Water-Quality Assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia--Effects of Agricultural Activities on, and Distribution of, Nitrate and Other Inorganic Constituents in the Surficial Aquifer

By Pixie A. Hamilton, Judith M. Denver, Patrick J. Phillips, and Robert J. Shedlock

---

U.S. GEOLOGICAL SURVEY

Open-File Report 93-40

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

Towson, Maryland
1993

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

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

For additional information write to:

Area Assistant Regional Hydrologist,
U.S. Geological Survey, WRD
8600 LaSalle Rd, 208 Carroll Bldg.
Towson, MD 21286

Copies of this report can be purchased from:

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

CONTENTS

FIGURES

Tables

WATER-QUALITY ASSESSMENT OF THE DELMARVA PENINSULA, DELAWARE, MARYLAND, AND VIRGINIA--EFFECTS OF AGRICULTURAL ACTIVITIES ON, AND DISTRIBUTION OF, NITRATE AND OTHER INORGANIC CONSTITUENTS IN THE SURFICIAL AQUIFER

By Pixie A. Hamilton, Judith M. Denver, Patrick J. Phillips, and Robert J. Shedlock

U.S. GEOLOGICAL SURVEY

Open-File Report 93-40

ERRATA

Please note that column headings on tables 11-15 on pages 83-87 are shifted and do not directly line up with columns of data (column headings on tables 11-15 on the computer disk placed in back of the report are correct). Column headings on printed tables will be corrected in final version of report as U.S. Geological Survey Water-Supply Paper 2355-C .

10/6/93

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

Multiply	By	To obtain
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
pound (lb)	0.4536	kilogram
pound per acre (lb/acre)	1.121	kilogram per hectare
ton	907.2	kilogram
million gallons per day (Mgal/d)	0.003785	million cubic meters per day

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

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

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

Abbreviated water-quality units used in report: Concentrations of dissolved oxygen, calcium, magnesium, potassium, sodium, alkalinity, sulfate, chloride, silica, nitrogen, and phosphorus are expressed in milligrams per liter (mg/L). Concentrations of barium, dissolved iron, and strontium are expressed in micrograms per liter (µg/L). Specific conductance is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Water-Quality Assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia--Effects of Agricultural Activities on, and Distribution of, Nitrate and Other Inorganic Constituents in the Surficial Aquifer

By P.A. Hamilton, J.M. Denver, P.J. Phillips, and R.J. Shedlock

Abstract

The Delmarva Peninsula, which includes most of Delaware and the entire Eastern Shore of Maryland and Virginia, consists of a flat to gently rolling central upland flanked by low plains that slope toward Chesapeake Bay, Delaware Bay, and the Atlantic Ocean. Total land area is about 6,050 square miles. Agriculture is the most prevalent land use, accounting for about 48 percent of the study area. As in many agricultural areas, crop yields are linked to the amounts and kinds of fertilizers that are applied to the soil. The potential movement of these chemicals into ground water is a concern among water-resource managers and residents of the Delmarva Peninsula because the flat topography and porous soils provide favorable conditions for chemicals applied on the land to move downward to the water table.

The chemical character of natural water (minimally affected by human activities) in the surficial aquifer is controlled primarily by the chemical properties of precipitation, in combination with mineral dissolution and biological activity in the aquifer. Like precipitation, natural ground water is moderately acidic (pH is about 5.8). Concentrations of dissolved constituents are low (indicated by a median specific conductance value of 115 microsiemens per centimeter at 25 degrees Celsius) because the surficial aquifer consists mostly of relatively insoluble quartz sand. In addition, the high permeability of the sediment increases ground-water-flow rates and reduces contact and reaction time between water and aquifer minerals.

Nitrate, derived from nitrification of ammonia in inorganic fertilizers and manure, is the dominant anion in agricultural areas. Concentrations of nitrate in 185 water samples collected in agricultural areas ranged from 0.4 to 48 milligrams per liter as nitrogen, with a median concentration of 8.2 milligrams per liter as nitrogen. Nitrate concentrations exceeded the U.S. Environmental Protection Agency (USEPA) maximum contaminant level for drinking water of 10 milligrams per liter as nitrogen in about 33 percent of the 185 water samples.

Ground water affected by agricultural activities contains significantly higher concentrations of dissolved constituents (indicated by a median specific conductance value of 170 microsiemens per centimeter at 25 degrees Celsius) than natural ground water. Concentrations of calcium and magnesium are higher because of liming of soils, and concentrations of potassium and chloride are higher because of applications of potash used to supplement the nitrogen-based fertilizers. Alkalinity concentrations commonly are lower in water affected by agricultural activities than in natural water because bicarbonate ion is consumed in buffering reactions with acid produced during nitrification of ammonia.

Effects of agricultural activities on the quality of ground water are not limited to the near-surface parts of the aquifer underlying farm fields but are common at or near the base of the aquifer, 80 to 100 feet below land surface. The median concentration of nitrate in water beneath agricultural areas collected from 24 wells deeper than 80 feet below land surface was 8.5 milligrams per liter as nitrogen, and nitrate concentrations in 9 of these water samples exceeded the USEPA maximum contaminant level for nitrate in drinking water.

Concentrations of nitrate and other inorganic constituents in water from the surficial aquifer differ among hydrogeomorphic regions of the Delmarva Peninsula. Hydrogeomorphic regions are characterized by related features--including surficial geology, geomorphology, topography, soil characteristics, and land use--that can impart characteristic regional ground-water-quality patterns. Six hydrogeomorphic regions are delineated on the peninsula--well-drained uplands, poorly drained uplands, poorly drained lowlands, fine-grained lowlands, surficial confined region, and the inner coastal plain.

Median concentrations of nitrate in water from the surficial confined region (about 1.1 milligrams per liter as nitrogen) and the lowlands (about 0.1 milligrams per liter as nitrogen) are significantly lower than the median concentration in water from the well-drained uplands (about 8.9 milligrams per liter as nitrogen). The surficial aquifer underlying the surficial confined region and lowlands commonly contains abundant fine sand, clay, silt, peat, and other organic matter. The clay and silt deposits inhibit downward flow, and, therefore, inhibit leaching and transport of fertilizers to the water table. In addition, anaerobic ground water in these regions inhibits nitrification of ammonia and promotes denitrification of nitrate. In contrast, the surficial aquifer underlying the uplands mainly consists of permeable quartz sand and gravel, allowing nitrate and other constituents to move more readily to the water table than in the surficial confined region and lowlands.

