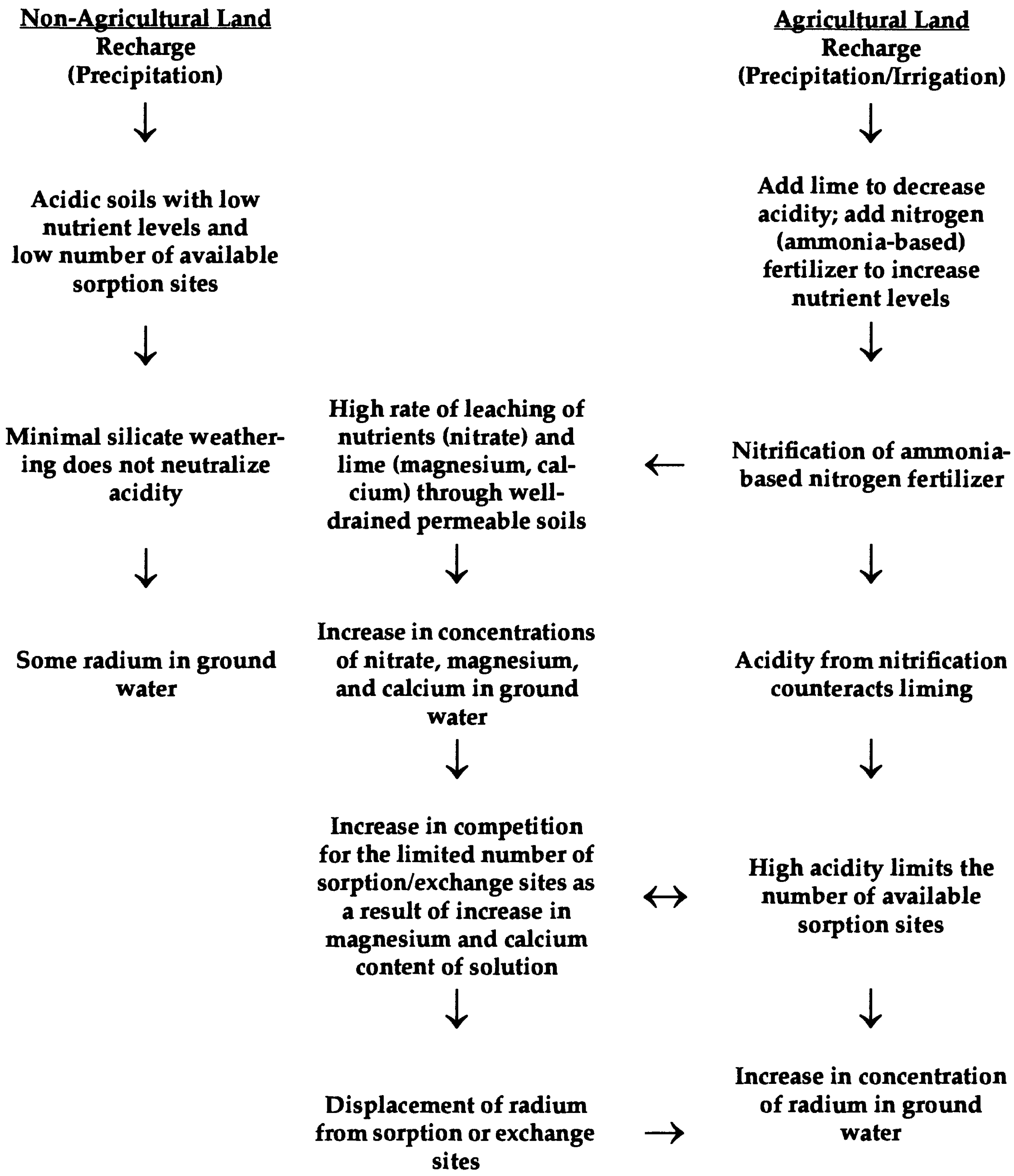


Figure 8. Processes leading to elevated concentrations of nitrate, magnesium, calcium, and radium in water in areas where agricultural land overlies the Kirkwood-Cohansey aquifer system, southern New Jersey Coastal Plain.

subject to increased competition from other divalent cations in agricultural areas relative to non-agricultural areas, and its mobility increases. In agricultural areas, radium mobility may also be enhanced relative to that in non-agricultural areas by changes in the sorbent surface due to the increase in the ionic strength of the solution.

SUMMARY AND CONCLUSIONS

Differences in the overall chemical quality and radium content of water in the Kirkwood-Cohansey aquifer system in agricultural and non-agricultural (forested) areas in southern New Jersey were determined from analytical results obtained from a regional sampling network of 42 wells. Differences in water quality, concentrations of dissolved radionuclides, and radium concentrations in the sediment with depth were also characterized with water-quality data collected from 15 nested observation wells and two nested piezometers that were installed at five sites in agricultural areas near ground-water divides (where ground-water flow is vertical).

Concentrations of dissolved radium-226 and radium-228 in water samples from the 42 wells were significantly higher in agricultural areas than in non-agricultural areas. Concentrations of radium-226 ranged from 0.21 to 8.9 pCi/L, with a median of 2.5 pCi/L, in 29 samples from wells in agricultural areas, and from 0.18 to 2.4 pCi/L, with a median of 0.64 pCi/L, in 13 samples from wells in non-agricultural areas. Similarly, concentrations of radium-228 ranged from <1 to 5.0 pCi/L, with a median of 1.8 pCi/L, in the samples from wells in agricultural areas, and from <1 to 2.4 pCi/L, with a median of <1 pCi/L, in the samples from wells in non-agricultural areas. The sum of the concentrations of radium-226 and radium-228 did not exceed the primary drinking-water standard of 5 pCi/L in any of the 13 ground-water samples from non-agricultural areas; however, this value was exceeded in 39 percent of the samples from agricultural areas. The median radium-228/radium-226 concentration ratio in all 42 ground-water samples was 1.08.

Concentrations of dissolved radon-222 in samples from the regional well network ranged from 80 to 1,300 pCi/L. These concentrations are much greater than those of dissolved radium-226, indicating that concentrations of radium-226, the radioactive parent of radon-222, in the aquifer material were sufficiently high to account for the concentration of dissolved radium-226 found in the water.

Concentrations of nitrate and many inorganic chemical constituents, including magnesium, calcium, barium, strontium, potassium, and chloride, also were significantly higher in samples from wells in agricultural areas than in samples from wells in non-agricultural areas. The largest difference, in general, was between the concentration of nitrate in water samples from wells in agricultural areas and that in samples from wells in non-agricultural areas. No difference was noted, however, in the pH between ground-water samples from agricultural and those from non-agricultural areas; all 42 samples were acidic (median pH of 4.76). Concentrations of both dissolved radium-226 and dissolved radium-228 were significantly correlated with concentrations of the same dissolved constituents, which are associated with agricultural land use. Correlation coefficients ranged from about +0.3 to about +0.5 and were significant at the 95-percent confidence level.

Results of analyses of samples from the 15 nested observation wells and two nested piezometers in agricultural areas indicate that concentrations of dissolved radium-226, radium-228, nitrate, magnesium, calcium, barium, strontium, and chloride are all significantly higher at shallow to medium depths (5 to 45 ft) below the water table than at greater depths in the aquifer. At three of the five sites, the sum of the concentrations of radium-226 and radium-228 exceeded 5 pCi/L in samples of water from either shallow or medium depths in the aquifer. The pH was lower (range 4.6-5.6) in water from shallow and medium depths than at the greatest depths (range 5.1-6.4). The correlation between the vertical distribution of radium and that of inorganic constituents associated with agricultural inputs, such as nitrate (from fertilizer) or calcium, strontium, magnesium, and barium (from lime), indicates that the alteration of the composition of the shallow ground water by the addition of agricultural chemicals has increased the mobility of radium, and that the correlation between concentrations of these dissolved constituents and concentrations of dissolved radium in water from the regional well network is not a geographic coincidence.

The concentration of radium-226 in 15 sediment samples from various depths in the aquifer ranged from 0.05 to 1.1 pCi/g, with a median of 0.35 pCi/g; the concentration of radium-228 ranged from 0.11 to 0.84 pCi/g, with a median of 0.40 pCi/g. The radium-228/radium-226 concentration ratio in the sediment samples ranged from 0.45 to 2.4 with a median of 1.0. Concentrations of both radionuclides were significantly higher in silty sand than in sand. The median radium-228/radium-226 concentration ratio in samples of water from the nested wells associated with the sediment was 1.1. In contrast, the concentration ratio of radium-228 to radium-226 in phosphate fertilizer is about 0.1, indicating that fertilizer is not the source of the radium. The close correspondence of the radium-228/radium-226 concentration ratios in the sediment and water indicates that the sediment is the likely source of the dissolved radium.

Concentrations of dissolved radon-222 in the 15 samples from the nested observation wells and 2 samples from the nested piezometers ranged from <80 to 1,100 pCi/L and did not correspond to those of dissolved radium-226. Concentrations of dissolved radon-222 were correlated, however, with the radioactivity of the adjacent aquifer sediment as determined by gamma-ray logging, rather than with depth or the chemical composition of the water sample. Concentrations of radium-226 in the aquifer material are sufficiently high to account for the dissolved radon-222.

Results of geochemical mass-balance and reaction-path model simulations of the chemical evolution of ground water from a solution representing the median composition of soil water in a non-agricultural (forested) area to one representing that of soil water in an agricultural area indicate that the generation of hydrogen ions by nitrification of ammonia-based fertilizer is nearly sufficient to consume the acid-neutralizing capacity of the solution, which is due mainly to the lime added to the soil and dissolved by infiltrating recharge. Although the acidity of the solution is maintained, therefore, by nitrification, the dissolution of lime causes concentrations of calcium and magnesium in the ground water to increase. The net mass of hydrogen ions generated per liter of solution by nitrification and the increase in the concentrations of calcium and magnesium in solution due to lime dissolution in agricultural areas, furthermore, are far greater than the amount of solutes and acid-neutralizing capacity added to the solution as a result of silicate-mineral weathering in the aquifer.

The sorption capacity of the aquifer materials (quartz, iron hydroxide) for the divalent radium cation is low in water with pH values below 5. Sorption of radium from solution is further diminished by increased concentrations of the divalent alkali-earth cations calcium and magnesium in solution. These cations effectively compete with radium for the same sorption sites on the sediment surface. Because water in the Kirkwood-Cohansey aquifer system is acidic and, in agricultural land use areas, contains abundant calcium and magnesium, the mobility of radium is further enhanced in agricultural areas relative to non-agricultural areas.

REFERENCES CITED

Ames, L.L., McGarrah, J.E., Walker, B.A., and Sutter, P.F., 1983, Uranium and radium sorption on amorphous ferric oxyhydroxide: Chemical Geology, v. 40, p. 135-148.

Andrews, J.N., and Wood, D.F., 1972, Mechanism of radon release in rock matrices and entry into ground waters: Institute of Mining and Metallurgy: London Transactions, Sec. B81, p. 198-209.

Bayliss, P., Erd, D.C., Morse, M.E., Sabina, A.P., and Smith, D.K., 1986, Mineral powder diffraction file--Search Manual--Chemical name, Hanawalt-Fink-mineral name: Swarthmore, Pa., JCPDS-International Center for Diffraction Data.

Bell, Christine, 1983, Radioactive mineral occurrences in New Jersey: New Jersey Geological Survey Open-File Report 83-5, 21 p.

Benes, P., Strejc, P., and Lukavec, Z., 1984, Interaction of radium with freshwater sediments and their mineral components: I. Ferric-hydroxide and quartz: Journal of Radioanalytical and Nuclear Chemistry, v. 82, no. 2, p. 275-285.

Bradbury, K.R., 1991, Tritium as an indicator of ground-water age in central Wisconsin: Ground Water, v. 29, no. 3, p. 398-404.

Brina, R., and Miller, A.G., 1992, Direct detection of trace levels of uranium by laser-induced kinetic phosphorimetry: Analytical Chemistry, v. 64, p. 1413-1418.

Brown, L.R., 1970, Human food production as a process in the biosphere: Scientific American, v. 223, p. 158-169.

Brutsaert, W.F., Norton, S.A., Hess, C.T., and Williams, J.S., 1981, Geologic and hydrologic factors controlling radon-222 in ground water in Maine: Ground Water, v. 19, no. 4, p. 407-417.

Bushaw, B.A., 1983, Kinetic analysis of laser-induced phosphorescence in uranyl phosphate for improved analytical measurements: U.S. Department of Energy Document PNL-SA-11455.

Claassen, H.C., 1982, Guidelines and techniques for obtaining water samples that accurately represent the water chemistry of an aquifer: U.S. Geological Survey Open-File Report 82-1024, 49 p.

Conover, W.J., 1980, Practical nonparametric statistics (2d ed.): New York, John Wiley, 493 p.

Cothern, C.R., 1987, Estimating the health risks of radon in drinking water: American Water Works Association Journal, v. 79, no. 4, p. 153-158.

Crerar, D.A., Knox, G.W., and Means, J.L, 1979, Biogeochemistry of bog iron in the New Jersey Pine Barrens: Chemical Geology, v. 24, p. 111-136.

Delwiche, C.C., 1970, The nitrogen cycle: Scientific American, v. 223, p. 71-80.

REFERENCES CITED--Continued

Demir, Ilham, 1989, Temporal variations and sources of Pb, Co, Cu, Ni, Fe, and Mo in shallow ground water of the McDonalds Branch basin, Lebanon State Forest, Burlington County, New Jersey: New Jersey Geological Survey Report 20, 19 p.

Denver, J.M., 1986, Hydrogeology and geochemistry of the unconfined aquifer, west-central and southwestern Delaware: Delaware Geological Survey Report of Investigations 41, 100 p.

Earle, S.A.M., and Drever, G.L., 1983, Hydrogeochemical exploration for uranium within the Athabasca Basin, Northern Saskatchewan: Journal Geochemical Exploration, v. 19, p. 57-73.

Exner, M.E., and Spalding, R.F., 1994, N-15 identification of nonpoint sources of nitrate contamination beneath cropland in the Nebraska Panhandle: Two case studies: Applied Geochemistry, v. 9, p. 73-81.

Farlekas, G.M., Nemickas, Bronius, and Gill, H.E., 1976, Geology and ground-water resources of Camden County, New Jersey: U.S. Geological Survey Water-Resources Investigations 76-76, 146 p.

Fishman, M.J., and Friedman, L.C., 1985, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 709 p.

Friedman, L.C., and Erdman, D.E., 1982, Quality assurance practices for the chemical and biological analyses of water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A6, 181 p.

Gunderson, L.C.S., and Peake, R.T., 1992, Radon in the Coastal Plain of Texas, Alabama, and New Jersey, *in* Gates, A.E., and Gunderson, L.C.S., eds., Geologic controls on radon: Geological Society of America Special Paper 271, Boulder, Colo., p. 53-64.

Hardt, W.F.,and Hilton, G.S., 1969, Water resources and geology of Gloucester County, New Jersey: State of New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply, Special Report No. 30, 130 p.

Heaton, T.H.E., 1986, Isotopic studies of nitrogen pollution in the hydrosphere and atmosphere: A review: Chemical Geology, v. 59, p. 87-102.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hendry, M.J., 1988, Do isotopes have a place in ground-water studies?: Ground Water, v. 26, no. 4, p. 410-415.

Hess, C.T., Michel, Jacqueline, Horton, T.R., Pritchard, H.M., and Coniglio, W.A., 1985, The occurrence of radioactivity in public water supplies in the United States: Health Physics, v. 48, no. 5, p. 553-586.

Isphording, W.C., 1970, Petrology, stratigraphy and redefinition of the Kirkwood Formation (Miocene) of New Jersey: Journal of Sedimentary Petrology, v. 40, p. 986-997.

REFERENCES CITED--Continued

Johnson, M.E., 1950, Geologic map of New Jersey, revised: New Jersey Department of Conservation and Economic Development, scale 1:250,000.

Johnson, J.H., 1978, Soil survey of Atlantic County, New Jersey: U.S. Department of Agriculture, Soil Conservation Service, 61 p.

King, P.T., Michel, Jacqueline, and Moore, W.S., 1982, Ground-water geochemistry of Ra-228, Ra-226, and Rn-222: Geochimica Cosmochimica Acta, v. 46, p. 1173-1182.

Korner, L.A., and Rose, A.W., 1977, Radon in streams and ground water of Pennsylvania as a guide to uranium deposits: U.S. Energy Research and Development Association, Open-File Report GJBX - 60(77), Grand Junction, Colo., 151 p.

Kozinski, Jane, Szabo, Zoltan, Zapecza, O.S., and Barringer, T.H., 1995, Natural radioactivity in, and inorganic chemistry of, ground water in the Kirkwood-Cohansey aquifer system in southern New Jersey: U.S. Geological Survey Water-Resources Investigations Report 92-4144, 182 p.

Krieger, H.L., and Whittaker, E.L., 1980, Prescribed procedures for measurement of radioactivity in drinking water: U.S. Environmental Protection Agency Manual EPA-600/4-80-032, 111 p.

Lacombe, Pierre, and Rosman, Robert, 1995, Hydrology of the unconfined aquifer system, upper Maurice River Basin and adjacent areas in Gloucester County, New Jersey, 1986-87: U.S. Geological Survey Water-Resources Investigations Report 92-4128, 5 sheets.

Langmuir, Donald, and Melchoir, Daniel, 1985, The geochemistry of Ca, Sr, Ba, and Ra sulfates in some deep brines from the Palo Duro Basin, Texas: Geochimica Cosmochimica Acta, v. 49, p. 2423-2432.

Langmuir, Donald, and Riese, A.C., 1985, The thermodynamic properties of radium: Geochimica Cosmochimica Acta, v. 49, p. 1593-1601.

Lord, D.G., Barringer, J.L., Johnsson, P.A., Schuster, P.F., Walker, R.L., Fairchild, J.E., Sroka, B.N., and Jacobsen, Eric, 1990, Hydrochemical data from an acidic deposition study at McDonalds Branch basin in the New Jersey Pinelands, 1983-86: U.S. Geological Survey Open-File Report 88-500, 132 p.

Louis, J.B., and Vowinkel, E.F., 1989, Effect of agricultural chemicals on groundwater quality in the New Jersey Coastal Plain, *in* Weigmann, D.L., ed., Pesticides in terrestrial and aquatic environments: Blacksburg, Va., Virginia Water Resources Research Center, p. 80-89.

Lyle, Mitchell, Heath, G.R., and Robbins, J.M., 1984, Transport and release of transition elements during early diagenesis: Sequential leaching of sediments from MANOP sites M and H. Part I. pH 5 acetic acid leach: Geochimica Cosmochimica Acta, v. 48, p. 1705-1715.

Martino, R.L., 1981, The sedimentology of the late Tertiary Bridgeton and Pennsauken Formations in southern New Jersey: New Brunswick, N.J., Rutgers University, unpublished Ph.D. dissertation, 299 p.

Mays, C.W., Rowland, R.E., and Stehney, A.F., 1985, Cancer risk from the lifetime intake of Ra and U isotopes: Health Physics, v. 48, no. 5, p. 635-647.

