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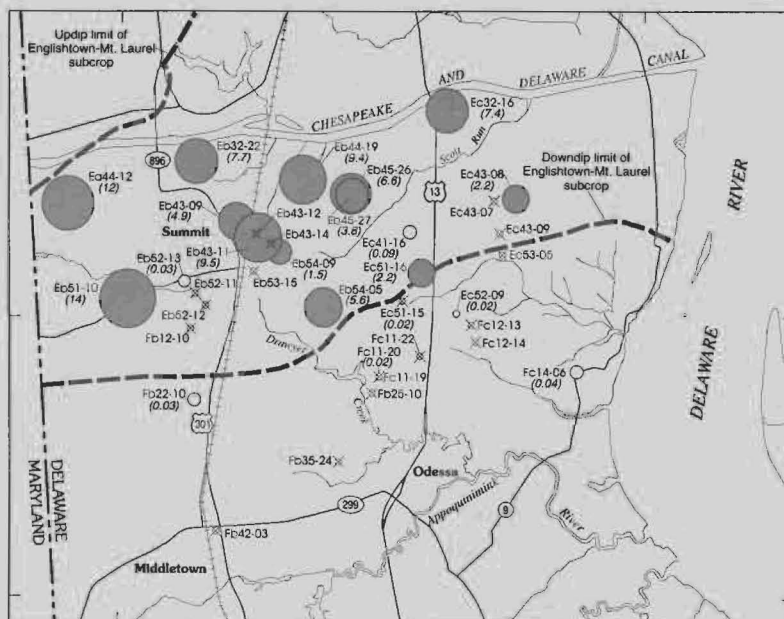
## REPORT OF INVESTIGATIONS NO. 52

# QUALITY AND GEOCHEMISTRY OF GROUND WATER IN SOUTHERN NEW CASTLE COUNTY, DELAWARE

by

L. Joseph Bachman and Matthew J. Ferrari

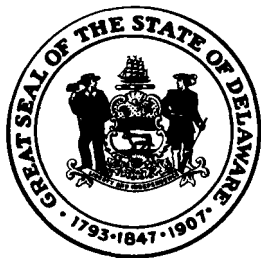
U.S. Geological Survey



Prepared by the United States Geological Survey  
under the Joint-Funded Program with  
the Delaware Geological Survey

University of Delaware  
Newark, Delaware

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# QUALITY AND GEOCHEMISTRY OF GROUND WATER IN SOUTHERN NEW CASTLE COUNTY, DELAWARE

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## ABSTRACT

Water samples were collected from 63 wells in southern New Castle County to assess the occurrence and distribution of dissolved inorganic chemicals in ground water. Rapid growth is projected for the study area, and suitable sources of potable drinking water will need to be developed. The growth in the study area could also result in degradation of water quality. This report documents water quality during 1991-92 and provides evidence for the major geochemical processes that control the water quality.

Ground water in the study area is produced from unconsolidated clastic sediments of the Atlantic Coastal Plain. The stratigraphic units have been grouped into three hydrostratigraphic divisions: the Magothy and Potomac aquifer system, the Englishtown-Mt. Laurel aquifer system, and the Rancocas aquifer. These units are covered by surficial deposits of the Columbia Formation whose thickness ranges from less than 10 ft to more than 60 ft. The Magothy and Potomac aquifer system is entirely confined in the study area. The Englishtown-Mt. Laurel aquifer system and the Rancocas aquifer are confined in their down-dip extent and function as an unconfined surficial aquifer with the Columbia Formation in their up-dip extent. The aquifers are composed primarily of quartz sand; the Magothy and Potomac has abundant lignite and pyrite, and the Englishtown-Mt. Laurel and Rancocas usually contain high, but uneven distributions, of glauconite, and calcium carbonate shell fragments as calcite and aragonite.

Ground-water flow paths are only partially documented in this area. Flow in the Magothy and Potomac is generally from north to south. Sundstrom and others (1967) reported that there is some northward flow in the Magothy and Columbia to the Chesapeake and Delaware Canal (C&D). Analysis of water levels in the Potomac aquifer system south of the C&D Canal suggests that there is some flow in the Potomac toward localized pumping centers to the north. Flow in the surficial unconfined aquifers is from local drainage divides to perennial streams. Flow paths in the confined parts of the Englishtown-Mt. Laurel and Rancocas aquifers are poorly documented.

Ground-water in the study area shows considerable evidence of natural and anthropogenic chemical degradation, but in most cases the quality is suitable for use as drinking water. In confined aquifers, dissolved iron generally exceeds the Secondary Maximum Contaminant Level (SMCL) of 300 µg/L (micrograms per liter) set by the U.S. Environmental Protection Agency (USEPA). In unconfined aquifers, iron concentrations are low, mostly below 300 µg/L. Elevated nitrite plus nitrate-nitrogen (>0.4 mg/L) concentrations are most commonly found in unconfined aquifers; in confined aquifers most samples have nitrite plus nitrate-nitrogen concentrations of less than the detection limit of 0.02 mg/L. Of 63 samples collected, 27 samples exceeded the SMCL for iron, and three samples exceeded the USEPA Maximum Contaminant Level (MCL) of 10 mg/L for nitrite plus nitrate-nitrogen. Nitrate-nitrogen concentrations for 20 of the 63 samples were above 0.4 mg/L, however, which indicates the water composition was affected by human activity.

Twenty-one samples were collected for analysis of dissolved radon. Fourteen of 15 samples from the Englishtown-Mt. Laurel aquifer system and Rancocas aquifer exceeded a proposed USEPA MCL of 300 picocuries per liter (pCi/L). Radon did not exceed 200 pCi/L in the six samples from the Magothy and Potomac aquifer systems.

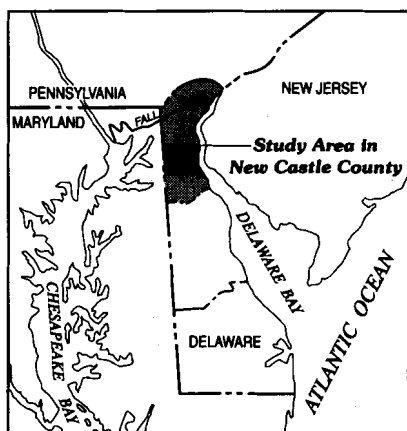
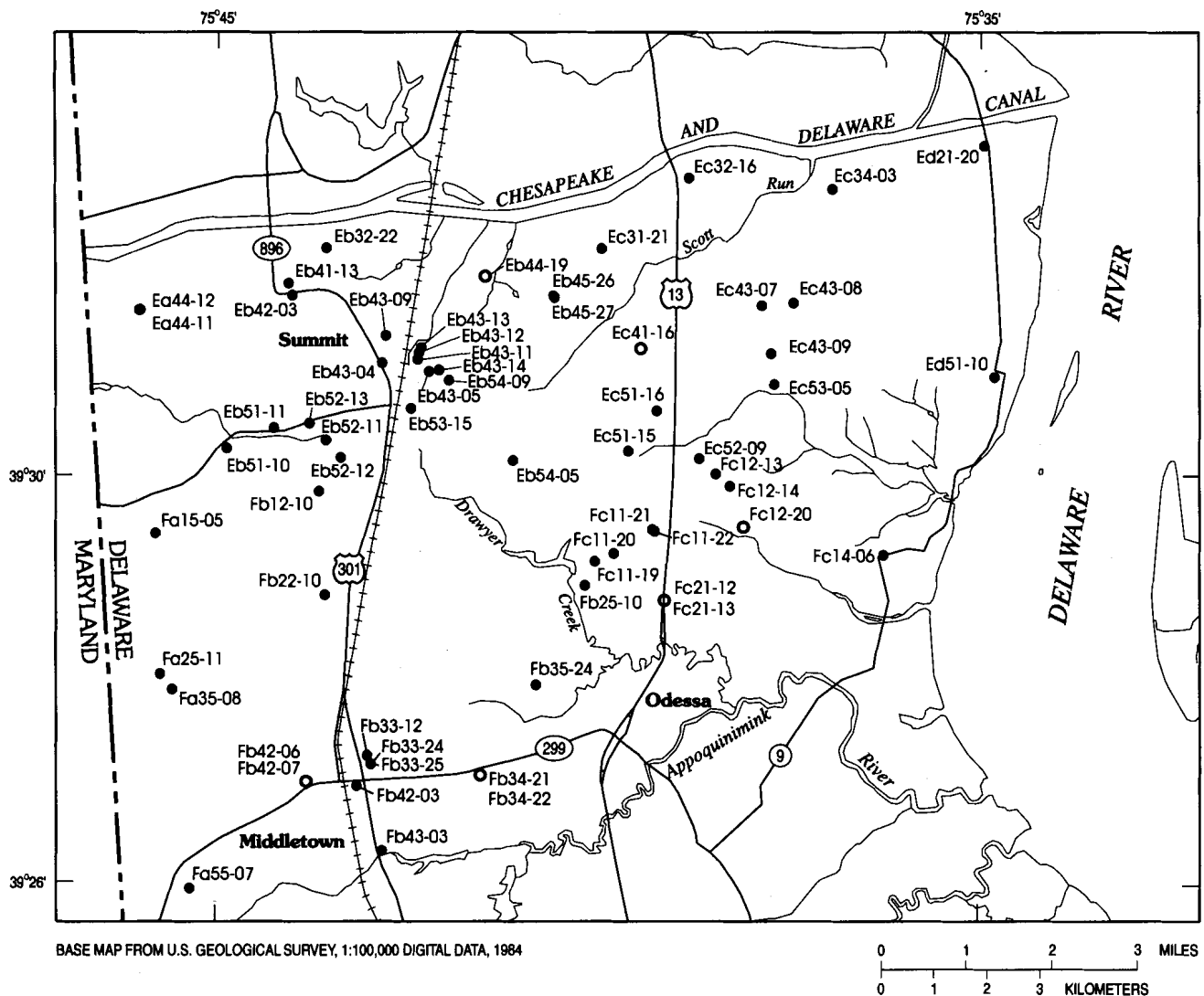
The occurrence and distribution of dissolved chemical constituents in aquifer waters of the study area is consistent with geochemical processes documented by others in nearby parts of the mid-Atlantic Coastal Plain. Relations among dissolved iron, pH, bicarbonate, and dissolved oxygen indicate that the concentration of iron is most likely controlled by dissolution and precipitation of ferric oxyhydroxides and dissolution of glauconite in anoxic parts of the aquifers. The relations among nitrate, pH, bicarbonate, dissolved oxygen, and dissolved iron indicate that the chemical conditions under which nitrate-nitrogen is found are the exact opposite of those that favor mobilization of iron.

## INTRODUCTION

New Castle County is undergoing rapid residential, industrial, and commercial growth. From 1995 to 2020, the population in that part of the county south of the C&D Canal (Fig. 1) is expected to increase by more than 153 percent, (from 21,400 to 32,800 people) with a corresponding increase of more than 169 percent (from 6,941 to 11,740) in the number of housing units (Delaware Population Consortium, 1995). This area has the lowest population density in the county, 113 people per square mile, as compared to a county-wide total of 1,067 people per square mile (Delaware Population Consortium, 1995), and it has been an area of active and continued expansion of commercial, industrial, and residential development.

Southern New Castle County relies exclusively on ground water for water supply because surface-water resources are limited. The expansion of ground-water supply systems associated with population growth and development could cause declining water-levels and water-quality degradation. Knowledge of the distribution of potable ground-water and of the geochemical controls on water quality is essential to develop and manage dependable ground-water supplies in the area south of the C&D Canal.

Both natural processes and human activities can degrade ground-water quality. Several naturally occurring substances in ground water cause localized and possibly extensive water-quality problems. The most common degradation from natural sources is high concentrations of dis-



#### EXPLANATION

- Fb35-24 ● Municipal or domestic water-supply well and well number
- Fb42-06  
Fb42-07 ○ Observation well and well numbers (Two numbers next to a well symbol indicate that the site is a two-well nest.)

Figure 1. Map showing location of study area and wells sampled during study.

solved iron and radon. Fertilizer use, on-site wastewater disposal, spray irrigation of treated wastewater, and the use of salt to de-ice roads could all affect ground-water quality. Increased withdrawals of water from aquifers near brackish water bodies, such as the Delaware River or the C&D Canal, could reverse head gradients and cause brackish water to enter the aquifers.

USEPA has established regulatory limits for drinking water from public water supplies under the Safe Drinking Water Act of 1974 as amended in 1986 (USEPA, 1992; Public Law 99-339). "Maximum Contaminant Levels" (MCLs) are enforceable standards set as close as possible to levels that will not result in adverse health effects to persons drinking the water. "Secondary Maximum Contaminant

Levels" (SMCLs) are established as guidelines for determining desirable levels of constituents that could affect the esthetic quality of the water. MCLs and SMCLs apply only to public water-supply systems, but they also provide guides for the potability of drinking water from wells used for private water supply.

Earlier studies of wells in the study area and surrounding regions indicate that nitrate and iron may be the most common ground-water quality problems in the study area (Rima and others, 1964; Otton and Mandle, 1984; Hamilton and others, 1991). High concentrations of radon and possibly sodium may also be water-quality problems. Nitrate from septic systems and fertilized agricultural areas can cause water-quality problems in the surficial aquifer and subcrop areas of confined aquifers. Concentrations of nitrite plus nitrate-nitrogen or of nitrate-nitrogen above the MCL of 10 mg/L are commonly reported in the Delmarva Peninsula (Miller, 1972; Robertson, 1979; Bachman, 1984; Denver, 1986, 1989; Andres, 1991; Hamilton and others, 1993). High nitrate concentrations are known to cause methemoglobinemia in infants (USEPA, 1992). The USEPA MCL for nitrate-nitrogen is 10 mg/L (USEPA, 1992). Concentrations of nitrate-nitrogen higher than those found naturally, about 0.4 mg/L according to Hamilton and others (1993), in ground water discharging to streams may also contribute to eutrophication of lakes, ponds, and estuaries.

Iron-bearing minerals are found throughout the aquifers of the study area, and concentrations of dissolved iron above the SMCL of 300  $\mu\text{g/L}$  (USEPA, 1992) are commonly reported where reducing conditions are present. Manganese is also commonly associated with the iron-bearing minerals, and manganese concentrations above the USEPA SMCL of 50  $\mu\text{g/L}$  (USEPA, 1992) are common. Iron and manganese concentrations above the SMCL may result in objectionable tastes and odors of the water and may also result in staining of laundry and plumbing fixtures. Dissolved radon gas was detected in water from several wells screened in aquifers that contain glauconite. Radon is a known carcinogen, and high concentrations in water could degas and result in exposure to those using the water (USEPA, 1986, 1991). In addition to radon, water from glauconitic aquifers may contain elevated concentrations of dissolved sodium ( $>20$  mg/l) because of cation-exchange reactions (Chapelle and Knobel, 1983; Spoljaric, 1986).

Mapping the distribution of major chemical constituents and understanding geochemical controls on water chemistry are essential for identifying prospective areas for future water supply and to prudently develop the ground-water resources of the county. In response to the need for a better understanding of ground-water quality in the study area, the Delaware Geological Survey (DGS) and the U.S. Geological Survey (USGS) began this cooperative study in 1991. This report presents the results of that study.

### **Purpose and Scope**

This report describes the occurrence and distribution of selected inorganic chemical constituents in the principal aquifers underlying that part of New Castle County, Delaware, south of the C&D Canal and north of Appoquinimink River (Fig. 1). The report also identifies geochemical controls on the quality of ground water in

these aquifers. The occurrence and distribution of nitrogen, iron, and radon are described in relation to the MCLs and SMCLs established by USEPA. The report is based on water-quality samples collected by the U.S. Geological Survey during 1991-92 from 63 water-supply and observation wells. The report also describes the areal distribution of limitations on ground-water use in the study area because of poor water quality.

### **Description of Study Area**

Southern New Castle County lies wholly within the Atlantic Coastal Plain, which extends from Cape Cod, Massachusetts, to central Georgia. The study area includes approximately 75 square miles in the northern portion of the Delmarva Peninsula (Fig. 1). The study area is bounded on the north by the C&D Canal, on the south by the Appoquinimink River, on the east by the Delaware River, and on the west by the Delaware-Maryland state line. Topography is relatively flat. Land surface elevations range from sea level near the Delaware River to about 70 feet (ft) above sea level along the drainage divide between the Delaware River and the Chesapeake Bay.

### **Acknowledgments**

This study was conducted under the Joint-Funded Program between the DGS and the USGS. Staff of the DGS, under the supervision of Robert R. Jordan, State Geologist, provided drilling and well logging services. A. Scott Andres and John H. Talley of DGS, and Scott W. Phillips and Robert J. Shedlock of the USGS reviewed the manuscript. Tim Auer and Jean Hyatt of the USGS drafted the figures.

The authors thank the many private citizens, companies, and government agencies who provided data or access to data collection during this study. Assistance in obtaining records on existing wells was provided by Kathleen R. Butoryak and A. Scott Andres of the DGS, R. Peder Hansen and Thomas G. Russell of the Water Resources Agency of New Castle County, and Stewart E. Lovell and John T. Barndt of the Delaware Department of Natural Resources and Environmental Control. Available chemical analyses of public water-supply systems were provided by Edward G. Hallock of the Delaware Department of Health and Social Services, Division of Public Health. Tidewater Utilities, Inc. and the Town of Middletown gave us permission to sample several of their public-supply wells, and the U.S. Army Corps of Engineers gave permission to drill observation wells on Federal property. Thanks are also given to the Delaware Department of Transportation for giving permission to drill on highway rights-of-way in the study area. Finally, appreciation is extended to all of the homeowners in the study area who allowed us to sample their private wells.

### **METHODS OF STUDY**

The chemistry of water in the principal aquifers was characterized initially by reviewing and compiling previously published information on water quality, rock mineralogy, and ground-water flow. This initial characterization was supplemented with related information from areas adjacent to the study area.

Computer and paper files of the USGS, as well as the files of the DGS, Delaware Department of Natural Resources and Environmental Control (DNREC), Water Resources Agency for New Castle County (WRANCC), and the Public Health Division of the Delaware Department of Health and Social Services were used to locate existing wells suitable for sampling. Wells were selected to provide the best available coverage of the aquifers in the study area. Fifty-one existing wells were found in this manner and sampled. An additional twelve wells were installed by the DGS where areal coverage was incomplete. The locations of these wells are shown in Figure 1.

Water level data could not be collected from the majority of existing wells in the study area because they are completed with jet pumps and have closed, pressurized plumbing systems. The incomplete areal coverage of the wells from which water level data were collected made it difficult to adequately interpret flow paths within the aquifers in the study area. Thus, all descriptions of ground-water flow directions are inferred from previously published work.

Water samples were collected for chemical analysis during August-September 1991, June 1992, and November 1992. The sampling methods used are outlined in the *National Handbook of Recommended Methods for Water-Data Acquisition* (U.S. Geological Survey, 1977). Samples were collected by means of the pumps installed in existing wells and a small-diameter, battery-powered positive-displacement submersible pump in observation wells. The wells were purged until a minimum of three casing volumes of water had been pumped, or until pH, specific conductance, and temperature stabilized. Samples were filtered through cellulose nitrate membrane filters with 0.1 micrometer ( $\mu\text{m}$ ) pore diameter. Analysis of the filtered samples represents an estimate of the concentration of dissolved constituents in ground water. The sample aliquot for analysis of cations and iron and aluminum was acidified with 1 milliliter (ml) of reagent-grade nitric acid per 250 ml of sample. The aliquot for the analysis of nitrogen species (nutrients) was filtered, chilled, and treated with 0.5 ml of mercuric chloride solution per 125 ml of samples to prevent biological activity from changing the nutrient composition of the water sample. All samples were chilled on ice to 4° to 8°C and shipped by overnight mail to the USGS Florida District Quality of Water Service Unit (FQWSU) in Ocala, Florida, where the chemical analyses were performed.

Dissolved oxygen, pH, alkalinity, specific conductance, and water temperature were all measured in the field using methods described by Fishman and Freidman (1985). Meters used for field analyses were calibrated at least daily. Concentrations of major cations, iron, manganese, and aluminum were determined using atomic absorption spectrometry, and anions were analyzed by ion chromatography (Fishman and Freidman, 1985). Ammonia plus organic nitrogen was determined by Kjeldahl method (Fishman and Freidman, 1985). Nitrite plus nitrate-nitrogen was determined by the cadmium reduction method (Fishman and Freidman, 1985). Because nitrate-nitrogen is generally stable under conditions found in the aquifer, and because nitrite concentrations form a very small percentage of the concentration of nitrite plus nitrate-nitrogen, results of the nitrite plus nitrate-nitrogen analysis were considered to be

roughly equivalent to nitrate-nitrogen concentration. The term "nitrate-nitrogen" will be used to describe the results of analyses for nitrite plus nitrate nitrogen.