Nitrate concentrations are variable locally, depending on ground-water flow and land use. In near-surface ground water (less than 30 feet below land surface), nitrate concentrations generally reflect recharge through overlying land within about 100 to 200 feet of a well. Nitrate concentrations in ground water are highest beneath farmland and lowest beneath woodlands and marshes. Nitrate concentrations in ground water are elevated beneath residential areas because of septic-tank effluent and lawn fertilizers. Elevated concentrations of nitrate in deep ground water reflect recharge through distant agricultural or residential land rather than through agricultural or residential land directly around a well. In some areas of the Delmarva Peninsula, deep ground water containing elevated nitrate concentrations is overlain by ground water with lower nitrate concentrations. This vertical variability of nitrate concentration is most common beneath marshes and woodlands adjacent to streams and other discharge areas. In these areas, the near-surface ground water is recharged through soils covered with natural vegetation, and the deep ground water is recharged through soils in distant agricultural or residential land.

Aquifer composition, in combination with ground-water flow and land use, affects the local stratification of nitrate in water from the surficial confined region and lowlands. Nitrate concentrations commonly are elevated in ground water beneath agricultural or residential areas where the composition of the surficial aquifer is sandy. Nitrate concentrations are minimal or less than the laboratory reporting limit in ground water beneath agricultural or residential areas underlain by fine sand, clay, silt, peat, and other organic matter.

INTRODUCTION

The Delmarva Peninsula, which includes most of Delaware and the entire Eastern Shore of Maryland and Virginia (fig. 1), remains primarily a rural area where about half of its land area (total land area of 6,050 mi^2) is used for agriculture. As in many agricultural areas, crop yields are linked to the amounts and kinds of fertilizers that are applied to the soil. The potential movement of these chemicals into ground water is a concern among water-resource managers and residents of the Delmarva Peninsula because the flat topography and porous soils provide favorable conditions for chemicals applied on the land to move downward to the water table. One of the major tasks of this investigation has been to assess the effects of agricultural activities on ground-water quality on the peninsula.

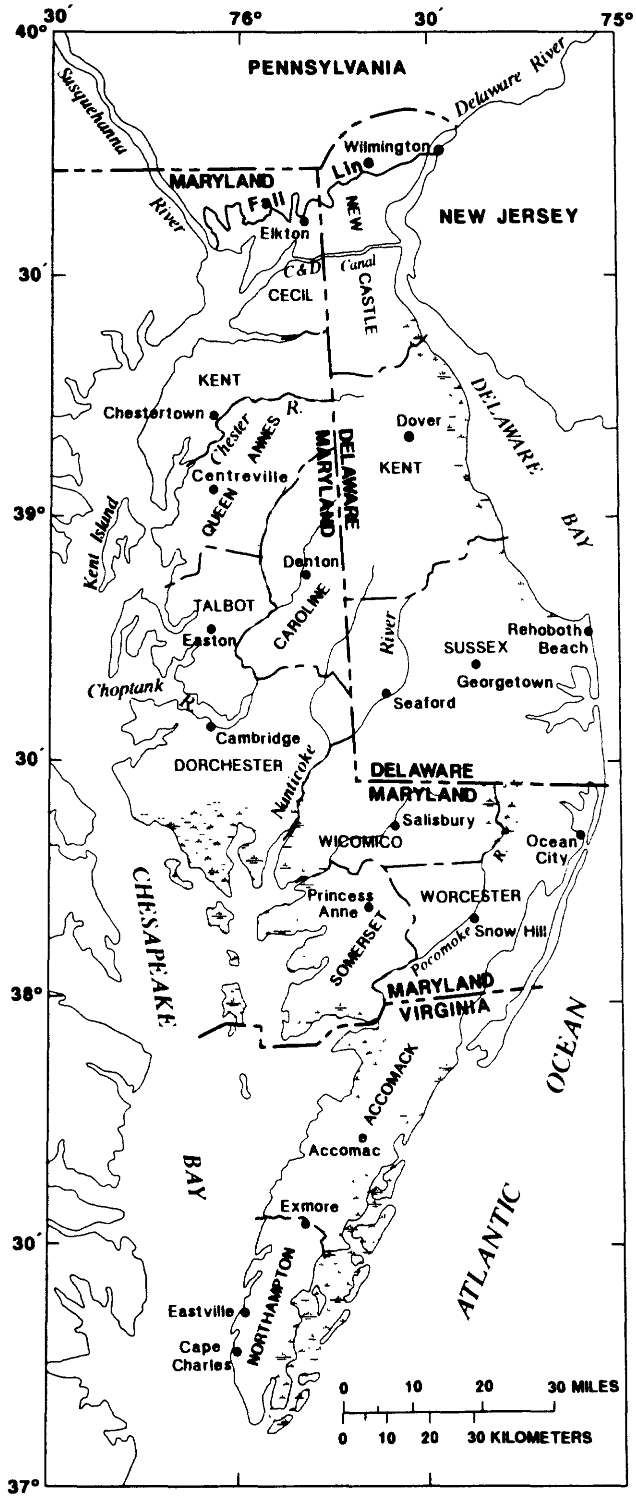


Figure 1. Location of the Delmarva Peninsula.

The peninsula is one of seven pilot project areas in the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (Hirsch and others, 1988). Four surface-water projects and three ground-water projects began in 1986 as part of a pilot program to test and refine methods for regional assessments and to help assess the need for and feasibility of the full-scale program. The full-scale NAWQA Program, which began in 1991, includes investigations of 60 major river basins and aquifer systems throughout the Nation that account for a large percentage of the Nation's population and freshwater use. Long-term goals of the full-scale program are to:

1. Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's surface-water 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 observed water-quality conditions and trends.

Results of the NAWQA Program are available to water managers, policymakers, and the public, and they 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-management and water-quality-management practices (Hirsch and others, 1988).

