USGS
science for a changing world

Prepared in cooperation with the
New Jersey Department of Environmental Protection

Occurrence of Radium-224, Radium-226, and Radium-228 in Water of the Unconfined Kirkwood-Cohansey Aquifer System, Southern New Jersey

Scientific Investigations Report 2004-5224

U.S. Department of the Interior
U.S. Geological Survey

Occurrence of Radium-224, Radium-226, and Radium-228 in Water of the Unconfined Kirkwood-Cohansey Aquifer System, Southern New Jersey

By Zoltan Szabo, Vincent T. dePaul, Thomas F. Kraemer, and Bahman Parsa

In cooperation with the
New Jersey Department of Environmental Protection

Scientific Investigations Report 2004-5224

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

U.S. Geological Survey, Reston, Virginia: 2005

For sale by U.S. Geological Survey, Information Services
Box 25286, Denver Federal Center
Denver, CO 80225

For more information about the USGS and its products:
Telephone: 1-888-ASK-USGS
World Wide Web: http://www.usgs.gov/

Contents

Figures

Tables

Conversion Factors, Vertical Datum, and Abbreviated Water-Quality Units

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
ounce, fluid (fl. oz)	0.02957	liter (L)
ounce, fluid (fl. oz)	29.57	milliliter (mL)
gallon (gal)	3.785	liter (L)
million gallons per day (Mgal/d)	3,785	million liters per day (ML/d)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)
ounce, avoirdupois (oz)	28,349	milligram (mg)
ounce, avoirdupois (oz)	28,349,000	microgram (µg)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
Radioactivity		
picocuries per liter	2.22	radioactive disintegrations per minute
becquerel per liter (Bq/L)	1	radioactive disintegrations per second
picocuries per liter	0.037	becquerels per liter

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Water-quality abbreviations

nm	=	nanometer
µm	=	micrometer
ng/L	=	nanograms per liter (parts per trillon)
µg/L	=	micrograms per liter (parts per billion or ppb)
mg/L	=	milligrams per liter (parts per million or ppm)
µg/kg	=	micrograms per kilogram (parts per billion)
mg/m^3	=	milligrams per cubic meter
M	=	Molar, or moles
µM	=	micromolar
Ac	=	actinium
Cs	=	cesium
Pb	=	lead
Po	=	polonium
Ra	=	radium
Rn	=	radon
Th	=	thorium
U	=	uranium
KeV	=	kiloelectron volts
SSMDC	=	sample specific minimum detectable concentration
PE	=	precision estimate
pCi	=	picocurie
pCi/L	=	picocurie per liter
pCi/g	=	picocurie per gram
LRL	=	laboratory reporting limit
<	=	less than

Occurrence of Radium-224, Radium-226, and Radium-228 in Water of the Unconfined Kirkwood-Cohansey Aquifer System, Southern New Jersey

By Zoltan Szabo, Vincent T. dePaul, Thomas F. Kraemer, and Bahman Parsa

Abstract

Water in the unconfined Kirkwood-Cohansey aquifer system in the New Jersey Coastal Plain contains elevated concentrations (above 3 pCi/L (picocuries per liter)) of the alpha-particle-emitting radionuclide radium-224. Previously, water from the aquifer system had been found to contain radium-226 and radium-228. This observation is of concern because the previously undetected presence of radium-224 may pose an additional, quantifiable health risk that currently is not accounted for by the Maximum Contaminant Level (MCL) of 5 pCi/L for combined radium (the sum of radium-226 plus radium-228 is termed "combined radium") in drinking water.

Water samples were collected from a regional network of 88 wells for determination of concentrations of radium-224, radium-226, and radium-228; gross alpha-particle activity; and concentrations of major ions and selected trace elements. Both gamma and alpha spectroscopic techniques were used to determine concentrations of radium-224, which ranged from <0.5 to 16.8 pCi/L (median 2.1 pCi/L, interquartile range 1.2-3.7 pCi/L). Concentrations of radium-226 and radium-228 in the same samples ranged from <0.5 to 17.4 pCi/L (median 1.7 pCi/L, interquartile range 0.9-2.9 pCi/L) and <0.5 to 12.8 pCi/L (median 1.6 pCi/L, interquartile range, 0.9-2.6 pCi/L), respectively. Concentrations of radium-224 typically were greater than those of the other two radium radionuclides, as evidenced by the highest median, third quartile, and maximum concentrations, as well as the highest concentration among the three radium radioisotopes in 52 (59 percent) of the 88 samples.

Concentrations of 5.0 to 5.5 pCi/L of radium-224 result in a gross alpha-particle activity of about 15 pCi/L (the MCL) 36 to 48 hours, respectively, after sample collection when ingrowth of radium-224 progeny radionuclides is considered, even with the unlikely assumption that no other alpha-particle-emitting radionuclide is present in the water. Concentrations of 3.4 to 3.7 pCi/L radium-224 result in a gross alpha-particle activity of 10 pCi/L 36 to 48 hours, respectively, after sample collection when ingrowth of Ra-224 progeny radionuclides is considered. In this latter case, it is possible that the summed alpha-particle activity from radium-226 present at a concentration less than or equal to 5 pCi/L (the MCL for combined radium) and from radium-224 present at a concentration about 3.4 pCi/L or greater may exceed the 15-pCi/L MCL for gross alpha-particle activity. In this study, gross alpha-particle activities were measured within 48 hours after sample collection and were found to exceed the MCL of 15 pCi/L in nearly half (43) of the 88 samples collected. The concentration of radium-224 exceeded that of radium-226 in 55 (62.5 percent) of the 88 samples.

Concentrations of radium-224 correlate strongly with those of both radium-226 and radium-228 (Spearman correlation coefficients r=0.74 and 0.91, respectively). Concentrations of radium-224, radium-226, and radium-228 were greatest in the most acidic ground water. Concentrations of radium-224 and combined radium-226 and radium-228 in samples of ground water with pH less than 4.7 exceeded 5 pCi/L in 33 and 67 percent of the samples, respectively. Concentrations of radium-224, radium-226, and radium-228 (measured separately) were greatest in water from the southern part of the aquifer outcrop area. In water from the northern part of the aquifer system outcrop area, radium-224 concentrations were as high as 3.6 pCi/L, and concentrations of combined radium and gross alpha-particle activity in some samples exceeded their respective MCLs.

The presence of gross alpha-particle activities greater than 15 pCi/L and combined radium-226 and radium-228 concentrations greater than 5 pCi/L in the southwestern part of the aquifer system outcrop area is common and had been documented before 1997. Results of this study confirm these earlier findings. In northeastern and southeastern parts of the aquifer outcrop area, gross alpha-particle activities exceeded 15 pCi/L only in isolated areas (primarily central Ocean County and southeastern Atlantic County) but with greater frequency in this study (when the 48-hour holding time for gross alpha-particle activity analysis was used) than in previous investigations (before 1997), indicating that radium-224 contributes considerable gross alpha-particle activity to drinking water produced from the aquifer system.

Introduction

Radionuclides are ubiquitous trace elements in rocks, soils, and waters; therefore, exposure to naturally occurring radioactivity in varying degrees occurs universally. Most naturally occurring radionuclides are formed through the decay of uranium-238 and thorium-232. Uranium-235 is a third naturally occurring, long-lived radionuclide, but its abundance is less than 1 percent that of uranium-238. Both uranium and thorium decay slowly and produce other, intermediate radioactive elements, such as radium, which in turn undergo still further radioactive decay. These radioactive progenies exhibit different chemical properties, have shorter half-lives, and emit various types of radiation at different rates and energies than either parent isotope (Durrance, 1986; Zapecza and Szabo, 1988).

Radioactive decay is the emission of particles and energy from the nucleus of an atom (a radionuclide) with an unstable configuration within the nucleus. The emitted particles are classified as either alpha particles (a nucleus of a helium-4 atom) or beta particles (an electron), each with a characteristic level of kinetic energy specific to the nuclide. Energy also is emitted in the form of gamma rays, also with intensity specific to the nuclide. The radiation that is emitted can strip electrons from atoms with which it collides, causing the atom it contacts to become ionized. Cellular tissue can be damaged by exposure to ionizing radiation. This tissue damage can increase the risk of incurring cancer (U.S. Environmental Protection Agency, 1999).

The ionizing radiation emitted by radium is alpha and beta radiation. Alpha particles move slowly and cannot penetrate skin. Beta particles can penetrate skin, but only the surficial layer. If radium is ingested, however, especially dissolved in water, then the emitted alpha- and beta-particle radiation can come into contact with, ionize, and damage internal cell tissue. The risk incurred from the alpha-particle emissions depends on the way the body metabolizes the ingested radionuclide (Durrance, 1986, p. 90).

The various isotopes of naturally occurring radium are radium-223 (Ra-223), radium-224 (Ra-224), radium-226 (Ra-226), and radium-228 (Ra-228). Ra-224, the fifth radionuclide in the thorium-232 decay series (fig. 1), is derived from the decay of thorium-228 (Th-228) and has the shortest half-life (3.64 days) of the radium isotopes (Ra-223, 11.43 days; Ra-228, 5.75 years; Ra-226, 1,602 years). The half-life of a radionuclide is defined as the time required for one-half of the original amount of the radionuclide to decay. The half-lives may range from long (years) to short (seconds, hours, or a few days) intervals. Ra-223, Ra-224, and Ra-226 decay by emitting an alpha particle, whereas Ra-228 emits a beta particle in decay to actinium-228 (Ac-228) (fig. 1). Ra-224 decays directly to radon-220 (Rn-220), which has a half-life of less than 1 minute, and eventually to stable lead-208 (Pb-208) through other intermediate products; of these products, only lead-212 (Pb-212) has a half-life that is longer than 1 hour (fig. 1). Radium-226 decays to radon-222 (Rn-222), which has a half-life of 3.8 days; because of its relatively long half-life relative to Rn-220, it is Rn-222 that typically is naturally abundant in ground water, soil gas, and, in places, indoor air. Radium-223 is derived from the decay of uranium-235 (U-235) and, therefore, is likely to be less abundant than the other naturally occurring radium radionuclides.

Naturally occurring Ra-224 can enter ground water from aquifer solids by radioactive decay of the parent isotope (Th-228) in the solids by alpha recoil, by chemical processes such as dissolution of aquifer materials or desorption from rock or sediment surfaces, or by radioactive decay of the parent isotope in solution (unlikely except in extremely acid or alkaline waters, as Th generally is insoluble). The occurrence, distribution, and concentration of the parent Th-228 radionuclide in the solids, therefore, are a major control on the occurrence of Ra-224. Alpha recoil is a process whereby kinetic energy is imparted to the product nuclide during alpha decay, damaging the crystal lattice surrounding the atom and allowing the atom to break free from the solid structure. Through recoil in the opposite direction from the emitted alpha particle, the product radionuclide may be directly "ejected" into pores or eventually may be preferentially leached (dissolved) at the locus of crystal lattice damage (a process termed "track etching" by Fleischer (1980)) depending on the proximity of the parent radionuclide to the mineral-grain boundary. Once Ra-224 is in the aqueous environment, its concentration is governed by its short half-life (3.64 days), the sorptive properties of the aquifer material, and the geochemical setting.

Radium in drinking water is known to increase the risk of cancer, primarily bone and sinus cancers (Mays and others, 1985). Human bone tissue accumulates radium much like it does calcium and strontium, rather than allowing it to be removed from the body. The bones are then exposed to tissue-damaging alpha or beta radiation. Tissue damage from continuous exposure may cause malignancies. Risk increases with increased exposure. Mays and others (1985) estimated the cancer risk from Ra-224 to be less than that from Ra-226 because the short half-life of Ra-224 limits the radiation dose to the bone. Because of the short half-life of Ra-224, however, much of the Ra-224 decays on bone surfaces, where it may have enhanced effectiveness (Mays and others, 1985; Schleien, 1992). Reevaluation by the U.S. Environmental Protection Agency (USEPA) in 1999 indicates that the lifetime cancer risk from the ingestion of Ra-224 is less than that from ingestion of an equal amount of Ra-226 or Ra-228 (U.S. Environmental Protection Agency, 1999) but greater than that suggested in the aforementioned study by Mays and others (1985).

The U.S. Environmental Protection Agency (USEPA) has established a Maximum Contaminant Level (MCL) for Ra in public drinking-water supplies because of health risks associated with its ingestion. The MCL is 5 pCi/L for combined radium, which is defined as the sum of Ra-226 and Ra-228. The MCL for gross alpha-particle activity is 15 pCi/L. These MCLs are set on the approximate order of magnitude of a 1 in 20,000 risk of incurring a fatal cancer if 2 L of water per day is consumed for 70 years. The MCLs had interim status since 1976 and were finalized in 2000 (U.S. Environmental Protection Agency, 1976; U.S. Environmental Protection Agency, 2000a).

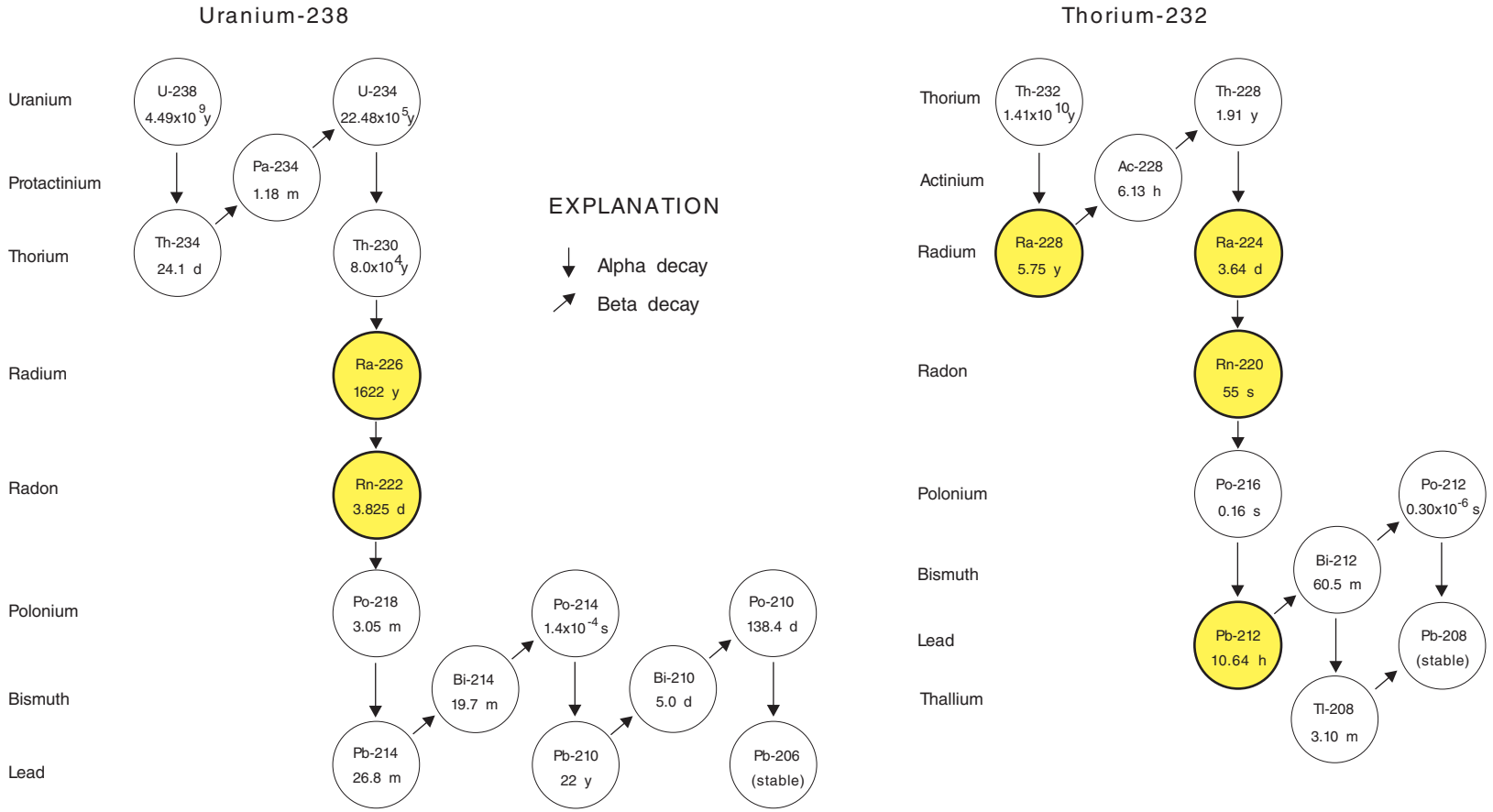

Figure 1. Uranium-238 and thorium-232 radioactive decay series (Modified from Hall and others, 1985).

Table 1. Effect of time-dependence of alpha-particle ingrowth and decay for radium-224 and progeny on measured gross alpha-particle activity for selected radium-224 concentrations

[Factors computed by Parsa, 1998; all concentrations and activities in picocuries per liter]

Time after sample collection (hours)	Theoretical gross alpha-particle activity from a radium-224 concentration of:			Theoretical radium-224 concentration required to obtain a gross alpha-particle activity of:		
	1	3	5	3	5	15
2	2.99	8.97	14.95	1.00	1.67	5.02
4	3.05	9.15	15.25	.98	1.64	4.92
6	3.10	9.30	15.50	.97	1.61	4.84
12	3.19	9.57	15.95	.94	1.57	4.70
24	3.16	9.48	15.80	.95	1.58	4.75
36	2.99	8.97	14.95	1.00	1.67	5.02
48	2.77	8.31	13.85	1.08	1.81	5.42
72	2.32	6.96	11.60	1.29	2.16	6.47
96	1.93	5.79	9.65	1.55	2.59	7.77
144	1.32	3.96	6.60	2.27	3.79	11.36
192	.90	2.70	4.50	3.33	5.56	16.67
384	.19	.57	.95	15.79	26.32	78.95
576	.04	.12	.20	75.00	125.00	375.00

Currently, no MCL is proposed for Ra-224. A range of concentration values from 3 to 12 pCi/L has been suggested informally as an MCL or action level (AL); in the absence of additional regional data regarding the occurrence of this radionuclide (U.S. Environmental Protection Agency, 2000b), no value has yet reached the stage of a proposed MCL or AL.

Until recent work by Parsa (1998) and Szabo and others (1998a), only long-lived Ra-226 and Ra-228 had been documented to be present in appreciable concentrations in ground water. The presence of elevated concentrations of Ra-226 and Ra-228 in water from many aquifers, including the Kirkwood-Cohansey aquifer system in southern New Jersey, has been reported previously (Kozinski and others, 1995; Szabo and dePaul, 1998). Results of the studies by Parsa (1998) and Szabo and others (1998a) indicate that Ra-224 also may be prevalent in the ground water.

The composition of water in the Kirkwood-Cohansey aquifer system was investigated further for the presence of radionuclides other than Ra-226 and Ra-228 for several reasons. First, the presence of elevated gross alpha-particle radioactivity could not be explained by the concentrations of Ra-226 alone (Kozinski and others, 1995; Szabo and dePaul, 1998). Second, gross alpha-particle activities in water from the aquifer system have been shown to vary temporally (Parsa, 1998). The variation could not be explained in terms of variation in the concentration of Ra-226; repeated sampling of a set of four wells screened in the aquifer showed little temporal variation in the concentration of Ra-226 (Szabo and others, 1997). Other factors related to laboratory procedures that introduce variability into values of gross alpha-particle activity, such as the internal standard chosen (Janzer, 1980) and the dissolved-solids content and composition of the sample matrix (U.S. Environmental Protection Agency, 1997; Jeter, 1998), could not account for the observed variability. Therefore, additional study was needed to determine whether the presence of a previously undetermined radioisotope could be causing the variability and, if so, to determine the distribution of the radioisotope(s) in the ground water.

The concern is that the previously undetected presence of Ra-224 may pose an additional, quantifiable health risk that currently is not accounted for by the 5-pCi/L MCL for combined radium in drinking water. The concentration of Ra-224 is not included in the definition of combined radium as posed by USEPA in 1976 (U.S. Environmental Protection Agency, 1976) nor by the 15-pCi/L MCL for gross alpha-particle activity because the current analytical technique, as proposed by USEPA in 1976 (U.S. Environmental Protection Agency, 1976), does not include a sample-holding time; therefore, the alpha-particle activity because of short-lived radionuclides, such as Ra-224, may not be detected during analysis.

Theoretical calculations by Parsa (1998) indicate that Ra-224, if present, contributes considerable gross alpha-particle activity to a water sample for about 7 days after sample collection. These calculations (1998) indicate that for each picocurie per liter of Ra-224 that is present in the sample, almost 3 pCi/L of gross alpha-particle activity will be present in the sample 48 hours after collection (table 1). Forty-eight hours after sample-collection time, a water sample with 5.41 pCi/L Ra-224 would emit 15 pCi/L of alpha-particle activity (because of short-lived progeny ingrowth) and, thus, equal the MCL for gross alpha-particle activity (table 1). The theoretical calculations and initial measurements made by Parsa (1998) indicate that gross alpha-particle activities greater than the 15-pCi/L MCL may occur in water from the aquifer system with greater frequency than was detected in previous investigations because alpha-particle activity from Ra-224 was not detected using the analytical protocol (which allowed unlimited holding time) in effect at the time (1997). Additional mathematical analysis indicates that a sample held for 8 days after collection before analysis must contain 16.7 pCi/L of Ra-224 to generate 15 pCi/L of alpha-particle radioactivity because of rapid decay of both Ra-224 and progeny. Samples collected before 1997 commonly were held as long as 16 to 24 days before analysis; these long holding times would require the presence of 15.8 and 75 pCi/L of Ra-224 in the sample, respectively, to emit even 3 pCi/L of alpha-particle activity. For determination of gross alpha-particle activity using standard 100-minute counting times with a 0.3-L sample aliquot and a well-maintained low-background gas-proportional counter, 3 pCi/L typically is the minimum reliably quantified level and represents the standard laboratory reporting limit (LRL) for many radiation laboratories. Thus, the

amount of Ra-224 that must be present in the water before a substantial effect on gross alpha-particle activity is noted 16 to 24 days after sample-collection time is considerable. It is likely that a considerable amount of alpha-particle activity from Ra-224 was not detected by the analytical protocol used before 1997. Determination of the concentration of Ra-224, if present, and measurements of gross alpha-particle activity within 48 hours after sample collection are important to determine the actual amount of alpha-particle activity to which the water consumer is exposed by ingestion of drinking water, as ingestion in almost all cases occurs in the first three days after withdrawal of water from the aquifer system.

In the response to results of the investigation by Parsa (1998) and Szabo and others (1998a), the New Jersey Department of Environmental Protection (NJDEP) implemented changes in analytical protocols to ensure that the contribution to alpha-particle radioactivity from the presence of Ra-224 in drinking water would be detected by gross alpha-particle activity analysis. A 48-hour holding time for gross alpha-particle activity analysis of drinking water was implemented for compliance purposes in the State of New Jersey in 2002 (New Jersey Department Environmental Protection, 2002). The NJDEP also requires gross alpha-particle analysis within 48 hours for water samples collected from private wells in compliance with the Private Well Testing Act (PWTA) (New Jersey Department Environmental Protection, 2002). Analysis within 48 hours of sample collection ensures that most of the alpha-particle activity emitted by Ra-224 is detected (Parsa, 1998). The implementation of the revised protocol is being phased in by region; the new protocol was implemented first in the southern part of the Kirkwood-Cohansey aquifer system on the basis of the many instances of high concentrations of radioactivity in that region reported by Szabo and dePaul (1998), Szabo and others (1998a), and Parsa (1998). In the Notice of Data Availability (NODA) (U.S. Environmental Protection Agency, 2000b) that accompanied the Radionuclide Rule of 2000 (U.S. Environmental Protection Agency, 2000a), the USEPA recommended determination of concentrations of Ra-224 in aquifers and regions where Ra isotopes are present in ground water. The U.S. Geological Survey (USGS) and the NJDEP have been working cooperatively to characterize Ra-224 concentrations and radium-isotope ratios in water from major aquifers where radium is considered likely to be present, and, in 2000, Szabo and others (2000) reported initial findings that Ra-224 is common in water from the Kirkwood-Cohansey aquifer system.

As part of this ongoing work, the USGS, in cooperation with the NJDEP, investigated the presence of elevated and varying gross alpha-particle activities in the Kirkwood-Cohansey aquifer system that are not explained by the concentrations of long-lived alpha-particle-emitting radionuclides, such as Ra-226 and U-238. Therefore, these alpha-particle activities indicate that one or more additional alpha-particle-emitting radionuclide(s) may be present in the water. The known presence of Ra-228 in the water from the aquifer indicates that Ra-224, ultimately derived from Ra-228 (fig. 1), may be present. Knowledge of the distribution of Ra-224 could be used by NJDEP as it continues to implement its regional plan for the 48-hour holding time analytical protocol for gross alpha-particle activity analysis (New Jersey Department Environmental Protection, 2002).

Purpose and Scope

This report documents the occurrence of the short-lived radioisotope of radium, Ra-224, in water from the Kirkwood-Cohansey aquifer system underlying southern New Jersey—particularly in areas where the water is used for drinking-water supply—and compares its distribution to those of the radium isotopes Ra-226 and Ra-228. The concentration of Ra-224 is compared to gross alpha-particle activity measured within 48 hours after sample collection to determine whether the presence of previously unmeasured Ra-224 may account for some of the unexpected elevated gross alpha-particle activity reported previously (Parsa, 1998) for water from the aquifer that cannot be ascribed to the presence of Ra-226 alone. The distribution of Ra-224 in the aquifer is evaluated by aquifer region, aquifer chemistry, and overlying land use.

Study Area

The Kirkwood-Cohansey aquifer system is a regionally extensive, unconfined aquifer system that underlies more than 8,000 km^2 (square kilometers) of the southern New Jersey part of the Coastal Plain physiographic province. This aquifer system has the greatest surficial extent of any aquifer system in southern New Jersey (fig. 2). The study area consists of all or parts of seven counties in which the Cohansey Sand crops out. In order from north to south, these counties are Ocean, Burlington, Camden, Gloucester, Atlantic, Salem, and Cumberland. The aquifer system is the predominant or sole source of drinking water in much of southern New Jersey. Most private domestic wells in the area draw water from this aquifer. A recent estimate (1994) indicates that approximately 84 Mgal/d were withdrawn from the aquifer system (Nawyn, 1997); of this amount, more than 75 percent is for potable use (drinking water).

Hydrogeologic Setting

In most parts of southern New Jersey, the Kirkwood-Cohansey aquifer system is composed of two hydraulically connected, southeastward-dipping geologic formations, the Cohansey Sand and the Kirkwood Formation. Aquifer thickness ranges from less than 50 ft near the outcrop of the Kirkwood Formation to approximately 500 ft near Cape May. The Cohansey Sand, middle Miocene in age, is a marginal marine deposit composed of a light-colored, medium to coarse-grained quartz sand with some gravel and silt (Zapecza, 1989). The Kirkwood Formation, early to middle Miocene in age, is

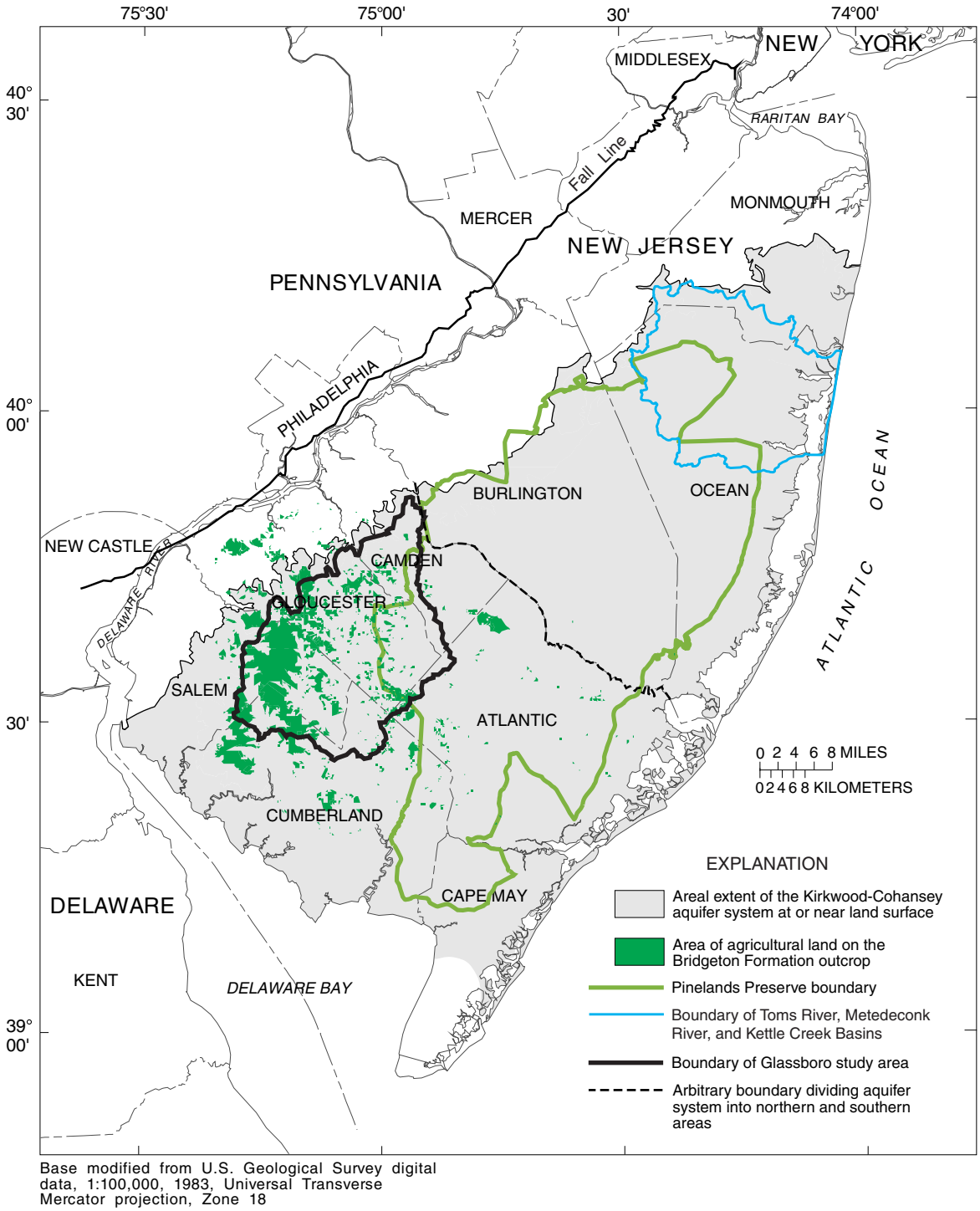

Figure 2. The Kirkwood-Cohansey aquifer system, southern New Jersey, and associated geographic features.

composed of clays interbedded with sand and gravel in coastal areas grading to a fine- to medium-grained quartz sand and silty sand inland. A discontinuous surficial deposit of feldspathic gravel known as the Bridgeton Formation (Owens and Minard, 1979; Martino, 1981) is present on topographic highs, primarily in southwestern New Jersey, directly overlying the Cohansey Sand and, in some places, the Kirkwood Formation. In this region, these three units are hydraulically connected to form the aquifer system. The Cohansey Sand has the largest surface area, cropping out over the extent of the aquifer (fig. 2).

The predominant source of recharge to the Kirkwood-Cohansey aquifer system is precipitation that falls directly onto the aquifer system outcrop. Ground water flows from topographic highs to streams along both shallow and deep flow systems (Rhodehamel, 1973), with a small percentage of the water bypassing local streams to constitute regional flow to major rivers. About half the water entering the aquifer system as recharge in a typical first-order stream basin is discharged to the nearby stream within about 20 years (Rice and Szabo, 1997). A numerical model of ground-water flow and head (water-level) distribution in a 400-mi^2 area of the southwestern part of the aquifer (Glassboro study area) indicates that less than 3 percent of the water in that part of the aquifer was recharged more than 210 years ago (Kauffman and others, 2001). The aquifer system is highly conductive; regional-scale numerical flow models in two study areas, the Toms River- Metedeconk River-Kettle Creek study area in the northeastern part and the Glassboro study area in the southwestern part, commonly are calibrated using a horizontal conductivity of 80 to 100 ft/d (Nicholson and Watt, 1997; Kauffman and others, 2001).

Land Use

Land in the area underlain by the outcrop of the Kirkwood-Cohansey aquifer system is largely undeveloped because the Pinelands Preserve covers much of the southeastern part of the State (fig. 2). Urbanization has encroached appreciably on both agricultural and previously undeveloped areas since 1973 (table 2a). This urbanization has occurred predominantly in the southwestern and northeastern parts of the aquifer outcrop area. From 1973 to 1997, the amount of agricultural and undeveloped land declined, and the amount of urban land increased. The net increase in urban land was approximately 235 km^2 (table 2a). Kauffman and others (2001) show that agricultural, urban, and undeveloped land each occupy nearly the same percentage of the outcrop area if the distribution of land use only in the southwestern and northeastern parts of the extent of the aquifer, which is where the population centers and large ground-water withdrawals are located, is considered. Demand for water supply in these rapidly urbanizing areas has increased greatly; in the southwestern part of the aquifer outcrop area (Glassboro study area), withdrawals for water supply nearly doubled from 1980 to 1996 (Kauffman and others, 2001).

Table 2a. Summary of land use in the Kirkwood-Cohansey aquifer system outcrop area, southern New Jersey, 1973, 1986, and 1995-97

[Northern area, Burlington County and north; southern area, south of Burlington County; see figure 2; GIRAS Geographic Information Retrieval and Analysis System of the U.S. Geological Survey; ITU, Integrated Terrain Units]

Region	Total area	Urban		Agricultural		Undeveloped	
	Square kilometers	Square kilometers	Percent	Square kilometers	Percent	Square kilometers	Percent
GIRAS73							
Outcrop area	8,040	1,081	13.5	1,407	17.5	5,550	69.0
Northern area	3,330	474	14.2	264	7.9	2,595	77.8
Southern area	4,670	606	13.0	1,143	24.5	2,922	62.5
ITU 1986							
Outcrop area	8,060	1,176	14.6	1,080	13.4	5,801	72.0
Northern area	3,360	529	15.7	184	5.5	2,649	78.6
Southern area	4,690	646	13.8	895	19.1	3,151	67.1
ITU 1995-97							
Outcrop area	8,060	1,315	16.3	1,020	12.7	5,721	71.0
Northern area	3,360	593	17.6	168	5.0	2,602	77.3
Southern area	4,690	722	15.4	852	18.2	3,118	66.4

Previous Investigations of Radionuclide Occurrence in the Aquifer System

The USGS, in cooperation with the NJDEP, has conducted a series of studies of natural radioactivity in water from the Kirkwood-Cohansey aquifer system. Zapecza and Szabo (1989) reported elevated combined radium concentrations (above 5 pCi/L) in ground water and associated the highest concentrations with the outcrop of the Bridgeton Formation. Kozinski and others (1995) conducted a study of the effects of geology, ground-water chemistry, and land use on the distribution of natural radionuclides in water in the Kirkwood-Cohansey aquifer system in a five-county area of southern New Jersey. Szabo and others (1997), in an investigation of the effects of agricultural activities on Ra mobility and the distribution of Ra concentrations with depth in water in the aquifer system, found that concentrations of Ra were highest in acidic (pH less than 4.8) water from shallow to medium depths (20 to 65 ft below land surface) in which nitrate concentrations exceeded 3 to 5 mg/L. Rice and Szabo (1997) show results of simulations with local (small-scale) ground-water flow models that indicate that nitrate- and Ra-laden water can flow from agricultural areas to non-agricultural areas within the general hydrogeologic setting of the aquifer. A public-health perspective on the presence of radioactivity in water from the aquifer summarized in the guidance document is provided by N.J. Department of Environmental Protection (1997). Szabo and dePaul (1998) summarized the available data on radium in water from the Kirkwood-Cohansey aquifer system as of 1997, and reviewed relations of Ra concentrations with geology, water chemistry, and land use. They reported that concentrations of combined radium greater than or equal to 5 pCi/L were found most frequently in the southwestern portion of the aquifer outcrop area (Szabo and dePaul, 1998, fig. 1). They also reported that gross alpha-particle activity was greater than or equal to 15 pCi/L in 14 percent of the 127 water samples collected from the aquifer system by the USGS prior to 1997 (median activity 5.4 pCi/L); however, samples typically were analyzed about 20 days after collection.

Differences in gross alpha-particle activity among water samples from the same wells completed in the Kirkwood-Cohansey aquifer system were first documented by Parsa (1998). The initial design of a sampling experiment to test various hypotheses regarding this temporal variation in gross alpha-particle activity, including a specific test to assess the effect of holding time before analysis, was described by Szabo and others (1998a). Gross alpha-particle activities in water from wells initially sampled by Szabo and dePaul (1998) and analyzed with no adherence to strict holding times differed from those determined when the wells were resampled and gross alpha-particle activity was measured within 72 hours (Szabo and others, 1998a).

Methods

Water samples were collected from a regional network of 88 wells (fig. 3) to determine the distributions of Ra-224 and other radium isotopes, gross alpha-particle activity, and inorganic constituents in water in the Kirkwood-Cohansey aquifer system. The wells in the sampling network were classified in two ways: according to dominant land use and by a modified "land-use gradient" scheme. Concentrations of Ra-224 at each well were determined by one or more of various available research methods. The results obtained with the various methods were compared. Statistical methods were used to compare the distributions of Ra radionuclides to land use and to concentrations of ancillary water constituents.

Design of Sampling Network and Sampling Procedures

The regional network of wells was designed to obtain samples that would be generally representative of water in the aquifer, but with preference to areas where withdrawals for drinking-water supply were extensive. Regional differences in aquifer hydrology and chemistry were considered in the selection process by distributing the wells to be sampled among as many of the individual drainage basins within the areal extent of the aquifer as possible. Surface-water divides coincide with flow-basin boundaries and approximate the ground-water flow divides of the shallow flow systems within the aquifer (Modica and others, 1997; Rice and Szabo, 1997). The drainage basins, ranging in scale from regional flow systems to subwatersheds in size, are characterized by individual 11-digit Hydrologic Unit Codes (HUCs) as defined by Ellis and Price (1995) and are at least 8.2 km^2 in size. By associating the water-quality data for a well with the HUC in which the well is located, the well's contributing area is at least partly approximated and constrained (that is, flow is not likely to be derived from outside the basin). The selected wells are distributed in 24 drainage basins (HUC11) that cover 47 percent of the surface area of the outcrop of the aquifer system.