Michel, Jacqueline, and Moore, W.S., 1980, Radium-228 and radium-226 content of ground water in Fall Line aquifers: Health Physics, v. 38, p. 663-671.

Miller, R.L., and Sutcliffe, H., Jr., 1985, Occurrence of natural radium-226 radioactivity in ground water of Sarasota County, Florida: U.S. Geological Survey Water-Resources Investigations Report 84-4237, 34 p.

Nathwani, J.S., and Phillips, C.R., 1979, Adsorption of ^{226}Ra by soils in the presence of Ca^{2+} ions. Specific adsorption (II): Chemosphere, v. 5, p. 293-299.

Nemeth, W.K., and Parsa, Bahman, 1992, Density correction of gamma-ray detection efficiency in environmental samples: Radioactivity and Radiochemistry, v. 3, no. 3, p. 32-39.

Nemickas, Bronius, and Carswell, L.D., 1976, Stratigraphic and hydrologic relation of the Piney Point aquifer and the Alloway Clay member of the Kirkwood Formation in New Jersey: U.S. Geological Survey Journal of Research, v. 4, no. 1, p. 1-7.

Nirdosh, I., Trembley, W.B., Muthuswami, S.V., and Johnson, C.R., 1987, Adsorption-desorption studies on the radium-silica system: Canadian Journal of Chemical Engineering, v. 65, p. 928-934.

Ostlund, H.G., and Dorsey, H.G., 1977, Rapid electrolytic enrichment and hydrogen gas proportional counting of tritium, *in* Low-radioactivity measurements and applications: Proceedings of the International Conference on Low-Radioactivity Measurements and Applications, October 6-10, 1975, The High Tatras, Czechoslovakia, Slovenske Pedagogicke Nakladateistvo, Bratislava, Slovakia.

Owens, J.P., and Minard, J.P., 1979, Upper Cenozoic sediments of the lower Delaware Valley and the northern Delmarva Peninsula: New Jersey, Pennsylvania, Delaware, and Maryland: U.S. Geological Survey Professional Paper 1067-D, 48 p.

Owens, J.P., and Sohl, N.F., 1969, Shelf and deltaic paleoenvironments in the Cretaceous-Tertiary formations of the New Jersey Coastal Plain, *in* Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania, and guidebook of excursions: New Brunswick, N.J., Rutgers University Press, p. 235-278.

Owens, J.P., Bybell, L.M., Paulachok, Gary, Ager, T.A., Gonzalez, V.M., and Sugarman, P.J., 1988, Stratigraphy of the Tertiary sediments in a 945-foot-deep corehole near Mays Landing in the southeastern New Jersey Coastal Plain: U.S. Geological Survey Professional Paper 1484, 39 p.

Owens, J.P., Hess, M.M., Denny, C.S., and Dwornick, E.J., 1983, Post-depositional alteration of surface and near-surface minerals in selected Coastal Plain formations of the Middle Atlantic States: U.S. Geological Survey Professional Paper 1067-F, 45 p.

REFERENCES CITED--Continued

Parkhurst, D.L., Thorstenson, D.C., and Plummer, L.N., 1980, PHREEQE--A computer program for geochemical calculations: U.S. Geological Survey Water-Resources Investigations Report 80-96, 193 p.

Parkhurst, D.L., Plummer, L.N., and Thorstenson, D.C., 1982, BALANCE--A computer program for calculating mass transfer for geochemical reactions in ground water: U.S. Geological Survey Water-Resources Investigations Report 82-14, 29 p.

Pritchard, H.M., and Gesell, T.F., 1977, Rapid measurements of Rn-222 concentrations in water with a commercial liquid scintillation counter: Health Physics, v. 33, p. 577.

Rhodehamel, E.C., 1973, Geology and water resources of the Wharton Tract and the Mullica River Basin in southern New Jersey: New Jersey Department of Environmental Protection, Division of Water Resources Special Report 36, 58 p.

Rice, D.E., and Szabo, Zoltan, 1997, Relation of ground-water flow paths and travel time to the distribution of radium and nitrate in current and former agricultural areas of the Kirkwood-Cohansey aquifer system, New Jersey Coastal Plain: U.S. Geological Survey Water-Resources Investigations Report 96-4165B, 48 p.

Roessler, C.E., Smith, Z.A., Bolch, W.E., and Prince, R.J., 1979, Uranium and radium-226 in Florida phosphate materials: Health Physics, v. 37, p. 269-277.

Rooney, J.G., 1971, Ground-water resources of Cumberland County, New Jersey: New Jersey Department of Environmental Protection, Special Report No. 34, 83 p.

Rosenau, J.C., Lang, S.M., Hilton, G.S., and Rooney, J.G., 1969, Geology and ground-water resources of Salem County, New Jersey: New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply, Special Report No. 33, 142 p.

Severson, R.C., and Shacklette, H.T., 1988, Essential elements and soil amendments for plants: Sources and use for agriculture: U.S. Geological Survey Circular 1019, 48 p.

Spalding, R.F., and Sackett, W.M., 1972, Uranium in runoff from the Gulf of Mexico distributive province: Anomalous concentrations: Science, v. 175, p. 629-631.

Stumm, W., and Morgan, J.J., 1981, Aquatic chemistry: New York, John Wiley, 631 p.

Sugarman, P.J., Miller, K.G., Owens, J.P, Feigenson, M.D., 1993, Strontium-isotope and sequence stratigraphy of the Miocene Kirkwood Formation, southern New Jersey: Geological Society of America Bulletin, v. 105, p. 423-436.

Szabo, Zoltan, 1990, Uranium, radium, and radon in ground water from the rock aquifers of the Piedmont Province and the Kirkwood-Cohansey aquifer system of the Coastal Plain Province, New Jersey, *in* Kroll, R.L., and Brown, J.O., eds., Aspects of ground water in New Jersey (Seventh Annual Meeting of the Geological Association of New Jersey): Kean College, Union, N.J., p. H1-H11.

REFERENCES CITED--Continued

Szabo, Zoltan, Rice, D.E., Ivahnenko, Tamara, and Vowinkel, E.F., 1994, Delineation of the distribution of pesticides and nitrate in an unconfined aquifer in the New Jersey Coastal Plain by flow-path analysis, *in* Weigman, D.L., ed., New directions in pesticide research, development, management, and policy: Proceedings of the Fourth National Conference on Pesticides, November 1-3, 1993, Blacksburg, Va., Virginia Water Resources Research Center, p. 100-119.

Thatcher, L.L., Janzer, V.J., and Edwards, K.W., 1977, Methods for determination of radioactive substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A5, 95 p.

Turekian, K.K., and Wedepohl, K.H., 1961, Distribution of the elements in some major units of the Earth's crust: Geological Society of America Bulletin, v. 72, p. 175-196.

U.S. Environmental Protection Agency, 1978, Radon in water sampling program: U.S. Environmental Protection Agency EPA/EERF, Manual 78-1, 11 p.

U.S. Environmental Protection Agency, 1979a, National secondary drinking-water regulations: U.S. Environmental Protection Agency, Office of Drinking Water, EPA-570/g-76-000, 37 p.

U.S. Environmental Protection Agency, 1979b, Methods for the chemical analysis of water and wastes: Washington, D.C., Government Printing Office, p. 353.2-1.

U.S. Environmental Protection Agency, 1988, Maximum contaminant levels (subpart B of part 141, National interim primary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1988, p. 530-533.

U.S. Environmental Protection Agency, 1989, Proposed rule, National primary and secondary drinking water regulations (sections 141.50, 141.51, 141.61, and 141.62 of part 141 and 143.3 of part 143): U.S. Federal Register, v. 54, no. 97, p. 22,062-22,160.

U.S. Environmental Protection Agency, 1991a, National primary drinking water regulations: Radionuclides--Notice of proposed rulemaking: U.S. Federal Register, v. 56, no. 138, p. 33,050-33,127.

U.S. Environmental Protection Agency, 1991b, National primary drinking water regulations: Final rule for lead and copper (sections 141.11, 141.32, and 141.51 of part 141): U.S. Federal Register, v. 56, no. 110, p. 26,460-26,564.

Wanty, R.B., Lawrence, E.P., and Gunderson, L.C.S., 1992, A theoretical model for the flux of radon from rock to ground water, *in* Gates, A.E., and Gunderson, L.C.S., eds., Geologic controls on radon: Boulder, Colo., Geological Society of America Special Paper 271, p. 73-78.

Watt, M.K., and Johnson, M.L., 1992, Water resources of the unconfined aquifer system of the Great Egg Harbor River Basin, New Jersey, 1989-90: U.S. Geological Survey Water-Resources Investigations Report 91-4126, 5 sheets.

REFERENCES CITED--Continued

Wershaw, R.L., Fishman, M.J., Grabble, R.R., and Lowe, L.E., 1987, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, 80 p.

Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey Techniques of Water-Resources Investigations, book 1, chap. D2, 24 p.

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

Zapecza, O.S., and Szabo, Zoltan, 1988, Natural radioactivity in ground water--A review: National Water Summary 1986--Hydrologic events and ground-water quality: U.S. Geological Survey Water-Supply Paper 2325, p. 50-57.

_____ 1989, Source of natural radioactivity in ground water in the Kirkwood-Cohansey aquifer system, southwestern Coastal Plain, New Jersey: Geological Society of America Abstracts with Programs, Northeastern Section, v. 21, no. 2, p. 78.

GLOSSARY

Absorption: Process by which substances in gaseous, liquid, or solid form are assimilated or taken up by other substances, generally the surfaces of solids.

Alkalinity: The acid-neutralizing capacity of water; generally assumed to be due to the bicarbonate ion in waters with pH from 4.5 to 8.3.

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.

Anion: Ion that has a negative electrical charge.

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 radionuclide undergoing the decay.

Cation: Ion that has a positive electrical charge.

Confidence level: In statistics, a given probability chosen as a cutoff above which a result is declared to be indistinguishable from natural variability.

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

Correlation coefficient: A statistic used to measure the strength of a relation between two variables.

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).

Emanation coefficient: A factor ranging from 0 to 1 that describes the efficiency of rock or sediment with respect to release of radon to pore space, whether filled with gases or ground water. For rock below the water table, the factor is computed by dividing the activity of radon in the water by the difference between the activity of the radioactive parent in the rock or sediment and the activity of the parent in the water in a unit volume containing both the water and rock.

Fall Line: Imaginary line marking the boundary between the ancient, resistant, crystalline rocks of the Piedmont physiographic province of the Appalachian Mountains, and the younger, softer, generally unconsolidated sediments of the Atlantic Coastal Plain physiographic province in the eastern United States. Along rivers, this line commonly is reflected by waterfalls.

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.

Gamma log: A log of the natural radioactivity of the sediment penetrated by a well.

Gamma ray: A photon that has neither mass nor electrical charge that is emitted by the nucleus of a decaying radionuclide.

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

Ground-water divide: Ridge in the water table (or other potentiometric surface); ground water moves in both directions normal to the ridge line.

Ion exchange: Reversible chemical replacement of an ion bonded at the liquid-solid interface by an ion in solution.

Isotope: Any of two or more forms of an element that have different atomic weights as a result of a difference in the number of neutrons found in the nucleus. The chemical properties of isotopes are identical.

Maximum contaminant level: Maximum permissible level of a contaminant in water that 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 concentration 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.

Glossary--Continued

Nitrification: Chemical reaction, usually mediated by bacteria in the presence of water, in which there is a transfer of electrons from a nitrogen atom or ammonia ion, thus increasing the net charge (valence) of nitrogen to +5.

Outcrop area: As used in this report, area where a geologic or hydrogeologic unit is exposed at land surface.

Oxidation: Chemical reaction in which electrons are transferred from an ion or atom, thus increasing its net charge or valence.

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 (3.7×10^{10} radioactive disintegrations per second). One picocurie represents 2.22 radioactive disintegrations per minute.

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 of gamma rays. The radioactive decay produces a different element.

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

Radionuclide: A specific isotope of an element that is radioactive (will undergo a form of radioactive decay, either alpha, beta, or gamma). Individual radionuclides are distinguished by their atomic weight and atomic number.

Recharge: Process of addition of water to the ground-water system.

Reduction: Chemical reaction in which electrons are transferred to an atom or ion, thus decreasing its net charge or valence.

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.

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

Trace elements: As used in this report, metallic elements, generally, but not exclusively, with atomic number greater than 20 in Groups III through V (including transition elements) of the Periodic Table. (Lithium, beryllium, barium, strontium, and aluminum are also referred to as trace elements in this report, though they do not fit at least one of the above criteria.) These elements are present in very low concentrations or amounts in water and rock, and generally have low solubility, but many are highly toxic when ingested even in small amounts.

Appendixes

Appendix 1A. Selected well-record information for wells used to assess quality of water in the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91

[--, data unavailable; USGS, U.S. Geological Survey]

USGS well number	Municipality	New Jersey permit number	Latitude (degrees)	Longitude (degrees)	Date of construction	Altitude of land surface (feet above sea level)	Depth of well (feet below land surface)	Top of open interval (feet below land surface)	Bottom of open interval (feet below land surface)	Primary use of water[1]
05- 454	Tabernacle Township	--	394812	0744031	09-00-1975	66	142	137	142	U
05- 455	Tabernacle Township	--	394812	0744031	09-00-1975	66	51	46	51	U
05- 608	Washington Township	--	394300	0743830	07-10-1975	63	160	155	160	U
05- 609	Washington Township	--	394300	0743830	07-10-1975	62	45	35	45	U
05- 709	Woodland Township	32-00726	395251	0743202	07-14-1971	110	107	87	102	P
05- 1092	Woodland Township	32-08688	395308	0743453	12-15-1982	125	85	55	85	T
07- 690	Winslow Township	31-27120	394337	0750041	12-01-1987	160	100	80	100	J
07- 691	Gloucester Township	31-24727	394414	0750015	04-22-1986	160	80	60	75	P
07- 694	Winslow Township	31-26187	394543	0745827	02-06-1987	145	64	44	64	U
07- 695	Winslow Township	31-27029	394348	0750041	08-07-1987	165	50	30	50	U
07- 696	Winslow Township	31-22838	394427	0745935	04-10-1985	175	65	45	65	U
09- 168	Woodbine Borough	37-00239	391430	0744848	08-24-1967	46	157	135	157	P
09- 349	Dennis Township	--	391318	0745307	--	15	40	36	40	P
11- 689	Upper Deerfield Township	30-04397	393250	0751330	10-28-1986	130	78	71	78	H
11- 690	Upper Deerfield Township	30-05097	393306	0751401	05-04-1988	130	100	40	100	I
11- 695	Upper Deerfield Township	34-00791	393105	0751222	04-14-1970	120	130	110	130	T
15- 38	Elk Township	--	394057	0751007	11-23-1951	140	45	41	45	H
15- 1030	Washington Township	31-31399	394354	0750259	07-24-1989	150	54	44	54	U
15- 1044	Washington Township	31-27872	394416	0750132	12-12-1987	150	60	50	60	H
15- 1048	Monroe Township	31-27529	394217	0750039	08-10-1988	160	144	100	141	P
15- 1049	Washington Township	31-21916	394303	0750504	10-19-1984	115	70	60	70	H
15- 1050	Washington Township	31-18078	394308	0750505	06-16-1981	130	50	45	50	H
15- 1065	Washington Township	31-28782	394327	0750210	01-11-1989	150	85	59	85	P
29- 88	Dover Township	33-01147	395933	0741312	08-15-1966	40	86	66	86	P
29- 428	Lakehurst Borough	29-01088	400039	0741930	05-29-1954	60	36	26	36	P

Appendix 1A. Selected well-record information for wells used to assess quality of water in the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

[--, data unavailable; USGS, U.S. Geological Survey]

USGS well number	Municipality	New Jersey permit number	Latitude (degrees)	Longitude (degrees)	Date of construction	Altitude of land surface (feet above sea level)	Depth of well (feet below land surface)	Top of open interval (feet below land surface)	Bottom of open interval (feet below land surface)	Primary use of water[1]
29- 488	Manchester Township	28-06885	395729	0742343	06-19-1970	150	143	123	143	P
29- 586	Manchester Township	32-01985	395714	0742112	06-00-1976	100	90	61	81	P
29- 735	Manchester Township	32-02893	395745	0742124	06-13-1977	165	173	148	173	P
33- 223	Pittsgrove Township	30-01147	393236	0751230	12-05-1967	120	94	54	94	I
33- 462	Pittsgrove Township	31-22844	393449	0750528	05-01-1985	95	70	60	70	H
33- 464	Alloway Township	31-01428	393203	0751705	11-22-1974	115	58	48	58	H
33- 672	Alloway Township	30-01061	393213	0751716	12-30-1965	100	31	26	31	H
33- 673	Upper Pittsgrove Township	30-02961	393408	0751423	05-25-1983	145	52	42	52	I
33- 674	Upper Pittsgrove Township	30-03217	393514	0751253	11-05-1983	150	80	70	80	H
33- 675	Upper Pittsgrove Township	30-03706	393657	0751357	05-21-1985	135	50	40	50	H
33- 676	Upper Pittsgrove Township	30-04205	393823	0751349	05-19-1986	145	40	35	40	H
33- 677	Upper Pittsgrove Township	30-03680	393840	0751212	05-07-1985	129	40	20	40	U
33- 678	Upper Pittsgrove Township	30-02290	393914	0751302	09-11-1980	120	19	15	19	H
33- 679	Upper Pittsgrove Township	30-04519	393401	0751448	01-05-1987	140	66	56	66	H
33- 682	Alloway Township	34-03273	393359	0751728	00-00-1989	140	70	--	--	H
33- 684	Pittsgrove Township	35-04479	393047	0750542	11-15-1984	105	70	63	70	H
33- 685	Upper Pittsgrove Township	--	393852	0751334	00-00-1952	140	40	--	--	H

[1] Use of water:

H - Domestic	P - Public supply
I - Irrigation	T - Institutional
J - Industrial (cooling)	U - Unused

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91

[USGS, U.S. Geological Survey; deg C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 deegrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; <, less than; tot. rec., total recoverable; --, data not available]