Purpose and Scope

The purpose of this report is to describe the effects of agricultural applications of inorganic fertilizers, manure, and lime on concentrations of nitrate and other inorganic constituents in water from the surficial aquifer in the Delmarva Peninsula. Chemistry of ground water affected by agricultural activities is compared to chemistry of natural (minimally affected by human activities) ground water. The report includes maps that illustrate the spatial distribution of major ions in natural water and of nitrate and other inorganic constituents in ground water affected by agricultural land use, such as calcium and magnesium from applications of lime and potassium and chloride from applications of potash fertilizers. Comparisons of ground-water quality are described in this report on the basis of land use, soil characteristics, aquifer composition, ground-water flow, and hydrogeomorphic region to explain regional and local patterns, areal and vertical, of selected constituents in water from the surficial aquifer. The scope of this work includes evaluation of water-quality data for 193 wells in the surficial aquifer collected by the USGS during 1976-87 and analyses of water-quality and ancillary data for more than 200 wells completed in the surficial aquifer collected for the Delmarva NAWQA project during June 1988-March 1991.

Acknowledgments

Special thanks are given for the continuous support of members on the Delmarva NAWQA liaison committee, established to guide the planning, implementation, and evaluation of the pilot study. Thanks also are extended to residents of the Delmarva Peninsula who allowed access to their properties for well drilling and sampling.

DESCRIPTION OF STUDY AREA

The Delmarva Peninsula is roughly oval, extending about 150 mi north to south and about 70 mi east to west at its widest point (fig. 1). The study area 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 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. 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 land-surface elevations are about 200 ft in the necks between tidal streams at the extreme northern end of Chesapeake Bay. Excluding these necks, the highest elevation is about 80 ft in the central uplands. Topographic relief is greatest along tidal streams and their tributaries in the northern one-third of the peninsula. For example, relief in the area of bluffs along the Chesapeake and Delaware (C & D) Canal is 50 to 60 ft, and relief in valleys of tidal streams and tributaries commonly is more than 40 ft.

The extent to which streams are incised into surficial sediments is variable in the study area. Poorly drained areas (consisting of sluggish streams that flow through low-gradient, poorly incised valleys with poorly drained soils and seasonally wet areas) are common in the central uplands on the broad drainage divide between the Chesapeake and Delaware Bays. Well-drained areas flank the central uplands and consist of more deeply incised streams, better-drained soils, and greater depths to the water table. Lowlands on the fringes of the peninsula along the Chesapeake and Delaware Bays consist of broad and deep valleys in the tidal reaches of streams.

Hydrogeology

The Delmarva Peninsula is underlain by a wedge of unconsolidated sediments that thickens to the south and east. Sediment thickness ranges 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 age and primarily consist of sand, clay, silt, gravel, and variable amounts of shells. The wedge of sediments dips to the south and southeast and is underlain by Precambrian igneous and metamorphic rocks and sedimentary rocks of Cretaceous age, 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 and associated confining units (fig. 2), and Harsh and Laczniak (1990) identified a series of six confined aquifers and associated confining units. The series of confined aquifers is overlain by an extensive surficial aquifer that is under water-table (unconfined) conditions in most of the study area. The surficial aquifer is the focus of the Delmarva NAWQA pilot study because it supplies water to the underlying confined aquifers and because it is used extensively. About one-half of the 170 Mgal/d pumped from wells on the peninsula is withdrawn from the surficial aquifer.

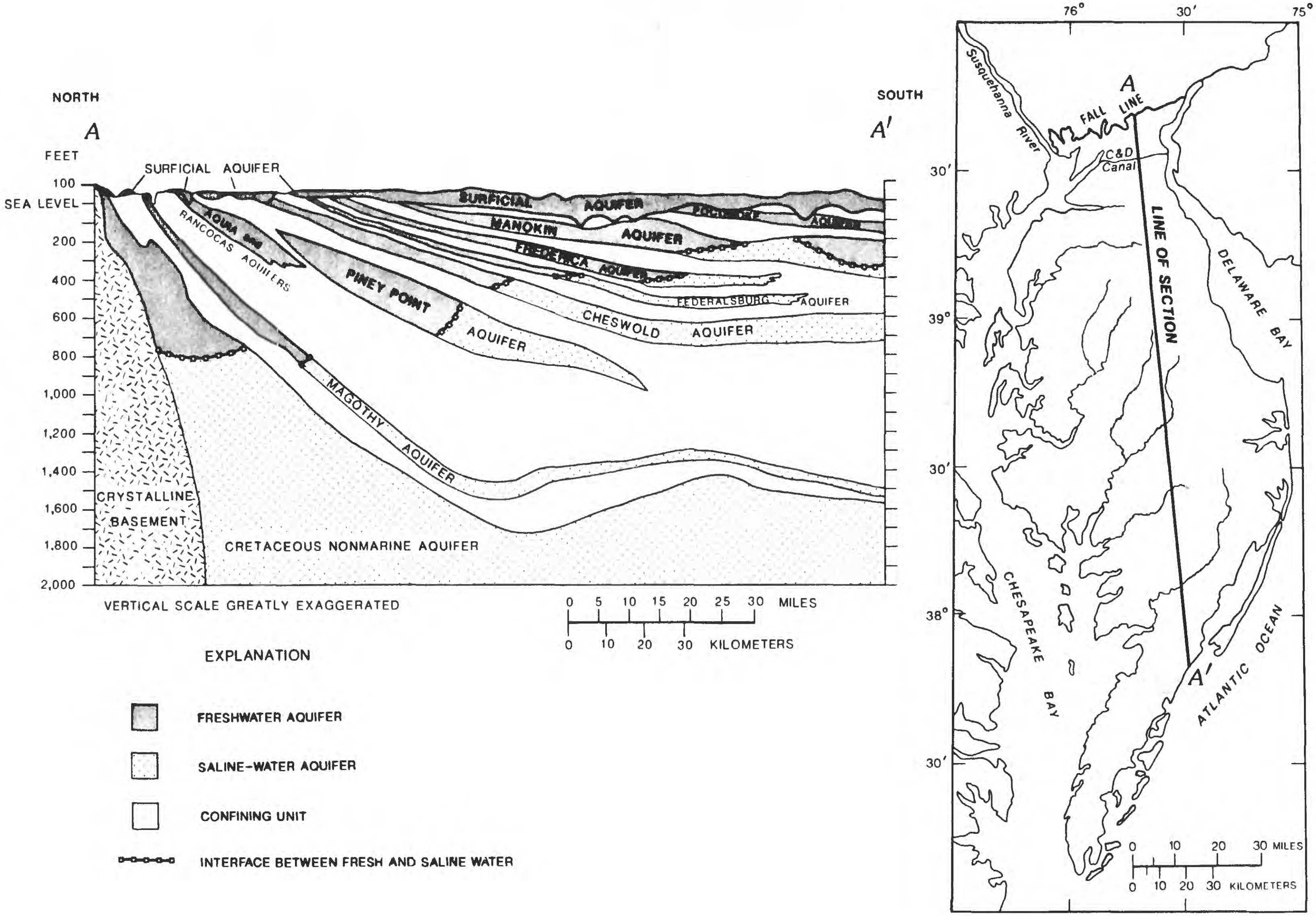


Figure 2. Hydrogeologic section across the Delmarva Peninsula.

