Water-Quality Assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia—Analysis of Available Ground-Water-Quality Data Through 1987

National Water-Quality Assessment

United States
Geological
Survey
Water-Supply
Paper 2355–B

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Cover illustration shows the Delmarva Peninsula and the other National Water-Quality Assessment pilot project areas.

Chapter B

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By P.A. HAMILTON, R.J. SHEDLOCK, and P.J. PHILLIPS

U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2355

NATIONAL WATER-QUALITY ASSESSMENT—DELMARVA PENINSULA

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, Jr., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

March 3, 1849

UNITED STATES GOVERNMENT PRINTING OFFICE : 1991

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

Library of Congress Cataloging in Publication Data

Hamilton, P.A.
Water-quality assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia—Analysis of available ground-water-quality data through 1987 / by P.A. Hamilton, R.J. Shedlock, and P.J. Phillips.
p. cm.—(U.S. Geological Survey water-supply paper ; 2355–B)
Includes bibliographical references (p.).
Supt. of Docs. no.: I 19.13:2355–B
1. Water, Underground—Delmarva Peninsula. 2. Water, Underground—Delmarva Peninsula—Quality. I. Shedlock, R.J. II. Phillips, P.J. III. Title. IV. Series.
GB1016.H36 1991
363.73'942'097521—dc20 90–3990
CIP

FOREWORD

One of the great challenges faced by the Nation's water-resources scientists is providing reliable water-quality information to guide the management and protection of our water resources. That challenge is being addressed by Federal, State, Interstate, and local water-resources agencies and by academic institutions. Many of these organizations are collecting water-quality data for a host of purposes, including compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research to advance our understanding of water-quality processes. In fact, during the past two decades, tens of billions of dollars have been spent on water-quality data-collection programs. Unfortunately, the utility of these data for present and future regional and national assessments is limited by such factors as the areal extent of the sampling network, the frequency of sample collection, the varied collection and analytical procedures, and the types of water-quality characteristics determined.

In order to address this deficiency, the Congress appropriated funds for the U.S. Geological Survey, beginning in 1986, to test and refine concepts for a National Water-Quality Assessment (NAWQA) Program that, if fully implemented, would:

1. Provide a nationally consistent description of water-quality conditions for a large part of the Nation's water resources;
2. Define long-term trends (or lack of trends) in water quality; and
3. Identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends.

As presently envisioned, a full-scale NAWQA Program would be accomplished through investigations of a large set of major river basins and aquifer systems that are distributed throughout the Nation and that account for a large percentage of the Nation's population and freshwater use. Each investigation would be conducted by a small team that is familiar with the river basin or aquifer system. Thus, the investigations would take full advantage of the region-specific knowledge of persons in the areas under study.

Four surface-water projects and three ground-water projects are being conducted as part of the pilot program to test and refine the assessment methods and to help determine the need for and the feasibility of a full-scale program. An initial activity of each pilot project is to compile, screen, and interpret available data to provide an initial description of water-quality conditions and trends in the study area. The results of this analysis of available data are presented in individual reports for each project.

The pilot studies depend heavily on cooperation and information from many Federal, State, Interstate, and local agencies. The assistance and suggestions of all are gratefully acknowledged.

Philip Cohen
Chief Hydrologist

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

For readers who wish to convert measurements from the inch-pound system of units used in this report to the metric system of units, the conversion factors are listed below:

Multiply inch-pound units	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
million gallons per day (Mgal/d)	0.003785	million cubic meters per day (Mm^3/d)

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

$$°F=1.8°C+32$$

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

Analysis of Available Ground-Water-Quality Data Through 1987 for the Delmarva Peninsula—Delaware, Maryland, and Virginia

By P.A. Hamilton, R.J. Shedlock, *and* P.J. Phillips

EXECUTIVE SUMMARY

Since 1986, Congress has annually appropriated funds for the U.S. Geological Survey to test and refine concepts for a National Water-Quality Assessment (NAWQA) Program. The long-term goals of a full-scale program would be to (1) provide a nationally consistent description of current water-quality conditions for a large part of the Nation's surface- and ground-water resources, (2) define long-term trends (or lack of trends) in water quality, and (3) identify, describe, and explain, as possible, the major factors that affect the observed water-quality conditions and trends.

At present (1988), the assessment program is in a pilot phase in seven project areas throughout the country. These seven areas represent diverse hydrologic environments and water-quality conditions. One of the areas is the Delmarva Peninsula, which is representative of the hydrology and physiography of the Northern Atlantic Coastal Plain. This report completes one of the initial activities undertaken as part of the Delmarva Peninsula pilot project—to compile, screen, and interpret available water-quality data. The report illustrates the diversity, availability, and accessibility of data sources; identifies geographic areas for which data are lacking; and illustrates regional ground-water-quality conditions and problems. A summary of Federal, State, and local agencies serving as repositories for water-quality data is presented, as is a description of the range of chemical constituents for which information is available, the ease of retrieving and summarizing the data, and general characteristics of the data for use in a regional ground-water-quality assessment. The report also provides an initial assessment of ground-water quality on the Delmarva Peninsula and highlights areas for which pertinent water-quality data are lacking.

The Delmarva Peninsula

The Delmarva Peninsula consists of a flat to gently rolling central upland flanked by low plains that slope toward Chesapeake Bay, Delaware Bay, and the Atlantic Ocean. The peninsula comprises more than 6,000 square miles within the Coastal Plain physiographic province, and includes most of Delaware and the entire Eastern Shore of Maryland and Virginia. The peninsula is used heavily for agriculture, which accounts for about half of the land use.

The Coastal Plain physiographic province is underlain by a wedge of unconsolidated sediments that thickens seaward, ranging from 0 feet at the Fall Line to more than 8,000 feet along the Atlantic Coast in Maryland. On the basis of hydrologic and lithologic properties of these unconsolidated sediments, a series of confined aquifers and intervening confining units has been identified throughout the peninsula. The confined aquifers are overlain by an extensive surficial aquifer, which is under water-table (unconfined) conditions throughout most of the study area.

Ground-water use from these confined and surficial aquifers averaged about 170 million gallons per day during 1985–86. Commercial and industrial use, as well as use by suppliers to the public (including municipalities, county-operated systems, and private water companies), accounts for more than half (51 percent) of the total withdrawals in Delaware and Maryland, and for about 43 percent of the withdrawals in Virginia. Irrigation and agricultural use accounts for more than 35 percent of the total withdrawals throughout the peninsula. The balance of the water use is largely for self-supplied domestic purposes (individually owned wells). In Delaware and Maryland, about 52 percent of ground-water withdrawals are from the surficial aquifer.

Sources of Water-Quality Data

Water-quality data are available from 3 Federal, 5 State, and 14 local agencies, as well as from various nonprofit organizations and universities throughout

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Manuscript approved for publication January 12, 1989.

Delaware, Maryland, and Virginia. It was not feasible to incorporate data from all these agencies in this report. Six sources provided readily accessible data on inorganic constituents: the U.S. Geological Survey; the U.S. Environmental Protection Agency (STORET data base); the National Uranium Resource Evaluation Program; the Delaware Water Resources Center; the Wicomico County (Md.) Health Department; and the Virginia Water Project, Inc. Three sources provided data on organic compounds: the U.S. Geological Survey; the Virginia Water Project, Inc.; and the Virginia Department of Health.

Water-quality data have been collected to meet diverse objectives, ranging from monitoring for compliance with drinking-water standards and criteria to conducting research on specific ground-water issues. Ideally, these data could be readily combined into one data base for use in a regional ground-water-quality assessment. However, certain characteristics of existing data limit their usefulness for a regional assessment of ground water. Data-base structure and format (computer storage or paper files), as well as differences among agencies in procedures for collecting and analyzing the data, may preclude the combination of data from different sources to form a meaningful regional assessment. Common limitations of the data include (1) lack of information on quality control, (2) inconsistent sampling, preservation, and analytical techniques among and within agencies, (3) the clustering of sampling wells around known or suspected areas of contamination, which can impose a bias on water-quality assessments, (4) improper construction of wells, and (5) lack of information on sampling locations, well depths, well construction, and aquifer characteristics.

Analysis of Available Water-Quality Data

Ground water on the Delmarva Peninsula is suitable for most purposes. Its natural quality is controlled predominantly by the chemical properties of rain and snowmelt, the mineralogy of soils and the aquifer material, the residence time in the ground-water system, and the nearby presence of saline water. Deposits making up the surficial aquifer are composed of quartz, feldspar, and clay minerals, and generally are lacking in carbonate minerals. Water in the surficial deposits is acidic, soft, low in alkalinity, and low in sodium and total dissolved solids content because of the sediment composition and the relatively low pH of precipitation. As ground water from the surficial aquifer recharges the confined aquifers and flows through differing suites of minerals and redox conditions, its chemistry changes. Water in the confined aquifers generally is less acidic and harder than water in the surficial aquifer, and it has a higher total dissolved solids content. All the confined aquifers contain saline water downdip, and this limits their potential use because of pumpage-induced encroachment of elevated concentrations of chloride, sodium, and total dissolved solids into the freshwater zones.

Specific conclusions from the analysis of available water-quality data are described in the following paragraphs. The conclusions focus on constituents for which the U.S. Environmental Protection Agency (EPA) has established drinking-water standards and criteria. Drinking-water *standards* have been established for some constituents to protect human health (referred to as "maximum contaminant levels"), and drinking-water *criteria* have been set for other constituents to provide acceptable aesthetic and taste characteristics (referred to as "secondary maximum contaminant levels").

Data for pH and major inorganic constituents (such as hardness, sodium, chloride, sulfate, and total dissolved solids) are relatively abundant. Data for pH of water from more than 2,100 wells indicate that the pH is low (acidic) throughout the surficial aquifer. The pH of water in the majority of wells in the surficial aquifer is less than the minimum EPA secondary maximum contaminant level (pH 6.5). Data for hardness of water from more than 1,000 wells indicate that elevated concentrations are common in the upper confined aquifers: nearly 50 percent of the concentrations exceed 100 milligrams per liter as calcium carbonate—a concentration considered objectionable for ordinary domestic purposes. The main cause of hardness is dissolution of calcite in shells. Data for sodium and total dissolved solids concentrations in water from more than 1,500 and 1,400 wells, respectively, indicate that elevated concentrations of both constituents are common in the southern part of the deeper confined aquifers. In this part of the peninsula, about 60 percent of the sodium concentrations exceed 270 milligrams per liter—a recommended level for humans on salt-restricted diets—and about 90 percent of the total dissolved solids concentrations exceed the EPA secondary maximum contaminant level of 500 milligrams per liter. The probable causes of these high concentrations are the decomposition of minerals in the sediments along ground-water flow paths and the presence of saline water. Data for chloride concentrations in water from more than 1,700 wells indicate that concentrations exceed the EPA secondary maximum contaminant level of 250 milligrams per liter in both the surficial and confined aquifers. These concentrations most likely result from human activity, such as excessive pumping near coastal areas, road salting, or the application of potassium chloride in agricultural areas. Data for sulfate concentrations in water from more than 1,000 wells indicate that the EPA secondary maximum contaminant level of 250 milligrams per liter rarely is exceeded in any of the aquifers.

Data for nitrate concentrations in ground water have been collected from more than 4,300 wells that are widely distributed both areally and vertically throughout the peninsula. The data indicate that elevated nitrate concentrations are prevalent in the surficial aquifer. For example, more than 18 percent of the nitrate concentrations in the surficial aquifer exceed the EPA maximum contaminant level of 10 milligrams per liter as nitrogen. Elevated concentrations probably result from human activities related to domestic effluent, animal wastes, and application of fertilizers. The highest nitrate concentrations are in agricultural and urban areas, and are associated with well-drained sediments where nitrogen is readily oxidized. The lowest nitrate concentrations are in woodlands, and are associated with poorly drained and relatively impermeable sediments. Three major factors limit analysis of the distribution of nitrate concentrations in ground water: (1) insufficient preservation of samples, which may result in conversion of nitrate to other nitrogen forms by bacterial action, which in turn may result in measured nitrate concentrations lower than those actually present in ground water (for example, some agencies do not use mercuric chloride, which improves the stability of nitrate concentrations); (2) improper well construction, which may interfere with the collection of representative samples of ground water; and (3) insufficient well and sample information (well depth, well location, and well construction), which precludes accurate analysis of nitrate levels associated with specific geographic regions.

Data for iron, manganese, and fluoride are relatively abundant, but data for other trace elements (such as arsenic, barium, cadmium, chromium, copper, lead, mercury, and selenium) and for radionuclides are limited. Data for dissolved and total iron concentrations in water from more than 500 and 2,100 wells, respectively, indicate that concentrations commonly are elevated in both the surficial and confined aquifers. More than half the concentrations exceed the EPA secondary maximum contaminant level of 300 micrograms per liter. Iron is a natural constituent in ground water. It is derived largely from iron-bearing sediments in reducing environments. The highest iron concentrations in the surficial aquifer are in areas where the sediments are poorly drained and fine grained, and ground water most likely is under reducing and low pH conditions; the lowest concentrations are in well-drained areas. Data for manganese concentrations in water from more than 1,300 wells indicate that elevated levels are prevalent in the surficial aquifer; in this aquifer, more than 60 percent of the concentrations exceed the EPA secondary maximum contaminant level of 50 micrograms per liter. Manganese also is a natural constituent in ground water and commonly is associated with reducing environments and elevated iron concentrations. Analysis of iron and manganese concentrations provides some insight into factors that can contribute to elevated concentrations; however, as with nitrate, the analysis is limited by inconsistent preservation and sampling techniques and by improper well construction. For example, nitric acid, which prevents precipitation of iron compounds in the presence of oxygen during sample collection and storage, is not used by several agencies. In addition, corrosion of well casings or improperly developed wells may increase iron concentrations above background ground-water quality.

Data for fluoride concentrations in water from more than 750 wells indicate that elevated concentrations are common in the southern part of the deeper confined aquifers; there, more than 17 percent of the concentrations exceed the EPA maximum contaminant level, and 38 percent exceed the EPA secondary maximum contaminant level (4 and 2 milligrams per liter, respectively). These elevated fluoride concentrations are a result of natural processes and most likely are related to the sediment mineralogy.

Data on organic compounds are sparse, both in range of constituents and in geographic distribution. Analyses are available for 14 wells in the surficial aquifer in Maryland, for 37 wells in the surficial aquifer in Virginia, and for 27 wells in the confined aquifers in Virginia. Organic compounds were detected in the surficial aquifer in two wells in Maryland and in one well in Virginia. The prevalent use of pesticides, the shallow depths to the water table, the high permeability of the soils, and high rates of recharge are favorable conditions for the migration of pesticides to ground water. A comprehensive analysis of pesticides in ground water is needed, as is an assessment of factors that govern pesticide fate and transport.

INTRODUCTION

Background

Since 1986, Congress has annually appropriated funds for the U.S. Geological Survey to test and refine concepts for a National Water-Quality Assessment (NAWQA) Program. The long-term goals of the program would be to

1. Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's surface- and ground-water resources,
2. Define long-term trends (or lack of trends) in water quality, and
3. Identify, describe, and explain, as possible, the major factors that affect the observed water-quality conditions and trends.

The results of the NAWQA Program will be made available to water managers, policy makers, and the public, and will provide an improved scientific basis for evaluating the effectiveness of water-quality management programs and for predicting the likely effects of future changes in land- and water-quality-management practices. Concepts for a full-scale NAWQA Program have been described by Hirsch and others (1988).

The NAWQA Program is organized into study units on the basis of known hydrologic systems. For ground water, the study units are large parts of aquifers or aquifer systems, and for surface water, the study units are major river basins. The study units are large, including areas of a few thousand to several tens of thousands of square miles.

At present (1988), the assessment program is in a pilot phase in seven project areas throughout the country. These seven areas represent diverse hydrologic environments and water-quality conditions. Pilot project areas focusing primarily on ground water include the Carson basin in Nevada and California, the Central Oklahoma aquifer in Oklahoma, and the Delmarva Peninsula in Delaware, Maryland, and Virginia. Pilot project areas focusing primarily on surface water include the lower Kansas River basin in Kansas and Nebraska, the Kentucky River basin in Kentucky, the Upper Illinois River basin in Illinois, Indiana, and Wisconsin, and the Yakima River basin in Washington.

One of the initial activities undertaken in each pilot project is to compile, screen, and interpret the large amount of water-quality data available for each study unit. These data have been collected for widely different purposes by a diverse group of organizations. This preliminary water-quality assessment will help in establishing priorities and formulating plans for concurrent project field activities, as well as provide the foundation for more detailed regional assessments of ground-water quality within each study area.

Purpose and Scope

The purposes of this report are to describe the sources and spatial distribution of existing water-quality data for the Delmarva Peninsula and to provide a preliminary assessment of water-quality conditions. The report illustrates the availability, accessibility, and diversity of data sources; identifies geographic regions for which data are lacking; and describes regional ground-water-quality variations and problems. A summary of Federal, State, and local agencies serving as repositories for water-quality data is presented, as is a description of the range of chemical constituents for which information is available, the method of filing (computer or paper files), the ease of retrieving and summarizing the data, and general characteristics of the data for regional ground-water-quality assessment. Maps that describe regional water chemistry are included. Summary statistics and graphical summaries of chemical constituents for which drinking-water-quality standards and criteria have been established are presented to identify potential water-quality problems. Also included are maps illustrating the spatial distribution and regional variations of selected constituents, including nitrate, iron, and manganese, in the surficial aquifer. The scope of this work includes an evaluation of available and accessible ground-water-quality data collected from 1944 through 1987. Most of the data discussed in this report are accessible from computer files. Data from paper files that are organized in a central filing system and that include a manageable number of sample analyses also are discussed.

Acknowledgments

Special thanks are given to members of the liaison committee for the Delmarva project for their continuous support during this effort. The authors also thank Thomas Mersky, U.S. Environmental Protection Agency, Region 3, Philadelphia, Pa., James King, Department of Environment, Snow Hill, Md., and Jason Gray, Virginia Water Project, Inc., Roanoke, Va., for providing water-quality data.

DESCRIPTION OF STUDY AREA

Location and Physiography

The study area, referred to in this report as the "Delmarva Peninsula," lies within the Coastal Plain physiographic province and includes most of Delaware and the entire Eastern Shore of Maryland and Virginia. It is bounded on the north by the Fall Line, which separates the Coastal Plain physiographic province from the Piedmont physiographic province; on the west by Chesapeake Bay; and on the east by the Atlantic Ocean and Delaware Bay. The peninsula is oval in shape, extending about 150 mi (miles) north to south, and about 70 mi east to west at its widest point (fig. 1).

The Delmarva Peninsula consists of a flat to gently rolling central upland flanked by low plains that slope toward Chesapeake Bay, Delaware Bay, and the Atlantic Ocean. The coastline along Chesapeake Bay is irregular because of tidal streams that drain into the bay. Tidal streams are not as prevalent along Delaware Bay, resulting in a much smoother coastline. Both coastlines are fringed with tidal wetlands that extend into the lowlands. The coastline along the Atlantic Ocean is characterized by barrier beaches, tidal lagoons, and marshes.

Maximum altitudes, about 200 ft (feet), are in the necks between tidal streams at the extreme north end of Chesapeake Bay. Excluding these necks, the highest altitude (about 80 ft) is in the central uplands. Topographic relief is greatest along tidal streams and their tributaries in the northern third of the peninsula. For example, bluffs along the Chesapeake and Delaware Canal have 50 to 60 ft relief, and valleys of tidal streams and tributaries commonly have relief of more than 40 ft.

The extent to which streams in the study area are incised into surficial sediments varies and seems to be related to differences in physiography, soil type, and drainage among several large subregions. For example, poorly drained areas are present in the central uplands on the broad drainage divide between Chesapeake and Delaware Bays. These areas are characterized by small, sluggish streams flowing in low-gradient, poorly developed valleys having poorly drained soils and seasonally wet areas. Well-drained areas flank the poorly drained uplands and are

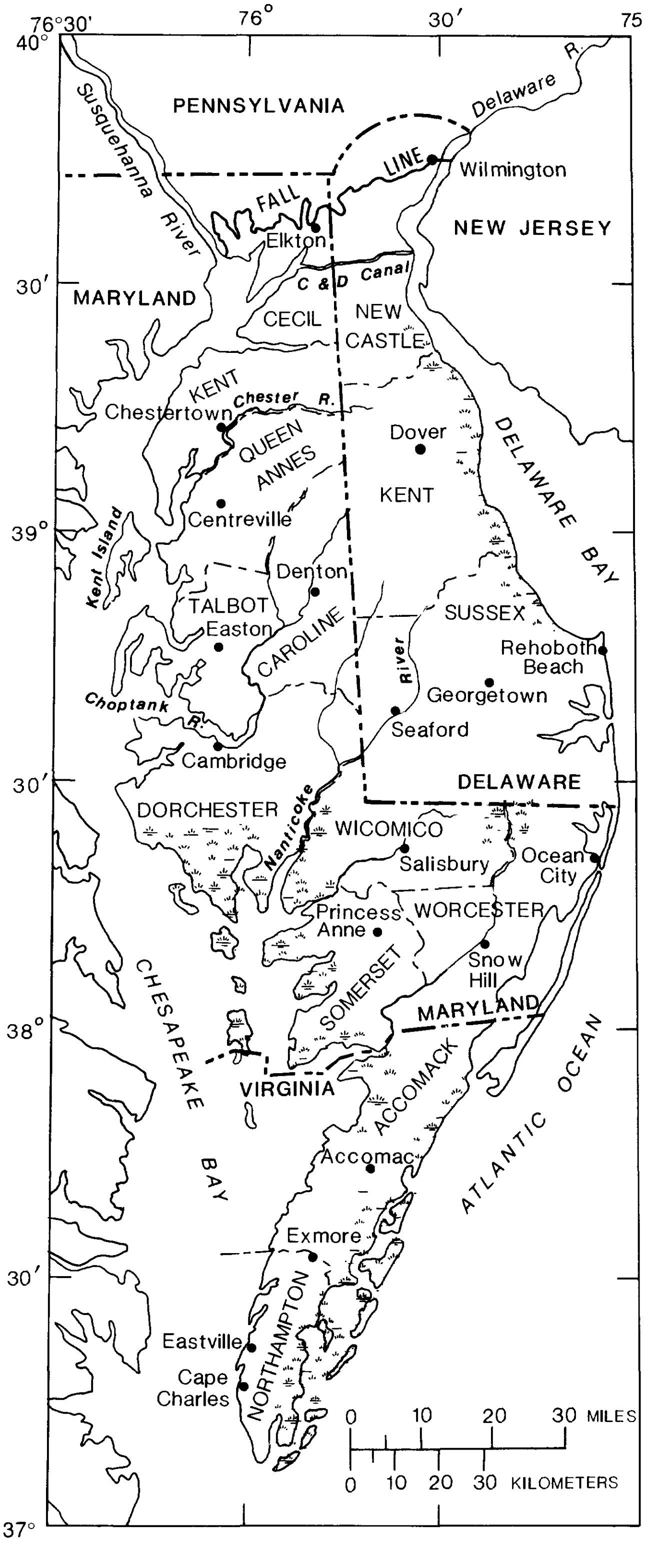


Figure 1. Location of study area.

characterized by more deeply incised streams. As a result, the soil is better drained and depths to the water table are greater than in the poorly drained regions. Lowlands are present on the fringes of the peninsula along Chesapeake and Delaware Bays. These lowlands are characterized by broad and relatively deep valleys of the tidal reaches of streams along Chesapeake Bay in the northern and central parts of the peninsula.

Population and Land Use

The population of the Delmarva Peninsula is approximately 600,000 (U.S. Bureau of the Census, 1986). Urban centers include Dover, Del., and Salisbury, Cambridge, and Easton, Md. The population in these urban areas ranges from about 9,000 to 20,000. The population of coastal resorts, including Rehoboth Beach, Del., and Ocean City, Md., ranges from a few thousand in the winter to several hundred thousand in the summer.

U.S. Geological Survey (USGS) land-use and land-cover data were used to estimate land-use areas on the peninsula. These data, compiled and digitized at a scale of 1:250,000 (U.S. Geological Survey, 1979a, 1979b, 1979c, 1979d, 1980a, 1980b), were generated using National Aeronautics and Space Administration (NASA) high-altitude areal photo coverage and the National High Altitude Program (NHAP) coverage of the Delmarva Peninsula between 1972 and 1973. Some land-use changes have occurred on the peninsula since 1973; for example, woodlands have been converted for agricultural use, and agricultural areas have been converted to urban areas, particularly north of the Chesapeake and Delaware Canal and in the Salisbury, Md., area.

Total land area is about 6,050 mi^2 (square miles). Agriculture is the most prevalent land use, accounting for about 48 percent of the study area (table 1). Most of the agricultural land is in soybean-corn rotation, with crops sold for feed. Truck farming also is common. The area also is one of the Nation's leading producers of broiler chickens. The remaining land uses are urban, wetland, barren land, and woodland (table 1). The northern part of New Castle County, Del., contains the most extensive urban and industrial development. Industry also is located in larger towns throughout the peninsula. Food processing and other small industries are present in smaller cities and towns. Most of the areas bordering the bays and ocean are fringed with wetlands and tidal marsh and are classified as wet-

Table 1. Land use on the Delmarva Peninsula

Land use	Area (square miles)	Percentage of total land area
Agricultural	2,917	48
Woodland	1,877	31
Wetland	787	13
Urban	403	7
Barren land	74	1
Total	6,058	100

lands. Barren land includes the barrier beaches along the Atlantic coastline. Woodlands, present throughout the peninsula, commonly are interspersed with agricultural areas. The degree of interspersion is highly related to physiography. The well-drained parts of central Kent County, Md., for example, are dominated by large agricultural tracts, while the poorly drained uplands to the east typically are smaller plots with interspersed woodlands and agricultural areas.

Hydrogeologic Setting

The quality of ground water is influenced by the length of flow paths and the types and order of minerals encountered along flow paths. Variations in geologic materials that constitute the aquifer system must be understood in order to understand natural patterns in ground-water quality. Therefore, a brief discussion of the hydrogeologic setting on the Delmarva Peninsula is presented below.

The Coastal Plain physiographic province is underlain by a wedge of unconsolidated sediments that thickens seaward, ranging from 0 ft at the Fall Line to more than 8,000 ft along the Atlantic Coast of Maryland. These sediments range from Cretaceous to Holocene in age and consist primarily of sand, clay, silt, and gravel, with variable amounts of shells. The wedge of sediments dips to the south and southeast and is underlain by Precambrian granitic and metamorphic or Mesozoic sedimentary rock, commonly referred to as the "basement."

On the basis of hydrologic and lithologic properties of these unconsolidated sediments, Cushing and others (1973) identified a series of nine confined aquifers (fig. 2). Six confined aquifers in Virginia have been identified by Harsh and Laczniak (1986). The approximate stratigraphic position of these aquifers is shown in table 2. A detailed correlation of the aquifers across State lines was not attempted in this table or study. The intent here is to identify and combine major aquifers by approximate age. The confined aquifers are grouped into three divisions, designated upper, middle, and lower confined aquifers, on the basis of age, as well as depth and depositional environment (table 2). Description of the geology and hydrogeology of the confined aquifers is limited to those that contain freshwater (fig. 3). The confined aquifers are overlain by an extensive surficial aquifer, which is under water-table (unconfined) conditions in most of the study area.

The surficial aquifer is composed of several geologic formations that form a sandy deposit covering 90 percent of the study area. It lies on an erosional surface that includes several major and many minor Pleistocene paleochannels. This aquifer has been called the Quaternary aquifer (Cushing and others, 1973), the Pleistocene aquifer (Andres, 1986), and the Columbia aquifer (Bachman, 1984a). The geology and hydrogeology of these surficial deposits have been described by several authors, including Rasmussen and Slaughter (1955), Jordan (1964), Hansen (1966), Owens and Denny (1979), Bachman (1984a), and Mixon (1985).

The sediments represent several time-stratigraphic units and originate from fluvial, marine and marginal-marine, estuarine, and eolian depositional environments (fig. 4). In the interior of the peninsula in Delaware and Maryland, the surficial aquifer is made up mainly of the Pensauken Formation, primarily a red gravelly sand, and the Beaverdam Sand, consisting of light-colored, fine to coarse sand and thin gravel beds. In Delaware, these two units are grouped together as the Columbia Group (Jordan, 1962). In southern Delaware and adjoining areas of Maryland, the Beaverdam Sand is overlain by silt and clay of the Walston Silt and Omar Formation, which function as confining units. All three of these formations are overlain by a surficial sand called the Parsonsburg Sand (Denny and others, 1979). The interior of Virginia is composed of marine sand and gravelly sand of the Omar, Nassawadox, and Wachapreague Formations (Mixon, 1985).

Surficial deposits along the Atlantic Coast include the Ironshire and Sinepuxent Formations of Owens and Denny (1979). The Ironshire Formation is a gravelly sand of barrier-beach origin, and the Sinepuxent Formation is a silty shallow marine sand. The margins on the western side of the peninsula are underlain by the Kent Island Formation, an estuarine deposit consisting of clay, silt, and sand. This formation, mostly clay and silt along Chesapeake Bay in Maryland, is used as only a local source of water. The Kent Island Formation becomes progressively sandier to the south in Virginia.

The surficial deposits are considered Pleistocene in age by all previous workers except Owens and Denny (1979), who thought the Pensauken Formation to be of Miocene age and the Beaverdam Sand and Walston Silt to be of Pliocene age. The study area also contains Holocene deposits, including mud, silt, and sand in the tidal marshes and barrier island sands.

The saturated thickness of the surficial aquifer varies across the study area because of the presence of impermeable materials, variations in depth to the water table, and the presence of subcropping aquifers. In the northern part of the peninsula the saturated thickness generally is less than 20 ft, except in several paleochannels where the saturated thickness exceeds 50 ft (Spoljaric and Woodruff, 1970). The aquifer thickens southward. In the central and southern parts of the peninsula, for example, the saturated thickness commonly exceeds 40 ft, and exceeds 100 ft in several of the major paleochannels (Bachman, 1984a; Mixon, 1985). Where the surficial aquifer directly overlies subcropping sands of the confined aquifers, the effective saturated thickness is enhanced because the aquifers function as one hydrologic unit.

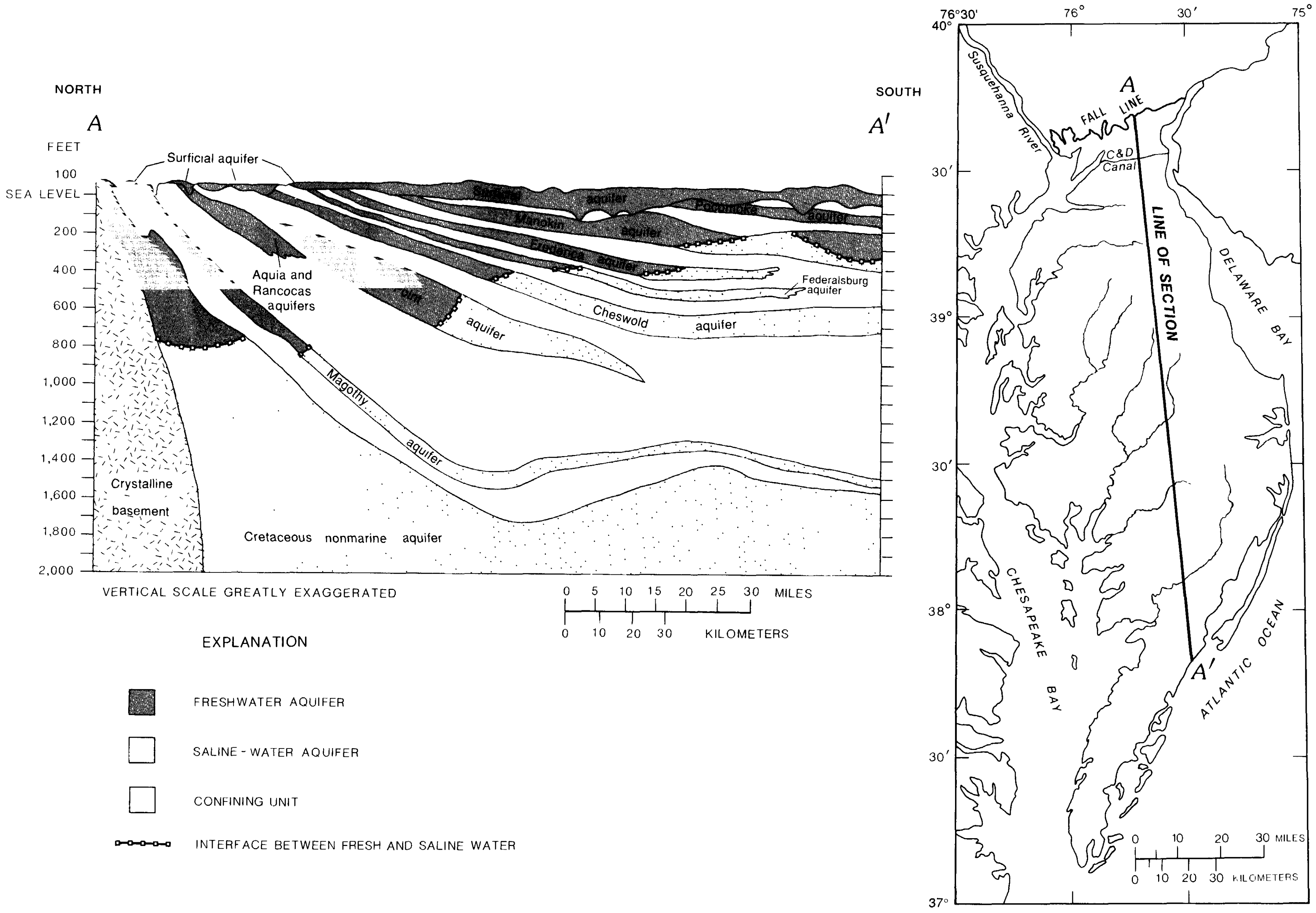


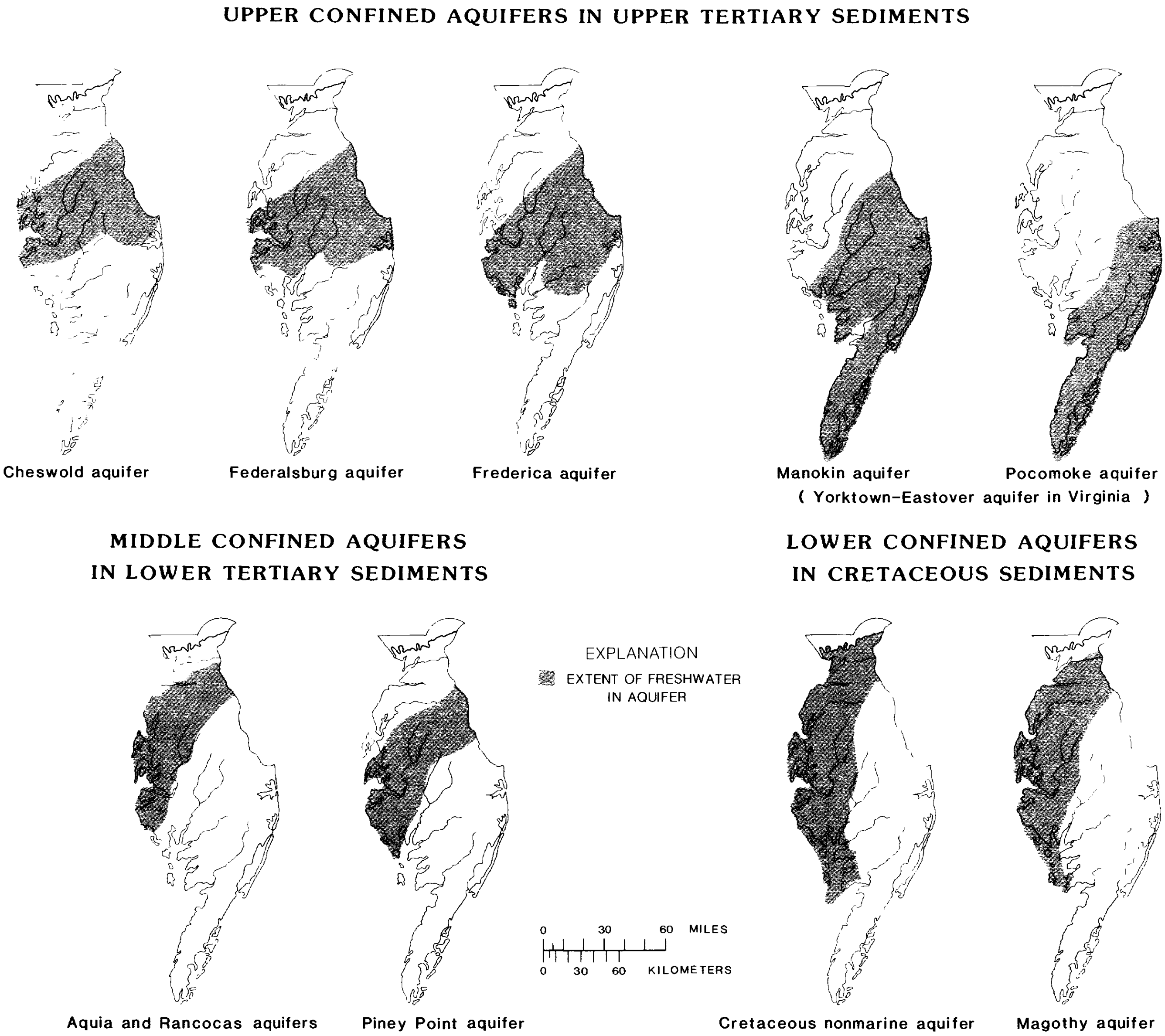
Figure 2. Hydrogeologic section across the Delmarva Peninsula (modified from Cushing and others, 1973).