Quality control and quality assurance procedures used by the FQWSU laboratories are described by Freidman and Erdman (1983). In addition, during November 1992, replicate samples were collected in the field and shipped to the laboratory to be analyzed as regular samples. The precision of chemical analyses as determined by these field replicates was generally similar to precision values published by Fishman and Freidman (1985) for the analytical methods. Data from complete chemical analyses were reviewed to assure that the ionic mass balances were within 10 to 20 percent and that historical analyses, if available, were roughly consistent with analyses from this study.

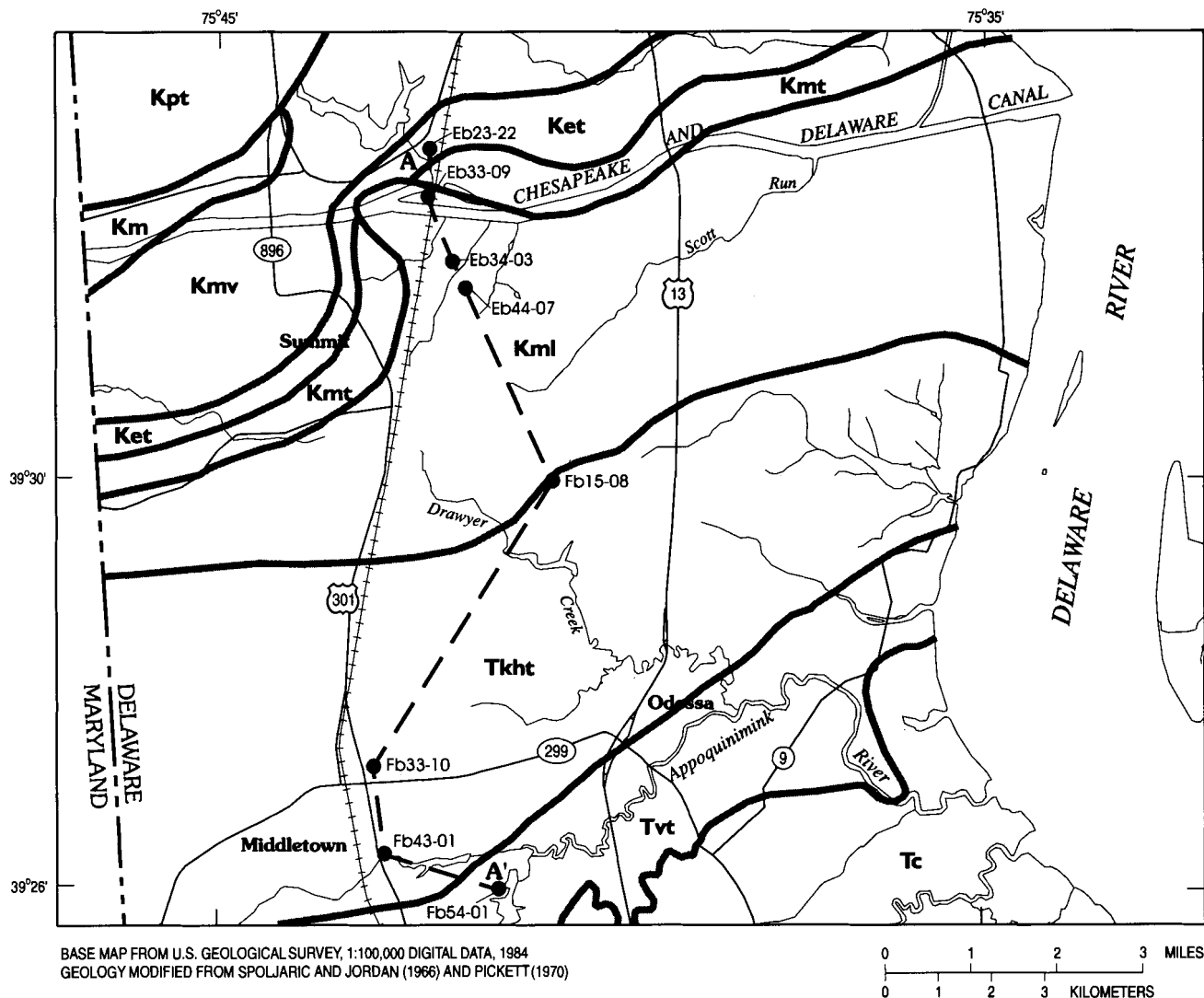
Results of the chemical analyses are stored on the National Water Information System (NWIS) data base of the USGS. Results were retrieved from the data base and analyzed with the SPSS statistical package (SPSS, Inc., 1986) and the SAS system (SAS Institute, 1989).

## GEOHYDROLOGIC FRAMEWORK

An analysis of ground-water quality in the Delmarva Coastal Plain by Hamilton and others (1991) demonstrated that many of the lithostratigraphic units in the sedimentary sequence can be grouped into informal hydrostratigraphic divisions (aquifer systems) with similar water quality. This approach will be used in this report, although the divisions used here will be slightly different from those of Hamilton and others (1991). The divisions presented here take into account local variations in lithology and ground-water flow, rather than taking into account the perspective of the entire Delmarva Peninsula. The areal extent of the hydrostratigraphic divisions, and the vertical relations among the divisions are shown in the map and cross section in Figures 2 and 3.

### Regional Configuration of Aquifer Systems

Ground water in the study area flows in unconsolidated sands and silty clays that are part of the Atlantic Coastal Plain. The crystalline basement rocks slope seaward and are overlain by seaward-thickening deposits of unconsolidated sediments (Cushing and others, 1973). Thickness of the deposits within the study area ranges from approximately 700 ft at the C&D Canal to approximately 1,600 ft at the Appoquinimink River (Sundstrom and Pickett, 1971). The depositional environments range from fluvial (Potomac Formation), 60 to 80 percent of the sedimentary thickness, through marginal-marine (Magothy Formation), to marine (Matawan Group, Mt. Laurel Formation, Rancocas Group, and Calvert Formation) (Pickett, 1970; Spoljaric, 1976). Ages range from Early Cretaceous to Miocene (Table 1). Fluvial deposits of the Columbia Formation (Pleistocene) comprise the surficial sands and gravels that unconformably overlie the older formations and form the upper part of the water table or unconfined aquifer system. Although the Columbia Formation is a very important part of the aquifer systems investigated, it was not considered as a regional aquifer system as part of this study. Major emphasis was placed on the deeper portions of the unconfined aquifers and on the confined aquifers.



## EXPLANATION

### FORMATIONS :

**Kpt** Potomac  
**Km** Magothy  
**Kmv** Merchantville

**Ket** Englishtown  
**Kmt** Marshalltown  
**Kml** Mt. Laurel

**Tkht** Hornerstown  
**Tvt** Vincentown  
**Tc** Calvert

————— Geologic contact

A — — — — A' Line of geologic section  
(Shown in Figure 3)

Figure 2. Subcrop geologic map of study area.

Confined aquifers occur within the Potomac, Magothy, Englishtown, Mt. Laurel, Hornerstown, and Vincentown formations. Surficial deposits of the Columbia Formation blanket most of the area and form a locally productive water-table aquifer that provides recharge to underlying confined aquifers and base flow to streams. Distinct differences in lithology and water chemistry are found between the aquifers because the sediments comprising each were deposited in different depositional environments.

### Magothy and Potomac Aquifer System

Unconsolidated sediments of the Potomac Formation overlie the crystalline basement. Sands and gravels within the Potomac function as aquifers which are not heavily used in the study area at this time. Ground water in the Potomac Formation shares many chemical characteristics with ground water in the Magothy Formation which unconformably overlies the Potomac. These formations are mineralogically distinguished from overlying formations by lack of glauconite and calcareous material. In the study area,



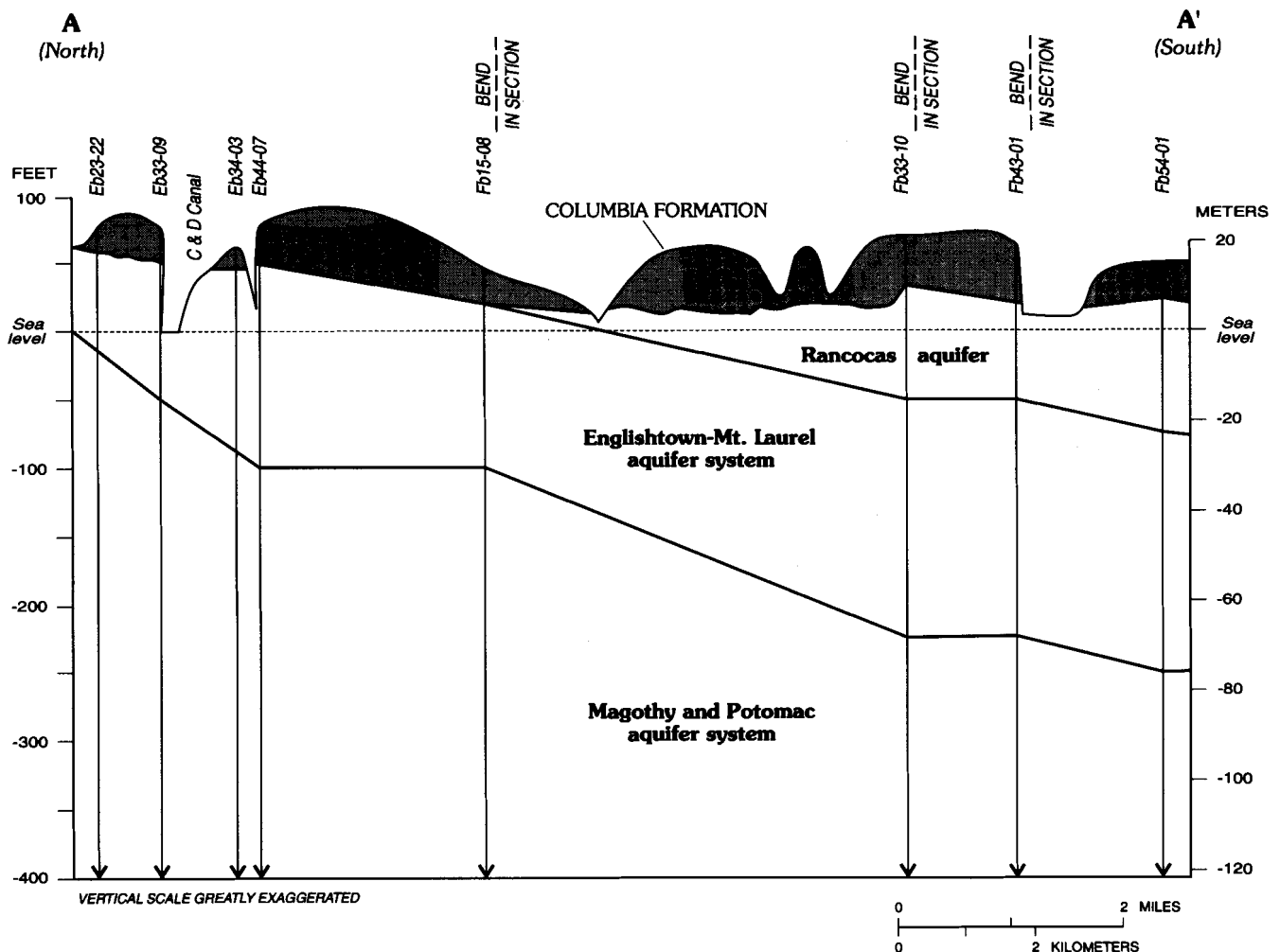


Figure 3. Cross section of trace A-A' showing hydrostratigraphic divisions of the subcrop geology, as shown in Figure 2.

both of these units contain deep confined aquifers. On the basis of relations observed in other parts of the Delmarva Peninsula, some hydraulic connections between aquifers in these formations occur (Hamilton and others, 1991). The chemical environment in these units is anoxic, and iron-bearing minerals such as pyrite and ferric oxyhydroxides are common. Hamilton and others (1991) grouped these units together as the "lower confined aquifers" hydrostratigraphic division, which in this report is referred to as the Magothy and Potomac aquifer system.

The unconsolidated sedimentary rocks of the Potomac Formation are nonmarine in origin and were deposited in a fluvial, or deltaic, environment (Marine and Rasmussen, 1955). Consequently, sands and clays tend to be discontinuous both horizontally and vertically. The sands and gravels, which function as aquifers, are quartzose and contain some lignite and feldspar. Thin layers of pipelike concretions of limonite cementation are also common (Sundstrom and Pickett, 1971; Jordan, 1983). Pyrite occurs in these formations and has been reported in the correlative Potomac Group in nearby parts of Maryland (Overbeck and Slaughter, 1958; Otton and Mandle, 1984). The Potomac Formation subcrops beneath the Columbia Formation north of the Chesapeake Canal and is overlain by the Magothy Formation in the study area. The Potomac thickens in a

downdip direction from 0 ft at the Fall Line to more than 8,000 ft along the Atlantic Coast in southeastern Delaware and Maryland (Hamilton and others, 1991). Within the study area, the thickness of the Potomac ranges from approximately 600 ft at the C&D Canal to approximately 1,200 ft at the Appoquinimink River south of Middletown (Sundstrom and Pickett, 1971). Utilization of the Potomac aquifers south of the C&D Canal has been limited due to the availability of adequate ground water from shallower aquifers (Talley, 1976). However, in anticipation of growth and development in the study area, there has been a considerable amount of test drilling and ground-water exploration in the Potomac during the past year and it is anticipated that the Potomac will be used increasingly for public water supplies.

The Magothy overlies the Potomac and represents the transition between nonmarine and marine sedimentary deposition (Rasmussen and others, 1958; Spoljaric, 1976). In outcrop along the banks of the C&D Canal in both Maryland and Delaware, Carter (1938) divided the Magothy into three lithologically distinct subunits. The lower subunit is a fine-grained micaceous sand, usually iron-stained, with small lenses of clay. The middle subunit consists of sand and clay. The sand is coarse, angular, nearly pure quartz, often described as "sugary," with a small

**TABLE 1**  
Hydrostratigraphic nomenclature for southern New Castle County, Delaware.

SYSTEM	SERIES	GROUP AND FORMATION		HYDROSTRATIGRAPHIC DIVISION
QUATERNARY	Holocene and Pleistocene	Holocene Sediments and Columbia Formation		Columbia aquifer (usually a surficial aquifer in hydraulic connection with an underlying unit)
TERTIARY	Miocene	Calvert Formation		Confining unit in southeast part of study area
	Paleocene	Rancocas Group	Vincentown Formation	Rancocas aquifer
			Hornerstown Formation	
CRETACEOUS	Upper Cretaceous	Mt. Laurel Formation		Englishtown-Mt. Laurel aquifer system
		Matawan Group	Marshalltown Formation	
			Englishtown Formation	
			Merchantville Formation	
		Magothy Formation		Magothy and Potomac aquifer system
	Lower Cretaceous	Potomac Formation		

amount of mica. The upper subunit is a clay with abundant lignite and pyrite with rare grains of amber. This subunit also contains nodules of gray siderite of varying shapes and sizes, up to 15 inches long (Carter, 1938). Pickett (1970) also described the presence of pyrite-filled limy concretions and sulfate blooms in the Magothy. The subunits identified in outcrops by Carter (1938) have not been identified in the subsurface to the southeast. The Magothy Formation ranges in thickness from approximately 40-50 ft thick south of the subcrop area to approximately 50-70 ft thick in the Middletown area (Cushing and others, 1973; R. N. Benson, DGS, written comm., 1995; Woodruff, 1990). Ground-water exploration in the vicinity of the C&D Canal to about five miles south indicates that the part of the Magothy Formation that functions as an aquifer is highly variable in thickness and is not areally continuous (J. H. Talley, DGS, oral comm., 1993).

#### Englishtown-Mt. Laurel Aquifer System

The aquifers in the marine Upper Cretaceous sediments are considered to be one hydrostratigraphic division, here called the Englishtown-Mt. Laurel aquifer system. This hydrostratigraphic division is composed of the Matawan Group and Mt. Laurel Formation (Sundstrom and Pickett, 1971; Talley, 1976; Groot and others, 1983). These aquifers were not described in detail by Cushing and others (1973), and Hamilton and others (1991) did not include them in their hydrostratigraphic divisions. Discontinuous sand bodies in these units form locally productive unconfined aquifers that are used for domestic, agricultural, and public water supplies.

The Matawan Group in central New Castle County is divided, from oldest to youngest, into the Merchantville, Englishtown, and Marshalltown formations. The Matawan Group subcrops in a northeast-southwest trending band that crosses the C&D Canal in the vicinity of Summit (Figs. 1

and 2). The Merchantville Formation overlies the Magothy Formation and represents a marine depositional environment (Pickett, 1970). In outcrop, the Merchantville Formation consists of micaceous, glauconitic sandy silt and silty fine sand (Pickett, 1970). The Englishtown Formation conformably overlies the Merchantville and consists of well-sorted, micaceous, fine sand, with some glauconite and thin interbedded layers of silty sand (Pickett, 1970). The Marshalltown Formation overlies the Englishtown unconformably and consists of massive, highly glauconitic, very silty fine sand (Pickett, 1970). All three formations are relatively thin. The Merchantville is approximately 40 ft thick at the C&D Canal (Pickett, 1987). Thickness of the Englishtown ranges from about 20 ft to about 40 ft in southern New Castle County (Sundstrom and Pickett, 1971). The Marshalltown is the thinnest of the three, with a thickness of about 10-16 ft in the C&D Canal area (Pickett, 1987). The Merchantville and Marshalltown formations are not considered to be aquifers and probably act as leaky confining beds (Woodruff, 1986).

The Mt. Laurel Formation subcrops within the study area from near the C&D Canal to several miles to the south (Fig. 2). Downdip to the southeast, the unit is correlated with the Monmouth Formation in Maryland (Pickett, 1970; 1976). The formation consists of medium to coarse quartzose sand that contains glauconite, abundant fossils, and some silt. It overlies the Marshalltown Formation, and the contact between the two is generally recognizable as a change from a heavily glauconitic sediment to a more calcareous one (Carter, 1938). Iron minerals, especially siderite, derived from the weathering of glauconite, and calcite from the solution of fossils have partially cemented the sand in places (Rima and others, 1964). Thickness increases downdip, reaching 85 ft at the Appoquinimink River and approximately 140 ft in southernmost New Castle County (Sundstrom and Pickett, 1971).

### **Rancocas Aquifer**

The Rancocas aquifer in Delaware occurs within the Rancocas Group comprising the Hornerstown and Vincentown formations. These formations subcrop in the southern part of the study area (Fig. 2) and correlate with the Brightseat and Aquia formations, respectively, in Maryland (Cushing and others, 1973). Both formations in the Rancocas are lithologically similar, consisting of quartzose and silty glauconitic sand. The Rancocas is commonly weathered, forming ironstones (limonite) (Pickett, 1970). Rima and others (1964) have identified thin indurated beds of calcareous material within the lower part of the Rancocas. The Hornerstown Formation is fine to medium in texture with abundant glauconite, whereas the Vincentown Formation tends to be coarser and more quartzose (Pickett, 1976). Thickness of the Rancocas is approximately 25 to 50 ft at the Appoquinimink River (Cushing and others, 1973) where it has been truncated by erosion before deposition of the Columbia Formation. The Rancocas aquifer forms both a locally productive unconfined aquifer with the overlying Columbia Formation and a locally productive confined aquifer to the south and southeast where it reaches a thickness greater than 100 ft.

### **Calvert Formation**

#### **(Upper Confining Unit) and Columbia Aquifer**

Sediments of the Calvert Formation subcrop in the southeastern part of the study area (Fig. 2). The formation is composed predominately of silty clays with minor amounts of sand and shells. It generally forms a confining layer above the Rancocas aquifer.

The sediments of the Columbia Formation unconformably overlie the older sediments of the Coastal Plain throughout most of the study area and form a water-table aquifer together with underlying deposits that are hydraulically connected. These fluvial sediments consist mainly of subarkosic fine to coarse quartz sand and gravel with some silt and clay. The mineral composition is described in more detail by Jordan (1964). In addition to quartz, the sands consist of potassium feldspar (mostly microcline), plagioclase feldspar, and muscovite. The authors have observed kaolinite, illite, and hydroxy interlayered vermiculite in the clay fraction of samples from the Columbia Formation collected from other parts of the Delmarva Peninsula. The sediments are colored brown, yellow, or red from abundant ferric oxyhydroxides. Although the sediments are mostly unconsolidated, bands of limonite-cemented conglomerate occur locally.