USGS well number	Date	Temperature, water (deg C)	Specific Conductance (µS/cm)	Solids, residue at 180 deg C, dissolved (mg/L)	Oxygen, dissolved (mg/L)	pH, water, field (standard units)	Alkalinity, lab (mg/L as $CaCO_3$)	Nitrogen ammonia, dissolved (mg/L as N)	Nitrogen nitrite, dissolved (mg/L as N)	Nitrogen ammonia+ organic, dissolved (mg/L as N)	Nitrogen NO_2+NO_3, dissolved (mg/L as N)
05- 454	09-20-90	13.0	52	54	<.1	6.4	15	0.020	<0.010	<0.20	<0.100
05- 455	09-20-90	12.0	44	11	2.5	4.6	1.8	<.010	<.010	.50	.700
05- 608	09-21-90	12.5	20	<1	6.8	4.9	2.5	<.010	<.010	.40	<.100
05- 609	09-21-90	12.0	36	28	--	5.0	2.3	.020	<.010	<.20	<.100
05- 709	07-10-90	13.0	32	--	3.9	4.7	<1.0	<.010	<.010	<.20	<.100
05-1092	07-10-90	13.0	126	--	6.2	4.7	6.7	<.010	<.010	<.20	1.20
07- 690	07-26-90	14.0	78	--	9.3	4.6	2.1	<.010	<.010	.50	5.40
07- 691	07-18-90	13.5	66	--	4.1	5.1	3.1	.060	<.010	<.20	.800
07- 694	08-22-90	14.0	18	--	8.1	4.7	2.5	.020	<.010	<.20	<.100
07- 695	07-19-90	17.5	158	--	6.7	4.9	2.9	.070	<.010	.30	1.60
07- 696	08-22-90	14.5	235	--	4.6	4.9	6.6	.020	<.010	.50	9.40
09- 168	09-04-90	14.5	120	--	.2	4.9	<1.0	.120	<.010	.20	.300
09- 349	09-05-90	14.5	83	--	--	5.8	6.4	.030	<.010	<.20	<.100
11- 689	07-26-90	14.0	362	--	9.1	5.0	9.6	.020	<.010	.50	27.0
11- 690	07-24-90	14.0	333	--	9.7	5.3	8.9	<.010	<.010	.70	17.0
11- 690	07-24-90	14.0	337	--	9.6	5.3	--	<.010	<.010	1.4	17.0
11- 695	07-25-90	13.5	175	--	10.1	4.8	2.7	<.010	<.010	.70	13.0
15- 038	07-25-90	14.5	112	--	8.0	4.5	1.9	<.010	<.010	1.5	6.60
15-1033	07-18-90	14.5	135	--	4.6	4.4	<1.0	<.010	<.010	.60	7.00
15-1044	07-25-90	14.0	56	--	8.8	4.8	2.0	<.010	<.010	.60	3.40
15-1048	08-15-90	12.5	30	--	6.7	5.0	2.2	<.010	<.010	<.20	.400
15-1049	08-23-90	14.0	72	--	2.5	4.9	2.8	.030	<.010	.50	3.70
15-1050	08-08-90	13.5	117	--	6.3	4.7	2.2	.020	<.010	.60	8.70
15-1065	07-17-90	13.5	92	--	8.7	4.9	2.1	.020	<.010	.50	4.70
29- 88	07-12-90	13.0	126	--	6.2	4.7	1.9	<.010	<.010	.60	3.00
29- 428	07-12-90	13.5	129	--	3.1	5.1	2.9	.030	<.010	.50	1.30
29- 488	07-13-90	13.0	34	--	.1	4.7	1.5	.020	<.010	<.20	<.100
29- 586	07-11-90	14.0	77	--	5.5	4.7	1.4	<.010	<.010	.40	1.30
29- 735	07-11-90	13.0	57	--	3.3	4.5	<1.0	.020	<.010	<.20	.400
33- 233	07-24-90	15.5	218	--	6.9	5.5	9.0	<.010	<.010	.80	17.0
33- 462	04-24-91	14.0	47	44	.3	4.5	<1.0	.030	.050	<.20	.097
	08-22-91	14.0	62	--	.2	4.5	--	<.010	<.010	<.20	.050
33- 464	04-24-91	14.0	218	109	9.0	5.2	3.9	.020	.060	.40	12.0
	09-04-91	13.5	220	--	9.8	4.5	--	<.010	<.010	.50	12.0
33- 672	08-16-90	15.0	310	--	9.6	4.6	2.6	.010	<.010	.40	19.0
33- 673	08-09-90	13.5	298	--	8.3	5.0	5.7	.010	<.010	.70	11.0

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Phosphorus, dissolved (mg/L as P)	Phosphorus ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)
05- 454	09-20-90	0.120	0.090	0.5	3.5	0.35	4.0	2.2	2.2	4.5
05- 455	09-20-90	<.010	<.010	.6	.79	1.0	3.0	.70	5.8	3.6
05- 608	09-21-90	<.010	<.010	.4	.15	.20	1.6	.20	3.0	<1.0
05- 609	09-21-90	.020	<.010	.7	1.3	1.2	1.9	.40	3.2	7.2
05- 709	07-10-90	--	<.010	.3	.23	.27	1.7	.40	3.9	4.0
05-1092	07-10-90	--	.010	1.0	8.5	1.7	11	2.0	25	12
07- 690	07-26-90	--	<.010	.5	1.1	3.3	2.8	2.7	7.3	<1.0
07- 691	07-18-90	--	<.010	1.6	2.8	.95	6.3	1.5	9.5	7.7
07- 694	08-22-90	--	<.010	.4	.09	.18	1.2	.30	2.6	<1.0
07- 695	07-19-90	--	<.010	.7	5.5	2.4	21	2.6	39	11
07- 696	08-22-90	--	<.010	1.4	.67	.92	46	.60	36	12
09- 168	09-04-90	--	<.010	--	1.5	1.8	9.7	2.8	15	22
09- 349	09-05-90	--	<.010	--	1.5	1.6	3.9	2.0	5.7	10
11- 689	07-26-90	--	<.010	.7	26	21	4.2	2.1	24	23
11- 690	07-24-90	--	<.010	1.0	25	18	4.2	2.8	27	43
11- 690	07-24-90	--	<.010	1.1	--	--	--	--	--	--
11- 695	07-25-90	--	<.010	.3	12	4.9	5.4	2.3	16	<1.0
15- 38	07-25-90	--	<.010	.5	5.6	4.3	3.0	2.4	11	5.3
15-1033	07-18-90	--	<.010	.6	4.5	5.7	3.7	1.9	16	4.5
15-1044	07-25-90	--	<.010	.5	.70	2.8	2.1	.90	6.4	<1.0
15-1048	08-15-90	--	<.010	.3	1.3	.41	1.7	.90	3.3	3.5
15-1049	08-23-90	--	<.010	.3	3.1	2.4	3.6	2.3	7.7	2.8
15-1050	08-08-90	--	<.010	.3	4.2	5.2	4.0	2.2	12	<1.0
15-1065	07-17-90	--	<.010	.7	4.6	3.8	3.0	1.6	8.3	7.7
29- 88	07-12-90	--	<.010	.5	2.7	2.5	12	2.0	25	3.6
29- 428	07-12-90	--	<.010	.7	3.7	.99	15	1.1	31	5.1
29- 488	07-13-90	--	<.010	.4	.24	.24	2.0	.70	4.5	3.4
29- 586	07-11-90	--	<.010	.3	1.1	1.2	7.4	.80	17	1.1
29- 735	07-11-90	--	<.010	.3	.53	.55	4.0	.60	8.8	3.5
33- 233	07-24-90	--	.010	.8	28	8.9	2.6	5.5	14	37
33- 462	04-24-91	--	<.010	.3	.74	.49	2.0	1.1	<.10	9.5
	08-22-91	<.010	<.010	--	--	--	--	--	--	--
33- 464	04-24-91	--	<.010	--	8.4	13	3.1	3.3	22	3.3
	09-04-91	<.010	<.010	--	--	--	--	--	--	--
33- 672	08-16-90	--	<.010	1.1	12	17	9.9	3.1	44	4.7
33- 673	08-09-90	--	<.010	.6	27	9.3	8.2	3.5	25	47

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (μg/L)	Barium, dissolved (μg/L)	Beryllium, dissolved (μg/L)	Boron, dissolved (μg/L)	Cadmium, dissolved (μg/L)	Chromium, dissolved (μg/L)	Cobalt, dissolved (μg/L)
05- 454	09-20-90	<0.10	32	--	66	<0.5	--	<1	<5	<3
05- 455	09-20-90	<.10	6.2	--	52	<.5	--	<1	<5	<3
05- 608	09-21-90	<.10	4.3	--	10	<.5	--	<1	<5	<3
05- 609	09-21-90	<.10	3.8	--	19	<.5	--	<1	<5	<3
05- 709	07-10-90	.20	7.1	<1	17	<.5	--	<1	<5	<3
05-1092	07-10-90	<.10	4.7	<1	49	<.5	--	<1	<5	<3
07- 690	07-26-90	<.10	6.4	--	270	.6	--	<1	<5	4
07- 691	07-18-90	.20	6.4	--	55	<.5	--	<1	<5	<3
07- 694	08-22-90	<.10	5.0	--	12	<.5	--	<1	<5	<3
07- 695	07-19-90	<.10	7.8	--	48	.6	--	<1	<5	<3
07- 696	08-22-90	.20	8.7	--	50	<.5	--	<1	<5	<3
09- 168	09-04-90	<.10	9.0	--	74	<.5	--	<1	<5	6
09- 349	09-05-90	<.10	21	--	35	<.5	--	<1	<5	<3
11- 689	07-26-90	.20	9.5	--	260	<.5	--	1	<5	<3
11- 690	07-24-90	.20	12	--	82	<.5	--	<1	<5	<3
11- 690	07-24-90	--	--	--	--	--	--	--	--	--
11- 695	07-25-90	<.10	7.8	--	170	<.5	--	<1	<5	<3
15- 38	07-25-90	<.10	8.5	--	210	.5	--	<1	<5	7
15-1033	07-18-90	.10	8.2	--	170	<.5	--	<1	<5	<3
15-1044	07-25-90	<.10	6.4	--	79	<.5	--	<1	<5	<3
15-1048	08-15-90	<.10	9.8	--	11	<.5	--	<1	<5	<3
15-1049	08-23-90	<.10	15	--	120	<.5	--	<1	<5	<3
15-1050	08-08-90	<.10	8.8	--	250	<.5	--	<1	<5	<3
15-1065	07-17-90	.20	7.6	--	180	<.5	--	<1	<5	<3
29- 88	07-12-90	<.10	6.6	<1	57	<.5	--	<1	<5	<3
29- 428	07-12-90	<.10	4.4	<1	25	<.5	--	<1	<5	<3
29- 488	07-13-90	.20	8.4	<1	20	.6	--	<1	<5	<3
29- 586	07-11-90	<.10	5.3	<1	30	<.5	--	<1	<5	<3
29- 735	07-11-90	.20	7.2	<1	28	.6	--	<1	<5	<3
33- 233	07-24-90	.20	9.9	--	120	<.5	--	<1	<5	<3
33- 462	04-24-91	<.10	18	<1	15	<.5	<10	<1	<5	<3
	08-22-91	--	--	--	--	--	--	--	--	--
33- 464	04-24-91	<.10	9.5	<1	100	<.5	20	<1	<5	6
	09-04-91	--	--	--	--	--	--	--	--	--
33- 672	08-16-90	.30	9.7	--	170	<.5	--	<1	<5	4
33- 673	08-09-90	<.10	9.6	--	83	<.5	--	<1	<5	<3

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Manganese, dissolved (µg/L)	Molybdenum, dissolved (µg/L)	Nickel, dissolved (µg/L)	Silver, dissolved (µg/L)	Strontium, dissolved (µg/L)	Vanadium, dissolved (µg/L)
05- 454	09-20-90	<10	2,000	<10	45	<10	<10	<1	41	<6
05- 455	09-20-90	<10	5	<10	17	<10	<10	<1	16	<6
05- 608	09-21-90	<10	4	<10	1	<10	<10	<1	3	<6
05- 609	09-21-90	30	<3	<10	34	<10	<10	<1	16	<6
05- 709	07-10-90	70	180	<10	9	<10	<10	<1	5	<6
05-1092	07-10-90	10	18	20	18	<10	<10	<1	39	<6
07- 690	07-26-90	<10	5	<10	25	<10	<10	1	19	<6
07- 691	07-18-90	<10	360	<10	76	<10	<10	<1	25	<6
07- 694	08-22-90	10	6	<10	<1	<10	<10	<1	1	<6
07- 695	07-19-90	10	8	10	34	<10	<10	<1	27	<6
07- 696	08-22-90	10	7	10	2	<10	<10	<1	2	<6
09- 168	09-04-90	<10	1,800	<10	34	<10	<10	<1	25	<6
09- 349	09-05-90	<10	5,000	<10	130	<10	<10	<1	22	<6
11- 689	07-26-90	<10	11	<10	6	<10	<10	<1	300	<6
11- 690	07-24-90	20	130	<10	15	<10	<10	<1	170	<6
11- 690	07-24-90	--	--	--	--	--	--	--	--	--
11- 695	07-25-90	<10	27	<10	13	<10	<10	<1	92	<6
15- 38	07-25-90	120	15	<10	55	<10	<10	<1	43	<6
15-1033	07-18-90	20	100	30	54	<10	<10	<1	54	<6
15-1044	07-25-90	<10	47	10	20	<10	<10	<1	15	<6
15-1048	08-15-90	<10	440	<10	8	<10	<10	<1	5	<6
15-1049	08-23-90	30	7	<10	38	<10	<10	<1	25	<6
15-1050	08-08-90	<10	9	<10	40	<10	<10	<1	53	<6
15-1065	07-17-90	<10	15	<10	28	<10	<10	<1	35	<6
29- 88	07-12-90	<10	29	<10	31	<10	<10	<1	21	<6
29- 428	07-12-90	10	620	<10	48	<10	<10	<1	24	<6
29- 488	07-13-90	<10	280	<10	8	<10	<10	<1	5	<6
29- 586	07-11-90	80	19	<10	18	<10	<10	<1	14	<6
29- 735	07-11-90	20	47	<10	11	<10	<10	<1	8	<6
33- 233	07-24-90	<10	98	<10	22	<10	<10	<1	150	<6
33- 462	04-24-91	<10	780	<1	9	<10	<10	<1	8	<6
	08-22-91	--	--	--	--	--	--	--	--	--
33- 464	04-24-91	60	18	3	19	<10	<10	<1	140	<6
	09-04-91	--	--	--	--	--	--	--	--	--
33- 672	08-16-90	<10	20	10	24	<10	20	<1	190	<6
33- 673	08-09-90	<10	6	<10	8	<10	<10	<1	120	<6

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91–Continued

USGS well number	Date	Zinc, dis-solved (µg/L)	Alumi-num, dis-solved (µg/L)	Lithium, dis-solved (µg/L)	Mercury, dis-solved (µg/L)	Gross alpha, dissolved (pCi/L as Th-230)	Gross alpha, 2 sigma, dissolved (pCi/L as Th-230)	Gross beta, dissolved (pCi/L as Cs-137)	Gross beta, 2 sigma, dissolved (pCi/L as Cs-137)	Tritium (pCi/L)	Tritium, 2 sigma (pCi/L)	Radium-226, dissolved, radon method (pCi/L)	Radium-226, 2 sigma, dissolved (pCi/L)
05- 454	09-20-90	7	<10	<4	--	0.05	0.50	2.2	.70	<5.7	5.1	0.35	0.05
05- 455	09-20-90	11	100	<4	--	3.34	.93	4.0	1.1	65	11	1.2	.17
05- 608	09-21-90	5	20	<4	--	1.90	.68	2.0	.70	88	9.6	.73	.10
05- 609	09-21-90	3	30	<4	--	1.20	.48	.7	.50	46	4.5	.34	.05
05- 709	07-10-90	75	200	<4	--	3.24	.98	2.4	.70	29	4.5	.76	.11
05-1092	07-10-90	11	220	<4	--	1.74	.89	3.7	.90	51	5.8	.54	.08
07- 690	07-26-90	22	110	<4	--	16.9	2.40	12	2.7	63	6.4	4.4	.61
07- 691	07-18-90	34	30	<4	--	5.50	1.20	3.7	1.1	48	5.1	2.5	.34
07- 694	08-22-90	4	30	<4	--	1.89	.57	1.3	.50	68	8.3	1.0	.14
07- 695	07-19-90	13	100	<4	--	11.8	2.11	10	2.3	48	5.1	2.5	.35
07- 696	08-22-90	7	140	<4	--	7.00	1.92	4.3	.99	58	--	1.5	.20
09- 168	09-04-90	75	--	<4	--	2.43	.88	4.0	1.1	--	--	.53	.08
09- 349	09-05-90	8	--	6	--	.90	.51	1.9	.70	--	--	.29	.04
11- 689	07-26-90	<3	20	<4	--	17.1	3.11	12	2.6	120	9.6	8.9	1.20
11- 690	07-24-90	5	20	<4	--	3.58	1.43	3.4	1.0	53	5.8	1.6	.22
11- 690	07-24-90	--	--	--	--	--	--	--	--	--	--	--	--
11- 695	07-25-90	28	70	<4	--	9.15	1.77	5.1	1.3	34	4.5	2.9	.40
15- 38	07-25-90	19	200	<4	--	10.8	1.82	9.5	2.2	53	5.8	2.6	.36
15-1033	07-18-90	13	270	<4	--	16.7	2.94	11	1.7	92	7.0	5.1	.71
15-1044	07-25-90	11	60	<4	--	7.14	1.36	4.0	1.1	78	7.0	2.7	.37
15-1048	08-15-90	11	200	<4	--	.66	.38	.9	--	42	--	.31	.05
15-1049	08-23-90	8	30	<4	--	1.23	.55	3.1	.90	29	5.8	1.2	.16
15-1050	08-08-90	40	130	<4	--	5.10	1.16	3.7	1.1	82	7.0	1.5	.21
15-1065	07-17-90	26	110	<4	--	8.21	1.56	5.1	1.3	71	6.4	2.2	.31
29- 88	07-12-90	30	170	<4	--	11.4	2.01	7.7	1.8	56	5.8	2.4	.33
29- 428	07-12-90	24	190	<4	--	4.79	1.64	5.5	1.4	75	8.3	1.2	.16
29- 488	07-13-90	6	100	<4	--	.65	.46	1.4	.60	20	3.8	.18	.03
29- 586	07-11-90	4	110	<4	--	6.27	1.51	3.3	.80	61	6.4	1.6	.22
29- 735	07-11-90	11	400	<4	--	--	--	4.8	1.0	63	6.4	.92	.13
33- 233	07-24-90	21	50	<4	--	15.4	2.85	12	2.7	58	5.8	4.9	.67
33- 462	04-24-91	16	--	<4	.2	7.04	1.38	3.1	.90	2.0	1.0	1.7	.28
	08-22-91	--	--	--	--	--	--	--	--	--	--	--	--
33- 464	04-24-91	5	--	<4	.2	15.8	2.60	9.3	2.2	--	--	7.3	1.20
	09-04-91	--	--	--	--	--	--	--	--	--	--	--	--
33- 672	08-16-90	9	150	<4	--	5.42	1.55	7.6	--	52	--	3.5	.48
33- 673	08-09-90	160	30	<4	--	2.32	1.16	4.6	1.3	50	5.8	.49	.07
33-673	08-09-90	--	--	--	--	1.50	.93	.32	1.0	--	--	--	--