Description of the Surficial Aquifer

The surficial aquifer is composed of several sandy deposits covering about 90 percent of the study area. This aquifer has been called the Quaternary aquifer (Cushing and others, 1973), the Columbia aquifer (Bachman, 1984a), and the Pleistocene aquifer (Andres, 1986). The geology and hydrogeology of deposits that comprise the surficial aquifer have been described by several authors, including Rasmussen and Slaughter (1955), Jordan (1962; 1964), Hansen (1966), Denny and others (1979), Owens and Denny (1978; 1979a; 1979b), Owens and Minard (1979), Hansen (1981), Bachman (1984a), Owens and Denny (1984), and Mixon (1985). Most of the geologic and hydrogeologic interpretations in this report are made on the basis of geologic units described in Owens and Denny (1979b), Owens and Minard (1979), and Mixon (1985).

Sediments that comprise the surficial aquifer represent several time-stratigraphic units and were deposited in fluvial, estuarine, and marine and marginal -marine environments. The deposits are considered Pleistocene in age by all previous investigators except Owens and Denny (1979b), who considered the Pensauken Formation of Miocene age and the Beaverdam Sand and Walston Silt of Pliocene age. The study area also contains Holocene deposits of mud, silt, and sand in the tidal marshes and sand on the barrier islands.

The surficial aquifer in the interior of the peninsula in Delaware and Maryland is comprised mainly of the Pensauken Formation and the Beaverdam Sand. In Delaware, these two units are grouped together as the Columbia Group (Jordan, 1962). The Pensauken Formation underlies most of the northern part of the peninsula, from near the headwaters of Chesapeake Bay south to an irregular line that connects Milford, Del., and Cambridge, Md. (Owens and Denny, 1979b). The unit is a red gravelly sand of Miocene age that was deposited in an estuarine-fluvial environment. Most of the Pensauken sediment was transported from the Delaware River valley. Its mineral composition is a feldspathic quartz sand containing plagioclase (oligoclase) and orthoclase (microcline) feldspars, primarily derived from feldspathic rocks of the Piedmont physiographic province. The formation also contains reworked Coastal Plain sediments, mainly glauconitic sand from the underlying Aquia Formation. Sediments in the Pensauken Formation are more weathered than younger sediments to the south (Owens and Minard, 1979).

The Beaverdam Sand underlies much of Delaware and southern Maryland. This unit lies unconformably on the Pensauken Formation from its northern limit to an irregular line that connects Salisbury, Md., and Rehoboth Beach, Del. South of this irregular line, the Beaverdam Sand lies unconformably on the Calvert and Choptank Formations (Owens and Denny, 1979b). The Beaverdam Sand consists of light-colored, fine to coarse sand and thin gravel beds. The unit is of Late Pliocene age and is marginal marine in origin. Similar to the Pensauken Formation, the mineral composition is highly feldspathic and contains plagioclase and orthoclase feldspars. In some areas, the mineral composition is mature and contains reworked heavy minerals from the underlying Calvert and Choptank Formations (Owens and Denny, 1979b).

In southern Delaware and adjoining areas of Maryland, the Beaverdam Sand is overlain by silt and clay of the Walston Silt and Omar Formation (fig. 3). The Walston Silt underlies an area near Salisbury, Md., and consists of a deeply weathered barrier to back-barrier sequence of clay and silt of Late Pliocene age (Owens and Denny, 1979b). The Omar Formation is a barrier to back-barrier sequence deposited more recently early in the Pleistocene Epoch. The Omar Formation predominantly consists of dark-colored clay and silt interstratified with thin beds of light-colored sand and peaty beds. The Omar Formation consists of thick beds of light-colored sand interstratified with the dark clay and silt (Owens and Denny, 1979b; Mixon, 1985) in some parts of the peninsula.

The Omar Formation, Walston Silt, and Beaverdam Sand are overlain in areas by a light-colored sand called the Parsonsburg Sand (fig. 3). The Parsonsburg Sand is fluviatile-eolian in origin and probably consists of sandy beds of the Omar Formation or Walston Silt that were reworked during a high stand of the sea (Owens and Denny, 1979b).

The surficial aquifer in the interior of the Virginia part of the peninsula is comprised of the Omar and Nassawadox Formations and the Joynes Neck Sand of Pleistocene age (Mixon, 1985). The Omar Formation in Virginia primarily consists of medium to coarse grained sand and gravel interbedded with some silt, clay, and peat. The unit represents a different marginal-marine depositional environment from the Omar Formation to the north; the Omar Formation in Virginia primarily was deposited in high-en-