The Columbia Formation is generally less than 40 ft thick in most of the study area, and, therefore, does not usually form the major part of the saturated thickness of the water-table aquifer. The Columbia aquifer is very important because it occurs at land surface and is the formation through which ground-water recharge occurs. In addition, the hydrologic characteristics of this near-surface aquifer render it particularly susceptible to contamination. In some areas, however, the Columbia consists of channel deposits filling paleochannels eroded into the older sediments. These channels were mapped by Spoljaric (1967) and Spoljaric and Woodruff (1970), and the areas of thick (>40 ft)

Columbia deposits are displayed in maps by Woodruff (1986, 1990). The thick (>40 ft) deposits tend to be found in the interfluvial uplands east of U.S. Route 301 and the Conrail Railroad track between Summit and Middletown.

### **Ground-Water Flow**

The configuration of the potentiometric surface in the confined aquifers of the study areas has been only partially mapped. Martin (1984) used digital simulations to map the potentiometric surface of aquifers within the Potomac Formation. Under prepumping conditions, the simulation showed that flow in these aquifers was from north to south, with the recharge areas being north of the C&D Canal. According to Cushing and others (1973), water in the Magothy Formation is recharged within the study area and flows north towards the C&D Canal and south to down-dip parts of the aquifer system outside of the study area. The divide between northward and southward flow is two to five miles south of the C&D Canal. The Columbia Formation and Rancocas Group form a water-table aquifer in which water is recharged in uplands and discharges to perennial streams. The map of the configuration of the water table prepared by Sundstrom and Pickett (1971) shows a ground-water divide running roughly parallel to U.S. Route 301 between Summit and Middletown. Water flows westward from the divide to streams flowing into Chesapeake Bay. Eastward flow is to a number of tidal tributaries of the Delaware River, including Drawyer Creek and Appoquinimink River. In the northern part of the study area, water in the surficial deposits flows northward into the C&D Canal or into streams draining into the canal. Water table maps have not been published for aquifers in the Englishtown-Mt. Laurel aquifer system, but in much of the study area, the sediments of the Englishtown-Mt. Laurel are in hydraulic connection with the Columbia Formation and Rancocas Group, so it seems likely that localized flow systems similar to those in the Columbia and Rancocas are also present in the Englishtown-Mt. Laurel.

### **QUALITY AND GEOCHEMISTRY OF GROUND WATER**

The quality of water in the aquifers of the study area is generally suitable for most uses, but where aquifers are unconfined, dissolved nitrate may exceed the USEPA MCL, and where aquifers are confined dissolved iron concentrations may exceed the USEPA SMCL. The occurrence of dissolved constituents in the aquifers of the study area is consistent with predictions based on descriptions of geochemical processes found to occur in other aquifers in the Atlantic Coastal Plain (Back, 1966; Knobel and Chapelle, 1986).

#### **General Water Quality**

The distribution of concentrations of inorganic constituents is shown in Table 2. The median concentrations for most constituents are within the water-quality criteria established by USEPA, but a sizable minority of samples are outside the criteria for a number of constituents. The constituents with the greatest number of samples exceeding the criteria are iron (43 per cent of samples above the SMCL of

TABLE 2

Statistical summary of chemical constituents in the ground water of the study area.

Samples collected from 1991 through 1992. Water-Quality Criteria refer to Maximum Contaminant Levels (MCLs) and Secondary Maximum Contaminant Levels (SMCLs) that would indicate whether the water is potable. Hardness values were calculated by dividing the sum of the concentrations, in milliequivalents per liter, of calcium, magnesium, and iron by 50, according to the method described by Hem (1985).

Constituent	Number of analyses	Minimum	25th Percentile	Median	75th Percentile	Maximum	Number of samples exceeding water-quality criteria
Specific conductance, in $\mu\text{S}/\text{cm}$	63	86	180	235	261	1,130	
Dissolved oxygen, in mg/L	60	0	0.6	0.95	4.5	10.8	
pH (standard units)	63	5.1	6.3	7.2	7.5	7.9	19 samples outside MCL range of 6.5-8.5
Bicarbonate, in mg/L	63	5.0	52	109	138	170	
Ammonia plus organic nitrogen, in mg/L as N	63	0.1	0.1	0.19	0.2	0.51	
Nitrite plus nitrate, in mg/L as N	63	<0.02	<0.02	<0.02	2.2	15	3 samples above MCL of 10 mg/L
Dissolved organic carbon, in mg/L	62	0.1	0.3	0.4	0.6	3.9	
Calcium, in mg/L	63	2.1	14	33	42	58	
Magnesium, in mg/L	63	0.4	2	3	4.4	16	
Sodium, in mg/L	63	2.4	3.1	3.7	7.5	160	
Potassium, in mg/L	63	1.1	2.1	2.7	3.9	16	
Chloride, in mg/L	63	0.8	2.2	3.9	10	300	1 sample above MCL of 250 mg/L
Sulfate, in mg/L	63	0.2	4.4	8.1	11	80	
Fluoride, in mg/L	63	0.1	0.2	0.2	0.3	0.5	
Silica, in mg/L	63	7.6	12	15	18	34	
Iron, in $\mu\text{g}/\text{L}$	63	9.0	44	230	1,300	21,000	27 samples above SMCL of 300 $\mu\text{g}/\text{L}$
Manganese, in $\mu\text{g}/\text{L}$	63	5	10	20	50	1,400	14 samples above SMCL of 50 $\mu\text{g}/\text{L}$
Aluminum, in $\mu\text{g}/\text{L}$	63	<10	<10	<10	10	30	
Hardness, Ca, Mg, Fe, in mg/L of $\text{CaCO}_3$	63	8.6	65	102	118	156	
Radon, in pCi/L	21	89	190	440	570	1,700	14 samples above proposed MCL of 300 pCi/L

300  $\mu\text{g}/\text{L}$ ), pH (25 per cent of samples outside the SMCL range of 6.5 to 8.5), and nitrite plus nitrate-nitrogen (5 per cent of samples above the MCL of 10 mg/L). Of the 21 samples collected for radon analysis, over half exceeded a proposed MCL of 300 pCi/L (U.S. Environmental Protection Agency, 1986).

Hardness is a property related to the concentration of polyvalent metal cations (Hem, 1985). Water from the aquifers of the study area is soft to moderately hard. Total hardness is caused by calcium, magnesium, and iron and ranges from 8.6 to 156 mg/L of  $\text{CaCO}_3$  with a median value of 103. Although there is no health-related water quality standard for hardness, those who use water that is moderately hard to hard (>60 mg/L of  $\text{CaCO}_3$ , Hem, 1985), may wish to soften their water to prevent excessive consumption of soap and to prevent scaling on pipes and plumbing fixtures.

The water from wells sampled during the study could represent a mixture of two or more geochemical populations. Figures 4 to 6 are normal probability plots of dissolved oxygen, sodium, and nitrite plus nitrate-nitrogen. They all have the characteristic sigmoidal-shape frequency curves that are representative of mixed geochemical populations (Sinclair, 1974; Rose and others, 1979). The populations are partitioned by the inflection point on the curve. Thus, for Figure 4, dissolved oxygen is divided into a population with concentrations greater than about 2 mg/L and a population with concentrations less than 2 mg/L. The parti-

tion between the two populations of sodium (Fig. 5) is about 10 mg/L, and that for nitrite plus nitrate-nitrogen (Fig. 6) is at about 0.2 - 0.5 mg/L. The partition for nitrite plus nitrate-nitrogen is very close to the value of 0.4 that was reported by Hamilton and others (1993) and Shedlock and others (1993) for ground water from the surficial aquifer in the Delmarva Peninsula. Therefore, in this report, a concentration of 0.4 mg/L will be used to partition populations of nitrite plus nitrate-nitrogen concentrations. The interpretation of Hamilton and others (1993) was that waters with nitrate concentrations of less than 0.4 mg/L were considered "natural" waters, and those with higher nitrate concentrations were considered waters affected by anthropogenic sources of nitrogen.

#### Comparison of Concentrations Between Hydrostratigraphic Divisions

Concentrations of dissolved constituents differ between the hydrostratigraphic divisions. Tables 3, 4, and 5 list summary statistics for each division. The differences between hydrostratigraphic divisions are shown in Figures 7, 8, and 9 for three constituents of environmental interest. Differences in medians of water samples from hydrostratigraphic divisions were tested using the nonparametric Kruskal-Wallis test (Conover, 1980). For the three constituents (dissolved iron, radon, and nitrite plus nitrate-nitrogen), hydrostratigraphic division medians show statistically significant differences.

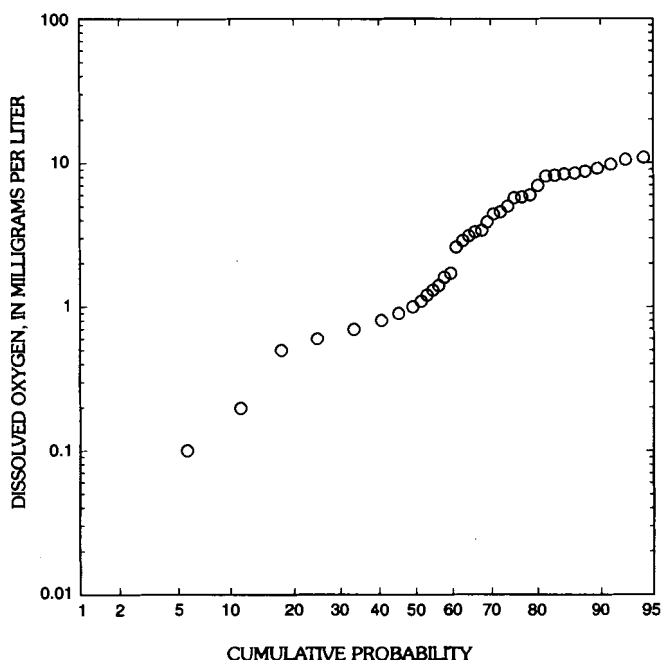


Figure 4. Probability plot showing frequency distribution of dissolved oxygen concentrations of samples collected from the study area.

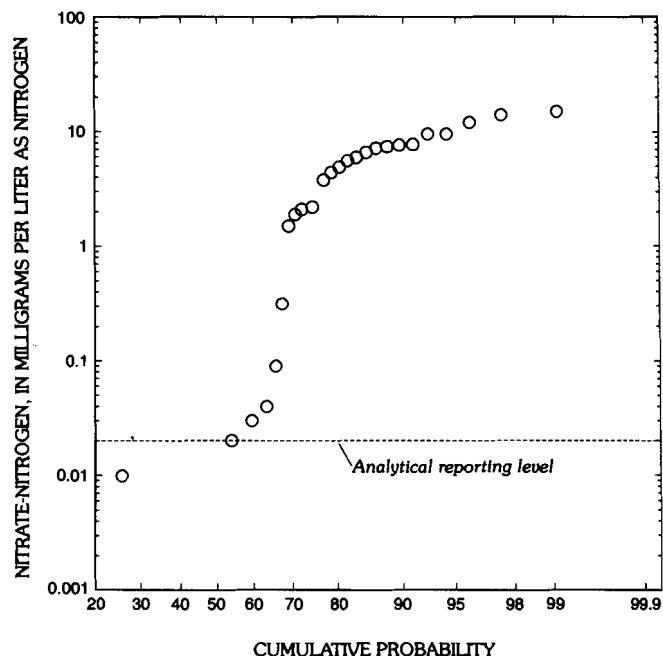


Figure 6. Probability plot showing frequency distribution of dissolved nitrate-nitrogen concentrations of samples collected from the study area.

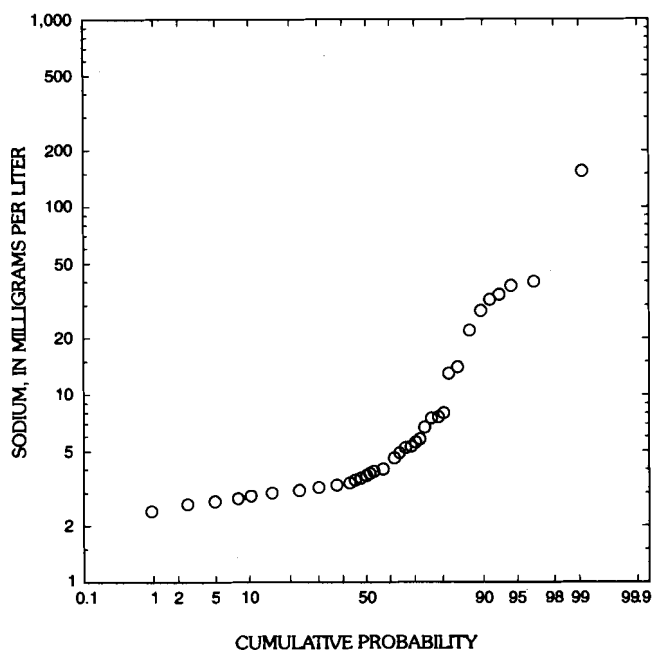


Figure 5. Probability plot showing frequency distribution of dissolved sodium concentrations of samples collected from the study area.

The most striking pattern displayed in Figures 7-9 is that hydrostratigraphic divisions with high iron tend to have low nitrate-nitrogen, and visa versa. Iron concentrations greater than the SMCL of 300  $\mu\text{g/L}$  are found in all the divisions, but are most common in the Magothy and Potomac aquifer system (Fig. 7). Iron concentrations are above the SMCL in all of the samples from the Magothy and Potomac aquifer system. None of the samples from the Magothy and Potomac aquifer system exceeded the MCL for nitrate-nitrogen (Fig. 9). The maximum nitrate-nitrogen concentra-

tions are similar for the Englishtown-Mt. Laurel aquifer system and the Rancocas aquifer. The proportion of samples with nitrate-nitrogen concentrations higher than 0.4 mg/L is higher in the Rancocas (55 percent) than it is in the Englishtown-Mt. Laurel (35 percent) of samples higher than 0.4 mg/L.

The explanation for this pattern is probably the fact that the Magothy and Potomac is entirely confined in the study area, whereas the other two hydrostratigraphic units are found under both confined and unconfined conditions. Parts of the Magothy and Potomac north of the study area are unconfined aquifers and may have high nitrate-nitrogen and low iron concentrations. Water in confined aquifers tends to be anoxic, which results in conditions favorable for mobilization of iron and removal of nitrate from the water by denitrification. Furthermore, much of the recharge to the confined parts of aquifers is by leakage through poorly permeable confining layers. These tend to retard the passage of nitrate-rich water from the surficial aquifer to deeper confined aquifers.

Although the concentrations of constituents are different in each hydrostratigraphic division, the water types, based on the relative amounts of major ions, show some overlap (Figs. 10-12). Ground-water in the study area is generally either a calcium-magnesium-nitrate-chloride-sulfate-type water or it is a calcium-magnesium-bicarbonate-type. Waters of mixed cationic composition are most prevalent in the Rancocas. There are a few wells, all in the Magothy and Potomac aquifer system, that yield sodium bicarbonate-type water (Fig. 10). Bicarbonate-type water in the Rancocas aquifer usually contains nitrate-nitrogen concentrations less the 0.4 mg/L whereas bicarbonate-type water in the Englishtown-Mt. Laurel aquifer system contains nitrate-nitrogen concentrations above and below 0.4 mg/L.

TABLE 3

Statistical summary of chemical constituents in the ground water from the Magothy and Potomac aquifer system.

Samples collected from 1991 through 1992. Water-Quality Criteria refer to Maximum Contaminant Levels (MCLs) or Secondary Maximum Contaminant Levels (SMCLs) that would indicate whether the water is potable. Hardness values were calculated by dividing the sum of the the concentrations, in milliequivalents per liter, of calcium, magnesium, and iron by 50, according to the method described by Hem (1985).

Constituent	Number of analyses	Minimum	25th Percentile	Median	75th Percentile	Maximum	Number of samples exceeding water-quality criteria
Specific conductance, in $\mu\text{S}/\text{cm}$	15	135	162	180	229	276	
Dissolved oxygen, in mg/L	14	0	0.2	0.65	0.9	3.9	
pH (standard units)	15	5.8	6.7	7	7.2	7.5	2 samples outside MCL range of 6.5-8.5
Bicarbonate, in mg/L	15	60	87	109	135	143	
Nitrite plus nitrate, in mg/L as N	15	<0.02	<0.02	<0.02	0.02	0.31	
Dissolved organic carbon, in mg/L	14	0.2	0.4	0.5	0.6	1.2	
Calcium, in mg/L	15	2.1	12	18	24	33	
Magnesium, in mg/L	15	0.4	3.1	4	5	6.3	
Sodium, in mg/L	15	2.7	3.6	4.6	22	40	
Potassium, in mg/L	15	2.1	2.7	3.9	5	7	
Chloride, in mg/L	15	0.8	1.4	1.7	1.9	19	
Sulfate, in mg/L	15	2.3	4.7	6.4	7.3	9.6	
Fluoride, in mg/L	15	<0.2	0.2	0.2	0.2	0.3	
Silica, in mg/L	15	7.6	7.8	8.6	13	18	
Iron, in $\mu\text{g}/\text{L}$	15	360	1,200	2,000	5,400	14,000	15 samples above SMCL of 300 $\mu\text{g}/\text{L}$
Manganese, in $\mu\text{g}/\text{L}$	15	10	10	30	120	180	6 samples above SMCL of 50 $\mu\text{g}/\text{L}$
Aluminum, in $\mu\text{g}/\text{L}$	15	<10	<10	<10	10	30	
Hardness, Ca, Mg, Fe, in mg/L of $\text{CaCO}_3$	15	8.6	53	71	85	110	
Radon, in pCi/L	6	89	100	120	150	190	

TABLE 4

Statistical summary of chemical constituents in the ground water from the Englishtown-Mt. Laurel aquifer system.

Samples collected from 1991 through 1992. Water-Quality Criteria refer to Maximum Contaminant Levels (MCLs) or Secondary Maximum Contaminant Levels (SMCLs) that would indicate whether the water is potable. Hardness values were calculated by dividing the sum of the the concentrations, in milliequivalents per liter, of calcium, magnesium, and iron by 50, according to the method described by Hem (1985).

Constituent	Number of analyses	Minimum	25th Percentile	Median	75th Percentile	Maximum	Number of samples exceeding water-quality criteria
Specific conductance, in $\mu\text{S}/\text{cm}$	36	128	215	252	261	1,130	
Dissolved oxygen, in mg/L	35	0.1	0.6	1.04	4.6	9.7	
pH (standard units)	36	5.4	6.4	7.5	7.6	7.9	10 samples outside MCL range of 6.5-8.5
Bicarbonate, in mg/L	36	5	59	118	146	170	
Nitrite plus nitrate, in mg/L as N	36	<0.02	<0.02	<0.2	3.8	14	2 samples above MCL of 10 mg/L
Dissolved organic carbon, in mg/L	36	0.2	0.3	0.4	0.6	2.7	
Calcium, in mg/L	36	12	35	40.5	44	50	
Magnesium, in mg/L	36	1.2	1.7	2.45	4.1	16	
Sodium, in mg/L	36	2.4	3	3.25	4.6	160	
Potassium, in mg/L	36	1.1	1.7	2.4	3.7	16	
Chloride, in mg/L	36	1.8	2.6	4.3	7.3	300	1 sample above MCL of 250 mg/L
Sulfate, in mg/L	36	1.6	5.3	8.7	13	42	
Fluoride, in mg/L	36	0.1	0.2	0.3	0.4	0.5	
Silica, in mg/L	36	10	14	15.5	18	30	
Iron, in $\mu\text{g}/\text{L}$	36	10	40	200	360	1,600	9 samples above SMCL of 300 $\mu\text{g}/\text{L}$
Manganese, in $\mu\text{g}/\text{L}$	36	<10	10	10	20	60	1 sample above SMCL of 50 $\mu\text{g}/\text{L}$
Aluminum, in $\mu\text{g}/\text{L}$	36	<10	<10	<10	10	30	
Hardness, Ca, Mg, Fe in mg/L of $\text{CaCO}_3$	36	39	98	114	122	145	
Radon, in pCi/L	8	210	365	465	985	1,700	7 samples above proposed MCL of 300 pCi/L

TABLE 5

Statistical summary of chemical constituents in the ground water from the Rancocas aquifer.

Samples collected from 1991 through 1992. Water-Quality Criteria refer to Maximum Contaminant Levels (MCLs) or Secondary Maximum Contaminant Levels (SMCLs) that would indicate whether the water is potable. Hardness values were calculated by dividing the sum of the concentrations, in milliequivalents per liter, of calcium, magnesium, and iron by 50, according to the method described by Hem (1985).