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Radium-228, dissolved (pCi/L)[1]	Radium-228, 2 sigma, dissolved (pCi/L)	Radium-228/ Radium-226 ratio, dissolved[2]	Uranium, dissolved (μg/L)	Uranium, 2 sigma, dissolved (μg/L)	Radon-222 (pCi/L)	Radon-222, 2 sigma (pCi/L)	Methiocarb, total, recoverable (μg/L)	Propoxur, total, recoverable (μg/L)	Ametryne, dissolved, recoverable (μg/L)	Ametryne, total, (μg/L)
05- 454	09-20-90	[1]<1.0(0.51)	0.4	[2](1.46)	<0.01	<1	650	59	--	--	--	--
05- 455	09-20-90	2.4	.9	2.00	.02	<1	<80	83	--	--	--	--
05- 608	09-21-90	[1]<1.0(.82)	.5	[2](1.12)	.01	<1	110	64	--	--	--	--
05- 609	09-21-90	[1]<1.0(.93)	.7	[2](2.74)	<.01	<1	84	45	--	--	--	--
05- 709	07-10-90	[1]<1.0(.67)	.5	[2](.88)	.04	<1	880	260	--	--	--	--
05-1092	07-10-90	[1]<1.0(.74)	.5	[2](1.37)	.06	<1	640	260	--	--	--	--
07- 690	07-26-90	2.2	.7	.50	.03	<1	430	43	--	--	--	--
07- 691	07-18-90	1.7	.7	.68	.01	<1	290	55	--	--	--	<.10
07- 694	08-22-90	[1]<1.0(.89)	.4	[2](.89)	.01	<1	260	57	--	--	--	--
07- 695	07-19-90	5.0	1.5	2.00	.13	<1	210	53	--	--	--	<.10
07- 696	08-22-90	1.4	.5	.93	.07	--	370	64	--	--	--	--
09- 168	09-04-90	[1]<1.0(.48)	.4	[2](.91)	.02	<1	110	65	--	--	--	--
09- 349	09-05-90	[1]<1.0(.20)	.3	[2](.69)	<.01	<1	97	54	--	--	--	--
11- 689	07-26-90	3.8	1.1	.43	.04	<1	380	73	--	--	--	<.10
11- 690	07-24-90	[1]<1.0(.59)	.5	[2](.87)	.04	<1	440	60	--	--	--	--
11- 690	07-24-90	--	--	--	--	--	400	69	--	--	--	--
11- 695	07-25-90	3.2	.9	1.10	.09	<1	440	61	--	--	--	<.10
15- 38	07-25-90	4.0	1.1	1.54	.09	<1	130	62	--	--	--	--
15-1033	07-18-90	3.6	1.3	.71	.09	<1	280	55	--	--	--	--
15-1044	07-25-90	1.6	.6	.59	.08	<1	500	63	--	--	--	<.10
15-1048	08-15-90	[1]<1.0(.31)	.3	[2](1.00)	.02	--	550	79	--	--	--	--
15-1049	08-23-90	[1]<1.0(.51)	.3	[2](.43)	.05	<1	430	53	--	--	--	--
15-1050	08-08-90	--	--	--	.04	<1	460	31	--	--	--	--
15-1065	07-17-90	2.2	.9	1.00	.02	<1	260	40	--	--	--	<.10
29- 88	07-12-90	1.7	.9	.71	.04	<1	260	45	--	--	--	--
29- 428	07-12-90	2.1	.8	1.75	.04	<1	280	43	--	--	--	--
29- 488	07-13-90	[1]<1.0(.32)	.4	[2](1.78)	<.01	<1	130	38	--	--	--	--
29- 586	07-11-90	1.7	.8	1.06	.07	<1	340	50	--	--	--	--
29- 735	07-11-90	1.9	.8	2.07	.05	<1	220	49	--	--	--	--
33- 233	07-24-90	2.5	.8	.51	.03	<1	400	63	--	--	--	<.10
33- 462	04-24-91	[1]<1.0(.89)	.4	[2](.52)	.14	<1	1,000	270	<.5	<.5	<.05	--
	08-22-91	--	--	--	--	--	580	52	<.5	<.5	<.05	--
33- 464	04-24-91	3.5	1.0	.48	.07	<1	680	63	<.5	<.5	<.05	--
	09-04-91	--	--	--	--	--	770	56	<.5	<.5	<.05	--
33- 672	08-16-90	1.9	.7	.54	.10	--	730	50	--	--	--	--
33- 673	08-09-90	--	--	--	.02	<1	860	68	--	--	--	--

Footnotes at end of table.

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Propazine, dissolved, recoverable (µg/L)	Propazine, total (µg/L)	Trifluralin, total, recoverable (mg/L)	Perthane, total (µg/L)	Methomyl, total (µg/L)	Propham, total (µg/L)	Simetryne, total (µg/L)	Simazine, total (µg/L)	Prometone, total (µg/L)	Prometryne, total (µg/L)
05- 454	09-20-90	--	--	--	--	--	--	--	--	--	--
05- 455	09-20-90	--	--	--	--	--	--	--	--	--	--
05- 608	09-21-90	--	--	--	--	--	--	--	--	--	--
05- 609	09-21-90	--	--	--	--	--	--	--	--	--	--
05- 709	07-10-90	--	--	--	--	--	--	--	--	--	--
05-1092	07-10-90	--	--	--	--	--	--	--	--	--	--
07- 690	07-26-90	--	--	--	--	--	--	--	--	--	--
07- 691	07-18-90	--	<.10	<.10	<.1	<.5	<.5	<.10	<.10	<.10	<.10
07- 694	08-22-90	--	--	--	--	--	--	--	--	--	--
07- 695	07-19-90	--	<.10	<.10	<.1	<.5	<.5	<.10	<.10	<.10	<.10
07- 696	08-22-90	--	--	--	--	--	--	--	--	--	--
09- 168	09-04-90	--	--	--	--	--	--	--	--	--	--
09- 349	09-05-90	--	--	--	--	--	--	--	--	--	--
11- 689	07-26-90	--	<.10	<.10	<.1	<.5	<.5	<.10	<.10	<.10	<.10
11- 690	07-24-90	--	--	--	--	--	--	--	--	--	--
11- 690	07-24-90	--	--	--	--	--	--	--	--	--	--
11- 695	07-25-90	--	<.10	<.10	<.1	--	--	<.10	<.10	<.10	<.10
15- 38	07-25-90	--	--	--	--	--	--	--	--	--	--
15-1033	07-18-90	--	--	--	--	--	--	--	--	--	--
15-1044	07-25-90	--	<.10	<.10	<.1	<.5	<.5	<.10	<.10	<.10	<.10
15-1048	08-15-90	--	--	--	--	--	--	--	--	--	--
15-1049	08-23-90	--	--	--	--	--	--	--	--	--	--
15-1050	08-08-90	--	--	--	--	--	--	--	--	--	--
15-1065	07-17-90	--	<.10	<.10	<.1	<.5	<.5	<.10	<.10	<.10	<.10
29- 88	07-12-90	--	--	--	--	--	--	--	--	--	--
29- 428	07-12-90	--	--	--	--	--	--	--	--	--	--
29- 488	07-13-90	--	--	--	--	--	--	--	--	--	--
29- 586	07-11-90	--	--	--	--	--	--	--	--	--	--
29- 735	07-11-90	--	--	--	--	--	--	--	--	--	--
33- 233	07-24-90	--	<.10	<.10	<.1	<.5	<.5	<.10	<.10	<.10	<.10
33- 462	04-24-91	<.05	--	--	--	<.5	<.5	--	--	--	--
	08-22-91	<.05	--	--	--	<.5	<.5	--	--	--	--
33- 464	04-24-91	<.05	--	--	--	<.5	<.5	--	--	--	--
	09-04-91	<.05	--	--	--	<.5	<.5	--	--	--	--
33- 672	08-16-90	--	--	--	--	--	--	--	--	--	--
33- 673	08-09-90	--	--	--	--	--	--	--	--	--	--

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Naphthalene, polychlor., total (µg/L)	Aldrin, total (µg/L)	Lindane, total (µg/L)	Chlordane, total (µg/L)	DDD, total (µg/L)	DDE, total (µg/L)	DDT, total (µg/L)	Dieldrin, total (µg/L)	Endosulfan, total (µg/L)
05- 454	09-20-90	--	--	--	--	--	--	--	--	--
05- 455	09-20-90	--	--	--	--	--	--	--	--	--
05- 608	09-21-90	--	--	--	--	--	--	--	--	--
05- 609	09-21-90	--	--	--	--	--	--	--	--	--
05- 709	07-10-90	--	--	--	--	--	--	--	--	--
05-1092	07-10-90	--	--	--	--	--	--	--	--	--
07- 690	07-26-90	--	--	--	--	--	--	--	--	--
07- 691	07-18-90	<.10	<.010	<.010	<.1	<.010	<.010	<.010	<.010	<.010
07- 694	08-22-90	--	--	--	--	--	--	--	--	--
07- 695	07-19-90	<.10	<.010	<.010	<.1	<.010	<.010	<.010	<.010	<.010
07- 696	08-22-90	--	--	--	--	--	--	--	--	--
09- 168	09-04-90	--	--	--	--	--	--	--	--	--
09- 349	09-05-90	--	--	--	--	--	--	--	--	--
11- 689	07-26-90	<.10	<.010	<.010	<.1	<.010	<.010	<.010	<.010	<.010
11- 690	07-24-90	--	--	--	--	--	--	--	--	--
11- 690	07-24-90	--	--	--	--	--	--	--	--	--
11- 695	07-25-90	<.10	<.010	<.010	<.1	<.010	<.010	<.010	<.010	<.010
15- 38	07-25-90	--	--	--	--	--	--	--	--	--
15-1033	07-18-90	--	--	--	--	--	--	--	--	--
15-1044	07-25-90	<.10	<.010	<.010	<.1	<.010	<.010	<.010	<.010	<.010
15-1048	08-15-90	--	--	--	--	--	--	--	--	--
15-1049	08-23-90	--	--	--	--	--	--	--	--	--
15-1050	08-08-90	--	--	--	--	--	--	--	--	--
15-1065	07-17-90	<.10	<.010	<.010	<.1	<.010	<.010	<.010	<.010	<.010
29- 88	07-12-90	--	--	--	--	--	--	--	--	--
29- 428	07-12-90	--	--	--	--	--	--	--	--	--
29- 488	07-13-90	--	--	--	--	--	--	--	--	--
29- 586	07-11-90	--	--	--	--	--	--	--	--	--
29- 735	07-11-90	--	--	--	--	--	--	--	--	--
33- 233	07-24-90	<.10	<.010	<.010	<.1	<.010	<.010	<.010	<.010	<.010
33- 462	04-24-91	--	--	--	--	--	--	--	--	--
	08-22-91	--	--	--	--	--	--	--	--	--
33- 464	04-24-91	--	--	--	--	--	--	--	--	--
	09-04-91	--	--	--	--	--	--	--	--	--
33- 672	08-16-90	--	--	--	--	--	--	--	--	--
33- 673	08-09-90	--	--	--	--	--	--	--	--	--

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Endrin, total (μg/L)	Toxaphene, total (μg/L)	Heptachlor, total (μg/L)	Metolachlor, dissolved (μg/L)	Heptachlor epoxide, total (μg/L)	Methoxychlor, total (μg/L)	PCB, total (μg/L)	Atrazine, total (μg/L)	Atrazine, dissolved, recoverable (μg/L)
05- 454	09-20-90	--	--	--	--	--	--	--	--	--
05- 455	09-20-90	--	--	--	--	--	--	--	--	--
05- 608	09-21-90	--	--	--	--	--	--	--	--	--
05- 609	09-21-90	--	--	--	--	--	--	--	--	--
05- 709	07-10-90	--	--	--	--	--	--	--	--	--
05-1092	07-10-90	--	--	--	--	--	--	--	--	--
07- 690	07-26-90	--	--	--	--	--	--	--	--	--
07- 691	07-18-90	<.010	<1	<.010	--	<.010	<.01	<.1	<.10	--
07- 694	08-22-90	--	--	--	--	--	--	--	--	--
07- 695	07-19-90	<.010	<1	<.010	--	<.010	<.01	<.1	<.10	--
07- 696	08-22-90	--	--	--	--	--	--	--	--	--
09- 168	09-04-90	--	--	--	--	--	--	--	--	--
09- 349	09-05-90	--	--	--	--	--	--	--	--	--
11- 689	07-26-90	<.010	<1	<.010	--	<.010	<.01	<.1	<.10	--
11- 690	07-24-90	--	--	--	--	--	--	--	--	--
11- 690	07-24-90	--	--	--	--	--	--	--	--	--
11- 695	07-25-90	<.010	<1	<.010	--	<.010	<.01	<.1	<.10	--
15- 38	07-25-90	--	--	--	--	--	--	--	--	--
15-1033	07-18-90	--	--	--	--	--	--	--	--	--
15-1044	07-25-90	<.010	<1	<.010	--	<.010	<.01	<.1	<.10	--
15-1048	08-15-90	--	--	--	--	--	--	--	--	--
15-1049	08-23-90	--	--	--	--	--	--	--	--	--
15-1050	08-08-90	--	--	--	--	--	--	--	--	--
15-1065	07-17-90	<.010	<1	<.010	--	<.010	<.01	<.1	<.10	--
29- 88	07-12-90	--	--	--	--	--	--	--	--	--
29- 428	07-12-90	--	--	--	--	--	--	--	--	--
29- 488	07-13-90	--	--	--	--	--	--	--	--	--
29- 586	07-11-90	--	--	--	--	--	--	--	--	--
29- 735	07-11-90	--	--	--	--	--	--	--	--	--
33- 233	07-24-90	<.010	<1	<.010	--	<.010	<.01	<.1	<.10	--
33- 462	04-24-91	--	--	--	<.05	--	--	--	--	<.05
	08-22-91	--	--	--	<.05	--	--	--	--	<.05
33- 464	04-24-91	--	--	--	<.05	--	--	--	--	<.05
	09-04-91	--	--	--	<.05	--	--	--	--	<.05
33- 672	08-16-90	--	--	--	--	--	--	--	--	--
33- 673	08-09-90	--	--	--	--	--	--	--	--	--

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Sevin, total (µg/L)	Mirex, total (µg/L)	Alachlor, dissolved, recoverable (µg/L)	Alachlor, total, recoverable (µg/L)	1-Naphthol, total, recoverable (µg/L)	Cyanazine, total (µg/L)	3-Hydrx carbofuran, total recoverable (µg/L)	Aldicarb sulfoxide, total recoverable (µg/L)
05- 454	09-20-90	--	--	--	--	--	--	--	--
05- 455	09-20-90	--	--	--	--	--	--	--	--
05- 608	09-21-90	--	--	--	--	--	--	--	--
05- 609	09-21-90	--	--	--	--	--	--	--	--
05- 709	07-10-90	--	--	--	--	--	--	--	--
05-1092	07-10-90	--	--	--	--	--	--	--	--
07- 690	07-26-90	--	--	--	--	--	--	--	--
07- 691	07-18-90	<.5	<.01	--	<.10	--	<.10	--	--
07- 694	08-22-90	--	--	--	--	--	--	--	--
07- 695	07-19-90	<.5	<.01	--	<.10	--	<.10	--	--
07- 696	08-22-90	--	--	--	--	--	--	--	--
09- 168	09-04-90	--	--	--	--	--	--	--	--
09- 349	09-05-90	--	--	--	--	--	--	--	--
11- 689	07-26-90	<.5	<.01	--	<.10	--	<.10	--	--
11- 690	07-24-90	--	--	--	--	--	--	--	--
11- 690	07-24-90	--	--	--	--	--	--	--	--
11- 695	07-25-90	--	<.01	--	<.10	--	<.10	--	--
15- 38	07-25-90	--	--	--	--	--	--	--	--
15-1033	07-18-90	--	--	--	--	--	--	--	--
15-1044	07-25-90	<.5	<.01	--	<.10	--	<.10	--	--
15-1048	08-15-90	--	--	--	--	--	--	--	--
15-1049	08-23-90	--	--	--	--	--	--	--	--
15-1050	08-08-90	--	--	--	--	--	--	--	--
15-1065	07-17-90	<.5	<.01	--	<.10	--	<.10	--	--
29- 88	07-12-90	--	--	--	--	--	--	--	--
29- 428	07-12-90	--	--	--	--	--	--	--	--
29- 488	07-13-90	--	--	--	--	--	--	--	--
29- 586	07-11-90	--	--	--	--	--	--	--	--
29- 735	07-11-90	--	--	--	--	--	--	--	--
33- 233	07-24-90	<.5	<.01	--	<.10	--	<.10	--	--
33- 462	04-24-91	<.5	--	<.05	--	<.5	--	<.5	<.5
	08-22-91	<.5	--	<.05	--	<.5	--	<.5	<.5
33- 464	04-24-91	<.5	--	<.05	--	<.5	--	<.5	<.5
	09-04-91	<.5	--	<.05	--	<.5	--	<.5	<.5
33- 672	08-16-90	--	--	--	--	--	--	--	--
33- 673	08-09-90	--	--	--	--	--	--	--	--

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Aldicarb sulfone, total recoverable (μg/L)	Metribuzin, total recoverable (μg/L)	Metolachlor, total recoverable (μg/L)	Oxyamyl, total recoverable (μg/L)	Carbofuran, total recoverable (μg/L)	Aldicarb, total recoverable (μg/L)	Metribuzin sencor, dissolved (μg/L)	Delta ^{15}N stable isotope ratio, nitrate (per mil)
05- 454	09-20-90	--	--	--	--	--	--	--	--
05- 455	09-20-90	--	--	--	--	--	--	--	--
05- 608	09-21-90	--	--	--	--	--	--	--	--
05- 609	09-21-90	--	--	--	--	--	--	--	--
05- 709	07-10-90	--	--	--	--	--	--	--	--
05-1092	07-10-90	--	--	--	--	--	--	--	--
07- 690	07-26-90	--	--	--	--	--	--	--	--
07- 691	07-18-90	--	<.10	<.10	--	--	--	--	-1.4
07- 694	08-22-90	--	--	--	--	--	--	--	--
07- 695	07-19-90	--	<.10	<.10	--	--	--	--	4.2
07- 696	08-22-90	--	--	--	--	--	--	--	--
09- 168	09-04-90	--	--	--	--	--	--	--	--
09- 349	09-05-90	--	--	--	--	--	--	--	--
11- 689	07-26-90	--	<.10	<.10	--	--	--	--	4.3
11- 690	07-24-90	--	--	--	--	--	--	--	--
11- 690	07-24-90	--	--	--	--	--	--	--	--
11- 695	07-25-90	--	<.10	<.10	--	--	--	--	2.6
15- 38	07-25-90	--	--	--	--	--	--	--	--
15-1033	07-18-90	--	--	--	--	--	--	--	--
15-1044	07-25-90	--	<.10	<.10	--	--	--	--	3.2
15-1048	08-15-90	--	--	--	--	--	--	--	--
15-1049	08-23-90	--	--	--	--	--	--	--	--
15-1050	08-08-90	--	--	--	--	--	--	--	--
15-1065	07-17-90	--	<.10	<.10	--	--	--	--	2.5
29- 88	07-12-90	--	--	--	--	--	--	--	--
29- 428	07-12-90	--	--	--	--	--	--	--	--
29- 488	07-13-90	--	--	--	--	--	--	--	--
29- 586	07-11-90	--	--	--	--	--	--	--	--
29- 735	07-11-90	--	--	--	--	--	--	--	--
33- 233	07-24-90	--	<.10	<.10	--	--	--	--	--
33- 462	04-24-91	<.5	--	--	<.5	<.5	<.5	<.05	--
	08-22-91	<.5	--	--	<.5	<.5	<.5	<.05	--
33- 464	04-24-91	<.5	--	--	<.5	<.5	<.5	<.05	2.6
	09-04-91	<.5	--	--	<.5	<.5	<.5	<.05	1.9
33- 672	08-16-90	--	--	--	--	--	--	--	--
33- 673	08-09-90	--	--	--	--	--	--	--	--

[1] Measured concentration of radium-228 is less than the minimum reporting limit of 1 pCi/L and is given in parentheses.