The sampling network included 47 production wells, 10 private self-supply (domestic) wells, and 31 observation wells (app. 1). Observation wells and, to a lesser extent, self-supply wells were used to supplement the network in those areas where no production wells were available to maximize the geographic distribution of water-quality data collected. Information on the construction, altitude, and location of wells included in this report (app. 1) are stored in the Ground-Water Site Inventory (GWSI) database maintained by the USGS. In this database, wells are assigned a 6-digit unique well number that consists of a 2-digit county code followed by a 4-digit

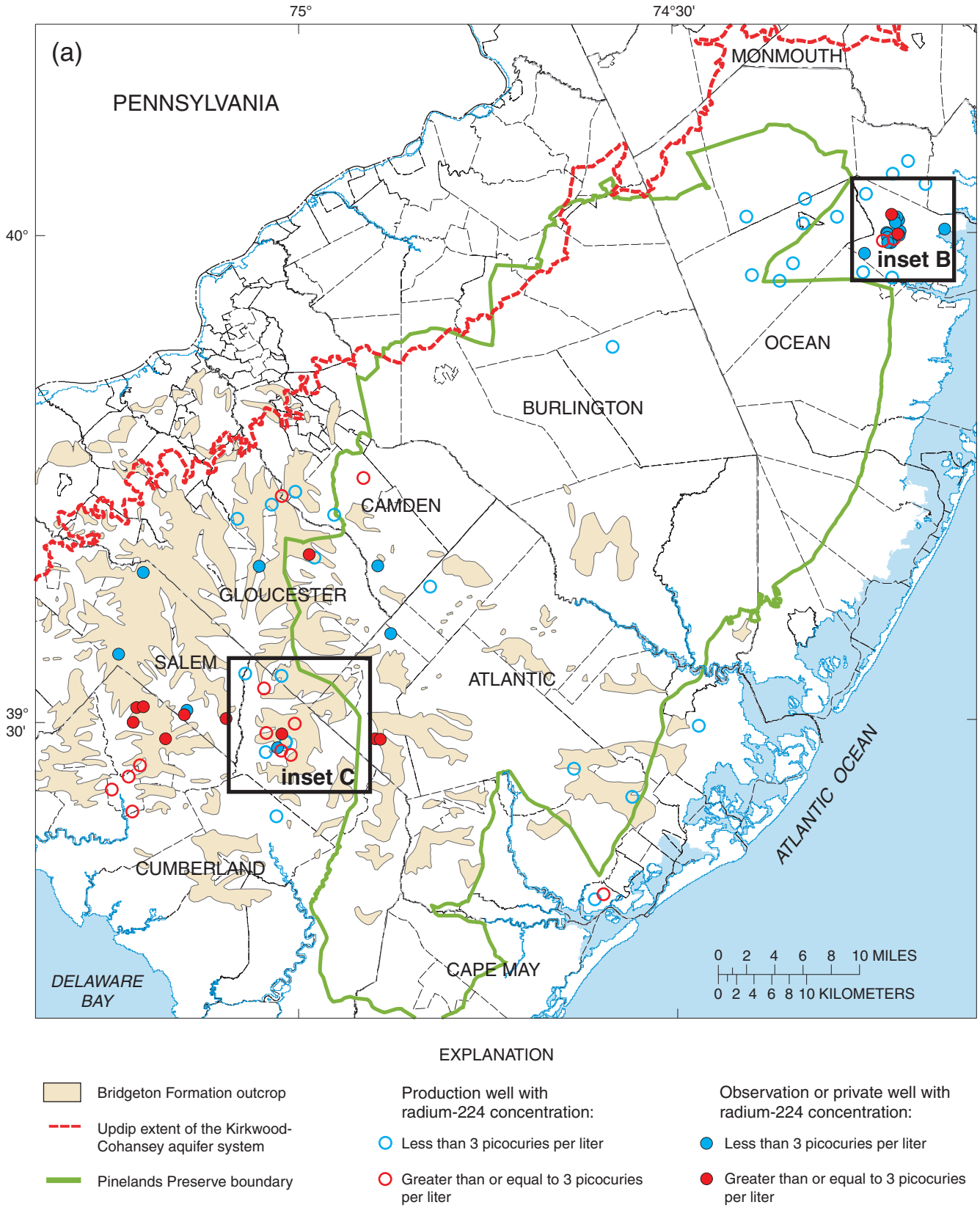

Figure 3a. The Kirkwood-Cohansey aquifer system, location of the Bridgeton Formation outcrop and radium-224 concentrations in southern New Jersey in (a) all sampled wells, 1997-99.

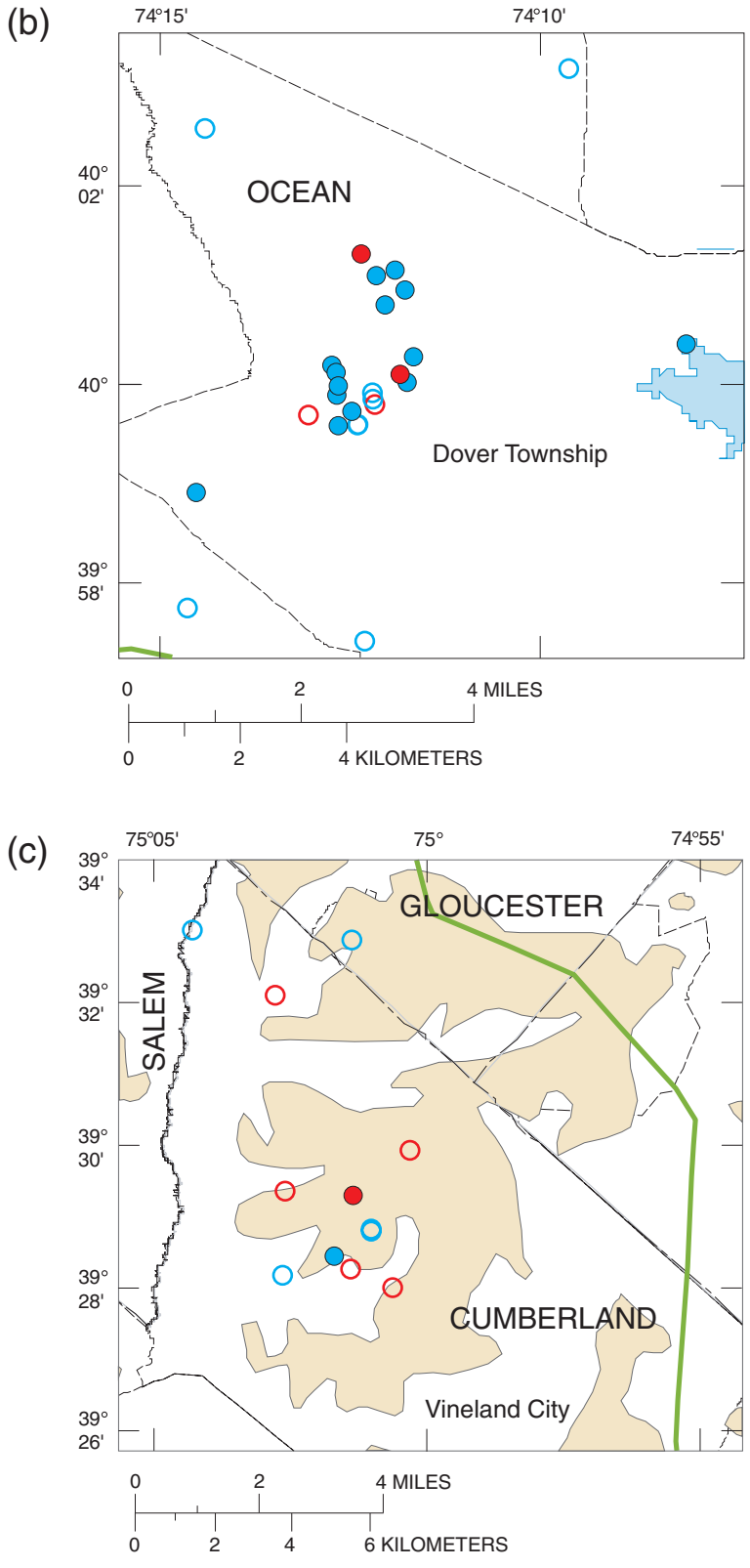

Figure 3b,c. The Kirkwood-Cohansey aquifer system, location of the Bridgeton Formation outcrop and radium-224 concentrations in southern New Jersey in (b) sampled wells in Dover Township, New Jersey; and (c) sampled wells in Vineland, New Jersey.

sequence number. County codes used in this study are 01 (Atlantic), 05 (Burlington), 07 (Camden), 11 (Cumberland), 15 (Gloucester), 29 (Ocean), and 33 (Salem). For example, well number 290627 is the 627th well inventoried in Ocean County. The water-quality data reported in appendixes 2, 3, and 4 are stored in the USGS National Water Information System (NWIS) database. Data in appendixes 3 and 4 are sorted by geographic location, from south to north, to facilitate geographical analysis; the USGS well number is reported to facilitate comparison with previously published data.

Sampling density was not uniform over the extent of the aquifer despite efforts to include wells in each drainage basin. Sampling density was greatest in the southwestern and northeastern parts of the outcrop area—specifically, Cumberland and Gloucester Counties in the southwest and Ocean County in the northeast (app. 1; figs. 2 and 3). The large rural and suburban population in these areas depends almost solely on water from the Kirkwood-Cohansey aquifer system. Furthermore, concentrations of combined Ra-226 and Ra-228 in these areas are known to exceed the 5-pCi/L MCL (Szabo and dePaul, 1998). The selection of wells in these two areas was generally, but not completely, random; 13 wells were selected on the basis of previously determined elevated concentrations of combined radium.

Sampling density was lowest in the central part of the outcrop area of the Cohansey Sand—specifically, in Burlington, southern Ocean, and northern Atlantic Counties—because the presence of the Pinelands Preserve (figs. 2 and 3) precludes the presence of a dense population and, therefore, public-supply wells in the area. Because sampled wells were not distributed evenly throughout the study area, the dataset of Ra-224, Ra-226, and Ra-228 concentrations and gross alpha-particle activities may be biased and not completely representative of the distribution in the entire aquifer. The objective of the sampling, however, was to characterize the distribution of Ra-224 in those parts of the aquifer where water is used for drinking-water supply.

Samples were collected using "ultra-clean" field techniques designed for low-level trace-element sampling in order to eliminate possible contamination from airborne particulates, sample handling, and manufacturing or detergent residues, as described by Ivahnenko and others (1996). Samples were collected only after the evacuation of three borehole volumes of water and upon stabilization of field parameters (pH, water temperature, dissolved-oxygen concentration, specific conductance, and turbidity). All samples to be analyzed for radionuclides, trace elements, nutrients, and major cations and anions were filtered using a 0.45-micron disposable polysulfone capsule filter and were collected within a portable glove chamber (Ivahnenko and others, 1996). Samples to be analyzed for radionuclides, trace elements, and major cations were preserved onsite with laboratory-grade nitric acid within a separate portable glove chamber immediately upon collection. Filters and sample tubing were discarded after single use.

Quality-Assurance Program

The quality-assurance program included analysis of field-equipment blanks and sequential duplicate samples that were collected randomly throughout the sampling period. Because analytical methods for Ra-224 have not been standardized, quality-assurance samples were collected along with approximately 20 percent of the environmental samples from the 88 sites. About 6 percent of the samples were collected with a sequential replicate sample that was submitted as a separate blind sample to one laboratory, and about 13 percent of the samples were submitted to the laboratory with the accompanying equipment blank. The equipment blanks, using USGS-certified inorganic blank water (IBW), were collected both in the field and in the laboratory using the same protocols as those used for the environmental samples. (See Ivahnenko and others (1996) for a detailed description of this process.) Results of analysis of equipment blanks (app. 2) were closely monitored to ensure that the samples had not been contaminated during either the sampling process in the field or handling in the laboratory. The equipment blanks were analyzed for a wide variety of trace-element constituents that are indicative of contamination during sample handling. The blank samples also were analyzed for radionuclides, including Ra-224, to ensure that the sample-handling and analytical techniques did not result in a high bias for extremely dilute samples. In addition to these standard quality-assurance samples, 25 percent of the samples analyzed for Ra-224 were split between two laboratories (USGS Research Laboratory in Reston, Va., and the State of New Jersey Department of Health and Senior Services Radiation Laboratory in Trenton, N.J.). The two laboratories used nearly identical approaches to gamma spectral analysis as described in the section on analytical methods (below).

Analytical Methods

Because theoretical calculations (Parsa, 1998) indicate that Ra-224, if present, contributes considerable gross alpha-particle activity to a water sample, analytical techniques needed to be tested to determine whether concentrations of Ra-224 could be quantified routinely. Moreover, integration of analysis for Ra-224 with analysis for Ra-226, Ra-228, and other radionuclides for which standard analytical methodology already present was considered to be desirable. Both Parsa (1998) and Szabo and others (1998a; 1998b) initially proposed determination of Ra-224 concentrations by gamma spectrometry; the one drawback of the technique, however, is that it is not routinely deployed for standard analysis of many other naturally occurring radionuclides in drinking water. Therefore, an additional technique, alpha spectrometry, also was investigated.

Radium-224

Water samples were analyzed for naturally occurring Ra-224 by both alpha and gamma spectrometry. The gamma-spectrometric techniques used in this study are described by Parsa (1998) and Szabo and others (1998b), and are slightly modified from the initial research technique of Elsinger and others (1982). Gamma spectrometry, the primary method used in this study, has been adopted as a standard analytical method for Ra-224 (American Association of Public Health, 2004) to determine the concentrations of Ra-224 as well as the concentrations of Ra-226 and Ra-228 (62 of the 88 samples). Alpha spectrometry was the method used to determine the concentration of alpha-particle-emitting radionuclides of radium (Ra-224 and Ra-226) for selected samples (26 of 88). The alpha-spectrometric technique used is slightly modified from the initial method of Sill and others (1979). Both analytical methods for determination of the concentration of Ra-224 require the isolation of radium from the water sample by co-precipitation with a barium or lead sulfate carrier and purification of the precipitate, which is then collected onto filter paper. The concentration of Ra-224 is determined by using the various radiation-counting instruments to count gamma emissions or alpha particles for the different techniques as described below. After the counting procedure was complete, the concentration of Ra-224 and those of the other Ra radionuclides (in the case of gamma-spectrometric measurement) or that of Ra-226 (in the case of alpha-spectrometric measurement) was back-calculated to the time of sample collection using the known rate of radioactive decay.

The gamma-spectrometric technique is advantageous because it can be used to determine the concentrations of Ra-224, Ra-226, and Ra-228 all in the same sample aliquot. A germanium-lithium or hyper-pure germanium high-efficiency (40 percent) well-type detector or medium-efficiency (10 percent) plate-surface detector typically is used to analyze the gamma-ray spectra emitted by the radium-bearing barium sulfate or lead sulfate precipitate. Gamma emissions from the Ra-224 (or the Pb-212 progeny) in the lead sulfate precipitate were counted sooner after precipitation than those in the barium sulfate precipitate; hence, the lead sulfate precipitate was used with the plate detector and the barium sulfate was used with the well-type detector. The detector can resolve narrow differences in emitted gamma energy. The analyst can determine the identity of individual isotopes on the basis of known gamma-ray energy emitted during radioactive decay. Quantification of concentration (including that of Ra-224) is possible by determining the magnitude of the detector response at known energies. Two to three 1,000-minute counts are required for quantification. Ra-224 concentration results are comparable whether using the barium sulfate or lead sulfate precipitate and whether using the high-efficiency well-type or medium-efficiency plate-surface detector as long as the counting time after sampling is optimized to be most suitable for either approach (Szabo and others, 1998b). Therefore, both analytical approaches were used interchangeably in this study, depending on instrument availability. The long counting times require optimizing instrument availability for any large-volume sampling operation, such as the characterization of an extensive aquifer system in this study.

The alpha-spectrometric technique has been used widely to measure many alpha-particle-emitting radionuclides but only recently has been used routinely for determination of concentrations of radionuclides of Ra. Improvements in separation, purification, and co-precipitation chemistry (Sill and Williams, 1981) have allowed the formation of crystals of barium sulfate of uniform size. The radium-bearing barium sulfate precipitate is placed into a vacuum chamber at a standard distance (determined and fixed within each laboratory to optimize counting efficiency on the basis of the detector geometry) from the silicon semiconductor detector. These crystals must be of uniform size to ensure that the radium is a uniform distance from the detector across the entire precipitate-bearing planchet. The uniform sample geometry maximizes the precision and accuracy of the alpha-spectrometric measurement technique for Ra. The detector can determine the amount of alpha radiation that is emitted at known energies, thereby enabling quantification of individual radionuclide concentrations on the basis of the known energy of emissions for each radionuclide and the magnitude of the detector response at those energies. The alpha-spectrometric determination of Ra-224 concentrations required a single count for 100 minutes.

Radium-226, Radium-228, and Ancillary Constituents

Concentrations of Ra-226, when not determined by gamma spectrometry (Elsinger and others, 1982) or alpha spectrometry (Sill and others, 1979), were determined primarily by the planchet counting method and in some cases by the radon de-emanation method (Krieger and Whittaker, 1980; U.S. Environmental Protection Agency, 1997). Concentrations of Ra-228 were determined by the beta counting of the ingrown Ac-228 progeny (Parsa and Hoffman, 1992; U.S. Environmental Protection Agency, 1997) and, in about half of the samples, by gamma spectrometry (Elsinger and others, 1982).

Gross alpha-particle and beta-particle activity were measured within 48 hours of sample collection (maximum allowable, 72 hours), as recommended by USEPA and NJDEP (U.S. Environmental Protection Agency, 2000b; New Jersey Department Environmental Protection, 2002) on the basis of work by Parsa (1998) and Szabo and others (1998a), using planchet counting with Th-230 and cesium-137 (Cs-137) as the standards. Unlike in the approach used for individual radionuclide concentrations, neither gross alpha-particle nor gross beta-particle activity was back-calculated to the time of sample collection because these measurements represent the overall alpha-particle and beta-particle activity of the mix of all the radionuclides present in the sample at the time the measurement was made. Unless the concentration of all the radionuclides present in the sample is specifically known, time-dependent corrections of gross alpha-particle and beta-particle activities cannot be made. Concentrations of Rn-222 were also determined by liquid scintillation counting within 48 hours of sample collection

(Pritchard and Gesell, 1977), and concentrations were back-calculated to the time of sample collection.

Concentrations of non-radioactive inorganic and organic constituents were determined by standard methods (Fishman and Friedman, 1989). Trace-element concentrations in blank samples run through the pumping equipment were determined by inductively coupled plasma mass spectrometry (ICP-MS) (Faires, 1993).

Reporting of Radionuclide Concentrations

The raw, unrounded values for all radionuclide concentrations, in picocuries per liter (pCi/L), are reported directly. The laboratory also reports the precision estimate (PE), which is another term for measurement uncertainty or measurement error, computed at two standard deviations (2-Sigma) about the count value.

The 2-Sigma PE is provided by the laboratory for each analysis because the rate of radioactive decay varies at any instant in time, even if the long-term decay rate as defined by the half-life of the radionuclide is stable. All measurements of radioactivity, therefore, are associated with a degree of uncertainty, which is known as the counting error. The degree of error of the radioactivity measurement defines the minimum confidence interval, which is commonly expressed as two standard deviations (two sigma) about the mean–that is, 95 of 100 measurements of radioactivity of the sample would fall within the range denoted by the reported radioactivity, plus or minus the reported degree of error (PE).

The laboratory reporting level (LRL) is defined as the minimum quantity of a specific radionuclide that can routinely and reliably be quantified under typical instrument operating conditions. These conditions include typical background radioactivity counts, typical volumes of sample analyzed, typical count times, and typical sample matrix. The LRL was targeted in a range of 0.5 to 1 pCi/L for the individual radionuclides determined in this study. This criterion was met in all cases. The LRL for Ra-224 concentration also was in the range from 0.5 to 1 pCi/L. Concentrations of radionuclides below the LRL in a given sample are indicated as less than the LRL (app. 2). The LRL of 1 pCi/L could not be obtained for gross alpha-particle and gross beta-particle activity because of the low sensitivity of the instruments used. The LRLs for gross alpha-particle and gross beta-particle activity typically are 3 and 4 pCi/L, respectively. In selected cases, the volume of standard sample aliquots for gross alpha-particle and beta-particle analysis was increased in order to quantify activity below 3 and 4 pCi/L, respectively. Because many of the analytical techniques used in this study are still considered to be in the research phase of development, in this report the LRL is referred to when evaluating a sample result unless otherwise specified.

Instruments that count radioactivity record both the radioactivity of the water sample and the background radioactivity during the time of sample analysis. Quantifying small amounts of radiation is difficult because the analytical instruments do record background radiation. The radiation emitted from the radionuclide being quantified must be clearly distinguishable above the background radiation. Ambient background radiation is of considerable concern in gamma-ray measurements (Knoll, 1989) because gamma rays are attenuated little by travel through air; hence, the gamma-ray detector needs to be shielded in order to reduce the natural background. Alpha particles, on the other hand, are strongly attenuated in air; hence, background for the alpha-particle counting instruments typically is very low (0.1 pCi/L or less) unless the counting chamber or detector itself has been contaminated with alpha-emitting radionuclides from a poorly prepared, highly radioactive, or gaseous sample. The minimum quantity of a specific radionuclide detected above the background level by the counting instrument for any given analysis is defined as the minimum detectable activity; further, the counted radioactivity must differ from the background count by three times the standard deviation of the counts associated with blank samples (Currie, 1968) (includes background plus sample matrix effects). This minimum value is computed individually for each radionuclide analysis on the basis of the instrument operating conditions at the time of analysis. The sample-specific minimum detectable concentration (SSMDC) determined by the laboratory for each individual sample is reported (app. 3). The analytical and reporting terms for radionuclides are defined in the glossary at the back of this report.

Land-Use Classification and Statistical Analysis

Level 1 land-use categories of Anderson and others (1976) were aggregated into three general classifications: agricultural, residential/urban, and undeveloped land. The land use was defined in a circular buffer zone with a 500-m radius for sampled wells with a production capacity of 10 gal/min or less and a 1,000-m radius for sampled wells with a production capacity of more than 10 gal/min. The smaller buffer radius of 500 m was used for wells with low pumping rates on the basis of the initial protocols proposed by Koterba and others (1995) for this type of evaluation. The modification that includes a larger buffer radius where buffer radius was assigned on the basis of discharge was based on the results of the ground-water flow model simulations reported by Stackelberg and others (2000) for the aquifer. Their simulation results lend credence to the assumption that recharge areas probably are larger for wells with large pumping capacity than for those with small pumping capacity.

Another limitation of the circular-fixed-buffer-radius method for defining land use in the potential area of recharge to the well is encountered when the buffer zone crosses the drainage-basin boundary and extends into one or more adjacent drainage basins. Results of ground-water flow model simulations by Stackelberg and others (2000) indicate that a well producing a large volume of water—for example, 1 Mgal/d—may draw in some water from small parts of the adjoining basins. In the absence of an aquifer-system-wide flow model to test each large-volume production well to determine whether cross-basin flow is likely, the simple approach adopted in this study

was to clip the circular buffer zones where they crossed drainage-basin boundaries; these boundaries included both topographic highs, which serve as surface-water (and ground-water) divides, and streams, which serve as zones of ground-water discharge, as demonstrated by the ground-water flow model simulations by Rice and Szabo (1997) and Modica and others (1997). This method, even with these modifications, is probably over-simplified, because the circular buffer zone does not necessarily coincide wholly with the well's contributing area; nevertheless, the approach is considered adequate for the initial evaluation of the distribution of Ra-224 reported here. It also is an adequate method for the initial comparison of Ra-224 distribution with those of Ra-226 and Ra-228 because the initial evaluation of distribution with land use for these radionuclides (Kozinski and others, 1995) was done using circular buffer zones with an 800-m radius for all wells sampled.

Sampled wells initially were assigned to one of the three land-use categories on the basis of the predominant land use (highest percentage) within the assigned buffer zone (table 2a). Many of the sampled wells in the population centers in the southwestern and northeastern parts of the aquifer (Glassboro and Toms River-Metedeconk River-Kettle Creek study areas) are associated, however, with a mixed land use of about 30 percent agricultural, 30 percent urban/residential, and 30 percent forested/undeveloped land (Kauffman and others, 2001). The assigned predominant land use for a case such as just described may be biased. Where the three land uses were about equal, this predominant-land-use analytical approach was, therefore, not considered adequate for use as a tool for initial evaluation and to guide subsequent analysis.

The quality of water intercepted by wells in mixed-land-use areas is most likely to be affected by leachates emanating from soil underlying the land-use type where most recharge and water flow to the well originates. In southern New Jersey, the quality of water intercepted by wells in mixed-land-use areas is more likely to be affected by the agricultural and urban/residential land, which typically is found on hillslopes and hilltops upgradient from wells (Rice and Szabo, 1997; Kauffman and others, 2001), than by forested/undeveloped land, which typically is found near wetlands downgradient from wells. As evidence of the importance of the presence of agricultural land on ground-water quality, Stackelberg and others (2000) showed that concentrations of nitrate were greater, and pesticides were detected more frequently, in samples from wells whose buffer zones contained as little as 10 percent agricultural land than in samples from wells whose buffer zones contained less than 10 percent agricultural land. With the use of a geochemical mass-balance model, Szabo and others (1997) found that nitrate is the major constituent in water derived from agricultural inputs to the aquifer. Kozinski and others (1995) and Rice and Szabo (1997) have shown that elevated concentrations of Ra-226 and Ra-228 are related to the presence of agricultural land and the presence of nitrate concentrations greater than 3 or 5 mg/L. Additionally, much residential development in southern New Jersey occurs on land that was formerly agricultural (Ayers and others, 2000), and ground-water quality at depth likely was affected by the previous agricultural land use. An implication of conversion of agricultural to residential land use is that the effects of agricultural land on ground-water quality in many residential areas likely are underestimated when recent land-use coverages are used in the analysis.

Because of these documented effects of agricultural land use on water quality, a second land-use classification system based on the degree of agricultural and residential development in the vicinity of the sampled wells was designed. This approach is termed the "second-tier classification system" using the "agricultural gradient land-use approach;" it is similar to the approach taken by Ayers and others (2000, fig. 21) to evaluate the effects of agricultural and urban land use on streamwater quality. Ayers and others (2000) ranked stream basins on the basis of the amount of agricultural land in the basin. In the current study, because of the large number of sampled wells and the large degree of uncertainty in the extent of the wells' contributing areas, a grouping system was used, in which the groups represent wells with significant but different amounts (predominant, abundant, and minor) of agricultural effect in the recharge area. In this approach, wells whose buffer zones contained agriculture as the predominant land use (highest percentage) were assigned to the "agriculture-predominant" land-use group. Wells were assigned to a mixed agricultural land-use subcategory if 10 percent and more of the total buffer area contained agricultural land but agricultural land use was not dominant, or ranged up to 32 percent. This approach is reasonable because results of small-scale simulations of ground-water flow indicate that water with elevated nitrate and radium concentrations can flow from up-gradient agricultural areas to areas with other land use (Rice and Szabo, 1997). By using this gradient-based classification scheme, each of the 37 wells was assigned to either the agriculture-predominant (19 wells) or the mixed agricultural/residential (18 wells) category (table 2b).

Table 2b. Summary of land-use classification schemes used in this study in southern New Jersey for contributing areas around sampled wells

[%, percent]

Land-use category	Number of sites (total=88)		
By gradient			
Agriculture-dominant	19	]	37
Mixed-agriculture-10% to dominant	18		
Urban/residential-dominant	26		26
Mixed-urban/residential-10% to dominant	20	]	25
Forested/undeveloped-greater than 90%	5		
By predominance			
Agriculture-dominant	19		
Urban/residential-dominant	36		
Forested/undeveloped-dominant	33		

More than half of the 51 remaining wells were located in areas that consisted of less than 10 percent agricultural land and where residential/urban land not only was the dominant land-use type but accounted for more than 50 percent of the total land area within the assigned buffer zone. These wells (26) were classified as residential/urban-dominated. Twenty wells were located in areas where forested/undeveloped land was the dominant land-use type but where residential/urban land constituted from 10 to 30 percent of the total land area within the buffer zone. Wells for which undeveloped land is dominant in the buffer zone but residential/urban land is also present were categorized as mixed undeveloped/residential. Residential land, like agricultural land, is found most commonly on hilltops and slopes upgradient from wells, whereas forested/undeveloped land typically is located downgradient from wells and commonly is associated with wetlands. The category that contained the smallest number of wells (5), the undeveloped category, consisted of wells whose buffer zones contained 90 percent or more forested/undeveloped land. The buffer zones of some of these wells also contained either residential or agricultural land-upgradient from the wells. Wells 330907 and 330908, for example, are in forested parkland but large agricultural fields are present upgradient. Water samples from these two wells contained high concentrations of nitrate, likely derived from the agricultural land more than 500 m upgradient from the wells. Because 88 wells were assigned to five land-use categories, some of the groups contained fewer than 20 wells. Some of the categories were combined so that each would contain a minimum of approximately the 20 samples recommended to be necessary for statistical testing of group distributions (Helsel and Hirsch, 1992). The agriculture-predominant and mixed agricultural/residential land-use groups were combined and the mixed residential/forested (with forested land dominant) and forested/undeveloped land-use groups were combined. Thus, the 88 wells were classified as follows: 37 agricultural plus mixed agricultural/other, 26 residential/urban-dominated, and 25 mixed undeveloped/residential plus undeveloped (table 2b). These three groups were sufficiently close in size to be considered adequate for statistical-testing purposes.

Relations among concentrations of Ra-224, Ra-226, Ra-228, and other inorganic constituents were characterized by use of Spearman correlations. This test is a non-parametric statistical technique that determines the co-linearity of the ranked values of two continuous variables (Helsel and Hirsch, 1992). Results of the statistical tests were considered significant at the 95-percent confidence level. At this confidence level, the implication is that the sampling, if repeated 100 times, would result in a correlation among the variables 95 times; in other words, there is only 1 chance in 20 of obtaining the correlation by chance. Comparisons of concentration distributions between groups of Ra-isotope and inorganic-constituent data were made using the Wilcoxon rank-sum nonparametric test, the Kruskall-Wallis nonparametric test, and the Tukey-Kramer multiple comparison test, all of which are based on the ranked concentration data (Helsel and Hirsch, 1992). The Wilcoxon rank-sum test, which is used to determine whether the distributions of two sample populations are the same or different, was used to determine whether concentrations of radionuclides differed between two classes of data. For example, analysis results from the northern outcrop areas (Burlington County and north, centered around the Toms-Metedeconk River area) and the southern outcrop areas (Camden County and south, centered around the Glassboro study area) were compared in this manner. The Kruskall-Wallis test was used to determine whether concentrations of Ra-224 differed among sites located in areas of differing land use. This procedure is used to determine whether two or more sample populations are identical by testing the null hypothesis that the individual group mean rank is identical to that for the entire dataset. If the null hypothesis was rejected (groups differed from the overall population data set), then the Tukey-Kramer multiple comparison test was used to determine which of the population rank means differed significantly from one another.

For relational statistics, results of water-quality analyses of samples from two wells (330817 and 330818) were not included because the inorganic water chemistry was not representative of the water collected from the other 86 wells in the study. Water from both these wells contained high concentrations of chloride, calcium, and potassium, and water from well 330818 also contained a high concentration of sodium. These wells were near roadways and may have been contaminated with road salt. Well 330817 also was near a lime stockpile, which may be the source of the elevated calcium concentrations. The anomalous data from the samples from these two wells strongly affected the magnitude of the correlation coefficients. For the Tukey-Kramer multiple comparison test, two additional analysis results—those for the samples from wells 330907 and 330908—also were excluded from the analysis because these wells, although located in forested land, were downgradient from large agricultural fields; consequently, the samples from these wells contained highly elevated concentrations of nitrate, a compound typically leached to ground water from agricultural soils.

Occurrence of Radium-224, Other Radionuclides, and Gross Alpha-Particle Activity

Concentrations of Ra-224, Ra-226, Ra-228, Rn-222, other radionuclides, and gross alpha-particle and beta-particle activity in the 88 ground-water samples are presented in appendix 3; concentrations of ancillary inorganic constituents are presented in appendix 4. Concentrations of Ra-224, Ra-226, and Ra-228 often were determined by more than one technique; results for all measurement techniques are listed in appendix 3, and the concentration used for statistical and mapping purposes is printed in bold type. Concentrations of the radium radionuclides determined by more than one technique could not be distinguished on the basis of the precision estimate (PE).

Locations of the sampled wells and the distribution of Ra-224 are shown in figure 3. The frequency of occurrence of specified concentrations, distributional statistics, relations among parameters, and statistically significant differences in pH and concentrations of radionuclides and selected major ions among aquifer-region and land-use groups are reported in tables 3, 4, 5, and 6, respectively.

Table 3. Percentage of samples in which the concentration of radium radionuclides equaled or exceeded the specified concentration, Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99

[Total number of samples = 88; pCi/L, picocuries per liter]

Radionuclide	Percentage of samples in which concentration equaled or exceeded:		
	1 pCi/L	3 pCi/L	5 pCi/L
Radium-224	76	32	13
Radium-226	69	23	9
Radium-228	74	20	10
Radium-226+Radium-228	82	49	30

Radium-224

Radium-224 was detected at concentrations greater than 1.0 pCi/L in 67 (76 percent) of the 88 samples of water from the Kirkwood-Cohansey aquifer system (table 3, app. 3); concentrations ranged from less than 0.5 pCi/L to 16.8 pCi/L, with a median of 2.1 pCi/L and interquartile range from 1.2 to 3.7 pCi/L (table 4). A histogram of Ra-224 concentrations indicates that 7 percent (6 of 88) are greater than 10 pCi/L, 12.5 percent (11 of 88) are greater than 5 pCi/L, and 32 percent (28 of 88) are greater than or equal to 3 pCi/L (fig. 4). The Ra-224 concentration was highest (16.8 pCi/L) in a sample from a medium-depth (61 ft below land surface) observation well (011274) in an agricultural area of western Atlantic County (fig. 3). The remaining five samples in which Ra-224 concentrations exceeded 10 pCi/L were from agricultural areas in Camden, Cumberland, and Salem Counties (fig. 3). At least one well from each county in which five or more wells were sampled produced water with a Ra-224 concentration less than 1 pCi/L; wells producing water with low and high concentrations of Ra-224 generally were interspersed.

Radium-226 and Radium-228

The concentrations of Ra-226 and Ra-228 in the 88 water samples ranged from less than 0.5 to 17.4 pCi/L (median, 1.7 pCi/L; interquartile range, 0.9-2.9 pCi/L) and less than 0.5 to 12.8 pCi/L (median, 1.6 pCi/L; interquartile range 0.9-2.6 pCi/L), respectively (table 4). Most of the samples contained Ra-226 and Ra-228 in about equal concentrations (app. 3). At a few wells (about 10 of 88), the concentration of either Ra-226 or Ra-228 substantially exceeded the concentration of the other; a similar observation was made by Kozinski and others (1995). As selected examples, the concentration of Ra-228 was substantially greater than that of Ra-226 in water from wells 011277, 110923, 110937, and 330907 (4.69 and 0.99, 7.70 and 3.50, 7.07 and <1.0, and 11.3 and 6.38 pCi/L, respectively), whereas the concentration of Ra-226 was much greater than that of Ra-228 in water from wells 110816, 111013, 290496, and 330908 (5.32 and 2.22, 8.38 and 2.87, 3.40 and 1.16, and 12.63 and 7.22 pCi/L, respectively).

Concentrations of combined Ra in the water samples ranged from less than 1 pCi/L to 30.2 pCi/L, with a median of 3.2 pCi/L (interquartile range, 2.0-5.6 pCi/L). Concentrations in 26 samples (30 percent) exceeded the MCL of 5 pCi/L (table 3); this percentage is nearly identical to that determined by Szabo and dePaul (1998) (33 percent) using data from a larger sample set. Of the 26 samples, 24 also contained Ra-224 at concentrations greater than or equal to 3 pCi/L. The highest concentration of combined radium measured (30.2 pCi/L) was in a sample from the same medium-depth (61 ft below land surface) observation well (011274) in western Atlantic County that produced the water with the highest Ra-224 concentration (fig. 3). Each of the 10 samples with Ra-224 concentrations of 5 pCi/L or greater also contained combined radium at a concentration greater than 5 pCi/L. Nine percent of the samples (8 of 88) contained combined radium at concentrations greater than 10 pCi/L, and 49 percent (43 of 88) contained 3 pCi/L or greater (table 3). On the other hand, the concentration of combined radium was less than1 pCi/L in 18 percent of the samples (16 of 88); both Ra-226 and Ra-228 concentrations were less than 1 pCi/L in 15 of the 21 samples in which the Ra-224 concentration also was less than 1.0 pCi/L.

Gross Alpha-Particle Activity

Gross alpha-particle activities ranged from 1.37 to 77.3 pCi/L, with a median of 14.9 pCi/L (interquartile range 6.8-23.9 pCi/L). This result indicates that gross alpha-particle activity exceeded the MCL in nearly 50 percent of the 88 samples. Gross alpha-particle activity was highest (77.3 pCi/L) in a sample from a well (070737) in an agricultural area of southern Camden County (fig. 3). Gross alpha-particle activity exceeded 70 pCi/L in 3 of the 88 samples, 50 pCi/L in 6, and 30 pCi/L in 13 of the 88 samples. The concentration of combined radium was greater than the 5 pCi/L MCL in all 13 of these samples. Gross alpha-particle activity was greater than 15 pCi/L in 24 of the 25 samples in which the concentration of combined radium exceeded 5 pCi/L; the gross alpha-particle activity in the sole remaining sample (from well 291350) was 14.4 pCi/L.

Gross alpha-particle and beta-particle activities were less than the respective LRLs in nearly 10 and 15 percent of samples, respectively. Unless otherwise specified, the LRL generally was used to evaluate analysis results for gross alpha-particle and gross beta-particle activity; in selected cases,

Table 4. Statistical summary of radionuclide, selected major-ion and trace-element concentrations and pH in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99: (a) for the complete data set, (b) by region, and (c) by land-use classification (gradient method).