Constituent	Number of analyses	Minimum	25th Percentile	Median	75th Percentile	Maximum	Number of samples exceeding water-quality criteria
Specific conductance, in $\mu\text{S}/\text{cm}$	12	86	128	173	260.0	446.0	
Dissolved oxygen, in mg/L	11	0.1	0.7	3	6.0	10.8	
pH (standard units)	12	5.1	5.5	5.9	7.3	7.8	7 samples outside of MCL range of 6.5-8.5
Bicarbonate, in mg/L	12	11	13	33	102	132	
Nitrite plus nitrate, in mg/L as N	12	<0.02	<0.02	1.9	7.2	15	1 sample above MCL of 10 mg/L
Dissolved organic carbon, in mg/L	12	0.1	0.1	0.4	1.5	3.9	
Calcium, in mg/L	12	5.3	7.9	11	36	41	
Magnesium, in mg/L	12	2	2.3	3	5	9.5	
Sodium, in mg/L	12	2.8	3.3	4.9	28	34	
Potassium, in mg/L	12	1.5	2.7	3.4	4	4	
Chloride, in mg/L	12	2.5	3.6	6.1	28	88	
Sulfate, in mg/L	12	0.2	0.3	5.9	20	48	
Fluoride, in mg/L	12	<0.2	<0.2	<0.2	0.3	0.5	
Silica, in mg/L	12	13	15	24	28	34	
Iron, in $\mu\text{g}/\text{L}$	12	9	11	59	3,600	21,000	3 samples above SMCL of 300 $\mu\text{g}/\text{L}$
Manganese, in $\mu\text{g}/\text{L}$	12	8	29	60	330	1,400	7 samples above SMCL of 50 $\mu\text{g}/\text{L}$
Aluminum, in $\mu\text{g}/\text{L}$	12	<10	<10	10	10	30	
Hardness, Ca, Mg, Fe, in mg/L of $\text{CaCO}_3$	12	24	31	64	109	110	
Radon, in pCi/L	7	330	470	540	920	1,300	7 samples above proposed MCL of 300 pCi/L

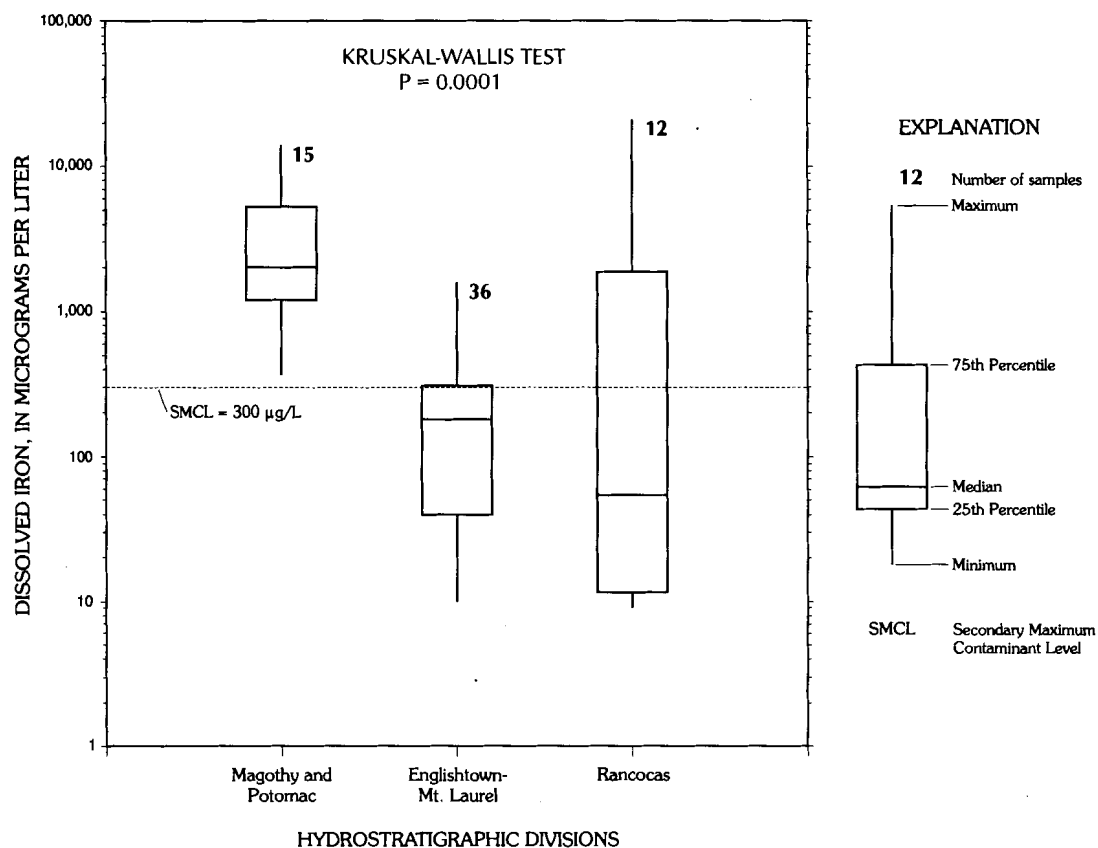


Figure 7. Boxplots showing distribution of dissolved iron among hydrostratigraphic divisions.

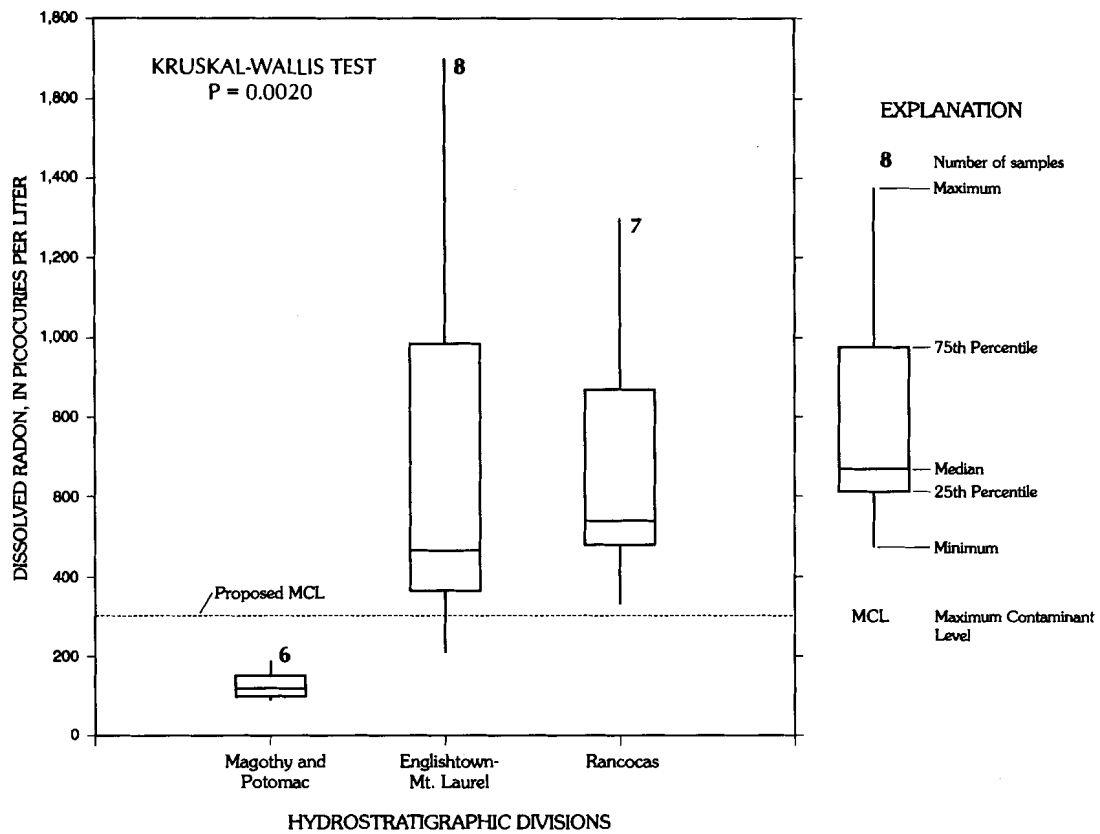


Figure 8. Boxplots showing distribution of dissolved radon among hydrostratigraphic divisions.

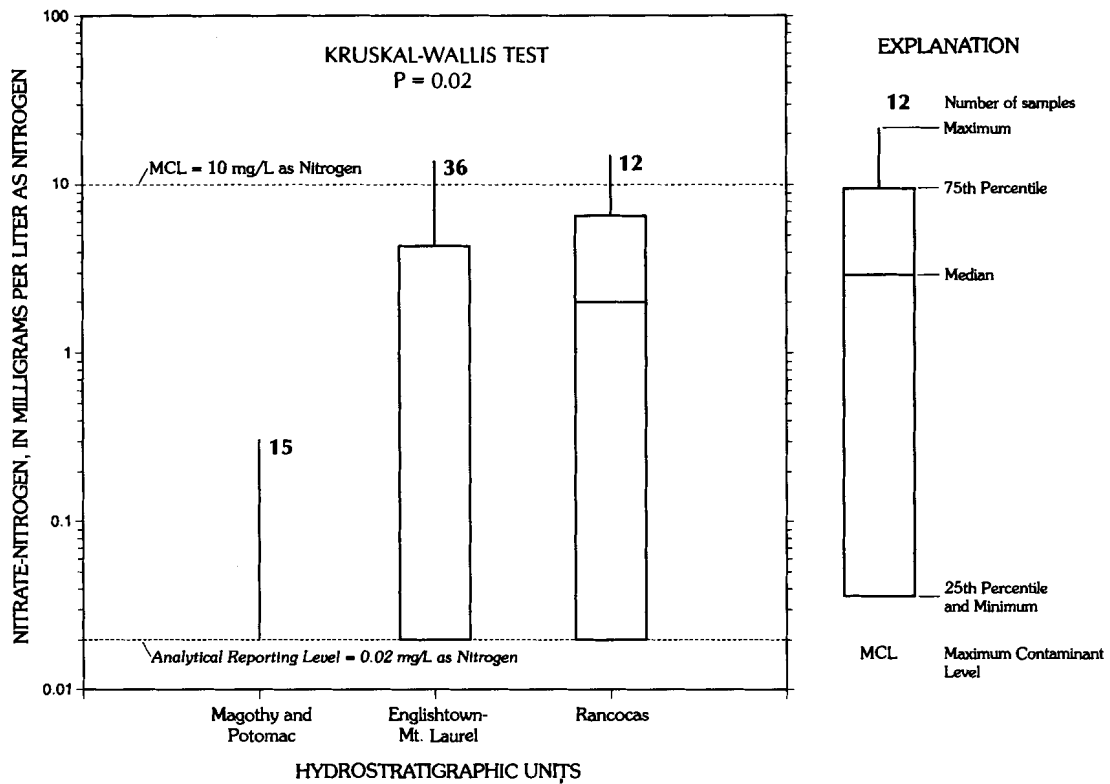


Figure 9. Boxplots showing distribution of dissolved nitrate-nitrogen among hydrostratigraphic divisions.



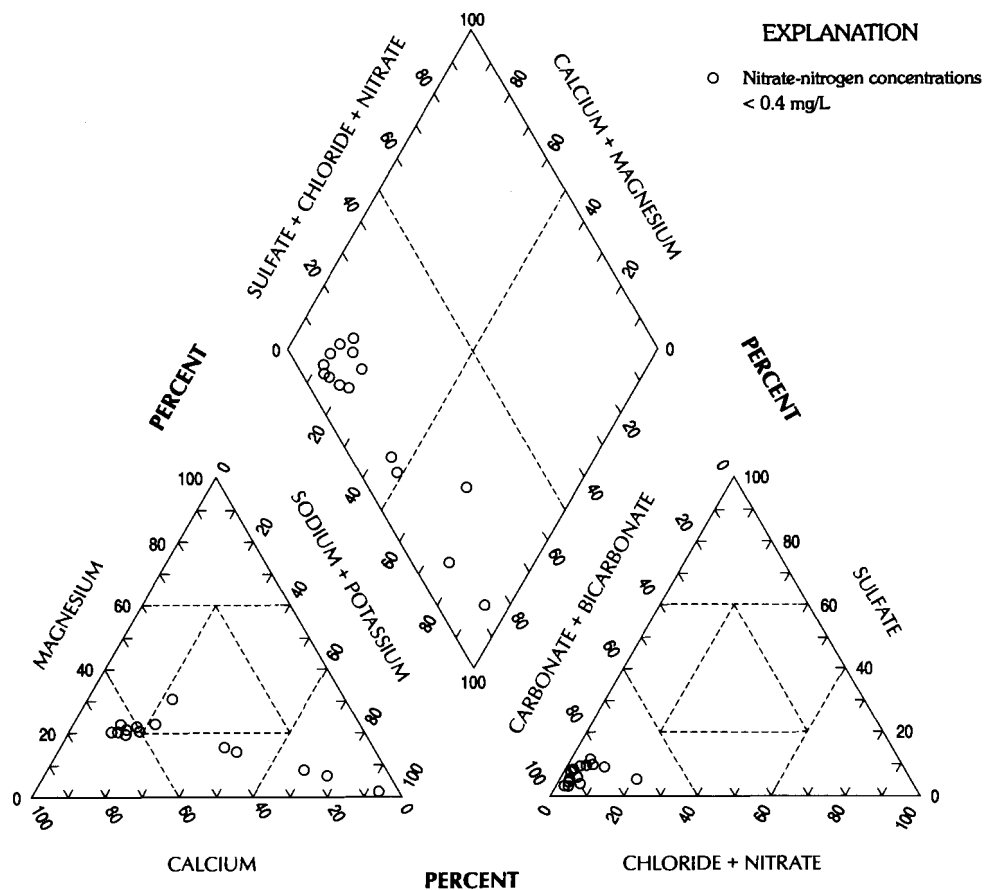


Figure 10. Trilinear diagram showing distribution of water types in the Magothy and Potomac aquifer system.

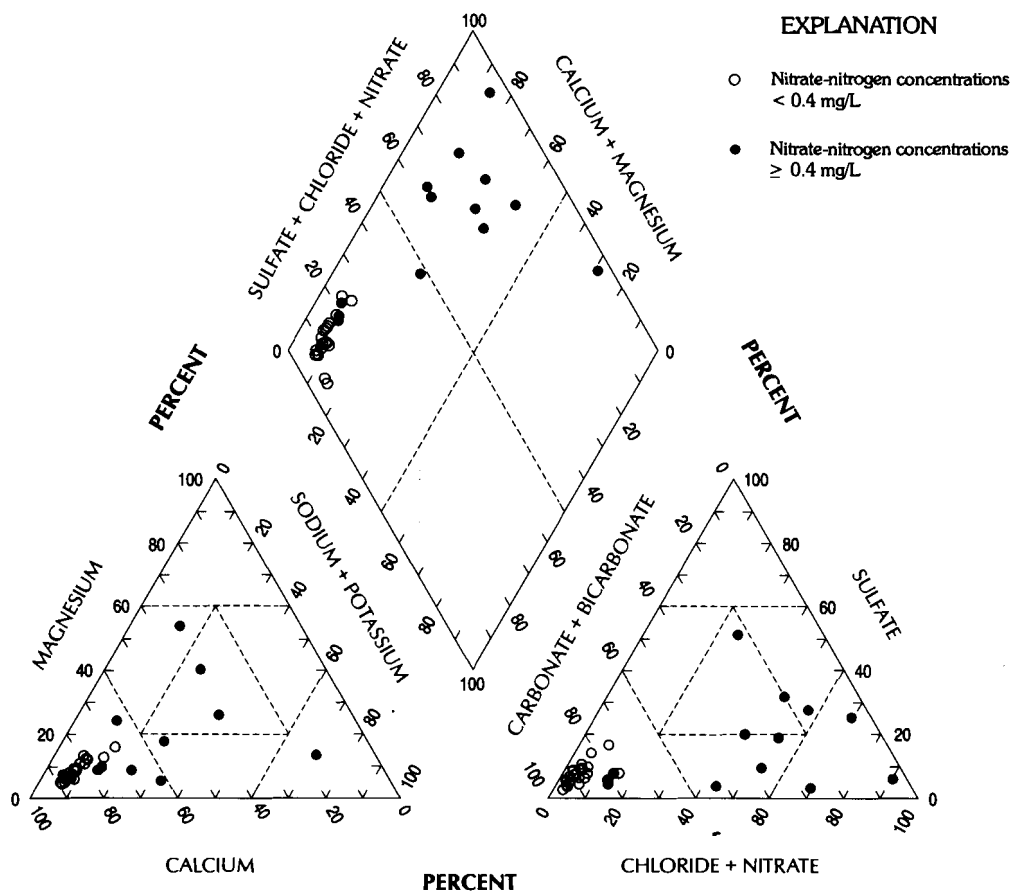


Figure 11. Trilinear diagram showing distribution of water types in the Englishtown-Mt. Laurel aquifer system.

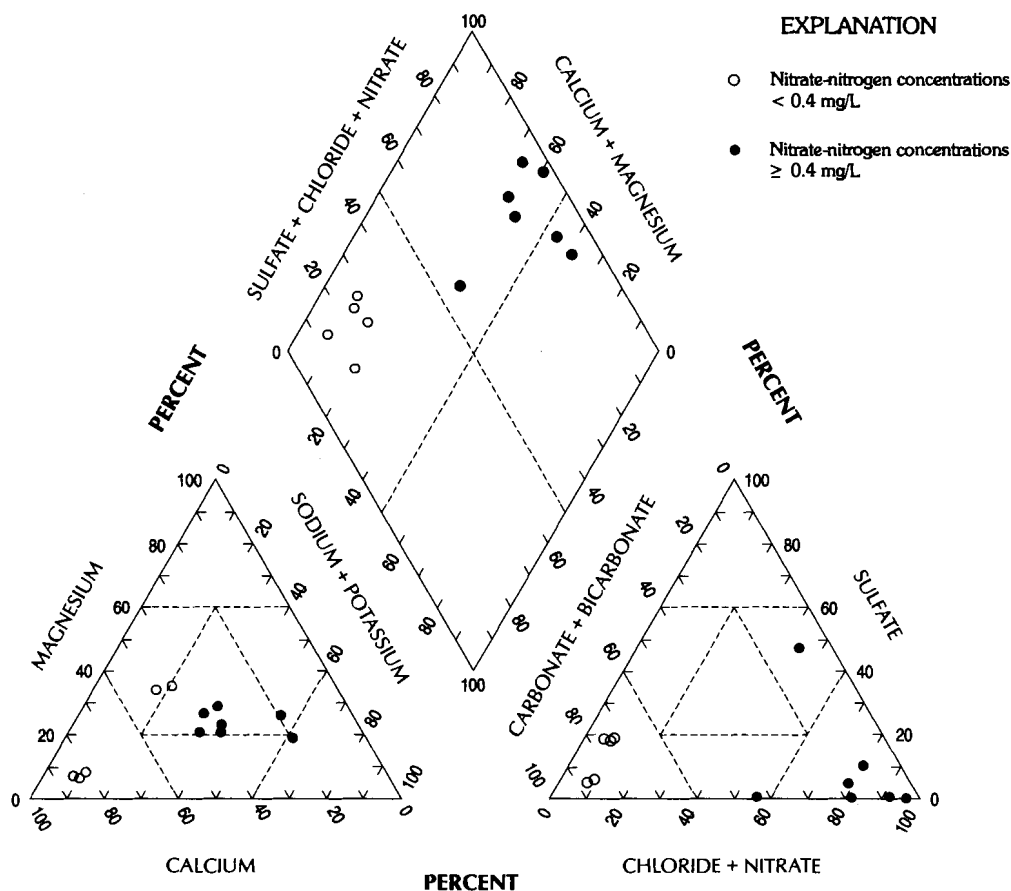


Figure 12. Trilinear diagram showing distribution of water types in the Rancocas aquifer.