[2] Radium-228/radium-226 isotope ratio was computed by using the measured radium-228 concentration less than the minimum reporting limit of 1 pCi/L; the isotope ratio is therefore uncertain and is given in parentheses.

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Temperature, water (deg C)	Specific conductance (µS/cm)	Solids, residue at 180 deg C, dissolved (mg/L)	Oxygen, dissolved (mg/L)	pH, water, field (standard units)	Alkalinity, lab (mg/L as $CaCO_3$)	Nitrogen ammonia, dissolved (mg/L as N)	Nitrogen nitrite, dissolved (mg/L as N)	Nitrogen ammonia+ organic, dissolved (mg/L as N)	Nitrogen NO_2+NO_3, dissolved (mg/L as N)
33- 674	08-09-90	13.5	156	--	6.4	4.5	1.0	0.150	<0.010	0.80	7.80
	04-26-91	14.0	163	84	5.9	4.5	1.3	<.010	<.010	1.0	7.50
	08-21-91	14.5	176	--	6.7	4.6	--	<.010	<.010	.60	8.00
33- 675	08-14-90	15.5	248	--	5.2	4.8	3.8	<.010	<.010	.40	8.20
33- 676	08-23-90	14.0	221	--	4.3	5.1	12	<.010	<.010	.90	13.0
33- 677	07-20-90	14.5	236	--	9.6	4.2	1.0	.010	<.010	.40	18.0
33- 678	08-16-90	15.5	115	--	.9	4.5	<1.0	<.010	<.010	.30	1.40
33- 679	08-09-90	14.0	395	--	9.4	4.6	2.9	.040	<.010	.50	12.0
	04-23-91	13.5	412	220	9.1	4.9	14	<.010	<.010	.60	16.0
	08-21-91	13.0	418	--	10.6	4.9	--	<.010	<.010	.60	14.0
	08-21-91	14.5	418	--	10.6	4.9	--	<.010	<.010	.40	14.0
33- 682	08-15-90	14.5	158	--	9.5	4.8	3.6	<.010	<.010	.50	6.10
33- 684	04-26-91	14.0	222	133	9.2	4.4	<1.0	<.010	<.010	.70	14.0
	08-22-91	15.0	211	--	10.3	4.4	--	<.010	<.010	.70	5.40
33- 685	08-14-90	21.0	415	--	7.4	5.2	12	.010	<.010	.50	16.0
	04-23-91	14.0	377	238	8.0	5.7	3.0	<.010	<.010	.40	13.0
	08-20-91	14.5	348	--	9.0	5.6	--	.040	<.010	.60	15.0

USGS well number	Date	Phosphorus, dissolved (mg/L as P)	Phosphorus ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)
33-674	08-09-90	--	0.010	0.3	9.3	3.7	7.2	1.4	20	7.1
	04-26-91	--	<.010	.3	9.3	3.7	7.6	1.5	20	7.8
	08-21-91	<0.010	<.010	--	--	--	--	--	--	--
33-675	08-14-90	--	.010	.6	13	11	9.0	3.7	23	41
33-676	08-23-90	--	<.010	1.2	8.8	3.8	26	2.3	26	8.5
33-677	07-20-90	--	<.010	.6	17	7.6	1.7	1.5	21	<1.0
33-678	08-16-90	--	<.010	2.4	3.7	2.9	3.6	1.2	13	18
33-679	08-09-90	--	<.010	.9	27	23	5.2	1.9	27	77
	04-23-91	--	<.010	.8	32	20	4.7	1.6	18	62
	08-21-91	<.010	<.010	--	--	--	--	--	--	--
	08-21-91	<.010	<.010	--	--	--	--	--	--	--
33-682	08-15-90	--	.010	.6	6.2	5.4	11	2.4	28	<1.0
33-684	04-26-91	--	<.010	.4	16	5.2	2.8	3.6	21	.50
	08-22-91	.020	<.010	--	--	--	--	--	--	--
33-685	08-14-90	--	<.010	1.2	39	19	5.1	5.4	25	61
	04-23-91	--	<.010	.8	28	24	5.9	2.0	26	80
	08-20-91	<.010	<.010	--	--	--	--	--	--	--

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (μg/L)	Barium, dissolved (μg/L)	Beryllium, dissolved (μg/L)	Boron, dissolved (μg/L)	Cadmium, dissolved (μg/L)	Chromium, dissolved (μg/L)	Cobalt, dissolved (μg/L)
33- 674	08-09-90	<0.10	11	--	50	<0.5	--	<1	<5	<3
	04-26-91	<.10	12	<1	52	<.5	<10	<1	<5	3
	08-21-91	--	--	--	--	--	--	--	--	--
33- 675	08-14-90	<.10	13	--	84	.6	--	<1	<5	<3
33- 676	08-23-90	.30	15	--	62	<.5	--	<1	<5	<3
33- 677	07-20-90	<.10	6.8	--	230	<.5	--	<1	<5	5
33- 678	08-16-90	.20	10	--	87	1	--	1	<5	6
33- 679	08-09-90	.20	10	--	49	<.5	--	<1	<5	<3
	04-23-91	<.10	12	<1	61	<.5	10	<1	<5	<3
	08-21-91	--	--	--	--	--	--	--	--	--
	08-21-91	--	--	--	--	--	--	--	--	--
33- 682	08-15-90	<.10	8.0	--	80	.6	--	<1	<5	<3
33- 684	04-26-91	<.10	7.0	<1	110	1	10	<1	<5	7
	08-22-91	--	--	--	--	--	--	--	--	--
33- 685	08-14-90	<.10	12	--	71	<.5	--	<1	<5	<3
	04-23-91	<.10	10	<1	47	<.5	10	<1	<5	<3
	08-20-91	--	--	--	--	--	--	--	--	--

USGS well number	Date	Copper, dissolved (μg/L)	Iron, dissolved (μg/L)	Lead, dissolved (μg/L)	Manganese, dissolved (μg/L)	Molybdenum, dissolved (μg/L)	Nickel, dissolved (μg/L)	Silver, dissolved (μg/L)	Strontium, dissolved (μg/L)
33- 674	08-09-90	20	92	<10	15	<10	<10	<1	26
	04-26-91	30	210	1	15	<10	<10	<1	26
	08-21-91	--	--	--	--	--	--	--	--
33- 675	08-14-90	<10	8	<10	18	<10	10	1	150
33- 676	08-23-90	<10	11	<10	8	<10	<10	<1	71
33- 677	07-20-90	20	9	10	33	<10	<10	<1	35
33- 678	08-16-90	<10	3,800	<10	94	<10	<10	2	44
33- 679	08-09-90	<10	6	<10	52	<10	<10	<1	270
	04-23-91	20	41	7	20	<10	<10	<1	200
	08-21-91	--	--	--	--	--	--	--	--
	08-21-91	--	--	--	--	--	--	--	--
33- 682	08-15-90	<10	10	<10	6	<10	<10	<1	62
33- 684	04-26-91	20	8	3	36	<10	<10	<1	62
	08-22-91	--	--	--	--	--	--	--	--
33- 685	08-14-90	410	19	<10	93	<10	<10	<1	230
	04-23-91	<10	6	2	54	<10	<10	<1	290
	08-20-91	--	--	--	--	--	--	--	--

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Vanadium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Aluminum, dissolved (µg/L)	Lithium, dissolved (µg/L)	Mercury, dissolved (µg/L)	Gross alpha, dissolved (pCi/L as Th-230)	Gross alpha, 2 sigma, dissolved (pCi/L as Th-230)	Gross beta, dissolved (pCi/L as Cs-137)	Gross beta, 2 sigma, dissolved (pCi/L as Cs-137)	Tritium (pCi/L)	Tritium, 2 sigma (pCi/L)	Radium-226, dissolved, radon method (pCi/L)
33- 674	08-09-90	<6	50	670	<4	--	15.8	2.44	4.5	1.2	44	5.1	3.2
	04-26-91	<6	42	--	<4	.2	10.1	1.72	3.8	1.1	50	6.0	3.6
	08-21-91	--	--	--	--	--	--	--	--	--	--	--	--
33- 675	08-14-90	<6	8	270	<4	--	8.32	1.96	8.1	--	45	--	3.6
33- 676	08-23-90	<6	7	20	<4	--	3.28	1.25	3.6	.90	92	14	.98
33- 677	07-20-90	<6	10	630	<4	--	--	--	2.9	.90	48	5.1	.45
33- 678	08-16-90	<6	48	910	<4	--	3.03	.92	3.0	--	54	--	.46
33- 679	08-09-90	<6	35	70	5	--	9.32	2.65	4.6	1.3	60	5.8	1.6
	04-23-91	<6	31	--	<4	.3	5.35	2.04	4.7	1.3	--	--	1.4
	08-21-91	--	--	--	--	--	--	--	--	--	--	--	--
	08-21-91	--	--	--	--	--	--	--	--	--	--	--	--
33- 682	08-15-90	<6	9	40	<4	--	4.71	1.25	5.8	1.4	44	--	2.1
33- 684	04-26-91	<6	12	--	<4	.2	11.7	2.08	8.6	2.1	48	4.0	4.6
	08-22-91	--	--	--	--	--	--	--	--	--	--	--	--
33- 685	08-14-90	<6	28	30	<4	--	.98	.99	5.9	--	57	--	.21
	04-23-91	<6	26	--	<4	.2	.36	.76	1.8	.80	--	--	.08
	08-20-91	--	--	--	--	--	--	--	--	--	--	--	--

USGS well number	Date	Radium-226, 2 sigma, dissolved (pCi/L)	Radium-228, dissolved (pCi/L)[1]	Radium-228, 2 sigma, dissolved (pCi/L)	Radium-228/ Radium-226 ratio dissolved[2]	Uranium, dissolved (µg/L)	Uranium, 2 sigma, dissolved (µg/L)	Radon-222 (pCi/L)	Radon-222, 2 sigma (pCi/L)	Methiocarb, total, recoverable (µg/L)	Propoxur, total, recoverable (µg/L)
33-674	08-09-90	0.45	--	--	--	0.36	<1	1,300	50	--	--
	04-26-91	.64	[1]<1.0(.96)	0.4	[2](.27)	.27	<1	1,300	49	<0.5	<.5
	08-21-91	--	--	--	--	--	--	1,300	39	<.5	<.5
33-675	08-14-90	.50	2.4	.8	.67	.08	--	230	36	--	--
33-676	08-23-90	.14	1.5	.5	1.53	.04	<1	510	53	--	--
33-677	07-20-90	.07	[1]<1.0(.41)	.7	[2](.91)	.07	<1	190	88	--	--
33-678	08-16-90	.07	[1]<1.0(.97)	.4	[2](2.11)	.11	--	110	45	--	--
33-679	08-09-90	.23	--	--	--	.27	<1	370	130	--	--
	04-23-91	.23	[1]<1.0(.96)	.5	[2](.69)	.22	<1	540	67	--	--
	08-21-91	--	--	--	--	--	--	520	31	<.5	<.5
	08-21-91	--	--	--	--	--	--	--	--	<.5	<.5
33-682	08-15-90	.29	1.3	.5	.62	.07	--	280	52	--	--
33-684	04-26-91	.80	4.0	1.1	.87	.05	<1	170	43	<.5	<.5
	08-22-91	--	--	--	--	--	--	230	51	<.5	<.5
33-685	08-14-90	.03	[1]<1.0(.54)	.3	[2](2.57)	.04	--	120	51	--	--
	04-23-91	.02	[1]<1.0(.12)	.3	[2](1.50)	.02	<1	300	65	--	--
	08-20-91	--	--	--	--	--	--	250	51	<.5	<.5

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Ametryne, dissolved, recoverable (μg/L)	Ametryne, total, (μg/L)	Propazine, water, dissolved, recoverable (μg/L)	Propazine, total (μg/L)	Trifluralin, total, recoverable (mg/L)	Perthane, total (μg/L)	Methomyl, total (μg/L)
33- 674	08-09-90	--	--	--	--	--	--	--
	04-26-91	<.05	--	<.05	--	--	--	<.5
	08-21-91	<.05	--	<.05	--	--	--	<.5
33- 675	08-14-90	--	--	--	--	--	--	--
33- 676	08-23-90	--	<.10	--	<.10	<.10	--	--
33- 677	07-20-90	--	<.10	--	<.10	<.10	<.1	<.5
33- 678	08-16-90	--	--	--	--	--	--	--
33- 679	08-09-90	--	<.10	--	<.10	<.10	<.1	<.5
	04-23-91	<.05	--	<.05	--	--	--	<.5
	08-21-91	<.05	--	<.05	--	--	--	<.5
	08-21-91	<.05	--	<.05	--	--	--	<.5
33- 682	08-15-90	--	--	--	--	--	--	--
33- 684	04-26-91	<.05	--	<.05	--	--	--	<.5
	08-22-91	<.05	--	<.05	--	--	--	<.5
33- 685	08-14-90	--	<.10	--	<.10	<.10	<.1	<.5
	04-23-91	<.05	--	<.05	--	--	--	<.5
	08-20-91	<.05	--	<.05	--	--	--	<.5

USGS well number	Date	Propham, total (μg/L)	Simetryne, total (μg/L)	Simazine, total (μg/L)	Prometone, total (μg/L)	Prometryne, total (μg/L)	Naphthalene, polychlor. total (μg/L)	Aldrin, total (μg/L)	Lindane, total (μg/L)
33-674	08-09-90	--	--	--	--	--	--	--	--
	04-26-91	<.5	--	--	--	--	--	--	--
	08-21-91	<.5	--	--	--	--	--	--	--
33-675	08-14-90	--	--	--	--	--	--	--	--
33-676	08-23-90	--	<.10	<.10	<.10	<.10	--	--	--
33-677	07-20-90	<.5	<.10	<.10	<.10	<.10	<.10	<.010	<.010
33-678	08-16-90	--	--	--	--	--	--	--	--
33-679	08-09-90	<.5	<.10	<.10	<.10	<.10	<.10	<.010	<.010
	04-23-91	<.5	--	--	--	--	--	--	--
	08-21-91	<.5	--	--	--	--	--	--	--
	08-21-91	<.5	--	--	--	--	--	--	--
33-682	08-15-90	--	--	--	--	--	--	--	--
33-684	04-26-91	<.5	--	--	--	--	--	--	--
	08-22-91	<.5	--	--	--	--	--	--	--
33-685	08-14-90	<.5	<.10	<.10	<.10	<.10	<.10	<.010	<.010
	04-23-91	<.5	--	--	--	--	--	--	--
	08-20-91	<.5	--	--	--	--	--	--	--

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Chlordane, total (μg/L)	DDD, total (μg/L)	DDE, total (μg/L)	DDT, total (μg/L)	Dieldrin, total (μg/L)	Endo-sulfan, total (μg/L)	Endrin, total (μg/L)	Toxa-phene, total (μg/L)	Hepta-chlor, total (μg/L)	Metola-chlor, dissolved (μg/L)
33-674	08-09-90	--	--	--	--	--	--	--	--	--	--
	04-26-91	--	--	--	--	--	--	--	--	--	<.05
	08-21-91	--	--	--	--	--	--	--	--	--	<.05
33-675	08-14-90	--	--	--	--	--	--	--	--	--	--
33-676	08-23-90	--	--	--	--	--	--	--	--	--	--
33-677	07-20-90	<.1	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	--
33-678	08-16-90	--	--	--	--	--	--	--	--	--	--
33-679	08-09-90	<.1	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	--
	04-23-91	--	--	--	--	--	--	--	--	--	<.05
	08-21-91	--	--	--	--	--	--	--	--	--	<.05
	08-21-91	--	--	--	--	--	--	--	--	--	<.05
33-682	08-15-90	--	--	--	--	--	--	--	--	--	--
33-684	04-26-91	--	--	--	--	--	--	--	--	--	<.05
	08-22-91	--	--	--	--	--	--	--	--	--	<.05
33-685	08-14-90	<.1	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	--
	04-23-91	--	--	--	--	--	--	--	--	--	<.05
	08-20-91	--	--	--	--	--	--	--	--	--	<.05

USGS well number	Date	Heptachlor epoxide, total (μg/L)	Methoxy-chlor, total (μg/L)	PCB, total (μg/L)	Atrazine, total (μg/L)	Atrazine, dissolved recoverable (μg/L)	Sevin, total (μg/L)	Mirex, total (μg/L)	Alachlor, dissolved, recoverable (μg/L)
33-674	08-09-90	--	--	--	--	--	--	--	--
	04-26-91	--	--	--	--	<.05	<.5	--	<.05
	08-21-91	--	--	--	--	<.05	<.5	--	<.05
33-675	08-14-90	--	--	--	--	--	--	--	--
33-676	08-23-90	--	--	--	<.10	--	--	--	--
33-677	07-20-90	<.010	<.01	<.1	<.10	--	<.5	<.01	--
33-678	08-16-90	--	--	--	--	--	--	--	--
33-679	08-09-90	.010	<.01	<.1	<.10	--	<.5	<.01	--
	04-23-91	--	--	--	--	.44	<.5	--	.07
	08-21-91	--	--	--	--	<.05	<.5	--	<.05
	08-21-91	--	--	--	--	<.05	<.5	--	<.05
33-682	08-15-90	--	--	--	--	--	--	--	--
33-684	04-26-91	--	--	--	--	<.05	<.5	--	<.05
	08-22-91	--	--	--	--	<.05	<.5	--	<.05
33-685	08-14-90	<.010	<.01	<.1	.20	--	<.5	<.01	--
	04-23-91	--	--	--	--	<.05	<.5	--	<.05
	08-20-91	--	--	--	--	<.05	<.5	--	.18

Appendix 1B. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from the Kirkwood-Cohansey aquifer system, southern and east-central New Jersey, 1990-91--Continued

USGS well number	Date	Alachlor, total, recoverable (μg/L)	1-Naphthol, total, recoverable (μg/L)	Cyanazine, total (μg/L)	3-Hydrx carbofuran, total recoverable (μg/L)	Aldicarb sulfoxide, total recoverable (μg/L)	Aldicarb sulfone, total recoverable (μg/L)	Metribuzin, total recoverable (μg/L)
33-674	08-09-90	--	--	--	--	--	--	--
	04-26-91	--	<.5	--	<.5	<.5	<.5	--
	08-21-91	--	<.5	--	<.5	<.5	<.5	--
33-675	08-14-90	--	--	--	--	--	--	--
33-676	08-23-90	<.10	--	<.10	--	--	--	<.10
33-677	07-20-90	<.10	--	<.10	--	--	--	<.10
33-678	08-16-90	--	--	--	--	--	--	--
33-679	08-09-90	<.10	--	<.10	--	--	--	<.10
	04-23-91	--	<.5	--	<.5	<.5	<.5	--
	08-21-91	--	<.5	--	<.5	<.5	<.5	--
	08-21-91	--	<.5	--	<.5	<.5	<.5	--
33-682	08-15-90	--	--	--	--	--	--	--
33-684	04-26-91	--	<.5	--	<.5	<.5	<.5	--
	08-22-91	--	<.5	--	<.5	<.5	<.5	--
33-685	08-14-90	7.5	--	.50	--	--	--	<.10
	04-23-91	--	<.5	--	<.5	<.5	<.5	--
	08-20-91	--	<.5	--	<.5	<.5	<.5	--