[Concentration units: radionuclides, (radium-224, radium-226, radium-228, radium-226 + radium=228, gross alpha- and beta-particle activity, radon-222), picocuries per liter; pH, standard units; major ions (nitrate + nitrite, calcium, magnesium, potassium), milligrams per liter; trace elements (barium, strontium), micrograms per liter. <, less than]

Constituent	Concentration									
	Number of samples	Minimum	10th percentile	25th percentile	Median	75th percentile	90th percentile	Maximum	Arithmetic mean	Standard deviation
Radium-224	88	<0.5	0.5	1.2	2.1	3.7	7.1	16.8	3.0	3.1
Radium-226	88	<.5	<.5	.9	1.7	2.9	4.8	17.4	2.3	2.7
Radium-228	88	<.5	<.5	.9	1.6	2.6	5.4	12.8	2.2	2.3
Radium-226 + Radium-228	88	<1	<1	2.0	3.2	5.6	9.4	30.2	4.6	4.7
Gross alpha-particle activity	88	<3	3.3	6.8	14.9	23.9	39.0	77.3	18.5	16.7
Gross beta-particle activity	88	<4	<4	5.6	8.7	15.4	24.0	57.2	12.0	10.3
Radon-222	77	52.0	124.0	191.0	237.0	362.0	511.0	1,007.0	294.9	198.4
pH	88	4.1	4.3	4.5	4.7	4.9	5.1	5.8	4.7	.3
Nitrate plus nitrite	88	<.05	.1	1.0	2.5	5.1	11.2	23.7	4.2	5.0
Calcium	87	.1	.8	1.5	3.3	5.5	16.0	32.5	5.6	7.0
Magnesium	87	.3	.8	1.3	2.6	3.7	7.3	14.7	3.4	3.0
Potassium	86	.2	.8	1.1	2.0	2.8	5.4	11.3	2.6	2.2
Barium	74	14.5	27.0	45.9	66.7	104.2	178.0	779.2	97.3	113.4
Strontium	81	2.7	9.6	15.5	24.9	48.0	78.0	149.7	37.1	32.0

Constituent	Concentration									
	Number of samples	Minimum	10th percentile	25th percentile	Median	75th percentile	90th percentile	Maximum	Arithmetic mean	Standard deviation
Northern outcrop										
Radium-224	36	<0.5	0.6	1.2	1.9	2.5	3.2	3.6	1.8	0.9
Radium-226	36	<.5	.6	.9	1.3	1.9	2.9	3.4	1.5	.8
Radium-228	36	<.5	<.5	.8	1.4	1.8	2.3	2.4	1.3	.7
Combined radium	36	<1	<1	2.0	2.8	3.6	4.6	5.6	2.8	1.3
Gross alpha	36	<3	4.3	6.8	12.7	15.4	20.0	28.3	12.3	6.5
Gross beta	32	< 4	<4	4.4	7.3	9.0	11.3	16.2	7.0	3.5
Radon-222	30	91.0	142.0	193.0	219.5	286.0	444.5	1,007.0	271.5	172.7
pH	36	4.2	4.3	4.7	4.8	4.9	5.1	5.4	4.8	.3
Nitrate plus nitrite	36	<.05	.1	.8	1.2	1.9	3.2	5.0	1.5	1.2
Calcium	36	.1	.4	1.0	1.6	3.8	5.5	6.8	2.5	2.0
Magnesium	36	.3	.7	1.1	2.2	2.9	3.5	4.8	2.1	1.1
Potassium	35	.5	.8	1.0	1.9	2.5	3.5	5.4	2.0	1.3
Barium	28	14.5	2.0	30.3	46.9	68.2	80.5	154.5	51.6	29.9
Strontium	34	2.7	5.5	12.4	19.5	27.1	32.5	77.9	21.1	14.3
Southern outcrop										
Radium-224	52	<.5	.5	0.9	2.6	4.5	11.0	16.8	3.8	3.8
Radium-226	52	<.5	<.5	.8	1.9	3.7	5.7	17.4	2.9	3.3
Radium-228	52	<.5	<.5	1.0	2.0	3.4	7.1	12.8	2.9	2.8
Combined radium	52	<1	<1	1.9	4.4	7.6	11.5	30.2	5.8	5.8
Gross alpha	52	<3	2.6	6.7	18.8	31.6	50.5	77.3	22.8	20.0
Gross beta	50	<4	<4	6.9	12.2	19.7	31.5	57.2	15.3	11.8
Radon-222	47	52.0	104.0	184.0	249.0	387.0	585.0	990.0	309.8	213.6
pH	52	4.1	4.4	4.4	4.6	4.9	5.0	5.8	4.7	.3
Nitrate plus nitrite	52	<.05	.2	2.5	4.7	7.2	12.9	23.7	6.0	5.8
Calcium	51	.4	1.1	2.7	4.6	9.0	21.2	32.5	7.8	8.3
Magnesium	51	.3	.9	1.9	3.3	6.0	9.4	14.7	4.3	3.6
Potassium	51	.2	.9	1.5	2.1	3.0	7.0	11.3	2.9	2.6
Barium	46	16.2	33.8	53.6	78.7	135.0	287.8	779.2	125.1	135.0
Strontium	47	6.4	11.3	19.1	37.4	70.0	119.2	149.7	48.7	36.2

Table 4. Statistical summary of radionuclide, selected major-ion and trace-element concentrations and pH in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99: (a) for the complete data set, (b) by region, and (c) by land-use classification (gradient method).—Continued

Constituent	Concentration									
	Number of samples	Minimum	10th percentile	25th percentile	Median	75th percentile	90th percentile	Maximum	Arithmetic mean	Standard deviation
Agricultural/mixed agriculture										
Radium-224	37	<0.5	0.7	1.6	2.5	4.0	8.3	16.8	3.7	3.7
Radium-226	37	<.5	.6	1.1	2.1	3.5	5.7	17.4	3.1	3.3
Radium-228	37	<.5	<.5	1.3	2.1	3.1	6.7	12.8	2.8	2.7
Combined radium	37	<1	1.1	2.3	4.4	7.5	11.5	30.2	6.0	5.7
Gross alpha	37	<3	4.3	8.5	16.2	31.3	54.4	77.3	23.4	20.2
Gross beta	36	<4	5.2	7.2	13.3	19.9	28.0	57.2	15.8	11.8
Radon-222	33	52.0	124.0	191.0	249.0	379.0	511.0	982.0	301.5	203.8
pH	37	4.1	4.3	4.5	4.6	4.8	5.1	5.8	4.7	0.3
Nitrate plus nitrite	37	<.05	1.1	3.0	4.8	7.3	12.9	22.6	6.2	5.2
Calcium	37	.4	1.6	2.9	4.8	8.8	24.8	32.5	8.6	9.1
Magnesium	37	.8	1.4	2.3	3.5	6.0	9.4	14.7	4.6	3.3
Potassium	37	.9	1.3	1.8	2.4	3.5	7.9	11.3	3.4	2.7
Barium	34	30.0	48.4	59.0	78.7	135.0	254.0	441.5	128.3	142.4
Strontium	34	5.5	17.3	22.3	36.7	63.2	90.7	149.7	48.6	34.4
Urban/residential										
Radium-224	26	<0.5	0.5	1.3	2.0	2.7	4.6	11.1	2.5	2.3
Radium-226	26	<.5	.5	.9	1.4	2.1	3.4	5.3	1.7	1.2
Radium-228	26	<.5	<.5	.9	1.6	1.8	3.9	7.1	1.8	1.5
Combined radium	26	<1	<1	1.9	3.1	4.5	6.7	9.4	3.5	2.2
Gross alpha	26	<3	3.6	6.9	14.0	22.1	27.2	38.8	15.1	9.5
Gross beta	24	<4	<4	6.8	8.1	12.2	16.8	24.9	9.4	5.4
Radon-222	25	91.0	137.0	190.0	230.0	307.0	412.0	1,007.0	275.2	181.4
pH	26	4.4	4.4	4.6	4.8	4.9	5.0	5.2	4.8	.2
Nitrate plus nitrite	26	.3	.8	1.2	2.2	3.2	5.3	12.2	2.9	2.5
Calcium	25	.6	1.1	1.5	3.0	4.3	6.2	10.9	3.5	2.5
Magnesium	25	.9	1.1	2.0	2.9	3.5	4.3	12.3	3.0	2.2
Potassium	25	.8	.8	1.2	1.9	2.7	5.3	6.1	2.4	1.6
Barium	20	19.0	29.3	36.6	61.4	90.3	141.5	189.2	72.1	44.8
Strontium	23	9.7	14.6	16.1	24.6	42.0	77.9	121.7	34.9	28.3
Mixed-undeveloped/residential plus undeveloped										
Radium-224	25	<0.5	<0.5	0.6	1.5	2.6	3.9	11.7	2.4	2.9
Radium-226	25	<.5	<.5	.7	1.2	1.9	3.1	12.6	1.9	2.6
Radium-228	25	<.5	<.5	.6	1.3	1.7	3.0	11.3	1.8	2.4
Combined radium	25	<1	<1	1.2	2.4	3.3	5.5	19.9	3.7	4.8
Gross alpha	25	<3	<3	4.6	12.3	17.9	28.3	65.5	14.8	15.4
Gross beta	22	<4	<4	<4	5.7	8.6	15.4	41.2	8.8	10.2
Radon-222	19	101.0	104.0	192.0	223.0	369.0	585.0	990.0	309.2	1.9
pH	25	4.3	4.3	4.4	4.8	4.9	5.1	5.8	4.8	.4
Nitrate plus nitrite	25	<.05	<.05	.1	.8	1.6	2.7	23.7	2.5	5.7
Calcium	25	.1	.3	.8	1.1	3.5	9.0	16.1	3.3	4.4
Magnesium	25	.3	.3	.7	1.1	2.3	2.7	13.5	2.1	2.8
Potassium	24	.2	.5	.7	1.0	2.2	2.5	2.9	1.4	.8
Barium	20	14.5	17.3	22.0	44.7	57.3	184.2	385.1	69.7	94.7
Strontium	24	2.7	5.0	8.7	11.9	27.4	48.0	122.3	23.0	26.4

Table 5. Spearman rank correlation coefficients for relations of Radium-224, Radium-226, and Radium-228 concentrations to concentrations of selected constituents in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99

[All coefficients shown are significant at the 95-percent confidence level; -- indicates that the correlation coefficient is not significant at the 95-percent confidence level]

Radionuclide	Gross alpha-particle activity	Gross beta-particle activity	Radium-224	Radium-226	Radium-228	Combined radium	pH	Nitrate plus nitrite	Calcium	Magnesium
Radium-224	+ 0.89	+ 0.87	1	+ 0.74	+ 0.91	+ 0.88	- 0.36	+ 0.56	+ 0.48	+ 0.65
Radium-226	+ .77	+ .71	+ .74	1	+ .79	+ .91	--	+ .61	+ .33	+ .59
Radium-228	+ .83	+ .85	+ .91	+ .77	1	+ .95	- .38	+ .60	+ .43	+ .64

Table 6. Significance levels for Kruskal-Wallis statistical tests comparing concentrations of radionuclides, concentrations of selected inorganic ions, and pH by region (northern and southern outcrop) and land-use groups (by predominance: agricultural, residential, and undeveloped), Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99

[Statistical test result significant at the 95-percent confidence level indicating differences among the groups is shown in bold print]

Constituent	Region	Land use
Radium-224	**0.0213**	**0.0308**
Radium-226	**.0413**	**.0069**
Radium-228	**.0042**	**.0085**
Radium-226 + radium-228	**.0054**	**.0043**
Gross alpha-particle activity	**.0144**	**.0405**
Gross beta-particle activity	**.0003**	**.0010**
Radon-222	.3996	.7988
pH	**.0310**	.2561
Nitrate plus nitrite	**.0001**	**.0001**
Calcium	**.0005**	**.0012**
Magnesium	**.0034**	**.0001**

however, standard sample aliquots for these analyses were increased in order to quantify activity below the 3- and 4-pCi/L LRLs, respectively (app. 3). Gross alpha-particle activity was lowest (1.37 pCi/L) in the sample from well 111011; the concentrations of Ra-224, Ra-226, and Ra-228 were all 0.25 pCi/L or less in water from this well, constituting the lowest concentration of total radium in the 88 samples.

Quality-Assurance Results

The maximum difference between analytical results for concentrations of Ra-224 in the 22 split samples for any pair was 0.8 pCi/L. Concentrations in all but four of the pairs overlapped within the bounds of one standard deviation PE as defined by the counting error. Relative percent differences (RPD) for raw, unrounded values of the sample pairs ranged from 0 to 34 percent; RPDs generally increased as concentrations approached the LRL of 0.5 pCi/L. The maximum difference between analytical results for the five sample pairs for sequential replicates analyzed at the same laboratory was 0.6 pCi/L. The RPDs for these samples ranged from 8 to 25 percent. These results indicate that the Ra-224 concentration results are about equally precise and repeatable as results of other standard radionuclide analyses (Krieger and Whittaker, 1980; Parsa and Hoffman, 1992).

Sample contamination at the 1.0-pCi/L level was not detected in any pumping equipment blank sample for any radionuclide determined (app. 2). This result indicates that samples were not contaminated with radionuclides during any step of the sample-collection, sample-handling, and sample-analysis process.

Similarly, sample contamination at the 1-µg/L level was not detected for a host of trace elements used as indicators of various modes of sample contamination. Sample contamination was not noted for mercury, lead, or copper, which are typical aerosol contaminants, indicating that samples were not contaminated with aerosols in either field or laboratory handling (app. 2). Furthermore, no contamination with pump components such as chromium, nickel, molybdenum, and iron (Ivahnenko and others, 2001) was detected, indicating that sample contamination resulting from contact with pumping equipment did not occur or was minimal. Concentrations of manganese exceeded 1 µg/L in one pumping-equipment blank sample. Subsequent analysis of the associated tubing-and-filter blank sample indicated the absence of manganese at this concentration level, thereby indicating that the pump was the likely source of the manganese. This result is consistent with those obtained for pumping-equipment blank samples by Ivahnenko and others (2001). Several (8) blank samples showed minor contamination with boron and (or) aluminum. Boron may be an artifact of the acid preservative that was stored in borosilicate glass ampules, and concentrations of aluminum persistently are biased high at the analytical laboratory (Faires, 1993).

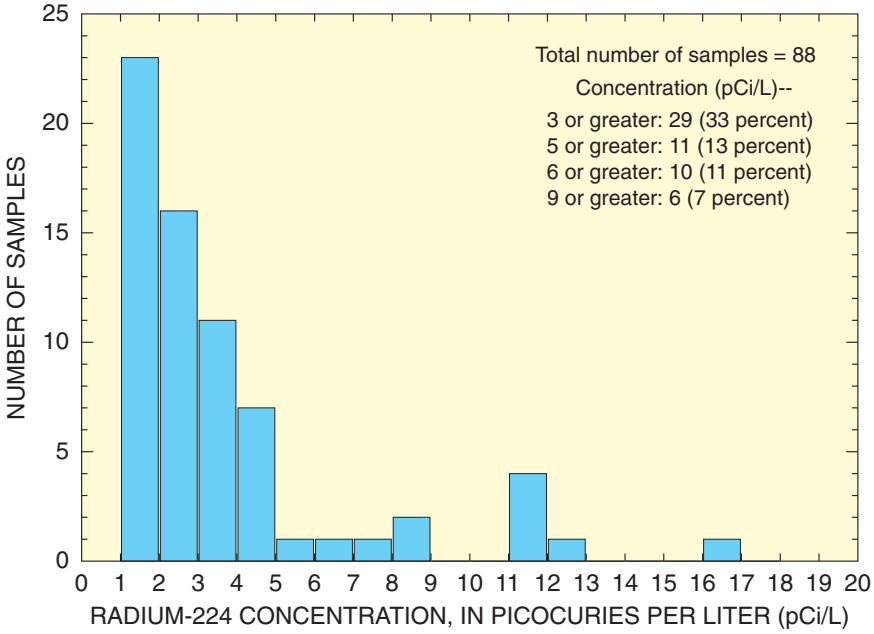

Figure 4. Radium-224 concentrations in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

Overall, analysis of the quality-assurance samples demonstrates that the water samples generally were free of random low-level sample contamination resulting from sample handling in the field and laboratory. Detection of trace concentrations of possible contaminants from pump components in the absence of detectable radionuclides in the blank samples indicates that, although low-level trace-element concentration results must be interpreted carefully, random contamination with radionuclides during sample handling is not of concern.

Factors Affecting Distribution of Radium-224

Radium-224 was detected at concentrations greater than 1.0 pCi/L in 67 of the 88 samples of water from the Kirkwood-Cohansey aquifer system. The detection frequency of Ra-224 was substantial at the 3 pCi/L, 5 pCi/L and 10 pCi/L levels (28, 11, and 6 of the 88 samples, respectively) (fig. 4). The occurrence, mobility, and distribution of Ra-224 are related to the presence of other constituents and to the physical characteristics of the aquifer system outcrop area.

Other Radioactive Constituents

Concentrations of Ra-224 were significantly correlated with those of Ra-228 (r = 0.91), Ra-226 (r = 0.74), and combined radium (r = 0.88) (table 5; fig. 5). The strong correlation with concentrations of Ra-228 is not surprising given that both radionuclides are part of the same decay series (the Th-232 series) and that Ra-228 decays indirectly, through Ac-228 and Th-228, to Ra-224 (fig. 1). The degree of correlation between concentrations of Ra-224 and Ra-226 is similar to the degree of correlation between concentrations of Ra-228 and Ra-226 (r = 0.77). This value closely matches the previously determined correlation coefficients of 0.75 and 0.67 reported for water from the aquifer by Kozinski and others (1995) and Szabo and others (1997), respectively. Concentrations of radium isotopes are strongly correlated because all are mobile under the same chemical conditions (Zapecza and Szabo, 1988) and because radium radionuclides can be mobilized as a result of radionuclide recoil effects (Fleischer, 1980). Moreover, both Ra-226 and Ra-228 are present in the aquifer materials (Szabo and others, 1997); concentrations of Ra-226 and Ra-228 each range from less than 0.1 to about 0.8 pCi/g of aquifer sediment. This occurrence in the sediment is a likely reason for concurrence in the water.

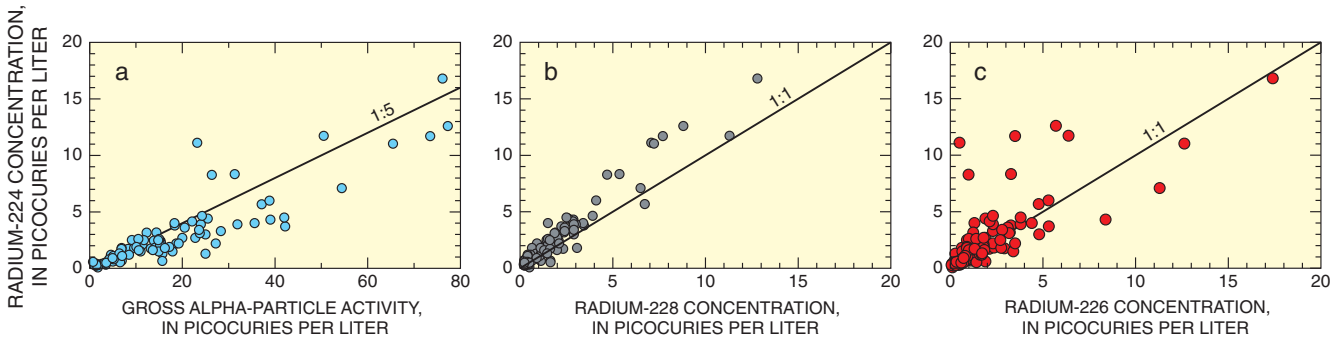

Figure 5. Relation of radium-224 concentrations to (a) gross alpha-particle activity, (b) radium-228 concentration and (c) radium-226 concentration in water from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

Radium-224 is an alpha-particle-emitting radionuclide that generally is present at the highest concentration of any radioisotope in water samples from the aquifer; the Ra-224 concentration was greater than both the Ra-226 and the Ra-228 concentrations in 52 (59 percent) of the 88 samples. Thus, a strong, significant correlation is expected between concentrations of Ra-224 and gross alpha-particle activity. Concentrations of Ra-224 were significantly correlated with gross alpha-particle activities determined within 48 hours of sample collection (Spearman rank correlation coefficient r = 0.89) (table 5). The ratio of gross alpha-particle activity to Ra-224 concentration was approximately 5:1 (fig. 5).

pH

Concentrations of Ra-224 generally were highest in the samples with the lowest pH and exhibited a moderately strong, statistically significant inverse relation to pH (r = -0.36; table 5). The importance of low pH in mobilizing radium can be verified by examining the distribution of elevated concentrations of Ra with respect to pH. The median pH of the 88 samples in this study was 4.7. Results of the Wilcoxon test indicate that concentrations of Ra-224 and combined Ra and gross alpha-particle activities in samples whose pH exceeded the median were statistically different from those in samples where the pH was less than this value; in all cases, the concentrations or activities were highest in the group with the lowest pH. Of the 46 samples with a pH less than or equal to 4.7, 22 (48 percent) contained Ra-224 at concentrations of 3 pCi/L or greater. Of this same subset of samples, 19 (41 percent) also contained combined Ra at concentrations that exceeded the 5-pCi/L MCL. Furthermore, of the 28 samples (32 percent of the 88) that contained Ra-224 at a concentration greater than or equal to 3 pCi/L, 21 (75 percent) had a pH less than or equal to 4.7 (fig. 6), 24 (83 percent) had a pH of 4.8 or less, and all but 1 had a pH less than 5.0. All 10 samples in which the Ra-224 concentration exceeded 5 pCi/L had a pH less than 5, and 8 (80 percent) had a pH less than or equal to 4.7. In contrast, only 19 percent (8 of 42) of the samples with a pH greater than 4.7 contained Ra-224 at concentrations of 3 pCi/L or greater, and the same percentage contained combined Ra at concentrations of 5 pCi/L or greater. Only one (7 percent) of the 15 samples that had a pH greater than 5 also contained Ra-224 at a concentration greater than 3 pCi/L (well 110002; pH, 5.1; Ra-224, 4.5 pCi/L; combined Ra, 6.3 pCi/L). Water from this well previously was found to have a pH of 5.1 and combined Ra of 5.2 pCi/L (Kozinski and others, 1995), indicating that this well is consistently intercepting water that contains abundant Ra but is slightly less acidic than the typical Ra-rich water from the aquifer. Only two samples that contained combined radium at a concentration greater than 5 pCi/L had a pH greater than 5 (fig. 6); the pH values were 5.1 and 5.5 (wells 291131 and 050161, respectively).

As pH decreases, all isotopes of radium (including Ra-224) become more mobile because the hydrogen ions compete effectively with radium for the available sorption or exchange sites (Szabo and others, 1997). Because the sorption and exchange capacity of the sediments that make up the Kirkwood-Cohansey aquifer system is extremely low, even a small increase in free hydrogen-ion content (decrease in pH) can result in a substantially diminished sorption (and exchange) capacity. The quartzose aquifer materials are virtually nonreactive and provide minimal buffering capacity; therefore, any chemical reaction that produces hydrogen ion can result in a large and rapid decrease in pH.

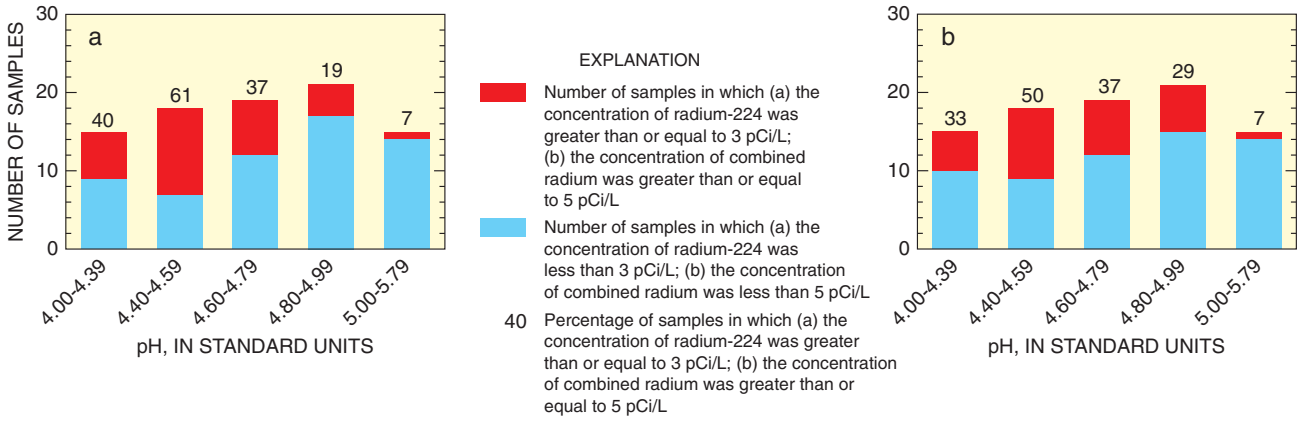

Figure 6. Number of water samples in which (a) the concentration of radium-224 was greater than or equal to 3 pCi/L and (b) the concentration of combined radium was greater than or equal to 5 pCi/L as a function of pH, Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

Geography

Concentrations of Ra-224, Ra-226, and Ra-228 varied geographically; concentrations were greater in samples from the southern part of the aquifer outcrop area (median concentrations 2.6, 1.9, and 2.0 pCi/L, respectively) than in samples from the northern part (median concentrations 1.9, 1.3, and 1.4 pCi/L, respectively). The northern part of the outcrop area includes Burlington and Ocean Counties. The southern part of the outcrop area includes Atlantic, Camden, Cumberland, Gloucester, and Salem Counties.

Concentrations of Ra-224 in 24 (45 percent) of the 53 samples from the southern part of the aquifer outcrop area exceeded 3 pCi/L, and concentrations of combined radium in 23 (43 percent) exceeded the 5-pCi/L MCL. Concentrations of Ra-224 in 11 samples from this part of the outcrop area exceeded 5 pCi/L; concentrations of combined radium and gross alpha-particle activities in these 11 samples exceeded their respective MCLs. All 11 samples were from wells in the southernmost part of the study area-western Atlantic, southern Camden, northern Cumberland, and eastern Salem Counties (figs. 3 and 8).

In the northern part of the study area, the samples in which the concentrations of Ra-224, Ra-226, and Ra-228 were highest were from wells centered in northeastern Ocean County (figs. 3a, 3b, 7, 8a, and 8b). The effect of Ra-224 on gross alpha-particle activity in the northern part of the outcrop area is sufficiently great that gross alpha-particle activities in 15 samples from this region (analyzed within 48 hours of collection) were greater than or equal to the 15-pCi/L MCL (fig. 8), whereas gross alpha-particle activities in all water samples collected prior to 1997 and analyzed about 30 days after sample collection were less than 15 pCi/L. In the current study, the wells that yielded water in which gross alpha-particle activity exceeded the MCL are in Dover, Manchester, and Lakewood Townships in Ocean County (fig. 7), an area that includes parts of the Toms River and Kettle Creek drainage basins (fig. 8). Concentrations of combined radium were greater than the 5-pCi/L MCL in three samples. The area of occurrence of elevated radioactivity that originated primarily from Ra-226 and Ra-228 and thus was detectable before 1997 was in selected areas in one county (Ocean), as opposed to the four-county area of radioactive water in the southern part of the aquifer outcrop area described above (fig. 8). In the current study, 4 stream basins (HUC11) in the northern portion of the aquifer have yielded at least one sample in which various criteria for radioactivity were exceeded, as opposed to 12 in the southern portion (fig. 9). Four samples in these stream basins in the northern part of the outcrop area contained concentrations of Ra-224 greater than 3 pCi/L (fig. 3) but less than 5pCi/L.

Water throughout the aquifer outcrop area is predominantly acidic, with a typical pH less than 5.0. The pH is only slightly lower in the southern part of the area than in the northern part (medians 4.6 and 4.8, respectively; table 4), but this difference is statistically significant. The southern part of the area differs from the northern part in the predominance of agricultural land and the presence of the Bridgeton Formation overlying the Cohansey Sand. The outcrop areas of the Bridgeton Formation generally coincide with areas of agricultural land use (Kozinski and others, 1995; Szabo and dePaul, 1998). Concentrations of Ra-224 (as well as those of combined radium) were highest in agricultural areas overlying the Bridgeton Formation in southwestern New Jersey (fig. 3). This spatial distribution of Ra-224 is consistent with results of previous work (Kozinski and others, 1995; Szabo and dePaul, 1998) for Ra-226 and Ra-228 distributions. Concentrations of chemical species that are related to agriculture, such as nitrate and the divalent cations calcium, magnesium, barium, and strontium, were significantly higher in the southern part of the outcrop area (Camden County

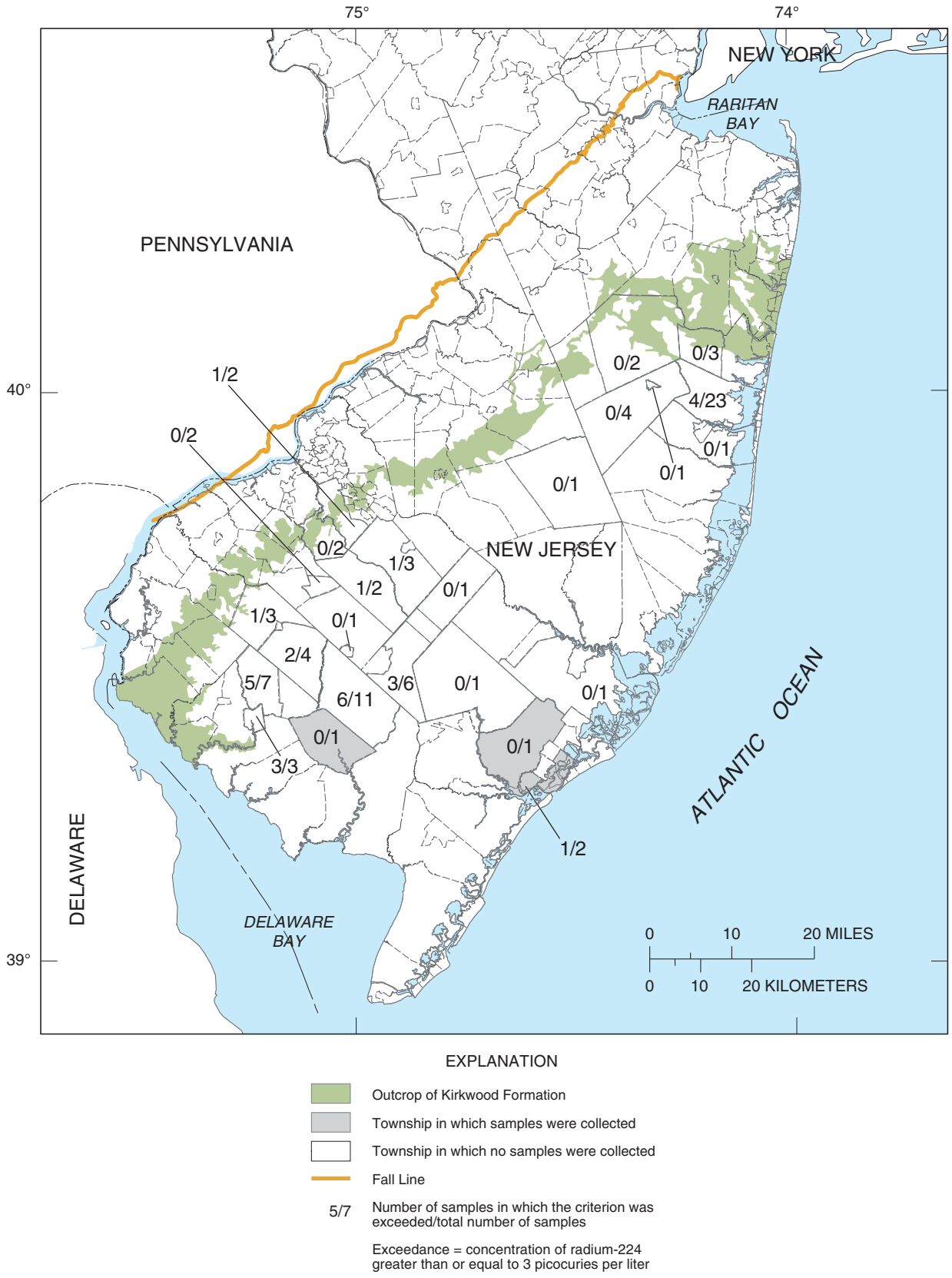

Figure 7a. Distribution by municipality of water samples collected and number of samples in which the criterion for radium-224 was exceeded, Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

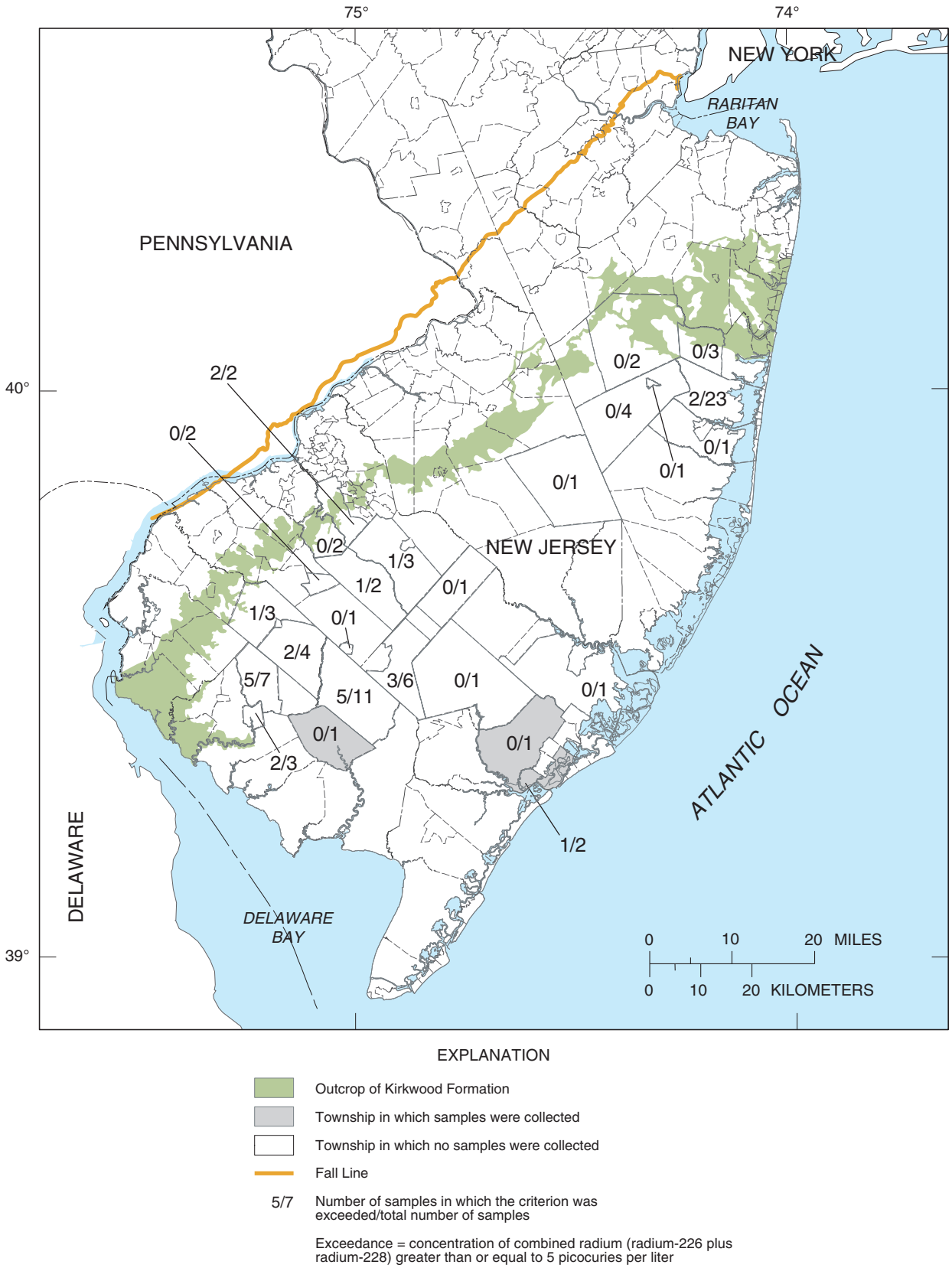

Figure 7b. Distribution by municipality of water samples collected and number of samples in which the criterion for combined radium was exceeded, Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

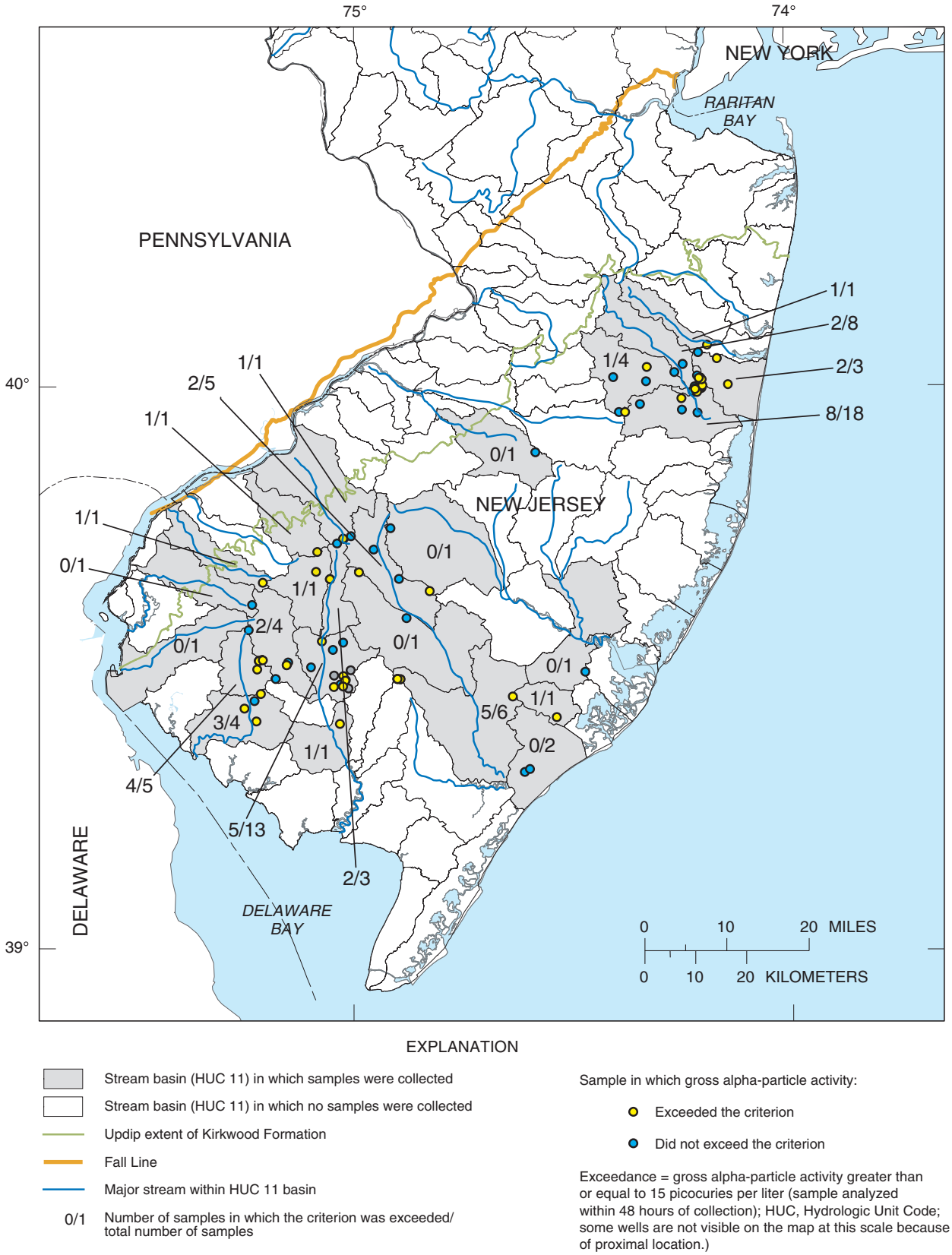

Figure 8a. Distribution by hydrologic unit code (HUC) of water samples collected and number of samples in which the criterion for gross alpha-particle activity was exceeded, Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

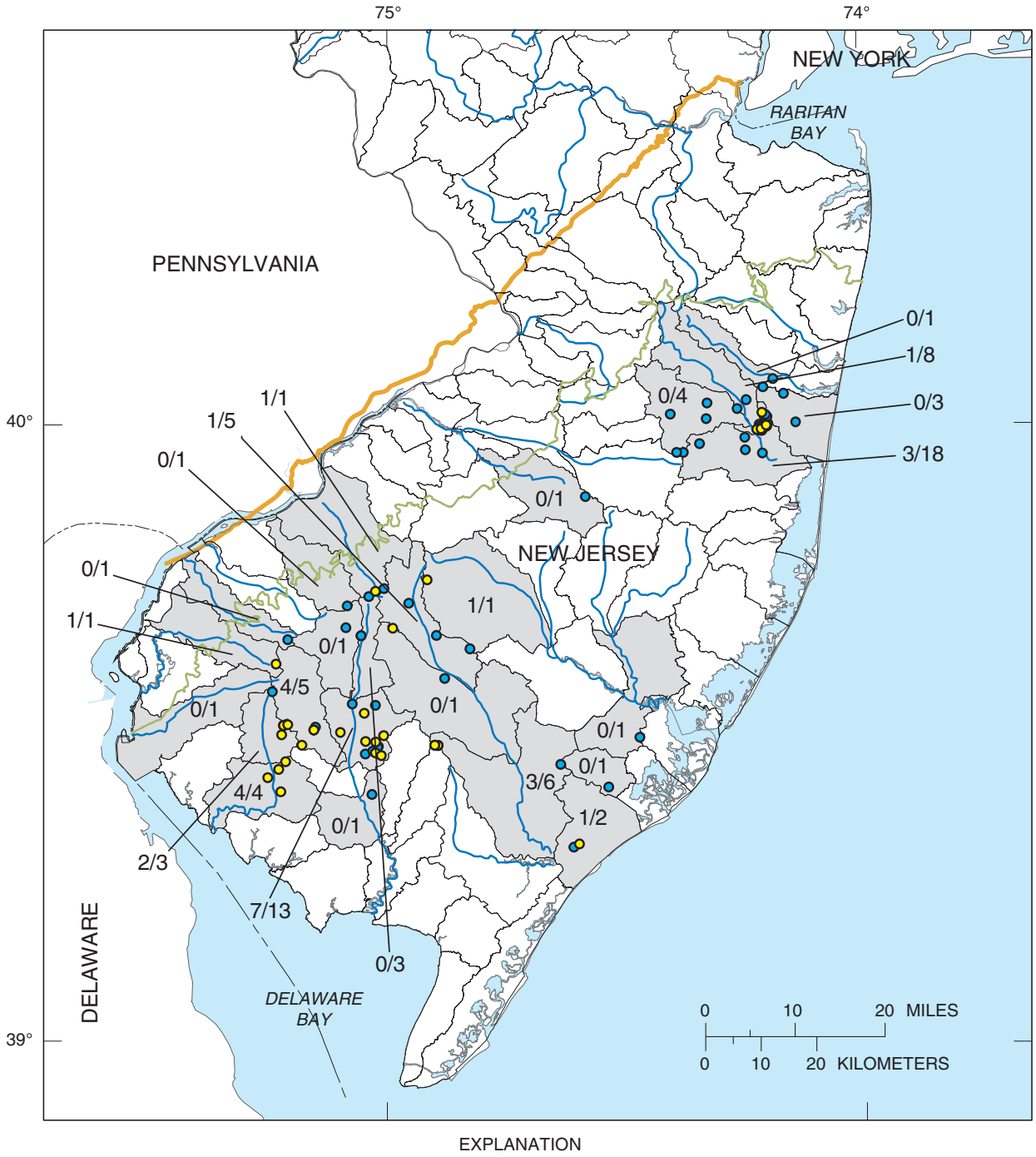

Figure 8b. Distribution by hydrologic unit code (HUC) of water samples collected and number of samples in which the criterion for radium-224 was exceeded, Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

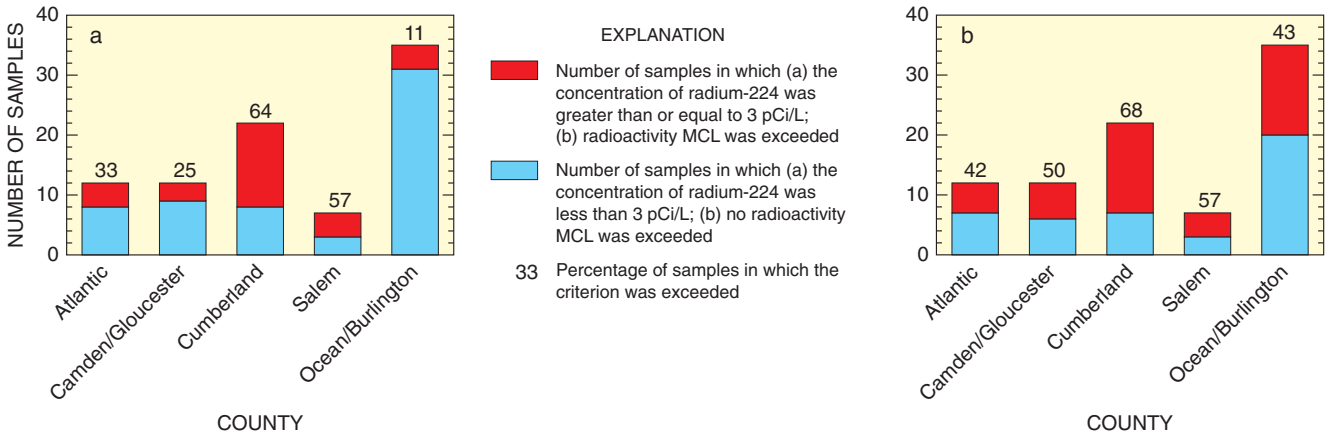

Figure 9. Number of water samples in which (a) the concentration of radium-224 was greater than or equal to 3 pCi/L, and (b) radioactivity maximum contaminant level was exceeded, by county or counties, Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-1999.

and south, centered about the Glassboro study area (fig. 2)) than in the northern part (Burlington County and north, centered about the Toms River-Metedeconk River Basin area). Median concentrations of these inorganic chemical constituents in water samples in the south were 4.7, 4.6, and 3.3 mg/L, and 79 and 37 µg/L, respectively, whereas those in the north were 1.2, 1.6, and 2.2 mg/L, and 47 and 19 µg/L, respectively (table 4b). (Application of these constituents to agricultural soils in southern New Jersey, as well as other sources, is discussed in detail by Kozinski and others (1995). A more generalized discussion of the history of soil amendments and their effects on groundwater quality through time is given by Bohlke and Denver (1995). The divalent cations compete with radium for sorption sites, thereby providing a second chemical mechanism of radium mobilization that enhances the mobilization effects of the acidic water. This second mechanism likely is more important in the southern part of the outcrop area than in the northern part, as concentrations of divalent cations (and nitrate) are higher in water from the southern part than in water from the northern part.