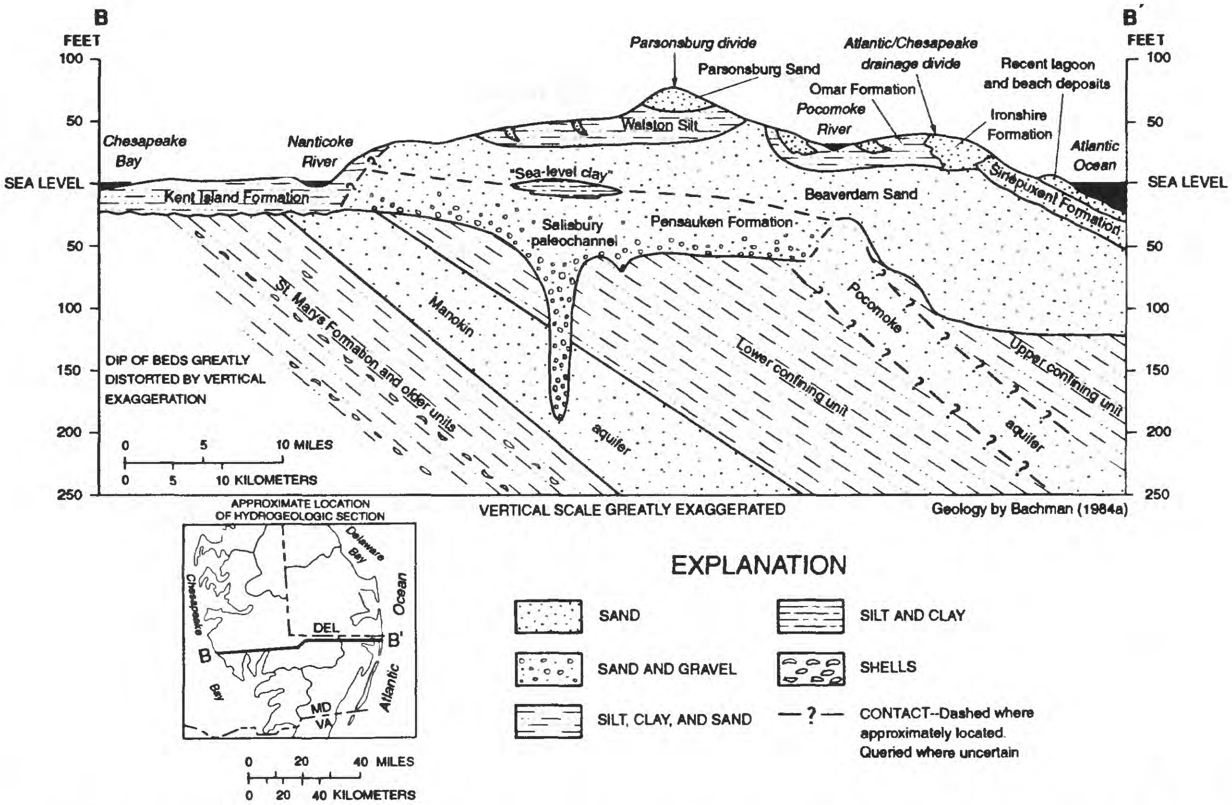


Figure 3. Schematic hydrogeologic section from Chesapeake Bay through Salisbury, Md., to Ocean City, Md.

ergy barrier and nearshore-shelf environments, rather than in lagoonal and estuarine environments. In the northern part of Accomack County, Va., however, some of the Omar Formation was deposited in a transgressive barrier to back-barrier environment and consists of peaty marsh deposits, dark lagoonal mud and sand, and barrier sand (Mixon, 1985). The Nassawadox Formation and Joynes Neck Sand consist of sandy and gravelly deposits of marginal-marine origin, deposited more recently in the Pleistocene than the Omar Formation.

Surficial deposits along the Atlantic coast in Delaware and Maryland include the Ironshire and Sinepuxent Formations of Pleistocene age (Owens and Denny, 1979b) (fig. 3). The Ironshire Formation is a gravelly sand of barrier-beach origin, and the Sinepuxent Formation is a silty sand of shallow marine origin. Most of the sediments along the Atlantic Ocean in Virginia are part of a coastal barrier-lagoon complex and estuarine marshes deposited in Holocene time (Mixon, 1985). These sediments consist of fine to coarse quartz and shell sand, muddy fine sand, and peat. Marginal-marine deposits of the Wachapreague Formation of Pleistocene age border the eastern side of uplands in Virginia (Mixon, 1985). These deposits consist of fine to coarse gravelly sand and some clay and silt. The margins along most of the western side of the peninsula are underlain by the Kent Island Formation of Pleistocene age. The Kent Island Formation is an estuarine deposit that consists of clay, silt, and sand. This formation mostly is clay and silt along Chesapeake Bay in Maryland and becomes progressively sandier to the south in Virginia (Owens and Denny, 1979b).

Occurrence and Flow of Ground Water in the Surficial Aquifer

The saturated thickness of the surficial aquifer is variable across the study area because of variations in the thickness of sand deposits and the presence of impermeable materials and underlying 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 it exceeds 100 ft in several of the major paleochannels (Bachman, 1984a; Mixon, 1985). Where the surficial aquifer directly overlies subcrop sands of the confined aquifers, the effective saturated thickness is enhanced because the aquifers function as one hydrologic unit.

The surficial aquifer is under water-table conditions throughout most of the study area. The water table is shallow (generally between 0 to about 10 ft below land surface) in the central uplands of the peninsula where streams are not incised deeply into the sediments. The water table is deeper in the well-drained uplands (as deep as 40 ft below land surface) than in the central uplands because tidal streams and tributaries incise deeply into surficial deposits. Water-table conditions are variable in the central part of the peninsula because of heterogeneous geology. The water table in this area generally is 0 to 10 ft below land surface. The water table usually is in the Parsonsburg Sand, which has a poor hydrologic connection with the underlying Beaverdam Sand because of less permeable intervening clay and silt deposits of the Walston Silt and Omar Formation. In areas where the Omar Formation is sandy or where the Walston Silt is absent, the Parsonsburg Sand and Beaverdam Sand commonly function as one hydrologic unit.

Flow in the surficial aquifer primarily is from water-table highs in the interfluvial areas toward streams and the coast. Ground-water discharges to streams, freshwater ponds and wetlands, tidal marshes, bays, and the Atlantic Ocean. Ground-water-flow paths generally are shorter than a few miles in length. In wetlands and in areas with a high density of streams or drainage ditches, ground-water-flow paths commonly are shorter than a few hundred feet.

Hydrogeomorphic Regions

Hydrogeomorphic regions are geographic areas of related hydrogeologic and areal characteristics--including surficial geology, topography, geomorphology, soil type, and land use--that can impart characteristic ground-water-flow and water-quality patterns (fig. 4). Six hydrogeomorphic regions of the Delmarva Peninsula have been delineated. Delineations were interpreted from county maps of soils and geology, USGS topographic maps, and 1:250,000-scale land-use and land-cover data.

The first region, referred to as "poorly drained uplands," includes the uplands in the central part of the peninsula. The uplands are poorly drained in the sense that they generally contain sluggish streams flowing through low-gradient and poorly incised valleys. Topography is hummocky and undulating. The soils and sediments in the poorly drained uplands are permeable but are poorly drained because the water table is shallow (about 0 to 10 ft below land surface, and generally less than 5 ft in seasonally wet periods). Ground-water-flow paths are short, ranging from hundreds of feet to generally less than 1 mi.