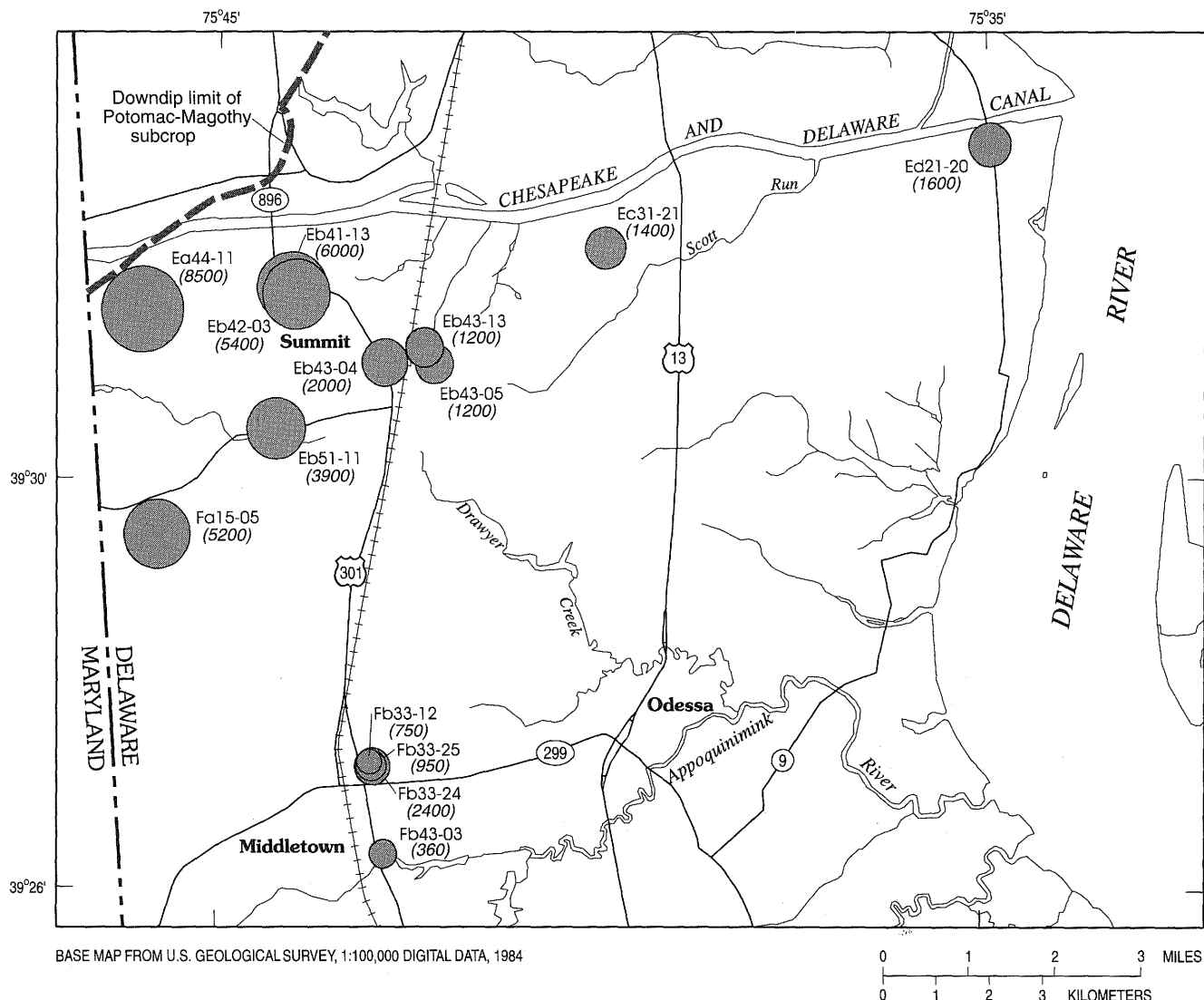
Maps showing the areal distribution of iron and nitrate in each hydrostratigraphic division (Figs. 13-18) further illustrate the inverse relation between the two constituents. In the Magothy and Potomac aquifer system, iron concentrations above 300  $\mu\text{g/L}$  are common (Fig. 13), and water samples from all wells had nitrate concentrations below 0.4 mg/L as N (Fig. 14). In the Englishtown-Mt. Laurel aquifer system, iron concentrations above 300  $\mu\text{g/L}$  are found in downdip areas where the aquifer is confined (Fig. 15), whereas nitrate-nitrogen concentrations above 0.4 mg/L are mostly found in the subcrop area where the aquifer is unconfined in the vicinity of Summit and the C&D Canal (Fig. 16). Iron concentrations are typically high in wells where nitrate-nitrogen concentrations are less than 0.4 mg/L. Similar patterns are found in the Rancocas aquifer (Figs. 17-18).

All seven Rancocas water samples and seven out of the eight water samples from the Englishtown-Mt. Laurel exceed the proposed MCL for radon of 300 pCi/L. None of the samples from the Magothy and Potomac exceeds 300 pCi/L. This pattern may be related to the presence of glauconite in the Englishtown-Mt. Laurel and Rancocas (Woodruff and others, 1992). Note, however, that all of the samples for radon analyses from the Magothy and Potomac aquifer system were collected from the Magothy aquifer. There is, thus, no information here about radon concentrations in the Potomac aquifer.

Wells that produce water of "good" quality tend to be found in the Englishtown-Mt. Laurel aquifer system. Water is defined as "good" quality if iron concentrations are below

the SMCL of 300  $\mu\text{g/L}$  and nitrate plus nitrite-nitrogen concentrations are less than 0.4 mg/L. Nitrite plus nitrate-nitrogen concentrations above 0.4 mg/L indicate that nitrogen from human sources is probably entering the aquifer, and that nitrogen concentrations could increase in the future. Of the 63 wells sampled, 16 meet these criteria of low iron and nitrite plus nitrate-nitrogen (Fig. 19). Fourteen of the wells were finished in the Englishtown-Mt. Laurel aquifer system, and two were finished in the Rancocas. Water from the Magothy and Potomac aquifer system has very little nitrogen, but all of the samples collected for this study exceed the SMCL for iron. The wells with good-quality water are widely distributed throughout the study area, although water with low iron and low nitrate-nitrogen was not found in shallow aquifers near the C&D Canal (Fig. 19). The most likely source for good quality water is the Englishtown-Mt. Laurel aquifer system. However, nitrate-nitrogen data shown in Figures 16 and 18 indicate that the Englishtown-Mt. Laurel aquifer system is locally vulnerable to contaminants applied on the land surface. Thus, to avoid the potential for surficial contaminants, such as nitrogen, it could be necessary to use water with high iron concentrations and accept the treatment costs.

Sodium, either from brackish water intrusion or natural ion-exchange reactions is not a major water-quality problem. Only seven of the 63 samples exceed a sodium concentration of 20 mg/L. Only one well has water with sodium and chloride of over 100 mg/L. This well, Ec32-16 (Fig. 1), is located near the U.S. Route 13 bridge over the C&D Canal, and the high concentrations of sodium



### EXPLANATION

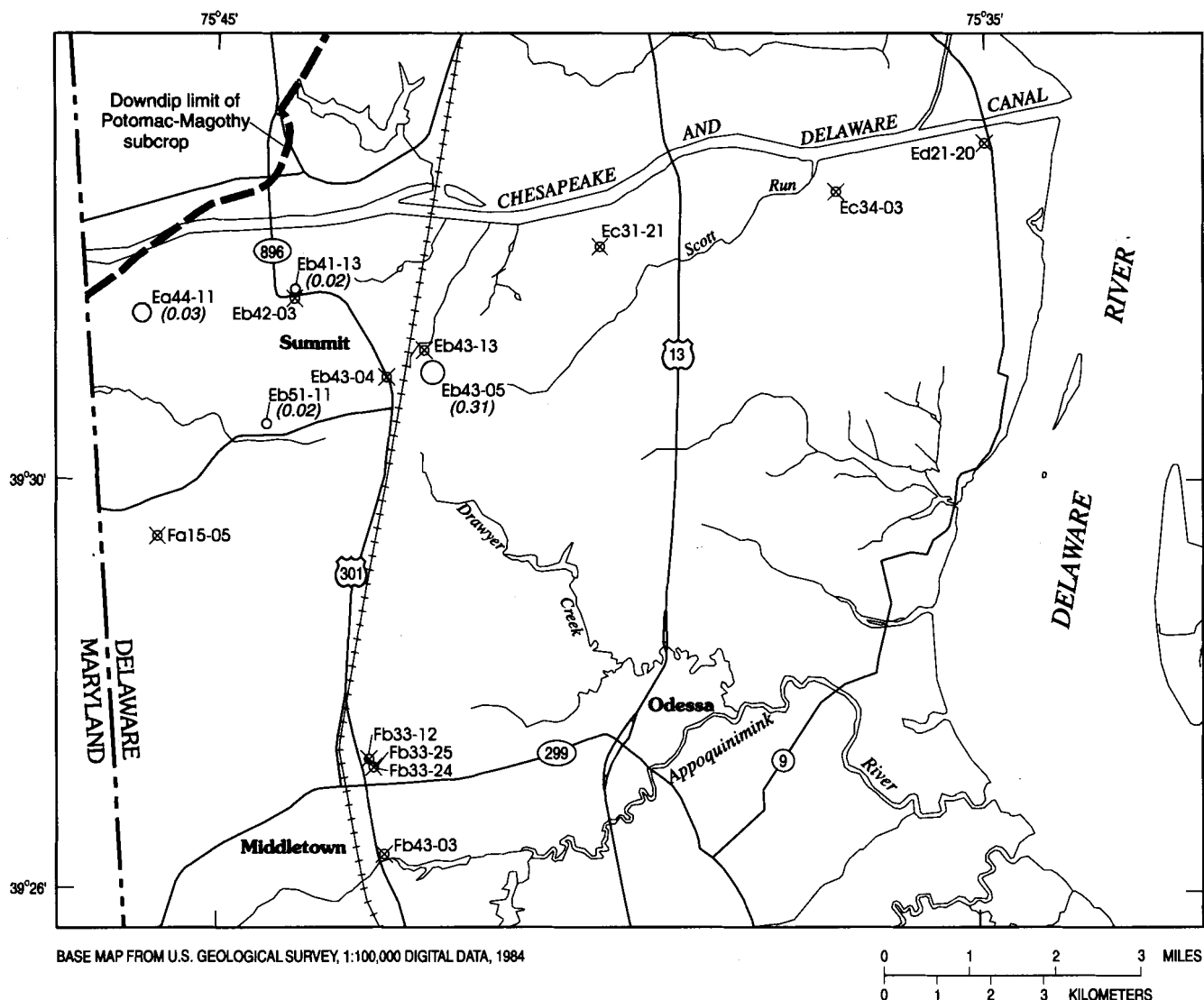
- Fb43-03 Well number
- Well with dissolved iron concentration in micrograms per liter ( $\mu\text{g/L}$ ). (Area of circle is proportional to the concentration.)
- (360) Dissolved iron concentration in  $\mu\text{g/L}$ .

Figure 13. Map showing areal distribution of dissolved iron in the Magothy and Potomac aquifer system.

(160 mg/L) and chloride (300 mg/L) are probably due to contamination from road salt rather than brackish water intrusion. Only sodium and chloride concentrations were found at high levels in the well; other ions that might be expected to be found in elevated concentrations in brackish water, such as calcium, magnesium, and sulfate, are found in concentrations similar to that of ground water not affected by brackish-water intrusion. Nitrate-nitrogen concentrations in Ec32-16 are clearly elevated (7.4 mg/L), further indicating that the chemical composition of water in this well was affected by contamination from the land surface. However, although no evidence for brackish water intrusion was found, the sampling network did not

include many wells located near the Delaware River and the C&D Canal. Brackish water intrusion similar to that reported by Phillips (1987) for areas north of the C&D Canal is possible in the study area, but more detailed sampling near the brackish water bodies is needed to fully evaluate that possibility.

The results of sampling a limited number of wells (21) for dissolved radon indicates that a very large percentage (14 samples or 67 percent) exceed a proposed USEPA MCL of 300 pCi/L. This does not mean that ground water in the study area has exceptionally high radon concentrations. Data reported by the USEPA (1986) in support of the proposed MCL indicate that, in ground water used for pub-



## EXPLANATION

Eb43-05 Well number

Wells with nitrate-nitrogen concentrations in milligrams per liter (mg/L). (Area of circle is proportional to the concentration.)

⊗ Less than 0.02

○ Equal to or greater than 0.02

(0.31) Nitrate-nitrogen concentration in mg/L as N.

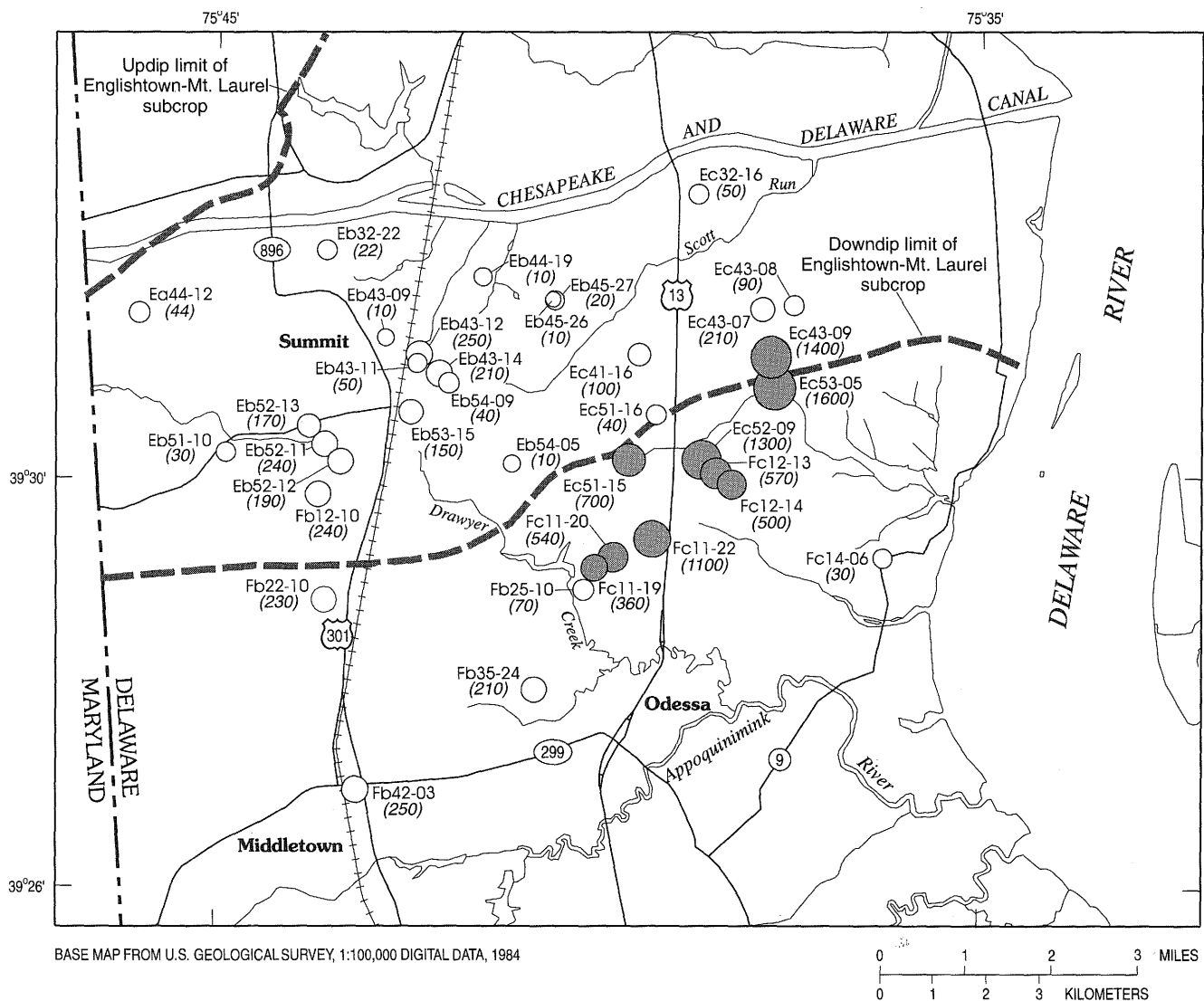
Figure 14. Map showing areal distribution of dissolved nitrate-nitrogen in the Magothy and Potomac aquifer system.

lic ground water drinking supplies, radon concentrations are commonly between 100 and 1,000 pCi/L. The results of the radon analyses collected for this study are in general agreement with other radon analyses collected from ground water across the Delmarva Peninsula. The proposed radon MCL is controversial, and there is a chance that its implementation may be prevented or delayed (Jan Auerbach, USEPA, oral communication, 1994). The proposed MCL was based on risk assessments that are described in more detail in the proposals for the MCL (USEPA, 1986; 1991).

Dissolved radon may also be removed from drinking water fairly easily and inexpensively by aeration, according to the USEPA (1986).

## Ground-Water Geochemistry

The chemical composition of ground water is determined by a large number of geochemical processes in the atmosphere, the soil zone, and within the aquifer (Table 6). Precipitation is in equilibrium with atmospheric gases, including naturally-occurring carbon dioxide (CO<sub>2</sub>) and oxides of



### EXPLANATION

Fc11-22 Well number

Wells with dissolved iron concentrations in micrograms per liter ( $\mu\text{g/L}$ ). (Area of circle is proportional to the concentration.)

○ Less than 300

● Equal to or greater than 300

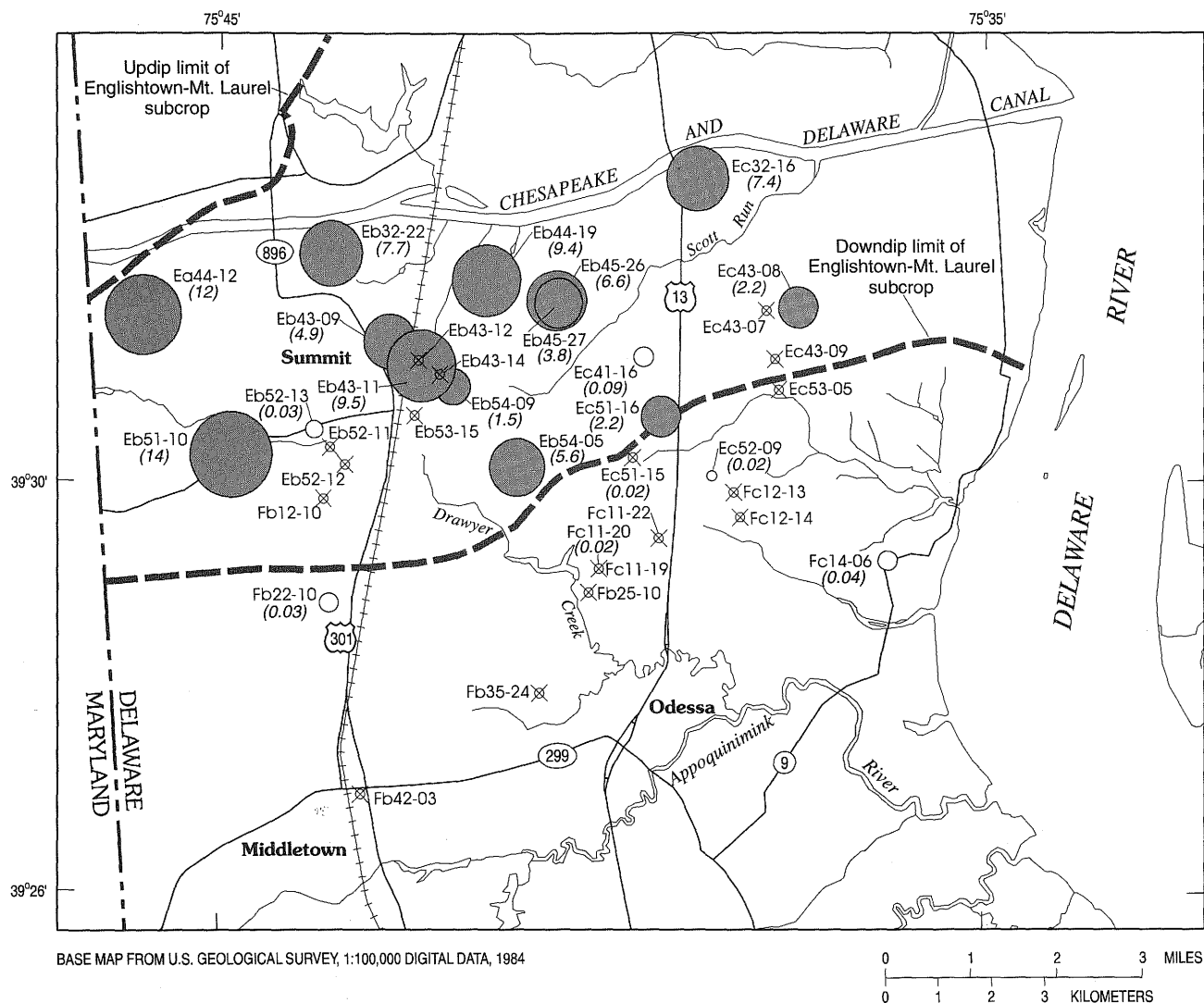
(1100) Dissolved iron concentration in  $\mu\text{g/L}$ .

Figure 15. Map showing areal distribution of dissolved iron in the Englishtown-Mt. Laurel aquifer system.

nitrogen and sulfur that are added to the atmosphere from industrial and powerplant emissions and motor vehicle exhaust. Water in equilibrium with carbon dioxide is slightly acidic, with a pH of 5.6 (Table 6, reaction 1). Sulfur and nitrogen oxides dissolve in atmospheric water vapor and form sulfuric and nitric acid. Rain water on the Delmarva Peninsula has a pH of 3.5 to 4.5 and contains about 2 to 6 mg/L of dissolved constituents (Bachman and Katz, 1986; Denver, 1986). As precipitation moves into the shallow aquifer the concentra-

tion of dissolved constituents increases about 3-fold by evapotranspiration (Denver, 1986), and biological activity in the soil further enriches the water in dissolved  $\text{CO}_2$ , and, thus, in carbonic acid ( $\text{H}_2\text{CO}_3$ ) (Table 6, reaction 1). The dilute, acidic recharge water then flows through the aquifer and reacts with minerals and organic matter.