Results of indirect measurements using various techniques have established that the Bridgeton Formation, found predominantly in the southern part of the outcrop area, contains higher concentrations of radionuclides than the underlying Cohansey Sand (Zapecza and Szabo, 1989; Duval, 1991; Gundersen and Peake, 1992). Results of direct radiochemical analysis of Bridgeton Formation sediments collected by Szabo and others (1997) indicate that Ra-226 and Ra-228 are more abundant than in sediment samples from the Cohansey Sand. Therefore, shallow wells underlying the Bridgeton Formation in southwestern New Jersey may be particularly vulnerable to contamination with Ra-224, Ra-226, and Ra-228 as acidic recharge containing agricultural leachates percolates through the permeable gravel. The geographic distribution of the naturally occurring radioactive materials in the Bridgeton Formation overlaps with the distribution of geochemical conditions exacerbated by intensive agricultural land-use practices that act in combination to maximize the potential for ground water in the southern (and especially southwestern) part of the Kirkwood-Cohansey aquifer system outcrop where elevated radium concentrations are found.

Nitrate

Two criteria—pH and nitrate concentration—were used initially to determine the likely frequency of occurrence of concentrations of combined radium greater than the 5-pCi/L MCL and of Ra-224 concentrations greater than or equal to 3 pCi/L (fig. 10). The selection of these two criteria was based on correlations of concentrations of radium isotopes with concentrations or values of inorganic constituents and physical or chemical properties obtained in this study (table 5) as well as on the results of previous work (Szabo and dePaul, 1998; Szabo and others, 1997; Kozinski and others, 1995). (Additionally, nitrate concentration can be used as a reasonable surrogate for the prevalence of agricultural land (Rice and Szabo, 1997; Kauffman and others, 2001).) Because nitrification generates acidity and because the concentration of nitrate typically is highest where the concentrations of divalent cations are highest (Szabo and others, 1997), it was hypothesized that combined-radium concentrations would exceed the MCL of 5 pCi/L far more frequently where the ground water was more acidic than was typical for the aquifer (pH less than the median of 4.8), and where nitrate concentrations were higher (greater than 5.0 mg/L) than typical nitrate concentrations of much less than 1.0 mg/L in

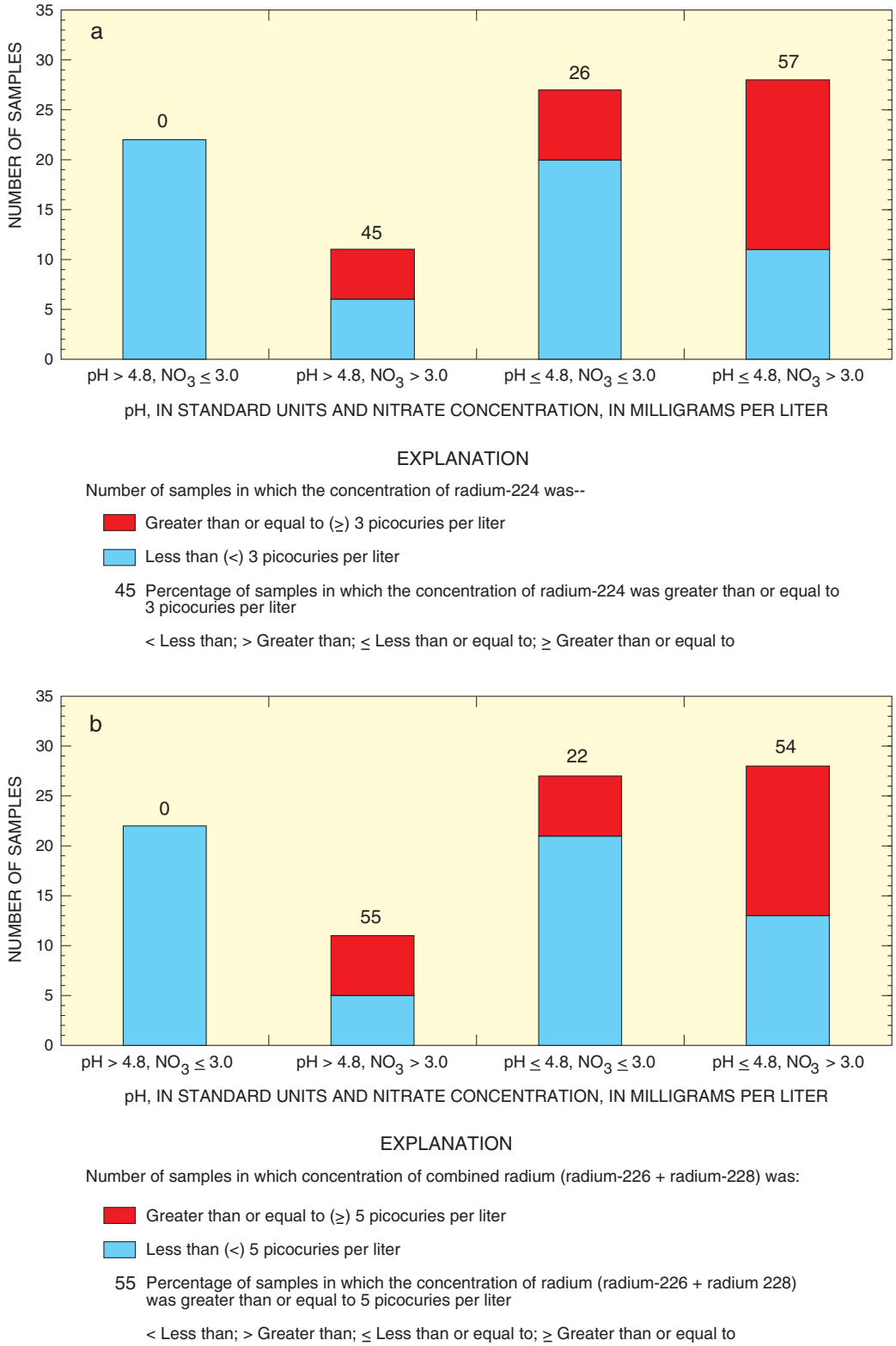

Figure 10. Number of water samples in which (a) the concentration of radium-224 was greater than or equal to 3 picocuries per liter and (b) the concentration of combined radium was greater than or equal to 5 picocuries per liter, as a function of selected ranges of pH and nitrate concentration, Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

undeveloped (forested) areas (Szabo and others, 1997). (Ultimately, the nitrate criterion was reduced from 5 to 3 mg/L, for reasons discussed below.) Because concentrations of combined Ra are strongly correlated to those of Ra-224 and to gross alpha-particle activities, this hypothesis also can be applied to estimate the frequency of occurrence of these other radioactive constituents (fig. 10). Therefore, the same two chemical criteria may be used to estimate the frequency of occurrence of gross alpha-particle activities greater than the MCL of 15 pCi/L (fig. 10).

Nitrate concentrations in production wells sampled in this study from the Kirkwood-Cohansey aquifer system tended to be lower than those from domestic or observation wells, and typically were less than 5 mg/L. The nitrate concentration in only 9 (19 percent) of the 47 production wells exceeded 5 mg/L. These nine wells were in Cumberland, Gloucester, and Salem Counties. The nitrate concentration in 9 additional production wells sampled in this study exceeded 3 mg/L (38 percent of the 47 sampled). These wells were in Atlantic and Camden Counties as well as the three counties mentioned above. The maximum nitrate concentration in any production well in Ocean County sampled during this study was 2.45 mg/L; the combined-radium and Ra-224 concentrations were less than 5 and 3 pCi/L, respectively, in water from this well. Szabo and dePaul (1998) similarly reported that the median nitrate concentration for samples from the Kirkwood-Cohansey aquifer system was 2.8 mg/L for production wells for samples they collected during 1989-1996, whereas the median concentration for samples from domestic wells was 5.8 mg/L. For each type of well, however, both this and previous studies confirm that the highest nitrate concentrations typically are in the southwestern part of the aquifer system outcrop area.

The number of samples in which the concentration of Ra-224 or of combined radium was either less than, or greater than or equal to, the specified concentration or value for each group of samples meeting the four pH and nitrate-concentration criteria combinations is shown in figure 10. The percentage of samples in each group in which the specified concentration of the radionuclide of interest was exceeded also is shown. Concentrations of Ra-224 greater than 3 pCi/L and concentrations of combined radium greater than 5 pCi/L occurred most frequently in the samples with low pH (less than 4.8) and elevated nitrate concentrations (greater than or equal to 3 mg/L). In more than half the samples with these two characteristics, the concentrations of concern for the Ra isotopes were exceeded. In the samples for which neither of these criteria was met, no Ra-224 concentration exceeded 3 pCi/L and only one combined-radium concentration exceeded 5 pCi/L.

Both Kozinski and others (1995) and Szabo and dePaul (1998) reported that concentrations of combined radium commonly exceeded 5 pCi/L in samples that contained nitrate at a concentration of only 3 mg/L. With the improved measurement procedures for radioactivity (the 48-hour holding time), the lower nitrate-concentration (3 mg/L) criterion, as opposed to the 5-mg/L criterion used by Kozinski and others (1995), can be indicative of samples with radioactivity in excess of the MCL or criterion of concern (3 pCi/L for Ra-224 concentration, for example), although the statistical level of confidence may not be as high as the 0.99-level of confidence reported by Kozinski and others (1995) for the 5-mg/L criterion. The objective of using trace chemical criteria is not to provide ultimate certainty as to the level of radioactivity (or any other trace contaminant) present in the water, but rather to provide inexpensive guidance to the likelihood that the level of radioactivity (or other trace contaminant) will exceed the level of concern. The focus of this study is not to use a "cut point" of nitrate concentration with nearly absolute certainty (for example, the 99-percent confidence level), but rather to test criteria levels that are adequate to indicate a reasonably high likelihood that the sample may be of concern when considering likely levels of radioactivity (or other trace contaminant concentrations). Therefore, in this study 3 mg/L was chosen as the nitrate-concentration "cut point" for water-quality groups used to estimate the frequency of combined-radium concentrations greater than the 5-pCi/L MCL and the selected concentration criterion of 3 pCi/L for Ra-224.

Overall, the most likely predictor of exceeding the 15-pCi/L MCL for gross alpha-particle activity, the 5-pCi/L MCL for combined radium, or the selected Ra-224 concentration of 3 pCi/L was the combination of a pH less than 4.8 and a nitrate concentration greater than 3 mg/L; one or more of these three radionuclide concentrations or activities of concern were exceeded in about 60 percent of the samples in this group (fig. 10). Of the 39 (44 percent) of the 88 samples in which the concentration of nitrate exceeded 3 mg/L, the concentration of Ra-224 exceeded 3 pCi/L in 22 (56 percent) (see fig. 10). Even in those water samples where pH was greater than 4.8, the concentration of Ra-224 was likely to exceed 3 pCi/L and the concentration of combined radium was likely to exceed 5 pCi/L if the sample also contained nitrate at a concentration of 3 mg/L or more (5 of 11 samples, or 45 percent). On the other hand, the specified Ra-224 concentration of 3 pCi/L was not exceeded in any sample in which the pH was greater than 4.8 and the nitrate concentration was less than 3 mg/L, and the 5-pCi/L MCL for combined radium was not exceeded in the 22 samples that met the same criteria (fig. 10). The results of the current study corroborate the importance of nitrate and associated dissolved mineral matter (derived from land-applied salts) for mobilizing Ra in the dilute acidic waters of the Kirkwood-Cohansey aquifer system as reported previously by Kozinski and others (1995).

Land Use

Concentrations of Ra-224, Ra-226, and Ra-228 in water samples showed statistically significant differences with predominant land use. Radium concentrations generally were higher in samples from agriculture-dominated areas than in samples from areas where other land uses were dominant (table 6). Differences between the concentrations of Ra-224, Ra-226, and Ra-228 in samples from the 35 wells in agricultural and mixed agricultural areas (median values 2.5, 2.1, and 2.1 pCi/L, respectively) and those in samples from the 25 wells

in undeveloped and light residential areas (median values 1.5, 1.2, and 1.3 pCi/L, respectively) also were statistically significant (tables 4c and 6; fig. 11). Results of the Wilcoxon rank sum test indicate that the mean of the ranked values of the concentrations of each of these radionuclides was significantly greater in agricultural areas than in nonagricultural areas (table 6). This result holds even for the second-tier classification system (the agricultural gradient land-use approach) described earlier, which is based not on predominant land use but on the presence of even a small amount of agricultural land (10 percent) within the appropriate circular buffer area about the well (table 7; fig. 11). Boxplots of the distributions of Ra-224 and combined-radium concentrations grouped by land use (fig. 11) show a decreasing concentration gradient from agricultural land (on the left) to little agriculture present, mostly undeveloped land (on the right). Tukey-Kramer groups statistically determined by analysis of ranks of radium radionuclide concentrations are delineated along the upper horizontal axis. Radium concentrations were highest in water from wells in agricultural areas regardless of the land-use classification system used in this analysis.

Most agricultural land in southern New Jersey overlies well-drained soils found on ridges (Rice and Szabo, 1997; Kauffman and others, 2001) and, therefore, is likely to coincide with the recharge area for water intercepted by downgradient wells. The effect of agricultural activities on water quality, therefore, is large; even a small percentage of agricultural land in the buffer zone surrounding a well can affect the quality of the water it yields. Undeveloped land typically is found in poorly drained, low-lying wetlands areas downgradient from wells; water recharged in such areas, therefore, is not likely to be intercepted by wells. Results of ground-water flow simulations (Rice and Szabo, 1997) indicate that most water recharged near wetlands follows short flowpaths and is discharged to the adjoining wetland within 5 to 10 years. Distributions of transient tracers measured in water samples collected by Szabo and others (1996), Rice and Szabo (1997), and Modica and others (1997, 1998) adjacent to streams in the study area are consistent with this interpretation.

Concentrations of divalent cations (such as calcium, magnesium, and strontium) in water in agricultural areas are elevated (above background concentrations) as a result of leaching of soil additives, along with nitrate, but without a corresponding increase in pH (tables 6 and 7). For example, the median concentrations of calcium and magnesium in agricultural areas (4.8 and 3.5 mg/L, respectively) are substantially higher than those in undeveloped/light-residential areas (1.1 and 1.1 mg/L, respectively) and also higher than those in urban areas (3.0 and 2.9 mg/L, respectively) (table 4). The additional divalent cations along with the hydrogen ions that are present as a result of the nitrification process compete effectively for sorption sites with radium (Szabo and others, 1997), providing a second mechanism for radium mobilization.

Effects of Improvements in Analytical Protocols on Measured Distributions of Radioactive Constituents

The median gross alpha-particle activity in the 88 water samples collected from the Kirkwood-Cohansey aquifer system by the USGS after 1997 (this study) was 14.9 pCi/L (table 4); gross alpha-particle activity in 49 percent of the samples exceeded the 15-pCi/L MCL. The median gross alpha-particle activity measured in water samples collected from the Kirkwood-Cohansey aquifer system by the USGS before 1997 was 5.4 pCi/L; gross alpha-particle activity in only 14 percent of those samples exceeded the 15-pCi/L MCL (Szabo and dePaul, 1998). The highest gross alpha-particle activity in this study (post-1997 sampling), 77.3 pCi/L, is nearly twice the 43.3-pCi/L maximum gross alpha-particle activity reported previously by Szabo and dePaul (1998) for samples collected before 1997. This large difference in gross alpha-particle activity represents formerly undetected radioactivity from short-lived alpha-particle-emitting radioisotopes, primarily Ra-224. These short-lived radionuclides and the alpha particles they emit are now detectable and quantifiable because of advances in analytical technology and strict compliance with the reduced laboratory holding time of 48 hours mandated by the State of New Jersey since September 2002 (New Jersey Department of Environmental Protection, 2002).

The analytical capability to detect and quantify the presence of short-lived radioisotopes (such as Ra-224) and the reduction in sample holding time for gross alpha-particle activity analysis has led to identification of ground waters that contain more radioactivity than previously had been known (figs. 8 and 9). When the new 48-hour gross alpha-particle measurement protocol was used, the 15-pCi/L gross alpha-particle activity MCL was exceeded (fig. 8) and Ra-224 was determined to be present in concentrations up to, or even higher than, 5 pCi/L in samples from some parts of southern New Jersey where previous measurements of gross alpha-particle activity had not indicated the presence of levels of concern, primarily central Ocean County in south-central New Jersey and, to a lesser extent, southeastern New Jersey. Gross alpha-particle activity exceeded 15 pCi/L in samples from some wells in Dover, Manchester, and Lakewood Townships (fig. 8c) in north-central and northeastern Ocean County, primarily in the Kettle Creek drainage basin (fig. 9c). With the new 48-hour measurement protocol, the MCL also was exceeded in southeastern New Jersey, in the downstreammost portion of the Great Egg Harbor River and Mill Creek drainage basins (fig. 9c). In these areas, gross alpha-particle activity in samples collected and analyzed before 1997 did not exceed the MCL or, alternatively, the samples had not been tested extensively for the presence of radium because gross alpha-particle activity was presumed to be low on the basis of a few (about 5)

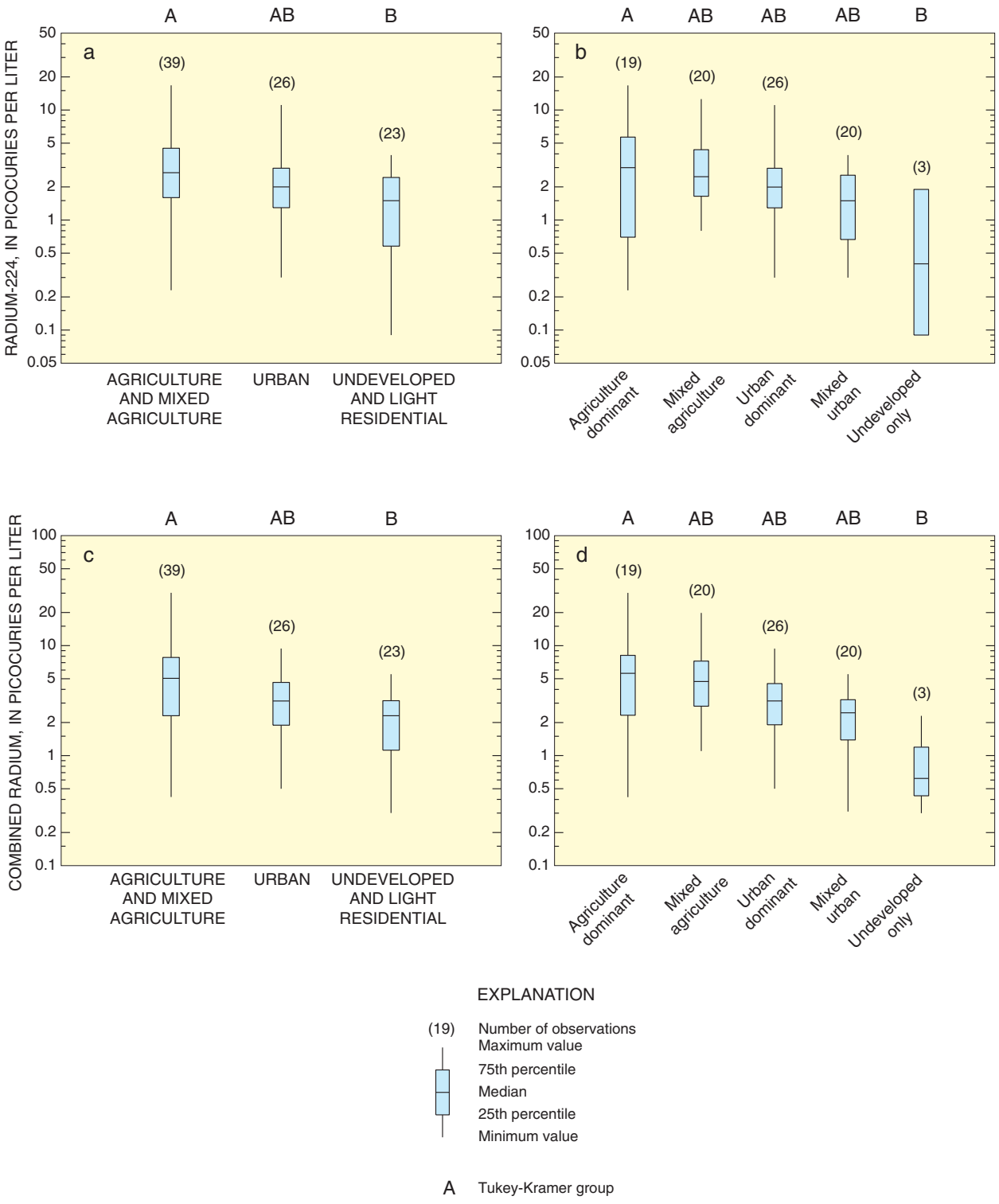

Figure 11. Distribution of concentration of radium-224 in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99, by (a) lumped land-use category and (b) narrowly defined land-use category; and distribution of concentration of combined radium (radium-226 plus radium-228) by (c) lumped land-use category and (d) narrowly defined land-use category.

Table 7. Results of Tukey-Kramer multiple comparison test to determine differences in ranks of constituent concentrations by land-use group for water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

[ND, no difference; *, not applicable; %, percent; Tukey groups: groups with the same letter designation (A, B, AB, BC, ABC) are not statistically different from each other; groups with different letter designations are statistically different from each other.

Constituent	Land-use code				
	1	2	3	4	5
	Five land-use categories (gradient)				
Radium-224	A	AB	AB	B	AB
Radium-226	A	A	AB	B	B
Radium-228	A	A	AB	B	AB
Radium-226 plus Radium-228	A	A	AB	B	B
Gross alpha-particle activity	A	AB	AB	B	B
Gross beta-particle activity	A	AB	BC	C	BC
Radon-222	ND	ND	ND	ND	ND
pH	ND	ND	ND	ND	ND
Nitrate plus nitrite	A	B	B	C	C
Magnesium	A	B	B	C	C
Calcium	A	B	BC	C	BC
Sodium	B	AB	A	B	AB
Potassium	A	AB	ABC	C	ABC
Strontium	A	B	BC	C	BC
Barium	A	A	AB	B	AB
Chloride	ND	ND	ND	ND	ND
	Combined land-use categories				
Radium-224	A	AB	B	*	*
Radium-226	A	AB	B	*	*
Radium-228	A	AB	B	*	*
Radium-226 plus Radium-228	A	AB	B	*	*
Gross alpha-particle activity	A	AB	B	*	*
Gross beta-particle activity	A	B	B	*	*
Radon-222	ND	ND	ND	*	*
pH	ND	ND	ND	*	*
Nitrate plus nitrite	A	B	C	*	*
Magnesium	A	A	B	*	*
Calcium	A	AB	B	*	*
Sodium	B	A	B	*	*
Potassium	A	A	B	*	*
Strontium	A	A	B	*	*
Barium	A	AB	B	*	*
Chloride	ND	ND	ND	*	*

Land-use	Land-use code		
	Five categories		Three categories
Agriculture-dominant	1	]	1
Mixed-agriculture-10% to dominant	2		
Urban/residential-dominant	3		2
Mixed-urban/residential-10% to dominant, agricultural less than 10%	4	]	3
Forested/undeveloped-greater than 90%	5		

measurements made without using the new protocols. Gross alpha-particle activities greater than 15 pCi/L when analysis was completed within 48 hours of sample collection also have been reported by Bolton (2000) for water from the Coastal Plain aquifers of Maryland, where such results had not previously been determined.

In many parts of southwestern New Jersey where samples of water had been collected from the Kirkwood-Cohansey aquifer system before 1997, the concentration of combined radium or gross alpha-particle activity was known to exceed the MCL (Szabo and dePaul, 1998). Southwestern New Jersey (Glassboro study area and vicinity—see fig. 2) typifies the scenario in which water from the aquifer was found to be more radioactive than previously had been known, but at least one sample collected before 1997 in each township and drainage basin to which the scenario applied contained either combined radium at a concentration greater than 5 pCi/L or gross alpha-particle activity greater than 15 pCi/L (figs. 9b, c). Therefore, the potential for the presence of elevated levels of radioactive constituents in water from the Kirkwood-Cohansey aquifer system used for drinking in southwestern New Jersey was already known (N.J. Department of Environmental Protection, 1997; Szabo and dePaul, 1998). Results of the current study, however, show that this water also contains Ra-224, in many places at concentrations greater than 3 or 5 pCi/L (figs. 8a, 9a), and, therefore, allow for a more accurate characterization of the actual radioactivity content of the drinking water than previously was possible.

The combined-radium concentration in at least one sample collected from the Toms River drainage basin (fig. 9c) before 1997 was greater than 5 pCi/L (Szabo and dePaul, 1998, fig. 1), but at the time this finding was considered to be an anomalous and isolated instance. During this study, however, gross alpha-particle activity resulting from the presence of Ra-224 and other radioactive constituents was found to be greater than 15 pCi/L in some parts of the Toms River drainage basin (primarily, but not solely, Berkeley Township). Because the gross alpha-particle-activity is now known to be greater than that determined before 1997, it can be concluded that water from the northeastern part of the Kirkwood-Cohansey aquifer system outcrop area also may commonly, not rarely, contain elevated radioactivity.

Contribution of Recently Detected Radium-224 to Gross Alpha-Particle Activity

The presence of Ra-224 and the additional alpha radiation emitted by the ground water in which it is found may pose an additional quantifiable health risk not directly accounted for by the USEPA MCL of 5 pCi/L that was established by the Radionuclide Rule of 2000 (U.S. Environmental Protection Agency, 2000a) for combined radium in drinking water. One of the major reasons for studying the occurrence, distribution, and mobility of naturally occurring radionuclides (Ra-224, or other commonly occurring radionuclides) is that the amount of the radionuclide present represents the objective, measurable physical phenomenon of radiation to which individuals may be exposed. The computation of the risk from the radiation exposure, however, represents an interpretation of the physical phenomenon of radiation and human exposure to it and may vary considerably depending on the risk model used (U.S. Environmental Protection Agency, 1999). Mays and others (1985) estimated the cancer risk from Ra-224 to be less than that from Ra-226. The short half-life of Ra-224 was considered to limit the radiation dose to the body (or to bone). Because of its short half-life, however, much of the ingested Ra-224 decays on bone surfaces, where its effectiveness in causing damage to living bone cells is enhanced. Nevertheless, recent reevaluation indicates that although the lifetime cancer risk from the ingestion of Ra-224 is greater than that suggested by Mays and others (1985), it is less than that from the ingestion of an equal amount of Ra-226 or Ra-228 (U.S. Environmental Protection Agency, 1999). Additional research to identify the metabolic pathways of Ra-224 in the body after ingestion will allow public-health officials to further refine estimates of the risk from radiation exposure because of ingestion of ground water that contains this radioactive constituent and/or its radioactive progeny.) The USEPA did not establish an MCL for Ra-224 concentration in drinking water with the implementation of the Radionuclide Rule of 2000 (U.S. Environmental Protection Agency, 2000a). In the absence of an MCL, the relative importance of the presence of Ra-224 in terms of its contribution to the total amount of radioactivity in ground water can be evaluated by comparing the distribution of Ra-224 concentrations to the distributions of Ra-226 concentrations, Ra-228 concentrations, and gross alpha-particle activities.

Of the 88 wells from which water samples were collected, 32 percent produced water containing Ra-224 at concentrations exceeding 3 pCi/L (fig. 4); concentrations exceeded 5, 6, and 9 pCi/L in 12.5, 11, and 7 percent of the samples, respectively (tables 3 and 4). The 5-pCi/L MCL for combined radium was exceeded in approximately 30 percent of the samples, whereas the 30^{th} percentile for the distribution of Ra-224 concentrations was 3.2 pCi/L. On the basis of concentration distributions alone, then, samples in which Ra-224 concentrations exceed about 3 pCi/L constitute about the same proportion of the sample population (have about the same frequency of occurrence) as those samples with a combined-radium concentration greater than the MCL.

The generalized regional distribution of radioactivity in drinking water produced from the Kirkwood-Cohansey aquifer system can be determined from the percentage of samples from each county in which either the MCL for gross alpha-particle activity, the MCL for combined radium, or the value of concern for Ra-224 (3 pCi/L) is exceeded. (County rather than HUC boundaries were used for this analysis because the number of samples associated with the individual HUCs was insufficient to evaluate regional trends.)

The number of samples collected in each of the seven counties, as well as the fraction in which each of the individual criteria was exceeded and the fraction in which at least one of

the criteria was exceeded, are shown in figure 9. Cumberland County in southwestern New Jersey appears to be the area of greatest concern because at least one of the three criteria was exceeded in 68 percent of the samples, and concentrations of Ra-224 exceeded 3 pCi/L in 64 percent. Ra-224 concentrations in about one-quarter to one-half the samples from each of the four remaining counties in the southernmost part of the State (Atlantic, Camden, Gloucester, and Salem Counties) exceeded 3 pCi/L (fig. 7a) and at least one MCL for radionuclide concentration or radioactivity was exceeded in nearly one-half the samples (fig. 7b). Data from Burlington County, in the north-central New Jersey Coastal Plain, are insufficient for adequate evaluation; therefore, analysis results for samples from Burlington and Ocean Counties were combined. In Burlington and Ocean Counties, at least one of the three criteria was exceeded in 37 percent of the samples, and concentrations of Ra-224 exceeded 3 pCi/L in 11 percent.

Of the sampled wells, Ra-224 concentrations in water from 12.5 percent (11 of 88) exceeded 5 pCi/L (table 3; fig. 4). All of these samples were from wells in the southwestern part of the aquifer system outcrop area, specifically western Atlantic, southern Camden, northern Cumberland, and eastern Salem Counties (fig. 3). Therefore, because Ra-224 emits alpha-particle radiation, the presence of water containing alpha-particle radioactivity at levels of concern (based on the USEPA MCL) is most prevalent in the southwestern part of the State. Because Ra-226 also emits alpha particles and has a long half-life, gross alpha-particle activity determined even without strict holding-time protocol is elevated in ground water in this part of the State, as previously documented by Szabo and dePaul (1998). The widespread occurrence of Ra-224 at concentrations greater than or equal to 3 pCi/L, coupled with the presence of Ra-226 at concentrations of nearly the same magnitude, likely causes alpha radioactivity in the ground water when determined within 48 hours of sample collection, to exceed the USEPA MCL, not only in southwestern New Jersey, but also in the north-central and northeastern parts of the New Jersey Coastal Plain, especially north-central Ocean County (figs. 3, 7, and 8).

Summary

Water from the Kirkwood-Cohansey aquifer system in the New Jersey Coastal Plain, which is used extensively for drinking-water supply, contains Ra-226 and Ra-228 at concentrations that exceed the USEPA 5-pCi/L MCL for combined radium. Water from the aquifer system also contains Ra-224 at concentrations that are sufficiently high to contribute considerable gross alpha-particle radioactivity to the water. Improvements in analytical technology have allowed gamma and alpha spectroscopic techniques to be used to determine concentrations of Ra-224. Concentrations of Ra-224 in samples collected from 88 wells during 1997-99 ranged from 0.5 to 16.8 pCi/L (median 2.1 pCi/L); concentrations in 32 percent of the samples exceeded 3 pCi/L. Concentrations of Ra-226 and Ra-228 in the same samples ranged from <0.5 to 17.4 pCi/L (median 1.7 pCi/L) and from <1 to 12.8 pCi/L (median 1.6 pCi/L), respectively. In 52 (59 percent) of the 88 samples, the concentration of Ra-224 was higher than the concentration of either of the two other radium radioisotopes. As part of ongoing work in the Kirkwood-Cohansey aquifer system, the USGS, in cooperation with the NJDEP, investigated the presence of elevated and varying gross alpha-particle activity in the aquifer system that is not explained by the concentrations of long-lived (years) alpha-particle-emitting radionuclides, such as Ra-226 and U-238. The aquifer system is regionally extensive (more than 3.00 mi^2) underlying southern New Jersey. The aquifer system is the predominant source of drinking water in this area.

Concentrations of Ra-224 correlate strongly with those of both Ra-228 and Ra-226 (Spearman correlation coefficients 0.91 and 0.74, respectively). Concentrations of Ra-224, Ra-226, and Ra-228 were greatest in the most acidic samples. Radioisotope concentrations in samples with a pH less than 4.7 exceeded the MCL for combined Ra and/or a concentration of Ra-224 of 3 pCi/L at a rate three times that of those in samples with a pH greater than 4.7. Of the 28 samples in which the concentration of Ra-224 was greater than or equal to 3 pCi/L, 21 (75 percent) had a pH less than or equal to 4.7, and all but 1 had a pH less than 5.0. Generally, concentrations of Ra-224, Ra-226, and Ra-228 were higher in water from the southwestern and south-central parts of the aquifer system outcrop area than in water from the northern part, and were higher in water from areas where agricultural land was dominant, or at least present, than in non-agricultural areas. These results are consistent with those reported previously. In the northeastern and southeastern parts of the outcrop area, however, concentrations of radium-224 greater than 3 pCi/L as well as concentrations of combined radium and alpha-particle activities in excess of the respective USEPA MCLs were detected, although previous measurements had not shown the water to contain radioactivity at these levels. Most of the samples that contained radionuclides at levels of concern were from north-central and northeastern Ocean County and southeastern Atlantic County.

The presence of Ra-224 poses an additional, quantifiable health risk not currently captured by the USEPA MCL for combined radium in drinking water. Additional documentation of the natural distribution of Ra-224 could help public-health officials in their efforts to estimate the amount of exposure that can be attributed to this radionuclide and to determine whether to establish an MCL for this constituent.