Table 2. Approximate stratigraphic position of aquifers in study area

		Modified from aquifer names in Cushing and others (1973)	Series	Aquifer names used in Harsh and Laczniak (1986)
	Surficial aquifer	Aquifer in Quaternary deposits	Holocene	Columbia aquifer
			Pleistocene	
			Pliocene	
				Yorktown-Eastover aquifer
		- - - - - - - -		
Confined aquifer divisions as defined in this report	Upper confined aquifers in upper Tertiary sediments		Miocene	
		Pocomoke aquifer		
		Manokin aquifer		St. Marys-Choptank aquifer
		Frederica aquifer		
		Federalsburg aquifer		Chickahominy-Piney Point aquifer
		Cheswold aquifer		
		////////////////	Oligocene	
	Middle confined aquifers in lower Tertiary sediments	Piney Point aquifer	Eocene	
		Aquia and Rancocas aquifers	Paleocene	
		- - - - - - - -	Upper Cretaceous	
	Lower confined aquifers in Cretaceous sediments	Magothy aquifer		Upper Potomac aquifer
		Cretaceous nonmarine aquifer		
			Lower Cretaceous	
				Middle Potomac aquifer
				Lower Potomac aquifer

EXPLANATION

- - - - - - - -	NO NAME ASSIGNED
////////////////	SECTION NOT PRESENT



UPPER CONFINED AQUIFERS IN UPPER TERTIARY SEDIMENTS

Cheswold aquifer

Federalsburg aquifer

Frederica aquifer

Manokin aquifer

Pocomoke aquifer (Yorktown-Eastover aquifer in Virginia)

MIDDLE CONFINED AQUIFERS IN LOWER TERTIARY SEDIMENTS

Aquia and Rancocas aquifers

Piney Point aquifer

LOWER CONFINED AQUIFERS IN CRETACEOUS SEDIMENTS

Cretaceous nonmarine aquifer

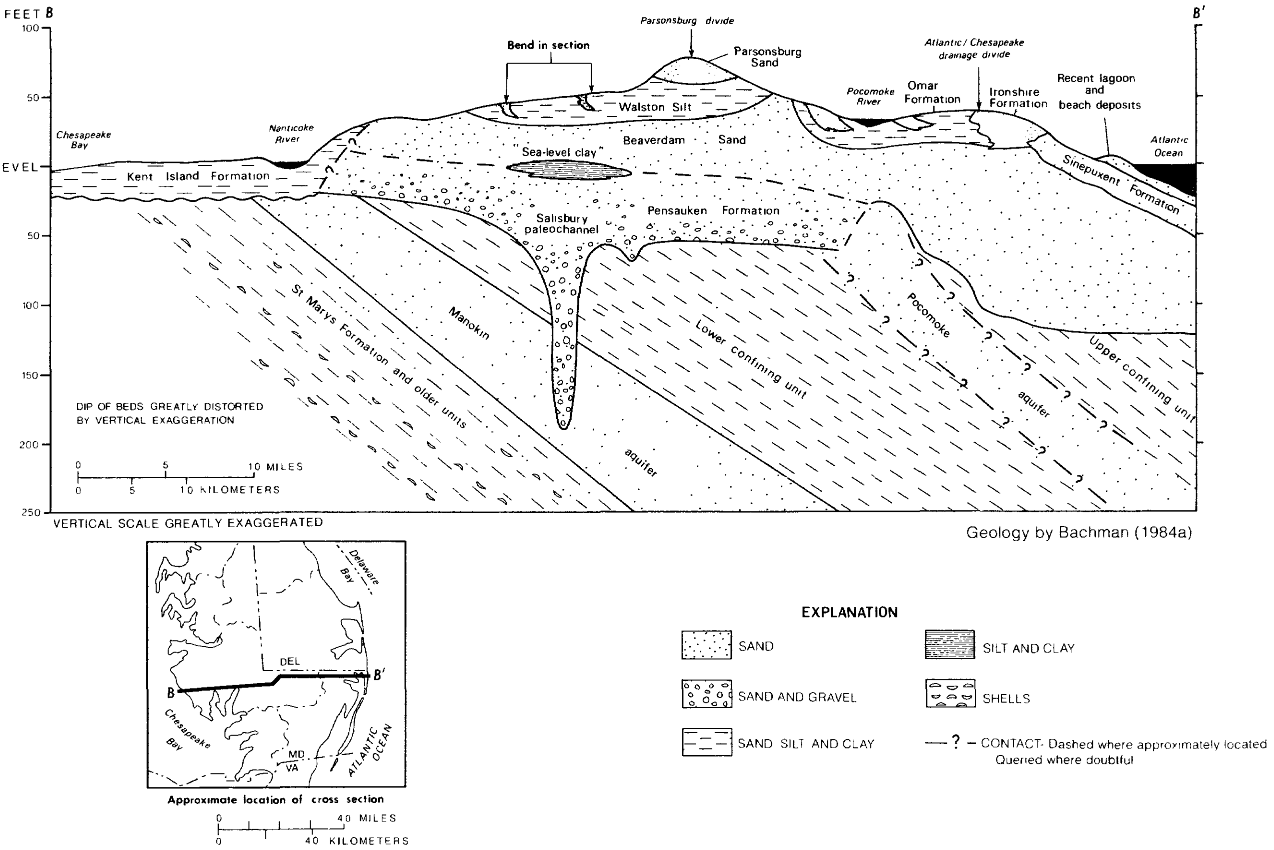
Magothy aquifer

Figure 3. Extent of aquifers containing freshwater in study area (modified from Cushing and others, 1973).

The surficial aquifer is under water-table conditions throughout the study area, except in the central part of the peninsula where it is confined by the Walston Silt and Omar Formation. The shallowest water-table conditions are in the central uplands of the peninsula, where streams are not deeply incised into the sediments. The depth to the water table generally is between 0 and about 20 ft below land surface. The deepest water-table conditions, as deep as 40 ft below land surface, are in the well-drained uplands, where tidal streams and tributaries incise deeply into surficial deposits.

Flow in the surficial aquifer is primarily from water-table highs in the interfluvial areas toward streams. The ground water also discharges to freshwater ponds and wetlands, tidal marshes, bays, and the Atlantic Ocean. Flow paths generally are short, averaging less than a few miles. In areas having a high stream density, drainage ditches, or wetlands, flow paths may be shorter than a few thousand feet. The localized flow systems probably extend down into the updip areas of the confined aquifers (Bachman, 1984a), resulting in localized flow systems in the underlying confined aquifers.

The uppermost confined aquifers, referred to in this report as "upper confined aquifers," are in upper Tertiary sediments. Included in this group (in ascending order) are the Cheswold, Federalsburg, and Frederica aquifers in the Choptank and Calvert Formations, and the Manokin and Pocomoke aquifers, which are equivalent to the lower part of the Yorktown-Eastover aquifer in the Yorktown and Eastover Formations in Virginia. The St. Marys-Choptank



Geology by Bachman (1984a)

Figure 4. Generalized section across the Delmarva Peninsula from Salisbury, Md., and Chesapeake Bay to Ocean City, Md., showing an interpretation of the relations between the surficial deposits and other geologic units (section based on work by Demarest, Biggs, and Kraft (1981), Owens and Denny (1979), Weigle (1974), Hansen (1966, 1981), and test-hole data collected by U.S. Geological Survey).

aquifer in the St. Marys and Choptank Formations in Virginia, as defined by Harsh and Laczniak (1986), is a saline aquifer and is not discussed in this report. All these aquifers are of Miocene age, although recent work by Mixon (1985) has shown that the upper parts of the Pocomoke and Yorktown-Eastover aquifers in southern Maryland and Virginia are probably of Pliocene age. These aquifers generally are composed of quartz sand deposited in a shallow marine environment. Parts of the Pocomoke and Yorktown-Eastover aquifers consist of sand that is moderately glauconitic.

The Cheswold, Federalsburg, and Frederica aquifers extend in a wide band across the central part of the peninsula (fig. 3). These aquifers are confined throughout their extent, except where they crop out along tidal streams and their tributaries. The Cheswold aquifer is separated from the underlying Piney Point and overlying Federalsburg aquifers by silt and clay beds. It ranges from 0 to 150 ft thick, and is a major water source for Dover, Del. The Federalsburg aquifer is overlain by silt and clay, and ranges from 0 to 100 ft thick. It is a major source of water in the central part of the peninsula. The overlying Frederica aquifer, which is capped by a thick silty clay, ranges from 0 to 150 ft thick. It also is a major source of water in the central part of the study area.

The Manokin and Pocomoke (Yorktown-Eastover) aquifers extend from Delaware Bay to the southern end of the peninsula along the Atlantic Ocean (fig. 3). The Manokin aquifer, which overlies the Frederica aquifer, ranges from 0 to 250 ft thick. Weigle (1974) distinguished an interval in the Manokin aquifer east of a line between Lewes and Gumboro, Del., as the Ocean City aquifer. The Ocean City aquifer is not, however, recognized in this report. The Manokin aquifer is overlain by silt and clay, which separate it from the Pocomoke aquifer. In some areas, the confining units between the Manokin and Pocomoke aquifers are thin or absent and the two aquifers function as a single hydrologic unit. The Manokin and Pocomoke (Yorktown-Eastover) are the principal aquifers in southern Maryland and Virginia and in the coastal resort towns of Ocean City, Md., and Rehoboth Beach, Del.

The aquifers referred to in this report as "middle confined aquifers" are in lower Tertiary sediments. They include the Aquia (called Rancocas in Delaware) and Piney

Point aquifers in the Aquia and Piney Point Formations and Rancocas Group. The Chickahominy-Piney Point aquifer in Virginia, in the Chickahominy Formation (including the overlying Old Church Formation) and the Piney Point Formation defined by Harsh and Laczniak (1986), is a saline aquifer and is not discussed in this report. The middle confined aquifers are of Paleocene and Eocene age and extend across the study area in a northeast–southwest-trending band (fig. 3). The aquifers are used mostly in the north-central and western parts of the peninsula (Miller and others, 1982). The Aquia aquifer subcrops below the surficial aquifer in the northern part of the study area and is confined throughout its extent, except where it crops out in the western part. It is separated from the underlying Magothy and overlying Piney Point aquifers by finer grained sediments. The Aquia aquifer consists primarily of glauconitic sand and ranges from 0 to 250 ft thick. It is a source of water mainly for towns along Chesapeake Bay, including Chestertown, Easton, and Oxford, Md. The Piney Point aquifer, which has been truncated by erosion, is the only confined aquifer that does not crop out or subcrop below the surficial aquifer. It contains some glauconite, generally less than the Aquia aquifer, and ranges from 20 to 270 ft thick. The aquifer is a source of water in Maryland, primarily for the towns of Cambridge and Denton, and in Delaware, primarily in the Dover area.

The aquifers referred to in this report as "lower confined aquifers" are in Cretaceous sediments. They include the Cretaceous nonmarine and Magothy aquifers described by Cushing and others (1973), and the Potomac aquifers described by Harsh and Laczniak (1986). The parts of these aquifers containing freshwater underlie a north-south band on the western side of the peninsula; generally, freshwater is not present in Virginia (fig. 3). These aquifers subcrop below the surficial aquifer in the northern part of the study area and are confined throughout their extent, except where they crop out along tidal streams on the western side of the peninsula. The Cretaceous nonmarine aquifer is in the Cretaceous Potomac Formation in Delaware (Jordan, 1962) (or Potomac Group where the rocks are divided in Maryland and Virginia) and is composed of a complex series of interbedded sand, silt, and clay that overlie the basement. The deposits are of continental, fluvial origin and consist of alternating channel sand and interchannel clay and silt. Because of the fluvial depositional environment, the sediments vary laterally and in some places thicken or thin over short distances. The aggregate thickness of water-bearing units ranges from 0 to about 150 ft in the freshwater part of the aquifer. The Cretaceous nonmarine aquifer is a primary source of water in the northern part of the study area near its subcrop area (Sundstrom and others, 1967). The Magothy aquifer in the Magothy Formation is a transitional unit between nonmarine and marine Cretaceous sediments. It is separated from the underlying Cretaceous nonmarine aquifer by a clay layer and is overlain by finer grained sediments. The Magothy aquifer is composed of sand which is areally extensive and more consistent in thickness than in the underlying Potomac Formation (Sundstrom and others, 1967). In most places where the thickness of the Magothy aquifer exceeds 50 ft, the clay layer separating it from the Cretaceous nonmarine aquifer is absent and the two aquifers function as one hydrologic unit. The Magothy aquifer supplies water to a large number of users near its subcrop area, as well as to the cities of Easton, Cambridge, and Crisfield, Md., in the western part of the peninsula.

Regional ground-water flow in the confined aquifers was investigated as part of a ground-water study in the Northern Atlantic Coastal Plain conducted during the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) Program (Meisler, 1986; Trapp, 1986; Leahy and others, 1988). For detailed descriptions of flow in the confined aquifers, the reader is referred to reports by Vroblesky and Fleck (1988) and Harsh and Laczniak (1986). General comments about recharge-discharge relations and regional flow are provided below.

The confined aquifers are recharged regionally in updip areas where they subcrop below the surficial aquifer. The one exception is the Piney Point aquifer, which is truncated at depth. The upper confined aquifers also are recharged locally throughout their extent because of the presence of localized flow systems. Ground water in the confined aquifers discharges primarily to major surface-water bodies, including Chesapeake and Delaware Bays, the Atlantic Ocean, back-barrier bays and lagoons along coastlines, and tidal streams. Discharge also occurs as leakage to other aquifers through confining units and to pumping wells.

Directions of ground-water flow are complex and differ among and within aquifers because of differences in (1) rates and distribution of pumpage, (2) water-table altitudes in outcrop and subcrop areas, (3) aquifer characteristics (for example, heterogeneity and anisotropy in hydraulic conductivity), and (4) the degree of hydraulic connection between the aquifers and discharge or recharge areas. The degree of hydraulic connection has been enhanced in some areas by downcutting of paleochannels into confining units during the Pleistocene (Vroblesky and Fleck, 1988). These channels are filled with sediments more permeable than the confining units but less permeable than the aquifers through which they cut.

Water Use

Total ground-water use in the study area during 1985–86 averaged 169.6 Mgal/d (million gallons per day). Water use in Delaware was 78.6 Mgal/d (A. Hodges, U.S. Geological Survey, written commun., 1988), water use in Maryland was 78.9 Mgal/d, (J.C. Wheeler, U.S. Geological. Survey, written commun., 1987), and water use in Virginia was 12.1 Mgal/d (R.J. Laczniak, U.S. Geological Survey, oral commun., 1988). In Delaware and Maryland, about 52 percent of ground-water withdrawals comes from the surficial aquifer. The surficial aquifer is the primary source of water in the southern counties of Delaware and Maryland. For example, withdrawals from the surficial aquifer in Sussex County, Del., and in Wicomico County, Md., represent 80 and 90 percent, respectively, of the total ground water used in those counties. Use of the confined aquifers predominates in the northern part of the study area where the surficial aquifer is thin or absent. Data on water use in Virginia, by aquifer, are not readily available.

In Delaware and Maryland, commercial and industrial use, as well as use by suppliers to the public (including municipalities, county-operated systems, and private water companies), accounts for more than half (51 percent) of the total withdrawals; about 70 percent of water for these uses is withdrawn from the confined aquifers. Irrigation and agricultural use accounts for 35 percent, and the balance of the water used (14 percent) is for self-supplied domestic purposes (individually owned wells). The majority of both agricultural and domestic withdrawals (about 78 and 66 percent, respectively) comes from the surficial aquifer.

In Virginia, commercial and industrial use, as well as use by suppliers to the public, accounts for 43 percent of the withdrawals; irrigation and agricultural use accounts for about 38 percent, and the balance (about 19 percent) is for self-supplied domestic use. Breakdowns of Virginia water use by aquifer are not readily available, but it is reported that few, if any, wells are installed in the surficial aquifer (R.J. Laczniak, U.S. Geological Survey, oral commun., 1988). The surficial aquifer is limited mostly to withdrawals from old domestic wells, and to withdrawals for irrigation and agricultural purposes.

SOURCES OF WATER-QUALITY DATA

Water-quality data are available from 3 Federal, 5 State, and 14 local agencies, as well as from nonprofit organizations and universities throughout Delaware, Maryland, and Virginia. Many of the data are related to regulatory or public-health functions. For example, water-quality data are collected routinely from public and domestic water supplies as mandated by State and local regulations. In addition, water-quality data are required for siting and operation of sanitary and industrial landfills, and hazardous-waste sites. State agencies also cooperate with the U.S. Environmental Protection Agency (EPA) in the administration of Federal water-quality regulations such as the Safe Drinking Water Act (SDWA), the Resources Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).

A large amount of water-quality data is housed by these various agencies. However, it was not feasible to incorporate all available data in this report. One limitation is that many of the data, particularly data housed by State and local agencies, are in paper files rather than in a computerized data base. In addition, the paper files commonly are housed in different offices within the same agency and are not duplicated in a central filing system, or are not in files exclusively dedicated to water quality. Most of the data discussed in this report are accessible from computer files. Data in paper files that are organized in a central filing system and that contain a manageable number of analyses also are included.

Major sources of water-quality data are listed in table 3, along with a brief description of (1) the purpose for collecting the data, and (2) the availability and accessibility of the data for water-quality assessment. Federal agencies are grouped and listed alphabetically in the table, and the remaining agencies are listed alphabetically by State. Six of these sources provided readily available data on inorganic constituents: the National Uranium Resource Evaluation Program; the U.S. Environmental Protection Agency–STORET; the U.S. Geological Survey; the Delaware Water Resources Center; the Wicomico County (Md.) Health Department; and, the Virginia Water Project, Inc. The number of wells at which inorganic constituents were sampled is given in table 4 by data source. Three of the data sources listed in table 3 provided data for selected organic compounds. A brief description of these sources is presented in this section.

National Uranium Resource Evaluation (NURE) Program data include information on nine inorganic constituents and properties. Data were retrieved for Delaware and Maryland only. The NURE Program was designed to assess national uranium resources. Neutron activation techniques primarily were used, and only constituents detected using these techniques were analyzed for the Delmarva Peninsula. All the samples were analyzed by the Savannah River Laboratory in Aiken, S.C. (Cook and others, 1981). A total of 710 wells, predominantly domestic wells (about 96 percent), are located throughout Delaware and Maryland, approximately 1 well per 5 mi^2. Information on well depths, well construction, and the aquifer from which the water is withdrawn is only partly available. On the basis of depth information for 437 of the 710 wells (median depth is 55 ft, and 75 percent are less than 150 ft deep), it is assumed that most wells are relatively shallow and are completed in the surficial or upper confined aquifers. All data were collected during the summers of 1977 and 1978.

Water-quality data housed in STORET at the U.S. Environmental Protection Agency include information on 23 inorganic constituents and properties for Virginia. State and local agencies in Delaware and Maryland do not use STORET to house their well-construction and water-quality data. All Virginia STORET data were collected and ana-

Table 3. Available data sources

Source	General purpose for collecting data and availability and accessibility of data for water-quality assessment
	Federal agencies
National Uranium Resource Evaluation Program	Collected to assess national uranium resources; data computerized and accessible; no organics data are available; information on well depths, well construction, and the aquifers from which the water is withdrawn is only partly available.
U.S. Environmental Protection Agency—Federal Data Repository System	Used to assess compliance with maximum contaminant levels of the Safe Drinking Water Act; data are computerized; no organics data are available; information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn is unavailable.
U.S. Environmental Protection Agency—STORET	Collected for general ground-water research and regulatory functions; data collected and analyzed by the Virginia Water Control Board (State and local agencies in Delaware and Maryland do not use STORET to house their well-construction and water-quality data); data are computerized and accessible; no organics data are available; information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn is available for all wells.
U.S. Geological Survey	Collected for general ground-water research; data are computerized and readily accessible; organics data are available; information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn is available for most wells.
	State and local agencies—Delaware
Delaware Division of Public Health	Collected for regulatory purposes from community, and Federal- and State-owned noncommunity, public-water supplies as required by Safe Drinking Water Act; data are contained in paper files and are not readily accessible (primarily because of the magnitude of analyses—about 50 analyses are received daily); organics data are sparse; the amount and adequacy of information on well depths, well locations, well construction, and the aquifers from which the water is withdrawn are unknown.
Delaware Geological Survey	Collected for general ground-water research; data are contained in paper files; no organics data are available; information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn is available for most wells.
Department of Natural Resources and Environmental Control	Collected for regulatory purposes (primarily for monitoring hazardous waste sites, landfills, and emergency spills); data are contained in paper files; some organics data are available; information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn is sparse.
Delaware Water Resources Center	Collected for general ground-water research; data are contained in paper files but are readily accessible because of the relatively small number of analyses and manageable structure of the data format; no organics data are available; well depths are known for some of the wells; information on well construction and the aquifers from which the water is withdrawn is unavailable.
Other (individual county health departments)	Collected for regulatory purposes; data are contained in paper files; the amount and adequacy of information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn are unknown.
	State and local agencies—Maryland
Maryland Department of the Environment	Collected for regulatory purposes; data are contained in paper files; organics data are sparse; the amount and adequacy of information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn are unknown.
Wicomico County Health Department	Collected for regulatory purposes; data are computerized and accessible; no organics data are available; well locations are available within grid coordinates accurate to the nearest 1,000 feet; well depths are available for all wells; information on well construction and the aquifers from which the water is withdrawn is unavailable.
Other county health departments	Collected for regulatory purposes; data are contained in paper files; the amount and adequacy of information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn are unknown.
	State and local agencies—Virginia
Northampton and Accomack County Health Departments	Collected for regulatory functions from noncommunity public-water supply systems to meet Safe Drinking Water Act requirements; data are contained in paper files; some organics data are available; information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn is available for some wells but in many cases is filed in another State agency.
Virginia Department of Health	Collected for regulatory functions from community, and Federal- and State-owned noncommunity, public-water supplies to meet Safe Drinking Water Act requirements; data are contained in paper files but are relatively accessible because of the small number of analyses; some organics data are available; information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn is sparse and in many cases is filed in another State agency.
Virginia Water Project, Inc.	Collected for general ground-water research; data are contained in paper files but are relatively accessible because of the small number of analyses; organics data are available; information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn is available for all wells.

Table 4. Number of wells at which inorganic constituents were sampled

[Compiled from National Uranium Resource Evaluation Program, U.S. Environmental Protection Agency—STORET, U.S. Geological Survey, Delaware Water Resources Center, Wicomico County (Md.) Health Department, and Virginia Water Project, Inc., data]

	National[1] Uranium Resource Evaluation Program	U.S. Environmental Protection Agency—STORET	U.S. Geological Survey	Delaware Water Resources Center	Wicomico County Health Department	Virginia Water Project, Inc.
Properties (field)						
Alkalinity	701	136	540	0	0	0
Dissolved oxygen	0	0	183	0	0	0
pH	710	90	895	446	0	48
Specific conductance	0	183	876	657	0	0
Temperature	710	0	761	0	0	48
Major inorganic constituents						
Calcium	0	130	779	0	0	0
Magnesium	356	126	778	0	0	0
Hardness, as $CaCO_3$	0	142	881	0	0	0
Potassium	0	104	750	0	0	0
Sodium	707	106	756	0	0	0
Chloride	0	140	934	675	0	0
Sulfate	0	127	849	0	0	48
Total dissolved solids	0	76	740	657[2]	0	0
Nutrients						
Ammonium	0	0[3]	307	0	0	0
Nitrite	0	119	179	0	0	0
Nitrate	0	124	889	681	2,584	47
Total nitrogen	0	0	156	0	0	0
Major metals and trace elements						
Aluminum	700	0	224	0	0	0
Antimony	0	0	6	0	0	0
Arsenic	0	8	46	0	0	0
Barium	0	0	149	0	0	0
Boron	0	0	159	0	0	0
Cadmium	0	8	159	0	0	0
Chromium	0	8	46	0	0	0
Copper	0	88	192	0	0	0
Fluoride	0	131	629	0	0	0
Iron (dissolved)	0	0	527	0	0	0
Iron (total)	0	125	416	193	1,398	45
Lead	0	18	171	0	0	0
Manganese	683	123	539	0	0	0
Mercury	0	0	45	0	0	0
Molybdenum	0	0	120	0	0	0
Nickel	0	14	7	0	0	0
Selenium	0	0	8	0	0	0
Silver	0	0	6	0	0	0
Vanadium	710	0	113	0	0	0
Zinc	0	71	190	0	0	46
Radionuclides						
Gross alpha	0	0	0	0	0	0
Gross beta	0	0	0	0	0	0
Radon 222	0	0	0	0	0	0
Uranium 238	710	0	0	0	0	0

[1] Data were retrieved for Delaware and Maryland only. Virginia data are available, however, and could be retrieved for later use, if necessary.

[2] Total dissolved solids content was calculated by multiplying specific conductance by 0.80 (Robertson, 1979).

[3] Data may exist for ammonia; however, this parameter was not retrieved. The data could be retrieved for later use, if necessary.

lyzed by the Virginia Water Control Board (VWCB) and are referred to in this report as "VWCB data." These data were collected since the early 1970's as part of (1) previous studies of ground-water quantity and quality on the Eastern Shore of Virginia (Virginia Water Control Board, 1975; Fennema and Newton, 1982), or (2) a statewide water-quality network program. The water-quality data are for 203 wells. Information on well locations, well depths, and well construction for the sites where water-quality data were collected is readily available. The wells are completed in the surficial and upper confined aquifers, which make up the freshwater system on the southern tip of the peninsula.

U.S. Geological Survey (USGS) data include information on a large number (37) of constituents and properties for 976 wells that are widely distributed throughout the peninsula. Information on well locations, well depths, well construction, and the aquifers from which the water is withdrawn is available. Vertical coverage is relatively extensive, including the surficial and all three confined aquifer divisions. The data were collected during previous USGS studies conducted from 1944 through 1987.

Data housed at the Delaware Water Resources Center (DWRC) include analyses for five inorganic constituents and properties for eastern Sussex County, Del. The data were collected during a reconnaissance study to examine ground-water quality, potential problems, and possible sources of contamination in the coastal parts of the county (Robertson, 1977). Data are kept in paper files but are relatively accessible because of the manageable filing system and the relatively small number of analyses. Data for 681 wells were retrieved and manually entered in the USGS computer. The wells are used for domestic, agricultural, and industrial purposes. Information on well depths, well construction, and the aquifers from which the water is withdrawn is only partly available. On the basis of depth information for 353 of the 681 wells (median depth is 60 ft, and 75 percent are less than 80 ft deep) and the relative thickness of surficial deposits in the county, it is assumed that most wells are completed in the surficial aquifer. All data were collected from September 1976 through January 1977. Water samples were analyzed in the field within 2 to 6 hours after collection (Robertson, 1979).

Data for iron and nitrate concentrations in water from 2,584 wells were retrieved from the Wicomico County Health Department in Maryland. (Turbidity levels and bacteria counts also are available but were not retrieved for use in this report.) Most of the water samples were collected from domestic wells to meet State and local drinking-water requirements. Well depths are available for each site. Information about the aquifers from which the water is withdrawn is lacking; however, on the basis of well depths, thickness of surficial deposits, and general knowledge of domestic ground-water use in the county, it is assumed that most of the wells are completed in the surficial aquifer (depths range from 20 to 370 ft below land surface, with a median depth of 80 ft). The measurements were made from 1979 through 1987.

Data collected by the Virginia Water Project, Inc. (VWP), include information about six inorganic constituents and properties for Virginia. The data were collected by the nonprofit organization to assess drinking-water quality of ground water pumped from older, pitcher-pump dug wells in rural, agricultural areas. Data for 48 wells, all about 30 ft deep and completed in the surficial aquifer, were manually entered in the USGS computer. Water samples were collected during the summer of 1987 and analyzed by the Virginia Tech STEHP (Student Environmental Health Project) laboratory in Blacksburg, Va.

Data for organic compounds are available from the USGS, the VWP, and the Virginia Department of Health. The USGS data include analyses for 11 constituents in water from 14 wells in Maryland. The wells are completed in the surficial aquifer and were sampled in 1983. The VWP data include analyses for nine constituents in 37 wells in Virginia. These wells also are completed in the surficial aquifer and, as discussed earlier, are older, pitcher-pump dug wells in rural, agricultural areas. Analyses for organic compounds housed by the Virginia Department of Health represent water samples collected from community public-water supplies, as well as from Federal- and State-owned noncommunity supplies, in order to meet the SDWA requirements. These data are stored in paper files but were accessible for use in this study because of the small number of systems. Selected herbicide and insecticide data were collected from 27 of the 38 public water-supply systems. Water samples were collected from 1980 through 1984. In general, each system consists of multiple wells which commonly are screened in more than one aquifer. Although accurate information on depths of these wells is not available for all the systems, the data that do exist (showing depths ranging from 55 to 1,000 ft) indicate that the wells are completed primarily in the confined aquifers.

GENERAL CHARACTERISTICS OF DATA FOR REGIONAL GROUND-WATER-QUALITY ASSESSMENT

Water-quality data have been collected by various organizations to meet diverse objectives ranging from monitoring for compliance with drinking-water standards and criteria to conducting research on specific ground-water issues. Ideally, these data could be readily combined into one data base for conducting a regional ground-water-quality assessment. However, certain characteristics of the available data limit their usefulness for a regional assessment of ground water. Data-base structure and format, as well as differences among agencies in procedures for collecting and analyzing the data, may preclude the combination of data from different sources to form a meaningful regional assessment. Common limitations of the data include (1) lack of information on quality control, (2) inconsistency in sampling, preservation, and analytical techniques among and even within agencies, (3) the clustering of sampling wells around known or suspected areas of contamination, which can bias water-quality assessments, (4) improper construction of wells, and (5) lack of information on sampling locations, well depths, well construction, and aquifer characteristics. These limitations, which affect the use and interpretation of the data in this report, are discussed below. The data bases are discussed in the order they appear in table 3.

Insufficient information on well depths and well construction is a limitation in using the NURE data to assess ground-water quality on a regional basis. Well depths, available for only 437 of the 710 wells, are based primarily on homeowner's knowledge and commonly are not accurate enough for water-quality assessment. Few well-construction data exist, and none of the wells is classified by aquifer.

Preservation and sampling techniques in the field are limitations in using the VWCB data (STORET) to assess water quality on a regional basis. Preservation procedures are limited to chilling the samples to 4 °C (degrees Celsius). Preservatives are not used in the field. The use of preservatives improves the stability of selected constituents. For example, mercuric chloride improves the stability of nitrate and prevents conversion to other nitrogen forms by bacterial action, and nitric acid prevents the formation of ferric iron precipitates. Because no preservatives are used at the time of sampling, reported nitrate concentrations may be lower than concentrations present in the ground water, and dissolved iron is not reported. In addition, no filtering is done in the field, and therefore all constituents are reported as total concentrations.

Changes in preservation procedures over time limit the usefulness of the USGS data. For example, preservation of nitrate concentrations in water samples collected prior to the mid-1970's included only chilling to 4 °C at the time of sampling. Preservation procedures since that time have included chilling and adding mercuric chloride, which improves the stability of nitrate concentrations. Nitrate concentrations reported for the earlier years may, therefore, be lower than actual concentrations in the ground water. Another limitation is the use of a variety of detection limits, primarily because of changing technology and the use of multiple laboratories.

A limitation in using the DWRC data in a regional ground-water-quality assessment is that the chemical constituents were analyzed in the field and, therefore, may not be as accurate as if analyzed in the laboratory. Chemical-sensing electrodes were used in the field to test for nitrate and chloride, and agreed within 8 and 20 percent, respectively, with selected samples analyzed for comparison by a public health laboratory. Total iron, analyzed using the 1-10 phenanthroline method and a colorimeter, was reproducible within 25 percent on the basis of a single comparison (Robertson, 1979). In addition, well depths were obtained primarily from homeowners and may not be accurate enough for a water-quality assessment, and information on well construction and aquifer characteristics is lacking.