The geochemical processes operating in the aquifers of the middle Atlantic Coastal Plain have been studied for many years and are generally well understood (Foster,



### EXPLANATION

Ec43-08 Well number

Wells with nitrate-nitrogen concentrations in milligrams per liter (mg/L). (Area of circle is proportional to the concentration.)

⊗ Less than 0.02

○ Equal to or greater than 0.02 and less than 0.4

● Equal to or greater than 0.4

(2.2) Nitrate-nitrogen concentration in mg/L as N.

Figure 16. Map showing areal distribution of dissolved nitrate-nitrogen in the Englishtown-Mt. Laurel aquifer system.

1950; Back, 1966; Knobel and Chapelle, 1986; Chapelle and Drummond, 1983; Knobel and Phillips, 1988). The processes can be classified as mineral dissolution reactions (Table 6, reactions 3, 4, 6, 7, and 9), redox reactions (Table 6, reactions 4, 5, and 6), and ion exchange reactions (Table 6, reaction 8). The mineral composition of the aquifer is an important control on the types of chemical reactions taking

place. In general, mineral dissolution reactions tend to result in increased concentration of base cations and silica as the water chemically evolves along a flow path. Dissolution reactions also tend to increase pH and bicarbonate concentrations (Table 6, reactions 6 and 7).

These processes are mostly natural interaction between ground water and the aquifer material, but water quality is also

TABLE 6

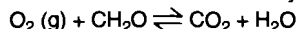
Geochemical processes controlling ground-water quality in the study area.

(c) denotes crystalline solids, (s) denotes amorphous or crystalline solids, (aq) denotes aqueous species, (g) denotes gases.

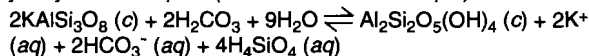
(1) *Generation of carbonic acid:*



(2) *Enrichment of carbon dioxide by organic matter:*



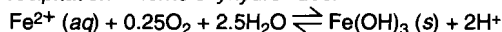
(3) *Hydrolysis of feldspars (microcline as an example):*



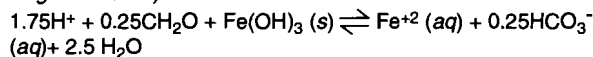
(4) *Dissolution of pyrite (partial reaction):*



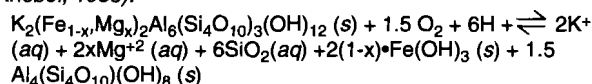
(5) *Precipitation of ferric oxyhydroxides:*



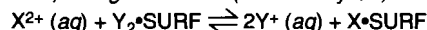
(6) *Dissolution of ferric oxyhydroxides (reduction of iron, oxidation of organic matter):*



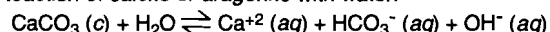
(7) *Incongruent dissolution of glauconite (after Chapelle and Knobel, 1983):*



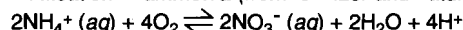
(8) *Cation exchange of an ion  $\text{X}^{2+}$  with an ion  $\text{Y}^+$  on a negatively charged exchange surface, SURF, which can be clay, glauconite, or organic matter (X is usually Ca, Y is usually Na):*



(9) *Reaction of calcite or aragonite with water:*



(10) *Nitrification of ammonia (from fertilizer and natural sources):*



affected by sources of contaminated recharge water. Fertilizer and septic tank effluent is commonly rich in reduced forms of nitrogen, such as ammonia and organic nitrogen. Nitrification (Table 6, reaction 10) is a common process in the oxidized soil zone, and explains why nitrogen in shallow ground water is predominantly in the form of nitrate.

Variation in mineral composition among the hydrostratigraphic divisions in the study area may lead to differ-

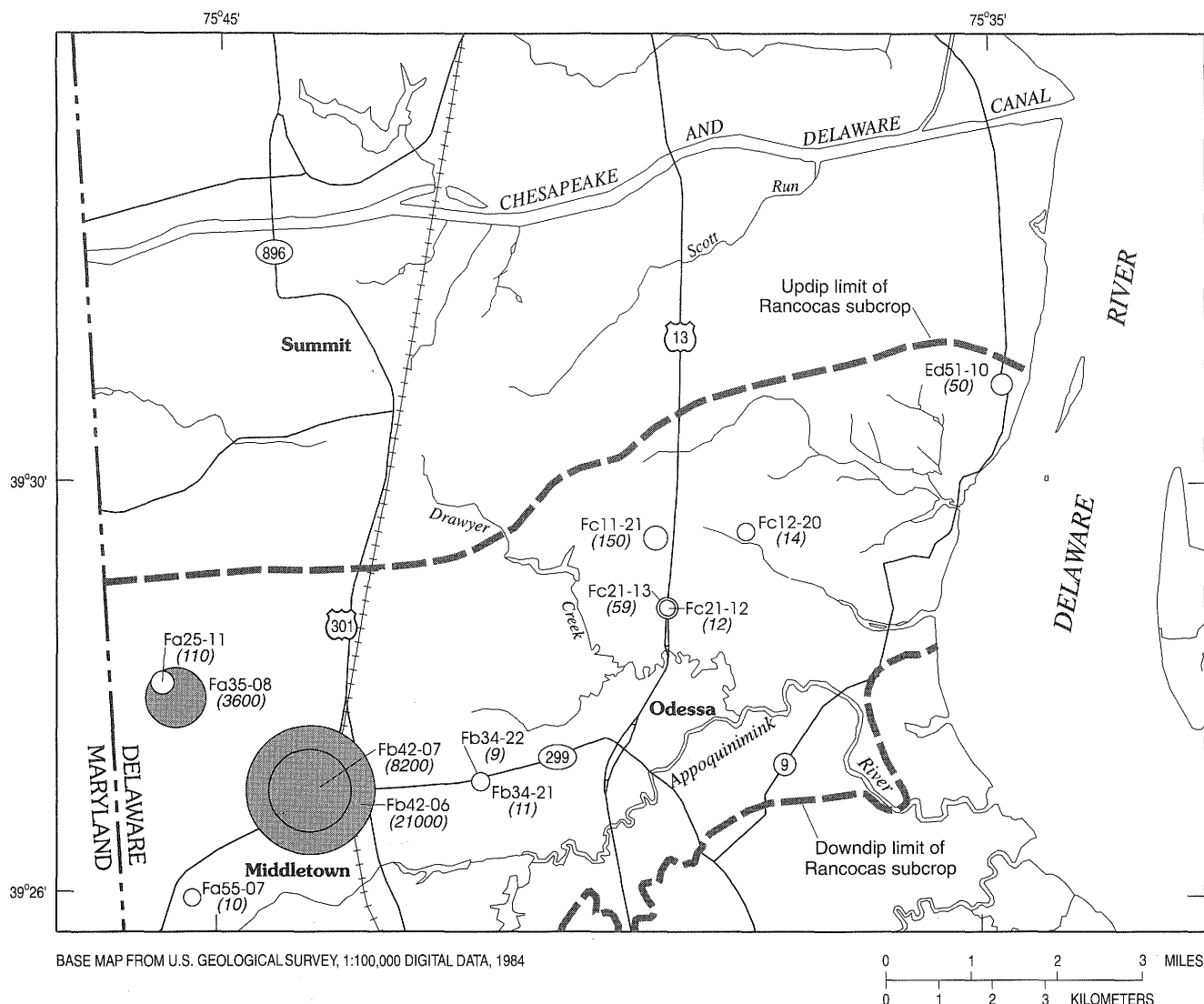
ences in the chemical composition of ground water in the aquifers of the study area. All of the aquifers contain quartz and aluminosilicate minerals, so silicate hydrolysis will result in an enrichment of silica and base cations as the water evolves. Pyrite and lignite are the predominant solid materials that affect water quality in the Magothy and Potomac aquifer system. Glauconite, calcite, and aragonite are more common minerals in the Englishtown-Mt. Laurel

TABLE 7

Values of Spearman's  $\rho$  correlation coefficient for water-quality constituents analyzed in the study area.

The first line is the value of Spearman's  $\rho$ , and the second line is the probability of exceeding that value under the null hypothesis of no correlation ( $\rho=0$ ). Entries in boldface have probability values of  $<0.05$ . Analysis based on 63 water samples.

	Ca	Mg	Na	K	Fe	SiO <sub>2</sub>	Al	SO <sub>4</sub> <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	NO <sub>3</sub>	Cl <sup>-</sup>	D.O.	pH
Ca	1.00 0.00	<b>-0.30</b> <b>0.02</b>	<b>-0.56</b> <b>&lt;0.01</b>	<b>-0.32</b> <b>0.01</b>	0.05 0.69	<b>0.25</b> <b>0.04</b>	<b>-0.28</b> <b>0.03</b>	<b>0.26</b> <b>0.04</b>	<b>0.72</b> <b>&lt;0.01</b>	<b>-0.31</b> <b>0.01</b>	-0.05 0.71	<b>-0.28</b> <b>0.03</b>	<b>0.68</b> <b>&lt;0.01</b>
Mg		1.00 0.00	<b>0.40</b> <b>&lt;0.01</b>	<b>0.66</b> <b>&lt;0.01</b>	0.02 0.85	-0.23 0.07	<b>0.39</b> <b>&lt;0.01</b>	-0.02 0.86	-0.23 0.07	0.15 0.22	-0.00 0.99	0.15 0.25	<b>-0.36</b> <b>&lt;0.01</b>
Na			1.00 0	<b>0.59</b> <b>&lt;0.01</b>	<b>-0.32</b> <b>0.01</b>	<b>-0.41</b> <b>&lt;0.01</b>	0.18 0.16	-0.08 0.54	<b>-0.42</b> <b>&lt;0.01</b>	<b>0.45</b> <b>&lt;0.01</b>	<b>0.26</b> <b>0.04</b>	<b>0.35</b> <b>&lt;0.01</b>	<b>-0.51</b> <b>&lt;0.01</b>
K				1.00 0	0.07 0.59	<b>-0.24</b> <b>0.05</b>	0.21 0.10	0.03 0.79	-0.10 0.44	0.01 0.95	-0.14 0.27	-0.06 0.67	-0.20 0.11
Fe					1.00 0.00	-0.01 0.92	-0.14 0.26	-0.11 0.41	<b>0.40</b> <b>&lt;0.01</b>	<b>-0.75</b> <b>&lt;0.01</b>	<b>-0.65</b> <b>&lt;0.01</b>	<b>-0.69</b> <b>&lt;0.01</b>	<b>0.29</b> <b>0.02</b>
SiO <sub>2</sub>						1.00 0.00	0.04 0.76	0.02 0.85	0.06 0.62	-0.06 0.64	0.13 0.31	-0.10 0.44	0.09 0.46
Al							1.00 0	<b>&lt;0.01</b> 0.99	<b>-0.43</b> <b>&lt;0.01</b>	<b>0.34</b> <b>&lt;0.01</b>	<b>0.32</b> <b>0.01</b>	<b>0.28</b> <b>0.03</b>	<b>-0.42</b> <b>&lt;0.01</b>
SO <sub>4</sub> <sup>-</sup>								1.00 0	-0.06 0.62	0.10 0.44	<b>0.27</b> <b>0.03</b>	0.03 0.85	0.00 0.99
HCO <sub>3</sub> <sup>-</sup>									1.00 0	<b>-0.69</b> <b>&lt;0.01</b>	<b>-0.53</b> <b>&lt;0.01</b>	<b>-0.57</b> <b>&lt;0.01</b>	<b>0.82</b> <b>&lt;0.01</b>
NO <sub>3</sub> <sup>-</sup>										1.00 0	<b>0.69</b> <b>&lt;0.01</b>	<b>0.73</b> <b>&lt;0.01</b>	<b>0.63</b> <b>&lt;0.01</b>
Cl <sup>-</sup>											1.00 0	<b>0.64</b> <b>&lt;0.01</b>	<b>-0.45</b> <b>&lt;0.01</b>
Dissolved Oxygen												1.00 0	<b>-0.48</b> <b>&lt;0.01</b>
pH													1.00 0



### EXPLANATION

Fb42-07 Well number

Wells with dissolved iron concentrations in micrograms per liter ( $\mu\text{g/L}$ ). (Area of circle is proportional to the concentration.)

○ Less than 300

● Equal to or greater than 300

(8200) Dissolved iron concentration in  $\mu\text{g/L}$ .

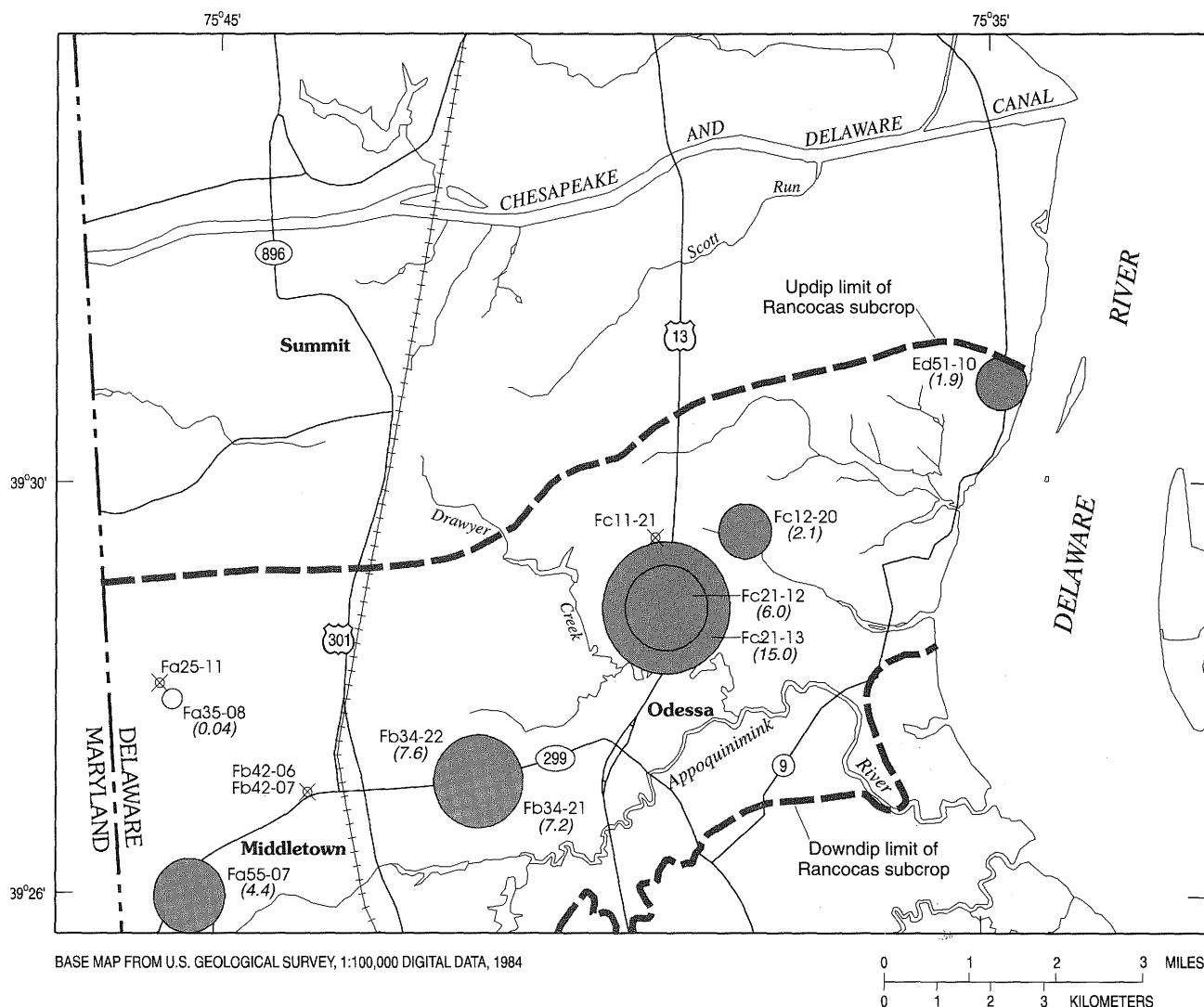
Figure 17. Map showing areal distribution of dissolved iron in the Rancocas aquifer.

aquifer system and in the Rancocas aquifer. Thus, water quality is probably controlled by pyrite dissolution and dissolution and precipitation of ferric oxyhydroxides in the Magothy and Potomac, whereas ion-exchange reactions and dissolution and precipitation of calcium carbonate minerals are the important processes acting in the Englishtown-Mt. Laurel aquifer system and Rancocas aquifer.

The relations among the constituents dissolved in ground water shown in Table 7 generally support the view that

processes shown in Table 6 are those controlling the chemical composition of the water in the study area. Table 7 contains values of Spearman's  $\rho$  correlation coefficient for thirteen water-quality constituents measured in this study. Spearman's  $\rho$  is essentially a correlation coefficient computed on the ranks of the data values (Conover, 1980). A nonparametric correlation coefficient, such as Spearman's  $\rho$  provides a less biased measure of association between variables than does the standard Pearson's correlation coefficient for data that





### EXPLANATION

Fa55-07 Well number

Wells with nitrate-nitrogen concentrations in milligrams per liter (mg/L). (Area of circle is proportional to the concentration.)

⊗ Less than 0.02

○ Equal to or greater than 0.02 and less than 0.4

● Equal to or greater than 0.4

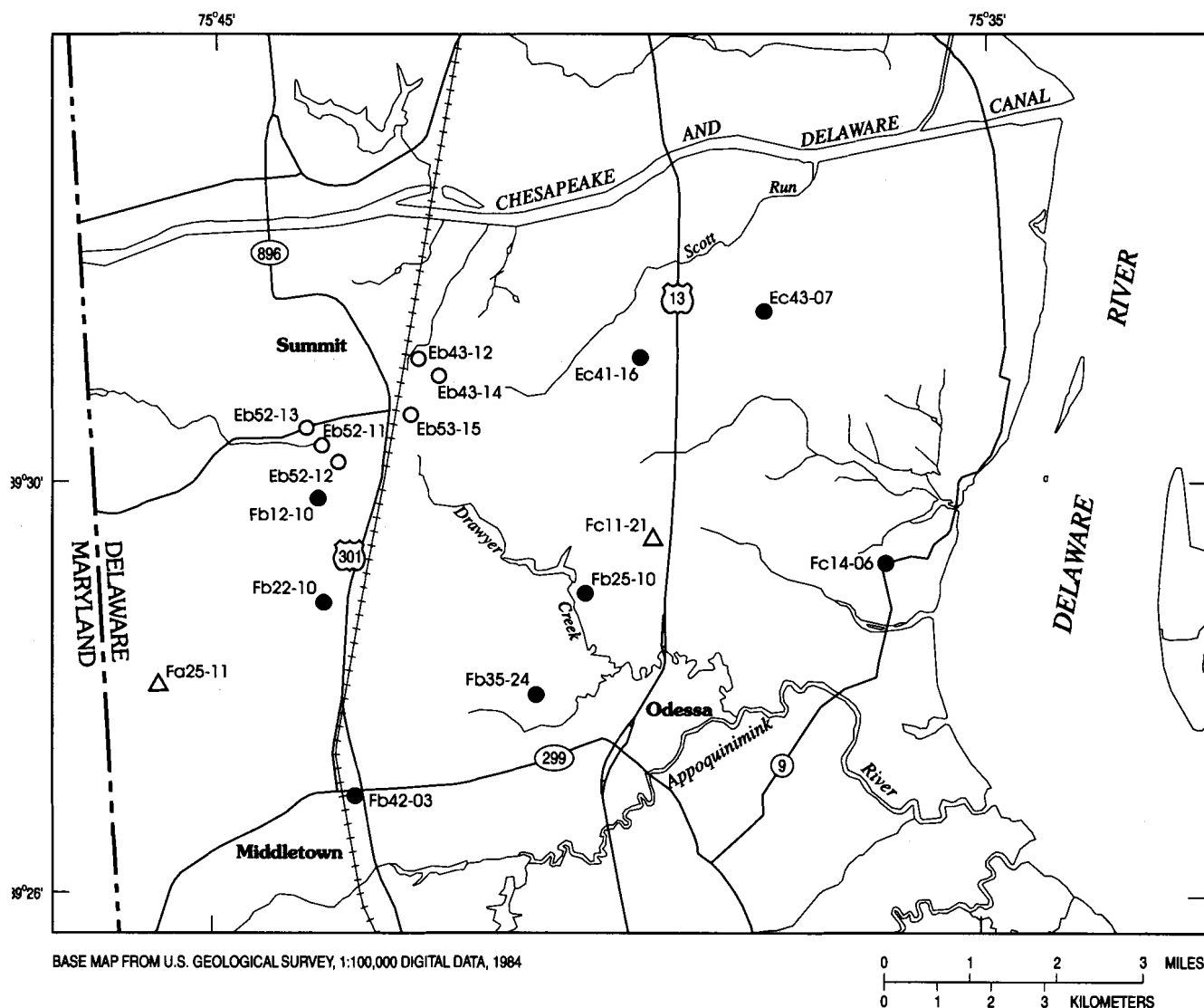
(4.4) Nitrate-nitrogen concentration in mg/L as N.