Acknowledgments

The authors gratefully acknowledge the following individuals at NJDEP for their assistance: Karl Muessig, the New Jersey State Geologist, for administering the project; Dr. Gerald Nicholls and Patricia Gardner for discussions outlining the risk posed to consumers from radium; Barker Hamill for alerting public water-supply purveyors and consumers to the findings of the study; Vincent Monaco for providing analysis results to individual public water-supply purveyors; and Alan Dillon and

John Fields for comparing radium-concentration results from mutually sampled wells and for incorporating the results into NJDEP databases. The authors thank the many water-system managers who allowed access to public-supply wells; special thanks are given Richard Ottens of United Water Toms River, Kevin Dixon of New Jersey American Water Company, and Paul Hoerner of the Vineland Water and Sewer Utility, and their respective staff members for their assistance in the collection of large numbers of samples from their water systems. The authors express appreciation to all private well owners who granted access to their wells for sampling. The authors also thank David Bolton (Maryland Geological Survey) and Joseph Ayotte (USGS) for their helpful reviews of the report.

References Cited

American Association of Public Health, 2004, Radium, Gamma Spectroscopy Method, *in* Standard methods for analysis of water and wastewater: Washington, D.C., 21st edition, Method 7500-E.

American Society for Testing and Materials, 1999, Measurement of radioactivity, *in* American Society for Testing and Materials Standards: v. 11.02, Philadelphia, Pa., p. 240.

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.

Ayers, M.A., Kennen, J.G., and Stackelberg, P.E., 2000, Water quality in the Long Island-New Jersey coastal drainages, New York and New Jersey, 1996-98: U.S. Geological Survey Circular 1201, 40 p.

Bohlke, J.K., and Denver, J.M., 1995, Combined use of groundwater dating, chemical, and isotopic analyses to resolve the history and fate of nitrate contamination in two agricultural watersheds, Atlantic coastal plain, Maryland: Water Resources Research, v. 31, p. 2319-2339.

Bolton, D.W., 2000, Occurrence and distribution of radium, gross alpha-particle activity and gross beta-particle activity in ground water in the Magothy Formation and the Potomac Group aquifers, upper Chesapeake Bay area, Maryland: Maryland Geological Survey Report of Investigations 70, 143 p.

Currie, L.A., 1968, Limits for qualitative detection and quantitative determination: Application to radiochemistry: Analytical Chemistry, v. 40, no. 3, p. 586-593.

Durrance, E.M., 1986, Radioactivity in geology: Principles and applications: Chichester, U.K., Ellis Horwood Limited, 441 p.

Duval, J.S., 1991, Use of aerial gamma-ray data to estimate relative amounts of radon in soil gas: U.S. Geological Survey Bulletin 1971, p. 155-162.

Ellis, W.H., Jr., and Price, C.V., 1995, Development of a 14-digit hydrologic coding scheme and boundary data set for New Jersey: U.S. Geological Survey Water-Resources Investigations Report 95-4134, 1 sheet.

Elsinger, R.J., King, P.T., and Moore, W.S., 1982, Ra-224 in natural waters measured by gamma-ray spectrometry: Analytica Chimica Acta, v. 144, p. 277-281.

Faires, L.M., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of metals in water by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92-634, 28 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: Techniques of Water-Resources Investigations of the U.S. Geological Survey, book 5, chap. A1, 545 p.

Fleischer, R.L., 1980, Isotopic disequilibrium of uranium: Alpha-recoil damage and preferential solution effects: Science, v. 207, p. 979-981.

Focazio, M.J., Szabo, Zoltan, Kraemer, T.F., Mullin, A.H., Barringer, T.H., and dePaul, V.T., 2001, Occurrence of selected radionuclides in ground water used for drinking water in the United States: A reconnaissance survey, 1998: U.S. Geological Survey Water-Resources Investigations Report 00-4273, 35 p.

Gundersen, L.C.S., and Peake, R.T., 1992, Radon in the Coastal Plain of Texas, Alabama, and New Jersey: Geological Society of America Special Paper 271, p. 53-64.

Hall, F.R., Donahue, P.M., and Eldridge, A.L., 1985, Radon gas in ground water in New Hampshire: National Water Well Association Proceedings of the Second Annual Eastern Regional Ground Water Conference, Worthington, Ohio, p. 86-100.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: New York, Elsevier, 522 p.

Ivahnenko, Tamara, Szabo, Zoltan, and Hall, G.S., 1996, Use of an ultra-clean sampling technique with inductively-coupled plasma-mass spectrometry to determine trace-element concentrations in water of the Kirkwood-Cohansey aquifer system, Coastal Plain, New Jersey: U.S. Geological Survey Open-File Report 96-142, 37 p.

Ivahnenko, Tamara, Szabo, Zoltan, and Gibs, Jacob, 2001, Changes in sample-collection and analytical techniques and effects on retrospective comparability of low-level concentration of trace elements in ground water: Water Research, v. 35, no. 15, p. 3611-3624.

Janzer, V. J., 1980, Discordant gross radioactivity measurements of natural and treated waters, *in* Kelly, J.J., ed., Effluent and environmental radiation surveillances: American Society for Testing and Materials Standards, Special Technical Publication 698, Philadelphia, Pa., p. 327-341.

Jeter, H.W., 1998, An extended-range method for gross alpha-/beta-particle measurements in water samples: Radiochemistry and Radioactivity, v. 9, no. 1, p. 16-25.

Kauffman, L.J., Baehr, A.L., Ayers, M.A., and Stackelberg, P.E., 2001, Effects of land use and travel time on the distribution of nitrate in the Kirkwood-Cohansey aquifer system in southern New Jersey: U.S. Geological Survey Water-Resources Investigations Report 01-4117, 49 p.

Knoll, G.F., 1989, Radiation detection and measurement: New York, Wiley & Sons, 754 p.

Koterba, M.T., Wilde, F.D., and Lapham, W.W., 1995, Groundwater data-collection protocols and procedures for the National Water-Quality Assessment Program: Collection and documentation of water-quality samples and related data: U.S. Geological Survey Open-File Report 95-399, 113 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, southern New Jersey, 1983-89: U.S. Geological Survey Water-Resources Investigations Report 92-4144, 130 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.

Martino, R.L., 1981, The sedimentology of the late Tertiary Bridgeton and Pensauken Formations in southern New Jersey: unpublished Ph.D. dissertation, New Brunswick, N.J., Rutgers University, 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, p. 635-647.

Modica, Edward, Reilly, T.E., and Pollock, D.W., 1997, Patterns and age distribution of ground-water flow to streams: Ground Water, v. 35, no. 3, p. 523-537.

Modica, Edward, Buxton, H.T., and Plummer, L.N., 1998, Evaluating the source and residence times of ground water seepage to streams, New Jersey Coastal Plain: Water Resources Research, v. 34, no. 11, p. 2797-2810.

Nawyn, J.P., 1997, Withdrawals of ground water and surface water in New Jersey, 1994: U.S. Geological Survey Fact Sheet FS-120-97, 4 p.

New Jersey Department Environmental Protection, 1997, A homeowner's guide to radioactivity in drinking water: Trenton, N.J., New Jersey Department Environmental Protection, 4 p.

New Jersey Department Environmental Protection, 2002, Private Well Testing Act; Regulations governing the certification of laboratories and environmental measurements: N.J. Administrative Code, Amendment 7:18: New Jersey Register, v. 34, 16 p.

Nicholson, R.S., and Watt, M.K., 1997, Simulation of groundwater flow in the unconfined aquifer system of the Toms River, Metedeconk River, and Kettle Creek Basins, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 97-4066, 100 p.

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, 47 p.

Parsa, Bahman, and Hoffman, A., 1992, Determination of Ra-228 in drinking water: Journal of Radioanalytical and Nuclear Chemistry, v. 158, p. 53-62.

Parsa, Bahman, 1998, Contribution of short-lived radionuclides to alpha-particle radioactivity in drinking water and their impact on the Safe Drinking Water Act regulations: Radioactivity & Radiochemistry, v. 9, no. 4, p. 41-50.

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 Special Report No. 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.

Schleien, B., 1992, The health physics and radiological health handbook: Silver Spring, Md., Scinta Corp., 734 p.

Sill, C.W., Hindman, F.D., and Anderson, J.I., 1979, Simultaneous determination of alpha-emitting radionuclides of Radium through Californium in large environmental and biological samples: Analytical Chemistry, v. 51, no. 8, p. 1307-1314.

Sill, C.W., and Williams, R.L., 1981, Preparation of actinides for alpha-spectrometry without electrodeposition: Analytical Chemistry, v. 53, p. 412-415.

Stackelberg, P.E., Kauffman, L.J., Baehr, A.L., and Ayers, M.A., 2000, Comparison of nitrate, pesticides, and volatile organic compounds in samples from monitoring and public-supply wells, Kirkwood-Cohansey aquifer system, southern New Jersey: U.S. Geological Survey Water-Resources Investigations Report 00-4123, 78 p.

Szabo, Zoltan, Rice, D.E., Plummer, L.N., Busenberg, Eurybades, Drenkard, Stefan and Schlosser, Peter, 1996, Age dating of shallow groundwater with chlorofluorocarbons, tritium/helium-3, and flow path analysis, southern New Jersey coastal plain: Water Resources Research, v. 32, no. 4, p. 1023-1038.

Szabo, Zoltan, Rice, D.E., McLeod, C.L., and Barringer, T.H., 1997, Relation of distribution of radium, nitrate, and pesticides to agricultural land use and depth, Kirkwood-Cohansey aquifer system, New Jersey Coastal Plain, 1990-91: U.S. Geological Survey Water-Resources Investigations Report 96-4165A, 107 p.

Szabo, Zoltan, and dePaul, V.T., 1998, Radium-226 and radium-228 in shallow ground water, southern New Jersey: U.S. Geological Survey Fact Sheet FS-062-98, 6 p.

Szabo, Zoltan, dePaul, V.T., and Parsa, Bahman, 1998a. Decrease in gross alpha-particle activity in water samples with time after collection from the Kirkwood-Cohansy aquifer system in southern New Jersey: Implications for Drinking Water Regulations: 63rd annual meeting, American Water Works Association, New Jersey section, Atlantic City, N.J., March 26-27, 1998 [abs.].

Szabo, Zoltan, dePaul, V.T., Kraemer, T.F., and Parsa, Bahman, 1998b, Comparison of results of two gamma-spectroscopic approaches for determining radium-224 concentrations in ground water: Rocky Mountain Conference on Analytical Chemistry, 40th annual meeting, Denver, Colo., July 25-August 1, 1998, abstract no. 344.

Szabo, Zoltan, dePaul, V.T., Kraemer, T.F., and Parsa, Bahman, 2000, Radium-224 in ground water and implication for monitoring: Geological Society of America Abstracts, v. 32, no. 1., p. A-77.

U.S. Environmental Protection Agency, 1976, National interim primary drinking-water regulations: Washington, D.C., Office of Water Supply, U.S. Environmental Protection Agency Report EPA-570/9-76-003.

U.S. Environmental Protection Agency, 1997, National primary drinking water regulations: Analytical methods for radionuclides: Federal Register, v. 62, no. 43, p. 10168-10175.

U.S. Environmental Protection Agency, 1999, Environmental Radiation Guidance Document No. 13: Washington, D.C., Office of Water Supply, U.S. Environmental Protection Agency Report EPA-2501/10-99-013.

U.S. Environmental Protection Agency, 2000a, National primary drinking water regulations; Radionuclides: Final rule, 40CFR parts 141 and 142: Washington, D.C., Federal Register, v. 65, no. 236.

U.S. Environmental Protection Agency, 2000b, National primary drinking water regulations; Radionuclides: Notice of data availability; Proposed rule: Washington, D.C., Office of Water, U.S. Environmental Protection Agency Report EPA-815-2-00-003.

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

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

Zapecza, O.S., and Szabo, Zoltan, 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, v. 21, no. 2, p. 78.

Appendix 1

Appendix 1. Selected well-record information for wells used to measure radioactive constituents in water from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

[Latitude longitude datum code: NAD27, North American Datum of 1927; NAD83, North American Datum of 1983. Altitudes are reported relative to the National Geodetic Vertical Datum of 1929. Code in parentheses in column headings is the code used to identify the item in the U.S. Geological Survey Ground-Water System Inventory (GWSI) database. --, not available]

U.S. Geological Survey well number (C5)	Municipality (C13)	New Jersey permit number (C213)	Latitude longitude datum code	Latitude (C9)	Longitude (C10)	Altitude of land surface (feet) (C16)	Depth of well (feet below land surface) (C28)	Top of open interval (feet below land surface) (C83)	Bottom of open interval (feet below land surface) (C84)
010151	Egg Harbor Twp	36-00428	NAD27	392524	0743329	45	208	172	208
010582	Somers Point City	36-00021	NAD27	391906	0743629	15	99.0	79	99.0
010589	Somers Point City	36-00388	NAD27	391924	0743550	19	159	129	159
010792	Hammonton Town	31-19462	NAD27	393823	0744929	120	218	178	218
010958	Hamilton Twp	36-12463	NAD27	392708	0743808	75	180	120	180
010973	Galloway Twp	36-14415	NAD27	392944	0742810	30	185	134	185
011240	Buena Vista Twp	31-49933.1	NAD83	393530.3	0745237.8	75	19	17	19
011272	Buena Vista Twp	35-18898	NAD27	392900	0745331	91	20	15	20
011273	Buena Vista Twp	35-18897	NAD27	392900	0745331	91	39	37	39
011274	Buena Vista Twp	35-18896	NAD27	392900	0745331	91	61	57	61
011277	Buena Vista Twp	35-18900	NAD27	392901	0745355	101	64.5	62.5	64.5
011278	Buena Vista Twp	35-18899	NAD27	392901	0745355	101	79.5	75.5	79.5
051092	Woodland Twp	32-08688	NAD27	395308	0743453	123	85	55	85
070490	Winslow Twp	31-05542	NAD83	394247.8	0745710.3	115	113	72	103
070603	Gloucester Twp	31-16697	NAD83	394414.2	0750022	160	120	100	120
070737	Winslow Twp	31-36453	NAD27	394505	0745450	160	119	91	111
070842	Winslow Twp	31-49664	NAD83	393939.3	0745341.5	100	14	12	14
070866	Gloucester Twp	31-32431	NAD27	394358	0750120	150	71	50.3	66
110002	Bridgeton City	34-00561	NAD27	392432	0751312	30	98.0	72.0	98.0
110013	Bridgeton City	34-00598	NAD27	392552	0751450	65	117	76.0	117
110186	Upper Deerfield Twp	54-00012	NAD83	393001	751306.5	110	172	147	172
110225	Vineland City	35-00962	NAD83	392810.9	750235.6	68.7	181	151	181
110226	Vineland City	35-00668	NAD83	392959.2	750015.0	100	162	132	162
110230	Vineland City	35-00017	NAD83	392851.9	750059.7	113	177	137	177
110238	Vineland City	55-00007	NAD27	392923	0750234	85	163	108	163
110252	Vineland City	35-00667	NAD83	392817.5	750115.8	83	175	145	175
110254	Vineland City	31-05227	NAD83	393209.5	750245.3	90	160	130	160
110255	Vineland City	35-00869	NAD83	392937.5	750338.4	75	174	140	170
110274	Upper Deerfield Twp	34-01195	NAD27	392722	0751235	100	110	70.0	110
110708	Vineland City	35-07632	NAD27	392801	0750037	80	163	117	163

Appendix 1. Selected well-record information for wells used to measure radioactive constituents in water from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey well number (C5)	Municipality (C13)	New Jersey permit number (C213)	Latitude longitude datum code	Latitude (C9)	Longitude (C10)	Altitude of land surface (feet) (C16)	Depth of well (feet below land surface) (C28)	Top of open interval (feet below land surface) (C83)	Bottom of open interval (feet below land surface) (C84)
110923	Upper Deerfield Twp	35-06947	NAD27	392901	0751034	112	130	120	130
110933	Bridgeton City	34-05096	NAD27	392640	0751328	84	110	86	106
110934	Millville City	35-17509	NAD27	392415	0750146	45	133	98	128
110937	Vineland City	35-17868	NAD83	392919.9	750116.8	114	69.5	67	69.5
110939	Vineland City	35-18084	NAD83	392827.8	750138.3	95	37	35	37
111000	Vineland City	31-40983	NAD83	393255.9	750358.8	75	148.5	105	145
111011	Upper Deerfield Twp	34-05931	NAD27	393056	0751254	102	18	13	18
111012	Upper Deerfield Twp	34-05930	NAD27	393056	0751254	102	39	37	39
111013	Upper Deerfield Twp	34-05929	NAD27	393056	0751254	102	60	58	60
111014	Upper Deerfield Twp	34-05932	NAD27	393100	0751222	121	60	58	60
150209	Newfield Boro	31-04599	NAD83	393251.7	750113.9	118	162	132	162
150375	Monroe Twp	31-14080	NAD83	394006.8	745834.3	148	147	118	147
151065	Washington Twp	31-28782	NAD83	394326.2	750208.9	152	85	59.2	85
151113	Washington Twp	31-34637	NAD27	394233	0750454	145	112	82	112
151264	Monroe Twp	31-51568	NAD83	394022.4	745909.3	145	53	50.5	53
151393	Clayton Boro	31-54007	NAD27	393939	0750309	130	34	32	34
151395	Clayton Boro	31-54005	NAD27	393939	0750309	130	70	68	70
290058	Dover Twp	33-01185	NAD27	395715	0741231	10	56.0	46.0	56.0
290088	Dover Twp	33-01147	NAD27	395933	0741312	40	86.0	66.0	86.0
290097	Dover Twp	33-01229	NAD27	395945	0741222	80	126	106	126
290127	Jackson Twp	29-05818	NAD27	400210	0741926	80	53.0	43.0	53.0
290437	Lakewood Twp	29-06181	NAD27	400427	0741109	55	62.0	43.0	62.0
290487	Manchester Twp	32-00874	NAD27	395708	0742130	180	92.0	61.0	92.0
290488	Manchester Twp	28-06885	NAD27	395729	0742343	150	143	123	143
290496	Manchester Twp	29-06442	NAD27	400104	0741651	85	87.0		
290591	Dover Twp	29-09781	NAD27	400226	0741431	90	102	82.0	102
290627	Dover Twp	33-02075	NAD27	395936	0741229	80	125	105	125
290628	Dover Twp	33-02076	NAD27	395936	0741219	80	135	115	135
290811	Manchester Twp	32-07287	NAD27	395812	0742026	140	117	97.0	117
290928	Berkeley Twp	33-13599	NAD27	395735	0741440	30	102.5	72	102.5
291032	Dover Twp	33-16164-0	NAD27	395848	0741442	65.79	88	74	85
291073	Lakewood Twp	29-17066	NAD27	400301	0740946	35	78	58	73
291086	Lakehurst Boro	29-09314	NAD27	400040	0741931	68	59	51	55
291115	Jackson Twp	48-00340	NAD27	400105	0742406	120	80		
291131	Lakewood Twp	29-27498	NAD27	400339	0741222	75	90	60	75

Appendix 1. Selected well-record information for wells used to measure radioactive constituents in water from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey well number (C5)	Municipality (C13)	New Jersey permit number (C213)	Latitude longitude datum code	Latitude (C9)	Longitude (C10)	Altitude of land surface (feet) (C16)	Depth of well (feet below land surface) (C28)	Top of open interval (feet below land surface) (C83)	Bottom of open interval (feet below land surface) (C84)
291216	Dover Twp	33-35775	NAD27	395927	0741232	80	131	109	126
291229	Dover Twp	--	NAD27	395936	0741239	70.00	110	100	110
291230	Dover Twp	29-26727	NAD27	395957	0741248	70	65	45	65
291231	Dover Twp	33-99983	NAD27	400002	0741252	60	55	35	55
291232	Dover Twp	29-26752	NAD27	395950	0741248	70	80	60	80
291233	Dover Twp	33-29984	NAD27	395946	0741249	60	70	50	70
291234	Dover Twp	--	NAD27	395928	0741249	60.00	85	65	85
291342	Dover Twp	33-16035	NAD27	395951	0741157	78	98	90	96
291343	Dover Twp	33-19959	NAD27	395958	0741201	83	98	83	93
291344	Dover Twp	29-25021	NAD27	400009	0741149	70	180	170	180
291345	Dover Twp	29-18822	NAD27	400014	0740816	7	77	67	77
291346	Dover Twp	29-16364	NAD27	400040	0741210	77	180	170	180
291347	Dover Twp	29-29026	NAD27	400048	0741153	80	110	100	110
291348	Dover Twp	33-16396	NAD27	400057	0741218	73	77	74	77
291349	Dover Twp	29-15469	NAD27	400059	0741205	76	70	66	70
291350	Dover Twp	29-16644	NAD27	400112	0741232	82	73	69	73
330778	Upper Pittsgrove Twp	30-07965	NAD27	393654	0751351	137	55	44	49
330817	Upper Pittsgrove Twp	30-11702	NAD83	393915.5	751220.9	142	22	20	22
330818	Upper Pittsgrove Twp	30-11704	NAD83	393413.2	751416.5	140	32	30	32
330836	Pittsgrove Twp	35-17396	NAD83	393016.9	750544.0	88	29	27	29
330907	Pittsgrove Twp	35-18877	NAD27	393030	0750905	95	48	46	48
330908	Pittsgrove Twp	35-18876	NAD27	393030	0750905	95	80	78	80
330911	Pittsgrove Twp	35-18873	NAD27	393046	0750852	72	62	60	62

Appendix 2

Appendix 2. Results of analyses for radionuclides, major ions, and selected trace elements in quality-assurance blank samples from the Kirkwood-Cohansey aquifer system, 1997-99.

[mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; <, less than; N, nitrogen; --, not analyzed; number in parentheses in heading is parameter code used to identfy the constituent, property, or characteristic in the U.S. Geological Survey water-quality database (NWIS) in which individual samples are identified by sample record numbers]

U.S. Geological Survey station identification number	Sample record number	Sample date (mm/dd/yy)	Nitrogen, ammonia, filtered (mg/L as N) (00608)	Nitrogen, nitrite, filtered (mg/L as N) (00613)	Nitrogen, NO_2+NO_3, filtered (mg/L as N) (00631)	Phosphorus, orthophos-phate, filtered (mg/L) (00731)	Calcium, filtered (mg/L) (00915)	Magne-sium, filtered (mg/L) (00925)	Sodium, filtered (mg/L) (00930)	Silica, filtered (mg/L) (00955)	Barium, filtered (µg/L) (001005)	Beryl-lium, filtered (µg/L) (01010)	Boron, filtered (µg/L) (01020)
400000074000097	99700324	7/28/97	--	--	--	--	0.002	0.002	0.045	<0.020	<0.20	<0.20	<2.00
394528075004301	99700307	9/11/97	<0.002	<0.001	<0.005	<0.001	<.002	<.001	<.025	<.020	<.20	<.20	<2.00
395848074144202	99800068	11/5/97	<.002	.001	<.005	<.001	.051	.005	<.025	.031	1.14	<.20	2.47
395812074202602	99800066	11/17/97	<.002	<.001	<.005	<.001	.022	<.001	<.025	<.020	<.20	<.20	4.98
400000074000098	99700257	8/18/97	--	--	--	--	<.002	<.01	<.20	--	<1.0	<.5	--
395945074122001	99800070	12/23/97	--	--	--	--	<.002	<.001	<.025	<.020	<.20	<.20	<2.00
395957074124801	99800293	6/4/98	<.002	<.001	<.005	.001	<.002	<.001	<.025	<.020	<.20	<.20	<2.00
400107074122501	99800296	8/26/98	<.002	<.001	<.005	<.001	.003	<.001	<.025	<.020	<.20	<.20	4.214
393001075130801	99900012	12/9/98	<.002	<.001	<.005	<.001	<.002	<.004	.034	<.05	--	--	--
400000074000097	99900062	6/21/99	.003	<.001	.006	.005	.006	.001	<.025	<.020	<.20	<.20	<2.00
395356074570805	99900104	8/4/99	<.002	<.001	<.005	.001	.003	.001	.025	<.020	<.20	<.20	<2.00
400339074122201	99800295	8/9/99	.002	.001	<.005	<.001	<.002	<.001	<.025	.054	<.20	<.20	<2.00
392920075011902	99900183	8/20/99	<.002	<.001	<.005	<.001	.012	.002	<.025	<.020	<.20	<.20	<2.00
393104075122201	99900141	9/15/99	--	--	--	--	.006	<.001	<.025	.022	<.20	<.20	<2.00
393818075132401	99900143	9/23/99	--	--	--	--	.005	.001	<.025	<.020	<.20	<.20	<.200

U.S. Geological Survey station identification number	Sample record number	Sample date (mm/dd/yy)	Cadmium, filtered (µg/L) (01025)	Chromium, filtered (µg/L) (01030)	Cobalt, filtered (µg/L) (01035)	Copper, filtered (µg/L) (01040)	Iron, filtered (µg/L) (01046)	Lead, filtered (µg/L) (01049)	Man-ganese, filtered (µg/L) (01056)	Thal-lium, filtered (µg/L) (01057)	Molyb-denum, filtered (µg/L) (01060)	Nickel, filtered (µg/L) (01065)	Silver, filtered (µg/L) (01075)
400000074000097	99700324	7/28/97	<0.30	<0.20	<0.20	<0.20	<3.00	<0.30	<0.10	<0.10	<0.20	<0.50	<0.20
394528075004301	99700307	9/11/97	<.30	<.20	<.20	<.20	3.16	<.30	<.10	<.10	<.20	<.50	<.20
395848074144202	99800068	11/5/97	<.30	<.20	.22	.24	<3.00	<.30	1.45	<.10	<.20	.53	<.20
395812074202602	99800066	11/17/97	<.30	<.20	<.20	<.20	<3.00	<.30	<.10	<.10	<.20	<.50	<.20
400000074000098	99700257	8/18/97	<1	<5	--	<10	<3.00	<10	<1.0	--	<10	<10	<1
395945074122001	99800070	12/23/97	<.30	<.20	<.20	<.20	<3.00	<.30	<.10	<.10	<.20	<.50	<.20
395957074124801	99800293	6/4/98	<.30	<.20	<.20	<.20	<3.00	<.30	<.10	<.10	<.20	<.50	<.20
400107074122501	99800296	8/26/98	<.30	<.20	<.20	<.20	<3.00	<.30	<.10	<.10	<.20	<.50	<.20
393001075130801	99900012	12/9/98	--	--	--	--	<10.0	--	<3.0	--	--	--	--
400000074000097	99900062	6/21/99	<.30	<.20	<.20	<.20	<3.00	<.30	<.10	<.10	<.20	<.50	<.20
395356074570805	99900104	8/4/99	<.30	<.20	<.20	<.20	<3.00	<.30	,.10	<.10	<.20	<.50	<.20
400339074122201	99800295	8/9/99	<.30	<.20	<.20	<.20	<3.00	<.30	<.10	<.10	<.20	<.50	<.20
392920075011902	99800183	8/20/99	<.30	<.20	<.20	<.20	<3.00	<.30	.34	<.10	<.20	.718	<.20
393104075122201	99900141	9/15/99	<.30	.44	<.20	<.20	<3.00	.30	.12	<.10	<.20	<.50	<.20
393818075132401	99900143	9/23/99	<.30	25.82	<.20	<.20	<3.00	<.30	.10	<.10	<.20	<.50	<.20

Appendix 2. Results of analyses for radionuclides, major ions, and selected trace elements in quality-assurance blank samples from the Kirkwood-Cohansey aquifer system, 1997-99.—Continued

U.S. Geological Survey station identification number	Sample record number	Sample date (mm/dd/yy)	Strontium, filtered (µg/L) (01080)	Zinc, filtered (µg/L) (01090)	Antimony, filtered (µg/L) (01095)	Aluminum, filtered (µg/L) (01106)	Uranium, natural, filtered (µg/L) (22703)	Mercury, filtered (µg/L) (71890)	Radium-224, filtered (p/CiL) (50833)	Radium-226, filtered (p/CiL) (09511)	Radium-228, filtered (p/CiL) (81366)	Lead-210, filtered, (pCi/L) (01753)	Polonium-210, filtered (p/CiL) (01953)
400020074600097	99700324	7/28/97	<0.10	<0.50	<0.20	1.17	<0.20	--	--	--	--	<1.5	--
394528075094301	99700307	9/11/97	<.10	<.50	<.20	1.64	<.20	<0.1	--	--	--	<1.5	--
395848074144202	99800068	11/5/97	.36	.89	<.20	1.65	<.20	<.1	<0.5	<0.5	<0.5	--	--
395812074202602	99800066	11/17/97	<.10	.93	<.20	1.14	<.20	<.1	<.5	<.5	<.5	--	--
400000074000098	99700257	8/18/97	<.5	<.3	--	--	--	--	--	--	--	--	
395745074122001	99800070	12/23/97	<.10	<.50	<.20	1.23	<.20		--	--	--	--	--
395957074124801	99800293	6/4/98	<.10	<.50	<.20	.94	<.20	<.1	<.5	.1	.2	<1.5	--
400107074122501	99800296	8/26/98	<.10	<.50	<.20	2.15	<.20	<.1	<1	.034	<1.0	<1	--
393001075130801	99900012	12/9/98	--	--	--	--	--	--	<1	.046	--	--	--
400000074000097	99900062	6/21/99	<.10	.7	<.20	<.30	<.20	<.1	<1	<.02	--	<1	<1.0
395356074570805	99900104	8/4/99	<.10	<.50	<.20	<.30	<.20	<.1	.018	<.02	--	.21	<1.0
400339074122201	99800295	8/9/99	<.10	<.50	<.20	<.30	<.20	<.1	<1	.05	--	--	--
392920075011902	99800183	8/20/99	<.10	3.833	<.20	<.30	<.20		<1	.02	--	<1	--
393104075122201	99900141	9/15/99	<.10	.75	<.20	.73	<.20	<.1	--	--	--	--	
393818075132401	99900143	9/23/99	<.10	.78	<.20	<.30	<.20	<.1	--	--	--	--	

Appendix 3

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

[pCi/L, picocuries per liter; µg/L, micrograms per liter; Cs-137, cesium-137; PE, precision estimate; CE, counting error; SSMDC, sample specific minimum detectable concentration; CL, critical level; --, not anayzed; <, less than. Bold type indicates result used in statistical analysis when more than one analytical technique was used. Associated quality assurance data indicator code: 10, field or lab equipment blank; 30, sequential replicate; 100, multiple types. Number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality database (NWIS) in which individual samples are identified by sample record numbers.]

U.S. Geological Survey station number	U.S. Geological Survey well number	Date (mm-dd-yy)	Time (eastern standard)	Sample record number	Gross alpha, filtered (as Thorium-230) (pCi/L) (04126)	Alpha count, PE 2 sigma, filtered (as Thorium-230) (pCi/L) (75987)	Alpha, filtered, (counting times not specified) (as Thorium-230) (pCi/L) (01503)	Alpha, filtered, CE 2 sigma (counting times not specified) (as Thorium-230) (pCi/L) (01504)
391905074363101	010582	06-30-98	1030	99800887	3.6	0.9	--	--
391924074354901	010589	07-19-99	1211	99900749	24.23	6.27	--	--
		07-19-99	1212	99903390	--	--	--	--
392415075014601	110934	09-29-97	1030	99701182	<3.0	1.7	<3.0	--
392430075131301	110002	07-08-97	1100	99700927	42	2.1	14.14	3.67
392455074320701	010151	07-20-99	1151	99900750	4.95	2.88	--	--
392552075145001	110013	06-24-97	1040	99700837	38.8	1.8	28.71	5.09
392640075132801	110933	07-14-97	1105	99701135	49.7	3.1	16.2	3.79
		10-14-97	1025	99800018	25.5	1.4	19.7	4.09
392708074380801	010958	09-22-97	1025	99701126	3.3	.5	--	--
392724075123603	110274	06-30-97	1050	99700901	35.6	1.9	18.94	4.25
392801075003701	110708	05-27-97	1020	99700827	54.4	3.3	46.5	6.72
		01-21-97	1100	99700485	--	--	2.0	4.8
392811075023601	110225	12-10-98	0900	99900160	16.24	3.66	--	--
392816075012101	110226	11-30-98	0900	99900113	23.76	4.56	--	--
392828075014002	110939	11-13-97	1500	99800162	--	--	--	--
		11-18-97	1100	99800299	11.4	1.4	--	--
392850075010301	110255	12-10-98	1100	99900159	6.88	2.53	--	--
392853075005801	110230	11-30-98	1100	99900112	6.4	2.66	--	--
392900074533101	110272	12-07-98	1205	99900173	15.69	3.72	--	--
392900074533102	110273	12-14-98	1405	99900174	9.09	3.17	--	--
392900074533103	110274	12-14-98	1205	99900175	76.14	8.43	--	--
392901074535503	110177	12-17-98	1343	99900201	26.38	4.94	--	--
392901074535504	110278	12-17-98	1140	99900202	31.31	5.36	--	--
392901075103401	110923	10-17-96	1215	99700720	--	--	--	--
392901075103401	110923	08-11-97	1125	99701125	40.02	5.71	73.5	2.3
392920075011902	110937	11-18-97	1555	99800308	--	--	--	--
		11-18-97	1600	99800309	--	--	--	--
		08-20-99	1200	99900989	23.21	5.13	--	--
		08-20-99	1210	99901267	--	--	--	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	U.S. Geological Survey well number	Date (mm-dd-yy)	Time (eastern standard)	Sample record number	Gross alpha, filtered (as Thorium-230) (pCi/L) (04126)	Alpha count, PE 2 sigma, filtered (as Thorium-230) (pCi/L) (75987)	Alpha, filtered, (counting times not specified) (as Thorium-230) (pCi/L) (01503)	Alpha, filtered, CE 2 sigma (counting times not specified) (as Thorium-230) (pCi/L) (01504)
392923075023401	110238	05-19-97	1115	99700700	31.9	1.5	--	--
392944074281001	010973	07-21-99	1149	99900751	<3.0	1.89	--	--
392957075001901	110252	11-30-98	1400	99900114	22.12	4.37	--	--
393001075130801	110186	12-09-98	1401	99900011	--	--	15.5	3.6
		12-09-98	1400	99900157	42.2	5.65	--	--
393015075054501	330836	06-16-98	1110	99801538	19	2.2	--	--
393030075090502	330907	11-18-98	1200	99900167	50.52	6.76	--	--
393030075090503	330908	11-30-98	1220	99900169	65.46	7.8	--	--
393046075085203	330911	11-23-98	1250	99900172	<3.0	1.8	--	--
393056075125401	111011	12-16-98	1320	99900196	<3.0	1.7	--	--
393056075125402	111012	12-16-98	1105	99900197	6.56	2.65	--	--
393056075125403	111013	12-15-98	1300	99900198	39	5.77	--	--
393100075122201	111014	12-10-98	1155	99900176	37.11	5.5	--	--
393208075024501	110254	05-12-97	1140	99700702	24	1.3	14.82	3.65