A limitation in using the Wicomico County Health Department data for regional ground-water-quality assessment involves the lack of or inaccuracy of information on well locations and well construction. Locations of the wells are available only in grid coordinates accurate to the nearest 1,000 ft. Lack of well-construction and aquifer information prevents accurate data analysis by aquifer. Finally, the data base may include duplicate analyses for the same well because analyses are listed by well owner, and an individual may own one well or many. These wells could bias a regional assessment of ground-water quality.

A limitation in using the Virginia Department of Health data for regional ground-water-quality assessment is insufficient information on well construction, locations, and depths. Many of the sampled systems involve multiple wells. Well-construction information that is available indicates that most of the wells are multiscreened and are completed in several confined aquifers; this precludes precise determination of the sample source.

A limitation in using the VWP data for water-quality assessment is that the data were collected to meet a specific objective and, therefore, may overrepresent known or suspected water-quality problems. Specifically, the VWP's sampling strategy focused on likely ground-water-quality problem areas (mainly nitrate and pesticide concentrations in rural, agricultural areas). A second limitation is that most of the wells are pitcher-pump dug wells, many of which are old and improperly constructed. Elevated concentrations of nitrate and pesticides could represent direct introduction of these compounds into the well rather than a problem with the ground water. A third limitation is that detection limits for several of the organic compounds are relatively high because of laboratory analytical limitations. Therefore, some trace constituents in concentrations below detection limits may not have been detected.

ANALYSIS OF AVAILABLE GROUND-WATER-QUALITY DATA

This section provides a preliminary analysis of water-quality conditions on the Delmarva Peninsula. Four major topics are addressed: (1) regional variations in water type, (2) suitability of ground water for human consumption, (3) areal and vertical distribution of water-quality constituents, and (4) potential effects of natural and human factors, such as physiography, geomorphology, and land use, on the distribution of nitrate, iron, and manganese concentrations in the surficial aquifer.

As discussed previously, there are inherent limitations in using existing data in a regionwide assessment. Assumptions are required to use the data. For example, it is assumed that all wells in the Delaware Water Resources Center and Wicomico County Health Department data bases are completed in the surficial aquifer. In addition, the areal and vertical distributions of many of the constituents are unknown, and this makes it impossible to fully understand regionwide ground-water quality. Despite these limitations, the analysis in this report provides an initial assessment of ground-water quality on the Delmarva Peninsula that is a useful foundation for a more detailed regional assessment. It also highlights areas for which pertinent water-quality data are lacking. Before the regionwide assessment was initiated, the water-quality data were reviewed, sorted, and reformatted for analysis. Six major factors were considered in this effort. They are discussed in the following paragraphs.

Individual data bases were analyzed separately.—The data housed by the different agencies generally were not combined and treated as one population. This approach was taken not only because data-base structures and formats differ considerably (as discussed in the previous section), but also to avoid potential geographical and statistical bias. For example, statistical bias would be introduced if the VWCB data, which covers only Virginia, were combined with the USGS data, which covers the entire peninsula. In such an analysis, the question would immediately arise whether differences in water-quality conditions in Virginia were real or were artifacts of different laboratory and sampling procedures used by the two agencies. Geographical bias would be introduced by combining data bases that span a local area but include a large amount of data (such as the 2,584 analyses compiled from the Wicomico County Health Department) with data bases that span the entire peninsula but contain fewer data (such as the 976 analyses compiled from the USGS).

Conclusions based on the individual data bases generally were consistent; however, inconsistent results among agencies were noted. Data compiled from the individual agencies are discussed in the following order in this section: USGS, NURE, VWCB, VWP, DWRC, and Wicomico County Health Department.

In general, the most recent analysis for each constituent at each well was used for statistical analysis.—In the statistical analysis of individual constituents, only the most recent analysis at each well was included in order to avoid bias toward wells for which many analyses were available. One exception was that all Wicomico County Health Department data were included because duplicate analyses for a single well could not be distinguished. In the water-type analysis, which involves several constituents (major cations and anions), the most recent sample at a well that had been analyzed for all major cations and anions was used in the analysis.

Ionic charge-balance checks were computed to assess the general accuracy and usefulness of the water-quality analyses for major cations and anions for use in a regional assessment.—The general accuracy and usefulness of the water-quality analyses for major cations and anions was assessed by computing an ionic charge balance on the major cations (calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+}), and potassium (K^{+})) and anions (bicarbonate (HCO_3^-), chloride (Cl^-), nitrate (NO_3^-), and sulfate (SO_4^{-2})). Ionic charge-balance checks were computed on the most recent samples collected at each well that included the required set of constituents. Bicarbonate (HCO_3^-) concentrations represent a conversion from alkalinity measurements. Analyses for 556 of the 976 USGS wells include the necessary cations and anions, and 52 (about 9 percent) of these analyses have an ionic charge-balance error exceeding 10 percent. About 75 percent of these 52 analyses are for the surficial aquifer or subcrop area of confined aquifers, which typically have a low total dissolved solids content and, therefore, are particularly sensitive to a slight error in the concentration of even one constituent. Analyses for 97 of the 203 VWCB wells include the required set of constituents, and 25 (about 26 percent) of these analyses have an ionic charge-balance error exceeding 10 percent. Ionic charge-balance checks including iron as an additional cation (assumed to be in the dissolved ferrous form) also were made to assess its potential contribution to large ionic charge-balance errors. The inclusion of iron did not change the number of charge-balance errors in the majority of cases.

Analyses for individual constituents representing different laboratory analytical methods were combined in the statistical analysis, when reasonable. Dissolved and total concentrations were combined and analyzed as one population, except for iron.—Because of changes in preservation, sampling, and analytical techniques, as well as differences in needs and objectives of individual projects, many constituents in the USGS data base are analyzed using a variety of methods and reported as one of many parameter codes. When reasonable, the data were combined (for example, dissolved nitrite plus nitrate (parameter code 00631) was combined with dissolved nitrate (parameter code 00618) because nitrite generally is minimal). The procedure used to combine data for each constituent is presented in the appendix. The method of analysis for each constituent included in the NURE, VWCB, VWP, DWRC, and Wicomico County Health Department data bases also is presented in the appendix.

As shown in the appendix, dissolved and total concentrations for individual constituents were combined except for iron. This was done because generally the difference between dissolved and total concentrations is minimal (majority of analyses are within 10 percent). Differences in dissolved and total iron concentrations are much greater—46 (about 67 percent) of 69 analyses differ by more than 10 percent, and 31 analyses (about 45 percent) differ by more than 50 percent. The large differences between dissolved and total iron concentrations may be the result of (1) insufficient preservation at the time of sampling (ferrous iron is unstable and will readily convert to ferric precipitates when exposed to oxygen if not properly preserved), or (2) colloidal iron in samples due to corrosion of well casing or improperly developed wells.

The highest detection limit was used when various detection limits are present.—Various detection limits are common for selected constituents in the USGS data base. In most cases, the highest detection limit was used and all concentrations less than this limit were set to indicate a "nondetected" value. Exceptions were made for constituents that had a consistent detection limit except for one or two isolated analyses with an unusually high detection limit. In these cases, the one or two analyses with the high detection limit were eliminated, and the lower, more common detection limit was used.

Location and depth of wells were not field checked.—Because of the magnitude of data and time constraints, the depth and location of wells were not field checked. All well depths in subsequent discussions represent feet below land surface.

Regional Variations in Ground-Water Type

Water types, designated by the dominant cations and anions, are used in this report to illustrate basic differences in ionic composition of water within the aquifers (fig. 5). The ionic composition of water changes as water moves from the atmosphere through sediments and interacts with minerals. The principal constituents in precipitation are sodium, sulfate, chloride, and nitrate (Cushing and others, 1973). Precipitation is the predominant source of recharge to the ground-water flow system. The general composition of water in these recharge areas primarily reflects the chemistry of precipitation and is a mixture of sodium, calcium, and magnesium cations, and bicarbonate, chloride, and sulfate anions (represented as A in fig. 5). The chemistry of water is modified by contact with minerals as it moves from recharge areas through the ground-water flow system. It changes to calcium bicarbonate-type water (B in fig. 5) as a result of dissolution of calcite in shell material in the sediments. As ground water continues to move through the system, it interacts with cation-exchange minerals. Calcium and magnesium are removed from solution by cation-exchange processes and are replaced by sodium, resulting in sodium bicarbonate-type water (C in fig. 5). The sodium on the minerals most likely is from the loading of the mineral-exchange sites during periods of saltwater intrusion or marine deposition, or from formation of sodium-rich clay by weathering processes (Knobel and Chapelle, 1986). Near the limit of the freshwater system, the water type is altered again as ground water intermixes with saline water, resulting in sodium chloride-type water (D in fig. 5).

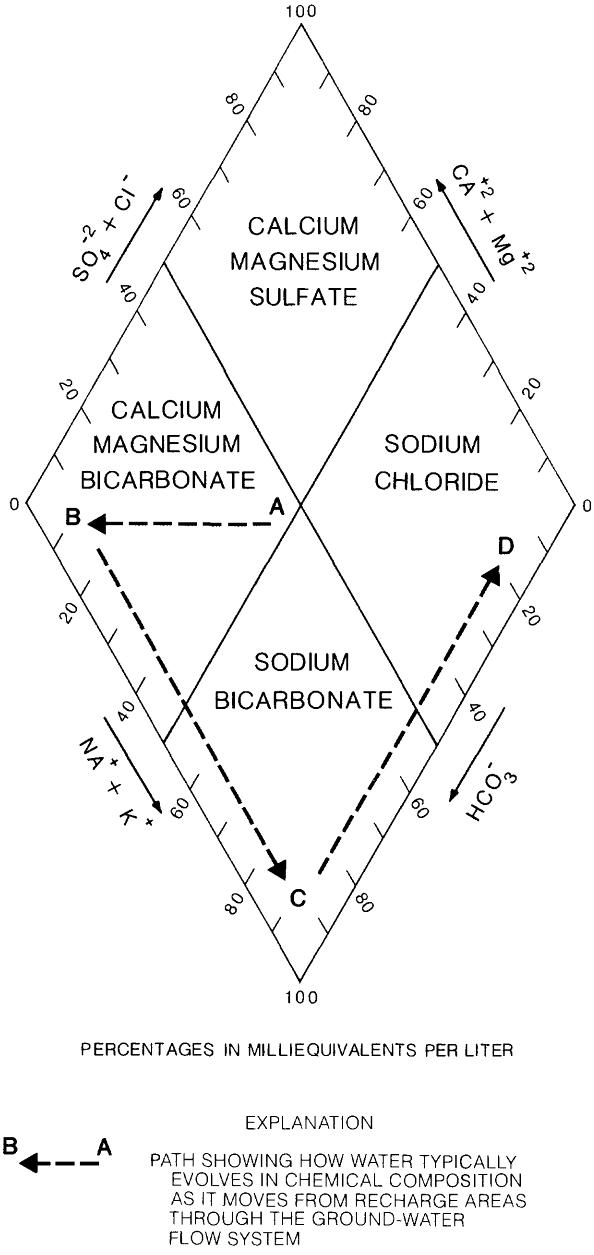


Figure 5. Classification of water types.

Total dissolved solids content increases as ground water moves through the system. Precipitation recharging the ground-water flow system contains low concentrations of total dissolved solids, ranging from 5 to 7 mg/L (milligrams per liter) (Denver, 1986). As this water enters the soil, evapotranspiration increases the total dissolved solids content by a factor of about three (Cushing and others, 1973). As the water moves through the sediments and interacts with minerals, it continues to increase in total dissolved solids content. Highest total dissolved solids are

Table 5. Number of analyses having an ionic charge-balance error of less than 10 percent
[Compiled from U.S. Geological Survey and Virginia Water Control Board data]

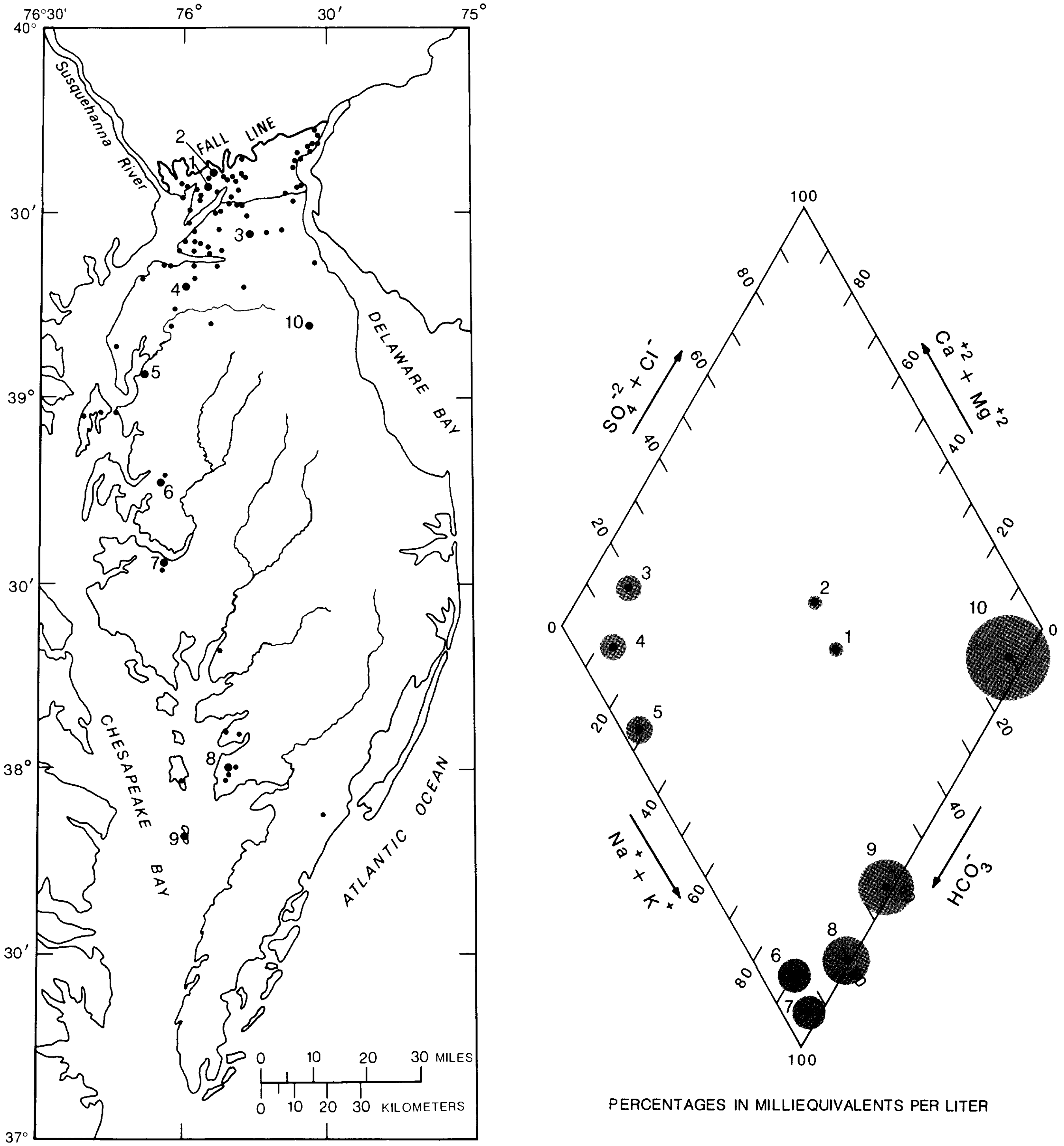
Aquifer	U.S. Geological Survey			Virginia Water Control Board		
	Total	Number of analyses having an ionic charge-balance error of less than 10 percent	Number of analyses having an ionic charge-balance error greater than 10 percent	Total	Number of analyses having an ionic charge-balance error of less than 10 percent	Number of analyses having an ionic charge-balance error greater than 10 percent
Surficial aquifer	264	81	183	14	8	6
Upper confined aquifers in upper Tertiary sediments	135	124	11	83	62	21
Middle confined aquifers in lower Tertiary sediments	106	104	2	0	0	0
Lower confined aquifers in Cretaceous sediments	116	89	27	0	0	0
Total	621	398	223	97	70	27

associated with sodium chloride-type water near the limit of the freshwater system.

The most recent water sample collected at each of the 976 USGS and 203 VWCB wells was used for water-type classification. A total of 621 and 97 of these analyses, respectively, include data for the complete set of the major cations (Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+}) and anions (HCO_3^-, SO_4^{-2}, and Cl^-) that are used in this report to classify water types. Because the water-type analysis is sensitive to inaccurate or outlying values, ionic charge-balance checks were calculated to screen out analyses exceeding a 10-percent error. Ionic charge balances were computed using only those constituents included in the water-type analysis, and, therefore, nitrate was not included as a major cation. The number of analyses having an ionic charge-balance error of less than 10 percent is presented in table 5. The percentage of analyses having an ionic charge-balance error exceeding 10 percent is greater when nitrate is excluded as a major cation than when nitrate is included. This particularly is true in the surficial aquifer; 183 (about 69 percent) of the 264 USGS analyses have an ionic charge-balance error exceeding 10 percent when nitrate is excluded, and only 30 (about 12 percent) of the 256 USGS analyses have an ionic charge-balance error exceeding 10 percent when nitrate is included.

U.S. Geological Survey data.—The locations of USGS wells with water-type analyses having an ionic charge-balance error of less than 10 percent are plotted in figures 6 through 9. The ionic composition of water was determined for each well. In the confined aquifers, the ionic composition of water is similar in wells located in the same geographic region. To increase clarity on the quadrilinear diagrams, therefore, water types are shown for only about 10 to 20 wells in each confined aquifer division. These wells, geographically distributed throughout the peninsula, were selected because they represent the water types in surrounding wells. The selected wells do not necessarily represent positions along ground-water flow paths. Ground-water flow (under both prepumping and pumping conditions) is complex within the confined aquifer divisions and needs to be examined further before relations between the ionic composition of water and position along flow paths are understood. Although ground-water flow may explain some of the regional patterns demonstrated in this section, it is not the intent of this preliminary analysis to document its influence on water types. In the surficial aquifer, regional trends in the ionic composition of water are not evident, and representative wells could not be selected. All analyses having an ionic charge-balance error of less than 10 percent are, therefore, shown on the quadrilinear diagram.

Locations of 10 selected wells in the lower confined aquifers and their corresponding positions on the quadrilinear diagram are shown in figure 6. Wells 1 and 2, located in the subcrop areas in the northern part of the peninsula where the aquifer lies close to the surface and is subject to direct recharge, are characterized by a mixed water composed of sodium, calcium, magnesium, chloride, sulfate, and bicarbonate ions. Wells 3, 4, and 5, located in the northern part of the peninsula, are characterized by calcium bicarbonate-type water. Wells 6 through 9, located in the central part of the peninsula, are characteristic of sodium bicarbonate-type water. Well 10, located in the northern part of the peninsula along the freshwater-saltwater interface, is enriched in chloride and is characteristic of sodium chloride-type water. Water-quality analyses are not available for the southern



EXPLANATION

• WELL WITH WATER-QUALITY ANALYSIS HAVING AN IONIC CHARGE-BALANCE ERROR LESS THAN 10 PERCENT

•3 WELL, WELL NUMBER, AND POSITION ON QUADRILINEAR DIAGRAM

0
100
500
1,000
5,000
10,000

● RADIUS OF CIRCLE INDICATES TOTAL DISSOLVED-SOLIDS CONCENTRATION, IN MILLIGRAMS PER LITER part of the peninsula; however, it is assumed that ground water in this area is similar to that in well 10 because of the presence of saline water. Total dissolved solids content, as shown by the circles in figure 6, is smallest in the subcrop areas and largest along the freshwater-saltwater interface (well 10).

Regionally, the ionic composition of water in the middle confined aquifers is similar to that in the lower confined aquifers. Locations of 14 selected wells and their corresponding positions on the quadrilinear diagram are shown in figure 7. Wells 1 through 5, located in the northern part of the peninsula, are characteristic of calcium bicarbonate-type water. Well 6, located on Kent Island, Md., is characteristic of calcium chloride-type water. The enriched chloride content probably is the product of saltwater movement induced by excessive pumping. Water in well 7 is rich in bicarbonate ion, with a mixture of calcium and sodium ions. The remaining wells, located in the central part of the peninsula, are characteristic of sodium bicarbonate-type water. Analyses are not available for the southern part of the peninsula; however, it is assumed that the ground water there probably is affected by the presence of saline water and would plot between a sodium bicarbonate- and sodium chloride-type water. Total dissolved solids content is not shown in the figure because of crowding; however, as in the lower confined aquifers, total dissolved solids content is smallest in the subcrop areas and largest along the freshwater-saltwater interface.

Locations of 18 wells in the upper confined aquifers and their corresponding positions on the quadrilinear diagram are shown in figure 8. Wells 1 through 4, located in the northern part of the peninsula, are characteristic of calcium bicarbonate-type water. Wells 5 through 13, located in the central part of the peninsula, are rich in bicarbonate ion, with varying mixtures of calcium and sodium ions, and in a few instances some magnesium ions. The varying mixtures probably relate to distance from recharge areas, which are present throughout the central part of the upper confined aquifers, and to differences in mineralogy of soil and aquifer sediment. Wells 10, 12, and 13 are enriched in chloride, which probably is the product of saltwater movement near coastal communities (wells 10 and 12), or of upward movement of saline water from underlying aquifers (well 13). Wells 14 through 18, located at the southern tip of the peninsula, are characteristic of calcium bicarbonate-type water. These wells are located in the recharge area in Virginia (along the drainage divide between Chesapeake Bay and the Atlantic Ocean). The enriched content of calcium and bicarbonate ions probably reflects direct recharge from the surficial aquifer and a relatively high carbonate content in surficial aquifer material. According to Cushing and others (1973), the sediments at the southern tip of the peninsula are of marine origin and contain abundant calcareous shells.

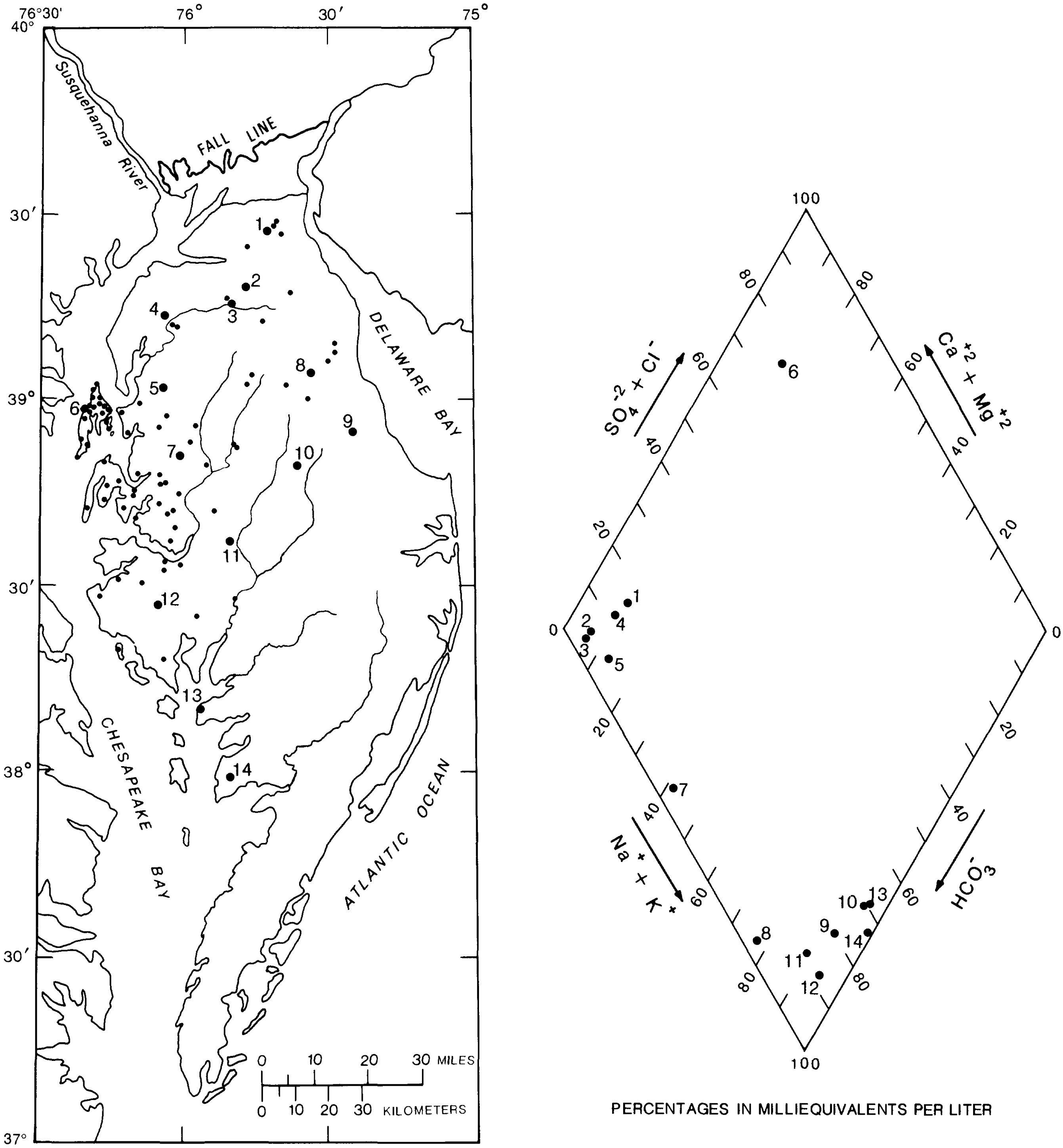
◀ **Figure 6.** Water types of ground water in the lower confined aquifers in Cretaceous sediments in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

Locations of wells in the surficial aquifer having an ionic charge-balance error of less than 10 percent and their respective positions on the quadrilinear diagram are shown in figure 9. The analyses are scattered throughout the quadrilinear diagram and are a mixture of sodium, calcium, and magnesium cations, and bicarbonate, chloride, and sulfate anions. Some analyses, mostly representing wells in the coastal areas, plot along the outer edge of the diagram where chloride is the dominant ion. Regional trends in the ionic composition of water in the surficial aquifer are not evident, probably because ground-water flow is more localized in shallow systems.

Virginia Water Control Board data.—Analyses for 83 wells in the upper confined aquifers indicate predominantly calcium bicarbonate-type water. These wells are located primarily along the recharge area. Approximately 10 percent of the analyses indicate sodium bicarbonate-type water. These analyses represent water in relatively deep wells in the upper confined aquifers and may reflect upward movement of saline water from underlying aquifers, or they represent water in wells located downgradient from the recharge area where ground water is beginning to mix with saline water. Analyses of water samples collected from eight wells in the surficial aquifer indicate a mixture of sodium, calcium, and magnesium cations, and bicarbonate, chloride, and sulfate anions.

Factors affecting the ionic composition of water.—The ionic composition of water varies regionally in the confined aquifers. Factors that may affect ionic composition are position along ground-water flow path, residence time in the ground-water system (or "age" of water), and the nearby presence of saline water (Back, 1966; Knobel and Chapelle, 1986). In addition, the mineralogy of aquifer sediment contributes significantly to water type. For example, Knobel and Chapelle (1986) found that ground water in the Aquia aquifer changes from a calcium bicarbonate- to sodium bicarbonate-type water as it moves through glauconite-rich sediments. Glauconite has a high capacity to exchange cations, and because it is formed in a marine environment, sodium is the predominant cation on the exchange sites (Knobel and Chapelle, 1986).

It was beyond the scope of this report to document the influence and relative importance of ground-water flow, age of ground water, saline water, or mineralogy of aquifer sediment on the ionic composition of water within the confined aquifers because of the complexity of the ground-water system. However, a few statements can be made from the preliminary water-type analysis. In updip areas where the confined aquifers are directly recharged by the surficial aquifer, the ionic composition of water reflects precipitation and the materials in the overlying surficial aquifer. The



EXPLANATION

- WELL WITH WATER-QUALITY ANALYSIS HAVING AN IONIC CHARGE-BALANCE ERROR LESS THAN 10 PERCENT

●6 WELL, WELL NUMBER, AND POSITION ON QUADRILINEAR DIAGRAM composition of the ground water is modified in the downdip areas as the water encounters calcite in shell material, ion-exchange minerals, and saline water. Although ground water in the downdip areas of a particular aquifer is not necessarily in the most distal part of the flow system, it is at least in an intermediate position along flow paths. Therefore, in most of the aquifers, water in the downdip areas generally is "older" than water in the updip areas, and the transit time allows for geochemical changes to occur. One exception to this may be in the updip areas where paleochannels are present. Paleochannels may serve as discharge zones for "older" water flowing along regional ground-water flow paths. Another exception may be in downdip areas of the upper confined aquifers where localized flow and recharge areas are prevalent throughout their extent.

Processes affecting the ionic composition of water in the surficial aquifer are not well documented. The chemistry of precipitation is a major factor affecting the ionic composition of ground water in the surficial aquifer. Additional factors include local geology, length of the flow path, vegetative cover, soil, topography, land use, and agricultural practices. Some of these factors have been assessed in previous studies. For example, Bachman (U.S. Geological Survey, written commun., 1986) found that geologic differences in the surficial aquifer affect ground-water flow and, in turn, help determine the composition of the ground water. Bachman found that in the northern part of the peninsula, where the aquifer is thin and clay layers are sparse, the flow systems are relatively short and gradients are steep. The ground water in this area is enriched in calcium and nitrate. Farther south, where the aquifer is thicker and clay layers are more prevalent, flow systems are longer and gradients are flatter. Ground water in these areas is relatively high in sodium and silica.

General Ground-Water Quality

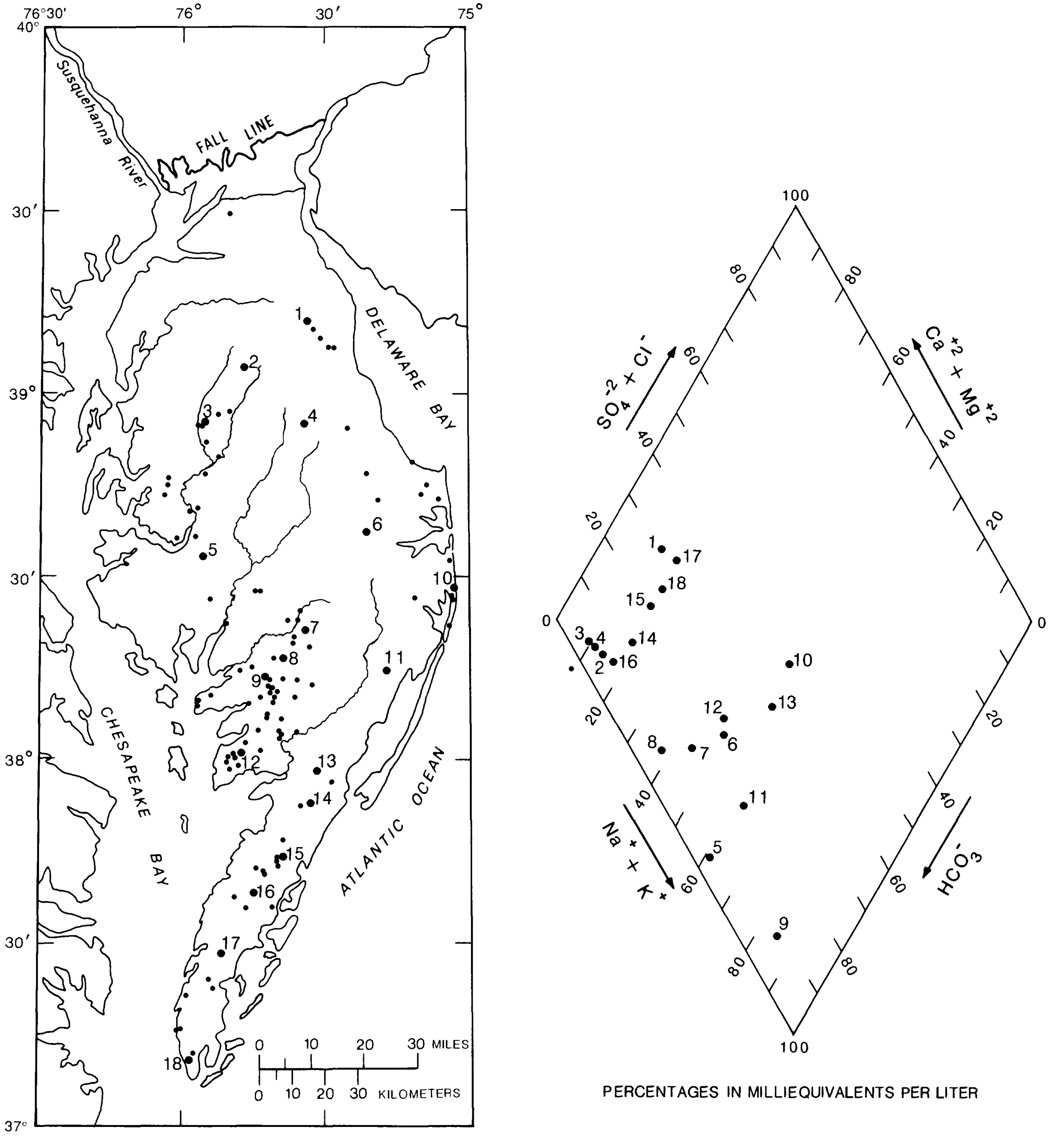
Ground water on the Delmarva Peninsula is suitable for most purposes. As discussed earlier, the natural quality is predominantly controlled by the chemical properties of rain and snowmelt, the mineralogy of soils and aquifer materials, the residence time in the ground-water system, and the nearby presence of saline water. Human activity throughout the peninsula, however, has affected ground-water quality.

The surficial aquifer is composed mainly of quartz, feldspar, and clay minerals, and generally lacks carbonate minerals. (Carbonate minerals are common in Virginia because of shell material in the marine sediments.) Ground water in the surficial aquifer generally is characterized by acidic conditions, softness, low alkalinity, and a low sodium and total dissolved solids content, because of the composition of the sediment, the relatively low concentrations of inorganic constituents, and the low pH (between 4 and 5) of precipitation. Natural water-quality problems throughout the surficial aquifer include elevated iron and manganese concentrations and low pH. Human activities affecting water-quality conditions in the surficial aquifer relate to septic system effluent and agricultural fertilizers, resulting in elevated nitrate concentrations. Local incidences of elevated chloride concentrations may derive from domestic septic effluent, road salting, and agricultural practices (application of potassium chloride), as well as saltwater intrusion induced by pumping.