USGS well number	Date	Metolachlor, total recoverable (μg/L)	Oxyamyl, total recoverable (μg/L)	Carbofuran, total recoverable (μg/L)	Aldicarb, total recoverable (μg/L)	Metribuzin sencor, dissolved (μg/L)	Delta ^{15}N stable isotope ratio, nitrate (per mil)
33-674	08-09-90	--	--	--	--	--	3.6
	04-26-91	--	<.5	<.5	<.5	<.05	3.6
	08-21-91	--	<.5	<.5	<.5	<.05	3.2
33-675	08-14-90	--	--	--	--	--	--
33-676	08-23-90	<.10	--	--	--	--	10.4
33-677	07-20-90	<.10	--	--	--	--	1.2
33-678	08-16-90	--	--	--	--	--	--
33-679	08-09-90	<.10	--	--	--	--	--
	04-23-91	--	<.5	<.5	<.5	<.05	4.4
	08-21-91	--	<.5	2.6	<.5	<.05	3.8
	08-21-91	--	<.5	2.5	<.5	<.05	--
33-682	08-15-90	--	--	--	--	--	--
33-684	04-26-91	--	<.5	<.5	<.5	<.05	4.0
	08-22-91	--	<.5	<.5	<.5	<.05	3.9
33- 685	08-14-90	<.10	--	--	--	--	5.1
	04-23-91	--	<.5	1.8	<.5	<.05	4.2
	08-20-91	--	<.5	<.5	<.5	<.05	3.3

Appendix 2A. Selected well-record information for nested observation wells and temporary piezometers installed in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1990-91

[USGS, U.S. Geological Survey; ft, feet; --, data unavailable]

USGS well number	New Jersey permit number	Latitude (degrees)	Longitude (degrees)	Date of construction	Altitude of land surface (ft above sea level)	Depth of well (ft below land surface)	Top of open interval (ft below land surface)	Bottom of open interval (ft below land surface)
				Seabrook site				
[1]11-696	--	393047	0751249	11-19-1991	102	13	11	13
11-692	34-03742	393104	0751222	09-28-1990	119.6	38	33	38
[1]11-700	--	393047	0751249	11-21-1991	102	53	51	53
11-693	34-03743	393104	0751222	09-27-1990	119.7	78	73	78
11-694	34-03744	393104	0751222	09-26-1990	119.9	115	105	110
				Cross Keys site				
15-1051	31-33952	394314	0750145	05-25-1990	155	27	22	27
15-1052	31-33953	394314	0750145	05-24-1990	155	65	60	65
15-1053	31-33954	394314	0750145	05-23-1990	155	97	92	97
				Glassboro site				
15-1054	31-33949	394221	0750722	06-05-1990	155	36	31	36
15-1055	31-33950	394221	0750722	06-07-1990	155	66	61	66
15-1056	31-33951	394221	0750722	06-06-1990	155	84	79	84
				Southern Washington Township site				
15-1057	31-33946	394242	0750330	05-18-1990	150	27	22	27
15-1063	31-34116	394242	0750330	06-08-1990	155.8	40	35	40
15-1058	31-33947	394242	0750330	05-22-1990	150	75	70	75
15-1059	31-33948	394242	0750330	05-17-1990	150	100	95	100
				Upper Pittsgrove Township site				
33-680	30-06586	393818	0751324	05-16-1990	140	32	27	32
33-681	30-06587	393818	0751324	05-15-1990	140	45	40	45

[1] Temporary piezometer.

Appendix 2B. Lithologic description of core samples from selected intervals of the Bridgeton Formation, Cohansey Sand, and Kirkwood Formation in wells near Cross Keys, in southern Washington Township, in Glassboro, in upper Pittsgrove Township, and near Seabrook, southwestern New Jersey

Sample depth (feet below land surface)	Sample description
	Seabrook site--wells 11-693 and 11-694
	Bridgeton Formation (?)
0-1	Moderate yellowish-brown (10 YR 5/4) fine sand and silt; poorly sorted; subangular grains; mostly quartz, contains organic matter and soil features, such as roots.
1-1.5	Fine to medium dark yellowish-brown (10 YR 4/2) sand, with abundant clayey matrix, very compact; moderately well-sorted; subangular grains; mostly quartz, but contains numerous weathered, clayey, and iron-stained decomposed grains of unknown mineralogy, possibly feldspar.
5-6.5	Medium moderate yellowish-brown (10 YR 5/4) sand, with granular sand and quartzose gravel; poorly sorted; subangular to subrounded grains, with subrounded granules and pebbles; mostly quartz, rare dark minerals.
10-11.5	Same as above.
15-16	Medium to very coarse dark yellowish-orange (10 YR 6/6) sand to gravel, with gravel up to 1 centimeter in diameter, with slightly silty matrix with minor amounts of very fine and fine sand in the matrix; moderately poorly sorted; subangular grains to subrounded gravel; mostly quartz, common small dark minerals.
20-20.6	Same as above.
25-26	Medium to coarse dark yellowish-orange (10 YR 6/6) sand, with minor amounts of very coarse sand and quartz granules and pebbles to 1 centimeter in size, and minor amounts of fine sand matrix; well to moderately well-sorted; subangular to subrounded; quartz dominant, rare dark minerals.
30-31	Medium to coarse dark yellowish-orange (10 YR 6/6) sand, with occasional moderate red-orange (10 R 6/6) lenses of sand, that are semi-indurated with light-colored clay and possibly hematite groundmass; occasional granules; moderately well-sorted; grains predominantly subrounded; predominantly quartz, small amounts of finer dark angular minerals, and trace amounts of blocky, small, light brown minerals.
35-35.8	Same as above, but **no lenses of finer materal.**
	Cohansey Sand (?)
40-41.5	Medium to fine gray-orange pink (5 YR 7/2) sand, with lenses of very pale orange (10 YR 8/2) silt, and with some moderate orange-pink (10 R 7/4) silty matrix; well-sorted; subangular to subrounded; predominantly quartz, common angular smaller black minerals, common angular to subangular red flakes (possibly hematite).
50-51.5	Medium very light gray (N8) sand; very well-sorted; subrounded to some subangular; mostly quartz, occasional angular to subangular black minerals that commonly are nearly the same size as the grains of quartz.

Appendix 2B. Lithologic description of core samples from selected intervals of the Bridgeton Formation, Cohansey Sand, and Kirkwood Formation in wells near Cross Keys, in southern Washington Township, in Glassboro, in upper Pittsgrove Township, and near Seabrook, southwestern New Jersey--Continued

Sample depth (feet below land surface)	Sample description
	Seabrook site--wells 11-693 and 11-694--Continued
	Cohansey Sand (?)--Continued
60-61.8	Medium to fine gray-orange (10 YR 7/4) sand; well-sorted; subrounded, with rare subangular or rounded grains; almost all quartz, rare but distinct, very elongate, large (often nearly the same size as the quartz grains) angular to subangular, black minerals.
70-71.4	Same as above, with trace amounts of elongate flakes of a red mineral (possibly hematite).
75-75.5	Same as above, with trace amounts of elongate flakes of a red mineral (possibly hematite).
80-80.6	Fine dark yellowish-orange (10 YR 6/6) sand, some coarse sand and granules, some very fine sand; fairly well-sorted; subrounded to subangular; predominantly quartz, rare black equant to elongate minerals, with grain size ranging from significantly smaller than quartz grains to the size of quartz grains.
85.5-86.5	Olive-gray (5 Y 3/2) silt to very fine silty sand; very well-sorted; subrounded to subangular; mostly quartz, fairly common subangular black minerals of smaller grain size than the quartz, very rare muscovite flakes, trace amounts of unindentified small solid white discoid grains (possibly clay or weathered clayey feldspar).
90-91.3	Medium dark yellowish-orange (10 YR 6/6) sand; well-sorted; subrounded; nearly all quartz, rare dark minerals, quartz grains coated with iron oxide, trace amounts of minute red flakey mineral (possibly hematite).
95-96	Fine to medium sand, mottled grayish-orange (10 YR 7/4) and yellowish-orange (10 YR 7/6), traces of silt matrix; fairly well-sorted; subrounded; quartz predominant, rare dark minerals.
105-106.5	Fine to very coarse yellowish-orange (10 YR 7/6) sand, slightly silty, some quartz granules; poorly sorted; subrounded; all quartz.
	Cross Keys site--wells 15-1052 and 15-1053
	Bridgeton Formation (?)
21-22	Medium to fine dark yellowish-orange (10 YR 6/6) sand, with pebbles of quartz; well-sorted; rounded; predominantly quartz, with occasional weathered feldspar, trace amounts of blocky black minerals, and trace amounts of bright orange to red minerals (possibly hematite).
25-26	Medium pale yellowish-orange (10 YR 8/6) sand; well-sorted; rounded; predominantly quartz, with small amounts of bright orange-red blocky minerals (hematite), and trace amounts of blocky black minerals.
30-31.5	Medium to coarse grayish-orange (10 YR 7/4) sand, with lenses of coarse to very coarse grayish-orange (10 YR 7/4) pebbly sand; poorly to moderately poorly sorted; subrounded to rounded grains; predominantly quartz, with iron oxide coatings present on larger quartz pebbles, and trace amounts of dark minerals.

Appendix 2B. Lithologic description of core samples from selected intervals of the Bridgeton Formation, Cohansey Sand, and Kirkwood Formation in wells near Cross Keys, in southern Washington Township, in Glassboro, in upper Pittsgrove Township, and near Seabrook, southwestern New Jersey--Continued

Sample depth (feet below land surface)	Sample description
	Cross Keys site--wells 15-1052 and 15-1053--Continued
	Cohansey Sand
35-36.3	Fine to medium dark yellowish-orange (10 YR 6/6) sand, with occasional rounded quartz granules, occasionally grading into medium to coarse moderate yellowish-brown (10 YR 5/4) sand with depth; moderately well- to well-sorted; subrounded grains; mostly quartz, trace amounts of dark minerals.
40-41.2	Same as above.
45-45.8	Same as above.
50-51	Same as above.
55-55.8	Same as above.
70-71.3	Coarse to medium dark yellowish-orange (10 YR 6/6) sand, with subangular quartz granules; poorly sorted; subrounded to rounded; mostly quartz, abundant blocky to elongate dark minerals of small but variable grain size.
76.5-77	Coarse to very coarse very pale orange (10 YR 8/2) sand, with a few larger subangular quartz granules; poorly sorted; subangular to subrounded; mostly quartz, with few dark minerals.
80-80.8	Same as above. Contains more large quartz pebbles and contains trace amounts of badly weathered blocky minerals (possibly feldspar).
85-87	Medium to coarse dark yellowish-orange (10 YR 6/6) sand, with lenses of well-sorted fine to medium sand and poorly sorted very coarse sand, with abundant rounded quartz granules, and localized lenses of silty matrix; moderately poorly to moderately well-sorted; subrounded grains with rounded granules; mostly quartz, small amounts of clayey matrix, blocky weathered feldspar, and blocky dark minerals.
90-91.3	Medium to coarse grayish-yellow (5 Y 8/4) sand, with larger subrounded quartz granules; poorly sorted; subrounded to subangular grains; mostly quartz, trace amounts of elongate dark minerals.
95-96	Medium moderate yellowish-brown (10 YR 5/4) sand with lenses of moderate brown (5 YR 4/4) sand, with small number of subrounded quartz granules; well-sorted; subangular to subrounded grains; mostly quartz, trace amounts of small dark minerals.
	Kirkwood Formation
105-106.6	Very fine sand or silt in a olive-black (5 Y 2/1) clay matrix, with grains of subrounded quartz; fairly well-sorted; subangular smaller grains; mostly quartz, with abundant clay, and trace amounts of mica.

Appendix 2B. Lithologic description of core samples from selected intervals of the Bridgeton Formation, Cohansey Sand, and Kirkwood Formation in wells near Cross Keys, in southern Washington Township, in Glassboro, in upper Pittsgrove Township, and near Seabrook, southwestern New Jersey--Continued

Sample depth (feet below land surface)	Sample description
	Glassboro site--wells 15-1055 and 15-1056
	Bridgeton Formation (?)
7-7.5	Fine dark yellowish-orange (10 YR 6/6) sand, with common clay matrix, and with lenses of light brown (5 YR 5/6) fine sand; moderately well- to well-sorted; subangular; predominantly quartz, with trace amounts of subangular black minerals.
7.5-9.5	Same as above.
9.5-10	Medium to fine grayish-orange (10 YR 7/4) sand, with some clay matrix; moderately well- to well-sorted; subangular; mostly quartz, with trace amounts of blocky black minerals.
11.7-12	Same as above.
12-12.5	Medium to fine light olive-gray (5 Y 6/1) sand, with some clay matrix, and lenses of fine light brown (5 YR 5/6) sand; moderately well- to well-sorted; subangular; mostly quartz, with trace amounts of blocky black minerals.
12.5-14.5	Fine to very fine light olive-gray (5 Y 6/1/) sand, with some clay matrix, and lenses of fine to very fine dark yellowish-orange (10 YR 6/6) sand and lenses of pebbles and granules; moderately well- to well-sorted; subangular to subrounded; mostly quartz, with thin streaks composed entirely of blocky black minerals.
	Cohansey Sand (?)
17.5-20	Medium to fine dusky yellow (5 Y 6/4) sand with lenses of light brown (5 YR 5/6) clay, silty clay, and fine sand; moderately well- to well-sorted; subangular; mostly quartz, with rare elongate black minerals.
21.5-22.5	Medium to fine dusky yellow (5 Y 6/4) sand with lenses of light olive-gray (5 Y 5/2) clayey to silty fine sand; moderately well- to well-sorted; subangular grains; mostly quartz, trace amounts of elongate black minerals.
22.5-25	Medium to fine dusky yellow (5 Y 6/4) sand; moderately well-sorted; angular to subangular grains; mostly quartz, with abundant angular black minerals.
26.8-27	Medium to fine yellowish-gray (5 Y 7/2) sand; well-sorted; subangular; mostly quartz, with trace amounts of subangular black minerals.
31-32	Fine to very fine moderate reddish-orange (10 R 6/6) sand; well-sorted; subangular to subrounded grains; mostly quartz, rare elongate black minerals, small amounts of grain-coating red mineral (possibly hematite).
36-37	Medium to fine light brown (5 YR 5/6) sand, with clayey matrix; moderately well- to well-sorted; subangular; mostly quartz, rare elongate black minerals.
45.5-47	Medium to fine yellowish-gray (5 Y 7/2) sand, with clayey matrix; moderately well-sorted; subangular grains; very abundant quartz, abundant mica, common subangular black minerals.

Appendix 2B. Lithologic description of core samples from selected intervals of the Bridgeton Formation, Cohansey Sand, and Kirkwood Formation in wells near Cross Keys, in southern Washington Township, in Glassboro, in upper Pittsgrove Township, and near Seabrook, southwestern New Jersey--Continued

Sample depth (feet below land surface)	Sample description
	Glassboro site--wells 15-1055 and 15-1056--Continued
	Cohansey Sand (?)--Continued
50-52	Very fine dark yellowish-orange (10 YR 6/6) sand, with abundant clayey matrix; moderately well-sorted; subangular grains; mostly quartz, abundant elongate angular black minerals, trace amounts of mica.
55-57	Same as above.
65-66	Massive yellowish-gray (5 Y 7/2) clay, with occasional grains of quartz; predominantly clay, minor amounts of quartz, trace amounts of mica and elongate black minerals.
66-67	Coarse to medium moderate olive-brown (5 Y 4/4) sand, with occasional quartz granules; poorly to moderately well-sorted; minor amounts of clay matrix; subangular to subrounded; mostly quartz, trace amounts of elongate, angular black minerals.
70-71	Medium to fine moderate olive-brown (5 Y 4/4) sand, with abundant quartz granules; poorly to moderately well-sorted; subrounded; mostly quartz, abundant angular elongate black minerals.
75-75.5	Same as above.
	Kirkwood Formation (?)
85-85.5	Medium to fine grayish-olive (10 Y 4/2) sand; well-sorted; subangular grains; abundant quartz, minor amounts of subangular black minerals.
85.5-86	Very fine to fine to medium, olive-gray (5 Y 3/2) sand, with abundant clay matrix; well-sorted; subangular grains; abundant quartz, minor amounts of subangular black minerals.
92-93	Same as above.
	Southern Washington Township site--wells 15-1058 and 15-1059
	Bridgeton Formation
0.3-1.8	Coarse to medium moderate yellowish-brown (10 YR 5/4) sand, with large quartz pebbles, and trace clay or silt matrix; poorly sorted; pebbles and sand are subangular; mostly quartz.
1.8-2.5	Coarse to medium light brown (5 YR 5/6) sand, with trace clay or silt matrix, and large grains of weathered feldspar; poorly sorted; sand is subangular, large grains of quartz and feldspar are subangular; mostly quartz, with relatively abundant feldspar and small amounts of clay.
5-5.5	Light red (5 R 6/6) gravel, with coarse to very coarse sand matrix; poorly sorted; rounded; large quartz grains are the dominant component, with abundant red grain-coating mineral (possibly hematite).
5.5-6.8	Medium moderate yellowish-brown (10 YR 5/4) sand, with silty clay matrix, streaks of clay matrix are weathered to dark yellowish (10 YR 6/6), and large quartz and feldspar pebbles; poorly sorted; subangular; predominantly quartz, abundant feldspar, abundant clay minerals, and abundant small angular black minerals.