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Gross beta, filtered (as Cs-137) (pCi/L) (03515)	Beta, 2 sigma, filtered (as Cs-137) (pCi/L) (75989)	Beta, filtered, (counting times not specified) (as Cs-137) (pCi/L) (03504)	Beta, filtered, counting error, (counting times not specified) (as Cs-137) (pCi/L) (03503)	Radium-224, filtered, alpha count (pCi/L) (50833)	Radium-224, PE 2 sigma, filtered (pCi/L) (50834)	Radium-224, SS MDC, 2xCL, filtered, (pCi/L) (99324)	Radium-224, filtered, gamma slow count (pCi/L) (99918)	Radium-224, CE 1 sigma, filtered, gamma slow count (pCi/L) (99919)	Radium-224, filtered, gamma fast count (pCi/L) (99922)	Radium-224, PE 2 sigma, filtered, gamma fast count (pCi/L) (99923)	Radium-226, alpha count, filtered (pCi/L) (09503)
391905074363101	06-30-98	--	--	--	--	--	--	--	--	--	0.52	0.25	--
391924074354901	07-19-99	16.81	5.07	--	--	4.64	0.81	0.29	--	--	--	--	2.29
	07-19-99	--	--	--	--	--	--	--	--	--	--	--	--
392415075014601	09-29-97	<4.0	3.94	--	--	--	--	--	.3	.2	--	--	--
392430075131301	07-08-97	9.26	3.92	14	1	--	--	--	--	--	4.5	.4	--
392455074320701	07-20-99	5.53	4.09	--	--	.90	.29	.242	--	--	--	--	.719
392552075145001	06-24-97	17.25	4.33	19	1	--	--	--	**6.0**	.3	6.0	.5	--
392640075132801	07-14-97	29	1	8.84	3.88	--	--	--	--	--	3.4	.3	--
	10-14-97	15.22	4.24	11.8	.5	--	--	--	**4.4**	.3	4.2	.6	--
392708074380801	09-22-97	2	.2	--	--	--	--	--	**.5**	.1	.49	.07	--
392724075123603	06-30-97	11.54	4.1	15	1	--	--	--	**4.0**	.2	4.5	.4	--
392801075003701	05-27-97	33.15	4.99	24	1	--	--	--	**7.1**	.4	6.5	.4	--
392801075003701	01-21-97	21.4	5.5	--	--	--	--	--	**7.7**	.4	--	--	--
392811075023601	12-10-98	11.37	3.77	--	--	1.80	.46	.42	--	--	--	--	2.75
392816075012101	11-30-98	17.4	4.36	--	--	3.11	.56	.327	--	--	--	--	3.16
392828075014002	11-13-97	--	--	--	--	--	--	--	--	--	--	--	--
	11-18-97	8.1	0.7	--	--	--	--	--	--	--	2.1	.5	--
392850075010301	12-10-98	6.73	3.55	--	--	1.72	.40	.299		--	--	--	1.30
392853075005801	11-30-98	8.15	3.95	--	--	1.32	.30	.22		--	--	--	1.72
392900074533101	12-07-98	22.09	4.24	--	--	.66	.26	.33	--	--	--	--	.82
392900074533102	12-14-98	16.09	4.27	--	--	2.51	.5	.33		--	--	--	1.15
392900074533103	12-14-98	57.23	5.81	--	--	16.8	2.2	.6		--	--	--	17.4
392901074535503	12-17-98	22.56	4.54	--	--	8.28	1.36	.672	--	--	--	--	.98
392901074535504	12-17-98	25.31	4.65	--	--	8.34	1.35	.732	--	--	--	--	3.28
392901075103401	10-17-96	--	--	--	--	--	--	--	--	--	--	--	--
392901075103401	08-11-97	31.79	4.81	28	1	--	--	--	--	--	11.7	.9	--
392920075011902	11-18-97	--	--	--	--	--	--	--	--	--	--	--	--
	11-18-97	--	--	--	--	--	--	--	--	--	--	--	--
	08-20-99	24.93	4.81		--	11.11	1.68	.301	--	--	--	--	.50
	08-20-99	--	--	--	--	--	--	--	--	--	--	--	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Gross beta, filtered (as Cs-137) (pCi/L) (03515)	Beta, 2 sigma, filtered (as Cs-137) (pCi/L) (75989)	Beta, filtered, (counting times not specified) (as Cs-137) (pCi/L) (03504)	Beta, filtered, counting error, (counting times not specified) (as Cs-137) (pCi/L) (03503)	Radium-224, filtered, alpha count (pCi/L) (50833)	Radium-224, PE 2 sigma, filtered (pCi/L) (50834)	Radium-224, SS MDC, 2xCL, filtered, (pCi/L) (99324)	Radium-224, filtered, gamma slow count (pCi/L) (99918)	Radium-224, CE 1 sigma, filtered, gamma slow count (pCi/L) (99919)	Radium-224, filtered, gamma fast count (pCi/L) (99922)	Radium-224, PE 2 sigma, filtered, gamma fast count (pCi/L) (99923)	Radium-226, alpha count, filtered (pCi/L) (09503)
392923075023401	05-19-97	13	1	--	--	--	--	--	3.9	.2	3.4	.3	--
392944074281001	07-21-99	<4.0	3.858	--	--	.58	.65	.924	--	--	--	--	.33
392957075001901	11-30-98	12.56	4.14	--	--	4.15	.66	.261	--	--	--	--	2.11
393001075130801	12-09-98	--	--	10.9	3.8	3.16	.68	.53	--	--	--	--	**5.65**
	12-09-98	44.88	5.03	--	--	3.70	.72	.45	--	--	--	--	5.32
393015075054501	06-16-98	--	--	--	--	--	--	--	--	--	4.0	.4	--
393030075090502	11-18-98	41.23	5.21	--	--	11.73	1.44	--	--	--	--	--	6.38
393030075090503	11-30-98	34.95	5.1	--	--	11.03	1.6	--	--	--	--	--	12.63
393046075085203	11-23-98	8.16	3.96	--	--	<.09	.08	--	--	--	--	--	.12
393056075125401	12-16-98	5.58	3.75	--	--	<.23	.17	.25	--	--	--	--	.18
393056075125402	12-16-98	6.94	3.81	--	--	<.54	.26	.33	--	--	--	--	1.41
393056075125403	12-15-98	16.87	4.28	--	--	4.31	.78	.62	--	--	--	--	8.38
393100075122201	12-10-98	19.71	4.15	--	--	5.68	1.02	.574	--	--	--	--	4.77
393208075024501	05-12-97	15.43	4.19	12	.5	--	--	--	3.9	.2	3.1	.4	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Radium-226, filtered, planchet count (pCi/L) (09510)	Radium-226, filtered, radon method (pCi/L) (09511)	Radium-226 PE,2 sigma, filtered (pCi/L) (76001)	Radium-226, CE 2-sigma, filtered, (pCi/L) (09504)	Radium-226, filtered, gamma count (pCi/L) (50837)	Radium-226, PE 2 sigma filtered, gamma count (pCi/L) (50911)	Radium-228, filtered (pCi/L) (81366)	Radium-228, PE 2 sigma, filtered (pCi/L) (76000)	Radium-228, SS MDC, 2x CL filtered, (pCi/L) (99326)	Radium-228, filtered, gamma count (pCi/L) (50839)
391905074363101	06-30-98	0.6	--	--	0.23	--	--	<.0.5	--	--	--
391924074354901	07-19-99	--	--	0.40	--	--	--	3.91	1.08	0.734	--
	07-19-99	--	--	--	--	--	--	--	--	--	--
392415075014601	09-29-97	--	--	--	--	0.3	0.1	--	--	--	0.2
392430075131301	07-08-97	3.8	--	--	.5	--	--	2.5	--	--	--
392455074320701	07-20-99	--	--	.18	--	--	--	.894	.481	.788	--
392552075145001	06-24-97	4.6	--	--	.5	5.3	.3	3.9	--	--	**4.1**
392640075132801	07-14-97	1.8	--	--	.3	--	--	2.5	--	--	**--**
	10-14-97	1.8	--	--	.3	1.9	.1	2.3	--	--	**2.6**
392708074380801	09-22-97	--	--	--	--	.7	.1	<0.6	--	--	**.5**
392724075123603	06-30-97	3.8	4.1	.60	.5	4.3	.2	2.5	--	--	**3.4**
392801075003701	05-27-97	9.3	10.7	.80	.6	11.3	.6	6.0	--	--	**6.5**
392801075003701	01-21-07	--	11.5	1.8	--	11.9	.6	6.14	1.50	.85	**6.4**
392811075023601	12-10-98	--	--	.435	--	--	--	3.07	.91	.675	--
392816075012101	11-30-98	--	--	.46	--	--	--	1.86	.604	.789	--
392828075014002	11-13-97	--	--	--	--	--	--	--	--	--	--
392828075014002	11-18-97	**1.5**	1.7	.29	--	--	--	2.15	.685	--	--
392850075010301	12-10-98	--	--	.23	--	--	--	1.61	.598	.92	--
392853075005801	11-30-98	--	--	.27	--	--	--	1.46	.527	.806	--
392900074533101	12-07-98	--	--	.17	--	--	--	1.12	.506	--	--
392900074533102	12-14-98	--	--	.20	--	--	--	1.43	.507	.565	--
392900074533103	12-14-98	--	--	2.2	--	--	--	12.8	2.94	.61	--
392901074535503	12-17-98	--	--	.20	--	--	--	4.69	1.22	.593	--
392901074535504	12-17-98	--	--	.49	--	--	--	5.36	1.33	.775	--
392901075103401	10-17-96	--	3.85	.61	--	--	--	10.4	2.4	.572	--
392901075103401	08-11-97	3.5	--	--	.4	--	--	7.7	--	--	--
392920075011902	11-18-97	--	.74	.125	--	--	--	9.88	2.36	--	--
	11-18-97	--	--	--	--	--	--	--	--	--	--
	08-20-99	--	--	.087	--	--	--	7.07	1.62	.713	--
	08-20-99	--	--	--	--	--	--	--	--	--	--
392923075023401	05-19-97	3.4	3.8	.20	.4	**3.8**	.2	2.7	--	--	**2.9**
392944074281001	07-21-99	--	--	.23	--	--	--	.389	.389	.75	--
392957075001901	11-30-98	--	--	.32	--	--	--	2.85	.812	.847	--
393001075130801	12-09-98	--	--	.80	--	--	--	--	--	--	--
393001075130801	12-09-98	--	--	.75	--	--	--	2.22	.73	.968	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Radium-226, filtered, planchet count (pCi/L) (09510)	Radium-226, filtered, radon method (pCi/L) (09511)	Radium-226 PE,2 sigma, filtered (pCi/L) (76001)	Radium-226, CE 2-sigma, filtered, (pCi/L) (09504)	Radium-226, filtered, gamma count (pCi/L) (50837)	Radium-226, PE 2 sigma filtered, gamma count (pCi/L) (50911)	Radium-228, filtered (pCi/L) (81366)	Radium-228, PE 2 sigma, filtered (pCi/L) (76000)	Radium-228, SS MDC, 2x CL filtered, (pCi/L) (99326)	Radium-228, filtered, gamma count (pCi/L) (50839)
393015075054501	06-16-98	1.7	--	--	.3	--	--	1.5	--	--	--
393030075090502	11-18-98	--	--	.76	--	--	--	11.3	2.62	--	--
393030075090503	11-30-98	--	--	1.7	--	--	--	7.22	1.7	--	--
393046075085203	11-23-98	--	--	.048	--	--	--	.499	.37	.744	--
393056075125401	12-16-98	--	--	.062	--	--	--	.247	.312	.788	--
393056075125402	12-16-98	--	--	.24	--	--	--	1.64	.578	.84	--
393056075125403	12-15-98	--	--	1.08	--	--	--	2.87	.846	.888	--
393100075122201	12-10-98	--	--	.70	--	--	--	6.72	1.68	.665	--
393208075024501	05-12-97	2.1	--	--	.3	**2.3**	.2	2.6	--	--	**3.0**

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Radium-228, PE 2 sigma, filtered, gamma count (pCi/L) (50840)	Radium-228, filtered, CE 2 sigma (pCi/L) (81367)	Radon-222, total (pCi/L) (82303)	Radon-222, PE 2 sigma (pCi/L) (76002)	Lead-210, filtered (pCi/L) (17503)	Lead-210, PE 2 sigma, filtered (pCi/L) (75995)	Polonium-210, filtered (pCi/L) (19503)	Polonium-210, PE 2 sigma, filtered (pCi/L) (75998)	Uranium, natural, filtered (µg/L) (22703)	Uranium, natural, PE 2 sigma, filtered (µg/L) (75990)	Thorium-232, filtered (pCi/L) (75976)
391905074363101	06-30-98	--	--	233	20	--	--	--	--	--	--	--
391924074354901	07-19-99	--	--	--	--	0.70	0.417	<1	0.03	--	--	--
	07-19-99	--	--	--	--	--	--	--	--	--	--	-0.012
392415075014601	09-29-97	0.2	--	307	21	--	--	--	--	--	--	--
392430075131301	07-08-97	--	0.5	441	23	<1.5	.27	--	--	--	--	--
392455074320701	07-20-99	--	--	--	--	.114	.284	<1	.03	--	--	--
392552075145001	06-24-97	1.0	.6	472	24	.91	.405	--	--	--	--	--
392640075132801	07-14-97	--	.5	295	22	<1.5	.22	--	--	--	--	--
	10-14-97	.2	.5	--	--	--	--	--	--	--	--	--
392708074380801	09-22-97	.2	--	216	20	--	--	--	--	--	--	--
392724075123603	06-30-97	.4	.5	275	22	<1.5	.218	--	--	--	--	--
392801075003701	05-27-97	.8	.8	209	20	<1.5	.329	--	--	--	--	--
392801075003701	01-21-97	.8	--	--	--	1.02	.49	--	--	--	--	--
392811075023601	12-10-98	--	--	379	23	--	--	--	--	--	--	--
392816075012101	11-30-98	--	--	254	21	--	--	--	--	--	--	--
392828075014002	11-13-97	--	--	--	--	--	--	--	--	--	--	--
392828075014002	11-18-97	--	.5	412	28	--	--	--	--	<1	--	--
392850075010301	12-10-98	--	--	137	18	--	--	--	--	--	--	--
392853075005801	11-30-98	--	--	141	18	--	--	--	--	--	--	--
392900074533101	12-07-98	--	--	254	19	--	--	--	--	<1	.025	--
392900074533102	12-14-98	--	--	67	20	--	--	--	--	<1	.040	--
392900074533103	12-14-98	--	--	249	24	--	--	--	--	<1	.099	--
392901074535503	12-17-98	--	--	195	19	--	--	--	--	--	--	--
392901074535504	12-17-98	--	--	249	20	--	--	--	--	<1	.056	--
392901075103401	10-17-96	--	--	308	30	--	--	--	--	<1	--	--
392901075103401	08-11-97	--	.9	--	--	<1.5	.254	--	--	--	--	--
392920075011902	11-18-97	--	--	190	23	--	--	--	--	<1	--	--
	11-18-97	--	--	--	--	--	--	--	--	<1	--	--
	08-20-99	--	--	--	--	--	--	--	--	<1	--	--
	08-20-99	--	--	--	--	--	--	--	--	<1	--	--
392923075023401	05-19-97	.4	.6	406	22	<1.5	.307	--	--	--	--	--
392944074281001	07-21-99	--	--	--	--	.334	.334	<1	.055	--	--	--
392957075001901	11-30-98	--	--	230	20	--	--	--	--	--	--	--
393001075130801	12-09-98	--	--	--	--	--	--	--	--	--	--	--
393001075130801	12-09-98	--	--	451	26	--	--	--	--	--	--	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Radium-228, PE 2 sigma, filtered, gamma count (pCi/L) (50840)	Radium-228, filtered, CE 2 sigma (pCi/L) (81367)	Radon-222, total (pCi/L) (82303)	Radon-222, PE 2 sigma (pCi/L) (76002)	Lead-210, filtered (pCi/L) (17503)	Lead-210, PE 2 sigma, filtered (pCi/L) (75995)	Polonium-210, filtered (pCi/L) (19503)	Polonium-210, PE 2 sigma, filtered (pCi/L) (75998)	Uranium, natural, filtered (µg/L) (22703)	Uranium, natural, PE 2 sigma, filtered (µg/L) (75990)	Thorium-232, filtered (pCi/L) (75976)
393015075054501	06-16-98	--	.4	--	--	--	--	--	--	<1	--	--
393030075090502	11-18-98	--	--	493	25	--	--	--	--	<1	--	<1
393030075090503	11-30-98	--	--	990	31	--	--	--	--	<1	--	--
393046075085203	11-23-98	--	--	331	21	--	--	--	--	--	--	--
393056075125401	12-16-98	--	--	585	25	--	--	--	--	.042	.010	--
393056075125402	12-16-98	--	--	124	18	--	--	--	--	--	--	--
393056075125403	12-15-98	--	--	982	32	--	--	--	--	<1	.062	--
393100075122201	12-10-98	--	--	191	20	--	--	--	--	<1	.009	--
393208075024501	05-12-97	.4	.8	127	17	<1.5	.254	--	--	<1	--	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Thorium-232, PE 2 sigma, filtered, (pCi/L) (75999)	Thorium-230, filtered (pCi/L) (26503)	Thorium-230, PE 2 sigma, filtered (pCi/L) (75997)	Thorium-228, filtered (pCi/L) (61738))	Quality assurance data indicator code (99111)
391905074363101	06-30-98	--	--	--	--	--
391924074354901	07-19-99	--	--	--	--	30
	07-19-99	0.0175	0	0.18	1.67	30
392415075014601	09-29-97	--	--	--	--	--
392430075131301	07-08-97	--	--	--	--	--
392455074320701	07-20-99	--	--	--	--	--
392552075145001	06-24-97	--	--	--	--	--
392640075132801	07-14-97	--	--	--	--	--
	10-14-97	--	--	--	--	--
392708074380801	09-22-97	--	--	--	--	--
392724075123603	06-30-97	--	--	--	--	--
392801075003701	01-21-97	--	--	--	--	--
392801075003701	05-27-97	--	--	--	--	--
392811075023601	12-10-98	--	--	--	--	10
392816075012101	11-30-98	--	--	--	--	10
						10
392828075014002	11-13-97	--	--	--	--	
392828075014002	11-18-97	--	--	--	--	--
392850075010301	12-10-98	--	--	--	--	10
392853075005801	11-30-98	--	--	--	--	100
392900074533101	12-07-98	--	--	--	--	--
392900074533102	12-14-98	--	--	--	--	--
392900074533103	12-14-98	--	--	--	--	--
392901074535503	12-17-98	--	--	--	--	--
392901074535504	12-17-98	--	--	--	--	--
392901075103401	10-17-96	--	--	--	--	--
392901075103401	08-11-97	--	--	--	--	--
392920075011902	11-18-97	--	--	--	--	--
	11-18-97	--	--	--	--	--
	08-20-99	--	--	--	--	100
	08-20-99	--	--	--	--	100
392923075023401	05-19-97	--	--	--	--	--
392944074281001	07-21-99	--	--	--	--	--
392957075001901	11-30-98	--	--	--	--	10
393001075130801	12-09-98	--	--	--	--	100
393001075130801	12-09-98	--	--	--	--	100

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Thorium-232, PE 2 sigma, filtered, (pCi/L) (75999)	Thorium-230, filtered (pCi/L) (26503)	Thorium-230, PE 2 sigma, filtered (pCi/L) (75997)	Thorium-228, filtered (pCi/L) (61738))	Quality assurance data indicator code (99111)
393015075054501	06-16-98	--	--	--	--	--
393030075090502	11-18-98	.068	<1	.32	--	--
393030075090503	11-30-98	--	--	--	--	--
393046075085203	11-23-98	--	--	--	--	--
393056075125401	12-16-98	--	--	--	--	--
393056075125402	12-16-98	--	--	--	--	--
393056075125403	12-15-98	--	--	--	--	--
393100075122201	12-10-98	--	--	--	--	--
393208075024501	05-12-97	--	--	--	--	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	U.S. Geological Survey well number	Date (mm-dd-yy)	Time (eastern standard)	Sample record number	Gross alpha, filtered (as Thorium-230) (pCi/L) (04126)	Alpha count, PE 2 sigma, filtered (as Thorium-230) (pCi/L) (75987)	Alpha, filtered, (counting times not specified) (as Thorium-230) (pCi/L) (01503)	Alpha, filtered, CE 2 sigma counting error, (counting times not specified) (as Thorium-230) (pCi/L) (01504)
393254075012101	150209	09-05-96	1150	99600838	--	--	--	--
		09-16-97	1050	99701121	10.6	0.8	--	--
393302075041501	111000	12-10-98	1300	99900161	13.64	3.38	--	--
393413075141901	330818	06-10-98	1150	99800774	2.6	1.5	--	--
		09-27-99	1210	99901154	4.25	3.18	--	--
393531074523901	011240	12-12-96	1255	99700312	--	--	--	--
		08-23-99	1600	99900990	6.92	3.85	--	--
393654075135101	330778	08-18-97	1105	99701046	25.0	2.0	--	--
393823074492901	010792	10-21-97	1025	99800020	14.8	.9	--	--
393916075122201	330817	06-17-98	1040	99801537	6.0	1.4	3.5	1.1
393939075030901	151393	11-10-98	1500	99900230	--	--	--	--
393939075030903	151395	12-01-98	1200	99900192	14.12	3.35	--	--
393940074534201	070842	09-08-97	1130	99701122	<3.0	1.35	1.5	0.3
394022074591002	151264	11-14-97	1200	99800110	--	--	--	--
		12-16-97	1410	99800297	--	--	--	--
		08-23-99	1315	99900988	18.36	4.9	--	--
		08-23-99	1210	99901263	--	--	--	--
394026075050401	150375	10-06-97	1115	99801523	--	--	--	--
		10-06-97	1045	99800006	6.86	2.71	--	--
394233075045401	151113	09-02-97	1045	99701123	7.34	2.78	8.5	.8
394248074571001	070490	08-04-97	1145	99701047	4.2	.5	--	--
394327075021001	151065	06-02-97	1040	99700828	22.8	1.5	11.03	3.31
394358075012001	070866	07-21-97	1110	99701134	23.6	1.0	12.98	3.4
394414075001601	070603	06-16-97	1120	99700829	19.2	1.0	8.77	2.87
394503945050745	070737	08-25-97	1117	99701124	77	2	--	--
395308074345301	051092	08-22-97	1104	99701055	<3.0	1.48	--	--
		04-15-98	1020	99800580	7.0	0.9	--	--
395715074123101	290058	06-19-96	1200	99600610	<3.0	1.84	--	--
		06-22-98	1250	99800889	11.7	1.5	--	--
395722074222901	290487	11-12-97	1030	99800083	17.16	3.84	--	--
395722074231901	290488	05-11-98	1045	99800663	--	--	1.03	.24
395735074144001	290928	06-20-96	1130	99600614	--	--	<3.0	.679
		06-20-96	1135	99600615	--	--	--	--
395735074144001	290928	11-24-97	1100	99800166	10.5	1.1	--	--
395812074202602	290811	11-17-97	1125	99800106	10.1	.7	--	--
395848074144202	291032	11-05-97	1445	99800081	4.98	2.31	--	--
395927074123201	291216	12-03-97	1025	99800221	15.4	2.4	--	--
395928074124901	291234	06-02-98	1720	99801535	15.7	1.5	--	--
395933074131201	290088	06-18-96	1125	99600609	<3.0	.847	--	--
		06-18-96	1130	99600618	--	--	--	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Gross beta, filtered (as Cesium-137) (pCi/L) (03515)	Beta, PE 2 sigma, filtered (as Cesium-137) (pCi/L) (75989)	Beta, filtered, (counting times not specified) (as Cesium-137) (pCi/L) (03503)	Beta, filtered, counting error, 2 sigma (counting times not specified) (as Cesium-137) (pCi/L) (03504)	Radium-224, filtered (pCi/L) (50833)	Radium-224 PE 2 sigma, filtered (pCi/L) (50834)	Radium-224, SS MDC, 2X CL, filtered (pCi/L) (99324)	Radium-224, filtered, gamma, slow count (pCi/L) (99918)	Radium-224, CE 1 sigma, filtered, gamma slow count (pCi/L) (99919)	Radium-224, filtered, gamma fast count (pCi/L) (99922)	Radium-224, PE 2 sigma, filtered, gamma fast count (piCi/L (99923))	Radium-226, filtered, alpha count (pCi/L) (09503)
393254075012101	09-05-96	--	--	--	--	--	--	--	--	--	--	--	--
	09-16-97	5.6	0.4	--	--	--	--	--	**1.6**	0.1	1.7	0.2	--
393302075041501	12-10-98	10.21	3.72	--	--	1.62	0.379	0.299	--	--	--	--	1.841
393413075141901	06-10-98	--	--	--	--	--	--	--	--	--	.43	.3	--
	09-27-99	7.62	4.49	--	--	--	--	--	--	--	--	--	--
393531074523901	12-12-96	--	--	--	--	--	--	--	--	--	--	--	--
	08-23-99	7.94	4.43	--	--	.692	.143	.101	--	--	--	--	1.133
393654075135101	08-18-97	14.0	1.0	--	--	--	--	--	**3.0**	.2	3.3	.3	--
393823074492901	10-21-97	8.0	.4	--	--	--	--	--	--	--	2.5	.4	--
393916075122201	06-17-98	5.2	--	--	--	--	--	--	--	--	.74	.19	--
393939075030901	11-10-98	46.25	5.3	--	--	1.29	.362	.334	--	--	--	--	**.27**
393939075030903	12-01-98	8.52	3.62	--	--	1.83	.34	--	--	--	--	--	2.36
393940074534201	09-08-97	<4.0	3.59	2.0	0.3	--	--	--	**.4**	.1	.34	.5	--
394022074591002	11-14-97	--	--	--	--	--	--	--	--	--	--	--	--
	12-16-97	--	--	--	--	--	--	--	--	--	--	--	--
	08-23-99	19.57	4.85	--	--	3.79	.53	.183	--	--	--	--	3.27
	08-23-99	--	--	--	--	--	--	--	--	--	--	--	--
394026075050401	10-06-97	--	--	--	--	--	--	--	1.8	.1	--	--	--
	10-06-97	11.51	4.07	--	--	--	--	--	1.4	.1	--	--	--
394233075045401	09-02-97	9.96	3.96	4.0	.4	--	--	--	**1.2**	.1	.85	.11	--
394248074571001	08-04-97	3.2	.3	--	--	--	--	--	**.8**	.1	.87	.11	--
394327075021001	06-02-97	8.37	3.97	9.5	.6	--	--	--	**2.7**	.2	2.4	.3	--
394358075012001	07-21-97	14.56	4.15	11	1	--	--	--	**3.6**	.2	3.4	.3	--
394414075001601	06-16-97	7.82	3.91	9.0	.5	--	--	--	**2.2**	.1	1.6	.2	--
394505074545001	08-25-97	39	1	--	--	--	--	--	**12.6**	.7	12.5	1.0	1.0
395308074345301	08-22-97	<4.0	3.74	--	--	--	--	--	--	--	--	--	--
	04-15-98	4.1	.3	--	--	--	--	--	--	--	.84	.2	--
395715074123101	06-19-96	6.6	1.87	--	--	--	--	--	--	--	--	--	--
	06-22-98	7.3	.7	--	--	--	--	--	--	--	2.7	.2	--
395722074222901	11-12-97	13.2	4.08	--	--	--	--	--	1.9	.1	--	--	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Gross beta, filtered (as Cesium-137) (pCi/L) (03515)	Beta, PE 2 sigma, filtered (as Cesium-137) (pCi/L) (75989)	Beta, filtered, (counting times not specified) (as Cesium-137) (pCi/L) (03503)	Beta, filtered, counting error, 2 sigma (counting times not specified) (as Cesium-137) (pCi/L) (03504)	Radium-224, filtered (pCi/L) (50833)	Radium-224 PE 2 sigma, filtered (pCi/L) (50834)	Radium-224, SS MDC, 2X CL, filtered (pCi/L) (99324)	Radium-224, filtered, gamma, slow count (pCi/L) (99918)	Radium-224, CE 1 sigma, filtered, gamma slow count (pCi/L) (99919)	Radium-224, filtered, gamma fast count (pCi/L) (99922)	Radium-224, PE 2 sigma, filtered, gamma fast count (piCi/L (99923))	Radium-226, filtered, alpha count (pCi/L) (09503)
395722074231901	05-11-98	1.3	.2	--	--	--	--	--	--	--	.27	.18	--
395735074144001	06-20-96	4.3	1.07	--	--	--	--	--	--	--	--	--	--
	06-20-96	--	--	--	--	--	--	--	--	--	--	--	--
	11-24-97	--	--	--	--	--	--	--	**2.6**	.2	2.9	.7	--
395812074202602	11-17-97	--	--	--	--	--	--	--	**1.9**	.2	1.8	.3	--
395848074144202	11-05-97	<4.0	3.65	--	--	--	--	--	--	--	--	--	--
395927074123201	12-03-97	--	--	--	--	--	--	--	**2.2**	.2	2.8	.7	--
395928074124901	06-02-98	--	--	--	--	--	--	--	--	--	1.3	.2	--
395933074131201	06-18-96	6.5	1.51	--	--	--	--	--	--	--	--	--	--
	06-18-96	--	--	--	--	--	--	--	--	--	--	--	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Radium-226, filtered, planchet count (pCi/L) (09510)	Radium-226, filtered, radon method (pCi/L) (09511)	Radium-226, PE 2 sigma, filtered (pCi/L) (76001)	Radium-226, CE 2 sigma, filtered, (pCi/L) (09504)	Radium-226, filtered, gamma count (pCi/L) (50837)	Radium-226, PE 2 sigma, filtered, gamma count (pCi/L) (50911)	Radium-228, filtered (pCi/L) (81366)	Radium-228, PE 2 sigma filtered (pCi/L) (76000)	Radium-228, SS MDC, 2x CL, filtered, (pCi/L) (99326)	Radium-228, filtered, gamma count (pCi/L) (50839)
393254075012101	09-05-96	--	1.2	0.19	--	--	--	1.4	0.56	--	--
	09-16-97	1.1	--	--	0.3	**1.0**	0.2	1.3	--	--	**1.3**
393302075041501	12-10-98	--	--	.299	--	--	--	1.99	.69	0.788	--
393413075141901	06-10-98	.35	--	--	.19	--	--	<.47	--	--	--
	09-27-99	--	--	--	--	--	--	--	--	--	--
393531074523901	12-12-96	--	2.5	.42	--	--	--	2.7	.795	--	--
	08-23-99	--	--	.18	--	--	--	1.63	.58	.636	--
393654075135101	08-18-97	4.2	--	--	.4	**4.8**	.21	2.9	--	--	**2.9**
393823074492901	10-21-97	2.7	--	--	.4	--	--	1.6	--	.46	--
393916075122201	06-17-98	.31	--	--	.19	--	--	<.44	--	--	--
393939075030901	11-10-98	--	--	.083	--	<.27	.17	.85	.51	1.01	--
393939075030903	12-01-98	--	--	.34	--	--	--	1.26	.52	.87	--
393940074534201	09-08-97	<.29	**.154**	.032	.17	<.1	.2	**<0.52**	.74	.52	<.2
394022074591002	11-14-97	--	--	--	--	--	--	--	--	--	--
	12-16-97	--	3.32	.55	--	--	--	1.18	.49	--	--
	08-23-99	--	--	.43	--	--	--	3.44	.96	.629	--
	08-23-99	--	--	--	--	--	--	--	--	--	--
394026075050401	10-06-97	--	.89	--	--	.9	.2	1.3	--	--	**1.1**
	10-06-97	--	--	--	--	.9	.2	1.3	--	--	**1.1**
394233075045401	09-02-97	1.7	--	--	.3	**1.7**	.2	<.5	--	--	**.4**
394248074571001	08-04-97	.92	--	--	.28	**.6**	.2	<.6	--	--	**.5**
394327075021001	06-02-97	1.5	1.8	.3	.3	**1.8**	.2	1.7	--	--	**2.0**
394358075012001	07-21-97	2.7	--	--	.3	**2.8**	.2	2.5	--	--	**2.0**
394414075001601	06-16-97	2.6	3.2	.3	.3	**3.5**	.2	1.8	--	--	**2.1**
394505074545001	08-25-97	5.7	--	--	.5	**5.7**	1.2	7.5	.90	--	**8.8**
395308074345301	08-22-97	--	--	--	--	--	--	--	--	--	--
	04-15-98	.8	--	--	.22	--	--	<.8	--	--	--
395715074123101	06-19-96	--	.91	.15	--	--	--	1.7	.518	--	--
	06-22-98	.9	--	--	.25	--	--	1.8	--	--	--
395722074222901	11-12-97	--	--	--	--	1.8	.2	--	--	--	1.8
395722074231901	05-11-98	<.1	--	--	.18	--	--	<.5	--	--	--
395735074144001	06-20-96	--	.99	.18	--	--	--	1.6	.50	--	--
	06-20-96	--	--	--	--	--	--	--	--	--	--
	11-24-97	.97	--	--	.27	**1.0**	.2	1.6	.50	--	**1.7**
395812074202602	11-17-97	.95	--	--	.26	**.9**	.4	1.4	--	--	**1.4**
395848074144202	11-05-97	--	--	--	--	--	--	--	--	--	--
395927074123201	12-03-97	2.2	--	--	.3	**2.3**	.4	1.5	--	--	**1.8**
395928074124901	06-02-98	1.2	--	--	.3	--	--	.63	--	--	--
395933074131201	06-18-96	--	1.8	.33	--	--	--	2.2	.68	--	--
	06-18-96	--	--	--	--	--	--	--	--	--	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Radium-228, PE 2 sigma, filtered, gamma count (pCi/L) (50840)	Radium-228, filtered, CE 2 sigma (pCi/L) (81367)	Radon-222, total (pCi/L) (82303)	Radon-222, PE 2 sigma (76002)	Lead-210, filtered (pCi/L) (17503)	Lead-210, PE 2 sigma, filtered (pCi/L) (75995)	Polonium-210, filtered (pCi/L) (19503)	Polonium-210, PE 2 sigma, filtered (pCi/L) (75998)	Uranium-238, filtered (pCi/L) (22603)	Uranium-238, PE 2 sigma, filtered (pCi/L) (75991)	Uranium-234, filtered (pCi/L) (22610)
393254075012101	09-05-96	--	--	380	22	--	--	--	--	--	--	--
	09-16-97	0.2	0.4	387	24	--	--	--	--	--	--	--
393302075041501	12-10-98	--	--	90	18	--	--	--	--	--	--	--
393413075141901	06-10-98	--	--	225	20	--	--	--	--	--	--	--
	09-27-99	--	--	--	--	--	--	--	--	--	--	--
393531074523901	12-12-96	--	--	--	--	--	--	--	--	--	--	--
	08-23-99	--	--	373	23	--	--	--	--	--	--	--
393654075135101	08-18-97	.4	.5	330	25	<1.5	0.291	--	--	--	--	--
393823074492901	10-21-97	--	.4	52	16	--	--	--	--	--	--	--
393916075122201	06-17-98	--	--	225	20	--	--	--	--	--	--	--
393939075030901	11-10-98	--	--	190	21	--	--	--	--	--	--	--
393939075030903	12-01-98	--	--	101	17	--	--	--	--	--	--	--
393940074534201	09-08-97	.2	--	104	17	<1.5	.262	--	--	--	--	--
394022074591002	11-14-97	--	--	--	--	--	--	--	--	--	--	--
	12-16-97	--	--	184	21	--	--	--	--	--	--	--
	08-23-99	--	--	--	--	--	--	--	--	--	--	--
	08-23-99	--	--	--	--	--	--	--	--	--	--	--
394026075050401	10-06-97	.1	--	122	15	--	--	--	--	<0.1	--	<0.1
	10-06-97	.2	--	128	18	--	--	--	--	--	--	--
394233075045401	09-02-97	.2	--	859	28	<1.5	.326	--	--	--	--	--
394248074571001	08-04-97	.2	.6	250	20	--	--	--	--	--	--	--
394327075021001	06-02-97	.2	.4	242	20	<1.5	.298	--	--	--	--	--
394358075012001	07-21-97	.2	.6	286	22	<1.5	.266	--	--	--	--	--
394414075001601	06-16-97	.2	.5	511	25	<1.5	.378	--	--	--	--	--
394505074545001	08-25-97	1.2	.9	219	19	<1.5	.279	--	--	--	--	--
395308074345301	08-22-97	--	--	--	--	--	--	--	--	--	--	--
	04-15-98	--	--	--	--	--	--	--	--	--	--	--
395715074123101	06-19-96	--	--	110	19	--	--	<1	0.029	--	--	--
	06-22-98	--	.4	91	16	--	--	--	--	--	--	--
395722074222901	11-12-97	.2	--	286	22	--	--	--	--	--	--	--
395722074231901	05-11-98	--	--	118	18	--	--	--	--	--	--	--
395735074144001	06-20-96	--	--	210	19	<1.5	.301	<1	.034	--	--	--
	06-20-96	--	--	--	--	--	--	--	--	--	--	--
	11-24-97	.2	.5	196	19	--	--	--	--	--	--	--
395812074202602	11-17-97	.4	.4	192	20	--	--	--	--	--	--	--
395848074144202	11-05-97	--	--	252	20	--	--	--	--	--	--	--
395927074123201	12-03-97	.4	.5	254	20	--	--	--	--	--	--	--
395928074124901	06-02-98	--	.33	362	24	--	--	--	--	--	--	--
395933074131201	06-18-96	--	--	200	21	<1.5	.348	<1	.01	<.1	0.018	<.1
	06-18-96	--	--	--	--	--	--	--	--	--	--	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

Statin number	Date (mm-dd-yy)	Uranium-234, PE 2 sigma, filtered (pCi/L) (75992)	Uranium-235, filtered (pCi/L) (22620)	Uranium-235, PE 2 sigma, filtered (pCi/L) (75994)	Uranium, natural, filtered (µg/L) (22703)	Thorium-232, filtered (pCi/L) (75976)	Thorium-232, PE 2 sigma, filtered (pCi/L) (75999)	Thorium-230, filtered (pCi/L) (26503)	Thorium-230, PE 2 sigma, filtered (pCi/L) (75997)	Quality assurance data indicator code (99111)
393254075012101	09-05-96	--	--	--	<1	--	--	--	--	--
	09-16-97	--	--	--	--	--	--	--	--	--
393302075041501	12-10-98	--	--	--	--	--	--	--	--	10
393413075141901	06-10-98	--	--	--	<1	--	--	--	--	--
	09-27-99	--	--	--	--	--	--	--	--	--
393531074523901	12-12-96	--	--	--	<1	--	--	--	--	--
	08-23-99	--	--	--	<1	--	--	--	--	--
393654075135101	08-18-97	--	--	--	--	--	--	--	--	--
393823074492901	10-21-97	--	--	--	--	--	--	--	--	--
393916075122201	06-17-98	--	--	--	<1	--	--	--	--	--
393939075030901	11-10-98	--	--	--	--	--	--	--	--	--
393939075030903	12-01-98	--	--	--	<1	--	--	--	--	--
393940074534201	09-08-97	--	--	--	<1	--	--	--	--	--
394022074591002	11-14-97	--	--	--	--	--	--	--	--	10
	12-16-97	--	--	--	<1	--	--	--	--	--
	08-23-99	--	--	--	<1	--	--	--	--	30
	08-23-99	--	--	--	<1	--	--	--	--	30
394026075050401	10-06-97	--	--	--	.04	--	--	--	--	30
	10-06-97	--	--	--	--	--	--	--	--	30
394233075045401	09-02-97	--	--	--	<1	--	--	--	--	--
394248074571001	08-04-97	--	--	--	--	--	--	--	--	--
394327075021001	06-02-97	--	--	--	--	--	--	--	--	--
394358075012001	07-21-97	--	--	--	--	--	--	--	--	--
394414075001601	06-16-97	--	--	--	--	--	--	--	--	--
394505074545001	08-25-97	--	--	--	--	--	--	--	--	--
395308074345301	08-22-97	--	--	--	--	--	--	--	--	10
	04-15-98	--	--	--	--	--	--	--	--	--
395715074123101	06-19-96	--	--	--	<1	--	--	--	--	--
	06-22-98	--	--	--	--	--	--	--	--	--
395722074222901	11-12-97	--	--	--	--	--	--	--	--	--
395722074231901	05-11-98	--	--	--	--	--	--	--	--	--
395735074144001	06-20-96	--	--	--	<1	--	--	--	--	30
	06-20-96	--	--	--	<1	--	--	--	--	30
	11-24-97	--	--	--	--	--	--	--	--	--
395812074202602	11-17-97	--	--	--	--	--	--	--	--	--
395848074144202	11-05-97	--	--	--	--	--	--	--	--	10
395927074123201	12-03-97	--	--	--	--	--	--	--	--	--
395928074124901	06-02-98	--	--	--	<1	--	--	--	--	--
395933074131201	06-18-96	0.019	<0.1	0.008	<1	<1	0.011	<1	0.015	30
	06-18-96	--	--	--	<1	--	--	--	--	30

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Unique project number	Date (mm-dd-yy)	Time (eastern standard)	Sample record number	Gross alpha, filtered (as Thorium-230) (pCi/L) (04126)	Alpha count, PE 2 sigma, filtered (as Thorium-230) (pCi/L) (75987)
395933074131201	290088	01-13-97	1125	99700484	28.3	2.3
395936074122901	290627	12-08-97	1250	99800200	15.2	1.8
		12-08-97	1251	99800069	17.0	1.9
395936074123901	291229	06-02-98	1225	99801534	9.6	1.87
395936074124001	290628	12-01-97	1030	99800183	20.5	4.19
395945074122201	290097	12-17-97	1150	99800283	15.0	1.9
395946074124901	291233	06-02-98	1133	99801540	19.0	1.0
395950074124801	291232	06-03-98	1227	99801542	27.2	2.1
395951074115701	291342	09-01-98	1500	99801546	15.31	3.91
395957074124801	291230	06-04-98	1247	99801536	20.0	2.0
395958074120101	291343	09-02-98	1210	99801547	12.29	3.42
400002074125201	291231	06-03-98	1230	99801541	15.0	1.0
400009074114901	291344	08-26-98	1420	99801549	13.87	3.7
400014074081601	291345	09-09-98	1015	99801551	3.5	2.16
		09-09-98	1025	99800295	4.62	2.4
400037074193401	291086	04-13-98	1100	99801539	11.0	1.0
400040074121001	291346	09-02-98	1040	99801552	4.29	2.31
400048074115301	291347	08-25-98	1040	99801548	6.61	2.7
400057074121801	291348	08-31-98	1025	99801553	13.18	3.63
400059074120501	291349	09-01-98	1035	99801554	8.31	2.9
400105074240601	291115	04-29-98	1000	99800605	1.9	.3
400112074123201	291350	09-01-98	1145	99801555	14.41	3.62
400135074153901	290496	05-04-98	1050	99800662	15.2	1.0
400210074192601	290127	04-27-98	1050	99800606	5.2	.6
400226074143101	290591	06-14-96	1435	99600613	<3.0	.653
400226074143101	290591	02-10-97	1100	99700508	17.9	1.9
400301074094601	291073	04-22-98	1115	99800590	4.6	.6
400339074122201	291131	08-09-99	1408	99900871	15.09	4.15
		08-09-99	1409	99903391	--	--
400427074110701	290437	04-20-98	1050	99800589	5.1	.6