As ground water from the surficial aquifer recharges the confined aquifers and encounters different suites of minerals and redox conditions, its chemistry changes. Confined ground water is harder and less acidic than surficial ground water and has a higher total dissolved solids content. Natural water-quality problems in the confined aquifers include elevated iron and hardness concentrations. In addition, all the confined aquifers contain saline water downdip. This salinity limits their potential use because of pumpage-induced encroachment of elevated concentrations of chloride, sodium, and total dissolved solids into the freshwater zones.

Drinking-water standards and criteria have been established by the U.S. Environmental Protection Agency (1986a, 1986b) to safeguard public health and welfare (table 6). Levels set to protect human health commonly are referred to as "maximum contaminant levels" (MCL's). Levels set to safeguard human welfare provide acceptable aesthetic and taste characteristics and commonly are referred to as "secondary maximum contaminant levels" (SMCL's). Hardness and sodium are not regulated by the EPA but are included in table 6 and discussed in the report. Hardness, calculated as the sum of calcium and magnesium equivalents and reported in this paper as equivalent calcium carbonate, can become a nuisance by reducing lather formation and the effectiveness of soap as a cleanser, as well as by creating scale deposits. Hardness content as concentration of calcium carbonate ($CaCO_3$) is classified in one of four categories: (1) 0 to 60 mg/L, soft; (2) greater than 60 to 120 mg/L, moderately hard; (3) greater than 120 to 180 mg/L, hard; and (4) greater than 180 mg/L, very hard (Hem, 1985). Hardness becomes objectionable for ordinary domestic use at concentrations greater than 100 mg/L (Hem, 1985). Sodium concentrations greater than 270 mg/L may cause health problems for humans on restricted sodium diets (U.S. Environmental Protection Agency, 1976). The total number of wells and the percentage of wells where water does not meet the drinking-water standard or criterion for each constituent are given in table 6. Hardness, pH,

◀ **Figure 7.** Water types of ground water in the middle confined aquifers in lower Tertiary sediments in the Delmarva Peninsula (compiled from U.S. Geological Survey data).



EXPLANATION

• WELL WITH WATER-QUALITY ANALYSIS HAVING AN IONIC CHARGE-BALANCE ERROR LESS THAN 10 PERCENT

12● WELL, WELL NUMBER, AND POSITION ON QUADRILINEAR DIAGRAM nitrate, iron, and manganese concentrations do not meet the respective drinking-water standard or criterion in the largest percentage of wells.

Spatial Distribution and Statistical Summaries of Selected Constituents

The spatial distribution and statistical summaries of selected constituents are presented in this section. Data are grouped to illustrate water-quality patterns characteristic of aquifers, geographic regions, and land use. The nature of the groupings for each data base depends on the spatial distribution of data, as follows: (1) USGS data for constituents for which few analyses are available (trace elements, radionuclides, and organic compounds) are grouped into two broad hydrogeologic categories—surficial and confined; (2) USGS data for constituents for which large numbers of analyses are available (pH, hardness, sodium, chloride, sulfate, total dissolved solids, nitrate, iron, manganese, and fluoride) are grouped into four categories—the surficial aquifer, and the upper, middle, and lower confined aquifers; (3) VWCB data are grouped into the surficial and upper confined aquifers; (4) NURE, VWP, DWRC, and Wicomico County Health Department data are not separated by aquifer, either because much well-depth and aquifer information is lacking (NURE, DWRC, and Wicomico County Health Department data) or because all samples were collected from the same aquifer (VWP data).

Data for selected constituents in the USGS data base also were grouped geographically to illustrate water-quality patterns characteristic of certain regions. Two different sets of geographic regions were applied. The first set, referred to as "geographic regions of the confined aquifers," is used to demonstrate regional variations within updip and downdip parts of the three divisions of confined aquifers (fig. 10). The boundaries were selected primarily to provide three evenly spaced areas representing northern, central, and southern regions. However, the position of the boundaries also was influenced by aquifer extents (for example, the northern boundary was positioned at the limit of the upper confined aquifers as defined by Cushing and others (1973)). The analyses representing wells in the subcrop area of the lower confined aquifers (between the Fall Line and the Chesapeake and Delaware Canal) were treated separately because of water-quality differences suggested in the water-type analysis (fig. 10). In this area, the aquifers lie close to the surface, and, therefore, this ground water is subject to direct recharge from the surficial aquifer and reflects the water chemistry of the surficial aquifer. Analyses representing wells in the southern tip of the upper confined aquifers also were treated separately because of water-quality differences resulting from recharge through relatively high carbonate surficial material (fig. 10). Data for the surficial aquifer were not grouped into the regions described above because, as indicated in the water-type analysis, regional patterns are not evident.

The second set of geographic regions applies to the surficial aquifer. These regions, referred to in this report as "hydrogeomorphic regions," are those having a distinctive combination of hydrogeologic and areal characteristics, such as surficial geology, geomorphology, soil type, and physiography, that can impart a characteristic set of water-quality patterns. The relative importance of these characteristics in regional water quality may differ from region to region. For the purpose of this preliminary analysis, the peninsula was divided into six hydrogeomorphic regions (fig. 11). The first region, referred to as "poorly drained uplands," is composed of the uplands in the central part of the peninsula. The uplands are poorly drained in the sense that they generally contain small sluggish streams flowing in low-gradient, poorly developed valleys. They are characterized by hummocky topography, poorly drained but permeable sediments and soils, shallow depths to the water table (0 to 10 ft), and short ground-water flow paths. The second, and largest, region, referred to as "well-drained uplands," consists of the well-drained uplands that flank the central uplands. This region is relatively flat and consists of permeable soils and sediments that are more deeply incised by stream valleys. Depths to the water table are greater (about 10 to 40 ft), and flow paths are longer than in the central uplands. The third region, referred to as the "Walston Silt-Omar" region, is underlain by silt and clay of the Walston Silt and Omar Formation in southern Delaware and adjoining parts of Maryland that overlie the water-bearing part of the surficial aquifer (fig. 4). The uppermost surficial sediments are much less permeable than sediments in the well-drained and central uplands. The fourth region, referred to as "poorly drained lowlands," is underlain by the Sinepuxent and Ironshire Formations on the eastern side of the peninsula and by sandy deposits of the Kent Island Formation on the western side. It is characterized by poorly drained lowlands adjacent to tidal marshes and lagoons that have permeable but poorly drained soils and shallow depths to the water table. The fifth region, referred to as "fine-grained lowlands," is underlain by the finer grained deposits of the Kent Island Formation. The region is a broad, low-lying area fringing Chesapeake Bay, about 5 to 10 ft above sea level, and is characterized by shallow depths to the water table and poorly drained and relatively impermeable sediments. The sixth region, referred to as the "thin surficial aquifer" region, lies north of the Chesapeake and Delaware Canal where the surficial aquifer is thin or absent and the underlying aquifers subcrop beneath the surface.

◀ **Figure 8.** Water types of ground water in the upper confined aquifers in upper Tertiary sediments in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

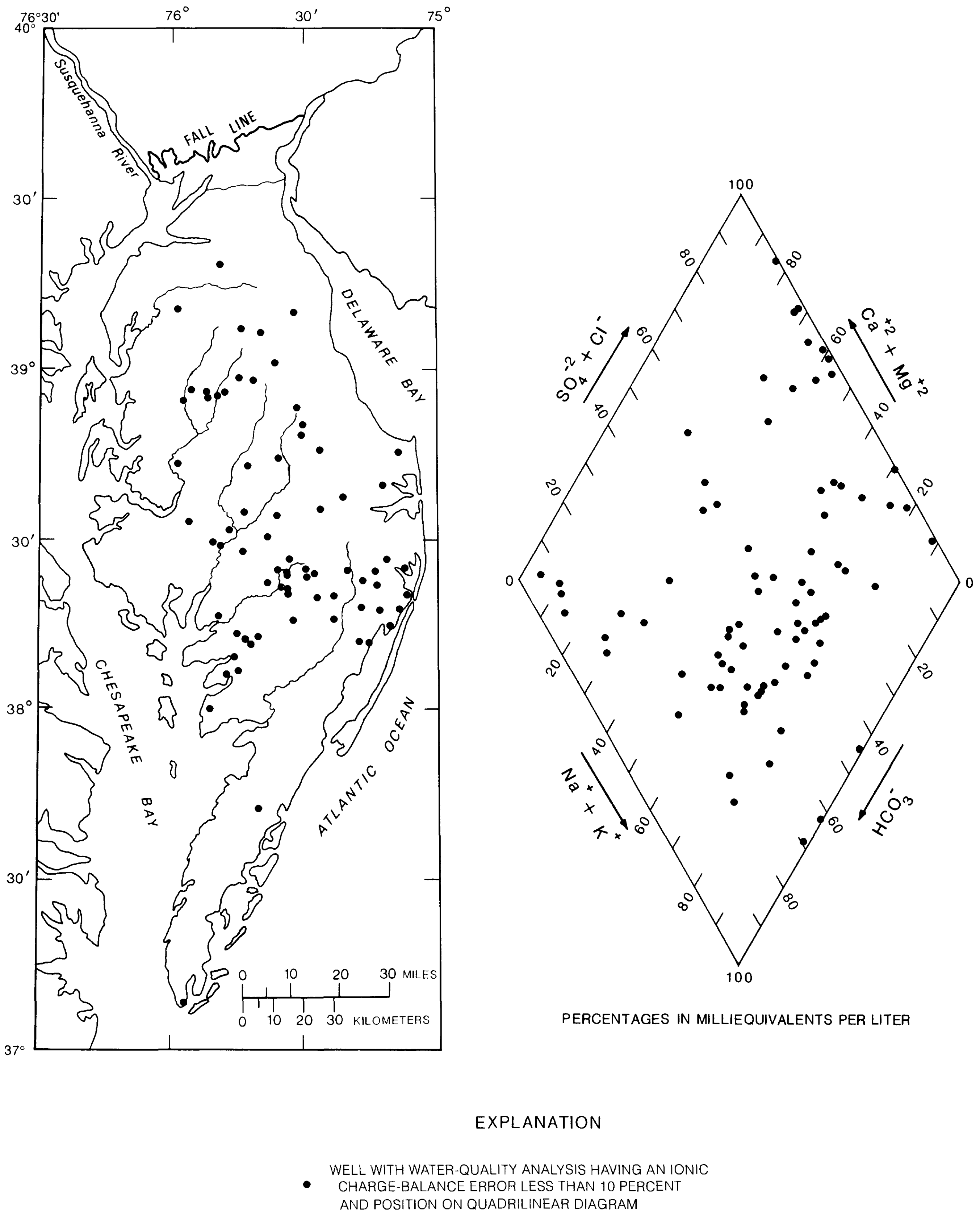


Figure 9. Water types of ground water in the surficial aquifer in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

Table 6. Drinking-water standards and criteria, and percentage of wells where water does not meet drinking-water standards and criteria

[Compiled from U.S. Geological Survey, National Uranium Resource Evaluation Program, Virginia Water Control Board, Virginia Water Project, Inc., Delaware Water Resources Center, and Wicomico County (Md.) Health Department data; mg/L, milligrams per liter; μg/L, micrograms per liter; pCi/L, picocuries per liter]

Water-quality constituent	Drinking-water standard or criterion[1]	U.S. Geological Survey		National Uranium Resource Evaluation Program		Virginia Water Control Board	
		Number of wells	Percentage of wells where water does not meet drinking-water standard or criterion	Number of wells	Percentage of wells where water does not meet drinking-water standard or criterion	Number of wells	Percentage of wells where water does not meet drinking-water standard or criterion
pH (standard units)[2]	6.5–8.5 (b)	895	49.7/1.1	710	70.8/0.6	90	8.9/8.9
Hardness, as $CaCO_3$	100 mg/L (c)	881	24.2	0	—	142	54.2
Sodium	270 mg/L (c)	756	6.0	707	0.6	106	4.7
Chloride	250 mg/L (b)	934	5.6	0	—	140	8.6
Sulfate	250 mg/L (b)	849	2.0	0	—	127	0.0
Total dissolved solids	500 mg/L (b)	740	13.0	0	—	76	13.2
Nitrate, as N	10 mg/L (a)	889	8.3	0	—	124	1.6
Arsenic	50 μg/L (a)	46	0.0	0	—	8	0.0
Barium	1 mg/L (a)	149	0.0	0	—	0	—
Cadmium	10 μg/L (a)	159	0.6	0	—	8	0.0
Chromium	50 μg/L (a)	46	0.0	0	—	8	0.0
Copper	1 mg/L (b)	192	0.0	0	—	88	0.0
Fluoride	4 mg/L (a)	629	1.0	0	—	131	0.0
Iron (total)	300 μg/L (b)	416	49.0	0	—	125	56.0
Lead	50 μg/L (a)	171	0.6	0	—	18	0.0
Manganese	50 μg/L (b)	539	36.9	683	70.7	123	30.1
Mercury	2 μg/L (a)	45	0.0	0	—	0	—
Selenium	10 μg/L (a)	8	0.0	0	—	0	—
Silver	50 μg/L (a)	6	0.0	0	—	0	—
Zinc	5 mg/L (b)	190	0.0	0	—	71	4.2
Gross alpha activity	15 pCi/L (a)	0	—	0	—	0	—
Radium 226 and 228 (combined)	5 pCi/L (a)	0	—	0	—	0	—

Water-quality constituent	Drinking-water standard or criterion[1]	Virginia Water Project, Inc.		Delaware Water Resources Center		Wicomico County Health Department	
		Number of wells	Percentage of wells where water does not meet drinking-water standard or criterion	Number of wells	Percentage of wells where water does not meet drinking-water standard or criterion	Number of wells	Percentage of wells where water does not meet drinking-water standard or criterion
pH (standard units)[2]	6.5–8.5 (b)	48	70.8/0.0	446	87.7/0.0	0	—
Hardness, as $CaCO_3$	100 mg/L (c)	0	—	0	—	0	—
Sodium	270 mg/L (c)	0	—	0	—	0	—
Chloride	250 mg/L (b)	0	—	675	0.7	0	—
Sulfate	250 mg/L (b)	48	0.0	0	—	0	—
Total dissolved solids	500 mg/L (b)	0	—	657[3]	1.4	0	—
Nitrate, as N	10 mg/L (a)	47	25.5	681	24.1	2,584	1.0
Arsenic	50 μg/L (a)	0	—	0	—	0	—
Barium	1 mg/L (a)	0	—	0	—	0	—
Cadmium	10 μg/L (a)	0	—	0	—	0	—
Chromium	50 μg/L (a)	0	—	0	—	0	—
Copper	1 mg/L (b)	0	—	0	—	0	—
Fluoride	4 mg/L (a)	0	—	0	—	0	—
Iron (total)	300 μg/L (b)	45	66.7	193	44.0	1,398	55.9
Lead	50 μg/L (a)	0	—	0	—	0	—
Manganese	50 μg/L (b)	0	—	0	—	0	—
Mercury	2 μg/L (a)	0	—	0	—	0	—
Selenium	10 μg/L (a)	0	—	0	—	0	—
Silver	50 μg/L (a)	0	—	0	—	0	—
Zinc	5 mg/L (b)	46	13.0	0	—	0	—
Gross alpha activity	15 pCi/L (a)	0	—	0	—	0	—
Radium 226 and 228 (combined)	5 pCi/L (a)	0	—	0	—	0	—

[1] Drinking-water standards and criteria are as follows (U.S. Environmental Protection Agency, 1986a, 1986b): (a) Maximum contaminant level; (b) Secondary maximum contaminant level; (c) No national drinking-water standard or criterion established. Hardness concentrations greater than 100 mg/L become objectionable for domestic purposes (Hem, 1985), and sodium concentrations greater than 270 mg/L are not recommended for humans on salt-restricted diets (U.S. Environmental Protection Agency, 1976).

[2] Two values separated by a slash are shown for pH—percentage of wells below the minimum (6.5) and percentage of wells above the maximum (8.5).

[3] Calculated by multiplying specific conductance by 0.80 (Robertson, 1979).

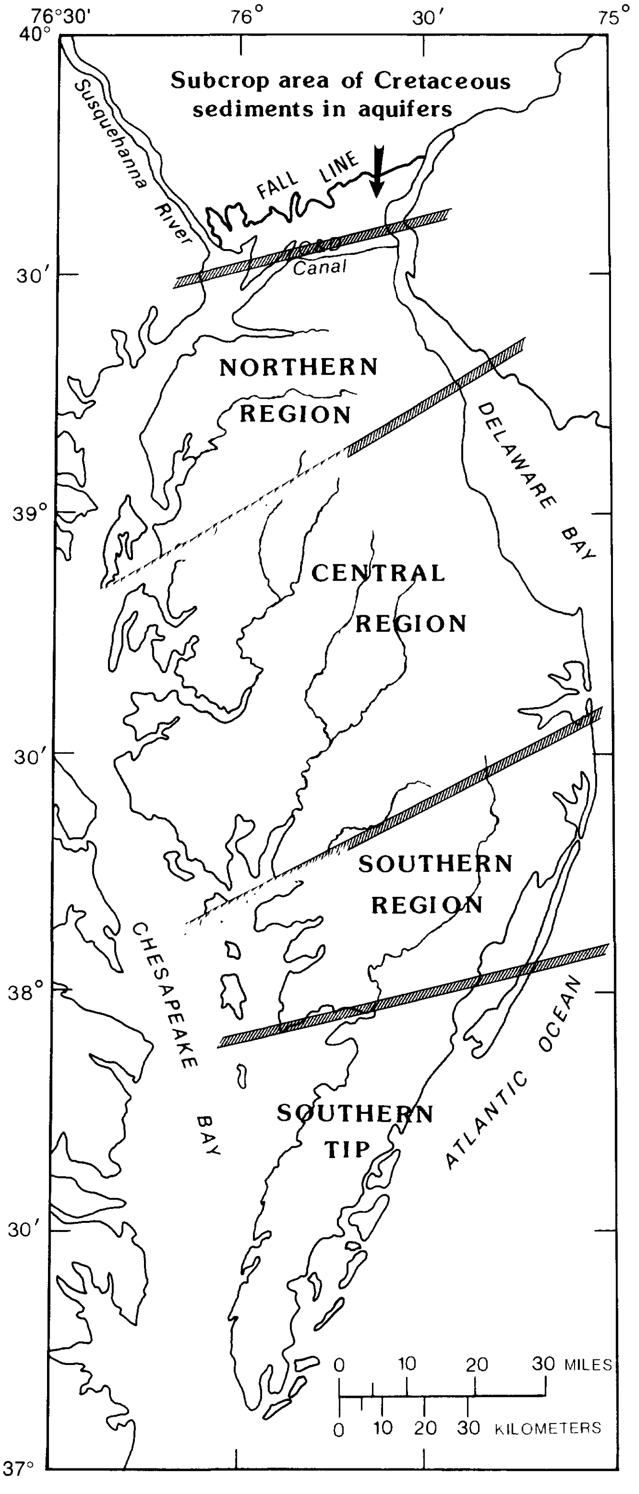


Figure 10. Locations of geographic regions of the confined aquifers in the Delmarva Peninsula used in the analysis of U.S. Geological Survey data.

This region is heterogeneous in physiography and surficial geology and has few unifying characteristics compared with the other regions. Finally, tidal marshes, tidal lagoons, and barrier islands are referred to as "other" and are not considered to constitute a hydrogeomorphic region.

In addition to comparisons made on the basis of hydrogeomorphic region, some comparisons also are made on the basis of land-use setting to further explain variations of selected constituents in the surficial aquifer. Land-use categories were identified from land-use and land-cover data (U.S. Geological Survey, 1979a, 1979b, 1979c, 1979d, 1980a, 1980b), which were compiled and digitized by the National Mapping Program at a scale of 1:250,000 (Fegeas and others, 1983). The use of these data for this purpose is limited because they were collected between 1972 and 1973 and may not reflect recent or current land use. Minimum delineated size of agricultural and woodland areas is 40 acres, and minimum delineated size of urban areas is about 10 acres. The relatively large resolution of the data may preclude accurate analysis of the effects of land use on ground-water quality, because land use in areas smaller than 10 acres surrounding or upgradient from a well may not be represented. For example, a well located in the middle of a 35-acre farm surrounded by a forest could be categorized as woodlands.

Boxplots are used to graphically summarize the variability in constituents by aquifer division, geographic region, and land-use setting. Drinking-water standards and criteria and laboratory detection limits are shown on the boxplots, where appropriate. Data for values below the laboratory detection limit are not shown. The total number of wells and the number of wells that do not meet the relevant drinking-water standard or criterion also are shown on each boxplot. The number of wells varies for each region and constituent. Where the number of wells is less than 12, all data are plotted rather than summarized by a boxplot.

Nonparametric statistical techniques are used in this report. Nonparametric statistics involve robust techniques that generally are not sensitive to outlying or inaccurate values or to the assumptions of equal variances and normality. Hypothesis tests are done to examine whether differences in data are due to chance variability or are real differences. The hypothesis tests involve a null hypothesis, which states that no real difference exists. One hypothesis test used in this report is the Kruskal-Wallis test—a nonparametric analysis of variance procedure involving ranks of the data rather than the data themselves (Iman and Conover, 1983). Also used in this report is the Mann-Whitney test, which is a nonparametric *t*-test procedure involving rank-transformed data (Iman and Conover, 1983). The Mann-Whitney test is used when comparing two categories, while the Kruskal-Wallis test is used when comparing more than two categories. The alpha value, or level of significance, that is used in hypothesis testing in this report is 0.05. This value represents the maximum probability of rejecting the null hypothesis when it actually is true. For each test, the probability (given as a *p*-value) representing the attained significance level also is presented. If the *p*-value is smaller than or equal to the alpha value, the null hypothesis is rejected.

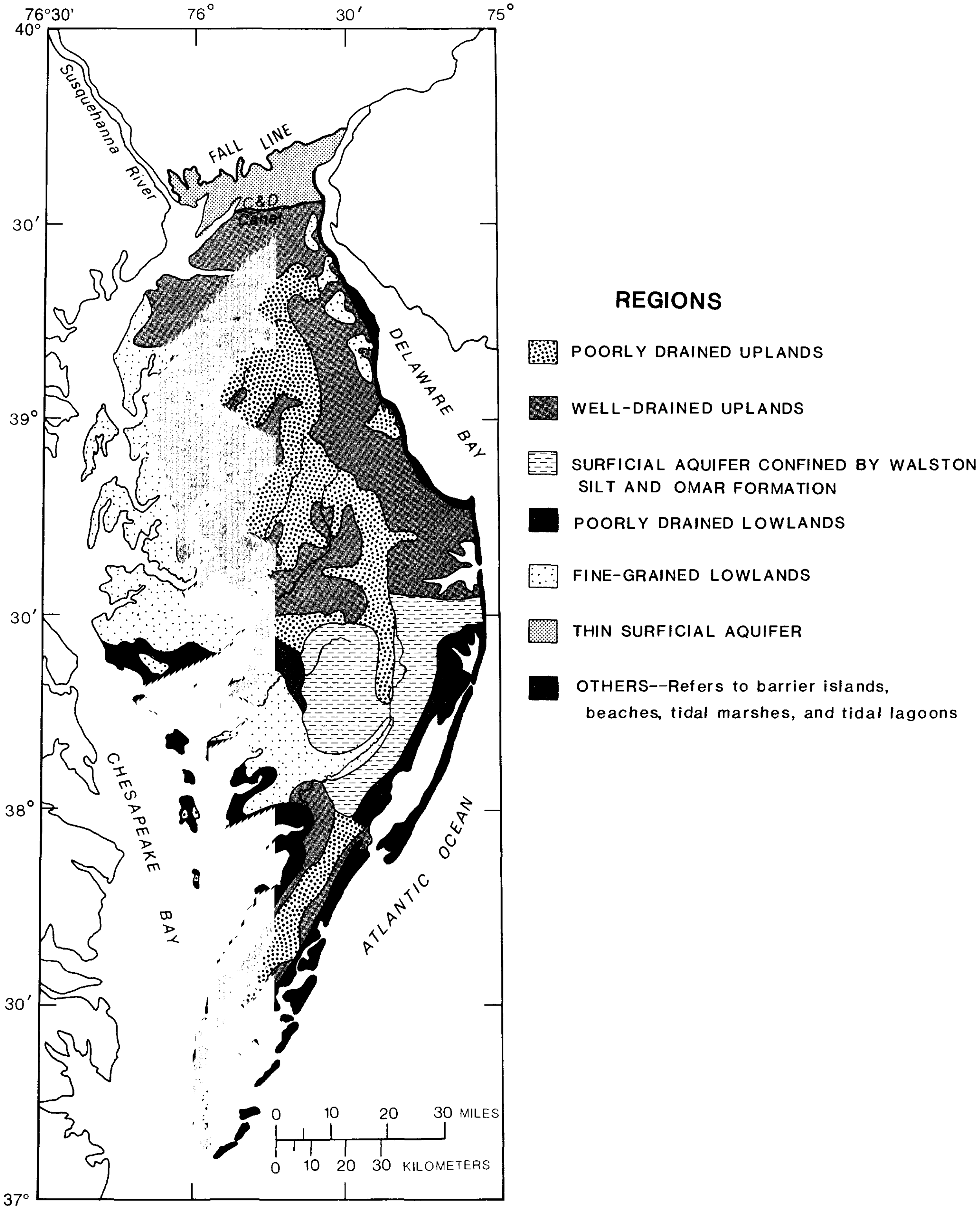


Figure 11. Preliminary boundaries of hydrogeomorphic regions in the surficial aquifer in the Delmarva Peninsula used in the analysis of U.S. Geological Survey data.

pH and Major Inorganic Constituents

Graphical summaries of available data for pH and major inorganic constituents are presented in figures 12 through 17. Water-quality data for these constituents have been collected from wells that are widely distributed both areally and vertically throughout the peninsula. These constituents routinely are included in analyses because they are used to describe the origin, general chemical composition, and aesthetic and taste characteristics of ground water.

pH

Data for pH in more than 2,100 wells were compiled from the USGS, NURE, VWCB, VWP, and DWRC data bases.

U.S. Geological Survey data.—Boxplots summarizing pH, compiled from USGS data, are shown in figure 12. Median pH in the surficial aquifer is 5.8. The pH does not exceed the maximum SMCL (pH 8.5); however, the pH is less than the minimum SMCL (pH 6.5) in 346 (about 81 percent) of the 426 wells in the surficial aquifer. Median pH in the confined aquifers ranges from 5.8 in the subcrop area of the lower confined aquifers to 8.4 in the southern part of the lower confined aquifers. The pH tends to increase downdip within the lower and middle confined aquifers. A possible factor in this increase is the dissolution of calcite, which releases calcium and bicarbonate ions and consumes hydrogen ions (Cushing and others, 1973). A regional pattern for pH in the upper confined aquifers is not apparent, probably because recharge areas for the aquifers are present in both the central and southern regions of the peninsula. Median pH in the southern tip of the upper confined aquifers (pH 7.7) is the highest median value in those aquifers. This high value most likely is a product of dissolution of the relatively abundant calcite in the form of calcareous shell material in the Virginia sediments. The pH exceeds the maximum SMCL in only 10 (about 1 percent) of the wells in the confined aquifers. The pH is less than the minimum SMCL in 99 (about 21 percent) of the 469 wells in the confined aquifers. Ground water is low in pH in the subcrop area of the lower confined aquifers, where water in 31 (about 69 percent) of the 45 wells has a pH lower than the minimum SMCL. Ground water has a low pH in the subcrop area, probably because it is subject to direct recharge from the acidic surficial aquifer.

National Uranium Resource Evaluation Program data.—Data for pH of water in 710 wells in Delaware and Maryland were compiled from the NURE data base. Aquifer information is not available, but it is assumed that most of the wells are relatively shallow and are completed in the surficial or upper confined aquifers. The pH ranges from 3.8 to 9.3, with a median of 5.9. The pH exceeds the maximum SMCL in only 4 (fewer than 1 percent) of the wells, and is less than the minimum SMCL in 503 (about 71 percent) of the wells.

Virginia Water Control Board data.—Data for pH of water in wells in the surficial and upper confined aquifers in Virginia were compiled from the VWCB data base. The pH of water in 13 wells in the surficial aquifer ranges from 4.6 to 7.5, with a median of 6.0. The pH is less than the minimum SMCL in 8 (about 62 percent) of the 13 wells. The pH of water in 77 wells in the upper confined aquifers ranges from 6.5 to 9.5, with a median of 7.7. Ground water in 8 (about 10 percent) of the wells has a pH exceeding the maximum SMCL. None of the pH values is less than the minimum SMCL.

Virginia Water Project, Inc., data.—Data for pH of water in 48 wells in the surficial aquifer in Virginia were compiled from the VWP data base. The pH ranges from 4.9 to 7.8, with a median of 6.0. Ground water in 34 (about 71 percent) of the 48 wells has a pH less than the minimum SMCL.

Delaware Water Resources Center data.—Data for pH of water in 446 wells in the surficial aquifer in eastern Sussex County, Del., were compiled from the DWRC data base. The pH ranges from 4.4 to 8.0, with a median of 5.9. The pH of water in 391 (about 88 percent) of the 446 wells is less than the minimum SMCL.

Discussion.—The pH is low throughout the shallow ground-water system on the Delmarva Peninsula. Most of the pH values compiled from the five data bases are less than the minimum SMCL. Low pH may pose water-quality problems with regard to disinfection, water softening, and corrosion control, and it could increase treatment and drinking-water costs. Ground water in only a few wells (about 1 percent) has a pH that exceeds the maximum SMCL, indicating that alkaline water is not common in the peninsula.

Hardness

Data for hardness concentrations in water from more than 1,000 wells were compiled from the USGS and VWCB data bases.

U.S. Geological Survey data.—Boxplots summarizing concentrations of hardness (as $CaCO_3$) compiled from USGS data are presented in figure 13. The median concentration in the surficial aquifer is relatively low (32 mg/L). Hardness concentrations exceeding 100 mg/L—the concentration at which water becomes objectionable for ordinary domestic use (Hem, 1985)—are present in 41 (about 11 percent) of the 386 wells in the surficial aquifer. The median concentration in the confined aquifers ranges from 6 mg/L in the southern part of the lower confined aquifers to 140 mg/L in the northern part of the middle confined aquifers. The median concentrations tend to decrease downdip within the lower and middle confined aquifers. This regional pattern is consistent with regional distributions of calcium and magnesium shown in the quadrilinear diagrams (figs. 6, 7). The median concentration in the southern tip of

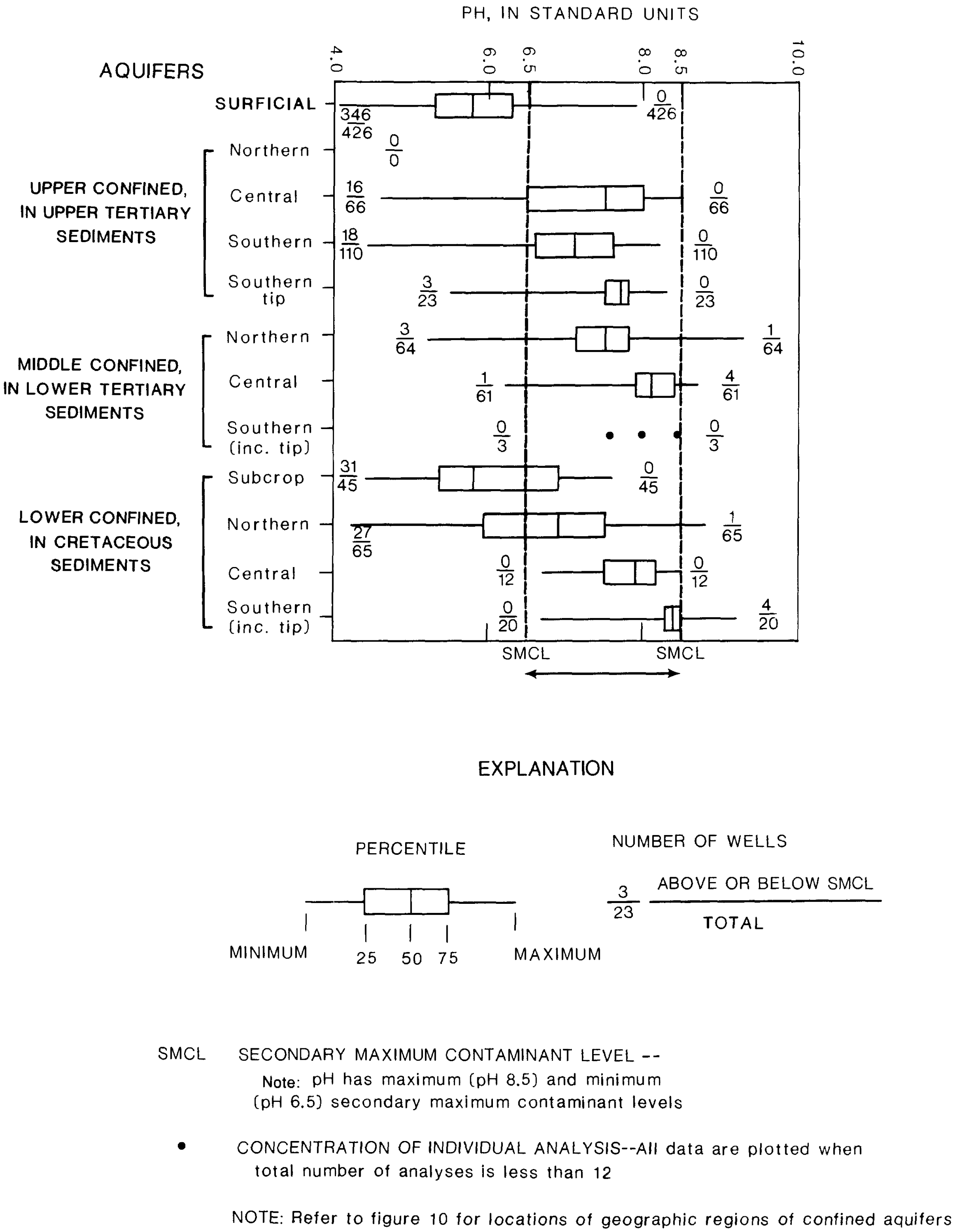


Figure 12. Graphical summary of available data for the pH of water from wells completed in aquifers in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

the upper confined aquifers is the highest in that aquifer division. This high concentration most likely is the result of direct recharge from the surficial aquifer, which is abundant in calcareous material. Concentrations exceed 100 mg/L in 172 (about 35 percent) of 495 wells in the confined aquifers. Elevated concentrations are present in all regions and in all aquifer divisions; however, hardness is most prevalent throughout most of the upper confined aquifers,

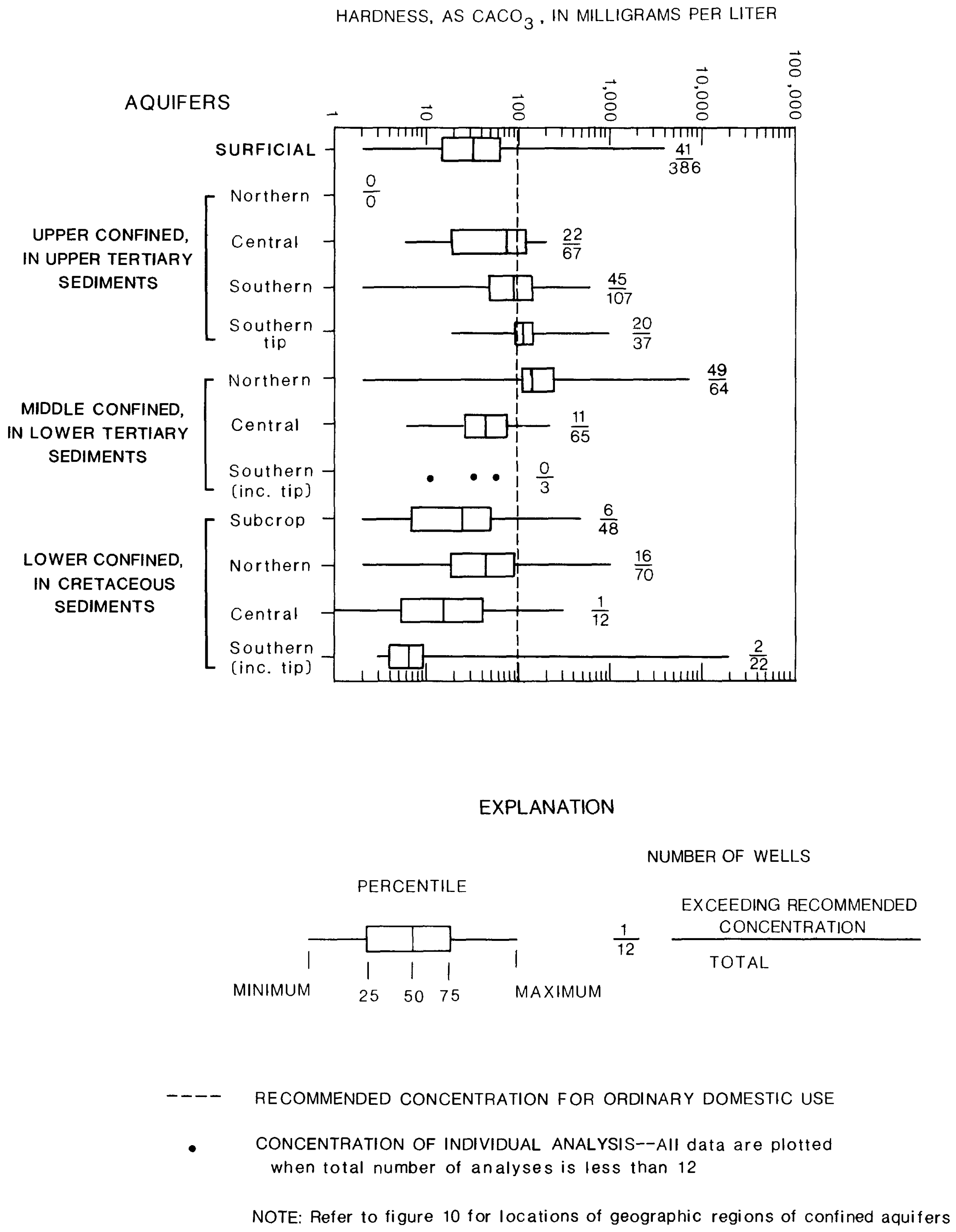


Figure 13. Graphical summary of available data for hardness concentrations in water from wells completed in aquifers in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

where 87 (about 41 percent) of the 211 wells have concentrations exceeding 100 mg/L, and in the northern part of the middle confined aquifers, where 49 (about 77 percent) of the 64 wells have concentrations exceeding 100 mg/L.