The second, and largest, region referred to as "well-drained uplands," includes uplands that flank the poorly drained uplands. This region consists of permeable soils and sediments that are more deeply incised by stream valleys than in the poorly drained uplands. Water-table gradients are relatively steep in this region because of deeply incised streams. The water table is deeper (about 10 ft below land surface) and ground-water-flow paths are longer in the well-drained uplands (generally greater than 1 mi) than in the poorly drained uplands.

The third region, referred to as the "surficial confined region," commonly is underlain by silt and clay of the Walston Silt and Omar Formation in southern Delaware and adjoining parts of Maryland. These minimally permeable deposits result in two distinct parts of the surficial aquifer; a shallow (less than 25 ft below land surface) and unconfined water-bearing part in the Parsonsburg Sand, and a deeper (greater than 25 ft below land surface) and semiconfined water-bearing part in the Beaverdam Sand. Sediments are poorly drained because of poorly incised streams and flat water-table gradients.

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 part of the Kent Island Formation on the western side. The region includes poorly drained lowlands adjacent to tidal marshes and lagoons. Soils are poorly drained because of a shallow water table (generally 0 to 10 ft below land surface), flat water-table gradients, and minimal stream incisement.

The fifth region, referred to as "fine-grained lowlands," is underlain by the remainder of the Kent Island Formation and includes the broad, low-lying area that fringes Chesapeake Bay, about 5 to 10 ft above sea level. The fine-grained lowlands are characterized

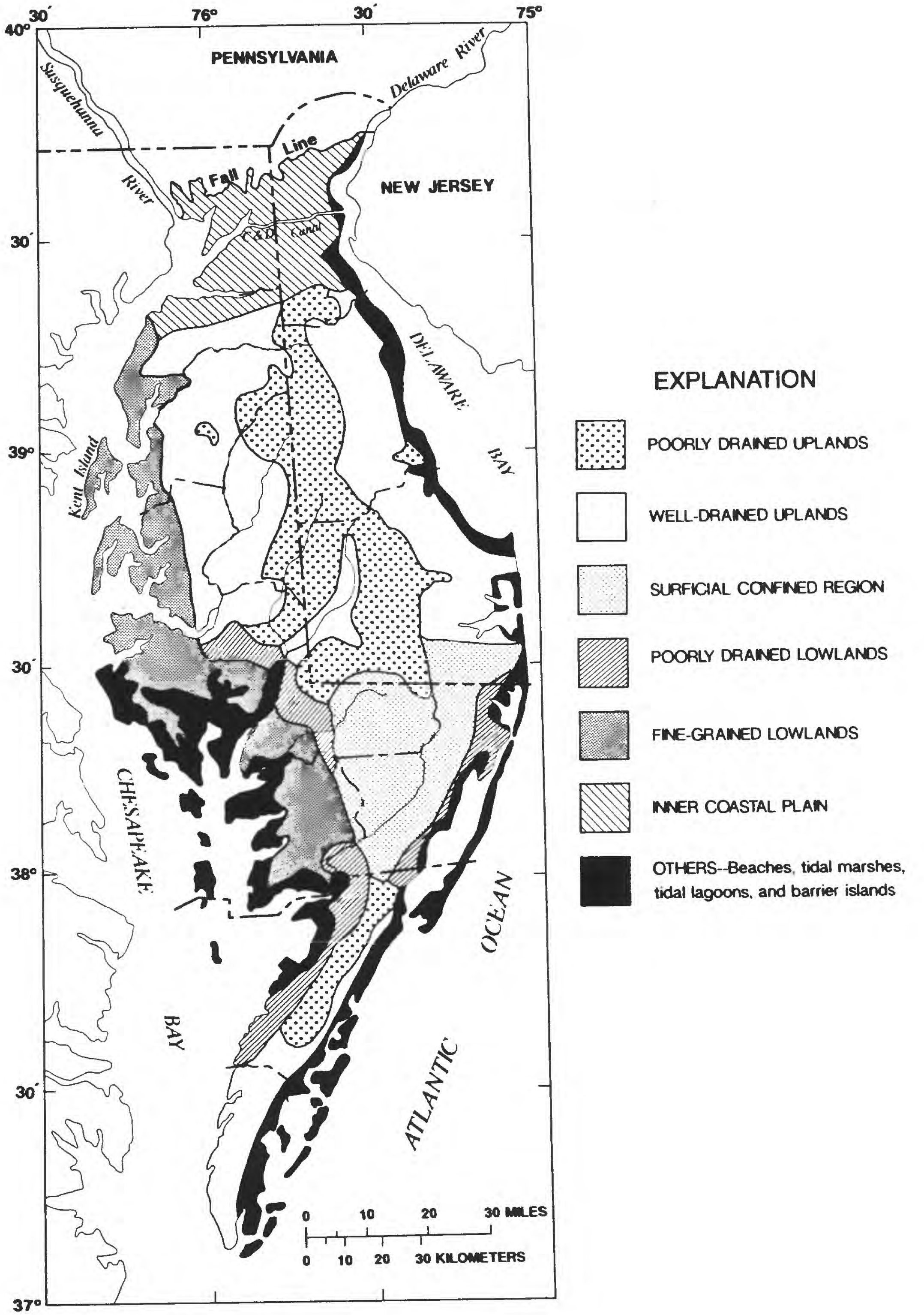


Figure 4. Hydrogeomorphic regions in the surficial aquifer in the Delmarva Peninsula.

by a shallow water table (generally 0 to 10 ft below land surface) and poorly drained sediments of low permeability.

The sixth region, referred to as the "inner coastal plain," lies in the northern part of the peninsula. The surficial aquifer generally is thin or absent in this region, and underlying aquifers subcrop beneath the surface. Soils generally are well-drained and permeable. This region contains the most intensely urbanized area of the peninsula, and it is heterogeneous in physiography, land use, and hydrology compared to other regions.

Beaches, tidal marshes, tidal lagoons, and barrier islands are included as "other areas" (fig. 4). Ground-water resources in these areas were not evaluated as part of the NAWQA study.

Land Use

Agriculture is the most prevalent land use (about 48 percent) in the study area. Most of the agricultural land is in soybean-corn rotation, and crops are sold for feed. In addition to grain crops, farmers in the study area produce fruits, vegetables, and nursery stock for local and regional markets. The peninsula also is one of the Nation's leading producers of broiler chickens. In Delaware, for example, about 140 million chickens are raised annually (Madison and Brunett, 1984).