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Gross beta, filtered (as Cs-137) (pCi/L) (03515	Gross beta, PE 2 sigma, filtered (as Cs-137) (pCi/L) (75989)	Radium-224, alpha count, filtered (pCi/L) (50833)	Radium-224, PE 2 sigma, filtered (pCi/L) (50834)	Radium-224, SS MDC, 2X CL, filtered (pCi/L) (99324)	Radium-224, filtered, gamma, slow count (pCi/L) (99918)	Radium-224, CE 1 sigma, filtered, gamma slow count (pCi/L) (99919)	Radium-224, filtered, gamma fast count (pCi/L) (99922)	Radium-224, PE 2 sigma, filtered, gamma fast count (pCi/L) (99923)	Radium-226, filtered, alpha count, (pCi/L) (09503)	Radium-226, filtered, planchet count (09510)	Radium-226, filtered, radon method (pCi/L) (09511)
395933074131201	01-13-97	--	--	--	--	--	**3.3**	0.2	--	--	--	**2.4**	2.8
395936074122901	12-08-97	--	--	--	--	--	**2.1**	.2	2.6	0.6	--	1.7	--
395936074122901	12-08-97	**--**	**--**	**--**	**--**	**--**	**2.4**	.2	2.0	.6	--	--	**2.2**
395936074123901	06-02-98	8.08	3.89	--	--	--	**1.3**	.1	1.8	.2	--	.62	**.72**
395936074124001	12-01-97	11.3	4.08	--	--	--	3.6	.2	--	--	--	--	--
395945074122201	12-17-97	7.7	.9	--	--	--	**--**	--	2.6	.7	--	1.4	--
395946074124901	06-02-98	8.8	.5	--	--	--	**--**	--	2.2	.2	--	1.9	--
395950074124801	06-03-98	--	--	--	--	--	**--**	--	2.2	.4	--	1.0	--
395951074115701	09-01-98	16.16	4.28	2.42	0.64	0.58	**--**	--	--	--	1.74	--	--
395957074124801	06-04-98	9.1	.5	--	--	--	**2.0**	.1	2.7	.3	--	1.9	--
395958074120101	09-02-98	9.57	3.95	3.16	.5	.36	**--**	--	--	--	1.24	--	--
400002074125201	06-03-98	7.3	.4	--	--	--	**--**	--	1.6	.4	--	1.1	--
400009074114901	08-26-98	7.39	3.88	2.46	.46	.36	**--**	--	--	--	1.46	--	--
400014074081601	09-09-98	<4.0	3.56	.32	.26	.44	**--**	--	--	--	.53	--	--
400014074081601	09-09-98	3.87	3.66	.49	.22	.28	**--**	--	--	--	.57	--	--
400037074193401	04-13-98	4.4	.4	--	--	--	**--**	--	1.5	.2	--	.65	--
400040074121001	09-02-98	5.31	3.74	.82	.20	.20	**--**	--	--	--	1.07	--	--
400048074115301	08-25-98	6.07	3.79	1.27	.5	--	**--**	--	--	--	--	<.93	--
400057074121801	08-31-98	9.28	3.96	1.77	.44	.36	**--**	--	--	--	2.92	--	--
400059074120501	09-01-98	6.67	3.81	1.73	.34	.29	**--**	--	--	--	2.11	--	--
400105074240601	04-29-98	1.5	.2	--	--	--	**--**	--	.34	.19	--	.43	--
400112074123201	09-01-98	12.53	4.07	3.18	.86	.78	**--**	--	--	--	3.21	--	--
400135074153901	05-04-98	7.0	.4	--	--	--	**1.2**	.1	1.5	.3	.93	3.4	4.1
400210074192601	04-27-98	2.9	.3	--	--	--	**--**	--	.8	.2	--	.67	--
400226074143101	06-14-96	<4.0	.956	--	--	--	**--**	--	--	--	--	--	1.7
	02-10-97	--	--	--	--	--	1.5	.1	--	--	--	2.0	1.8
400301074094601	04-22-98	2.9	.3	--	--	--	--	--	1.2	.3	--	1.6	--
400339074122201	08-09-99	5.61	4.2	2.44	.52	.39	--	--	--	--	1.26	--	--
	08-09-99	--	--	--	--	--	--	--	--	--	--	--	--
400427074110701	04-20-98	3.4	.3	--	--	--	--	--	1.1	.3	--	.93	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Radium-226, PE 2 sigma, filtered (pCi/L) (76001)	Radium-226, filtered, CE 2 sigma (pCi/L) (09504)	Radium-226, filtered gamma count (pCi/L) (50837)	Radium-226, PE 2 sigma, filtered, gamma count (pCi/L) (50911)	Radium-228, filtered (pCi/L) (81366)	Radium-228, PE 2 sigma, filtered (pCi/L) (76000)	Radium-228, SS MDC, 2X CL, filtered (pCi/L) (99326)	Radium-228, filtered, gamma count (pCi/L) (50839)	Radium-228, PE 2 sigma, filtered, gamma count (pCi/L) (50840)	Radium-228, filtered, CE 2 sigma (pCi/L) (81367)	Radon-222, total (pCi/L) (82303)
395933074131201	01-13-97	0.8	0.8	2.3	0.4	--	--	--	2.4	0.4	--	--
395936074122901	12-08-97	--	.3	**1.8**	.2	1.6	--	--	**1.5**	.2	0.50	223
395936074122901	12-08-97	--	--	1.8	.2	--	--	--	1.5	.2	--	--
395936074123901	06-02-98	.05	.23	.7	.2	.64	--	--	**.9**	.4	.41	237
395936074124001	12-01-97	--	--	3.1	.4	--	--	--	2.4	.2	--	284
395945074122201	12-17-97	--	.3	--	--	1.5	--	--	--	--	.50	221
395946074124901	06-02-98	--	.3	--	--	1.4	0.4	--	--	--	--	193
395950074124801	06-03-98	--	.3	--	--	.91	--	--	--	--	.38	206
395951074115701	09-01-98	.36	--	--	--	1.71	.66	--	--	--	--	218
395957074124801	06-04-98	.1	.3	--	--	**1.8**	.2	--	2	.6	.4	148
395958074120101	09-02-98	.19	--	--	--	1.91	.658	--	--	--	--	210
400002074125201	06-03-98	--	.3	--	--	1.3	--	--	--	--	.4	210
400009074114901	08-26-98	.24	--	--	--	2.08	.676	--	--	--	--	--
400014074081601	09-09-98	.12	--	--	--	<1.0	.38	--	--	--	--	154
400014074081601	09-09-98	.11	--	--	--	.45	.383	--	--	--	--	136
400037074193401	04-13-98	--	.16	--	--	1.3	--	--	--	--	.6	--
400040074121001	09-02-98	--	.17	--	--	<1.0	.481	--	--	--	--	477
400048074115301	08-25-98	.14	--	--	--	1.13	.483	--	--	--	--	194
400057074121801	08-31-98	.46	--	--	--	1.6	.596	--	--	--	--	164
400059074120501	09-01-98	.28	--	--	--	2.32	.747	--	--	--	--	177
400105074240601	04-29-98	--	.2	--	--	<.5	--	--	--	--	--	560
400112074123201	09-01-98	.56	--	--	--	2.37	.759	--	--	--	--	250
400135074153901	05-04-98	.60	.5	**3.9**	.2	1.16	--	--	**1.2**	.2	.37	1007
400210074192601	04-27-98	--	.23	--	--	<.55	--	--	--	--	--	210
400226074143101	06-14-96	.29	--	--	--	1.1	.407	--	--	--	--	420
	02-10-97	.30	--	**1.7**	.2	2.0	.644	--	**1.2**	.2	--	--
400301074094601	04-22-98	--	.2	--	--	.56	--	--	--	--	.39	369
400339074122201	08-09-99	.23	--	--	--	1.69	.56	0.515	--	--	--	--
	08-09-99	--	--	--	--	--	--	--	--	--	--	--
400427074110701	04-20-98	--	.18	--	--	1.05	--	--	--	--	.43	289

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Radon-222, PE 2 sigma (pCi/L) (76002)	Lead-210, filtered (pCi/L) (17503)	Lead-210, PE 2 sigma, filtered (pCi/L) (75995)	Polonium-210, filtered (pCi/L) (19503)	Polonium-210, PE 2 sigma, filtered (pCi/L) (75998)	Uranium-238, dissolved (pCi/L) (22603)	Uranium-238, PE 2 sigma, filtered (pCi/L) (75991)	Uranium-234, filtered (pCi/L) (22610)	Uranium-234, PE 2 sigma, filtered (pCi/L) (75992)	Uranium-235, filtered (pCi/L) (22620)	Uranium-235 PE 2 sigma, filtered (pCi/L) (75994)
395933074131201	01-13-97	--	<1.5	0.45	--	--	--	--	--	--	--	--
395936074122901	12-08-97	19	<1.5	.279	--	--	--	--	--	--	--	--
395936074122901	12-08-97	--	--	--	--	--	--	--	--	--	--	--
395936074123901	06-02-98	20	--	--	--	--	--	--	--	--	--	--
395936074124001	12-01-97	21	<1.5	.268	--	--	--	--	--	--	--	--
395945074122201	12-17-97	20	--	--	--	--	--	--	--	--	--	--
395946074124901	06-02-98	19	--	--	--	--	--	--	--	--	--	--
395950074124801	06-03-98	20	--	--	--	--	--	--	--	--	--	--
395951074115701	09-01-98	20	.304	.489	--	--	--	--	--	--	--	--
395957074124801	06-04-98	18	--	--	--	--	--	--	--	--	--	--
395958074120101	09-02-98	22	--	--	--	--	--	--	--	--	--	--
400002074125201	06-03-98	20	--	--	--	--	--	--	--	--	--	--
400009074114901	08-26-98	--	--	--	--	--	--	--	--	--	--	--
400014074081601	09-09-98	21	--	--	--	--	--	--	--	--	--	--
400014074081601	09-09-98	22	--	--	--	--	--	--	--	--	--	--
400037074193401	04-13-98	--	--	--	--	--	--	--	--	--	--	--
400040074121001	09-02-98	27	--	--	--	--	--	--	--	--	--	--
400048074115301	08-25-98	21	--	--	--	--	--	--	--	--	--	--
400057074121801	08-31-98	20	--	--	--	--	--	--	--	--	--	--
400059074120501	09-01-98	19	--	--	--	--	--	--	--	--	--	--
400105074240601	04-29-98	25	--	--	--	--	--	--	--	--	--	--
400112074123201	09-01-98	21	.853	.535	--	--	--	--	--	--	--	--
400135074153901	05-04-98	30	--	--	--	--	--	--	--	--	--	--
400210074192601	04-27-98	19	--	--	--	--	--	--	--	--	--	--
400226074143101	06-14-96	29	<1.5	.317	<1.0	0.016	<0.1	0.014	<0.1	0.01	<0.1	0.004
	02-10-97	--	<1.5	.466	--	--	--	--	--	--	--	--
400301074094601	04-22-98	22	--	--	--	--	--	--	--	--	--	--
400339074122201	08-09-99	--	--	--	--	--	--	--	--	--	--	--
	08-09-99	--	--	--	.048	.105	--	--	--	--	--	--
400427074110701	04-20-98	20	--	--	--	--	--	--	--	--	--	--

Appendix 3. Concentrations of radionuclides in water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Uranium, natural, filtered (µg/L) (22703)	Thorium-232, filtered (pCi/L) (75976)	Thorium-232, PE 2 sigma, filtered (pCi/L) (75999)	Thorium-230, filtered (pCi/L) (26503)	Thorium-230, PE 2 sigma, filtered (75997)	Thorium-228, filtered (pCi/L) (61738)	Tritium, total (pCi/L) (07000)	Tritium, PE 2 sigma (pCi/L) (75985)	Quality assurance data indicator code (99111)
395933074131201	01-13-97	--	--	--	--	--	--	--	--	--
395936074122901	12-08-97	--	--	--	--	--	--	--	--	100
395936074122901	12-08-97	--	--	--	--	--	--	--	--	100
395936074123901	06-02-98	<1	--	--	--	--	--	--	--	10
395936074124001	12-01-97	--	--	--	--	--	--	--	--	--
395945074122201	12-17-97	--	--	--	--	--	--	--	--	10
395946074124901	06-02-98	<1	--	--	--	--	--	--	--	--
395950074124801	06-03-98	<1	--	--	--	--	--	--	--	--
395951074115701	09-01-98	--	--	--	--	--	--	--	--	--
395957074124801	06-04-98	<1	--	--	--	--	--	--	--	10
395958074120101	09-02-98	--	--	--	--	--	--	--	--	--
400002074125201	06-03-98	<1	--	--	--	--	--	--	--	--
400009074114901	08-26-98	--	--	--	--	--	--	38.72	2.56	--
400014074081601	09-09-98	--	--	--	--	--	--	--	--	30
400014074081601	09-09-98	--	--	--	--	--	--	--	--	30
400037074193401	04-13-98	--	--	--	--	--	--	--	--	--
400040074121001	09-02-98	--	--	--	--	--	--	<.3	.576	--
400048074115301	08-25-98	--	--	--	--	--	--	--	--	--
400057074121801	08-31-98	--	--	--	--	--	--	--	--	--
400059074120501	09-01-98	--	--	--	--	--	--	--	--	--
400105074240601	04-29-98	--	--	--	--	--	--	--	--	--
400112074123201	09-01-98	--	--	--	--	--	--	--	--	--
400135074153901	05-04-98	--	--	--	--	--	--	--	--	--
400210074192601	04-27-98	--	--	--	--	--	--	--	--	--
400226074143101	06-14-96	<1	<1	0.013	<1	0.017	--	--	--	--
	02-10-97	--	--	--	--	--	--	--	--	--
400301074094601	04-22-98	--	--	--	--	--	--	--	--	--
400339074122201	08-09-99	--	--	--	--	--	--	--	--	100
	08-09-99	--	<1	.207	.077	.171	0.338	--	--	100
400427074110701	04-20-98	--	--	--	--	--	--	--	--	--

Appendix 4

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.

[NTU, nephelometric turbidity units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; ng/L, nanograms per liter; ANC, acid neutralizing capacity; $CaCO_3$, calcium carbonate; SiO_2, silica; N, nitrogen; $NO_2 + NO_3$, nitrite plus nitrate; SO_4, sulfate; P, phosphorus; C, carbon; --, not analyzed; <, less than; E, estimated; M, detected but not quantified. Associated quality assurance data indicator code: 10, field or laboratory equipment blank; 30, sequential replicate; 100, multiple types; number in parenthesis is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality database (NWIS) in which individual samples are identified by sample record numbers]

U.S. Geological Survey station number	U.S. Geological Survey well number	Date (mm-dd-yy)	Time (eastern standard)	Sample record number	Turbidity, field, unfiltered (NTU) (61028)	pH, field (standard units) (00400)	pH, lab (standard units) (00403)	Specific conduc-tance, lab (µS/cm) (90095)	Specific conduc-tance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	Temper-ature, water (deg C) (00010)	Calcium, filtered (mg/L) (00915)	Magnesium, filtered (mg/L) (00925)
391905074363101	010582	06-30-98	1030	99800887	0.1	5.1	--	148	162	4.8	13.4	--	--
391924074354901	010589	07-19-99	1211	99900749	.6	4.4	4.3	718	722	5.4	14.5	10.9	12.3
392415075014601	110934	09-29-97	1030	99701182	.1	4.9	5.5	68	72	4.3	14.7	2.35	1.25
392430075131301	110002	07-08-97	1100	99700927	.02	4.85	--	--	135	5.4	14.7	--	--
392455074320701	010151	07-20-99	1151	99900750	.3	4.3	4.3	65	64	2.6	13.0	1.01	.616
392552075145001	110013	06-24-97	1040	99700837	.1	4.7	--	--	155	6.2	13.6	--	--
392640075132801	110933	07-14-97	1105	99701135	.1	4.5	4.6	91	93	4.7	14.6	2.81	2.21
		10-14-97	1025	99800018	.1	4.4	4.8	91	93	5.0	14.5	2.66	2.25
392708074380801	010958	09-22-97	1025	99701126	.1	5.0	--	--	64	7.6	12.9	1.01	.983
392724075123603	110274	06-30-97	1050	99700901	.1	4.7	--	--	144	7.0	13.7	--	--
392801075003701	110708	01-21-97	1100	99700485	.1	4.7	--	--	400	4.01	13.8	--	--
		05-27-97	1020	99700827	.1	4.6	--	--	402	4.5	13.7	--	--
392811075023601	110225	12-10-98	0900	99900160	--	4.7	4.7	109	106	1.4	13.7	3.44	1.82
392816075012101	110226	11-30-98	0900	99900113	--	4.6	4.8	112	111	5.1	14.1	4.18	3.67
392828075014002	110939	11-13-97	1500	99800162	--	4.6	5.2	151	143	4.5	13.2	3.29	3.45
392828075014002	110939	11-18-97	1100	99801532	.1	4.68	--	--	169	4.87	-15.9	--	--
392850075010301	110255	12-10-98	1100	99900159	--	4.4	4.7	63	62	3.3	13.4	1.87	1.25
392853075005801	110230	11-30-98	1100	99900112	--	4.7	5.0	95	93	6.3	14.3	2.96	3.07
392900074533101	110272	12-07-98	1205	99900173	.1	4.6	--	--	203	10.3	15.0	17.5	4.79
392900074533102	110273	12-14-98	1405	99900174	.1	4.6	--	--	278	9.7	11.6	23.9	6.65
392900074533103	110274	12-14-98	1205	99900175	.3	4.46	--	--	319	8.9	11.4	13.2	14.7
392901074535503	110277	12-17-98	1343	99900201	.1	4.4	--	--	257	5.56	11.4	21.2	7.34
392901074535504	110278	12-17-98	1140	99900202	.2	4.1	--	--	283	8.37	12.4	24.8	6.83
392901075103401	110923	10-17-96	1215	99700720	.12	4.54	--	--	113.7	6.95	13.6	3.1	4.5
		08-11-97	1125	99701125	.08	5.08	5.3	110	119	6.09	15.5	2.84	4.03
392920075011902	110937	11-18-97	1555	99800308	.1	4.5	--	--	162	6.13	16.0	--	--
		11-18-97	1600	99800309	--	--	--	--	--	--	--	--	--
		08-20-99	1200	99900989	.34	4.6	4.7	150	158	6.4	16.9	6.18	3.63
		08-20-99	1210	99901267	.34	4.6	--	--	--	--	16.9	6.04	3.48
392923075023401	110238	05-19-97	1115	99700700	.1	4.9	--	--	106	5.93	14.2	--	--

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	U.S. Geological Survey well number	Date (mm-dd-yy)	Time (eastern standard)	Sample record number	Turbidity, field, unfiltered (NTU) (61028)	pH, field (standard units) (00400)	pH, lab (standard units) (00403)	Specific conduc-tance, lab (µS/cm) (90095)	Specific conduc-tance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	Temper-ature, water (deg C) (00010)	Calcium, filtered (mg/L) (00915)	Magnesium, filtered (mg/L) (00925)
392944074281001	010973	07-21-99	1149	99900751	.5	4.9	5.1	45	45	0.14	13.5	.59	.473
392957075001901	110252	11-30-98	1400	99900114	--	4.5	4.6	94	92	4.9	13.3	3.67	2.29
393001075130801	110186	12-09-98	1400	99900157	--	4.5	4.7	102	102	8.1	13.4	3.29	4.44
393015075054501	330836	06-16-98	1110	99801538	.14	4.49	--	--	343	9.69	13.4	28.9	5.98
393030075090502	330907	11-18-98	1200	99900167	.1	4.3	--	--	268	6.36	13.5	16.0	7.93
393030075090503	330908	11-30-98	1220	99900169	.1	4.3	--	--	328	5.82	13.9	16.1	13.5
393046075085203	330911	11-23-98	1250	99900172	.3	5.86	--	--	82	0.39	12.5	8.95	.800
		11-24-98	1251	99900235	--	--	--	--	--	--	--	--	--
393056075125401	111011	12-16-98	1320	99900196	.01	4.6	--	--	85	5.03	12.7	3.99	3.48
393056075125402	111012	12-16-98	1105	99900197	.1	5.1	--	--	70	6.8	11.8	5.11	2.00
393056075125403	111013	12-15-98	1300	99900198	1.7	4.5	--	--	159	4.87	11.6	8.81	3.74
393100075122201	111014	12-10-98	1155	99900176	.1	4.7	--	--	150	9.88	12.2	7.82	9.08
393208075024501	110254	05-12-97	1140	99700702	.2	4.4	4.1	119	118	1.65	13.3	3.52	2.32

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Potassium filtered (mg/L) (00935)	Sodium, filtered (mg/L) (00930)	ANC, unfltrd, titrated to 4.5, lab (mg/L as $CaCO_3$) (90410)	Bromide, filtered (mg/L) (71870)	Chloride, filtered (mg/L) (00940)	Silica, filtered (mg/L as SiO_2) (00955)	Nitrogen, ammonia, filtered (mg/L as N) (00608)	Nitrogen, ammonia + organic, filtered (mg/L as N) (00623)	Nitrogen, NO_2+NO_3, filtered (mg/L as N) (00631)	Nitrogen, nitrite, filtered (mg/L as N) (00613)	Phos-phorus ortho, filtered (mg/L as P) (00671)	Sulfate, filtered (mg/L as SO_4) (00945)
391905074363101	06-30-98	--	--	--	--	23.0	7.9	.037	--	2.58	<.010	<.010	13.6
391924074354901	07-19-99	3.41	82.9	<1	--	200	11.4	<.020	<.10	.649	<.010	<.010	15.9
392415075014601	09-29-97	1.03	6.2	4	.02	8.5	7.7	<.015	<.20	3.25	<.010	<.010	1.67
392430075131301	07-08-97	--	--	--	--	15.5	--	<.015	--	3.31	<.010	<.010	14.4
392455074320701	07-20-99	.90	3.7	<1	--	6.2	11.5	<.020	<.10	.192	<.010	<.010	10.3
392552075145001	06-24-97	--	--	--	--	15.2	--	.015	--	7.06	<.010	<.010	8.35
392640075132801	07-14-97	1.45	6.1	1	--	8.6	9.5	.032	--	2.82	<.010	.011	9.42
	10-14-97	1.48	6.1	--	.04	9.5	10.4	<.015	<.20	2.80	<.010	<.010	10.54
392708074380801	09-22-97	.55	7.2	3	.03	14.5	6.8	<.015	<.20	.104	<.010	<.010	1.23
392724075123603	06-30-97	--	--	--	--	14.9	--	.020	--	8.22	<.010	<.010	2.44
392801075003701	01-21-97	--	--	--	--	--	--	--	--	--	--	--	--
	05-27-97	--	--	--	--	97.0	--	<.015	--	5.03	<.010	<.010	2.98
392811075023601	12-10-98	1.95	8.0	2	.05	12.7	9.0	.411	.43	2.57	<.010	.010	12.55
392816075012101	11-30-98	2.35	6.1	2	.05	11.2	8.7	.028	<.10	6.71	<.010	<.010	4.12
392828075014002	11-13-97	5.34	11.2	6	.02	30.5	7.6	.064	<.10	1.79	<.010	<.010	3.84
392828075014002	11-18-97	--	--	--	--	--	--	--	--	--	--	--	--
392850075010301	12-10-98	1.35	3.2	<1	.03	5.1	10.1	<.020	<.10	2.76	<.010	.011	5.31
392853075005801	11-30-98	1.85	6.4	3	.05	10.8	8.1	.025	<.10	5.32	<.010	<.010	0.58
392900074533101	12-07-98	7.00	1.1	0	--	5.7	5.8	.020	--	7.26	<.010	<.010	48.75
392900074533102	12-14-98	11.3	1.0	0	--	7.1	6.4	.027	--	6.99	<.010	<.010	77.3
392900074533103	12-14-98	9.21	3.2	0	--	17.5	6.4	.034	--	22.6	<.010	<.010	18.1
392901074535503	12-17-98	7.08	1.9	0	--	11.1	5.7	<.020	--	8.14	<.010	<.010	53.88
392901074535504	12-17-98	7.91	2.9	2	--	11.4	5.7	<.020	--	11.2	<.010	<.010	52.7
392901075103401	10-17-96	1.8	5.6	0	--	12	7.2	<.015	<.20	7.9	0.01	<.010	<.1
	08-11-97	1.97	7.1	--	--	11.7	--	<.015	--	6.88	<.010	<.010	<.1
392920075011902	11-18-97	--	--	--	--	--	--	<.020	--	2.40	<.010	.016	--
	11-18-97	--	--	--	--	--	--	--	--	--	--	--	--
	08-20-99	4.90	8.9	--	--	19.0	6.5	<.020	<.10	1.80	<.010	<.010	21.1
	08-20-99	4.68	8.7	--	.07	19.8	6.2	--	--	--	--	--	21.0
392923075023401	05-19-97	--	--	--	--	10.7	--	<.015	--	4.82	<.010	<.010	4.33
392944074281001	07-21-99	1.60	3.5	0	--	6.1	17.7	<.020	<.10	<.050	<.010	.018	6.21
392957075001901	11-30-98	2.15	5.0	<1	.03	8.0	7.6	.027	<.10	4.70	<.010	<.010	6.52
393001075130801	12-09-98	1.80	3.5	<1	.04	10.4	9.2	<.020	<.10	5.94	<.010	.014	3.43
393015075054501	06-16-98	11.3	2.1	--	--	--	5.5	.067	--	20.8	<.010	<.010	--
393030075090502	11-18-98	2.87	4.7	0	--	20.7	6.3	<.020	--	18.5	<.010	<.010	3.35

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Potassium filtered (mg/L) (00935)	Sodium, filtered (mg/L) (00930)	ANC, unfltrd, titrated to 4.5, lab (mg/L as $CaCO_3$) (90410)	Bromide, filtered (mg/L) (71870)	Chloride, filtered (mg/L) (00940)	Silica, filtered (mg/L as SiO_2) (00955)	Nitrogen, ammonia, filtered (mg/L as N) (00608)	Nitrogen, ammonia + organic, filtered (mg/L as N) (00623)	Nitrogen, NO_2+NO_3, filtered (mg/L as N) (00631)	Nitrogen, nitrite, filtered (mg/L as N) (00613)	Phos-phorus ortho, filtered (mg/L as P) (00671)	Sulfate, filtered (mg/L as SO_4) (00945)
393030075090503	11-30-98	2.76	4.4	--	--	24.3	6.6	<.020	--	23.7	<.010	<.010	2.53
393046075085203	11-23-98	.77	1.7	13	--	3.5	18.0	.024	--	<.050	<.010	2.24	8.84
393046075085203	11-24-98	--	--	--	--	--	--	.029	--	<.050	<.010	2.20	--
393056075125401	12-16-98	3.02	2.3	4	--	4.1	7.9	<.020	--	2.34	<.010	<.010	16.69
393056075125402	12-16-98	1.32	2.1	5	--	6.2	9.8	.023	--	2.35	<.010	<.010	5.98
393056075125403	12-15-98	1.73	8.1	0	--	15.7	8.2	.023	--	5.87	<.010	<.010	14.14
393100075122201	12-10-98	2.21	4.3	2	--	16.7	8.7	<.020	--	12.8	<.010	<.010	0.14
393208075024501	05-12-97	2.10	4.9	--	--	8.6	12.1	<.015	--	2.15	<.010	<.010	20.1

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Carbon, organic, filtered (mg/L as C) (00681)	Aluminum, filtered (µg/L) (01106)	Barium, filtered (µg/L) (01005)	Boron, filtered (µg/L) (01020)	Cobalt, filtered (µg/L) (01035)	Iron, filtered (µg/L) (01040)	Lead, filtered (µg/L) (01049)	Manganese, filtered (µg/L) (01056)	Mercury, filtered (µg/L) (71890)	Mercury, filtered, amalgam pre-concentration (ng/L) (50287)	Nickel, filtered (µg/L) (01065)
391905074363101	06-30-98	.50	--	--	--	--	120	--	--	--	--	--
391924074354901	07-19-99	<.10	3500	153	E10	18.4	590	--	83.4	--	--	--
392415075014601	09-29-97	.30	94	48.8	118	<3.00	10	<1.00	6.6	.17	--	--
392430075131301	07-08-97	--	--	--	--	--	--	--	--	<.10	--	--
392455074320701	07-20-99	.10	480	32.2	E13	<7.00	650	--	8.4	--	--	--
392552075145001	06-24-97	--	--	--	--	--	--	--	--	<.10	--	--
392640075132801	07-14-97	--	319	51.6	31	<3.00	170	2.60	9.9	<.10	--	--
	10-14-97	.30	--	--	--	--	170	--	7.9	--	--	--
392708074380801	09-22-97	.20	71	33.8	10	<3.00	E9	<1.00	7.0	.14	--	--
392724075123603	06-30-97	--	--	--	--	--	--	--	--	<.10	--	--
392801075003701	01-21-97	--	--	--	--	--	--	--	--	3.6	--	--
	05-27-97	--	--	--	--	--	--	--	--	2.96	--	--
392811075023601	12-10-98	.40	--	--	--	--	580	--	35.7	--	--	--
392816075012101	11-30-98	.20	--	--	--	--	40	--	21.0	--	--	--
392828075014002	11-13-97	1.4	--	--	59	--	860	--	49.4	--	--	--‘
392828075014002	11-18-97	0.5	34	154	33	2.41	--	<1.00	14.6	--	--	3.77
392850075010301	12-10-98	.10	--	--	--	--	<10	--	9.4	--	--	--
392853075005801	11-30-98	.20	--	--	--	--	E8	--	17.7	--	--	--
392900074533101	12-07-98	1.1	840	68.6	27	3.90	60	1.14	36.5	--	.82	2.94
392900074533102	12-14-98	1.0	972	70.7	30	<3.99	E10	<1.21	37.9	--	1.33	3.75
392900074533103	12-14-98	.60	1470	779	21	<18.3	20	<1.00	82.0	--	9.93	17.3
392901074535503	12-17-98	1.2	874	55.8	32	--	40	--	78.5	--	1.47	--
392901074535504	12-17-98	1.4	1000	50.3	29	<5.90	40	<1.00	78.4	--	.78	4.80
392901075103401	10-17-96	--	177	254	10.5	4	<3	1	17	3.8	6277	3
	08-11-97	.30	--	--	--	--	--	--	--	--	5740	--
392920075011902	11-18-97	--	432	116	41	3.81	--	<1.00	44.9	--	98.2	5.96
	11-18-97	--	414	110	--	3.80	--	<1.00	43.1	--	95.6	5.94
	08-20-99	--	342	104	33	3.29	E6	<1.00	34.5	.47	--	4.12
	08-20-99	--	376	84.9	--	3.29	E7	<1.00	34.3	--	--	4.39
392923075023401	05-19-97	--	--	--	--	--	--	--	--	<.10	--	--
392944074281001	07-21-99	.20	83	53.6	<16	E4.27	960	--	11.7	--	--	--
392957075001901	11-30-98	.20	--	--	--	--	40	--	18.6	--	--	--
393001075130801	12-09-98	.20	--	--	--	--	<10	--	15.5	--	--	--
393015075054501	06-16-98	--	745	98.4	--	12.2	<10	<1.00		--	13.4	3.44
393030075090502	11-18-98	.40	1230	288	23	5.01	30	<1.00	38.9	--	10.7	6.18

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Carbon, organic, filtered (mg/L as C) (00681)	Aluminum, filtered (µg/L) (01106)	Barium, filtered (µg/L) (01005)	Boron, filtered (µg/L) (01020)	Cobalt, filtered (µg/L) (01035)	Iron, filtered (µg/L) (01040)	Lead, filtered (µg/L) (01049)	Manganese, filtered (µg/L) (01056)	Mercury, filtered (µg/L) (71890)	Mercury, filtered, amalgam pre-concentration (ng/L) (50287)	Nickel, filtered (µg/L) (01065)
393030075090503	11-30-98	.40	1310	385	E12	12.7	30	<1.00	60.0	--	3.19	13.7
392901075103401	11-23-98	.30	16	16.2	E10	--	3900	--	24.1	--	<.20	--
	11-24-98	--	--	--	--	--	--	--	--	--	<.20	--
393056075125401	12-16-98	.50	110	120	22	--	10	--	55.5	--	3.53	--
393056075125402	12-16-98	--	28	49.6	E14	--	460	--	14.2	--	E.15	--
393056075125403	12-15-98	.30	<441	59.2	E12	<5.44	960	<1.00	39.2	--	E.42	8.58
393100075122201	12-10-98	.30	138	442	E16	9.75	E6	<1.00	37.6	--	.94	4.12
393208075024501	05-12-97	--	699	80.6	10	6.54	1100	<1.00	62.3	.16	--	8.61

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Strontium, filtered (µg/L) (01080)	Zinc, filtered (µg/L) (01090)	Quality assurance data indicator code (99111)
391905074363101	06-30-98	52.0	--	--
391924074354901	07-19-99	122	103	30
392415075014601	09-29-97	17.0	58	--
392430075131301	07-08-97	--	--	--
392455074320701	07-20-99	9.56	44	--
392552075145001	06-24-97	--	--	--
392640075132801	07-14-97	23.1	11	--
	10-14-97	--	--	--
392708074380801	09-22-97	9.40	7	--
392724075123603	06-30-97	--	--	--
392801075003701	01-21-97	--	--	--
	05-27-97	--	--	--
392811075023601	12-10-98	--	--	10
392816075012101	11-30-98	--	--	10
392828075014002	11-13-97	--	--	10
392828075014002	11-18-97	35.31	1.44	--
392850075010301	12-10-98	--	--	10
392853075005801	11-30-98	--	--	100
392900074533101	12-07-98	90.4	3	--
392900074533102	12-14-98	75.2	3	--
392900074533103	12-14-98	78.0	12	--
392901074535503	12-17-98	54.6	<7	--
392901074535504	12-17-98	63.2	3	--
392901075103401	10-17-96	52	4	--
	08-11-97	--	--	--
392920075011902	11-18-97	26.0	5	--
	11-18-97	--	6	--
	08-20-99	21.5	8	--
	08-20-99	--	8	--
392923075023401	05-19-97	--	--	--
392944074281001	07-21-99	11.3	33	--
392957075001901	11-30-98	--	--	10
393001075130801	12-09-98	--	--	100
393015075054501	06-16-98	61.8	3	--
393030075090502	11-18-98	71.5	9	--

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Strontium, filtered (µg/L) (01080)	Zinc, filtered (µg/L) (01090)	Quality assurance data indicator code (99111)
393030075090503	11-30-98	122	18	--
393046075085203	11-23-98	48.0	<20	--
	11-24-98	--	--	--
393056075125401	12-16-98	32.6	<20	--
393056075125402	12-16-98	29.6	E9	--
393056075125403	12-15-98	57.6	4	--
393100075122201	12-10-98	90.7	3	--
393208075024501	05-12-97	35.5	21	--

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	U.S. Geological Survey well number	Date (mm-dd-yy)	Time (eastern standard)	Sample record number	Turbidity, field, unfiltered (NTU) (61028)	pH, field (standard units) (00400)	pH, lab (standard units) (00403)
393254075012101	150209	09-05-96	1150	99600838	.2	4.4	--
		09-16-97	1050	99701121	.1	4.4	4.8
393302075041501	111000	12-10-98	1300	99900161	--	4.7	5.0
393413075141901	330818	06-10-98	1150	99800774	.12	4.8	--
		09-27-99	1210	99901154	1.7	4.7	4.8
393531074523901	011240	12-12-96	1255	99700312	.1	4.3	--
		08-23-99	1600	99900990	.17	4.46	4.4
393654075135101	330778	08-18-97	1105	99701046	.1	5.0	--
393823074492901	010792	10-21-97	1025	99800020	.1	4.5	--
393916075122201	330817	06-17-98	1040	99801537	.08	4.65	--
393939075030901	151393	11-10-98	1500	99900230	.3	4.7	--
393939075030903	151395	12-01-98	1200	99900192	.1	4.9	--
393940074534201	070842	09-08-97	1130	99701122	.1	4.4	--
394022074591002	151264	11-14-97	1200	99800110	--	3.9	4.9
		12-16-97	1410	99800297	.1	4.8	--
394022074591002	151264	08-23-99	1315	99900988	.2	4.6	4.9
		08-23-99	1210	99901263	--	--	--
394026075050401	150375	09-28-88	0940	98801176	--	4.5	--
		10-06-97	1045	99800006	.1	4.3	--
394233075045401	151113	09-02-97	1045	99701123	.1	4.9	5.0
394248074571001	070490	08-04-97	1145	99701047	.1	5.8	5.8
394327075021001	151065	06-02-97	1040	99700828	.0	5.1	--
394358075012001	070866	07-21-97	1110	99701134	.1	4.8	5.2
394414075001601	070603	06-16-97	1120	99700829	.1	4.9	--
394505074545001	070737	08-25-97	1117	99701124	.1	4.9	--
395308074345301	051092	08-22-97	1104	99701055	--	5.2	5.6
		04-15-98	1020	99800580	.1	5.4	--
395715074123101	290058	06-19-96	1200	99600610	.3	5.1	--
		06-22-98	1250	99800889	.1	4.7	--
395722074222901	290487	11-12-97	1030	99800083	.1	4.7	4.9
395722074231901	290488	05-11-98	1045	99800663	.1	4.7	--
395735074144001	290928	06-20-96	1130	99600614	.1	5.0	--
		06-20-96	1135	99600615	.1	5.03	--
		11-24-97	1100	99800166	.1	4.7	4.9
395812074202602	290811	11-17-97	1125	99800106	.1	4.3	--
395848074144202	291032	11-05-97	1445	99800081	.82	4.9	5.4
395927074123201	291216	12-03-97	1025	99800221	.1	4.9	5.0
395928074124901	291234	06-02-98	1720	99801535	.68	4.8	--
395933074131201	290088	06-18-96	1125	99600609	.1	4.7	--
		06-18-96	1130	99600618	--	--	--