Virginia Water Control Board data.—Data for hardness concentrations in water from wells in the surficial and upper confined aquifers in Virginia were compiled from the VWCB data base. Concentrations in 20 wells in the surficial aquifer range from 48 to 242 mg/L. The median concentration is 92 mg/L, and 8 (40 percent) of the 20 concentrations exceed 100 mg/L. Concentrations in 122 wells in the upper confined aquifers range from 24 to 1,700 mg/L, with a median of 109 mg/L. Concentrations in 69 wells (about 57 percent) exceed 100 mg/L.

Discussion.—Excessive hardness is present in ground water throughout the upper confined aquifers. The main cause of this hardness is the dissolution of calcite in shell material common in the sediments. Elevated levels also are prevalent in the surficial aquifer in Virginia (as indicated by the VWCB data), reflecting the relatively abundant calcareous shell material in the Virginia marine sediments. Hard water can be a nuisance by reducing lather formation and the effectiveness of soap as a cleanser. In addition, hardness reflects the presence of calcium, which may precipitate to form coatings and encrustations on pumps and pipes.

Sodium

Data for sodium concentrations in water from more than 1,500 wells were compiled from the USGS, NURE, and VWCB data bases.

U.S. Geological Survey data.—Boxplots summarizing sodium concentrations compiled from USGS data are shown in figure 14. The median concentration in the surficial aquifer is relatively low (8 mg/L). Sodium concentrations exceeding 270 mg/L—the recommended level for humans on salt-restricted diets (U.S. Environmental Protection Agency, 1976)—are present in 3 (fewer than 1 percent) of 320 wells in the surficial aquifer. The median concentration in the confined aquifers ranges from 6 mg/L in the subcrop area and northern part of the lower confined aquifers to 280 mg/L in the southern part of the lower confined aquifers. Consistent with the quadrilinear diagrams (figs. 6, 7), concentrations tend to increase downdip within the lower and middle confined aquifers. A regional pattern is not apparent in the upper confined aquifers, probably because recharge areas for these aquifers are present in both the central and southern regions of the peninsula. Concentrations exceed 270 mg/L in 42 (about 10 percent) of 436 wells in the confined aquifers. Elevated concentrations are found throughout the peninsula and in all aquifer divisions; however, sodium is most prevalent in the southern part of the middle and lower confined aquifers, where concentrations in 11 (about 58 percent) of the 19 wells exceed 270 mg/L.

National Uranium Resource Evaluation Program data.—Data for sodium concentrations in water from 707 wells in the surficial and upper confined aquifers in Delaware and Maryland were compiled from the NURE data base. Concentrations range from 1 to 891 mg/L, with a median of 8 mg/L. Only 4 (fewer than 1 percent) of the 707 wells have concentrations that exceed 270 mg/L.

Virginia Water Control Board data.—Data for sodium concentrations in water from wells in the surficial and upper confined aquifers in Virginia were compiled from the VWCB data base. Concentrations in 14 wells in the surficial aquifer range from 7 to 170 mg/L, with a median of 13 mg/L. No concentrations exceed 270 mg/L. Concentrations in 92 wells in the upper confined aquifers range from 0 to 2,300 mg/L, with a median of 21 mg/L. Five wells (about 5 percent) have concentrations that exceed 270 mg/L.

Discussion.—Sodium concentrations are relatively low in the shallow ground-water system. Excessive levels are present in fewer than 10 percent of the wells in the confined aquifers, except in the southern part of the peninsula. The probable causes of this sodium are decomposition of minerals in the sediments along ground-water flow paths and the presence of saline water. Elevated levels of sodium should be avoided by humans on salt-restricted diets.

Chloride

Data for chloride concentrations in water from more than 1,700 wells were compiled from the USGS, VWCB, and DWRC data bases.

U.S. Geological Survey data.—Boxplots summarizing chloride concentrations compiled from USGS data are shown in figure 15. The median concentration is relatively low in the surficial aquifer (11 mg/L). Concentrations exceed the SMCL (250 mg/L) in 5 (about 1 percent) of the 411 wells in the surficial aquifer. The median concentration in the confined aquifers ranges from 2 mg/L in the central part of the lower confined aquifers to 71 mg/L in the southern part of the lower confined aquifers. Concentrations exceed the SMCL in 47 (about 9 percent) of 523 wells in the confined aquifers.

Virginia Water Control Board data.—Data for chloride concentrations in water from wells in the surficial aquifer and upper confined aquifers in Virginia were compiled from the VWCB data base. Concentrations in 18 wells in the surficial aquifer range from 12 to 450 mg/L, with a median of 21 mg/L. Only one concentration exceeds the SMCL. Concentrations in 122 wells in the upper confined aquifers range from 2 to 6,400 mg/L, with a median of 17 mg/L. Eleven wells (about 9 percent) have concentrations that exceed the SMCL.

Delaware Water Resources Center data.—Data for chloride concentrations in water from 675 wells in the surficial aquifer in Sussex County, Del., were compiled from the DWRC data base. Concentrations range from 6 to 440 mg/L, with a median of 19 mg/L. Only five wells (fewer than 1 percent) have concentrations that exceed the SMCL.

Discussion.—Elevated chloride concentrations are present in fewer than 10 percent of the wells in the confined

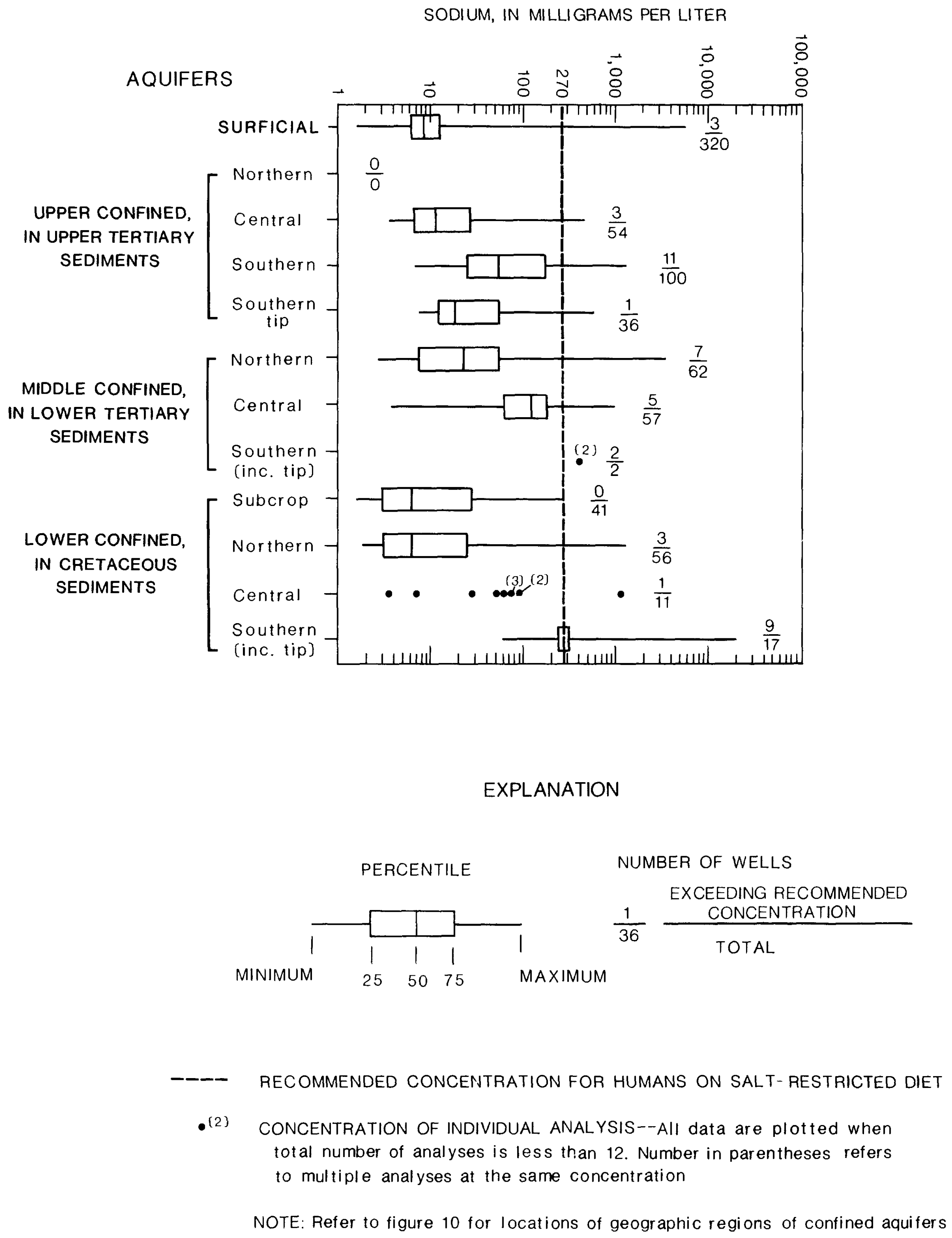
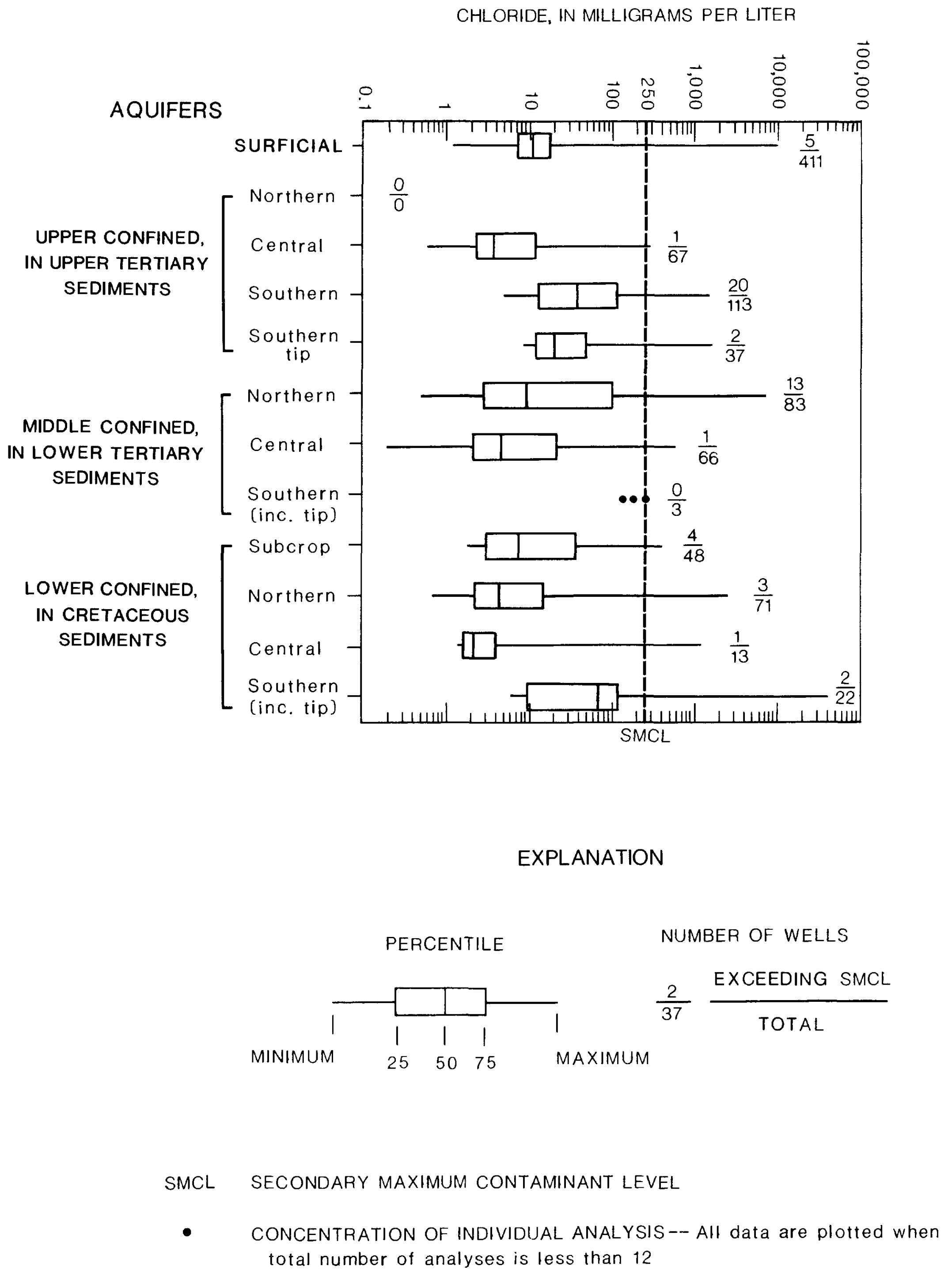


Figure 14. Graphical summary of available data for sodium concentrations in water from wells completed in aquifers in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

aquifers and fewer than 1 percent of the wells in the surficial aquifer. Elevated concentrations most likely reflect local water-quality problems influenced by human-related activities. For example, elevated concentrations in the surficial aquifer commonly present in the coastal areas may be the result of saltwater intrusion induced by pumping. In addition, local incidences of elevated chloride concentrations may be the result of domestic effluent, road salting, and the



NOTE: Refer to figure 10 for locations of geographic regions of confined aquifers

Figure 15. Graphical summary of available data for chloride concentrations in water from wells completed in aquifers in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

application of potassium chloride in agricultural areas. Elevated concentrations in the deeper aquifers most likely are the result of saltwater movement induced by excessive pumping. For example, saltwater intrusion has been documented in the Aquia aquifer on Kent Island in Queen Annes County, Md. Increased pumpage has been prohibited by the

Maryland Water Resources Administration until the problem has been further investigated (Wheeler and Maclin, 1987).

Sulfate

Data for sulfate concentrations in water from more than 1,000 wells were compiled from the USGS, VWCB, and VWP data bases.

U.S. Geological Survey data.—Boxplots summarizing sulfate concentrations compiled from USGS data are shown in figure 16. The median concentration in the surficial aquifer is 5 mg/L. Only 3 (fewer than 1 percent) of 361 wells in the surficial aquifer have concentrations that exceed the SMCL (250 mg/L). The median concentration in the confined aquifers ranges from 3 mg/L in the southern tip of the upper confined aquifers to 51 mg/L in the southern part of the lower confined aquifers. Concentrations tend to increase downdip within the middle and lower confined aquifers. A regional pattern is not apparent in the upper confined aquifers, probably because recharge areas are present in both the central and southern regions of the peninsula. Only 14 (about 3 percent) of 488 wells in the confined aquifers have concentrations that exceed the SMCL.

Virginia Water Control Board data.—Data for sulfate concentrations in water from wells in the surficial and upper confined aquifers in Virginia were compiled from the VWCB data base. Concentrations in 19 wells in the surficial aquifer range from 1 to 121 mg/L, with a median of 35 mg/L. Concentrations in 108 wells in the upper confined aquifers range from 1 to 222 mg/L, with a median of 2 mg/L. No concentrations exceed the SMCL.

Virginia Water Project, Inc., data.—Data for sulfate concentrations in water from 48 wells in the surficial aquifer in Virginia were compiled from the VWP data base. Concentrations range from 17 to 230 mg/L, with a median of 54 mg/L. None of the concentrations exceeds the SMCL.

Discussion.—Sulfate concentrations rarely exceed the SMCL in either the surficial or confined aquifers. Elevated levels of sulfate could be a nuisance by imparting objectionable tastes to the water and acting as a laxative.

Total Dissolved Solids

Data for total dissolved solids in water from more than 1,400 wells were compiled from the USGS, VWCB, and DWRC data bases.

U.S. Geological Survey data.—Boxplots summarizing total dissolved solids concentrations compiled from USGS data are shown in figure 17. The median concentration in the surficial aquifer is relatively low (89 mg/L). Concentrations exceed the SMCL (500 mg/L) in 5 (about 2 percent) of 292 wells in the surficial aquifer. The median concentration in the confined aquifers ranges from 78 mg/L in the subcrop area of the lower confined aquifers to 716 mg/L in the southern part of the lower confined aquifers. As shown in the quadrilinear diagrams (figs. 6, 7), concentrations increase downdip within the lower and middle confined aquifers. Concentrations exceed the SMCL in 91 (about 20 percent) of 448 wells in the confined aquifers. These elevated total dissolved solids concentrations are present throughout the peninsula and in all aquifers; however, they are most prevalent in the southern parts of the middle and lower confined aquifers, where 19 (about 90 percent) of the 21 wells have concentrations that exceed the SMCL.

Virginia Water Control Board data.—Data for total dissolved solids in water from wells in the surficial and upper confined aquifers in Virginia were compiled from the VWCB data base. Concentrations in nine wells in the surficial aquifer range from 12 to 954 mg/L, with a median of 162 mg/L. Only one concentration exceeds the SMCL. Concentrations in 67 wells in the upper confined aquifers range from 108 to 3,819 mg/L, with a median of 199 mg/L. Concentrations in nine wells (about 13 percent) exceed the SMCL.

Delaware Water Resources Center data.—Data for total dissolved solids in water from 657 wells in the surficial aquifer in eastern Sussex County, Del., were compiled from the DWRC data base. These concentrations were computed by multiplying specific-conductance measurements by a ratio of 0.80 (Robertson, 1979). Concentrations range from 24 to 912 mg/L, with a median of 100 mg/L. Nine (about 1 percent) of the 657 wells have concentrations that exceed the SMCL.

Discussion.—Ground water contains low total dissolved solids in the surficial aquifer. Elevated concentrations are present in fewer than 20 percent of the wells in the confined aquifers, except in the southern part of the peninsula. The probable causes of elevated dissolved solids concentrations are dissolution of minerals and the presence of saline water. Elevated concentrations could be a nuisance by imparting unpalatable mineral tastes to the water and could raise drinking-water costs because of scale deposits.

Nitrate

Previous studies have documented elevated nitrate concentrations in the surficial aquifer in the central and northern parts of the peninsula (Robertson, 1979; Ritter and Chirnside, 1982; Bachman, 1984b; Denver, 1986). Nitrate of natural origin is low (less than 0.2 mg/L) in ground water (Perlmutter and Koch, 1972). Elevated concentrations have been observed in shallow parts of the ground-water system; these elevated values probably are the result of human-related activities involving domestic effluent, animal wastes, and application of fertilizers.

In this report, nitrate concentrations are expressed in terms of the equivalent elemental nitrogen (N) content. Nitrate concentration expressed as nitrate ion can be con-

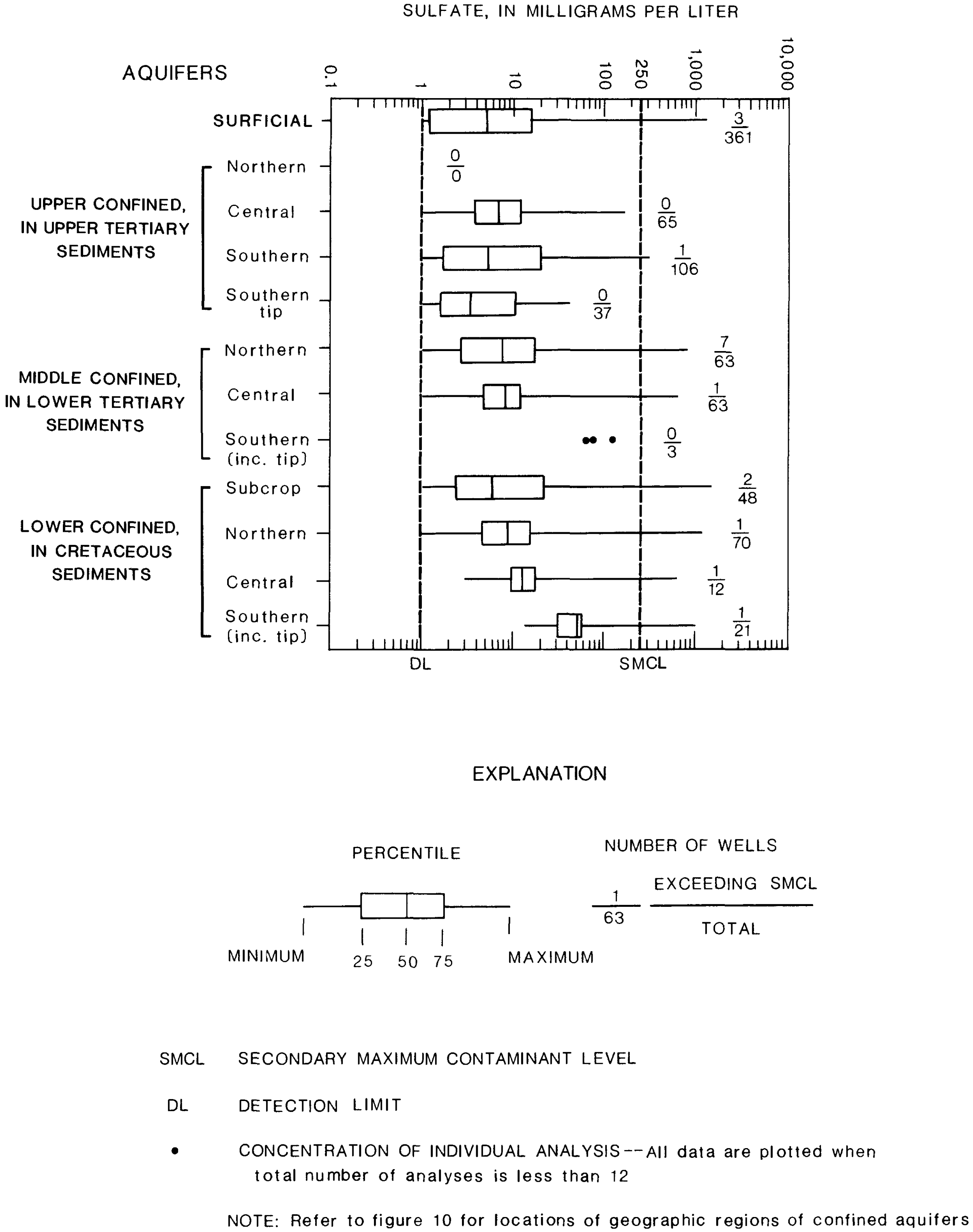
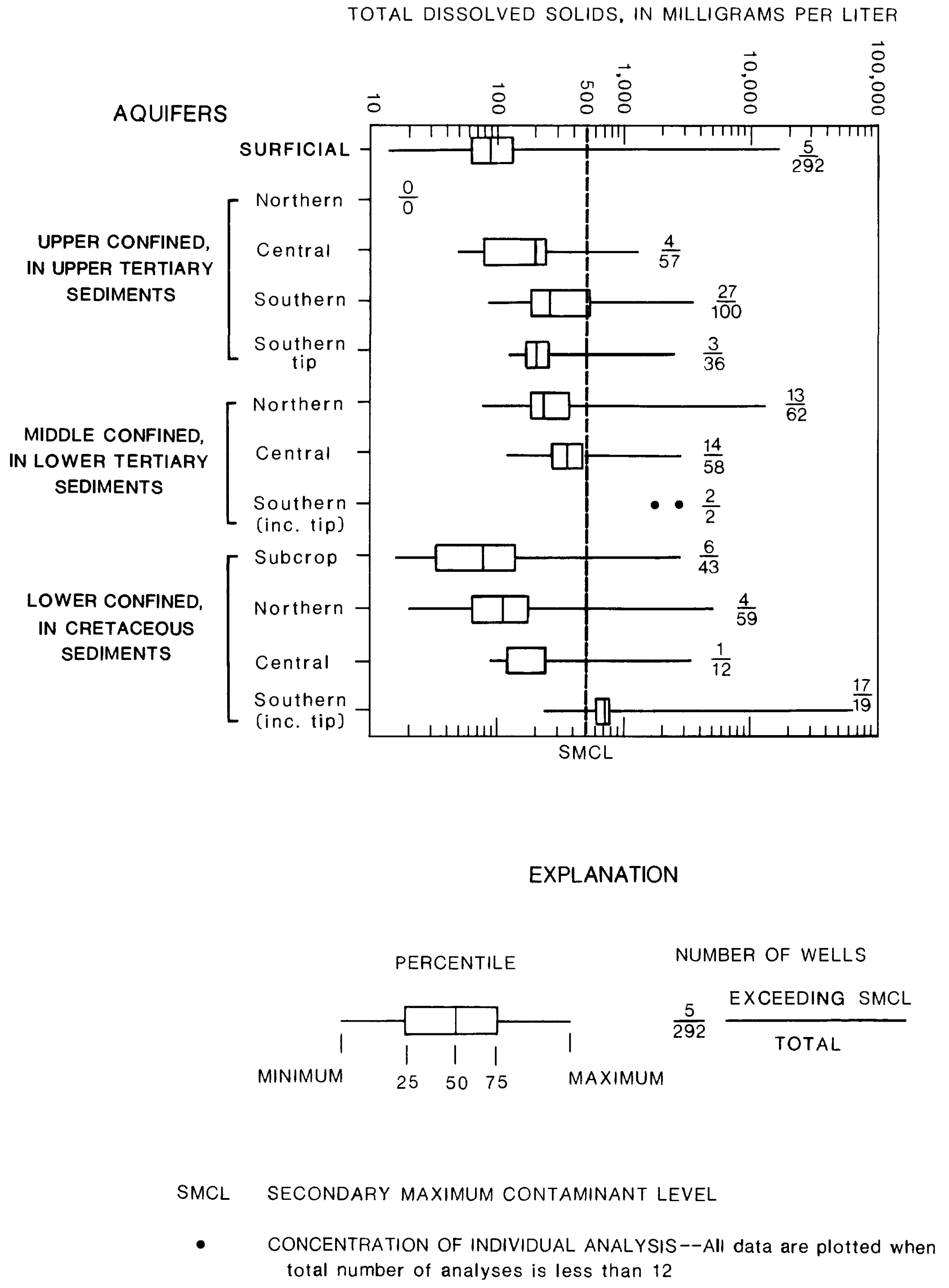


Figure 16. Graphical summary of available data for sulfate concentrations in water from wells completed in aquifers in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

verted to its equivalent elemental nitrogen concentration by dividing by 4.43. For example, 44 mg/L as NO_3 is equivalent to about 10 mg/L as N.

Data for nitrate concentrations in ground water have been collected from more than 4,300 wells that are distributed both areally and vertically throughout the peninsula.



NOTE: Refer to figure 10 for locations of geographic regions of confined aquifers

Figure 17. Graphical summary of available data for total dissolved solids concentrations in water from wells completed in aquifers in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

The data were compiled from the USGS, VWCB, VWP, DWRC, and Wicomico County Health Department data bases.

U.S. Geological Survey data.—Boxplots summarizing nitrate concentrations compiled from USGS data are shown in figure 18. The median concentrations are less than

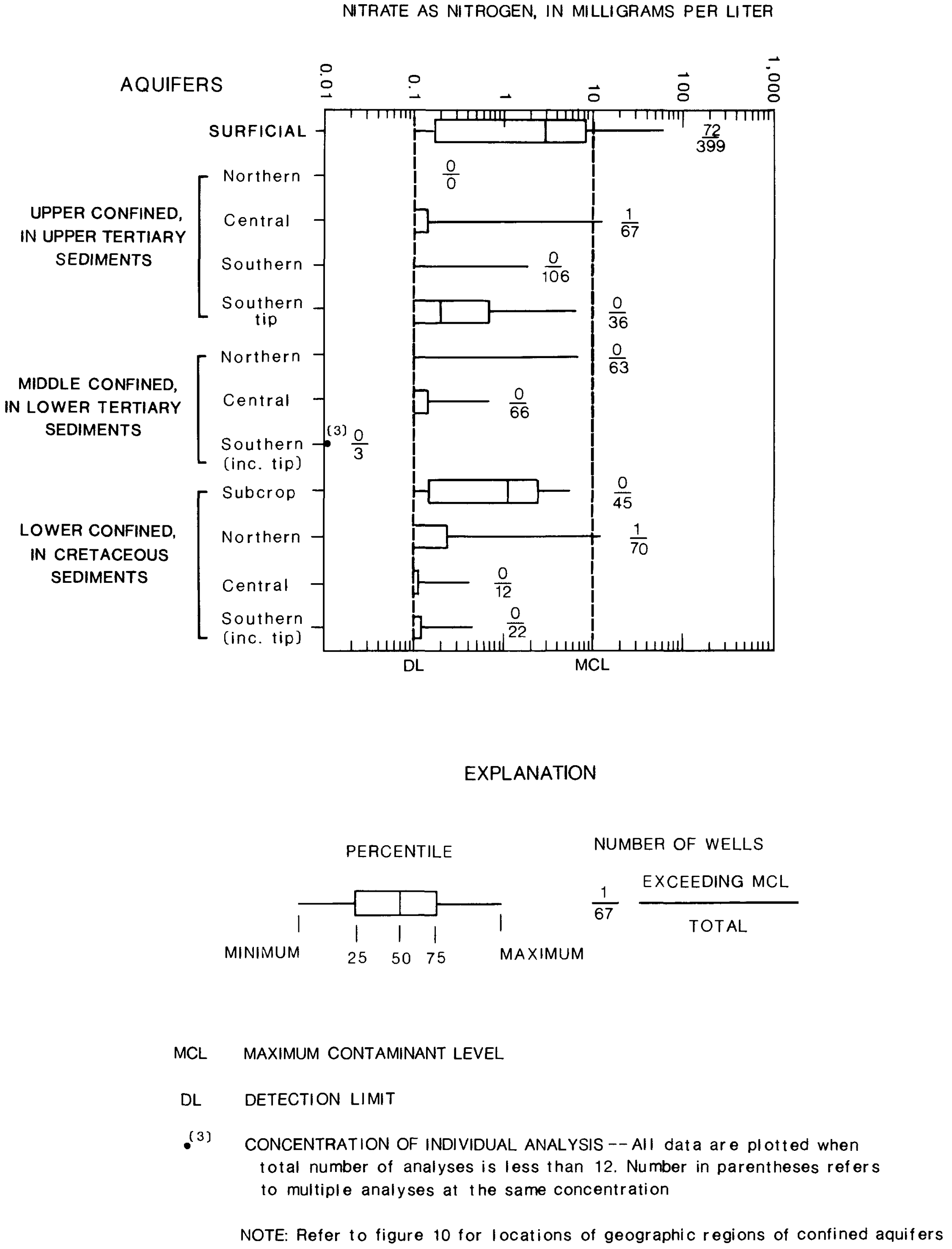


Figure 18. Graphical summary of available data for nitrate concentrations in water from wells completed in aquifers in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

the detection limit (0.1 mg/L) in all aquifers except the surficial aquifer (2.9 mg/L), the subcrop area of the lower confined aquifers (1.1 mg/L), and the southern tip of the upper confined aquifers (0.2 mg/L). Concentrations exceed the MCL (10.0 mg/L) in 72 (about 18 percent) of 399 wells in the surficial aquifer. Only 2 (fewer than 1 percent) of the 490 wells in the confined aquifers have nitrate concentrations that exceed the MCL.