Woodlands constitute about 31 percent of the land area and commonly are interspersed with agricultural areas. The degree to which agricultural lands and woodlands are interspersed differs among hydrogeomorphic regions. The well-drained uplands typically are dominated by large agricultural plots. Woodlands primarily are confined to stream borders. The well-drained uplands contain the lowest ratio of woodlands to agricultural land (about 0.4; table 1). The poorly drained uplands are dominated by small agricultural plots and contain a higher ratio of woodlands to agricultural land than the well-drained uplands (about 0.8; table 1). The ratio of woodlands to agricultural land is highest in the surficial confined region (greater than 1.2; table 1).

The remaining land areas are wetlands (about 13 percent), urban and residential areas (about 7 percent), and barren land (about 1 percent). Most of the areas that border the bays and ocean are fringed with wetlands and tidal marsh. The northern part of New Castle County, Del., contains the most extensive urban and industrial development on the peninsula. Industry also is in larger towns throughout the peninsula. Food processing and miscellaneous small industries are in less populated cities and towns. Barren land includes the barrier beaches along the Atlantic coastline.

METHODS OF STUDY

Regional and local assessment of ground water in the Delmarva Peninsula included analysis of water samples collected by the USGS during 1976-91. The samples were analyzed for concentrations of nitrate and other dissolved constituents that can affect water quality. Areas around the wells differ in land use and landscape, as well as in soil and geologic characteristics. This site diversity ensures that the NAWQA analysis includes a peninsulawide characterization of ground-water quality and problems, and a detailed assessment of cause-and-effect relations between water quality and ground-water flow, land use, soils, and geology.

Ground-Water Sampling Networks

Water-quality data discussed in this report represent two sampling networks. The first network, referred to as the "existing well network," includes ground-water samples collected by the USGS before the Delmarva NAWQA project started in 1987. The second network, referred to as the "Delmarva NAWQA well network," includes ground-water samples collected during the Delmarva NAWQA project during June 1988-March 1991.

Existing Well Network

Water-quality data for 976 wells, distributed areally and with depth throughout the peninsula, were collected during previous USGS studies during 1944-87. Common limitations with the data include (1) lack of information on quality control; (2) inconsistent sampling, preservation, and analytical techniques; and (3) lack of information on sampling locations and well construction (Hamilton and others, 1991). Quality-assurance guidelines and protocols have not been followed consistently through time, and therefore, it is not possible to estimate variability in selected water-quality constituents because of differences in field or laboratory handling. Preservation procedures used by

Table 1.--Land use and soils in hydrogeomorphic regions and counties in the Delmarva Peninsula.[1]

[n/a, information not available]

Hydrogeomorphic region	Ratio of woodlands to agricultural lands
Surficial confined region	1.230
Poorly drained lowlands	1.115
Fine-grained lowlands	0.822
Poorly drained uplands	.753
Inner coastal plain	.441
Well-drained uplands	.379

County and state	Ratio of woodlands to agricultural lands	Ratio of hydrologic soils Group D to Groups A plus B[2]
Somerset, Md.	1.424	5.95
Worcester, Md.	1.382	1.93
Wicomico, Md.	1.118	1.75
Dorcester, Md.	0.928	2.00
Accomack, Va.	.898	n/a
Sussex, Del.	.769	0.54
Cecil, Md.	.590	.23
Caroline, Md.	.518	.52
Northampton, Va.	.463	n/a
Kent, Del.	.409	.89
New Castle, Del.	.366	.53
Talbot, Md.	.347	1.14
Queen Annes, Md.	.306	.77
Kent, Md.	.240	.27

---

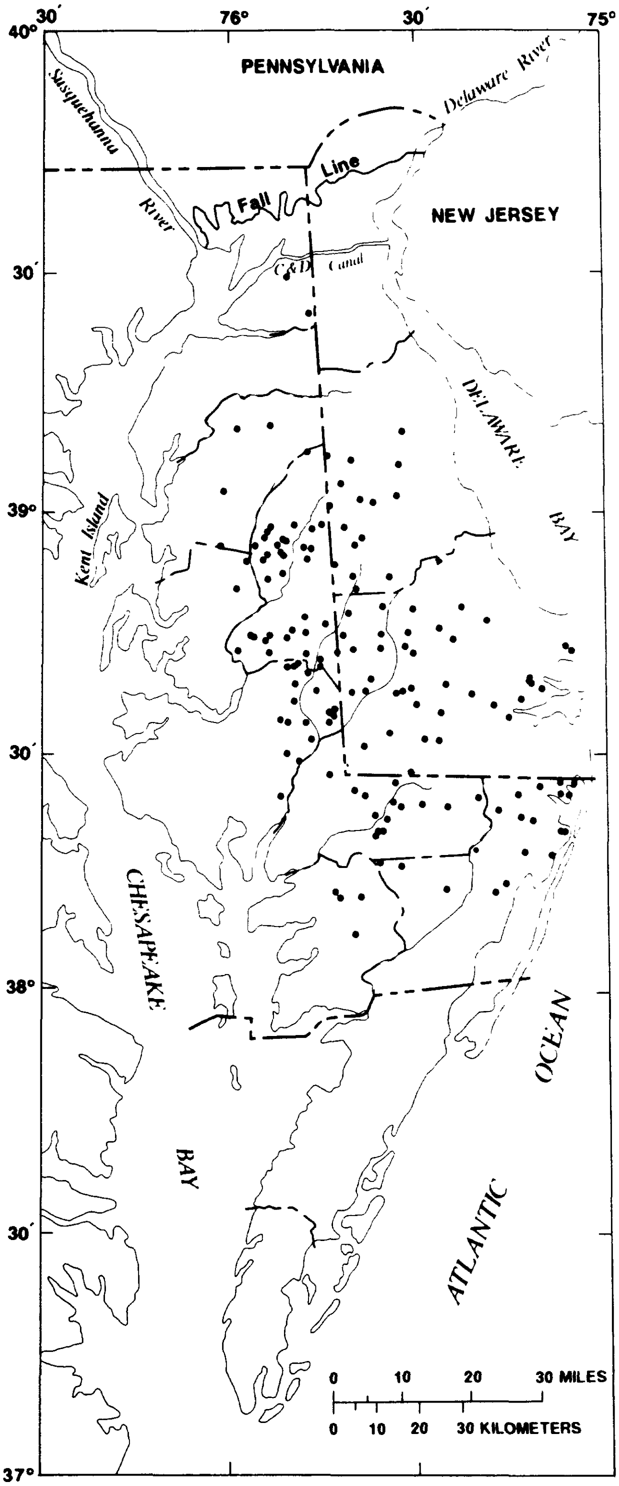
[1] Information on soils is not available by hydrogeomorphic regions; information is available only by county. In general, counties of Dorcester, Somerset, Wicomico, and Worcester, Md. are in the surficial confined region and lowlands of the peninsula; the remaining counties of the peninsula primarily are in the uplands and the inner coastal plain.