Appendix 2B. Lithologic description of core samples from selected intervals of the Bridgeton Formation, Cohansey Sand, and Kirkwood Formation in wells near Cross Keys, in southern Washington Township, in Glassboro, in upper Pittsgrove Township, and near Seabrook, southwestern New Jersey--Continued

Sample depth (feet below land surface)	Sample description
	Southern Washington Township site--wells 15-1058 and 15-1059--Continued
	Bridgeton Formation--Continued
10-12.5	Coarse dark yellowish-orange (10 YR 6/6) sand, some pebbles and granules, with streaks or nodules of clayey fine to medium sand, moderate yellowish-brown (10 YR 5/4); moderate sorting; subangular; predominantly large quartz crystals, some large feldspar grains, highly weathered, small amounts of clay minerals, and a red grain-coating mineral (possibly hematite).
15-17.5	Medium to coarse dark yellowish-orange (10 YR 6/6) sand; well-sorted; rounded to subrounded; clean, rounded quartz with little iron oxide staining, blocky and badly weathered feldspar grains, trace amount of dark minerals, and a large light olive-gray (5 Y 5/2) clay nodule; finer grained and more poorly sorted with depth, with increasing amounts of streaks of light brown (5 YR 5/6) clay matrix that contains occasional large quartz and feldspar pebbles, and streaks of moderate yellowish-brown (10 YR 5/4) and moderate red (5 R 4/6) clay.
	Cohansey Sand
25-27	Coarse grayish-orange (10 YR 7/4) sand, with occasional quartz granules; well-sorted; subangular to round, with most quartz granules well-rounded; predominantly quartz, with trace amounts of small dark minerals; most quartz granules and grains are translucent and show little to no iron oxide staining.
30-31.5	Coarse to medium very pale orange (10 YR 8/2) sand, with a few round quartz granules; well-sorted; subrounded; mostly quartz, with a few small dark minerals.
35-35.5	Coarse to medium very pale orange (10 YR 8/2) to almost white sand; moderate sorting; subrounded; predominantly translucent to white quartz grains, with very abundant small dark minerals, abundant orange to dark red iron oxide stains on larger subrounded quartz grains.
40-41	Same as above.
45-46	Fine to very fine dark yellowish-orange (10 YR 6/6) sand; very well-sorted; subangular to subrounded; primarily quartz and some small dark minerals.
55-56	Fine to very fine dark yellowish-orange (10 YR 6/6) sand, small amounts of silty matrix, occasional larger quartz grains; well-sorted to moderately sorted; subrounded to subangular, most large quartz grains are subangular; primarily quartz, with abundant fine black minerals, typically elongate, and occasional unidentified rounded to blocky reddish granules (possibly chert, or iron oxide-cemented quartz sand).
61-62	Fine to medium light brown (5 YR 5/6) sand, abundant clay matrix; moderately sorted; subrounded; predominantly quartz, minor amounts of abundant dark minerals, trace amounts of mica.
65.5-67	Same as above.
75-76.3	Coarse to very coarse dark yellowish-orange (10 YR 6/6) sand; poorly sorted; subrounded to subangular; predominantly quartz, minor amounts of large subrounded quartz granules, and minor subangular small dark minerals.

Appendix 2B. Lithologic description of core samples from selected intervals of the Bridgeton Formation, Cohansey Sand, and Kirkwood Formation in wells near Cross Keys, in southern Washington Township, in Glassboro, in upper Pittsgrove Township, and near Seabrook, southwestern New Jersey--Continued

Sample depth (feet below land surface)	Sample description
	Southern Washington Township site--wells 15-1058 and 15-1059--Continued
	Cohansey Sand--Continued
80-81	Fine to medium grayish-orange (10 YR 7/4) sand; well-sorted; subangular; mostly quartz, large amount of small, black minerals.
85-86	Medium to fine dark yellowish-orange (10 YR 6/6) sand, some quartz granules; very well-sorted; subangular; mostly quartz, minor amounts of black minerals.
	Kirkwood Formation
95-96.5	Fine to medium light olive-brown (5 Y 5/6) sand; very well-sorted; subangular; primarily quartz, with abundant fine black minerals.
100-101.5	Fine moderate olive-brown (5 Y 4/4) sand, some lenses of medium sand; well-sorted; subangular; predominantly quartz, many black minerals, trace amounts of mica.
110-112	Very fine greenish-black (5 G 2/1) sand; well-sorted; subangular; abundant quartz, very micaceous, very abundant elongate or blocky very fine black minerals,with black clay or organic coating on quartz grains.
115-117	Very fine greenish-black (5 G 2/1) sand with abundant silt; well-sorted; subangular; very abundant mica, very abundant blocky black minerals, occasional quartz grains present, quartz mostly blocky, gray (possibly clay) coating on some grains. Sulfur odor toward bottom of sample.
	Upper Pittsgrove Township site--wells 33-680 and 33-681
	Bridgeton Formation
0-0.8	Medium to fine grayish-brown (5 YR 3/2) sand; poorly to moderately well-sorted; subangular to subrounded grains; predominantly quartz, lenses of organic matter, more common at the top of the sample, quartz granules rare.
0.8-1.4	Fine moderate yellowish-brown (10 YR 5/4) sand, with fine clay matrix; moderately well-sorted; subangular to subrounded grains; primarily quartz.
2.5-5	Same as above.
5-7	Same as above.
7.5-8.2	Fine light olive-gray (5 Y 5/2) sand, with occasional lenses of light brown (5 YR 5/6) clay or silt; moderately well-sorted; subangular to subrounded grains; mostly quartz and some clay.
8.2-8.5	Fine grayish-orange (10 YR 7/4) sand, with a bleached, highly weathered zone of medium to fine sand; moderately well-sorted; subangular to subrounded grains; mostly quartz, trace amount of feldspar.
8.5-9.8	Silty clay, abruptly changing in color with depth from light olive gray (5 Y 5/2) to moderate yellowish-brown (10 YR 5/4) to light brown (5 YR 5/6).

Appendix 2B. Lithologic description of core samples from selected intervals of the Bridgeton Formation, Cohansey Sand, and Kirkwood Formation in wells near Cross Keys, in southern Washington Township, in Glassboro, in upper Pittsgrove Township, and near Seabrook, southwestern New Jersey--Continued

Sample depth (feet below land surface)	Sample description
	Upper Pittsgrove Township site--wells 33-680 and 33-681--Continued
	Bridgeton Formation--Continued
9.8-11.5	Medium to coarse light olive-gray (5 Y 6/1) sand, capped by pebble lens (9.8-10.0 ft); moderately poorly sorted; subangular to rounded grains; mostly quartz.
11.5-12	Coarse to medium light gray (N7) sand, with abundant granules and occasional pebbles; moderately poorly sorted; angular to subangular grains; mostly quartz.
17.5-19.5	Medium to coarse yellowish-gray (5 Y 7/2) sand, with occasional quartz granules with limonitic silty lenses; moderately well-sorted; angular to subrounded grains; mostly quartz, some clay, trace amounts of limonite.
	Cohansey Sand
47.5-48.5	Coarse to medium dark yellowish-orange (10 YR 6/6) sand, with abundant pebbles; poorly sorted; angular to subangular grains; mostly quartz.
	Kirkwood Formation
52.5-53.5	Massive olive-gray (5 Y 3/2) clay.

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991

[ft, feet; deg C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; <, less than; --, data not available; tot. rec., total recoverable]

USGS well number	Bottom of open interval (ft below land surface)	Date	Temperature, water (deg C)	Specific conductance (µS/cm)	Solids, residue at 180 deg C, dissolved (mg/L)	Oxygen, dissolved (mg/L)	pH, water, field (standard units)	Alkalinity, lab (mg/L as $CaCO_3$)	Nitrogen ammonia, dissolved (mg/L as N)
Seabrook site									
11-696	13	11-20-91	16.0	148	86	7.9	5.3	3.0	<0.010
11-692	38	05-01-91	20.0	152	96	10.2	5.1	3.0	<.010
		05-01-91	20.0	152	78	10.2	5.1	3.0	<.010
		12-20-91	12.0	134	97	10.0	4.9	3.6	.020
11-700	53	11-22-91	14.5	180	131	7.9	5.1	3.0	.060
11-693	78	05-01-91	18.0	295	142	9.6	4.6	1.8	<.010
		12-20-91	13.5	262	154	9.2	4.6	1.9	.020
11-694	110	03-28-91	14.0	82	--	--	5.6	--	--
		05-02-91	18.5	63	39	9.6	5.7	5.2	<.010
		12-23-91	13.5	59	55	10.0	5.6	6.2	.030
Cross Keys site									
15-1051	27	03-20-91	13.5	133	69	10	5.5	5.0	<.010
15-1052	65	03-19-91	13.5	100	59	8.9	5.6	6.4	.010
15-1053	97	03-19-91	13.0	65	31	5.7	5.7	1.7	<.010
Glassboro site									
15-1054	36	05-07-91	18.0	373	189	5.1	5.0	8.4	<.010
15-1055	66	03-26-91	14.5	190	104	7.0	5.5	8.6	.030
15-1056	84	03-22-91	14.5	125	76	.5	6.4	26	.350
Southern Washington Township site									
15-1057	27	03-22-91	13.5	540	337	8.8	4.9	4.0	<.010
		12-17-91	15.5	550	346	8.8	4.9	4.6	.010
15-1063	40	03-21-91	14.5	290	183	9.1	5.4	8.0	<.010
		12-17-91	14.0	261	191	9.3	5.2	6.2	.010
15-1058	75	03-21-91	13.5	147	129	7.1	5.4	12	<.010
		03-21-91	13.5	147	110	7.1	5.4	12	<.010
		12-27-91	14.0	126	87	8.1	4.9	5.1	.020
15-1059	100	03-20-91	14.0	59	34	4.0	5.6	6.8	<.010
		12-17-91	13.5	30	25	8.0	5.1	3.7	.010
Upper Pittsgrove Township site									
33-680	32	03-27-91	13.5	231	136	9.4	5.2	5.2	<.010
33-681	45	03-27-91	13.5	366	222	3.7	5.3	8.5	<.010

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991--Continued

USGS well number	Date	Nitrogen nitrite, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Phosphorus ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Chloride, dissolved (mg/L)
					Seabrook site						
11-696	11-20-91	<0.010	<0.20	1.90	<0.010	--	6.4	2.6	2.5	12	6.6
11-692	05-01-91	<.010	.50	6.90	<.010	0.8	11	5.6	2.9	1.8	8.2
	05-01-91	<.010	.60	6.70	<.010	.7	11	5.5	2.8	1.5	8.9
	12-20-91	<.010	<.20	7.20	<.010	--	10	5.4	2.7	1.6	8.6
11-700	11-22-91	.020	<.20	14.0	<.010	--	15	7.8	1.9	1.8	16
11-693	05-01-91	<.010	.40	23.0	<.010	.4	18	11	6.6	3.3	23
	12-20-91	<.010	<.20	23.0	<.010	--	18	12	5.6	3.4	23
11-694	03-28-91	--	--	--	--	--	--	--	--	--	--
	05-02-91	<.010	.50	5.10	.100	.4	3.6	1.5	5.8	1.2	4.9
	12-23-91	<.010	<.20	4.30	.220	--	3.2	1.2	4.9	1.2	3.9
					Cross Keys site						
15-1051	03-20-91	.020	.40	3.80	<.010	.9	13	2.9	1.8	4.0	5.2
15-1052	03-19-91	.010	.60	7.20	<.010	.4	6.5	4.6	2.0	2.0	8.1
15-1053	03-19-91	<.010	.30	3.50	<.010	.4	3.1	1.8	2.5	1.3	2.5
					Glassboro site						
15-1054	05-07-91	<.010	.50	4.20	<.010	1.0	22	5.3	33	4.0	59
15-1055	03-26-91	<.010	.40	2.70	<.010	1.2	6.3	6.0	17	4.6	50
15-1056	03-22-91	<.010	.50	.620	<.010	1.7	10	.96	8.2	7.7	13
					Southern Washington Township site						
15-1057	03-22-91	<.010	.50	4.00	<.010	1.9	45	17	27	2.6	83
	12-17-91	<.010	<.20	4.70	<.010	--	38	15	33	3.0	83
15-1063	03-21-91	<.010	.20	1.70	<.010	1.7	32	11	2.7	.70	20
	12-17-91	<.010	<.20	2.00	<.010	--	31	9.8	3.0	.70	23
15-1058	03-21-91	<.010	.40	8.20	<.010	.5	3.7	2.0	19	1.6	12
	03-21-91	<.010	.60	8.70	<.010	.6	3.7	2.1	19	1.6	12
	12-27-91	<.010	<.20	8.80	<.010	--	1.4	2.8	15	1.9	11
15-1059	03-20-91	<.010	<.20	.140	<.010	.3	2.0	.50	6.6	1.2	2.1
	12-17-91	<.010	<.20	.220	<.010	--	1.2	.33	1.9	1.1	2.1
					Upper Pittsgrove Township site						
33-680	03-27-91	<.010	.50	5.20	<.010	.6	24	8.5	2.9	1.1	13
33-681	03-27-91	<.010	.60	10.0	<.010	.9	24	15	4.7	20	18

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991--Continued

USGS well number	Date	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Beryllium, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Cobalt, dissolved (µg/L)	Copper, dissolved (µg/L)
Seabrook site											
11-696	11-20-91	32	0.20	7.3	--	44	<0.5	<1	<5	6	<10
11-692	05-01-91	16	<.10	7.7	<1	150	<.5	<1	<5	<3	14
	05-01-91	18	<.10	7.6	<1	150	<.5	<1	<5	<3	15
	12-20-91	17	<.10	7.2	--	150	<.5	<1	<5	<3	<10
11-700	11-22-91	.60	.20	7.2	--	220	<1	<1	<5	<5	<10
11-693	05-01-91	.10	.10	9.2	<1	440	<.5	<1	<5	3	25
	12-20-91	.50	<.10	8.7	--	490	<.5	<1	<5	<3	<10
11-694	03-28-91	--	--	--	--	--	--	--	--	--	--
	05-02-91	.40	<.10	8.3	<1	33	<.5	<1	<5	<3	2
	12-23-91	.50	<.10	7.9	--	34	<.5	<1	<5	<3	<10
Cross Keys site											
15-1051	03-20-91	28	<.10	5.3	<1	79	<.5	<1	<5	<3	1
15-1052	03-19-91	<1.0	<.10	6.4	<1	200	<.5	<1	<5	<3	1
15-1053	03-19-91	7.1	<.10	7.8	<1	77	<.5	<1	<5	<3	5
Glassboro site											
15-1054	05-07-91	42	.10	1.5	<1	6	<.5	<1	<5	<3	10
15-1055	03-26-91	5.6	<.10	6.8	<1	290	<.5	1	<5	<3	4
15-1056	03-22-91	11	.20	7.4	<1	7	<.5	<1	<5	<3	8
Southern Washington Township site											
15-1057	03-22-91	90	.20	9.7	<1	77	<.5	<1	<5	3	7
	12-17-91	97	.30	9.3	--	71	<.5	<1	<5	<3	<10
15-1063	03-21-91	82	.10	9.8	<1	140	<.5	<1	<5	<3	5
	12-17-91	82	<.10	8.9	--	130	<.5	<1	<5	<3	<10
15-1058	03-21-91	<1.0	<.10	8.5	<1	140	<.5	<1	<5	<3	4
	03-21-91	<1.0	<.10	8.4	<1	130	<.5	<1	<5	<3	5
	12-27-91	.20	<.10	8.6	--	230	<.5	<1	<5	<3	<10
15-1059	03-20-91	14	<.10	11	<1	9	<.5	<1	<5	<3	1
	12-17-91	5.7	<.10	10	--	11	<.5	<1	<5	<3	<10
Upper Pittsgrove Township site											
33-680	03-27-91	59	<.10	10	<1	69	<.5	<1	<5	<3	3
33-681	03-27-91	88	<.10	9.3	<1	43	<.5	<1	<5	<3	4

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991--Continued

USGS well number	Date	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Manganese, dissolved (µg/L)	Molybdenum, dissolved (µg/L)	Nickel, dissolved (µg/L)	Silver, dissolved (µg/L)	Strontium, dissolved (µg/L)	Vanadium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Aluminum, dissolved (µg/L)
Seabrook site											
11-696	11-20-91	[1]2,300	20	56	<10	<10	3	58	<6	480	--
11-692	05-01-91	52	3	41	<10	<10	<1	51	<6	43	120
	05-01-91	55	3	39	<10	<10	<1	50	<6	55	120
	12-20-91	12	<1	36	<10	<10	<1	50	<6	16	--
11-700	11-22-91	[1]3,100	<10	100	<10	<10	<1	93	<6	41	--
11-693	05-01-91	68	5	32	<10	<10	<1	180	<6	62	370
	12-20-91	7	2	32	<10	<10	<1	190	<6	21	--
11-694	03-28-91	--	--	--	--	--	--	--	--	--	--
	05-02-91	16	<1	8	<10	<10	<1	31	<6	12	50
	12-23-91	53	<1	9	<10	<10	<1	22	<6	16	--
Cross Keys site											
15-1051	03-20-91	<3	4	39	<10	<10	<1	69	<6	5	80
15-1052	03-19-91	<3	3	46	<10	<10	1	55	<6	4	30
15-1053	03-19-91	73	2	19	<10	<10	1	27	<6	8	130
Glassboro site											
15-1054	05-07-91	75	6	8	<10	<10	<1	100	<6	53	490
15-1055	03-26-91	12	<1	67	<10	<10	<1	79	<6	7	40
15-1056	03-22-91	900	1	15	<10	<10	<1	88	<6	<3	<10
Southern Washington Township site											
15-1057	03-22-91	5	6	96	<10	<10	<1	99	<6	<3	540
	12-17-91	15	2	81	<10	<10	<1	80	<6	21	--
15-1063	03-21-91	3	1	14	<10	<10	<1	67	<6	<3	40
	12-17-91	11	<1	10	<10	<10	<1	61	<6	13	--
15-1058	03-21-91	4	2	22	<10	<10	<1	32	<6	<3	<10
	03-21-91	4	5	21	<10	<10	<1	30	<6	<3	20
	12-27-91	6	1	12	<10	<10	<1	28	<6	10	--
15-1059	03-20-91	180	1	21	<10	<10	1	14	<6	6	<10
	12-17-91	110	<1	12	<10	<10	<1	9	<6	7	--
Upper Pittsgrove Township site											
33-680	03-27-91	4	<1	16	<10	<10	<1	120	<6	6	10
33-681	03-27-91	8	2	4	<10	<10	2	180	<6	5	40

Footnotes at end of table.