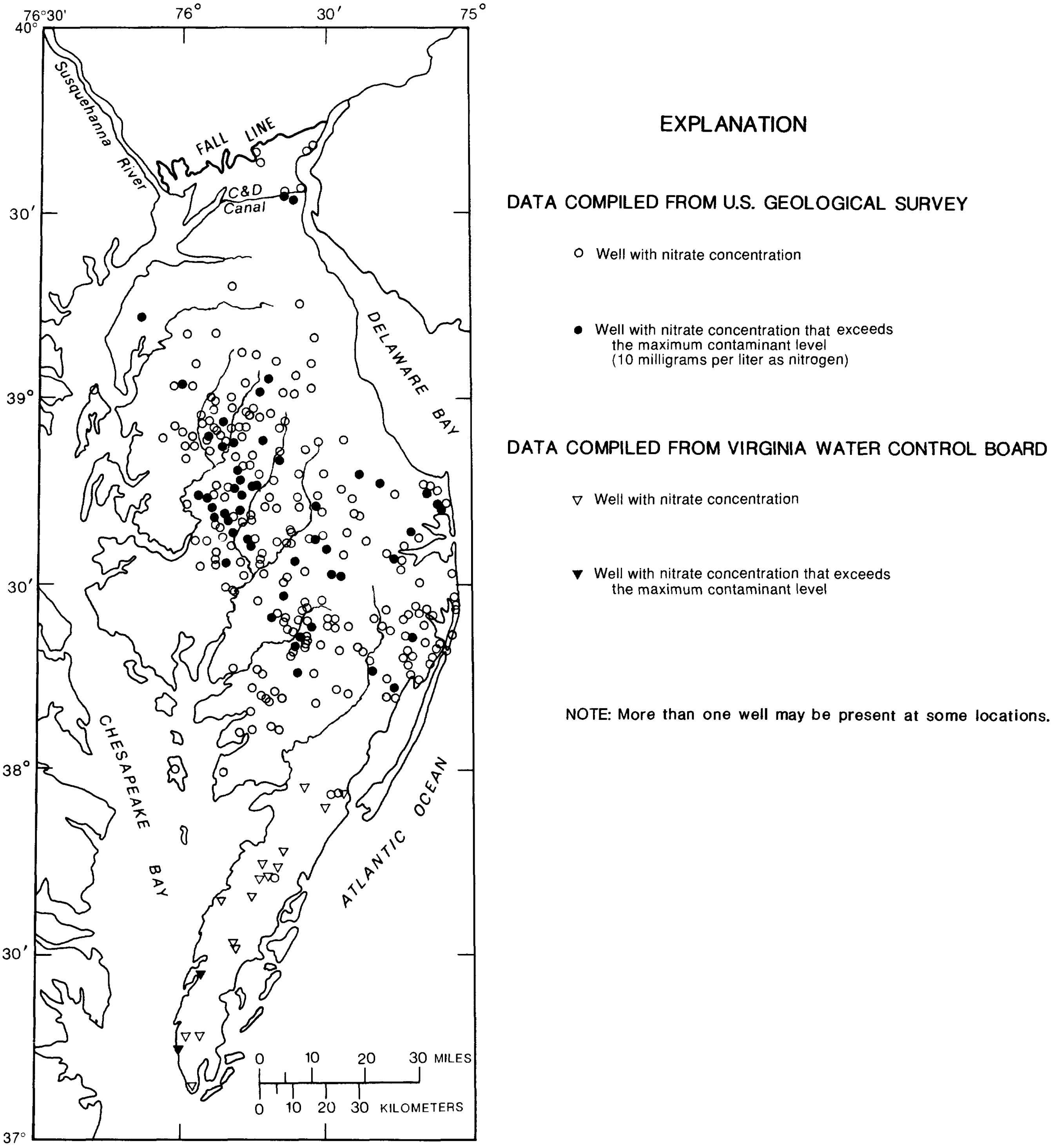


Figure 19. Distribution of available data for nitrate concentrations in water from wells completed in the surficial aquifer in the Delmarva Peninsula (compiled from U.S. Geological Survey and Virginia Water Control Board data).

Locations of wells in the surficial aquifer sampled by the U.S. Geological Survey for nitrate concentration are shown in figure 19. Nitrate data are available throughout the aquifer. Locations of wells in which concentrations exceed the MCL are highlighted (fig. 19). As shown in the figure, these wells are not confined to one region but are distributed throughout the peninsula.

The USGS data were divided into four categories used in previous studies (Ragone and others, 1980; Bachman, 1984b) to assess the influence of human activity on

Table 7. Categories used to assess the influence of human activity on nitrate concentrations

[mg/L, milligrams per liter; N, nitrogen; <, less than; >, greater than. From Bachman (1984b), Perlmutter and Koch (1972), and Ragone and others (1980)]

Nitrate (mg/L as N)	Explanation
<0.2	Water has not been affected by human activity.
0.2 to 3.0	Water may or may not be affected by human activity.
>3.0 to 10.0	Water clearly has been affected by human activity, but does not exceed maximum contaminant level of 10 mg/L as N.
>10.0	Water exceeds maximum contaminant level of 10 mg/L as N.

nitrate concentrations (table 7). Nitrate concentrations of less than 0.2 mg/L are assumed to be present because of natural factors—that is, the ground water has not been affected by human activity. Ground water containing concentrations of 0.2 to 3.0 mg/L may or may not have been affected by human activity, and ground water containing concentrations greater than 3.0 mg/L clearly has been affected by human activity. Nitrate concentrations in the surficial aquifer range from less than the detection limit (0.10 mg/L) to 59.0 mg/L, with a median of 2.9 mg/L. A total of 196 wells (about 50 percent) have concentrations greater than 3.0 mg/L, which indicates that the effects of human activity on nitrate concentrations are prevalent throughout the peninsula (table 8).

The USGS data also were separated by year of sample collection, well depth, broadly defined land-use setting, and hydrogeomorphic region to assess factors that may influence nitrate distribution. Individual analyses of variance on the ranks of the data (table 9) indicate that concentrations differ significantly (alpha=0.05) among categories within three of the these factors: among land-use settings (p=0.004), among hydrogeomorphic regions (p<0.001), and with year of sample collection (p<0.001). All four factors are discussed below.

Data for nitrate concentrations in water from wells in the surficial aquifer, compiled from the USGS data, were collected from 1944 through 1986; about half of these data were collected after 1982. Concentrations before 1975 were compared with those during and after 1975 because preservation techniques changed in the mid-1970's. Preservation of samples collected prior to the mid-1970's included chilling to 4 °C. Preservation procedures since that time include chilling as well as adding mercuric chloride, which improves the stability of nitrate concentrations. Median nitrate concentrations for the earlier and later analyses are 1.7 and 4.9 mg/L (fig. 20), respectively, and these differ significantly (Mann-Whitney test, p<0.001). Thus, the lower concentrations in the earlier years may in part be attributed to inadequate preservation at the time of sampling.

The relation between nitrate concentration and well depth was examined by use of graphical plots and statistical tests. Nitrate concentrations and depth of wells are shown in figure 21. A smooth line, involving the use of robust weighted least squares (Helsel and Hirsch, 1990), suggests that concentrations increase slightly as depth increases to about 40 ft, but decrease when depths exceed 50 ft. A regression analysis of the ranks of concentrations on well depths was significant (p=0.001). These findings indicate that nitrate concentrations are higher in the shallower parts of the surficial aquifer.

Nitrate data were separated by agricultural, urban, and woodland settings. The influence of different land-use settings on nitrate concentrations on the Delmarva Peninsula has been studied extensively. Ritter and Chirnside (1982) found that in selected areas of Kent and Sussex

Table 8. Frequency distribution of nitrate concentrations in the surficial aquifer

[Compiled from U.S. Geological Survey, Virginia Water Control Board, Virginia Water Project, Inc., Delaware Water Resources Center, and Wicomico County (Md.) Health Department data; mg/L, milligrams per liter; N, nitrogen]

Agency	Less than 0.2 mg/L as N		0.2 to 3.0 mg/L as N		Greater than 3.0 to 10.0 mg/L as N		Greater than 10 mg/L as N		Total	
	Number of wells	Percentage of wells	Number of wells	Percentage of wells	Number of wells	Percentage of wells	Number of wells	Percentage of wells	Number of wells	Percentage of wells
U.S. Geological Survey	106	27	97	24	124	31	72	18	399	100
Virginia Water Control Board	10	53	2	10.5	5	26	2	10.5	19	100
Virginia Water Project, Inc.	1	2	14	30	20	43	12	25	47	100
Delaware Water Resources Center	46	7	211	31	260	38	164	24	681	100
Wicomico County Health Department	925	36	915	35	717	28	27	1	2,584	100

Table 9. Statistical summary of factors contributing to nitrate, iron, and manganese concentrations

[Compiled from U.S. Geological Survey data; ft, feet; <, less than]

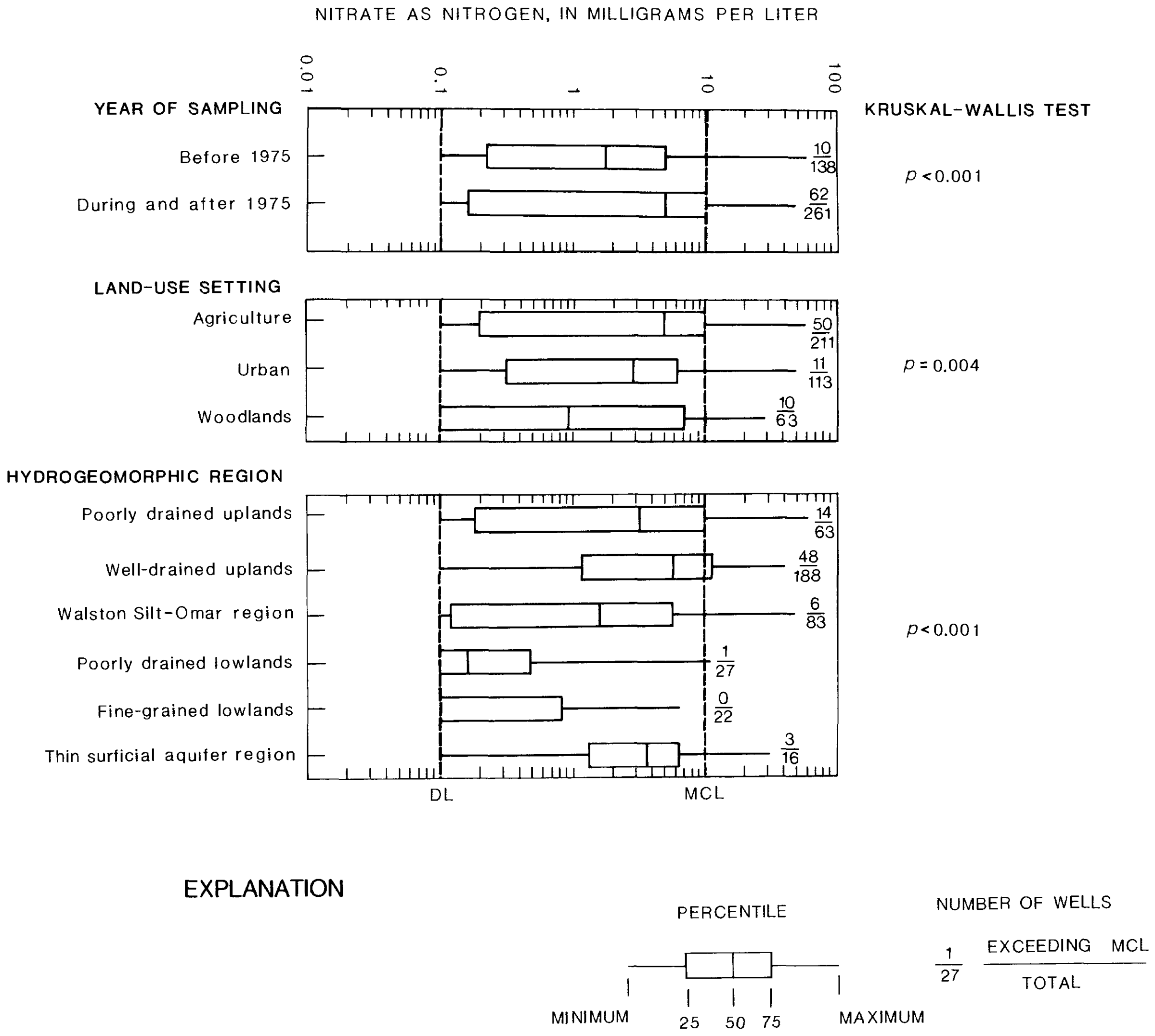
Constituent	Source	Hypothesis test[1]	Categories	*p*-value[2]
Nitrate	Time of sample	Mann-Whitney test	Before 1975 During or after 1975	<0.001
	Depth	Mann-Whitney test	50 ft or less Greater than 50 ft	0.087
	Land use	Kruskal-Wallis test	Agricultural Urban Woodlands	0.004
	Hydrogeomorphic region	Kruskal-Wallis test	Poorly drained uplands Well-drained uplands Walston Silt-Omar region Poorly drained lowlands Fine-grained lowlands Thin surficial aquifer region	<0.001
Iron, dissolved	Depth	Mann-Whitney test	50 ft or less Greater than 50 ft	0.520
	Land use	Kruskal-Wallis test	Agricultural Urban Woodlands	0.190
	Hydrogeomorphic region	Kruskal-Wallis test	Poorly drained uplands Well-drained uplands Walston Silt-Omar region Poorly drained lowlands Fine-grained lowlands Thin surficial aquifer region	<0.001
Iron, total	Depth	Mann-Whitney test	50 ft or less Greater than 50 ft	0.480
	Land use	Kruskal-Wallis test	Agricultural Urban Woodlands	0.650
	Hydrogeomorphic region	Kruskal-Wallis test	Poorly drained uplands Well-drained uplands Walston Silt-Omar region Poorly drained lowlands Fine-grained lowlands Thin surficial aquifer region	<0.001
Manganese	Depth	Mann-Whitney test	50 ft or less Greater than 50 ft	0.110
	Land use	Kruskal-Wallis test	Agricultural Urban Woodlands	0.120
	Hydrogeomorphic region	Kruskal-Wallis test	Poorly drained uplands Well-drained uplands Walston Silt-Omar region Poorly drained lowlands Fine-grained lowlands Thin surficial aquifer region	<0.001

[1] Hypothesis tests are done to examine whether differences in data among categories are due to chance variability or are real differences. The tests involve a null hypothesis which states that no real difference exists among the categories. An alpha value, or level of significance, is used in the hypothesis tests; the value represents the maximum probability of rejecting the null hypothesis when in fact it is true. The alpha value used in this report is 0.05.

[2] For each hypothesis test, the probability (or *p*-value) that represents the attained significance level is given. If the *p*-value is smaller than or equal to the alpha value, the null hypothesis is rejected and significant differences are assumed to exist among the categories.

Counties, Del., relatively low nitrate concentrations are associated with low-density residential areas. The highest concentrations are found in agricultural areas, particularly in areas of intensive poultry production or corn and soybean production. Bachman (1984b) found highest concentrations in agricultural and urban areas where soil is well drained. Robertson (1979) found highest concentrations in agricultural areas, particularly in areas of confined animal feeding operations, and lower concentrations in woodlands.

Boxplots of USGS nitrate concentrations separated by agricultural, urban, and woodland settings in the surficial aquifer are presented in figure 20. Median concentrations



MCL MAXIMUM CONTAMINANT LEVEL

DL DETECTION LIMIT

KRUSKAL-WALLIS TEST— Hypothesis test to examine real versus chance differences in data. The test involves a null hypothesis stating that no real difference exists. An alpha value, or level of significance, is used in the hypothesis test representing the maximum probability of rejecting the null hypothesis when it is actually true. The alpha value used in this report is 0.05

$p<0.001$ p-VALUE—Probability representing the attained significance level. If the p-value is smaller than or equal to the alpha value, the null hypothesis is rejected and significant differences are assumed to exist among the data

NOTE: Refer to figure 11 for locations of hydrogeomorphic regions

Figure 20. Graphical summary of available data for nitrate concentrations in water from wells completed in the surficial aquifer in the Delmarva Peninsula, grouped by year of sample collection, land-use setting, and hydrogeomorphic region (compiled from U.S. Geological Survey data).

differ significantly (Kruskal-Wallis test, $p=0.004$) and range from 0.9 mg/L in woodlands to 4.9 mg/L in agricultural areas. A pairwise significance test (Tukey) was used to further investigate patterns among the three land-use settings. The test indicates that nitrate concentrations do not differ significantly between urban and agricultural settings.

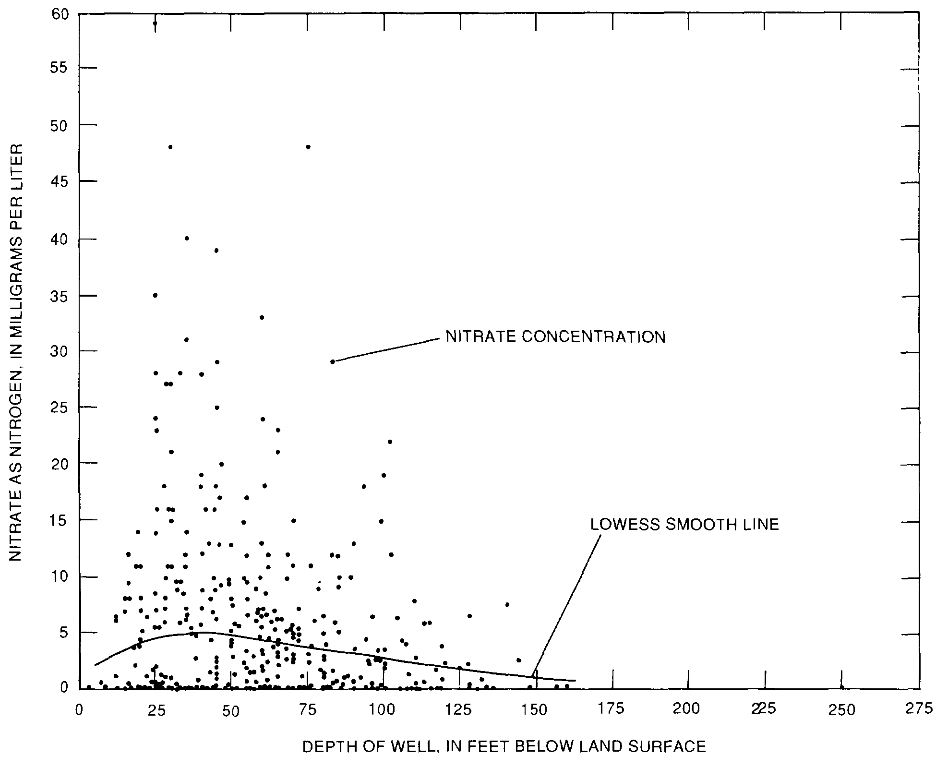


Figure 21. Nitrate concentrations with depth of wells (compiled from U.S. Geological Survey data).

The relatively high concentrations in urban areas may result from domestic effluent and the application of fertilizers on lawns.

Boxplots of USGS data for nitrate concentrations in the six hydrogeomorphic regions are presented in figure 20. The median concentrations range from less than the detection limit (0.1 mg/L) in the fine-grained lowlands to 5.8 mg/L in the well-drained uplands. Median concentrations differ significantly (Kruskal-Wallis test, $p<0.001$) among the six regions. The Tukey pairwise significance test was used to further investigate patterns among the regions. The test indicates that nitrate concentrations in the well-drained uplands are significantly higher than nitrate concentrations in the fine-grained lowlands, the poorly drained lowlands, and the Walston Silt-Omar region. In addition, concentrations in the fine-grained and poorly drained lowlands are significantly lower than in the Walston Silt-Omar region, the thin surficial aquifer region, and the poorly drained uplands. The analysis indicates that highest concentrations are in the better drained areas of the peninsula under conditions in which nitrogen is readily oxidized. Lower concentrations are in areas of poorly drained, fine-grained, and less permeable sediments.

One assumption in the statistical analyses is independence among possible factors affecting nitrate variability. A possible violation of this assumption would be a relation between land use and hydrogeomorphic region. The combined percentage of wells in agricultural and urban land (both associated with relatively high nitrate concentrations) within each hydrogeomorphic region is shown in table 10. As shown in the table, the percentage of wells in agricultural and urban areas is relatively uniform across the regions. Thus, land use does not appear to significantly influence the analysis of nitrate concentrations among hydrogeomorphic regions. The assumption also was tested by separating nitrate data by land use within each hydrogeomorphic unit. Median concentrations among land-use settings are not significantly different within each hydrogeomorphic region (Kruskal-Wallis test, p-values range from 0.09 to 0.63), except in the poorly drained uplands (Kruskal-Wallis test, $p=0.002$). This lack of significant differences also supports the assumption that land use is not a controlling variable in the analysis of differences in nitrate concentrations among the hydrogeomorphic regions.

This preliminary analysis indicates that year of sample collection, depth of well, land-use setting, and hydrogeomorphic region affect nitrate distribution throughout the Delmarva Peninsula. The analysis is limited in two ways. The first limitation involves the relative importance of, and relation between, the four factors. For example, the year of

Table 10. Percentage of wells in agricultural and urban land within each hydrogeomorphic region used in the analysis of nitrate concentrations

[Compiled from U.S. Geological Survey data]

Hydrogeomorphic region	Percentage of land use		
	Agricultural	Urban	Agricultural and urban
Poorly drained uplands	57.1	19.0	76.1
Well-drained uplands	65.4	17.6	83.0
Walston Silt-Omar region	38.6	45.8	84.4
Poorly drained lowlands	25.9	37.0	62.9
Fine-grained lowlands	45.5	31.8	77.3
Thin surficial aquifer region	18.7	81.3	100.0

sample collection may be affecting the land-use analysis. A higher percentage of samples from urban areas was collected prior to 1975 (more than 65 percent) compared with samples from agricultural areas and woodlands (about 22 and 19 percent, respectively), and this may have resulted in a median concentration in urban areas lower than that actually present in ground water. Depth of sample may be introducing additional variability in the land-use analysis because the sample water is originating from land uses other than that observed at the well. The second limitation involves other factors contributing to nitrate variability. The coefficient of determination (R^2) indicates that only 20 percent of the variability in the ranks of nitrate concentrations can be accounted for by the four factors discussed above. The remaining variability may be attributed to other factors (such as soil type), to limitations in the existing data (such as inconsistency in sampling procedures), and to limitations in the ancillary data (such as outdated and poor-resolution land-use data).

Virginia Water Control Board data.—Data for nitrate concentrations in water from wells in the surficial and upper confined aquifers in Virginia were compiled from the VWCB data base. Concentrations in 19 wells in the surficial aquifer range from less than the detection limit to 24 mg/L, with a median value of less than the detection limit. Concentrations in seven wells (about 37 percent) are greater than 3.0 mg/L (table 8), and concentrations in two wells (about 10 percent) exceed the MCL. Locations of the 19 wells in the surficial aquifer are shown in figure 19. Concentrations in 105 wells in the upper confined aquifers range from less than the detection limit (0.05 mg/L) to 6 mg/L; concentrations do not exceed the MCL in any wells.

Virginia Water Project, Inc., data.—Data for nitrate concentrations in water from 47 wells in the surficial aquifer in Virginia were compiled from the VWP data base. All samples were collected during the summer of 1987. The wells are relatively shallow (30 ft deep or less) and old, and are pitcher-pump type. Nitrate concentrations range from 0.1 to 75.9 mg/L, with a median of 4.8 mg/L. Concentrations are greater than 3.0 mg/L in 32 wells (about 68 percent) and exceed the MCL in 12 wells (about 25 percent) (table 8). All the wells are located in agricultural settings. These data indicate a significant nitrate problem in the shallow parts of the surficial aquifer in agricultural areas. However, improper construction of wells, as well as the age and type of wells, may be contributing to the elevated nitrate concentrations. The data, therefore, may not reflect typical nitrate concentrations in shallow ground water. In addition, the data were collected specifically to assess ground water in rural, agricultural areas suspected of having elevated nitrate concentrations and, therefore, may bias a regional water-quality assessment.

Delaware Water Resources Center data.—Data for nitrate concentrations in water from 681 wells in the surficial aquifer in eastern Sussex County, Del., were compiled from the DWRC data base. These samples were collected from September 1976 through January 1977. The median nitrate concentration is 5.3 mg/L. Concentrations are greater than 3.0 mg/L in 424 wells (about 62 percent) and exceed the MCL in 164 wells (about 24 percent) (table 8). The distribution of wells containing concentrations that exceed the MCL is fairly uniform throughout eastern Sussex County except in the southern part. Robertson has attributed the lower nitrate concentrations in the southern part of the county to the poorly drained, poorly aerated, and impermeable nature of soils there. Robertson has stated that the limit of the zone of oxidation is shallower in these areas because water tables are high (less than 5 ft), thus enhancing denitrification or slowing the oxidation of nitrogen (Robertson, 1979).

Wicomico County Health Department data.—Data for nitrate concentrations in water from 2,584 wells in the surficial aquifer were compiled from the Wicomico County Health Department data base. The water samples were collected from 1979 through 1987. Concentrations range from less than 0.2 to 64.1 mg/L, with a median of 0.7 mg/L. Concentrations in 744 wells (about 29 percent) are greater than 3.0 mg/L (table 8). Only 27 of the wells (about 1 percent) have concentrations that exceed the MCL (table 8). Nitrate concentrations that exceed the MCL are significantly fewer than reported in the other data bases. This may be attributable to the greater depth of the samples (median depth is 80 ft), and to the widespread presence of clay and silt (Walston Silt and Omar Formation), which characteristically are poorly drained and relatively impermeable.

Discussion.—The statistical analysis and map of nitrate concentrations support previous findings that elevated nitrate concentrations are present throughout the surficial aquifer. Elevated concentrations probably are the result of human activities related to domestic effluent, animal wastes, and the application of fertilizers. The highest nitrate concentrations are in agricultural and urban areas and are associated with well-drained sediments where nitrogen is readily oxidized. The lowest nitrate concentrations are in woodlands and are associated with poorly drained and relatively impermeable sediments.

Major Metals and Trace Elements

Statistical analyses of the distribution of 14 major metals and trace elements are presented in this section. Data for these constituents, except iron, manganese, fluoride, and uranium, generally are lacking.

Iron

Data for iron concentrations in ground water have been collected from wells that are fairly well distributed throughout the peninsula. Previous studies have documented the presence of elevated iron concentrations in both the shallow and deep ground-water systems (Cushing and others, 1973; Robertson, 1979; Harrington, 1981; Ritter and Chirnside, 1982; Denver, 1986). Iron is a natural constituent in ground water. Elevated concentrations most likely are derived from iron-rich sediments in reducing environments caused by oxidation of organic carbon (Robertson, 1979). Relations between iron and ancillary factors have been explored in previous studies. Robertson (1979) found that iron concentrations tend to be elevated in poorly drained and impermeable soils. Harrington (1981) related elevated dissolved iron concentrations to low topography, shallow depths to the water table, and poor drainage, all of which are associated with a reducing environment.

Data for dissolved iron concentrations in water from more than 500 wells were compiled from the USGS data base, and data for total iron concentrations in water from more than 2,100 wells were compiled from the USGS, VWCB, VWP, DWRC, and Wicomico County Health Department data bases.

U.S. Geological Survey data.—Boxplots summarizing data for dissolved and total iron concentrations compiled from USGS data are presented in figures 22 and 23. Median concentrations for dissolved and total iron in the surficial aquifer are 50 and 210 μg/L (micrograms per liter), respectively. Dissolved and total iron concentrations at 81 and 60 wells (about 30 and 38 percent, respectively) in the surficial aquifer exceed the SMCL of 300 μg/L. The median dissolved iron concentration in the confined aquifers ranges from less than the detection limit (10 μg/L) in the southern tip of the upper confined aquifers to 2,250 μg/L in the southern part of the upper confined aquifers. The median total iron concentration ranges from 120 μg/L in the central part of the middle confined aquifers to 4,050 μg/L in the southern part of the upper confined aquifers. Elevated dissolved and total iron concentrations are present throughout the peninsula, particularly in the northern region of the middle and lower confined aquifers and in the southern region of the upper confined aquifers. Of the wells in the confined aquifers, about 54 percent have dissolved iron concentrations and about 56 percent have total iron concentrations that exceed the SMCL.

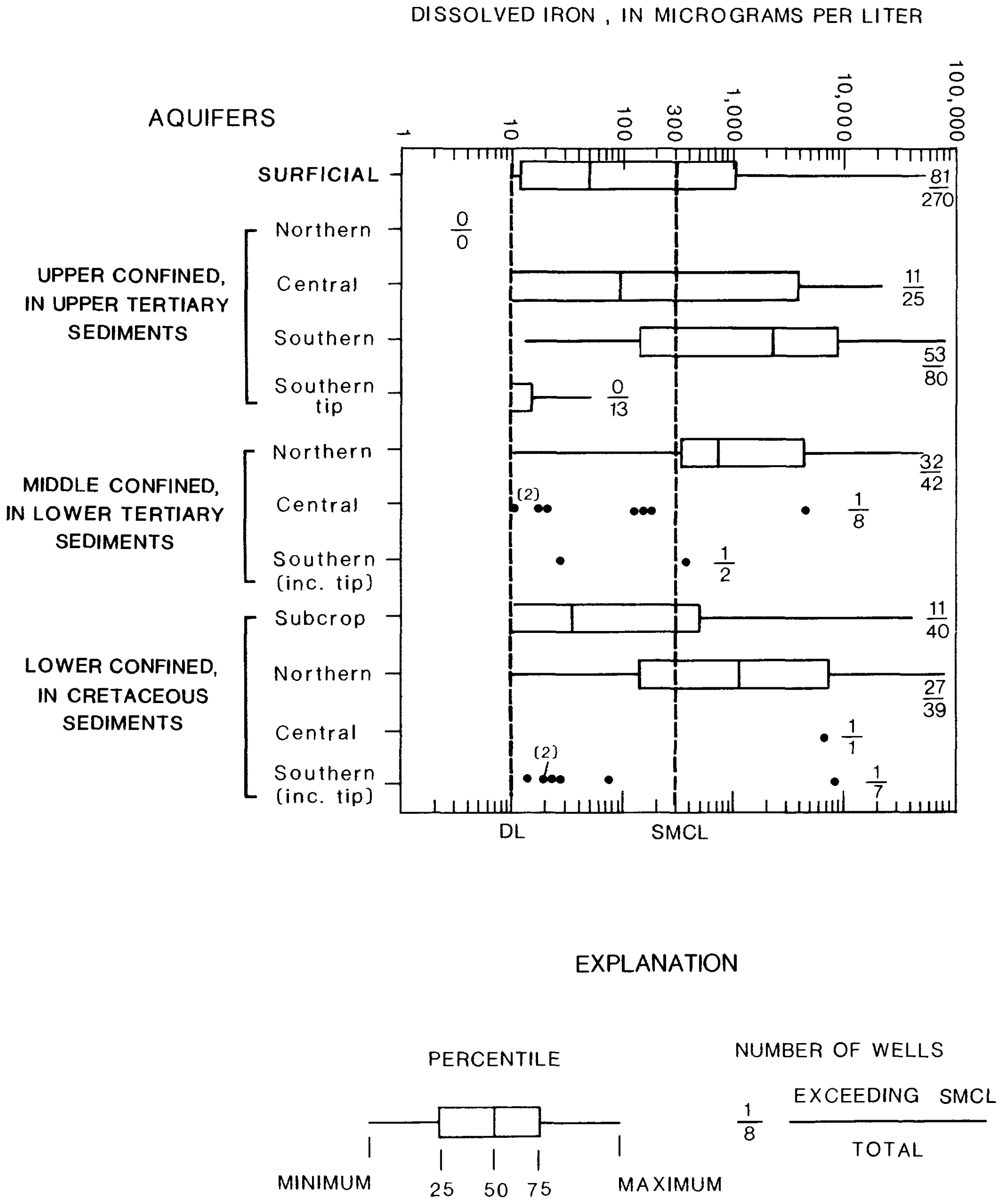
Locations of wells in the surficial aquifer sampled by the USGS for total iron concentration are shown in figure 24. Data for the northern and southern parts of the peninsula are sparse. Locations of wells in which total iron concentrations exceed the SMCL also are shown. These wells are present throughout the peninsula.

The USGS data were separated by well depth, broadly defined land-use setting, and hydrogeomorphic region to assess factors that may influence iron distribution. An analysis of variance on the ranks of the data (table 9) indicates that dissolved and total iron concentrations differ significantly among hydrogeomorphic regions ($p<0.001$). Individual analysis of variance tests for dissolved and total iron indicate no significant difference in concentrations among land-use settings ($p=0.190$ and 0.650, respectively) or with well depth ($p=0.520$ and 0.480, respectively). These factors are discussed below.

The relation between iron concentration and well depth was examined by use of graphical plots and statistical tests. Iron concentrations and depth of wells are presented in figure 25. A smooth line, involving the use of robust weighted least squares (Helsel and Hirsch, 1990), suggests that dissolved and total iron concentrations do not increase or decrease with increasing depth of well. A regression analysis of the ranks of iron concentrations on well depths was not significant for either dissolved or total iron concentrations ($p=0.900$ and 0.830, respectively).

Boxplots of data for iron concentrations in water from wells in the surficial aquifer separated by land-use setting are presented in figure 26. Median dissolved iron concentrations range from 33 μg/L in agricultural areas to 90 μg/L in urban areas. Median total iron concentrations range from 190 μg/L in urban areas to 280 μg/L in woodlands. The Kruskal-Wallis test indicates that there is no significant difference among the land-use settings in median dissolved or total iron concentrations ($p=0.190$ and 0.650, respectively).