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Specific conduc-tance, lab (µS/cm) (90095)	Specific conduc-tance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	Temperature, water (deg C) (00010)	Calcium, filtered (mg/L) (00915)	Magnesium, filtered (mg/L) (00925)	Potassium, filtered (mg/L) (00935)	Sodium, filtered (mg/L) (00930)	ANC, unfiltered, titrated to 4.5 lab (mg/L as $CaCO_3$) (90410)	ANC, unfiltered, titrated to 4.5 field (mg/L as $CaCO_3$) (00410)	Bromide, filtered (mg/L) (71870)
393254075012101	09-05-96	--	74	4.9	13.9	2.40	2.30	1.40	3.7	<.5	--	--
	09-16-97	63	65	4.3	13.2	1.90	2.02	1.23	3.3	--	--	--
393302075041501	12-10-98	92	90	4.2	13.1	2.87	2.81	2.53	5.3	2	--	.10
393413075141901	06-10-98	--	639	9.5	12.0	32.5	10.5	5.66	60.1	--	--	--
	09-27-99	604	622	8.8	15.5	43.4	15.1	4.46	27.9	2	--	.07
393531074523901	12-12-96	--	387	.6	15.4	14.0	5.10	9.60	20.0	--	--	--
	08-23-99	247	249	.8	16.1	8.89	3.58	6.10	16.5	--	--	--
393654075135101	08-18-97	--	343	5.6	15.2	15.4	13.2	2.73	19.4	5	--	--
393823074492901	10-21-97	--	54	9.9	13.3	1.59	1.44	1.83	3.2	--	--	--
393916075122201	06-17-98	--	348	9.4	12.4	30.3	9.40	4.22	3.8	--	--	--
393939075030901	11-10-98	--	41	3.5	13.1	.94	.861	.64	2.7	0	--	--
393939075030903	12-01-98	--	53	8.7	13.3	1.10	.924	.82	2.5	0	--	--
393940074534201	09-08-97	--	52	1.8	13.9	.42	.257	.20	1.8	--	--	--
394022074591002	11-14-97	105	99	.5	14.0	3.71	1.70	3.16	7.0	5	--	.04
	12-16-97	--	102	.6	14.7	--	--	--	--	--	--	--
	08-23-99	116	115	.5	16.4	4.71	1.94	3.49	8.1	--	--	--
	08-23-99	--	--	.5	--	4.41	1.86	3.56	8.0	--	--	.06
394026075050401	09-28-88	--	101	2.1	13.0	3.10	2.20	1.80	8.6	1	<1	--
	10-06-97	--	87	2.5	13.0	2.88	2.05	1.79	7.1	--	--	--
394233075045401	09-02-97	118	117	7.0	13.1	5.27	3.70	1.59	5.7	--	--	--
394248074571001	08-04-97	47	48	5.1	13.5	2.54	1.30	.88	3.0	--	--	--
394327075021001	06-02-97	--	133	6.5	13.2	--	--	--	--	--	--	--
394358075012001	07-21-97	101	102	7.8	13.2	4.60	3.34	1.65	4.4	4	--	--
394414075001601	06-16-97	--	117	6.5	13.8	--	--	--	--	--	--	--
394505074545001	08-25-97	--	63	7.6	13.2	1.77	2.86	.97	2.6	--	--	--
395308074345301	08-22-97	171	176	6.2	15.5	7.95	1.67	2.07	16.9	7	7	--
	04-15-98	--	153	5.5	14.1	6.82	1.41	1.88	16.0	--	--	--
395715074123101	06-19-96	--	292	.3	13.2	6.60	2.60	1.60	37.0	--	--	--
	06-22-98	172	185	.6	13.4	4.31	2.10	1.20	20.3	--	--	--
395722074222901	11-12-97	72	64	4.5	13.2	1.37	1.19	.76	7.2	--	--	--
395722074231901	05-11-98	28	28	4.7	12.9	.24	.270	.84	2.1	--	--	--
395735074144001	06-20-96	--	48	5.1	13.5	1.30	.910	.80	3.6	<.5	--	--
	06-20-96	--	48	5.1	13.5	--	--	--	--	--	--	--
	11-24-97	51	51	5.1	13.7	1.52	.850	.76	3.8	--	--	--
395812074202602	11-17-97	51	50	4.7	12.1	.50	.728	.52	4.4	--	--	--
395848074144202	11-05-97	70	65	9.0	12.2	1.01	1.59	1.09	7.0	--	--	--
395927074123201	12-03-97	328	311	5.4	12.9	1.54	4.83	1.68	47.5	--	--	--
395928074124901	06-02-98	125	130	4.2	17.2	5.53	2.95	4.58	8.6	--	--	--
395933074131201	06-18-96	--	124	6.2	13.3	2.90	2.30	2.20	12.0	--	--	--
	06-18-96	--	--	--	--	--	--	--	--	--	--	--

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Chloride, filtered (mg/L) (00940)	Fluoride, filtered (mg/L) (00950)	Silica, filtered (mg/L as SiO_2) (00955)	Sulfate, filtered (mg/L as SO_4) (00945)	Nitrogen, ammonia, filtered (mg/L as N) (00608)	Nitrogen, ammonia + organic, filtered (mg/L as N) (00623)	Nitrogen, NO_2+NO_3, filtered (mg/L as N) (00631)	Nitrogen, nitrite, filtered (mg/L as N) (00613)	Phosphorus, ortho, filtered (mg/L as P) (00671)	Carbon, organic, filtered (mg/L as C) (00681)
393254075012101	09-05-96	6.9	--	7.4	2.3	<.015	<.20	4.40	<.010	<.010	.10
	09-16-97	6.2	--	7.5	1.7	<.015	--	3.45	<.010	<.010	.20
393302075041501	12-10-98	10.1	<.1	7.2	1.3	<.020	<.10	5.32	<.010	<.010	.20
393413075141901	06-10-98	--	--	8.2	--	.023	--	16.0	<.010	<.010	--
	09-27-99	66.6	.1	9.9	102	<.020	.11	16.9	<.010	<.010	1.2
393531074523901	12-12-96	--	--	7.5	--	.610	.80	31.0	.010	<.010	1.7
	08-23-99	25.2	--	6.4	9.4	<.020	E.09	12.2	<.010	<.010	--
393654075135101	08-18-97	41.4	--	11.9	32.9	.028	--	10.8	.010	<.010	.50
393823074492901	10-21-97	5.9	--	6.3	.5	<.015	--	3.02	<.010	<.010	.20
393916075122201	06-17-98	--	--	7.6	--	.065	--	12.9	<.010	<.010	--
393939075030901	11-10-98	5.2	--	12.5	5.3	<.020	--	.105	<.010	<.010	<.10
393939075030903	12-01-98	3.8	--	6.6	2.4	.028	--	2.75	<.010	<.010	.10
393940074534201	09-08-97	2.9	--	4.5	12.2	<.015	--	<.050	<.010	<.010	1.2
394022074591002	11-14-97	14.6	.4	9.3	1.5	<.020	<.10	4.00	<.010	.021	.40
	12-16-97	--	--	--	--	<.020	--	3.83	<.010	<.010	.50
	08-23-99	13.7	--	9.7	2.4	.020	E.06	4.84	<.010	<.010	--
	08-23-99	13.9	<.1	9.2	1.3	--	--	--	--	--	--
394026075050401	09-28-88	11.0	<.1	11.0	8.0	<.010	.20	2.50	<.010	<.010	--
	10-06-97	11.6	--	10.8	13.7	<.015	--	1.90	<.010	<.010	--
394233075045401	09-02-97	12.8	--	8.4	12.2	.030	--	3.19	<.010	.012	.50
394248074571001	08-04-97	5.0	--	7.3	4.9	.049	--	.376	<.010	.022	--
394327075021001	06-02-97	10.7	--	--	15.2	<.015	--	5.23	<.010	<.010	--
394358075012001	07-21-97	9.3	--	6.1	7.6	<.015	--	4.77	<.010	<.010	--
394414075001601	06-16-97	13.7	--	--	9.1	<.015	--	3.85	<.010	<.010	--
394505074545001	08-25-97	5.1	--	6.4	.3	.039	--	4.01	<.010	<.010	.20
395308074345301	08-22-97	31.4	<.1	5.2	14.5	<.015	<.20	1.52	.013	<.010	.80
	04-15-98	27.1	--	4.7	11.7	.032	--	1.06	.141	<.010	.90
395715074123101	06-19-96	71.0	--	6.5	12.0	.380	.40	.210	<.010	<.010	2.5
	06-22-98	34.9	--	5.8	10.6	.197	--	.320	<.010	<.010	1.5
395722074222901	11-12-97	13.0	--	5.0	1.9	.044	--	1.49	.021	.015	.20
395722074231901	05-11-98	3.3	--	8.1	3.4	<.020	--	<.050	<.010	<.010	.20
395735074144001	06-20-96	6.1	--	6.2	3.3	.030	<.20	.920	<.010	<.010	.30
	06-20-96	--	--	--	--	--	--	--	--	--	--
	11-24-97	7.1	--	5.3	3.9	<.020	--	1.02	<.010	.024	.30
395812074202602	11-17-97	7.4	--	5.4	3.2	.021	--	1.13	<.010	<.010	.20
395848074144202	11-05-97	12.3	--	4.2	3.3	.021	--	1.07	.021	.019	.30
395927074123201	12-03-97	87.9	--	6.4	9.7	<.020	--	1.17	<.010	<.010	--
395928074124901	06-02-98	16.3	--	5.3	18.8	.035	--	.852	.014	.015	.50
395933074131201	06-18-96	20.0	--	6.9	7.5	.030	<.20	2.40	<.010	<.010	.60
	06-18-96	--	--	--	--	--	--	--	--	--	--

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Aluminum, filtered (µg/L) (01106)	Barium, filtered (µg/L) (01005)	Boron, filtered (µg/L) (01020)	Chromium, filtered (µg/L) (01030)	Cobalt, filtered (µg/L) (01035)	Copper, filtered (µg/L) (01040)	Iron, filtered (µg/L) (01046)	Lead, filtered (µg/L) (01049)
393254075012101	09-05-96	110	135	11	<1.0	2.00	8.0	20	<1.00
	09-16-97	--	--	--	--	--	--	--	--
393302075041501	12-10-98	--	--	--	--	--	--	<10	--
393413075141901	06-10-98	242	47.7	--	<1.0	4.80	1.0	<10	<1.00
	09-27-99	324	28.7	--	<1.0	--	1.1	<10	<1.00
393531074523901	12-12-96	5750	455	35	1.0	18.0	2.0	30	<1.00
	08-23-99	2420	189	42	<1.0	14.2	1.7	M	<1.00
393654075135101	08-18-97	88	114	14	--	<3.00	23.9	100	2.20
393823074492901	10-21-97	77	74.8	16	--	<3.00	4.1	30	<1.00
393916075122201	06-17-98	213	80.2	--	1.5	2.35	1.1	<10	<1.00
393939075030901	11-10-98	102	18.9	E9	--	--	--	E5	--
393939075030903	12-01-98	298	18.3	<16	<1.0	<1.00	<1.0	50	<1.00
393940074534201	09-08-97	1600	61.1	20	<1.0	1.42	<1.0	20	<1.00
394022074591002	11-14-97	--	--	33	--	--	--	M	--
	12-16-97	68	70.4	23	2.4	3.06	28.4	--	<1.00
	08-23-99	76	74.9	25	<1.0	6.83	1.4	E8	<1.00
	08-23-99	79	71.3	--	<1.0	9.23	1.0	<10	<1.00
394026075050401	09-28-88	210	70.0	--	<5.0	<3.00	<10.0	160	10.0
	10-06-97	233	69.0	10	--	<3.00	<1.0	190	<1.00
394233075045401	09-02-97	118	77.5	17	1.1	1.49	<1.0	120	<1.00
394248074571001	08-04-97	--	--	18	--	--	--	370	--
394327075021001	06-02-97	--	--	--	--	--	--	--	--
394358075012001	07-21-97	79	114	17	--	<3.00	--	30	--
394414075001601	06-16-97	--	--	--	--	--	--	--	--
394505074545001	08-25-97	25	79.9	8	--	<3.00	2.5	E8	2.30
395308074345301	08-22-97	288	45.6	--	<1.0	--	3.9	M	1.00
	04-15-98	--	--	--	--	--	--	<10	--
395715074123101	06-19-96	208	28.0	18	<1.0	1.00	<1.0	2300	1.00
	06-22-98	--	--	--	--	--	--	1100	--
395722074222901	11-12-97	87	37.4	13	--	<3.00	31.2	E6	3.20
395722074231901	05-11-98	--	--	--	--	--	--	240	--
395735074144001	06-20-96	102	21.0	15	<1.0	<1.00	12.0	70	7.00
	06-20-96	98	19.0	--	<1.0	<1.00	12.0	--	7.00
	11-24-97	--	--	--	--	--	--	--	--
395812074202602	11-17-97	119	24.0	12	--	<3.00	2.4	20	2.20
395848074144202	11-05-97	--	--	--	--	--	--	--	--
395927074123201	12-03-97	118	109	18	--	<3.00	2.0	10	1.20
395928074124901	06-02-98	66	35.8	--	1.3	<1.00	<1.0	<10	<1.00
395933074131201	06-18-96	133	53.0	23	<1.0	2.00	6.0	20	<1.00
	06-18-96	133	53.0	--	<1.0	2.00	6.0	--	1.00

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Manganese, filtered (µg/L) (01056)	Mercury, filtered (µg/L) (71890)	Mercury, filtered, amalgam pre-concentration (ng/L) (50287)	Nickel, filtered (µg/L) (01065)	Silver, filtered (µg/L as Ag) (01075)	Strontium, filtered (µg/L) (01080)	Zinc, filtered (µg/L) (01090)	Quality assurance data indicator code (99111)
393254075012101	09-05-96	30.0	.20	--	2.00	<1.0	18.0	32	--
	09-16-97	--	<.10	--	--	--	--	--	--
393302075041501	12-10-98	18.1	--	--	--	--	--	--	10
393413075141901	06-10-98	155	--	54.4	3.12	<1.0	122	3	--
	09-27-99	227	<.10	--	--	<1.0	--	E13	--
393531074523901	12-12-96	330	<.10	--	14.0	<1.0	110	277	--
	08-23-99	228	--	--	8.84	<1.0	96.2	146	--
393654075135101	08-18-97	26.3	<.10	--	--	--	150	65	--
393823074492901	10-21-97	15.8	<.10	--	--	--	19.1	119	--
393916075122201	06-17-98	54.9	--	2.55	2.83	<1.0	119	2	--
393939075030901	11-10-98	5.7	--	.79	--	--	7.98	E8	--
393939075030903	12-01-98	3.7	--	1.28	<1.00	<1.0	11.3	3	--
393940074534201	09-08-97	12.7	--	.86	2.33	<1.0	6.36	16	--
394022074591002	11-14-97	20.9	--	--	--	--	--	--	10
	12-16-97	22.8	--	2150	5.50	<1.0	21.2	5	--
	08-23-99	19.0	5.02	--	4.77	<1.0	21.9	45	30
	08-23-99	18.2	--	--	3.80	<1.0	--	9	30
394026075050401	09-28-88	19.0	<.10	--	<10.0	<1.0	27.0	11	30
	10-06-97	19.2	<.10	--	--	--	26.7	7	--
394233075045401	09-02-97	16.3	<.10	--	2.36	<1.0	37.4	2	--
394248074571001	08-04-97	--	--	--	--	--	11.4	--	--
394327075021001	06-02-97	--	<.10	--	--	--	--	--	--
394358075012001	07-21-97	--	<.10	--	--	--	24.5	--	--
394414075001601	06-16-97	--	<.10	--	--	--	--	--	--
394505074545001	08-25-97	20.2	<.10	--	--	--	17.3	53	--
395308074345301	08-22-97	14.8	<.10	--	--	<1.0	--	13	10
	04-15-98	--	--	--	--	--	29.2	--	--
395715074123101	06-19-96	32.0	<.10	--	4.00	<1.0	38.0	28	--
	06-22-98	--	--	--	--	--	24.9	--	--
395722074222901	11-12-97	21.0	--	122	--	--	15.5	8	--
395722074231901	05-11-98	--	--	--	--	--	4.84	--	--
395735074144001	06-20-96	17.0	.20	--	<1.00	<1.0	13.0	8	30
	06-20-96	18.0	.20	--	<1.00	<1.0	--	8	30
	11-24-97	--	--	66.4	--	--	--	--	--
395812074202602	11-17-97	9.5	--	<.16	--	--	7.99	<3	--
395848074144202	11-05-97	--	--	--	--	--	--	--	10
395927074123201	12-03-97	32.4	--	97.3	--	--	24.6	<3	--
395928074124901	06-02-98	21.8	--	2.57	1.37	<1.0	32.5	1	--
395933074131201	06-18-96	24.0	<.10	--	6.00	<1.0	22.0	29	30
	06-18-96	23.0	.20	--	6.00	<1.0	--	30	30

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	U.S. Geological Survey well number	Date (mm-dd-yy)	Time (eastern standard)	Sample record number	Turbidity, field, unfiltered (NTU) (61028)	pH, field (standard units) (00400)	pH, lab (standard units) (00403)
395933074131201	290088	01-13-97	1125	99700484	.1	4.8	--
395936074122901	290627	12-08-97	1250	99800200	.1	4.7	4.6
395936074123901	291229	06-02-98	1225	99801534	.1	5.03	--
395936074124001	290628	12-01-97	1030	99800183	.1	4.5	--
395945074122201	290097	12-17-97	1150	99800283	.1	5.1	5.2
395946074124901	291233	06-02-98	1133	99801540	.59	4.7	--
395950074124801	291232	06-03-98	1227	99801542	.52	5.2	--
395951074115701	291342	09-01-98	1500	99801546	.05	4.2	--
395957074124801	291230	06-04-98	1247	99801536	.68	4.88	--
395958074120101	291343	09-02-98	1210	99801547	.09	4.5	--
400002074125201	291231	06-03-98	1230	99801541	.80	4.8	--
400009074114901	291344	08-26-98	1420	99801549	.24	4.4	--
400014074081601	291345	09-09-98	1015	99801551	.18	4.9	--
		09-09-98	1025	99800295	--	--	--
400037074193401	291086	04-13-98	1100	99801539	.1	4.9	--
400040074121001	291346	09-02-98	1040	99801552	.3	4.5	4.5
400048074115301	291347	08-25-98	1040	99801548	.07	4.9	--
400057074121801	291348	08-31-98	1025	99801553	.07	4.9	--
400059074120501	291349	09-01-98	1035	99801554	.23	4.7	5.1
400105074240601	291115	04-29-98	1000	99800605	.7	5.1	--
400112074123201	291350	09-01-98	1145	99801555	.9	4.9	--
400135074153901	290496	05-04-98	1050	99800662	.1	4.8	--
400210074192601	290127	04-27-98	1050	99800606	.1	5.0	--
400226074143101	290591	06-14-96	1435	99600613	.1	4.66	5.2
		02-10-97	1100	99700508	.1	5.1	--
400301074094601	291073	04-22-98	1115	99800590	.1	4.8	--
400339074122201	291131	08-09-99	1408	99900871	.2	5.1	5.2
400427074110701	290437	04-20-98	1050	99800589	.1	4.3	--

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Specific conduc-tance, lab (µS/cm) (90095)	Specific conduc-tance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	Temperature water (deg C) (00010)	Calcium, filtered (mg/L) (00915)	Magnesium, filtered (mg/L) (00925)	Potassium, filtered (mg/L) (00935)	Sodium, filtered (mg/L) (00930)	ANC, unfiltered, titrated to pH 4.5 lab (mg/L as $CaCO_3$) (90410)	ANC, unfiltered, field (mg/L as $CaCO_3$) (00410)	Chloride, filtered (mg/L) (00940)
395933074131201	01-13-97	--	128	6.9	13.0	--	--	--	--	--	--	--
395936074122901	12-08-97	201	187	6.3	12.4	5.54	2.54	2.53	19.1	--	--	34.5
395936074123901	06-02-98	96	98	3.9	14.4	1.14	2.26	2.35	10.6	--	--	18.0
395936074124001	12-01-97	--	130	0.8	12.6	2.88	2.73	2.14	9.0	--	--	16.6
395945074122201	12-17-97	235	221	6.7	12.5	5.43	2.53	2.22	30.6	--	--	53.3
395946074124901	06-02-98	144	143	7.4	13.6	1.45	2.28	2.72	18.5	--	--	30.9
395950074124801	06-03-98	162	162	3.2	14.9	4.28	3.37	5.41	15.0	--	--	25.2
395951074115701	09-01-98	230	235	4.2	12.7	3.30	2.89	3.40	26.1	--	--	42.6
395957074124801	06-04-98	170	172	6.7	12.5	6.16	3.08	2.22	16.0	--	--	27.2
395958074120101	09-02-98	111	120	.3	13.5	1.75	2.57	2.49	8.8	--	--	16.6
400002074125201	06-03-98	136	121	8.1	12.5	5.20	2.21	1.95	13.1	--	--	19.2
400009074114901	08-26-98	185	189	5.7	12.8	6.75	4.22	3.53	13.2	<1	--	24.0
400014074081601	09-09-98	56	56	2.8	14.2	.62	1.13	1.05	5.2	--	--	8.8
		55	--	--	--	.62	1.129	0.97	5.102	--		8.79
400037074193401	04-13-98	--	108	10.6	15.0	3.02	.605	.68	13.6	--	--	21.9
400040074121001	09-02-98	72	74	.3	13.3	.35	.807	3.01	4.9	--	--	7.1
400048074115301	08-25-98	77	79	10.7	12.7	.938	3.514	1.04	5.057	--	--	8.5
400057074121801	08-31-98	187	191	10.3	13.5	2.21	3.26	1.85	24.3	--	--	41.5
400059074120501	09-01-98	76	78	10.6	13.7	.80	3.37	2.44	4.2	--	--	8.2
400105074240601	04-29-98	21	19	--	13.3	.13	.339	.51	1.7	--	--	3.5
400112074123201	09-01-98	80	88	9.5	12.7	1.37	2.34	2.90	6.3	--	--	12.9
400135074153901	05-04-98	80	77	8.4	13.5	2.60	1.99	1.86	5.9	--	--	10.6
400210074192601	04-27-98	80	75	8.8	13.9	3.17	1.11	.77	7.9	--	--	13.3
400226074143101	06-14-96	44	44	8.7	12.6	.25	1.20	1.00	3.9	1	--	7.2
	02-10-97	--	46	8.5	11.7	--	--	--	--	--	--	--
400301074094601	04-22-98	93	94	6.1	11.4	.77	1.38	.92	12.4	--	--	17.2
400339074122201	08-09-99	56	53	10.2	11.5	1.19	1.11	1.08	5.7	3	2	8.6
400427074110701	04-20-98	--	78	7.0	12.3	1.13	.773	.63	7.7	--	--	12.1

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Silica, filtered (mg/L as SiO_2) (00955)	Sulfate, filtered (mg/L as SO_4) (00945)	Nitrogen, ammonia, filtered (mg/L as N) (00608)	Nitrogen, ammonia + organic, filtered (mg/I as N) ((00623)	Nitrogen, NO_2+NO_3 filtered (mg/L as N) (00631)	Nitrogen, nitrite, filtered (mg/L as N) (00613)	Phosphorus ortho, filtered (mg/L as P) (00671)	Carbon, organic, filtered (mg/L as C) (00681)	Aluminum, filtered (µg/L) (01106)
395933074131201	01-13-97	--	--	--	--	--	--	--	.50	--
395936074122901	12-08-97	6.4	27.6	<.020	--	1.49	<.010	.014	.60	1790
395936074123901	06-02-98	5.5	2.1	<.020	--	1.79	.015	<.010	.50	26
395936074124001	12-01-97	8.5	28.2	<.020	--	.202	<.010	.029	.40	1350
395945074122201	12-17-97	5.3	11.4	<.020	--	1.56	<.010	<.010	.40	93
395946074124901	06-02-98	5.3	1.4	.046	--	1.96	.015	.017	.50	29
395950074124801	06-03-98	5.3	13.3	.036	--	2.53	.023	.013	.70	159
395951074115701	09-01-98	--	22.2	.056	--	.423	<.010	.014	.40	--
395957074124801	06-04-98	4.9	20.3	<.020	--	1.23	<.010	<.010	.60	118
395958074120101	09-02-98	--	15.3	<.020	--	.312	<.010	<.010	.30	--
400002074125201	06-03-98	4.8	14.1	.026	--	1.66	.015	.012	.60	81
400009074114901	08-26-98	--	25.9	.079	--	3.23	.010	.013	.40	431
400014074081601	09-09-98	--	3.3	.036	--	.886	<.010	<.010	.30	--
	09-09-98	--	3.5	.026	--	.899	<.010	.010	.20	--
400037074193401	04-13-98	4.2	5.8	.037	--	.794	.013	.018	.50	--
400040074121001	09-02-98	--	13.5	<.020	--	<.050	<.010	<.010	.30	500
400048074115301	08-25-98	--	.2	.088	--	4.98	.011	.018	.20	--
400057074121801	08-31-98	--	.9	<.020	--	3.18	<.010	.013	.30	--
400059074120501	09-01-98	--	.1	.048	--	4.56	<.010	.013	.20	--
400105074240601	04-29-98	4.5	.4	.024	--	.065	<.010	.033	.20	--
400112074123201	09-01-98	--	.2	.038	--	3.01	<.010	.013	.30	--
400135074153901	05-04-98	5.4	4.0	.050	--	2.45	<.010	.015	.30	--
400210074192601	04-27-98	4.1	7.0	.036	--	.750	<.010	.011	--	--
400226074143101	06-14-96	5.0	.8	.020	<.20	1.10	<.010	<.010	--	24
	02-10-97	--	--	<.015	<.20	1.20	.020	<.010	--	--
400301074094601	04-22-98	7.2	1.8	.034	--	1.56	<.010	.021	--	--
400339074122201	08-09-99	4.0	2.4	<.020	<.10	1.11	<.010	<.010	.40	14
400427074110701	04-20-98	3.7	5.7	.059	--	.839	<.010	.010	.30	--

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Barium, filtered (µg/L) (01005)	Boron, filtered (µg/L) (01020)	Chromium, filtered (µg/L) (01030)	Cobalt, filtered (µg/L) (01035)	Copper, filtered (µg/L) (01040)	Iron, filtered (µg/L) (01046)	Lead, filtered (µg/L) (01049)	Manganese, filtered (µg/L) (01056)	Mercury, filtered (µg/L) (71890)
395933074131201	01-13-97	--	--	--	--	--	--	--	--	<.10
395936074122901	12-08-97	45.9	<16	--	<12.0	<1.0	180	<1.00	52.9	--
395936074123901	06-02-98	64.8	--	<1.0	1.86	<1.0	<10	<1.00	20.3	--
395936074124001	12-01-97	80.5	<16	--	<12.0	10.4	70	<1.00	41.5	--
395945074122201	12-17-97	49.7	<16	--	2.60	6.7	<10	<1.00	44.4	--
395946074124901	06-02-98	58.0	--	2.1	1.79	1.0	10	<1.00	25.5	--
395950074124801	06-03-98	34.1	--	2.7	3.80	<1.0	<10	<1.00	108	--
395951074115701	09-01-98	49.4	--	--	2.60	--	180	<1.00	34.3	--
395957074124801	06-04-98	74.9	--	1.3	10.6	<1.0	30	<1.00	68.2	--
395958074120101	09-02-98	43.6	--	--	4.70	--	<10	<1.00	29.5	--
400002074125201	06-03-98	47.9	--	1.8	2.90	<1.0	<10	<1.00	57.1	--
400009074114901	08-26-98	48.4	--	--	1.40	--	90	<1.00	29.5	--
400014074081601	09-09-98	30.6	--	--	<1.00	--	<10	<1.00	10.6	--
	09-09-98	30.7	--		1.00		<10	<1.00	10.8	--
400037074193401	04-13-98	--	--	--	--	--	40	--	--	--
400040074121001	09-02-98	154	--	--	<1.00	--	840	<1.00	17.6	--
400048074115301	08-25-98	76.4	--	--	<1.00	--	<10	<1.00	22.6	--
400057074121801	08-31-98	71.6	--	--	1.20	--	20	<1.00	22.4	--
400059074120501	09-01-98	72.0	--	--	2.00	--	20	<1.00	20.5	--
400105074240601	04-29-98	--	--	--	--	--	30	--	--	--
400112074123201	09-01-98	30.0	--	--	1.10	--	<10	<1.00	8.4	--
400135074153901	05-04-98	--	--	--	--	--	20	--	--	--
400210074192601	04-27-98	--	--	--	--	--	20	--	--	--
400226074143101	06-14-96	27.0	14	<1.0	<1.00	4.0	E3	<1.00	13.0	.20
	02-10-97	--	--	--	--	--	--	--	--	<.10
400301074094601	04-22-98	--	--	--	--	--	20	--	--	--
400339074122201	08-09-99	14.5	18	--	<7.00	--	80	--	12.1	--
400427074110701	04-20-98	--	--	--	--	--	180	--	--	--

Appendix 4. Concentrations of inorganic constituents in, and physical properties of, water samples from the Kirkwood-Cohansey aquifer system, southern New Jersey, 1997-99.—Continued

U.S. Geological Survey station number	Date (mm-dd-yy)	Mercury, filtered, amalgam pre-concentration (ng/L) (50287)	Nickel, filtered (µg/L) (01065)	Strontium, filtered (µg/L) (01080)	Zinc, filtered (µg/L) (01090)	Quality assurance data indicator code (99111)
395933074131201	01-13-97	--	--	--	--	--
395936074122901	12-08-97	238	--	30.2	<20	100
395936074123901	06-02-98	45.4	1.59	46.0	5	10
395936074124001	12-01-97	14.9	--	21.1	22	--
395945074122201	12-17-97	12.2	--	32.4	<20	10
395946074124901	06-02-98	45.5	4.63	15.8	5	--
395950074124801	06-03-98	.93	13.3	77.9	7	--
395951074115701	09-01-98	E.44	--	19.9	--	--
395957074124801	06-04-98	10.9	10.0	38.6	9	10
395958074120101	09-02-98	2.01	--	14.6	--	--
400002074125201	06-03-98	58.9	2.99	24.6	4	--
400009074114901	08-26-98	1.27	--	30.6	--	--
400014074081601	09-09-98	E.25	--	9.69	--	30
400014074081601	09-09-98	E.36	--	9.50	--	30
400037074193401	04-13-98	--	--	19.2	--	--
400040074121001	09-02-98	E.14	--	22.3	--	--
400048074115301	08-25-98	.81	--	16.1	--	--
400057074121801	08-31-98	.57	--	14.6	--	--
400059074120501	09-01-98	<.10	--	13.9	--	--
400105074240601	04-29-98	--	--	2.74	--	--
400112074123201	09-01-98	<.22	--	5.50	--	--
400135074153901	05-04-98	--	--	27.1	--	--
400210074192601	04-27-98	--	--	21.0	--	--
400226074143101	06-14-96	--	2.00	5.00	3	--
	02-10-97	--	--	--	--	--
400301074094601	04-22-98	--	--	12.4	--	--
400339074122201	08-09-99	--	--	11.4	E15	100
400427074110701	04-20-98	--	--	10.9	--	--

Glossary

A

actinides A series of chemical elements, beginning with thorium and extending through uranium and the man-made elements with atomic masses greater than 92, that are grouped together because they may contain electrons in the 5f orbit. These elements have the highest atomic masses of all the elements and exceed the critical mass of 209 atomic mass units, the largest stable nucleus; therefore, they undergo radioactive decay to achieve a more stable nuclear configuration.

activity The amount of radioactivity in a given volume of material such as water or air. For water, activity generally is expressed in units of picocuries per liter (pCi/L) (see definition below).

alpha radiation Alpha radiation is a particle, consisting of two protons and two neutrons, spontaneously emitted from the nucleus of a subset of radioactive elements (mostly the heaviest elements) during radioactive decay. Alpha radiation is ionizing radiation, meaning that it strips electrons from adjacent atoms as it passes. Alpha radiation cannot penetrate skin; therefore, an alpha-particle-emitting radionuclide must be ingested in order to contact internal tissue. Because of their large size, alpha particles are likely to collide with cell tissue, causing tissue damage. An accumulation of tissue damage in the cell nucleus may lead to cell mutation and potential cancer formation.

alpha radioactivity, gross A laboratory measurement of total alpha radioactivity emitted by a sample. This measurement includes alpha-particle radioactivity emitted by isotopes of naturally occurring uranium, thorium, radium, and progeny such as polonium, as well as alpha-particle activity emitted from isotopes of plutonium or americium, which are not naturally occurring. Long-term measurement, usually conducted 20 to 30 days after sample collection, determines only the amount of alpha-particle radiation present in the sample from long-lived radionuclides, such as naturally occurring uranium-238 or radium-226, or the isotopes of plutonium and americium. Short-term measurement, on the order of hours or a few days after sample collection, determines the amount of alpha-particle radiation present in the sample from some short-lived radionuclides.

alpha radioactivity count An analytical technique used to determine total alpha radioactivity emitted by a chemically purified sample that contains only one radionuclide of interest. The alpha-particle activity is usually counted in a low-background, gas-proportional counter.

alpha recoil A process whereby kinetic energy is imparted to the product nuclide during alpha decay in the opposite direction from the emitted alpha particle, thereby damaging the crystal lattice surrounding the atom and potentially ejecting the atom or allowing it to break free from the solid structure. If the product atom is not ejected directly through recoil, it may eventually be preferentially dissolved at the locus of crystal lattice damage. The end result is the same: a substantial percentage of product radionuclides is mobilized into pore space that is potentially water-filled. Because the mass of a beta particle is so much smaller than that of an alpha particle, recoil during beta decay does not result in nearly as large an amount of radionuclide ejection as does alpha recoil.

alpha spectrometry An analytical technique used to determine the amount of alpha radiation emitted at specified energy levels, thus, allowing determination of individual radionuclide concentrations (from known energy levels of alpha particles unique to each radionuclide). The gridded-pulse-ionization chamber is the most sensitive and most commonly used instrument.

B

beta radiation Beta radiation is a particle, consisting of an electron, spontaneously emitted from the nucleus of a subset of radioactive elements during radioactive decay. Beta radiation, like alpha radiation, is ionizing radiation, meaning that it strips electrons from adjacent atoms as it passes. Beta radiation can only penetrate the surface layer of skin; therefore, a beta-particle-emitting radionuclide must be ingested in order to contact internal organs or tissues. An accumulation of tissue damage in the cell nucleus may lead to cell mutation and potential cancer formation.

beta radioactivity, gross A laboratory measurement of total beta radioactivity emitted by a sample. This measurement includes radioactivity emitted by naturally occurring progeny of uranium and thorium, such as radium-228 and lead-210, and many other naturally occurring beta-particle-emitting radioactive isotopes.

beta radioactivity count An analytical technique used to determine total beta radioactivity emitted by a chemically purified sample that contains only one radionuclide of interest. The beta-particle activity is counted in a low-background, gas-proportional counter.

C

contaminant As defined in the Safe Drinking Water Act, any physical, chemical, biological, or radiological substance or matter in water.

counting error or counting uncertainty Because radioactive elements decay randomly at any given instant, there is associated random variability or uncertainty with any measurement of radioactivity. The counting error comprises a major portion of the reported precision estimate (see definition below) of any analysis for radioactivity.

D

decay product of radiation The isotope remaining after radioactive decay.

G

gamma radioactivity Gamma radiation is a "packet" of energy, also known as a photon or photon particle, spontaneously emitted from the nucleus of most radioactive elements during radioactive decay. Gamma radiation is ionizing radiation, meaning that it strips electrons from adjacent atoms as it passes. Unlike alpha and beta radiation, gamma radiation can penetrate through skin into internal tissues. An accumulation of tissue damage in the cell nucleus from gamma radiation may lead to cell mutation and potential cancer formation. Many of the products of Ra-224 emit gamma radioactivity.

Geographic Information Retrieval and Analysis (GIRAS) Data files from the U.S. Geological Survey; GIRAS files contain land use/land cover information for areas in the United States, including attributes for land use, land cover, political units, hydrologic units, census and county subdivisions, federal landownership and State landownership. These datasets are available to the public in both map and digital form.

H

Hydrologic Unit Code (HUC) Numerical classification code for a drainage basin, ranging in scale from regional (2-digit code) to subwatershed (14-digit code). The scale of the drainage basins used in this report is the watershed unit, which is identified by an 11-digit code.

I

Integrated Terrain Unit (ITU) Mapping It is the process of adjusting terrain unit boundaries so that there is increased coincidence between the boundaries and occurrences of interdependent terrain variables such as hydrography, geology, physiography, soils, and vegetation units.

isotope One of various forms of a single element differing in the number of neutrons in the nucleus. Unstable isotopes of an element decay through the emission of a form of radioactivity.

L

Laboratory Reporting Level (LRL) A minimum concentration, pre-determined by laboratory personnel before a project begins as a level of detection that can be routinely achieved. It generally is based on typical radioactivity counting results under routine operating conditions in a given sample matrix using known standards (American Society for Testing and Materials, 1999), and generally is defined by the requirement that the counted radioactivity must differ from the background count by six or more times than the standard deviation of the background count. The LRL for the individual radionuclide concentrations determined in this study was 0.5 to 1 pCi/L. Matrix interference, typically in mineralized water samples or in samples with unusual compositions, may result in difficulty in sample analysis that results in detection capability limited even above the LRL.

M

matrix interference The presence of a compound in a sample which in some manner inhibits instrument response during analysis of some other (target) compound.

Maximum Contaminant Level (MCL) The maximum permissible level of a contaminant in water that is delivered to the free-flowing outlet of the ultimate user of a public water-supply system (except in the case of turbidity). The MCL is an expression of the acceptable health risk as a result of ingesting a unit of water containing a harmful substance (exposure). For radionuclides, health risk is developing or dying from cancer. The MCLs relevant to this study are 5 pCi/L for the sum of Ra-226 and Ra-228 (termed "combined radium") and 15 pCi/L for gross alpha-particle activity (including Ra-226 but excluding radon and uranium).

Minimum detectable concentration, sample-specific (SSMDC) The minimum quantity of a specific radionuclide detectable by the counting instrument for any given sample for a given analysis, defined by instrument operating conditions and variation in background radiation at the time of analysis. This value is computed individually for each radionuclide analysis on the basis of instrument operating conditions at the time. The computation is repeated for each individual sample analysis because of the variability in background radioactivity over time. In many cases, the SSMDC is less than the LRL (see definition above), in some cases, such as in a complex sample matrix, it may exceed the LRL. Because many of the analytical techniques used in this study are considered to be in the research phase of development, the LRL is referred to in this report when a sample result is evaluated, unless otherwise specified.

N

negative result A result from a radiation measurement (count) of a sample over a fixed interval of time where the measured radioactivity from the sample is less than the long-term average background radiation reported routinely by the instrument. In practical terms, the result is less than the sample-specific minimum detectable concentration and the LRL (see definitions above), and, therefore, indicates that radioactivity was not detected.

P

picocurie per liter The unit of measurement that expresses the amount of radioactivity. In water, one picocurie per liter (pCi/L) equals 2.2 radioactive disintegrations per minute per liter of water.

Precision Estimate (PE) or uncertainty A calculated measure of uncertainty of the laboratory analysis. The precision estimate for radionuclides includes many sources of error, some of which are unique to radionuclides. Because radioactive elements decay randomly at any given instant, any measurement of radioactivity has an associated uncertainty (also called "counting error") independent of, and in addition to, other laboratory sources of analytical uncertainty. Uncertainty can be reported in a variety of ways; the most common include (1) the sum of the laboratory and counting uncertainty, known as the "combined standard uncertainty" (CSU), or, less frequently, the "total propagated uncertainty", and (2) a "counting error" or "counting uncertainty" only. Since about 1980, most laboratories refer to the former as the "precision estimate" and the latter as the "counting uncertainty". There is a 67-percent or a 95-percent probability that the true value of the radionuclide concentration is within one or two standard deviations, respectively, of the radioactivity count plus or minus the precision estimate or counting uncertainty. The precision estimate or uncertainty term generally is smaller than the measured value except when the measured value is low (near the LRL (see definition above)). The uncertainty associated with the various radionuclide concentrations determined by the measurement techniques presented in this report are given as the two-standard-deviation precision estimates, unless otherwise indicated.

R

radionuclide An isotope (see definition above) of an element that emits radiation.

radium Radium is a naturally occurring radioactive element. There are four isotopes of natural radium: Ra-228, Ra-226, Ra-224, and Ra-223. Each results directly or indirectly from radioactive decay of either uranium or thorium (see definition below). Ra-226 has the longest half-life of the radium isotopes (1,620 years). Ra-224 has the shortest half-life of the radium isotopes (3.6 days).

T

thorium Thorium is a naturally occurring radioactive element. There are six isotopes of natural thorium: Th-234, Th-232, Th-231, Th-230, and Th-228, and Th-227. Th-232 is by far the most common, has the longest half-life

(14.1 billion years), and is the least radioactive (per unit mass). It is the initial member of the radioactive decay series that bears its name.

U

uranium Uranium is a naturally occurring radioactive element. It occurs naturally in rocks, soil, air, and water. There are three isotopes of natural uranium: U-238, U-235, and U-234. U-234 is the most radioactive (per unit mass). U-238 is by far the most common, has the longest half-life (4.5 billion years), and is the least radioactive (per unit mass). It is the initial member of the radioactive decay series that bears its name.

W

watershed The area that drains (contributes flow) to a specified surface-water body.

For additional information, write to:

U.S. Geological Survey
Water Resources Division
New Jersey District
Mountain View Office Park
810 Bear Tavern Rd., Suite 206
West Trenton, NJ 08628

or visit our Web site at:
http://nj.water.usgs.gov/