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991--Continued

USGS well number	Date	Lithium, dissolved (μg/L)	Mercury, dissolved (μg/L)	Gross alpha, dissolved (pCi/L as Th-230)	Gross alpha, 2 sigma, dissolved (pCi/L as Th-230)	Gross beta, dissolved (pCi/L as Cs-137)	Beta 2 sigma, dissolved (pCi/L as Cs-137)	Tritium (pCi/L)	Tritium 2 sigma (pCi/L)	Radium-226, dissolved, radon method (pCi/L)	Radium-226, 2 sigma, dissolved (pCi/L)	Radium-228, dissolved (pCi/L)^2	Radium-228, 2 sigma, dissolved (pCi/L)	Radium-228/ Radium-226 ratio, dissolved^3
Seabrook site														
11-696	11-20-91	<4	--	--	--	--	--	--	--	1.5	0.24	1.5	0.6	1.00
11-692	05-01-91	<4	<.1	3.22	1.03	5.9	1.1	47	3.0	.65	.13	2.8	.8	4.31
	05-01-91	<4	<.1	4.36	1.22	4.8	1.0	50	3.0	.69	.12	2.9	.8	4.20
	12-20-91	<4	<.1	--	--	--	--	42	3.0	.65	.11	3.4	1.0	5.23
11-700	11-22-91	<4	--	--	--	--	--	--	--	4.3	.73	26	5.9	6.05
11-693	05-01-91	--	--	37.1	5.14	18	4.0	--	--	--	--	--	--	--
	05-01-91	<4	<.1	43.3	5.63	17	2.4	130	4.0	13	2.30	5.6	1.4	.43
	12-20-91	5	3.4	--	--	--	--	100	6.0	14	2.30	7.3	1.8	.52
11-694	03-28-91	--	--	--	--	--	--	--	--	--	--	--	--	--
	05-02-91	<4	<.1	1.94	.68	1.9	.60	3.0	1.0	.76	.13	^{2}<1.0(.68)	.3	^{3}(1.12)
	12-23-91	<4	<.1	--	--	--	--	2.0	1.0	.64	.11	^{2}<1.0(.60)	.4	^{3}(1.07)
Cross Keys site														
15-1051	03-20-91	<4	<.1	2.92	.96	5.2	1.4	37	3.0	1.5	.29	1.6	.6	1.07
15-1052	03-19-91	<4	<.1	7.89	1.51	7.3	1.7	56	4.0	4.1	.66	4.0	1.1	.98
15-1053	03-19-91	<4	<.1	1.39	.58	2.1	.70	1.0	<.1	.76	.13	^{2}<1.0(.75)	.4	^{3}(.99)
Glassboro site														
15-1054	05-07-91	<4	<.1	4.23	1.61	6.2	1.6	55	4.0	.85	.14	^{2}<1.0(.77)	.3	^{3}(.91)
15-1055	03-26-91	<4	.7	6.50	1.64	5.7	1.1	50	3.0	3.3	.55	^{2}<1.0(.75)	.3	^{3}(.23)
15-1056	03-22-91	<4	<.1	.11	.26	7.5	1.7	53	4.0	.08	.02	^{2}<1.0(.18)	.4	^{3}(2.25)
Southern Washington Township site														
15-1057	03-22-91	<4	.3	8.01	2.83	12	2.0	47	3.0	1.7	.31	5.9	1.5	3.47
	12-17-91	6	.3	--	--	--	--	48	3.0	2.1	.36	6.1	1.6	2.90
15-1063	03-21-91	<4	<.1	10.2	2.43	3.9	1.0	47	3.0	4.2	.75	1.9	.7	.45
	12-17-91	5	<.1	--	--	--	--	45	3.0	5.1	.86	2.3	.7	.45
15-1058	03-21-91	<4	<.1	3.28	1.01	3.4	1.1	160	11	1.8	.29	^{2}<1.0(.65)	.5	^{3}(.36)
	03-21-91	<4	<.1	3.79	1.20	3.6	1.1	140	10	1.8	.30	1.1	.5	.61
	12-27-91	4	<.1	--	--	--	--	160	10	3.0	.51	1.4	.6	.47
15-1059	03-20-91	<4	<.1	.54	.43	1.4	.50	<1.0	<.1	.09	.02	^{2}<1.0(.27)	.3	^{3}(3.00)
	12-17-91	<4	<.1	--	--	--	--	1.0	1.0	.13	.03	^{2}<1.0(.07)	.4	^{3}(.54)
Upper Pittsgrove Township site														
33-680	03-27-91	<4	<.1	--	--	.8	.50	41	3.0	.07	.02	^{2}<1.0(.29)	.3	^{3}(4.14)
33-681	03-27-91	<4	.7	--	--	21	2.9	50	4.0	.97	.17	^{2}<1.0(.36)	.3	^{3}(.37)

Footnotes at end of table.

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991--Continued

USGS well number	Date	Uranium, dissolved (µg/L)	Uranium, 2 sigma water, dissolved (µg/L)	Radon-222 (pCi/L)	Radon-222, 2 sigma (pCi/L)	Bromacil, tot. rec. (µg/L)	Butachlor, tot. rec. (µg/L)	Butylate, tot. rec. (µg/L)	Carboxin, tot. rec. (µg/L)	Cycloate, tot. rec. (µg/L)
Seabrook site										
11-696	11-20-91	0.06	<1	<80	51	--	--	--	--	--
11-692	05-01-91	.02	<1	<80	79	<0.20	<0.10	<0.10	<0.20	<0.10
	05-01-91	.02	<1	<80	71	<.20	<.10	<.10	<.20	<.10
	12-20-91	.01	<1	110	45	<.20	<.10	<.10	<.20	<.10
11-700	11-22-91	.13	<1	99	35	--	--	--	--	--
11-693	05-01-91	.11	<1	420	84	<.20	<.10	<.10	<.20	<.10
	12-20-91	.12	<1	480	46	<.20	<.10	<.10	<.20	<.10
11-694	03-28-91	--	--	370	43	<.20	<.10	<.10	<.20	<.10
	05-02-91	.06	<1	280	63	<.20	<.10	<.10	<.20	<.10
	12-23-91	.03	<1	300	35	--	--	--	--	--
Cross Keys site										
15-1051	03-20-91	.04	<1	520	630	<.20	<.10	<.10	<.20	<.10
15-1052	03-19-91	.02	<1	190	62	<.20	<.10	<.10	<.20	<.10
15-1053	03-19-91	.04	<1	310	61	<.20	<.10	<.10	<.20	<.10
Glassboro site										
15-1054	05-07-91	.15	<1	410	30	<.20	<.10	<.10	<.20	<.10
15-1055	03-26-91	.16	<1	880	39	.30	<.10	<.10	<.20	<.10
15-1056	03-22-91	.03	<1	140	43	<.20	<.10	<.10	<.20	<.10
Southern Washington Township site										
15-1057	03-22-91	.17	<1	110	63	<.20	<.10	<.10	<.20	<.10
	12-17-91	.19	<1	290	74	<.20	<.10	<.10	<.20	<.10
15-1063	03-21-91	.06	<1	400	65	<.20	<.10	<.10	<.20	<.10
	12-17-91	.09	<1	480	72	<.20	<.10	<.10	<.20	<.10
15-1058	03-21-91	.04	<1	1,100	68	<.20	<.10	<.10	<.20	<.10
	03-21-91	.05	<1	1,000	69	<.20	<.10	<.10	<.20	<.10
	12-27-91	.09	<1	1,000	38	--	--	--	--	--
15-1059	03-20-91	<.01	<1	510	190	<.20	<.10	<.10	<.20	<.10
	12-17-91	.01	<1	440	71	--	--	--	--	--
Upper Pittsgrove Township site										
33-680	03-27-91	.04	<1	550	750	<.20	<.10	<.10	<.20	<.10
33-681	03-27-91	.01	<1	460	53	<.20	<.10	<.10	<.20	<.10

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991--Continued

USGS well number	Date	Diphenamid, tot. rec. (µg/L)	Hexazinone, tot. rec. (µg/L)	Methiocarb, tot. rec. (µg/L)	Propachlor, tot. rec. (µg/L)	Propoxur, tot. rec. (µg/L)	Terbacil, tot. rec. (µg/L)	Vernolate, tot. rec. (µg/L)	Propazine, tot. rec. (µg/L)	Trifluralin, tot. rec. (µg/L)	Perthane, tot. rec. (µg/L)
					Seabrook site						
11-696	11-20-91	--	--	--	--	--	--	--	--	--	--
11-692	05-01-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
	05-01-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
	12-20-91	<.10	<.20	<.5	<.10	<.5	<.20	<.10	<.10	.10	--
11-700	11-22-91	--	--	--	--	--	--	--	--	--	--
11-693	05-01-91	<.10	<.20	--	.10	--	<.20	<.10	<.10	<.10	<.1
	12-20-91	<.10	<.20	<.5	<.10	<.5	<.20	<.10	<.10	<.10	--
11-694	03-28-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
	05-02-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
	12-23-91	--	--	--	--	--	--	--	--	--	--
					Cross Keys site						
15-1051	03-20-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
15-1052	03-19-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	--
15-1053	03-19-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
					Glassboro site						
15-1054	05-07-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
15-1055	03-26-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
15-1056	03-22-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
					Southern Washington Township site						
15-1057	03-22-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
	12-17-91	<.10	<.20	<.5	<.10	<.5	.90	<.10	<.10	<.10	--
15-1063	03-21-91	<.10	<.20	--	<.10	--	1.0	<.10	<.10	<.10	<.1
	12-17-91	<.10	<.20	<.5	<.10	<.5	1.4	<.10	<.10	<.10	--
15-1058	03-21-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
	03-21-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
	12-27-91	--	--	--	--	--	--	--	--	--	--
15-1059	03-20-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
	12-17-91	--	--	--	--	--	--	--	--	--	--
					Upper Pittsgrove Township site						
33-680	03-27-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	<.1
33-681	03-27-91	<.10	<.20	--	<.10	--	<.20	<.10	<.10	<.10	--

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991--Continued

USGS well number	Date	Methomyl, total (µg/L)	Propham, total (µg/L)	Simetryne, total (µg/L)	Simazine, total (µg/L)	Prometone, total (µg/L)	Prometryne, total (µg/L)	Naphthalene, polychlor, total (µg/L)	Aldrin, total (µg/L)	Lindane, total (µg/L)	Chlordane, total (µg/L)
Seabrook site											
11-696	11-20-91	--	--	--	--	--	--	--	--	--	--
11-692	05-01-91	<.5	<.5	<.10	.60	<.20	<.10	<.10	<.010	<.010	<.1
	05-01-91	<.5	<.5	<.10	.60	<.20	<.10	<.10	<.010	<.010	<.1
	12-20-91	<.5	<.5	<.10	.90	<.20	<.10	--	--	--	--
11-700	11-22-91	--	--	--	--	--	--	--	--	--	--
11-693	05-01-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
	12-20-91	<.5	<.5	<.10	<.10	<.20	<.10	--	--	--	--
11-694	03-28-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
	05-02-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
	12-23-91	--	--	--	--	--	--	--	--	--	--
Cross Keys site											
15-1051	03-20-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
15-1052	03-19-91	<.5	<.5	<.10	<.10	<.20	<.10	--	--	--	--
15-1053	03-19-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
Glassboro site											
15-1054	05-07-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
15-1055	03-26-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
15-1056	03-22-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
Southern Washington Township site											
15-1057	03-22-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
	12-17-91	<.5	<.5	<.10	<.10	<.20	<.10	--	--	--	--
15-1063	03-21-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
	12-17-91	<.5	<.5	<.10	<.10	<.20	<.10	--	--	--	--
15-1058	03-21-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
	03-21-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
	12-27-91	--	--	--	--	--	--	--	--	--	--
15-1059	03-20-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
	12-17-91	--	--	--	--	--	--	--	--	--	--
Upper Pittsgrove Township site											
33-680	03-27-91	<.5	<.5	<.10	<.10	<.20	<.10	<.10	<.010	<.010	<.1
33-681	03-27-91	<.5	<.5	<.10	<.10	<.20	<.10	--	--	--	--

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991--Continued

USGS well number	Date	DDD, total (μg/L)	DDE, total (μg/L)	DDT, total (μg/L)	Dieldrin, total (μg/L)	Endo-sulfan, total (μg/L)	Endrin, total (μg/L)	Toxa-phene, total (μg/L)	Hepta-chlor, total (μg/L)	Hepta-chlor epoxide, total (μg/L)	Meth-oxychlor, total (μg/L)
Seabrook site											
11-696	11-20-91	--	--	--	--	--	--	--	--	--	--
11-692	05-01-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
	05-01-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
	12-20-91	--	--	--	--	--	--	--	--	--	--
11-700	11-22-91	--	--	--	--	--	--	--	--	--	--
11-693	05-01-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
	12-20-91	--	--	--	--	--	--	--	--	--	--
11-694	03-28-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
	05-02-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
	12-23-91	--	--	--	--	--	--	--	--	--	--
Cross Keys site											
15-1051	03-20-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
15-1052	03-19-91	--	--	--	--	--	--	--	--	--	--
15-1053	03-19-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
Glassboro site											
15-1054	05-07-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
15-1055	03-26-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
15-1056	03-22-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
Southern Washington Township site											
15-1057	03-22-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
	12-17-91	--	--	--	--	--	--	--	--	--	--
15-1063	03-21-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
	12-17-91	--	--	--	--	--	--	--	--	--	--
15-1058	03-21-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
	03-21-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
	12-27-91	--	--	--	--	--	--	--	--	--	--
15-1059	03-20-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
	12-17-91	--	--	--	--	--	--	--	--	--	--
Upper Pittsgrove Township site											
33-680	03-27-91	<.010	<.010	<.010	<.010	<.010	<.010	<1	<.010	<.010	<.01
33-681	03-27-91	--	--	--	--	--	--	--	--	--	--

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991--Continued

USGS well number	Date	PCB, total (μg/L)	Atrazine, total (μg/L)	Sevin, total (μg/L)	Mirex, total (μg/L)	De-isopropyl atrazine, total (μg/L)	Deethyl-atrazine, total (μg/L)
Seabrook site							
11-696	11-20-91	--	--	--	--	--	--
11-692	05-01-91	<.1	.80	<.5	<.01	<.20	<.20
	05-01-91	<.1	.80	<.5	<.01	<.20	<.20
	12-20-91	--	.90	<.5	--	.20	.30
11-700	11-22-91	--	--	--	--	--	--
11-693	05-01-91	<.1	<.10	<.5	<.01	<.20	<.20
	12-20-91	--	<.10	<.5	--	<.20	<.20
11-694	03-28-91	<.1	<.10	<.5	<.01	<.20	<.20
	05-02-91	<.1	<.10	<.5	<.01	<.20	<.20
	12-23-91	--	--	--	--	--	--
Cross Keys site							
15-1051	03-20-91	<.1	<.10	<.5	<.01	--	--
15-1052	03-19-91	--	<.10	<.5	--	--	--
15-1053	03-19-91	<.1	<.10	<.5	<.01	--	--
Glassboro site							
15-1054	05-07-91	<.1	.50	<.5	<.01	<.20	.20
15-1055	03-26-91	<.1	<.10	<.5	<.01	<.20	<.20
15-1056	03-22-91	<.1	<.10	<.5	<.01	--	--
Southern Washington Township site							
15-1057	03-22-91	<.1	<.10	<.5	<.01	--	--
	12-17-91	--	<.10	<.5	--	<.20	<.20
15-1063	03-21-91	<.1	<.10	<.5	<.01	<.20	<.20
	12-17-91	--	<.10	<.5	--	<.20	<.20
15-1058	03-21-91	<.1	<.10	<.5	<.01	--	--
	03-21-91	<.1	<.10	<.5	<.01	--	--
	12-27-91	--	--	--	--	--	--
15-1059	03-20-91	<.1	<.10	<.5	<.01	--	--
	12-17-91	--	--	--	--	--	--
Upper Pittsgrove Township site							
33-680	03-27-91	<.1	.30	<.5	<.01	<.20	.80
33-681	03-27-91	--	.40	<.5	--	<.20	.60

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991--Continued

USGS well number	Date	1-Naphthol, recoverable (μg/L)	Alachlor, total recoverable (μg/L)	Cyanazine, total (μg/L)	Ametryne, total (μg/L)	3-Hydrx carbofuranm total recoverable (μg/L)	Aldicarb sulfoxide, total recoverable (μg/L)	Aldicarb sulfone, total recoverable (μg/L)
Seabrook site								
11-696	11-20-91	--	--	--	--	--	--	--
11-692	05-01-91	<.5	1.1	<.20	<.10	<.5	<.5	<.5
	05-01-91	<.5	1.1	<.20	<.10	<.5	<.5	<.5
	12-20-91	<.5	.50	<.20	<.10	<.5	<.5	<.5
11-700	11-22-91	--	--	--	--	--	--	--
11-693	05-01-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
	12-20-91	<.5	<.10	<.20	<.10	<.5	<.5	<.5
11-694	03-28-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
	05-02-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
	12-23-91	--	--	--	--	--	--	--
Cross Keys site								
15-1051	03-20-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
15-1052	03-19-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
15-1053	03-19-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
Glassboro site								
15-1054	05-07-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
15-1055	03-26-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
15-1056	03-22-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
Southern Washington Township site								
15-1057	03-22-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
	12-17-91	<.5	<.10	<.20	<.10	<.5	<.5	<.5
15-1063	03-21-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
	12-17-91	<.5	<.10	<.20	<.10	<.5	<.5	<.5
15-1058	03-21-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
	03-21-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
	12-27-91	--	--	--	--	--	--	--
15-1059	03-20-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
	12-17-91	--	--	--	--	--	--	--
Upper Pittsgrove Township site								
33-680	03-27-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5
33-681	03-27-91	<.5	<.20	<.20	<.10	<.5	<.5	<.5

Appendix 2C. Results of analyses for inorganic chemical constituents, radionuclides, nutrients, and pesticides, and results of field measurements of dissolved-oxygen concentration, pH, and specific conductance in water samples from various depths in the Kirkwood-Cohansey aquifer system in agricultural areas of southwestern New Jersey, 1991--Continued

USGS well number	Date	Metribuzin, total recoverable (μg/L)	Metolachlor, total recoverable (μg/L)	Oxyamyl, total recoverable (μg/L)	Carbofuran, total recoverable (μg/L)	Aldicarb, total recoverable (μg/L)	Delta ^{15}N stable isotope ratio, nitrate (per mil)
Seabrook site							
11-696	11-20-91	--	--	--	--	--	--
11-692	05-01-91	.10	<.20	<.5	.5	<.5	3.90
	05-01-91	.10	<.20	<.5	.5	<.5	4.10
	12-20-91	.10	2.8	<.5	<.5	<.5	--
11-700	11-22-91	--	--	--	--	--	--
11-693	05-01-91	<.10	<.20	<.5	<.5	<.5	3.00
	12-20-91	<.10	<.20	<.5	<.5	<.5	--
11-694	03-28-91	<.10	<.20	<.5	<.5	<.5	--
	05-02-91	<.10	<.20	<.5	<.5	<.5	3.10
	12-23-91	--	--	--	--	--	--
Cross Keys site							
15-1051	03-20-91	<.10	<.20	<.5	<.5	<.5	.70
15-1052	03-19-91	<.10	<.20	<.5	<.5	<.5	.40
15-1053	03-19-91	<.10	<.20	<.5	<.5	<.5	1.50
Glassboro site							
15-1054	05-07-91	<.10	<.20	<.5	<.5	<.5	4.70
15-1055	03-26-91	<.10	<.20	<.5	<.5	<.5	5.80
15-1056	03-22-91	<.10	<.20	<.5	<.5	<.5	6.30
Southern Washington Township site							
15-1057	03-22-91	<.10	<.20	<.5	<.5	<.5	4.60
	12-17-91	<.10	<.20	<.5	<.5	<.5	--
15-1063	03-21-91	<.10	<.20	<.5	<.5	<.5	6.90
	12-17-91	<.10	<.20	<.5	<.5	<.5	--
15-1058	03-21-91	<.10	<.20	<.5	<.5	<.5	6.50
	03-21-91	<.10	<.20	<.5	<.5	<.5	6.30
	12-27-91	--	--	--	--	--	--
15-1059	03-20-91	<.10	<.20	<.5	<.5	<.5	--
	12-17-91	--	--	--	--	--	--
Upper Pittsgrove Township site							
33-680	03-27-91	<.10	<.20	<.5	<.5	<.5	3.00
33-681	03-27-91	<.10	<.20	<.5	<.5	<.5	7.90

[1] Possible colloidal iron mobilized during piezometer emplacement.

[2] Measured concentration of radium-228 less than the minimum reporting limit of 1 pCi/L is given in parentheses.

[3] Radium-228/radium-226 isotope ratio computed by using the measured radium-228 concentration less than the minimum reporting limit of 1 pCi/L; the isotope ratio is, therefore, uncertain and is given in parentheses.