Boxplots of data for iron concentrations in water from wells in the surficial aquifer separated by hydrogeomorphic region are presented in figure 27. Median dissolved iron concentrations range from 18 μg/L in the well-drained uplands to 4,200 μg/L in the fine-grained lowlands. Median total iron concentrations range from 70 μg/L in the thin surficial aquifer region to 4,100 μg/L in the fine-grained lowlands. Median concentrations of dissolved iron and total iron differ significantly (Kruskal-Wallis test, $p<0.001$) among the regions. A pairwise significance test (Tukey) was used to further investigate patterns among the regions. The test indicates that dissolved iron concentrations in the well-drained uplands are significantly lower than dissolved iron concentrations in the fine-grained lowlands, the poorly



SMCL SECONDARY MAXIMUM CONTAMINANT LEVEL

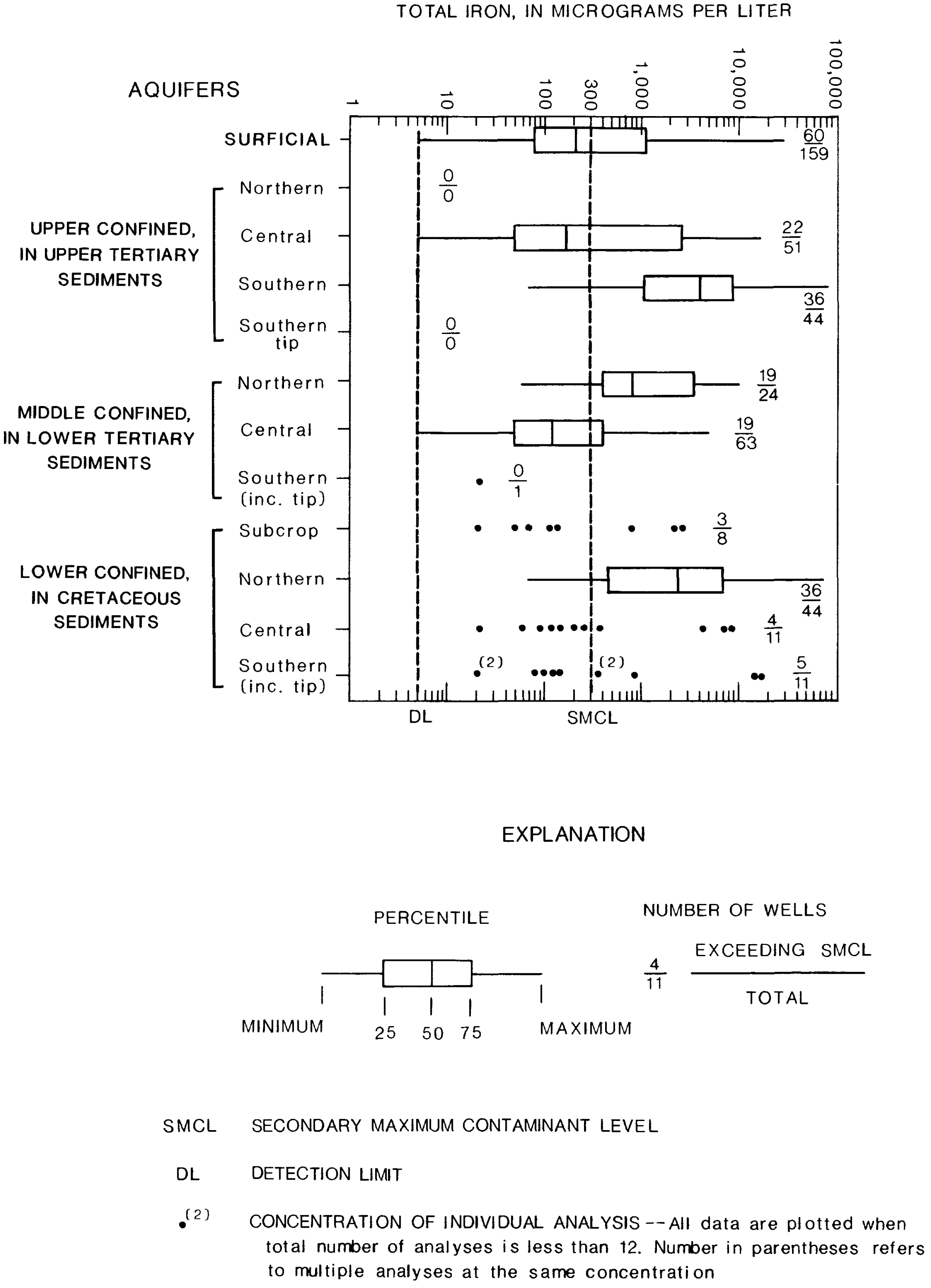
DL DETECTION LIMIT

●(2) CONCENTRATION OF INDIVIDUAL ANALYSIS -- All data are plotted when total number of analyses is less than 12. Number in parentheses refers to multiple analyses at the same concentration

NOTE: Refer to figure 10 for locations of geographic regions of confined aquifers

Figure 22. Graphical summary of available data for dissolved iron concentrations in water from wells completed in aquifers in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

drained lowlands, the poorly drained uplands, and the Walston Silt-Omar region. In addition, dissolved iron concentrations in the fine-grained lowlands are significantly higher than those in the poorly drained uplands. (Because of the relatively small number of analyses in four of the six groups, the Tukey test was not done for total iron



NOTE: Refer to figure 10 for locations of geographic regions of confined aquifers

Figure 23. Graphical summary of available data for total iron concentrations in water from wells completed in aquifers in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

concentrations.) This analysis indicates that the highest iron concentrations are in areas of fine-grained and poorly drained sediments. These areas most likely are under reducing and low pH conditions, in which ferric iron is reduced to soluble ferrous iron. The lowest concentrations are in well-drained areas.

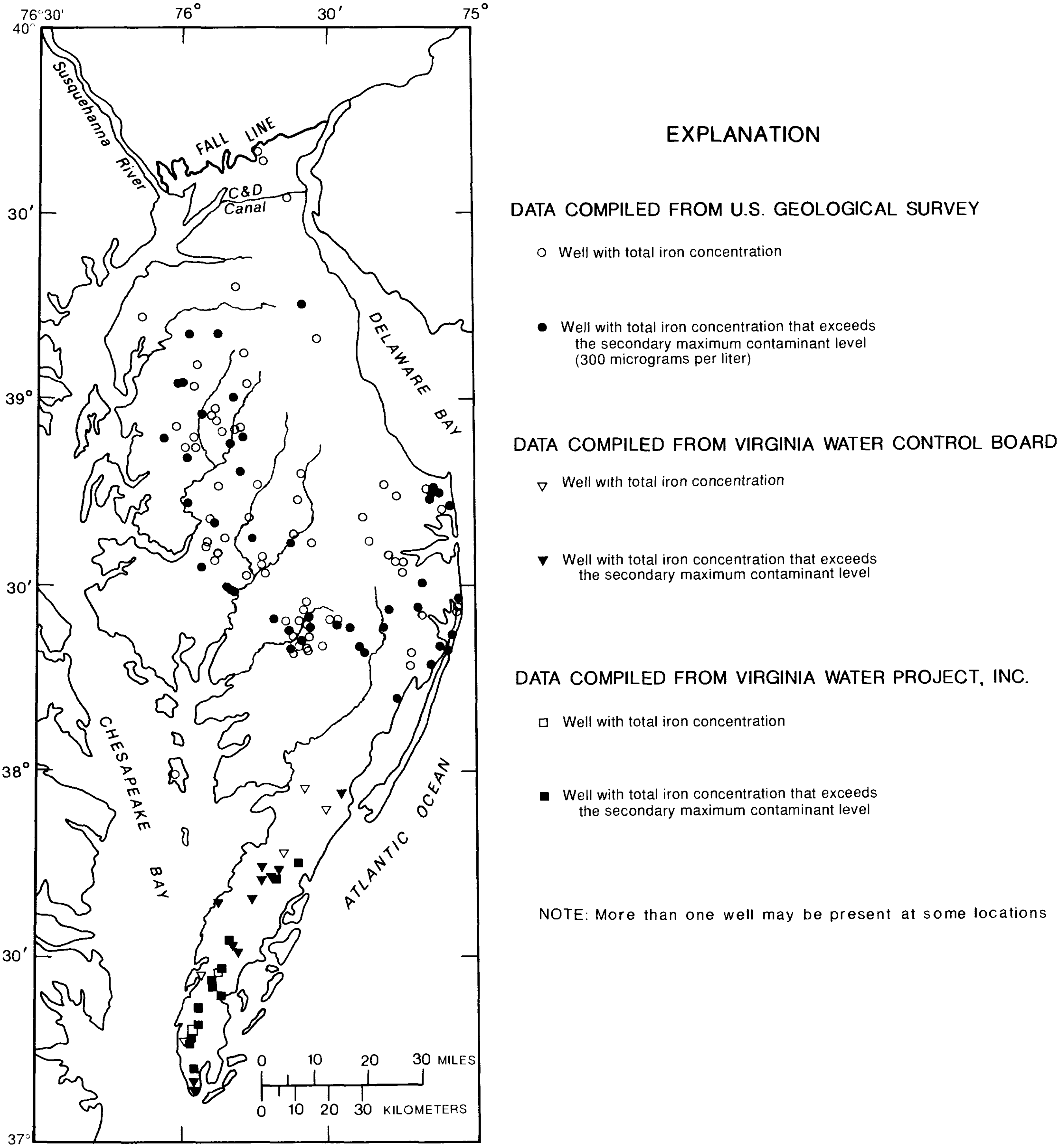


Figure 24. Distribution of available data for total iron concentrations in water from wells completed in the surficial aquifer in the Delmarva Peninsula (compiled from U.S. Geological Survey, Virginia Water Control Board, and Virginia Water Project, Inc., data).

Virginia Water Control Board data.—Data for total iron concentrations in water from wells in the surficial and upper confined aquifers in Virginia were compiled from the VWCB data base. Concentrations in 18 wells in the surficial aquifer range from 0 to 34,000 μg/L (no detection limit given), with a median of 960 μg/L; concentrations exceed the SMCL in 13 wells (about 72 percent) (fig. 24). Concentrations in 107 wells in the upper confined aquifers

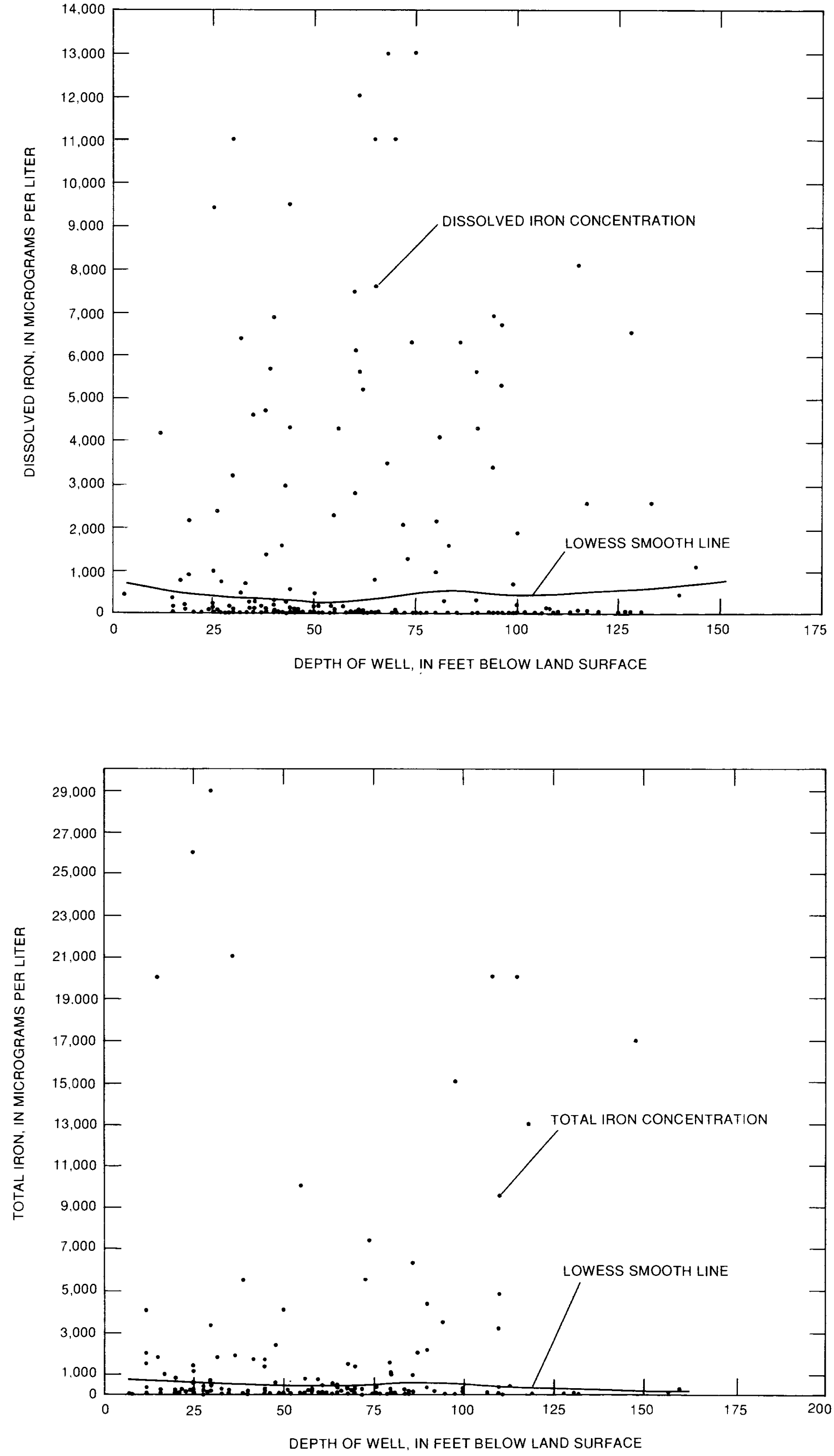
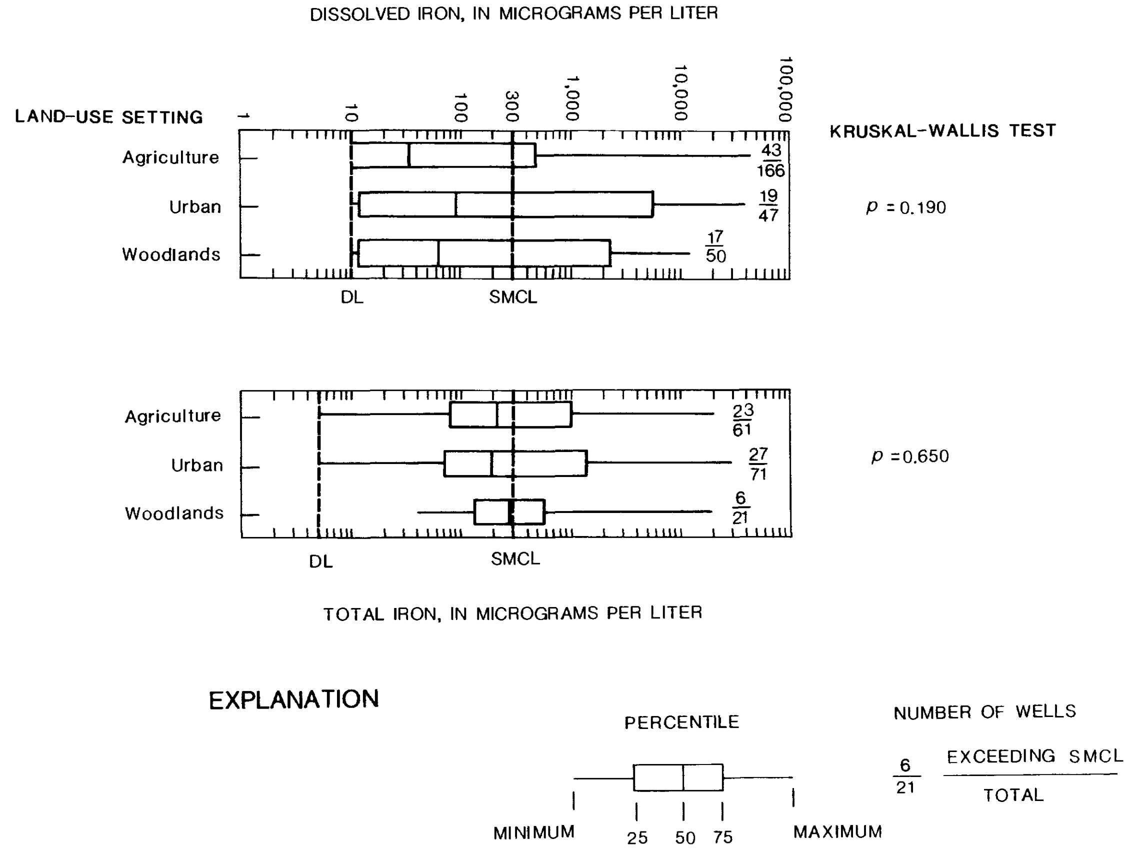


Figure 25. Dissolved and total iron concentrations with depth of wells (compiled from U.S. Geological Survey data).



SMCL SECONDARY MAXIMUM CONTAMINANT LEVEL

DL DETECTION LIMIT

KRUSKAL-WALLIS TEST—Hypothesis test to examine real versus chance differences in data. The test involves a null hypothesis stating that no real difference exists. An alpha value, or level of significance, is used in the hypothesis test representing the maximum probability of rejecting the null hypothesis when it is actually true. The alpha value used in this report is 0.05

$p < 0.001$ p-VALUE—Probability representing the attained significance level. If the p-value is smaller than or equal to the alpha value, the null hypothesis is rejected and significant differences are assumed to exist among the data

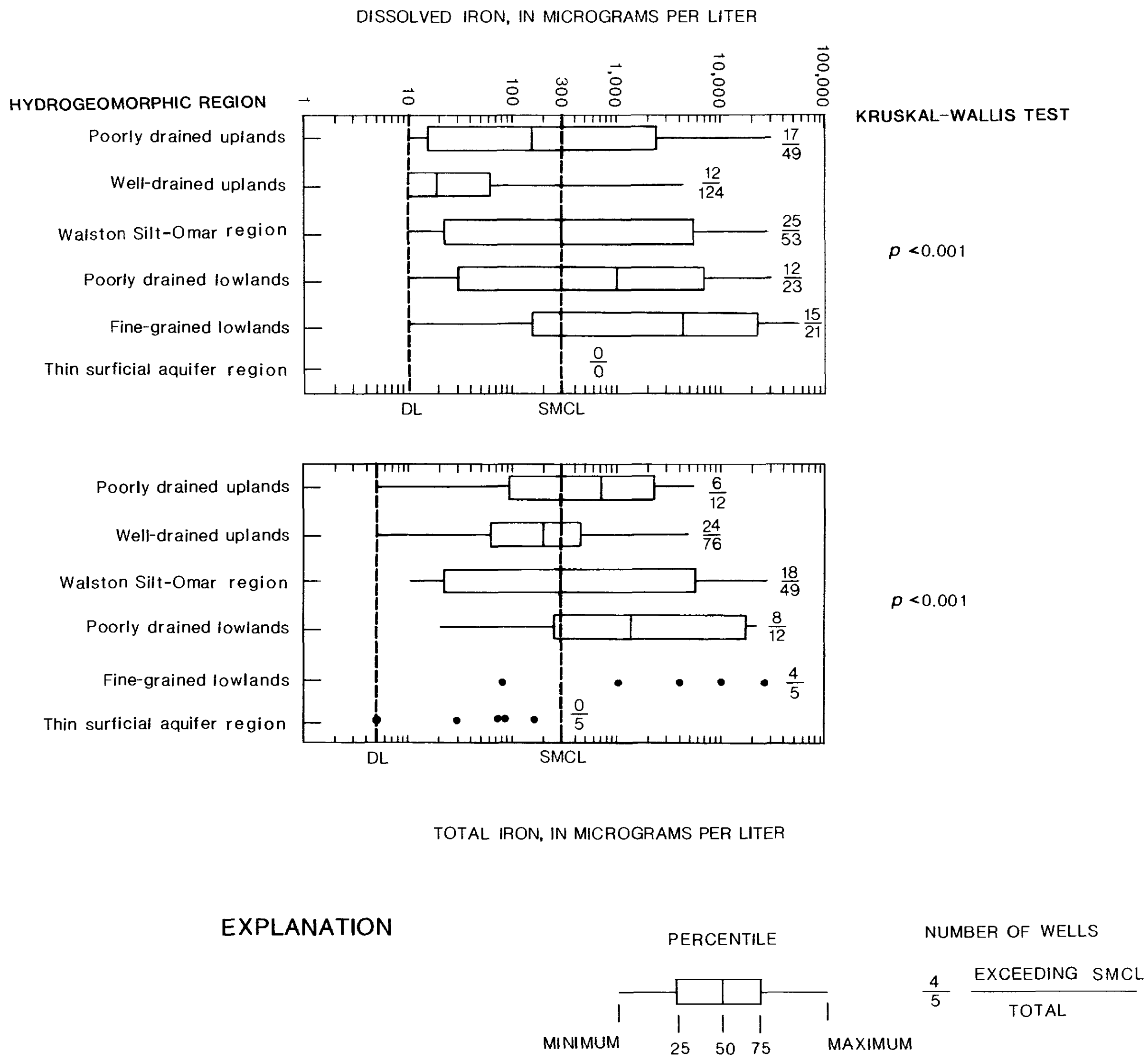
Figure 26. Graphical summary of available data for dissolved and total iron concentrations in water from wells completed in the surficial aquifer in the Delmarva Peninsula, grouped by land-use setting (compiled from U.S. Geological Survey data).

range from 0 to 25,000 µg/L, with a median of 380 µg/L; 57 wells (about 53 percent) have concentrations that exceed the SMCL.

Virginia Water Project, Inc., data.—Data for total iron concentrations in water from wells in the surficial aquifer in Virginia were compiled from the VWP data base. Concentrations in 45 wells range from 40 to 25,600 µg/L, with a median of 920 µg/L. Thirty (about 67 percent) of the 45 wells have concentrations that exceed the SMCL (fig. 24).

Delaware Water Resources Center data.—Data for total iron concentrations in water from 193 wells in the surficial aquifer in eastern Sussex County, Del., were compiled from the DWRC data base. Concentrations range from less than 100 to 21,000 µg/L, with a median of 300 µg/L. Concentrations in 85 wells (about 44 percent) exceed the SMCL. The majority of these 85 wells are located in the southern part of eastern Sussex County. Robertson (1979) attributed the elevated concentrations in this part of the county to the poorly drained, poorly aerated, and impermeable nature of soils there.

Wicomico County Health Department data.—Data for total iron concentrations in water from 1,398 wells in the surficial aquifer were compiled from the Wicomico County Health Department data base. Concentrations range from 0 (no detection limit given) to 39,000 µg/L, with a median of



SMCL	SECONDARY MAXIMUM CONTAMINANT LEVEL
DL	DETECTION LIMIT
	KRUSKAL-WALLIS TEST—Hypothesis test to examine real versus chance differences in data. The test involves a null hypothesis stating that no real difference exists. An alpha value, or level of significance, is used in the hypothesis test representing the maximum probability of rejecting the null hypothesis when it is actually true. The alpha value used in this report is 0.05
$p<0.001$	p-VALUE—Probability representing the attained significance level. If the p-value is smaller than or equal to the alpha value, the null hypothesis is rejected and significant differences are assumed to exist among the data
•	CONCENTRATION OF INDIVIDUAL ANALYSIS—All data are plotted when total number of analyses is less than 12

NOTE: Refer to figure 11 for locations of hydrogeomorphic regions

Figure 27. Graphical summary of available data for dissolved and total iron concentrations in water from wells completed in the surficial aquifer in the Delmarva Peninsula, grouped by hydrogeomorphic region (compiled from U.S. Geological Survey data).

410 µg/L. Concentrations in 781 wells (about 56 percent) exceed the SMCL. The wells with iron concentrations that exceed the SMCL are distributed throughout the county.

Discussion.—The statistical analysis and map of dissolved and total iron concentrations support previous findings that iron poses a water-quality problem within the surficial and confined aquifers in the study area. Elevated concentrations in the surficial aquifer commonly are present in areas of fine-grained and poorly drained sediments. Elevated iron concentrations may cause brownish discolorations on plumbing fixtures, cooking utensils, and laundered goods, and may impart a bitter or astringent taste to water.

Manganese

Data for manganese concentrations in ground water have been collected from wells that are fairly well distributed throughout the peninsula. Manganese is a natural constituent in ground water and commonly is associated with reducing environments and elevated iron concentrations (Denver, 1986). Data for manganese concentrations in water from more than 1,300 wells were compiled from the USGS, NURE, and VWCB data bases.

U.S. Geological Survey data.—Boxplots summarizing manganese concentrations compiled from USGS data are presented in figure 28. The median manganese concentration for the surficial aquifer is 40 μg/L. Concentrations in 76 wells (about 43 percent) in the surficial aquifer exceed the SMCL of 50 μg/L. The median manganese concentration in the confined aquifers ranges from less than the detection limit (10 μg/L) in the central part of the upper and middle confined aquifers to 67 μg/L in the southern part of the upper confined aquifers. As with iron concentrations, elevated manganese concentrations are present throughout the peninsula, particularly in the northern region of the middle and lower confined aquifers and in the southern region of the upper confined aquifers. Concentrations in 123 wells (about 34 percent) in the confined aquifers exceed the SMCL.

Locations of wells in the surficial aquifer sampled by the USGS for manganese concentration are presented in figure 29. Data for the northern and southern parts of the peninsula are sparse. Locations of wells in which manganese concentrations exceed the SMCL are highlighted (fig. 29). These wells are not confined to a particular area but are present throughout the peninsula.

The USGS data were separated by well depth, broadly defined land-use setting, and hydrogeomorphic region to assess factors that may influence manganese distribution. An analysis of variance on the ranks of data (table 9) indicates that manganese concentrations differ significantly among hydrogeomorphic regions ($p<0.001$). Individual analysis of variance tests indicate no significant difference among land-use settings ($p=0.120$) or with depth of wells ($p=0.110$). These factors are discussed below.

The relation between manganese concentration and well depth was examined with graphical plots and statistical tests. Manganese concentrations and depths of wells are shown in figure 30. A smooth line, involving the use of robust weighted least squares (Helsel and Hirsch, 1990), suggests that concentrations do not increase or decrease with increasing depth of well. A regression analysis of the ranks of concentrations on well depths was not significant ($p=0.124$).

Boxplots of USGS manganese concentrations separated by agricultural, urban, and woodland settings in the surficial aquifer are presented in figure 31. Median concentrations range from 23 μg/L in woodlands to 50 μg/L in agricultural areas. The Kruskal-Wallis test indicates no significant difference ($p=0.120$) in median concentrations among the three land-use settings.

Boxplots of USGS manganese concentrations separated by hydrogeomorphic region in the surficial aquifer are presented in figure 31. Median concentrations range from 20 μg/L in the Walston Silt-Omar region to 150 μg/L in the fine-grained lowlands. Median concentrations differ significantly (Kruskal-Wallis test, $p<0.001$) among the regions. A pairwise significance test (Tukey) was used to further investigate patterns among the regions. The test indicates that manganese concentrations in the fine-grained lowlands are significantly higher than manganese concentrations in the well-drained uplands, poorly drained uplands, and Walston Silt-Omar region.

National Uranium Resource Evaluation Program data.—Data for manganese concentrations in water from 683 wells completed in the surficial and upper confined aquifers in Delaware and Maryland were compiled from the NURE data base. Concentrations range from 3 to 6,150 μg/L, with a median of 80 μg/L. Concentrations in 483 wells (about 71 percent) exceed the SMCL.

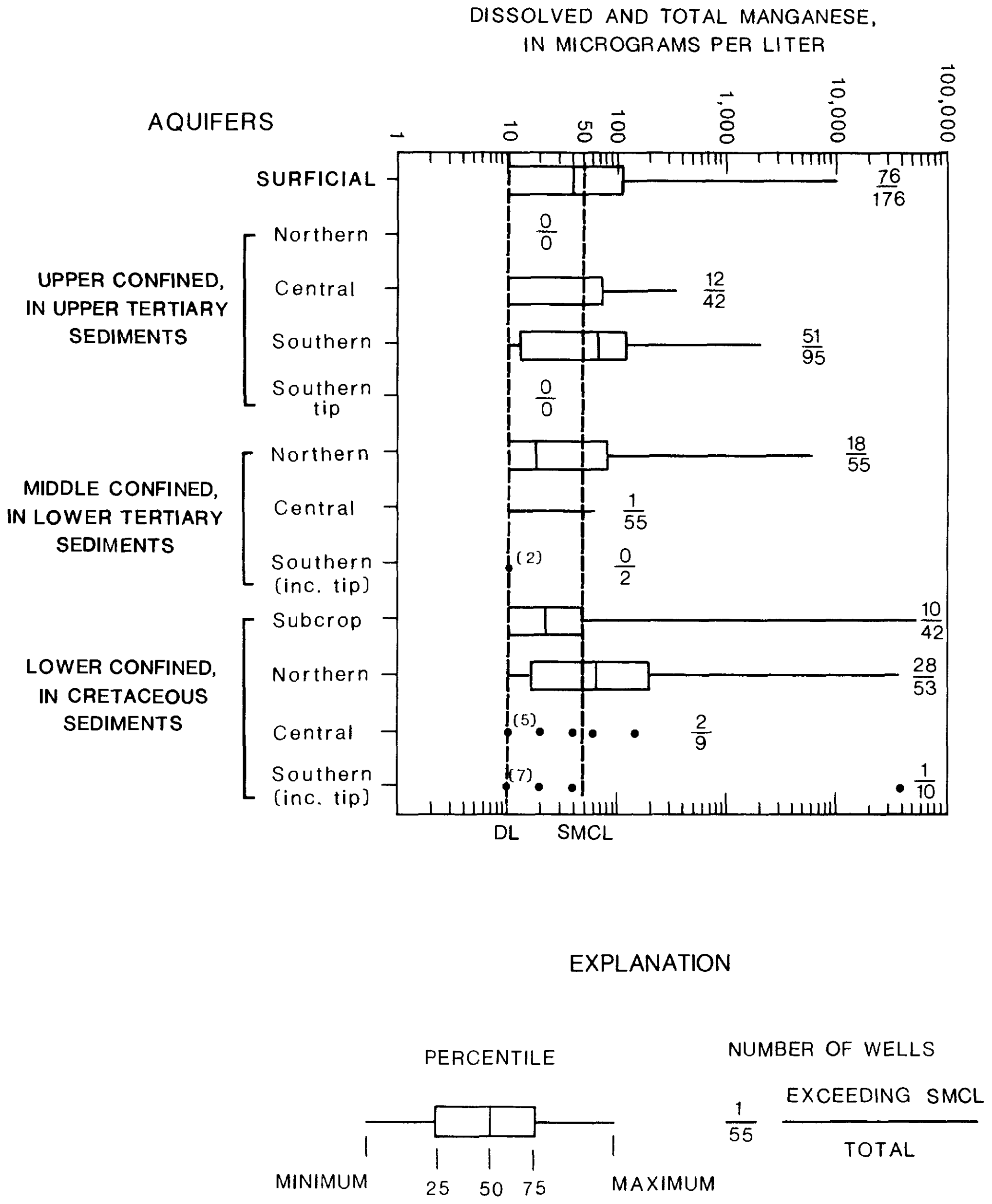
Virginia Water Control Board data.—Data for manganese concentrations in water from wells completed in the surficial and upper confined aquifers in Virginia were compiled from the VWCB data base. Manganese concentrations in 19 wells in the surficial aquifer range from 10 to 290 μg/L, with a median of 60 μg/L; concentrations in 11 wells (about 58 percent) exceed the SMCL (fig. 29). Manganese concentrations in 104 wells in the upper confined aquifers range from 0 (no detection limit given) to 200 μg/L, with a median of 30 μg/L; concentrations in 26 wells (about 25 percent) exceed the SMCL.

Discussion.—Elevated manganese concentrations are present throughout the peninsula, particularly in areas of fine-grained and poorly drained sediments. Elevated concentrations may cause brownish discolorations on plumbing fixtures, cooking utensils, and laundered goods, and may impart a bitter or astringent taste to water.

Fluoride

Data for fluoride concentrations in water from more than 750 wells were compiled from the USGS and VWCB data bases.