Figure 18. Map showing areal distribution of dissolved nitrate-nitrogen in the Rancocas aquifer.

have nonnormal distribution and censored values. In the case of the water quality data analyzed here, "censored values" refers to concentrations below the analytical reporting level.

The correlation coefficients in Table 7 are generally consistent with the processes shown in Table 6. Iron, for example, is significantly negatively correlated with nitrate-nitrogen and dissolved oxygen, as would be expected from

the redox chemistry of the three elements (Hem, 1985). Iron is also significantly positively correlated with bicarbonate and pH in accordance with reactions 5 and 6 in Table 6, the dissolution and precipitation of ferric oxyhydroxides. There does not appear to be a corresponding correlation between iron and sulfate. Dissolved iron, though in lower concentrations than in the other units, occurs in waters from the



### EXPLANATION

Fb35-24 Well number

Wells with nitrate-nitrogen concentrations less than 0.40 milligrams per liter (mg/L) and dissolved iron concentrations less than 300 micrograms per liter ( $\mu\text{g/L}$ ).

#### Aquifers :

- Englishtown
- Mt. Laurel
- △ Rancocas

Figure 19. Map showing areal distribution of wells where nitrate-nitrogen concentrations are less than 0.4 mg/L and iron concentrations are less than 300  $\mu\text{g/L}$ .

Englishtown-Mt. Laurel aquifer system and the Rancocas aquifer. These hydrostratigraphic units are not rich in pyrite, dissolved iron is derived from incongruent dissolution of glauconite and ferric oxyhydroxide (Table 6, reactions 6 and 7). Thus, iron in these units is not associated with sulfate. Furthermore, the Magothy and Potomac aquifer system, which does contain pyrite, is largely confined in the study area. The aquifer waters are anoxic, and so pyrite oxi-

dation is not likely. Neither silica and bicarbonate nor silica and magnesium are significantly correlated as would be expected from reactions 3 and 7 of Table 6. It is possible that either these reactions are not important in controlling the chemical composition of ground water in the study area, or the relationships are masked by interference from silica, magnesium, and bicarbonate from other reactions. Silica and potassium are significantly negatively correlated, which

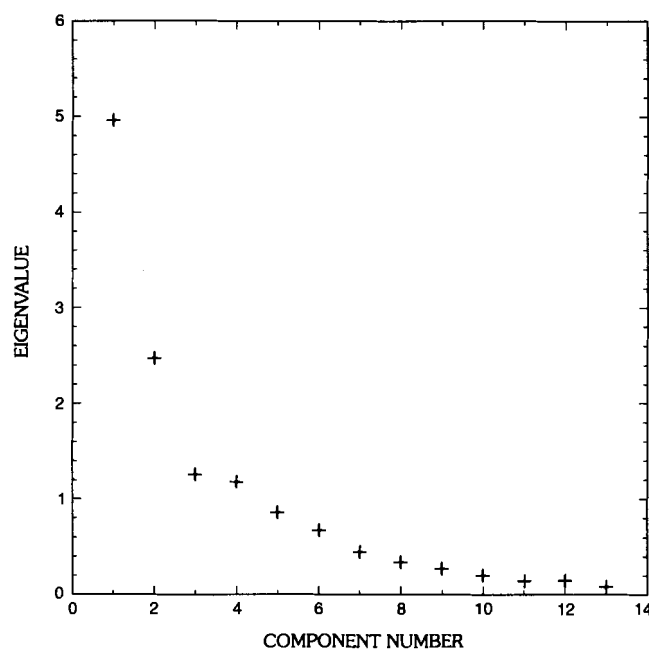


Figure 20. Scree plot of eigenvalues of the Spearman's correlation matrix.

contradicts the expected relation and reactions 3 and 7 of Table 6. Recharge waters tend to be lower in silica than water found in the downgradient part of the aquifer because the extent of mineral-water interactions is less in recharge areas than down gradient. It is possible that potassium from surficial sources such as potash fertilizers (Denver, 1986) or weathering of potassium-rich soil materials (Parker and others, 1989) is the major source of potassium to ground water, and so high potassium waters are generally found in low-silica recharge areas.

The structure of the correlations among the water-quality constituents was further examined using principal components analysis. In this technique, eigenvalues and eigenvectors are extracted from the matrix of correlation coefficients in order to group related variables and thus derive insight into relations among the variables (Davis, 1973) (a detailed explanation of eigenvalues and eigenvectors may be found in Anton (1984)). Each group of variables is called a "component," and accounts for a certain percentage of the total variation of the data. In this study a robust nonparametric principal components analysis was done using the matrix of Spearman's  $\rho$  shown in Table 7. The use of a rank transformation (such as Spearman's  $\rho$ ) applied to a standard parametric statistical technique is a commonly used statistical procedure (Conover, 1980), and it is appropriate in this case where many of the data appear to contain mixed populations, have nonnormal distributions, and have many censored data values. Furthermore, the principal components analysis is done here as an exploratory technique to examine the relations among water-quality constituents and not as a method for probabilistic hypothesis testing.

One of the most difficult parts of conducting a principal components analysis is determining the number of meaningful components (Davis, 1973). One can select as many components as there are variables in the correlation matrix, but most of them account for a small percentage of the total variation. A number of criteria are used to determine the

number of meaningful components to use in an analysis (Norušis, 1985). One method is to select components for which the eigenvalue is greater than 1, another is to select components for which the eigenvalues represent at least 10 percent of the total variance, and a third is to plot the eigenvalues in a so-called "scree plot" (Fig. 20). The eigenvalues that plot above the break in slope on such a plot represent the meaningful components in the analysis. For the data from the study area, the first four eigenvalues were greater than 1, and there appears to be a break in slope between eigenvalues number 4 and 5. Eigenvalues number 3 and 4 however, account for only 9.7 and 9.0 percent of the total variance, respectively. In the analysis shown here, four components were extracted, but the significance of the third and fourth components is uncertain.

The pattern of principal component loadings is shown in Table 8. Component 1 accounts for about 38 percent of the total variance. It includes nitrate and iron and the inorganic constituents associated with dissolution and precipitation of ferric oxyhydroxide (Table 6, reactions 5 and 6) and nitrification of ammonia (Table 6, reaction 10). The loadings of nitrate and iron are of opposite signs, which reflects their inverse correlation. Chloride also loads in this component, which reflects its strong correlation with nitrate (Table 7). No minerals in the aquifers of the study area contain appreciable amounts of chloride. It enters ground water as sea spray aerosols in precipitation, by dissolution of potash fertilizer (KCl) applied to agricultural fields, and as recharge from on-site wastewater disposal systems and deicing salt. Fertilizer and septic tank effluent are also sources of nitrate to ground water, but the fact that potassium does not have a very high loading on component 1 is evidence that effluent from on-site wastewater disposal systems may be a source of chloride and nitrate to the aquifers of the study area.

The other components are more difficult to interpret. Component 2 consists of potassium, magnesium, and sodium. It accounts for 19 percent of the total variance. Potassium enters ground water from dissolution of potash fertilizer. Magnesium enters ground-water from dissolution of dolomite applied on fields as agricultural lime. The association of sodium with potassium and magnesium could not be interpreted with the available data. Component 3 consists of calcium and sulfate with secondary loadings on pH and

TABLE 8

Pattern of principal component loadings.

Only loadings with an absolute value of more than 0.5 are shown.

Rank of	Component 1	Component 2	Component 3	Component 4
Nitrate	0.90			
Chloride	0.86			
Dissolved Oxygen	0.84			
pH	-0.57		0.54	
Bicarbonate	-0.67		0.53	
Iron	-0.86			
Potassium		0.86		
Magnesium		0.85		
Sodium		0.54		0.51
Aluminum				0.51
Calcium			0.81	
Sulfate			0.68	
Silica				0.75

bicarbonate. It accounts for 9.7 percent of the total variation. Component 3 may be related to dissolution and precipitation of calcium carbonate minerals, although it is unclear why sulfate would be associated with the other constituents. Component 4 consists of silica with secondary loadings on sodium and aluminum. This component may represent dissolution of aluminosilicate minerals, although it is unclear why magnesium would be associated with this component and why sodium and calcium have low loadings. The most common aluminosilicate minerals in the aquifers of the study area are microcline and oligoclase feldspar (Owens and Denny, 1979), which contain potassium, calcium, and sodium, but not magnesium. As mentioned previously, the selection of meaningful components is a subjective process. Given that components 3 and 4 each represent only 9 to 10 percent of the total variation of the data, it is possible that components 3 and 4 are not meaningful.

Dissolved radon was not included in the principal components analysis because of the small number of samples collected. Radon is derived from radioactive decay of uranium, and uranium may substitute for the large cations, such as potassium in the mineral structure of glauconite. Elevated uranium concentrations of glauconitic sediments in the study area were reported by Woodruff and others, 1992. This may explain the elevated radon concentrations found in the Englishtown-Mt. Laurel and Rancocas, both of which contain glauconite. More data are needed to assess the geochemical controls on the occurrence and distribution of radon in the aquifers of the Delaware Coastal Plain.

## SUMMARY AND CONCLUSIONS

Water samples collected from 63 wells finished in the Coastal Plain aquifers of southern New Castle County indicate considerable degradation of water quality from both natural and anthropogenic sources. However, most of the samples are currently within the criteria set by USEPA for safe drinking water. "Natural" water quality is also related to the hydrostratigraphic division from which the water sample was collected.

Naturally-occurring constituents that can degrade water quality include dissolved iron and radon. Dissolved iron is mainly a problem in confined parts of the aquifer systems, where anoxic conditions favor dissolution of glauconite in the Englishtown-Mt. Laurel aquifer system and Rancocas aquifer and dissolution of ubiquitous ferric oxyhydroxides throughout all the hydrostratigraphic divisions. Forty percent of the samples exceeded the USEPA SMCL for iron of 300 µg/L, and concentrations were as high as 21,000 µg/L. High iron concentrations were found in all hydrostratigraphic divisions, but in the Magothy and Potomac aquifer system, all of the samples were above the SMCL. In general, high iron concentrations are found in confined parts of each aquifer. Radon concentrations above a proposed USEPA MCL of 300 pCi/L are found exclusively in the Englishtown-Mt. Laurel aquifer system and the Rancocas aquifer. The highest concentration found was 1,700 pCi/L. The data collected here are insufficient for a more detailed assessment of radon occurrence. However, radon appears to be related to the occurrence of glauconite, and it may be derived from decay of uranium ions substituting for other ions in the glauconite mineral structure.

Anthropogenic constituents that can degrade water quality include nitrate and other chemicals applied to the land surface such as fertilizers, pesticides, and wastewater effluent, and chemicals that leak from storage tanks. In addition, heavy pumpage from aquifers near brackish-water bodies such as the Delaware River and C&D Canal can cause reversals of head gradients and induce brackish water intrusion into aquifers near the brackish water bodies.

Only 3 of 63 samples have nitrate-nitrogen values that exceed the USEPA MCL of 10 mg/L. However, concentrations above 0.4 mg/L probably reflect a human source of nitrate, and 20 of the 63 samples exceed that concentration. No samples were collected for analysis of pesticides or other potentially toxic chemicals. The common presence of anthropogenic nitrate-nitrogen, however, is evidence that other chemicals have the potential to enter parts of the aquifers in the study area. Nitrate-nitrogen concentrations in the Magothy and Potomac aquifer system are all below 0.4 mg/L. Concentrations in the Englishtown-Mt. Laurel and Rancocas range from below 0.4 mg/L to 15 mg/L. Where nitrate concentrations are low, the iron concentrations are typically above the USEPA SMCL of 300 µg/L. Only 16 of 63 samples contain a combination of low (<0.4 mg/L) nitrate concentrations and low (<300 µg/L) iron concentrations. All of the low-concentration samples were collected from unconfined parts of the Englishtown-Mt. Laurel and Rancocas and may be vulnerable to water quality degradation if land uses change and chemicals are applied to the land upgradient from the well.

No evidence was found for brackish-water intrusion into aquifers near brackish water bodies; however, the sampling network did not include any wells close to the Delaware River or C&D Canal, nor has research been conducted to document ground-water flow patterns in the Rancocas and Magothy aquifers and the Englishtown-Mt. Laurel aquifer system. More investigation also is needed to describe the hydraulic characteristics of these units and evaluate the potential for contamination from brackish-water bodies.

Degraded water quality is possible in all of the ground-water supplies in southern New Castle County. The deeper aquifers have widespread problems with high concentrations of dissolved iron. The shallow aquifers are vulnerable to contamination by chemicals applied to the land in recharge areas. Aquifers in marine deposits, such as the Englishtown-Mt. Laurel and Rancocas contain dissolved radon. Ensuring an adequate supply of potable water in southern New Castle County will require treatment of iron and may require treatment of radon-bearing water and control of land use to prevent application of chemicals in recharge areas of the shallow aquifers.

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## APPENDICES

### APPENDIX 1

Conversion factors, vertical datum, abbreviated water-quality units, and product disclaimer

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi <sup>2</sup> )	2.590	square kilometer

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

Chemical concentrations, water temperature, and specific conductance are given in metric units. Chemical concentration is expressed in milligrams per liter (mg/L), micrograms per liter (µg/L), or milliequivalents per liter (meq/L).

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by using the equation:

$$^{\circ}\text{F} = 1.8 (^{\circ}\text{C}) + 32$$

Specific conductance is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

Radioactivity is expressed in picocuries per liter (pCi/L). A picocurie is one-trillionth ( $1 \times 10^{-12}$ ) the amount of radioactivity represented by a curie (Ci). A curie is the amount of radioactivity that yields  $3.7 \times 10^{10}$  radioactive disintegrations per second. A picocurie yields 2.22 disintegrations per minute.

Use of trade names in this report does not imply endorsement by the U.S. Geological Survey or the Delaware Geological Survey.

### APPENDIX 2

Well records and chemical analyses of ground water in southern New Castle County.

Abbreviations for units of chemical analyses:

mg/L-milligrams per liter  
 µg/L-micrograms per liter  
 µS/cm-microsiemens per centimeter at 25 degrees Celsius  
 pCi/L-picocuries per liter

Well-Types:

O - Observation well  
 P-Public water-supply well  
 D-Domestic water-supply well

Aquifers:

Potomac-Magothy aquifer system  
 pt - Potomac Formation  
 m - Magothy Formation

Englishtown-Mt. Laurel aquifer system

et - Englishtown Formation  
 ml - Mt. Laurel Formation

Rancocas aquifer

rn - Rancocas aquifer

Columbia Formation

cl - Columbia Formation

**NOTE:** Only one well, Ea44-12, was finished in the Columbia Formation. At that location, the Columbia is in hydraulic connection with the Englishtown-Mt. Laurel aquifer system, and so concentrations from Ea44-12 were included as part of the data from the Englishtown-Mt. Laurel aquifer system.

## APPENDIX 2

Well records and chemical analyses of ground water in southern New Castle County.

DGS well number	Date of sample	Latitude	Longitude	Well type	Aquifer	Water level, in ft. below land surface	Total depth of well, in ft. below land surface	Depth of top of screen, in ft. below land surface	Depth of bottom of screen, in ft. below land surface
Ea44-11	06-18-92	39° 31' 34"	075° 46' 01"	P	m	38.82	97	—	—
Ea44-12	06-18-92	39° 31' 34"	075° 46' 02"	P	cl	6.38	22	—	—
Eb32-22	06-17-92	39° 32' 11"	075° 43' 34"	D	et	—	26	—	—
Eb41-13	09-06-91	39° 31' 50"	075° 44' 04"	D	m	51.40	145	125	145
Eb42-03	06-18-92	39° 31' 43"	075° 44' 01"	P	m	57.63	—	—	—
Eb43-04	09-04-91	39° 31' 04"	075° 42' 50"	D	m	—	225	210	225
Eb43-05	06-17-92	39° 30' 59"	075° 42' 13"	D	m	—	190	180	190
Eb43-09	09-10-91	39° 31' 20"	075° 42' 47"	D	et	—	38	28	38
Eb43-11	09-09-91	39° 31' 06"	075° 42' 22"	D	ml	—	39	35	39
Eb43-12	09-03-91	39° 31' 10"	075° 42' 21"	D	et	—	110	50	90
Eb43-13	09-12-91	39° 31' 13"	075° 42' 19"	D	m	—	177	165	177
Eb43-14	09-06-91	39° 31' 00"	075° 42' 05"	D	et	30.91	138	128	138
Eb44-19	11-09-92	39° 31' 56"	075° 41' 31"	O	ml	38.15	45	40	45
Eb45-26	09-10-91	39° 31' 44"	075° 40' 35"	D	ml	—	65	55	65
Eb45-27	08-30-91	39° 31' 43"	075° 40' 34"	D	ml	—	80	70	80
Eb51-10	08-29-91	39° 30' 13"	075° 44' 52"	D	et	—	60	50	60
Eb51-11	06-18-92	39° 30' 25"	075° 44' 15"	P	m	—	177	155	177
Eb52-11	09-09-91	39° 30' 18"	075° 43' 34"	D	et	7.34	80	60	80
Eb52-12	08-29-91	39° 30' 08"	075° 43' 22"	D	et	8.07	90	70	90
Eb52-13	09-11-91	39° 30' 28"	075° 43' 47"	D	et	—	70	50	70
Eb53-15	09-06-91	39° 30' 37"	075° 42' 27"	D	et	—	75	65	75
Eb54-05	08-29-91	39° 30' 07"	075° 41' 06"	D	ml	—	45	38	45
Eb54-09	09-09-91	39° 30' 54"	075° 41' 57"	D	ml	13.63	75	65	75
Ec31-21	09-11-91	39° 32' 12"	075° 39' 57"	D	m	—	185	165	185
Ec32-16	09-10-91	39° 32' 54"	075° 38' 48"	D	ml	—	70	60	70
Ec34-03	09-10-91	39° 32' 48"	075° 36' 55"	D	pt	—	317	300	317
Ec41-16	11-09-92	39° 31' 12"	075° 39' 27"	O	ml	15.40	44	39	44
Ec43-07	09-09-91	39° 31' 39"	075° 37' 50"	D	ml	30.10	130	120	130
Ec43-08	09-11-91	39° 31' 41"	075° 37' 25"	D	ml	—	96	88	96
Ec43-09	09-05-91	39° 31' 11"	075° 37' 43"	D	ml	37.10	120	110	120
Ec51-15	09-12-91	39° 30' 13"	075° 39' 35"	D	ml	—	141	76	141
Ec51-16	09-04-91	39° 30' 37"	075° 39' 13"	P	ml	—	180	120	180
Ec52-09	09-04-91	39° 30' 09"	075° 38' 39"	P	ml	—	160	100	160
Ec53-05	09-05-91	39° 30' 53"	075° 37' 40"	D	ml	—	73	63	73
Ed21-20	09-10-91	39° 33' 14"	075° 34' 55"	D	m	—	230	214	230
Ed51-10	09-12-91	39° 30' 58"	075° 34' 46"	D	rn	—	30	25	30
Fa15-05	09-04-91	39° 29' 23"	075° 45' 48"	P	m	—	210	180	210
Fa25-11	06-17-92	39° 28' 00"	075° 45' 44"	D	rn	—	90	80	90
Fa35-08	09-06-91	39° 27' 51"	075° 45' 34"	D	rn	—	95	87	95
Fa55-07	09-09-91	39° 25' 54"	075° 45' 19"	D	rn	—	100	20	100
Fb12-10	09-11-91	39° 29' 48"	075° 43' 39"	D	ml	—	100	90	100
Fb22-10	08-29-91	39° 28' 47"	075° 43' 34"	D	ml	—	113	110	113
Fb25-10	09-03-91	39° 28' 54"	075° 40' 09"	D	ml	—	150	130	150
Fb33-12	09-05-91	39° 27' 13"	075° 43' 00"	P	m	—	345	325	345
Fb33-24	08-30-91	39° 27' 08"	075° 42' 57"	P	pt	—	540	460	536
Fb33-25	09-03-91	39° 27' 08"	075° 42' 57"	P	pt	—	846	800	846
Fb34-21	11-03-92	39° 27' 04"	075° 41' 33"	O	rn	31.50	72	67	72
Fb34-22	11-04-92	39° 27' 04"	075° 41' 33"	O	rn	31.39	40	35	40
Fb35-24	09-09-91	39° 27' 55"	075° 40' 47"	D	ml	40.10	155	145	155
Fb42-03	09-05-91	39° 26' 55"	075° 43' 08"	P	ml	—	206	133	206
Fb42-06	11-02-92	39° 26' 57"	075° 43' 47"	O	rn	14.08	71	66	71
Fb42-07	11-03-92	39° 26' 57"	075° 43' 47"	O	rn	14.25	40	35	40
Fb43-03	09-05-91	39° 26' 17"	075° 42' 48"	P	m	—	375	326	375
Fc11-19	09-04-91	39° 29' 08"	075° 40' 01"	D	ml	—	194	184	194
Fc11-20	08-30-91	39° 29' 13"	075° 39' 46"	D	ml	—	117	107	117
Fc11-21	09-03-91	39° 29' 27"	075° 39' 16"	D	rn	—	54	47	54
Fc11-22	09-05-91	39° 29' 26"	075° 39' 14"	D	ml	52.50	155	145	155
Fc12-13	09-06-91	39° 30' 00"	075° 38' 26"	D	ml	—	120	110	120
Fc12-14	09-06-91	39° 29' 53"	075° 38' 15"	D	ml	43.67	170	150	170
Fc12-20	11-09-92	39° 29' 31"	075° 38' 06"	O	rn	24.06	35	30	35
Fc14-06	09-11-91	39° 29' 13"	075° 36' 13"	D	ml	—	150	140	150
Fc21-12	11-04-92	39° 28' 46"	075° 39' 07"	O	rn	29.68	65	60	65
Fc21-13	11-04-92	39° 28' 16"	075° 39' 07"	O	rn	28.68	40	35	40

# APPENDIX 2

Well records and chemical analyses of ground water in southern New Castle County (continued).