U.S. Geological Survey data.—Boxplots of fluoride concentrations compiled from USGS data are shown in



SMCL SECONDARY MAXIMUM CONTAMINANT LEVEL

DL DETECTION LIMIT

● CONCENTRATION OF INDIVIDUAL ANALYSIS --All data are plotted when total number of analyses is less than 12. Number in parentheses refers to multiple analyses at the same concentration

NOTE: Refer to figure 10 for locations of geographic regions of confined aquifers

Figure 28. Graphical summary of available data for dissolved and total manganese concentrations in water from wells completed in aquifers in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

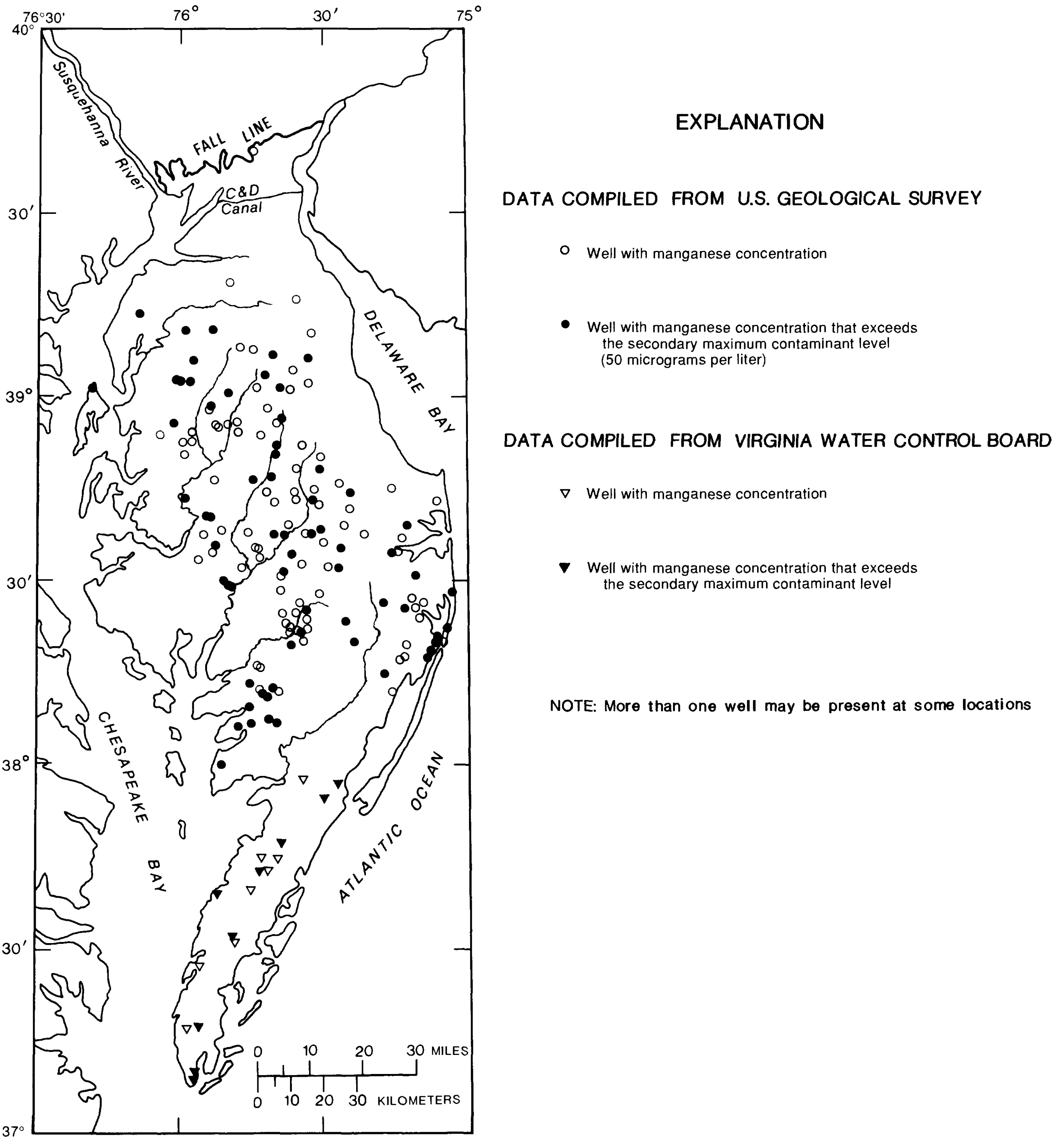


Figure 29. Distribution of available data for dissolved and total manganese concentrations in water from wells completed in the surficial aquifer in the Delmarva Peninsula (compiled from U.S. Geological Survey and Virginia Water Control Board data).

figure 32. Both the MCL (4 mg/L) and the SMCL (2 mg/L) for fluoride are presented on the boxplots. Fluoride concentrations are less than the detection limit (0.1 mg/L) in 140 (about 73 percent) of the 192 wells in the surficial aquifer. Concentrations do not exceed either the MCL or SMCL. The median fluoride concentration in the confined aquifers ranges from less than the detection limit in the subcrop area of the lower confined aquifers and the central part of the

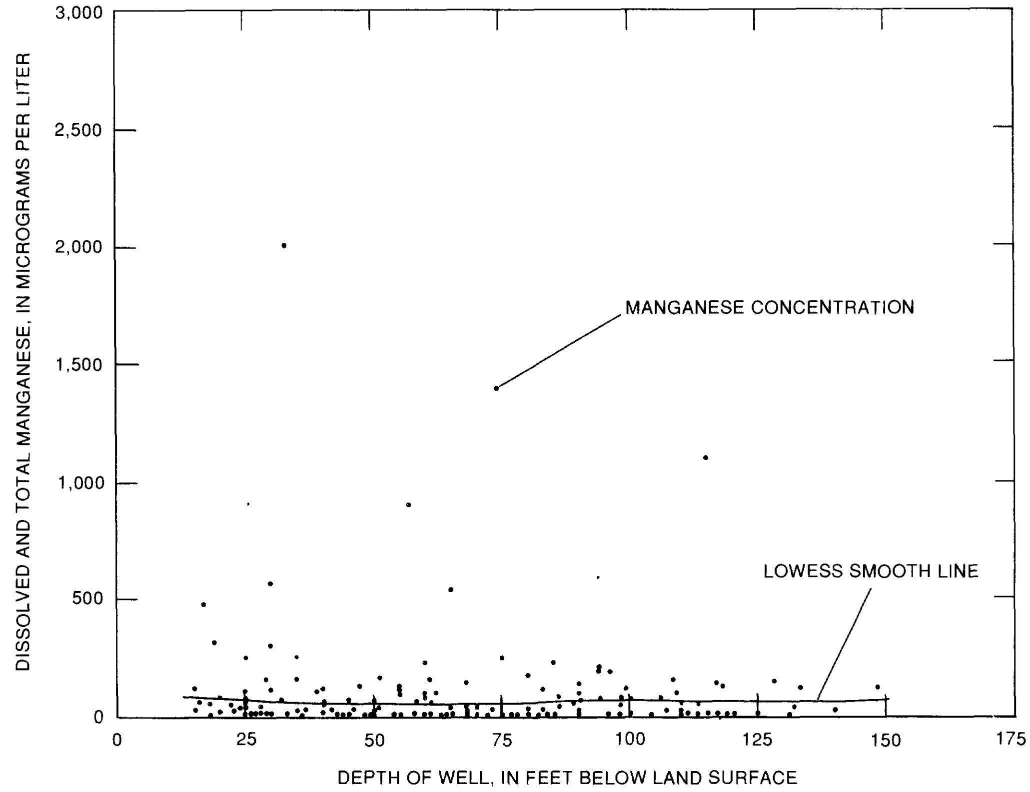


Figure 30. Dissolved and total manganese concentrations with depth of wells (compiled from U.S. Geological Survey data).

upper confined aquifers to 2.1 mg/L in the southern part of the lower confined aquifers. Median concentrations generally increase downdip in the middle and lower confined aquifers. This increase may be related to changes in the mineralogy of the sediments and to a relatively high pH (Cushing and others, 1973). A regional pattern is not apparent in the upper confined aquifers. Fluoride concentrations exceed the MCL and SMCL in 6 and 14 (about 1 and 3 percent) of the 437 wells, respectively, in the confined aquifers. Elevated concentrations are common in the southern part of the middle and lower confined aquifers, where 4 (about 17 percent) of the 24 concentrations exceed the MCL and 9 (about 38 percent) of the 24 concentrations exceed the SMCL.

Virginia Water Control Board data.—Data for fluoride concentrations in water from wells completed in the surficial and upper confined aquifers in Virginia were compiled from the VWCB data base. Concentrations in 20 wells in the surficial aquifer range from 0.01 to 0.52 mg/L, with a median of 0.10 mg/L. Concentrations in 111 wells in the upper confined aquifers range from 0.01 to 1.18 mg/L, with a median of 0.13 mg/L. None of the concentrations exceeds either the MCL or SMCL.

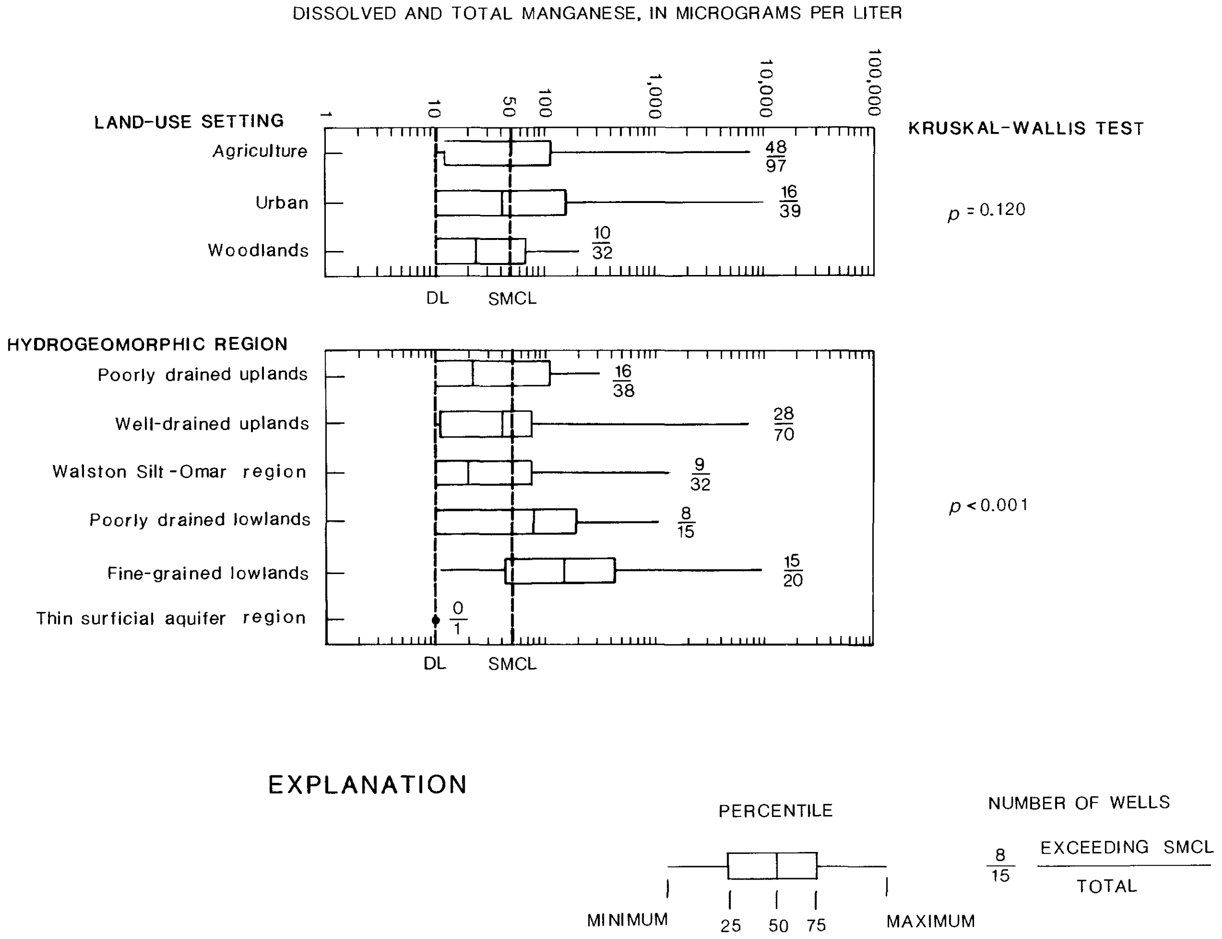
Discussion.—Fluoride concentrations generally are low throughout most of the peninsula. Elevated concentrations commonly are present in the southern parts of the deeper confined aquifers. These elevated concentrations most likely are related to sediment mineralogy. Elevated fluoride concentrations may cause objectionable mottling of teeth.

Other Trace Elements

Data for other selected trace-element concentrations are lacking. Because of high laboratory costs, many trace elements are sampled only to meet specific objectives of specialized projects. Data were compiled from the USGS, VWCB, and VWP data bases.

U.S. Geological Survey data.—Statistical analyses for selected trace elements compiled from USGS data are presented in table 11. The number of wells with detectable concentrations also are shown. The MCL for cadmium (10 μg/L) is exceeded at one well in the confined aquifers (20 μg/L), and the MCL for lead (50 μg/L) is exceeded at one well in the surficial aquifer (70 μg/L) (table 11).

Virginia Water Control Board data.—Statistical analyses for selected trace elements compiled from the VWCB data base are presented in table 12. The SMCL for zinc (5,000 μg/L) is exceeded at three wells in the confined aquifers.



SMCL SECONDARY MAXIMUM CONTAMINANT LEVEL

DL DETECTION LIMIT

KRUSKAL-WALLIS TEST--Hypothesis test to examine real versus chance differences in data. The test involves a null hypothesis stating that no real difference exists. An alpha value, or level of significance, is used in the hypothesis test representing the maximum probability of rejecting the null hypothesis when it is actually true. The alpha value used in this report is 0.05

$p < 0.001$ p-VALUE--Probability representing the attained significance level. If the p-value is smaller than or equal to the alpha value, the null hypothesis is rejected and significant differences are assumed to exist among the data

- CONCENTRATION OF INDIVIDUAL ANALYSIS--All data are plotted when total number of analyses is less than 12

NOTE: Refer to figure 11 for locations of hydrogeomorphic regions

Figure 31. Graphical summary of available data for dissolved and total manganese concentrations in water from wells completed in the surficial aquifer in the Delmarva Peninsula, grouped by land-use setting and hydrogeomorphic region (compiled from U.S. Geological Survey data).

Virginia Water Project, Inc., data.—Data for 46 zinc concentrations in water from wells in the surficial aquifer in Virginia were compiled from the VWP data base. Zinc concentrations range from 10 to 20,800 μg/L, with a median of 4,600 μg/L. Concentrations exceed the SMCL at six wells (about 13 percent).

National Uranium Resource Evaluation Program data.—Data for 710 uranium concentrations in ground water were compiled from the NURE data base. Uranium data were not separated by surficial and confined aquifers because information in the NURE data base is insufficient to differentiate wells in these aquifers. Dissolved uranium-238 concentrations range from less than the detection limit (0.002 μg/L) to 2.3 μg/L, with a median of 0.024 μg/L. Samples from 595 wells (about 84 percent) show detectable concentrations.

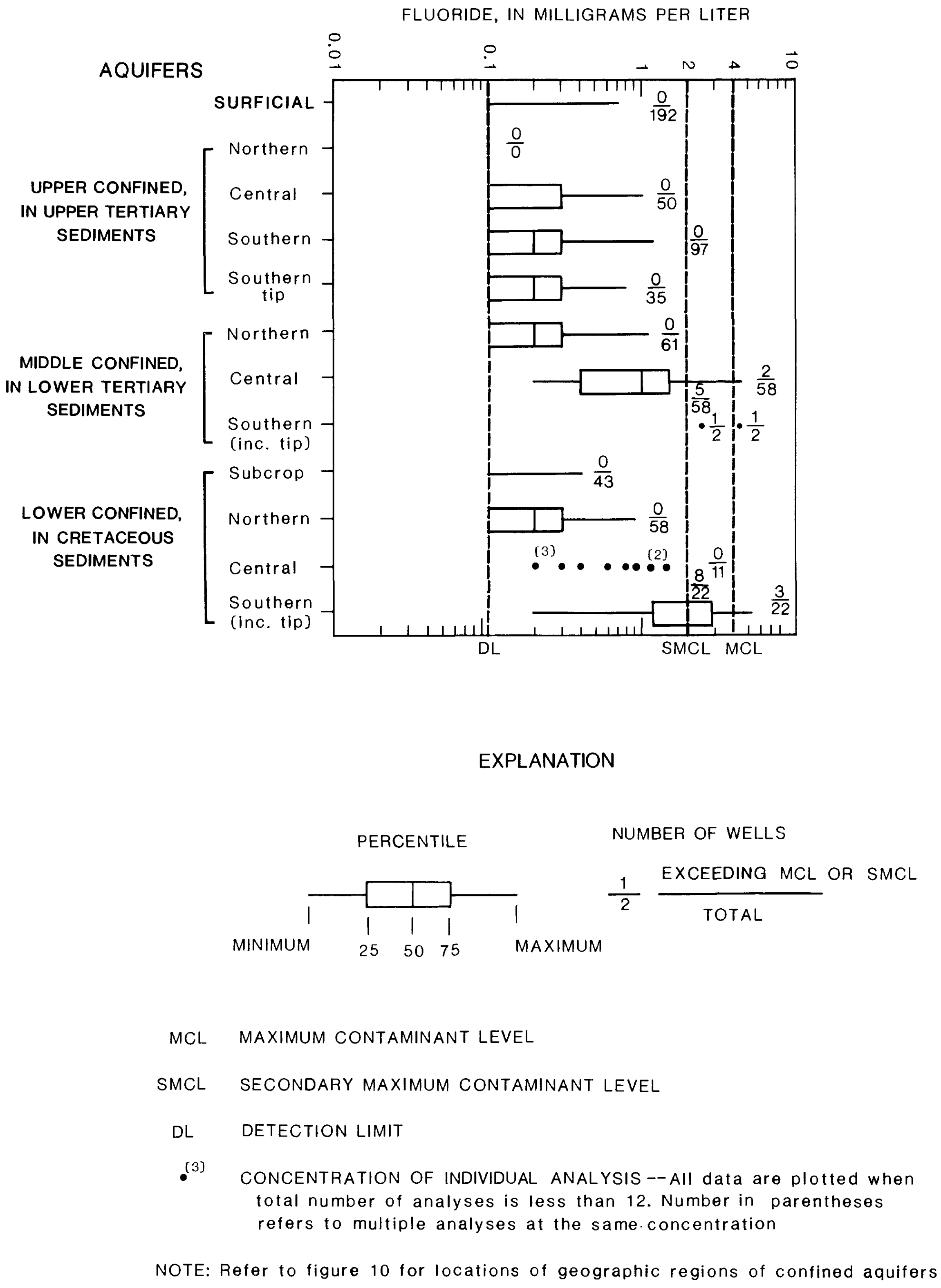


Figure 32. Graphical summary of available data for fluoride concentrations in water from wells completed in aquifers in the Delmarva Peninsula (compiled from U.S. Geological Survey data).

Discussion.—Occurrences of some trace elements may be attributed to a wide range of natural and anthropogenic sources. One source in the shallow aquifer system could be atmospheric precipitation, as demonstrated by Denver (1986). Many trace elements also occur in accessory minerals in the sediments (Denver, 1986). Several

Table 11. Statistical summary of trace-element concentrations: U.S. Geological Survey data
[μg/L, micrograms per liter]

Water-quality constituent	Detection limit (μg/L)	Drinking-water standard or criterion[1] (μg/L)	Number of wells	Median (μg/L)	Number of wells with detectable concentration	Number of wells where water does not meet drinking-water standard or criterion	Maximum (μg/L)
Surficial aquifer							
Arsenic	1	50 (a)	0	—	—	—	—
Barium	—	1,000 (a)	66	90.5	66	0	710
Cadmium	1	10 (a)	64	0.6	19	0	4
Chromium	10	50 (a)	0	—	—	—	—
Copper	10	1,000 (b)	87	3.2	27	0	220
Lead	10	50 (a)	76	5.9	19	1	70
Mercury	0.1	2 (a)	0	—	—	—	—
Selenium	1	10 (a)	0	—	—	—	—
Silver	1	50 (a)	0	—	—	—	—
Zinc	3	5,000 (b)	78	46.0	75	0	3,900
Confined aquifers							
Arsenic	1	50 (a)	46	1.0	40	0	4
Barium	—	1,000 (a)	83	31.0	83	0	1,000
Cadmium	1	10 (a)	95	0.5	32	1	20
Chromium	10	50 (a)	46	8.4	21	0	50
Copper	10	1,000 (b)	105	1.3	21	0	670
Lead	10	50 (a)	95	5.8	21	0	40
Mercury	0.1	2 (a)	45	0.1	31	0	1.2
Selenium	1	10 (a)	8	(2)	8	0	<1
Silver	1	50 (a)	6	(2)	6	0	<1
Zinc	3	5,000 (b)	112	25.0	86	0	4,100

[1] Drinking-water standards and criteria are as follows (U.S. Environmental Protection Agency, 1986a, 1986b): (a) Maximum contaminant level; (b) Secondary maximum contaminant level.

[2] All points below detection limit.

trace elements, such as copper and zinc, also are added to fertilizers. Galvanized pipe used as well casing in some wells may account for the few occurrences of high concentrations of zinc.

Organic Compounds

Data for organic-compound concentrations in ground water are scarce, both in range of constituents and geo-

Table 12. Statistical summary of trace-element concentrations: Virginia Water Control Board data
[μg/L, micrograms per liter]

		Surficial aquifer				Confined aquifers			
Water-quality constituent	Drinking-water standard or criterion[1] (μg/L)	Number of wells	Median (μg/L)	Number of wells where water does not meet drinking-water standard or criterion	Maximum (μg/L)	Number of wells	Median (μg/L)	Number of wells where water does not meet drinking-water standard or criterion	Maximum (μg/L)
Arsenic	50 (a)	0	—	—	—	8	1.0	0	1
Cadmium	10 (a)	0	—	—	—	8	1.0	0	1
Chromium	50 (a)	0	—	—	—	8	1.0	0	1
Copper	1,000 (b)	9	10.0	0	830	79	10.0	0	470
Lead	50 (a)	1	1.0	0	1	17	1.0	0	20
Zinc	5,000 (b)	9	10.0	0	980	62	30.0	3	18,000

[1] Drinking-water standards and criteria are as follows (U.S. Environmental Protection Agency, 1986a, 1986b): (a) Maximum contaminant level; (b) Secondary maximum contaminant level.

graphic distribution. The prevalent use of pesticides, combined with shallow depths to the water table, permeable soils, high recharge rates, and relatively flat topography, make the Delmarva Peninsula particularly vulnerable to contamination by pesticides. However, few data exist to document the existence of and (or) extent of these compounds in ground water. A preliminary study of the presence of two nematicides (1,2-dibromo-3-chloropropane (DBCP) and 1,2-dichloropropane (DCP)) in ground water conducted by the Wicomico County Health Department (Pinto, 1980) indicates probable contamination from these pesticides in some wells. Thirty-six wells, ranging from 30 to 100 ft in depth and used for domestic and irrigation purposes, were sampled. Concentrations of DBCP and DCP were detected in 3 and 13 wells, respectively. Four observation wells were drilled in an area where DBCP and DCP products had not been applied directly (approximately 50 ft from an area where they had been applied). Concentrations of DBCP and DCP were detected in three of these four wells, suggesting that movement of DBCP and DCP in soil and ground water has occurred (Pinto, 1980).

Research and monitoring studies of aldicarb in ground water on the Delmarva Peninsula have been conducted by the Rhone Poulenc Agricultural Company since 1979. In one study, seven samples were collected from drinking-water wells near potato fields to which aldicarb had been applied in Delaware (three in New Castle County in 1979 and four in Kent County in 1984). None of the samples showed detectable concentrations of aldicarb. Well depths, available for four of these sites, range from 15 to 400 ft. In another study, two samples were collected from drinking-water wells in Wicomico County, Md., in 1983. One of the two samples had a concentration of 3 μg/L, and the other showed no detectable concentration. In a third study, in Accomack County, Va., 78 samples were collected from 60 drinking-water wells near potato fields to which aldicarb had been applied. Detectable concentrations were found in 15 wells, and concentrations exceeded 10 μg/L (MCL) in 2 of these wells. These samples were collected from 1980 through 1987. Well depths, available for 37 of the 60 Accomack County wells, indicate that most of the wells are completed in the surficial aquifer (depths range from 20 to 270 ft, with a median of 50 ft) (R.L. Jones, Rhone Poulenc Agricultural Co., written commun., 1989).

Other potential sources of contamination of ground water by organic compounds, such as landfills, spills, underground storage tanks, and industrial processes, are not as widespread as fertilizer and pesticide use but have considerable potential for degrading ground-water quality. On the peninsula, 794 sites require permits, according to RCRA, which regulates the generation, transport, storage, treatment, and disposal of hazardous materials. Fifty-one sites have received final hazardous-waste permits, and the remaining sites have obtained interim status allowing continued operations until a final permit is issued (T. Mersky, U.S. Environmental Protection Agency, region 3, written commun., 1987). These RCRA facilities are widely distributed throughout the peninsula.

Twenty locations in the study area are included on the National Priority List under CERCLA, commonly known as Superfund (T. Mersky, U.S. Environmental Protection Agency, region 3, written commun., 1987). The sites are located primarily in the northern part of the peninsula around the heavily industrialized areas of New Castle County, Del. (11 are in New Castle County, Del., 6 are in Kent County, Del., 1 is in Sussex County, Del., and 2 are in Cecil County, Md.). In addition, the U.S. Environmental Protection Agency, region 3, maintains a file of ground-water contamination incidents. Information on these sites is obtained mostly through the media or from public complaints. Thirty-six incidents, occurring predominantly in the northern part of the peninsula, were included in this file as of October 1987 (T. Mersky, U.S. Environmental Protection Agency, region 3, written commun., 1987). Some of these sites may be Superfund or RCRA sites (for example, seven of the contaminant sources are reported as landfills that require a RCRA permit). Volatile organic compounds, detected in ground water at 22 of the 36 sites, are reported most frequently.

A study of synthetic organic compounds in Delaware water supplies completed in August 1980 (CABE Associates, 1980) suggests that ground-water contamination is common in highly industrialized areas. Water samples were collected from 42 sites throughout Delaware (84 percent of the sites are public or industrial wells). The wells, completed primarily in the surficial aquifer, range from 25 to 352 ft in depth. CABE Associates detected synthetic organic compounds in 35 percent of the wells. Tetrachlorethylene and chloroform were detected most commonly. The majority of contaminated wells are in the heavily industrialized areas of New Castle County.

Three additional sources provided data on selected organic compounds: the U.S. Geological Survey, the Virginia Water Project, Inc., and the Virginia Department of Health. These data are described below.

U.S. Geological Survey data.—USGS data include analyses for 11 triazine herbicides (ametryne, atraton, atrazine, cyanazine, cyprazine, prometone, prometryne, propazine, simazine, simetone, and simetryne) collected in August and September of 1983 from 14 wells in Maryland (fig. 33). The wells, completed in the surficial aquifer, range from 20 to 110 ft in depth. Concentrations of the constituents are less than the detection limit (0.1 μg/L) at all but two wells—atrazine was detected at one well at a concentration of 0.4 μg/L, and atraton was detected at one well at a concentration of 0.1 μg/L (fig. 33).

Virginia Water Project, Inc., data.—VWP data include 37 analyses for nine organic compounds in common use in Virginia (fig. 33, table 13). All wells are located in

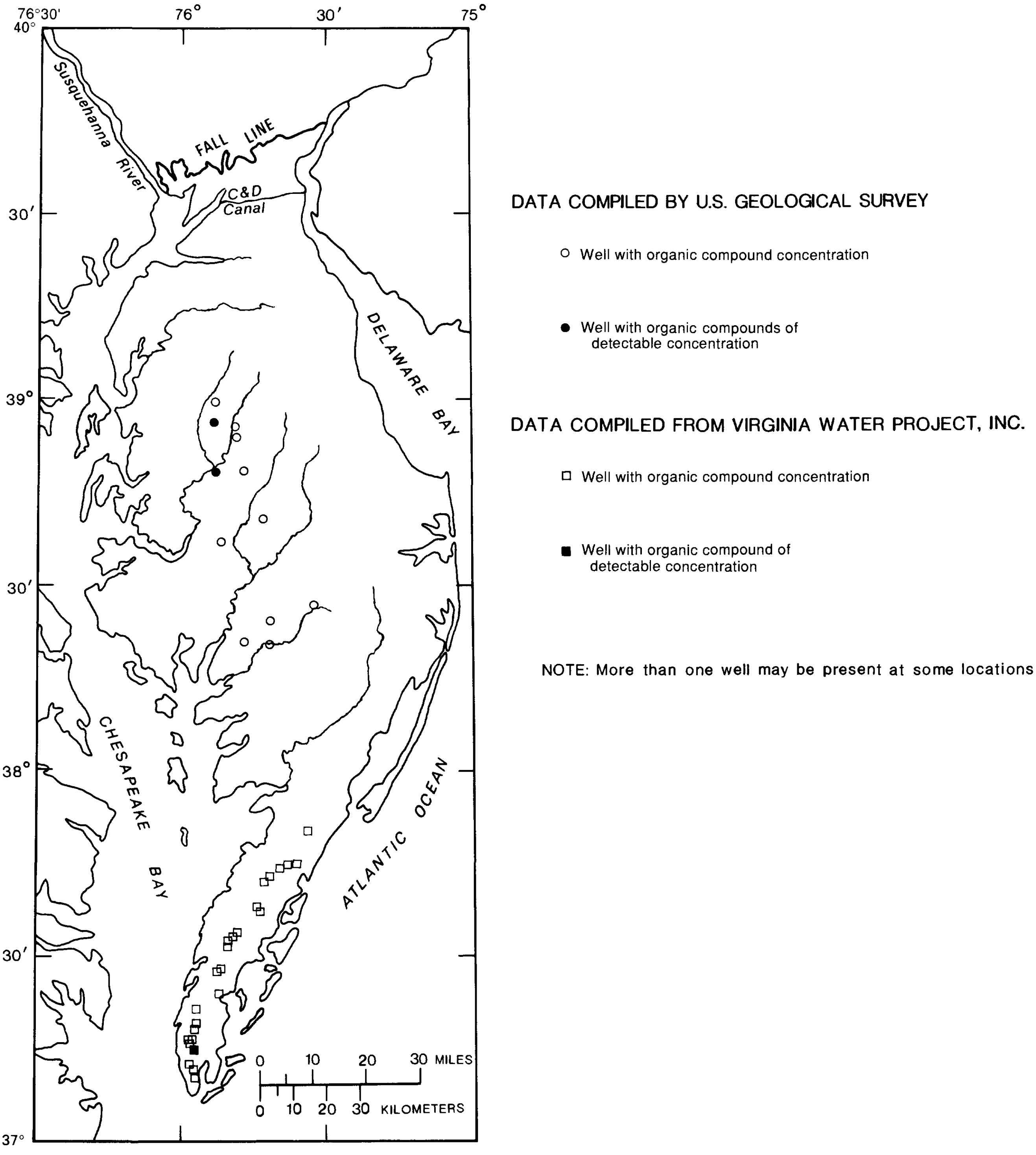


Figure 33. Distribution of available data for organic-compound concentrations in water from wells completed in the surficial aquifer in the Delmarva Peninsula (compiled from U.S. Geological Survey and Virginia Water Project, Inc., data).

agricultural areas and are completed in the surficial aquifer (approximately 30 ft in depth). Detection limits for the constituents are presented in table 13. The high detection limits for aldicarb and carbofuran are a result of limits within the laboratory. Concentrations of all constituents are less than the respective detection limits except at one well, where alachlor was detected at a concentration of 6.3 μg/L (fig. 33).

Virginia Department of Health data.—Data for organic compounds from the Virginia Department of Health

Table 13. Organic compounds commonly used in Virginia
[Compiled from Virginia Water Project, Inc., data]

Common name	Trade name	Detection level (micrograms per liter)
Alachlor	Lasso	<2
Aldicarb		<10
Benzene		<1
Carbofuran		<10
Carbophenothion	Endyl	<1
Metolachlor		<5
Metribuzin	Lexone, Sencor	<1
Metribuzin, trifluralin pergollon	Salute	<1

were collected from community public-water supplies, as well as some Federal- or State-owned noncommunity supplies. The wells supplying these systems are completed primarily in the confined aquifers and range from 55 to 1,000 ft in depth. Analyses for chlorophenoxy-acid herbicides (2,4-D, and 2,4,5-TP) and (or) chlorinated hydrocarbon insecticides (endrin, lindane, methoxychlor, and toxaphene) were conducted on water samples from 27 systems collected between 1980 and 1984. None of these compounds was detected.

Discussion.—Insufficient data exist to evaluate the existence of and (or) extent of contamination from pesticides and other synthetic organic compounds in the ground water of the Delmarva Peninsula.

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APPENDIX: Structure of data sets for each inorganic constituent

[Compiled from U.S. Geological Survey, National Uranium Resource Evaluation Program, Virginia Water Control Board, Virginia Water Project, Inc., Delaware Water Resources Center, and Wicomico County (Md.) Health Department data. Dash indicates no available data; numbers in parentheses are parameter codes]

Constituent	U.S. Geological Survey	National Uranium Resource Evaluation Program[1]	Virginia Water Control Board	Virginia Water Project, Inc.	Delaware Water Resources Center	Wicomico County Health Department
Alkalinity, as $CaCO_3$	Field, total (00410) Lab, total[2] (90410)	Not specified	Field, total (00410)	—	—	—
Dissolved oxygen	Field (00300)	—	—	—	—	—
pH	Field (00400)	Not specified	Field (00400)	Field	Field	—
Specific conductance	Field, microsiemens/ cm (00095)	Lab	Field, micromho (00094)	—	Field	—
Temperature	Field, degrees celsius (00010)	Field, degrees celsius	Field, degrees celsius (00010)	Field, degrees celsius	—	—
Calcium	Dissolved (00915)	—	Total (82032)	—	—	—
Magnesium	Dissolved (00925)	Total	Total (82033)	—	—	—
Hardness, as $CaCO_3$	Total (00900)	—	Total (00900)	—	—	—
Potassium	Dissolved (00935) Total (00937)	—	Total (82034)	—	—	—
Sodium	Dissolved (00930) Total (00929)	Total	Total (82035)	—	—	—
Chloride	Dissolved (00940)	—	Total[3] (00940)	—	Field	—
Sulfate	Dissolved (00945)	—	Total[3] (00945)	Total	—	—
Total dissolved solids	180 deg. residue (70300) 105 deg. residue (00515) Sum of const. (70301)	—	105 deg. residue (00515)	—	Calculated from conductance[4]	—
Ammonium	Ammonia as N, dissolved (00608) Ammonia as NH_4, dissolved (71846) Ammonia as N, total (00610)	—	Ammonia as N[5], total (00610) (Data not retrieved)	—	—	—
Nitrite	NO_2 as N, dissolved (00613) NO_2 as NO_2, dissolved (71856) NO_2 as N, total (00615)	—	NO_2 as N, total (00615)	—	—	—
Nitrate	NO_2+NO_3 as N, dissolved (00631) NO_3 as N, dissolved (00618) NO_3 as NO_3, dissolved (71851) NO_2+NO_3 as N, total (00630) NO_3 as N, total (00620)	—	NO_2+NO_3 as N, total (00630) NO_3 as N, total (00620)	NO_3 as N (unspecified if total or dissolved)	Field, NO_3 as NO_3	NO_3 as N (unspecified if total or dissolved)

APPENDIX: Structure of data sets for each inorganic constituent—Continued

[Compiled from U.S. Geological Survey, National Uranium Resource Evaluation Program, Virginia Water Control Board, Virginia Water Project, Inc., Delaware Water Resources Center, and Wicomico County (Md.) Health Department data. Dash indicates no available data; numbers in parentheses are parameter codes]

Constituent	U.S. Geological Survey	National Uranium Resource Evaluation Program[1]	Virginia Water Control Board	Virginia Water Project, Inc.	Delaware Water Resources Center	Wicomico County Health Department
Total nitrogen	Total as N (00600)	—	—	—	—	—
Aluminum	Dissolved (01106) Total (01105)	Total	—	—	—	—
Antimony	Dissolved (01095)	—	—	—	—	—
Arsenic	Dissolved (01000) Total (01002)	—	Total (01002)	—	—	—
Barium	Dissolved (01005) Total (01007)	—	—	—	—	—
Boron	Dissolved (01020) Total (01022)	—	—	—	—	—
Cadmium	Dissolved (01025) Total (01027)	—	Total (01027)	—	—	—
Chromium	Dissolved (01030) Total (01034)	—	Total (01034)	—	—	—
Copper	Dissolved (01040) Total (01042)	—	Total (01042)	—	—	—
Fluoride	Dissolved (00950) Total (00951)	—	Total (00951)	—	—	—
Iron (dissolved)	Dissolved (01046) Ferrous (01047) Ferric+Ferrous, dissolved (01048)	—	—	—	—	—
Iron (total)	Total (01045)	—	Total (01045)	Total	Field	Total
Lead	Dissolved (01049) Total (01051)	—	Total (01051)	—	—	—
Manganese	Dissolved (01056) Total (01055)	Total	Total (01055)	—	—	—
Mercury	Dissolved (71890)	—	—	—	—	—
Molybdenum	Dissolved (01060)	—	—	—	—	—
Nickel	Dissolved (01065) Total (01067)	—	Total (01067)	—	—	—
Selenium	Dissolved (01145)	—	—	—	—	—
Silver	Dissolved (01075) Total (01077)	—	—	—	—	—
Vanadium	Dissolved (01085)	Total	—	—	—	—
Zinc	Dissolved (01090) Total (01092)	—	Total (01092)	Total	—	—
Uranium	—	Total	—	—	—	—

[1] Data were retrieved only for Delaware and Maryland. Virginia data are available, however, and could be retrieved for later use, if necessary.

[2] Field and lab values were combined only for the water-type analysis.

[3] Parameter codes indicate dissolved values; however, Virginia Water Control Board analyses represent total values.

[4] Total dissolved solids content was calculated by multiplying specific conductance by 0.80 (Robertson, 1979).

[5] Virginia Water Control Board data may exist for ammonia; however, this parameter was not retrieved. The data could be retrieved for later use, if necessary.