DGS well number	Date of sample	Altitude of land surface in ft. above sea level	Depth of hole, in ft.	Specific conductance, in $\mu\text{S}/\text{cm}$	pH	Temperature, in degrees Celsius	Oxygen, dissolved mg/L	Calcium, dissolved mg/L as Ca	Magnesium, dissolved mg/L as Mg
Ea44-11	06-18-92	40	—	135	5.8	13.5	0.2	10	4.0
Ea44-12	06-18-92	40	23	225	5.4	13.5	8.1	12	12
Eb32-22	06-17-92	70	—	295	6.0	15.0	5.8	18	13
Eb41-13	09-06-91	70	145	137	6.5	15.0	0.8	14	3.1
Eb42-03	06-18-92	70	—	176	6.1	14.0	0.2	20	3.7
Eb43-04	09-04-91	72	230	226	7.0	14.0	1.4	31	5.6
Eb43-05	06-17-92	60	190	229	7.2	16.5	0.1	31	6.3
Eb43-09	09-10-91	62	38	311	5.6	16.0	4.6	19	8.3
Eb43-11	09-09-91	65	39	186	6.3	15.0	7.0	26	1.7
Eb43-12	09-03-91	50	110	261	7.7	15.0	—	46	2.5
Eb43-13	09-12-91	50	177	236	7.3	14.5	0.0	33	6.2
Eb43-14	09-06-91	71	138	252	7.7	14.0	0.6	41	4.1
Eb44-19	11-09-92	65	45	312	6.1	9.0	8.2	42	3.2
Eb45-26	09-10-91	60	65	128	6.0	17.5	9.7	12	2.3
Eb45-27	08-30-91	73	80	132	6.4	16.5	5.0	16	1.2
Eb51-10	08-29-91	52	60	342	6.5	16.0	8.5	38	1.9
Eb51-11	06-18-92	45	177	177	6.7	14.0	3.9	24	4.4
Eb52-11	09-09-91	61	80	253	7.5	14.0	0.2	47	1.4
Eb52-12	08-29-91	65	90	235	6.3	18.5	0.8	43	1.3
Eb52-13	09-11-91	65	70	215	7.5	15.5	1.3	39	1.2
Eb53-15	09-06-91	70	75	208	7.7	15.5	0.7	37	1.5
Eb54-05	08-29-91	66	65	210	6.3	16.0	5.7	25	5.7
Eb54-09	09-09-91	71	75	199	7.4	14.0	1.6	35	1.5
Ec31-21	09-11-91	60	185	207	7.0	16.5	0.5	24	5.0
Ec32-16	09-10-91	52	70	1130	5.7	15.0	9.1	32	16
Ec34-03	09-10-91	15	317	160	6.7	16.0	0.0	13	3.3
Ec41-16	11-09-92	50	45	328	7.7	13.5	8.7	58	2.8
Ec43-07	09-09-91	55	130	272	7.6	13.5	0.2	44	4.1
Ec43-08	09-11-91	49	96	246	7.2	16.0	2.9	43	1.8
Ec43-09	09-05-91	52	120	277	7.4	14.5	0.6	50	1.8
Ec51-15	09-12-91	52	141	261	7.5	14.0	0.1	46	2.4
Ec51-16	09-04-91	55	180	206	7.1	13.0	3.3	35	1.6
Ec52-09	09-04-91	62	160	258	6.6	16.5	1.0	42	3.4
Ec53-05	09-05-91	20	73	254	7.6	14.5	0.5	45	1.6
Ed21-20	09-10-91	7	230	276	7.3	15.0	—	12	2.8
Ed51-10	09-12-91	11	30	260	5.2	14.0	—	8.4	5.0
Fa15-05	09-04-91	58	210	162	6.7	14.5	1.1	19	4.1
Fa25-11	06-17-92	60	90	236	7.3	15.0	0.1	41	2.0
Fa35-08	09-06-91	64	95	165	7.5	15.5	0.7	36	2.3
Fa55-07	09-09-91	65	100	86	5.9	18.5	3.4	5.3	2.7
Fb12-10	09-11-91	72	100	242	7.6	15.0	3.1	43	2.3
Fb22-10	08-29-91	71	113	252	7.5	15.5	0.6	44	1.8
Fb25-10	09-03-91	42	152	268	7.9	19.0	1.7	42	4.2
Fb33-12	09-05-91	70	345	206	7.2	15.5	0.9	18	4.1
Fb33-24	08-30-91	70	540	180	6.9	17.5	0.6	14	3.3
Fb33-25	09-03-91	70	846	180	7.2	19.5	0.8	2.1	0.40
Fb34-21	11-03-92	60	80	128	5.8	15.5	6.0	7.8	3.0
Fb34-22	11-04-92	60	40	340	5.8	14.5	10.5	11	9.1
Fb35-24	09-09-91	56	155	256	7.6	15.0	1.2	43	3.4
Fb42-03	09-05-91	65	206	239	7.6	16.0	0.9	38	3.5
Fb42-06	11-02-92	60	85	173	6.6	13.5	0.5	11	4.7
Fb42-07	11-03-92	60	40	137	6.6	14.5	2.6	9.8	4.8
Fb43-03	09-05-91	30	375	235	7.5	16.0	0.7	8.4	2.0
Fc11-19	09-04-91	50	194	261	7.4	13.5	0.5	45	3.0
Fc11-20	08-30-91	48	117	254	7.8	14.5	0.7	44	2.8
Fc11-21	09-03-91	68	54	203	7.8	15.5	0.9	40	2.1
Fc11-22	09-05-91	67	155	183	7.6	15.5	0.7	37	1.9
Fc12-13	09-06-91	50	120	236	7.6	14.5	0.6	40	2.6
Fc12-14	09-06-91	50	170	241	7.5	15.5	0.7	41	2.5
Fc12-20	11-09-92	40	38	166	5.2	15.0	8.4	10	4.1
Fc14-06	09-11-91	9	150	268	7.6	19.0	1.0	40	5.5
Fc21-12	11-04-92	40	75	109	5.5	15.0	4.4	7.9	2.3
Fc21-13	11-04-92	40	40	446	5.1	14.0	10.8	28	9.5



## APPENDIX 2

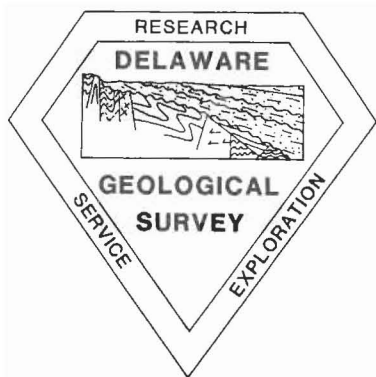
Well records and chemical analyses of ground water in southern New Castle County (continued).

DGS well number	Date of sample	Sodium, dissolved mg/L as Na	Potassium, dissolved mg/L as K	Bicarbonate, field, mg/L as $\text{HCO}_3^-$	Sulfate, dissolved mg/L as $\text{SO}_4^{2-}$	Chloride, dissolved mg/L as $\text{Cl}^-$	Fluoride, dissolved mg/L as $\text{F}^-$	Silica, dissolved mg/l as $\text{SiO}_2$
Ea44-11	06-18-92	3.9	2.7	60	5.0	1.9	0.20	18
Ea44-12	06-18-92	4.0	3.0	5	22.0	15.0	<0.10	14
Eb32-22	06-17-92	13	5.1	19	42.0	28.0	<0.10	10
Eb41-13	09-06-91	3.3	2.1	63	6.4	1.7	0.20	15
Eb42-03	06-18-92	4.0	2.4	87	7.0	5.2	0.20	16
Eb43-04	09-04-91	3.6	3.9	135	4.7	1.7	0.20	7.6
Eb43-05	06-17-92	5.2	5.1	141	4.0	1.6	0.20	8.8
Eb43-09	09-10-91	14	16	18	35.0	41.0	<0.10	12
Eb43-11	09-09-91	4.6	1.6	59	8.1	10.0	0.20	17
Eb43-12	09-03-91	3.2	2.2	155	6.6	2.0	0.20	17
Eb43-13	09-12-91	4.6	4.6	143	3.9	1.6	0.20	8.8
Eb43-14	09-06-91	3.1	3.2	137	6.4	1.8	0.20	15
Eb44-19	11-09-92	8.0	2.5	35	80.0	5.6	0.30	15
Eb45-26	09-10-91	5.6	2.3	48	1.6	12.0	<0.10	14
Eb45-27	08-30-91	5.2	1.9	50	1.9	7.3	0.20	15
Eb51-10	08-29-91	22	2.5	52	28.0	23.0	0.20	13
Eb51-11	06-18-92	3.0	2.8	104	5.4	2.3	0.20	12
Eb52-11	09-09-91	2.9	1.7	118	13.0	3.3	0.20	15
Eb52-12	08-29-91	2.7	1.8	120	11.0	4.2	0.40	18
Eb52-13	09-11-91	2.8	1.5	122	15.0	3.3	0.20	14
Eb53-15	09-06-91	2.4	1.4	106	9.2	2.8	0.40	15
Eb54-05	08-29-91	3.8	2.4	40	18.0	15.0	0.10	14
Eb54-09	09-09-91	3.0	1.4	102	5.4	5.2	0.50	15
Ec31-21	09-11-91	5.8	4.7	109	5.5	1.4	0.20	7.8
Ec32-16	09-10-91	160	0.9	20	28.0	300.0	<0.10	11
Ec34-03	09-10-91	4.0	3.1	98	2.3	1.9	0.20	8.1
Ec41-16	11-09-92	3.2	2.1	138	12.0	17.0	0.40	15
Ec43-07	09-09-91	4.0	3.3	148	8.4	5.1	0.30	12
Ec43-08	09-11-91	3.0	1.3	111	8.7	6.2	0.30	12
Ec43-09	09-05-91	3.2	1.4	170	8.2	6.1	0.40	16
Ec51-15	09-12-91	3.1	1.7	146	9.1	3.2	0.40	18
Ec51-16	09-04-91	3.4	1.1	115	4.1	4.5	0.30	16
Ec52-09	09-04-91	3.6	4.0	144	8.7	3.9	0.40	22
Ec53-05	09-05-91	3.1	1.8	151	9.6	5.5	0.40	18
Ed21-20	09-10-91	40	5.0	113	6.9	19	0.20	7.6
Ed51-10	09-12-91	28	4.0	13	48	28	<0.10	28
Fa15-05	09-04-91	2.7	2.6	82	6.8	1.9	0.30	13
Fa25-11	06-17-92	3.3	4.0	106	22	6.1	0.50	28
Fa35-08	09-06-91	3.3	3.8	102	20	3.6	0.50	27
Fa55-07	09-09-91	4.9	2.3	33	<0.20	4.3	<0.10	24
Fb12-10	09-11-91	2.6	2.2	133	10	3.9	0.30	21
Fb22-10	08-29-91	3.2	3.7	105	20	7.2	0.20	30
Fb25-10	09-03-91	6.7	4.1	151	3.2	2.5	0.30	17
Fb33-12	09-05-91	22	7.0	143	9.0	0.90	0.20	7.8
Fb33-24	08-30-91	14	6.1	109	7.3	1.0	0.20	7.8
Fb33-25	09-03-91	38	2.7	101	8.7	1.8	0.20	8.6
Fb34-21	11-03-92	7.6	3.6	11	0.30	11	<0.10	21
Fb34-22	11-04-92	34	3.1	33	15	64	<0.10	14
Fb35-24	09-09-91	3.0	3.7	146	8.4	2.2	0.30	23
Fb42-03	09-05-91	3.1	3.8	115	9.6	2.2	0.20	17
Fb42-06	11-02-92	2.8	2.7	67	10	2.5	0.30	24
Fb42-07	11-03-92	3.7	2.7	57	3.4	3.2	0.30	34
Fb43-03	09-05-91	40	5.0	117	9.6	0.80	0.30	7.6
Fc11-19	09-04-91	3.3	3.2	160	9.5	2.9	0.40	19
Fc11-20	08-30-91	3.3	2.5	143	4.8	2.2	0.40	18
Fc11-21	09-03-91	3.5	1.5	132	5.9	6.0	0.30	13
Fc11-22	09-05-91	3.1	1.6	118	4.4	4.4	0.30	15
Fc12-13	09-06-91	3.0	2.6	117	5.3	2.2	0.40	18
Fc12-14	09-06-91	3.4	2.4	154	4.2	2.4	0.40	17
Fc12-20	11-09-92	7.5	3.7	6	0.50	39	<0.10	15
Fc14-06	09-11-91	7.5	4.8	151	3.2	2.2	0.40	15
Fc21-12	11-04-92	5.3	3.4	13	2.2	10	<0.10	16
Fc21-13	11-04-92	32	4.0	11	0.30	88	<0.10	15

## APPENDIX 2

Well records and chemical analyses of ground water in southern New Castle County (continued).

DGS well number	Date of sample	Nitrogen, NO <sub>2</sub> <sup>-</sup> + NO <sub>3</sub> mg/L as N	Nitrogen, ammonia + organic, mg/L as N	Aluminum, dissolved µg/L as Al	Iron, dissolved µg/L as Fe	Manganese, dissolved µg/L as Mn	Radon 222, Total pCi/L	Carbon, organic, dissolved mg/L as C
Ea44-11	06-18-92	0.030	0.25	10	8,500	180	110	—
Ea44-12	06-18-92	12.0	<0.20	30	44	44	490	<0.2
Eb32-22	06-17-92	7.70	<0.20	30	22	<5	210	0.7
Eb41-13	09-06-91	0.020	<0.20	<10	6,000	120	—	0.6
Eb42-03	06-18-92	<0.020	0.21	20	5,400	130	150	<0.2
Eb43-04	09-04-91	<0.020	0.25	<10	2,000	30	—	0.4
Eb43-05	06-17-92	0.310	0.51	30	1,200	14	100	<0.2
Eb43-09	09-10-91	4.90	<0.20	<10	10	10	1,700	0.6
Eb43-11	09-09-91	9.50	<0.20	<10	50	10	—	0.3
Eb43-12	09-03-91	<0.020	<0.20	<10	250	10	—	0.4
Eb43-13	09-12-91	<0.020	<0.20	<10	1,200	10	—	0.4
Eb43-14	09-06-91	<0.020	0.20	<10	210	10	—	0.8
Eb44-19	11-09-92	9.40	<0.20	20	10	14	440	1.2
Eb45-26	09-10-91	6.60	<0.20	10	10	301	400	0.3
Eb45-27	08-30-91	3.80	0.20	10	20	10	—	0.3
Eb51-10	08-29-91	14.0	<0.20	<10	30	10	—	0.5
Eb51-11	06-18-92	0.020	<0.20	30	3,900	75	190	<0.2
Eb52-11	09-09-91	<0.020	<0.20	<10	240	10	—	0.3
Eb52-12	08-29-91	<0.020	<0.20	<10	190	40	—	1.4
Eb52-13	09-11-91	0.030	<0.20	10	170	20	360	0.2
Eb53-15	09-06-91	<0.020	<0.20	<10	150	20	—	0.4
Eb54-05	08-29-91	5.60	<0.20	10	10	<10	—	0.4
Eb54-09	09-09-91	1.50	<0.20	<10	40	10	—	0.3
Ec31-21	09-11-91	<0.020	0.30	<10	1,400	30	130	0.5
Ec32-16	09-10-91	7.40	<0.20	<10	50	10	—	0.7
Ec34-03	09-10-91	<0.020	<0.20	10	14,000	140	—	0.5
Ec41-16	11-09-92	0.090	<0.20	20	100	280	150	0.4
Ec43-07	09-09-91	<0.020	<0.20	<10	210	10	—	0.4
Ec43-08	09-11-91	2.20	<0.20	<10	90	10	—	0.2
Ec43-09	09-05-91	<0.020	<0.20	10	1,400	30	—	0.5
Ec51-15	09-12-91	<0.020	<0.20	<10	700	20	—	0.5
Ec51-16	09-04-91	2.20	<0.20	<10	40	<10	—	1.9
Ec52-09	09-04-91	0.020	0.22	10	1,300	50	—	0.5
Ec53-05	09-05-91	<0.020	<0.20	<10	1,600	20	—	0.3
Ed21-20	09-10-91	<0.020	<0.20	<10	1,600	10	89	0.6
Ed51-10	09-12-91	1.90	<0.20	<10	50	60	—	0.8
Fa15-05	09-04-91	<0.020	<0.20	<10	5,200	110	—	0.5
Fa25-11	06-17-92	<0.020	<0.20	30	110	8	540	<0.2
Fa35-08	09-06-91	0.040	<0.20	<10	3,600	40	—	0.8
Fa55-07	09-09-91	4.40	<0.20	<10	10	<10	—	0.4
Fb12-10	09-11-91	<0.020	<0.20	<10	240	20	—	0.3
Fb22-10	08-29-91	0.030	<0.20	10	230	20	—	0.4
Fb25-10	09-03-91	<0.020	<0.20	10	70	20	—	0.5
Fb33-12	09-05-91	<0.020	0.37	<10	750	10	—	0.6
Fb33-24	08-30-91	<0.020	0.25	<10	2,400	50	—	1.2
Fb33-25	09-03-91	<0.020	0.20	<10	950	30	—	0.6
Fb34-21	11-03-92	7.20	<0.20	<20	11	220	—	0.1
Fb34-22	11-04-92	7.60	<0.20	<20	9	330	330	1.7
Fb35-24	09-09-91	<0.020	<0.20	<10	210	10	—	0.3
Fb42-03	09-05-91	<0.020	<0.20	10	250	<10	—	0.4
Fb42-06	11-02-92	<0.020	<0.20	<20	21,000	170	470	1.5
Fb42-07	11-03-92	<0.020	<0.20	<20	8,200	1400	490	3.9
Fb43-03	09-05-91	<0.020	0.30	<10	360	<10	—	0.4
Fc11-19	09-04-91	<0.020	0.25	10	360	10	—	2.7
Fc11-20	08-30-91	0.020	<0.20	<10	540	20	—	1.2
Fc11-21	09-03-91	<0.020	<0.20	<10	150	50	—	0.4
Fc11-22	09-05-91	<0.020	<0.20	<10	1,100	60	—	0.3
Fc12-13	09-06-91	<0.020	<0.20	<10	570	10	—	0.4
Fc12-14	09-06-91	<0.020	<0.20	<10	500	10	—	0.4
Fc12-20	11-09-92	2.10	<0.20	<20	14	41	820	0.3
Fc14-06	09-11-91	0.040	<0.20	<10	30	10	370	0.6
Fc21-12	11-04-92	6.00	<0.20	<20	12	29	1300	<0.1
Fc21-13	11-04-92	15.0	<0.20	30	59	390	920	<0.1



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