[2] Hydrologic soil groups are differentiated by runoff potential. Soils in Group A have the lowest runoff potential and Group D soils have the highest runoff potential when thoroughly wetted (Maryland Department of State Planning, 1973).

USGS laboratories have changed with time. For example, preservation of nitrate in water samples collected before the mid-1970's was done by chilling the sample to 4^0 C (degrees celsius) at the time of sample collection; the more recent standard procedure calls for chilling and adding the preservative mercuric chloride, which improves the stability of nitrate. Therefore, early nitrate data may be characterized by misleadingly low reported concentrations. Laboratory reporting limits also have been lowered with time because of improvements in technology.

Five criteria were used in this investigation to reduce data limitations. The criteria minimize differences in sample collection, sample preservation, and quality control. The criteria are as follows: (1) water samples must be from wells screened in the surficial aquifer for which information on location, depth, and construction is available; (2) water samples must be from after the mid-1970's; (3) water samples must include analyses for all major cations (Ca^{+2}, Mg^{+2}, Na^+, K^+, and Fe^{+2}) and anions (HCO_3-, SO_4-2, Cl^-, and NO_3-); (4) the difference in the charge balance of the major ions must be less than 10 percent; and (5) the data must be computerized and readily accessible. Only one water sample (generally the most recent) collected from each well was used in this investigation in order to avoid bias toward wells with multiple analyses. In most cases, the highest reporting limit was used, and all concentrations less than this limit were considered less than the reporting limit. For a few constituents, however, one or two analyses with unusually high reporting limits were eliminated, and a consistently lower and more common reporting limit was used.

Water samples collected at 193 of the 976 wells met the criteria. Locations of the 193 wells in the surficial aquifer are shown in figure 5. These wells are distributed throughout the peninsula except in the northern part and the southern tip. Location and depth of the wells were not field checked because of time constraints, the large amount of data, and the lack of information on specific sampling locations.



EXPLANATION

- WELL SAMPLED DURING 1976-87--More than one well is present at some locations

Figure 5. Locations of wells in the surficial aquifer in the Delmarva Peninsula sampled by the U.S. Geological Survey during 1976-87.

Delmarva National Water-Quality Assessment Well Network

The Delmarva NAWQA well network is designed to assess ground-water quality relative to differences in study-area features, such as soil type, land use, hydrogeomorphic region, geology, and ground-water flow. Study-area features are regionally and locally variable on the peninsula and, therefore, sampling networks were designed to evaluate regional and local ground-water quality. The term "regional scale" describes networks that characterize ground-water quality throughout the peninsula, an area about 6,000 mi^2. Regional-scale networks provide a broad geographic description of water-quality characteristics and identify the regional extent of ground-water problems, contamination, and degradation. The term "local scale" describes networks that characterize ground-water quality within areas that range from less than 1 to 7 mi^2. Local-scale studies identify cause-and-effect relations between ground-water quality and natural and human factors. The sampling networks at different scales are linked; water-quality variations described at the local scale are critical in explaining observed variability at the regional scale. The regional- and local-scale well networks are described below.

The regional-scale networks consist of two sets of wells. The first includes wells in a peninsulawide network, referred to as the "areal network" (fig. 6). The second includes wells along five lines of section that trend roughly west to east from Chesapeake Bay to the Atlantic Ocean, referred to as the "transect network" (fig. 6).

The areal-network wells are distributed among 35 sites throughout the peninsula and are unbiased with respect to known or suspected areas of contamination. Sites were selected with minimal bias by subdividing the study area into 12.5- by 12.5-minute grid cells. Cell boundaries were adjusted to obtain 32 polygons of approximately equal area. A site within each polygon was selected randomly, and state and county records were used to identify existing homeowner wells suitable for sampling near each site. Supplemental sites were selected in three polygons to increase the geographic distribution of wells.

In most cases, the areal-network sites consist of an existing homeowner well and a shallower observation well within a 1/4 mi of each other. The existing well generally is screened 15 to 30 ft below the water table in that part of the surficial aquifer used for domestic (individual well) and public water supplies. The shallower well is screened within about 10 ft below the water table and is considered more vulnerable to contamination than the deeper well. At a few sites where the existing well was not suitable for sampling, shallow and deep wells both were installed during the NAWQA study. Wells were installed according to NAWQA protocol developed by Hardy and others (1988). Site and well-construction information for wells in the areal network that are completed in the surficial aquifer and sampled for chemical analysis is listed in table 2 (placed in the back of report). [1]

The transect network consists of 80 wells; 39 of the wells were sampled for chemical analysis (fig. 6). These wells were not selected randomly as in the areal network but were targeted to represent areas of differing hydrogeology and geomorphology. Locations of the transect wells primarily were selected to depict changes in the thickness and hydrogeologic characteristics of the surficial aquifer and to show regional profiles of the water table. Most of the transect sites consist of one observation well screened within about 10 ft of the water table. Where the surficial aquifer is thick, a second observation well was installed near the bottom. Site and well-construction information for wells in the transect network that are completed in the surficial aquifer and sampled for chemical analysis is listed in table 3 (placed in the back of report).

The local-scale networks include wells along general ground-water-flow paths in seven areas that encompass several square miles or less (fig. 6). The local-scale well networks are on the major west-east transects and provide data for the three largest of the six hydrogeomorphic regions (well-drained uplands, poorly drained uplands, and the surficial confined region). Six of the networks predominantly are in agricultural settings. The remaining network is in a forested wetland. Ten to twenty wells were installed at various depths within each local-scale network. Site and well-construction information for wells in five local-scale networks sampled for chemical analysis is listed in tables 4-8 (placed in the back of the report).[2]

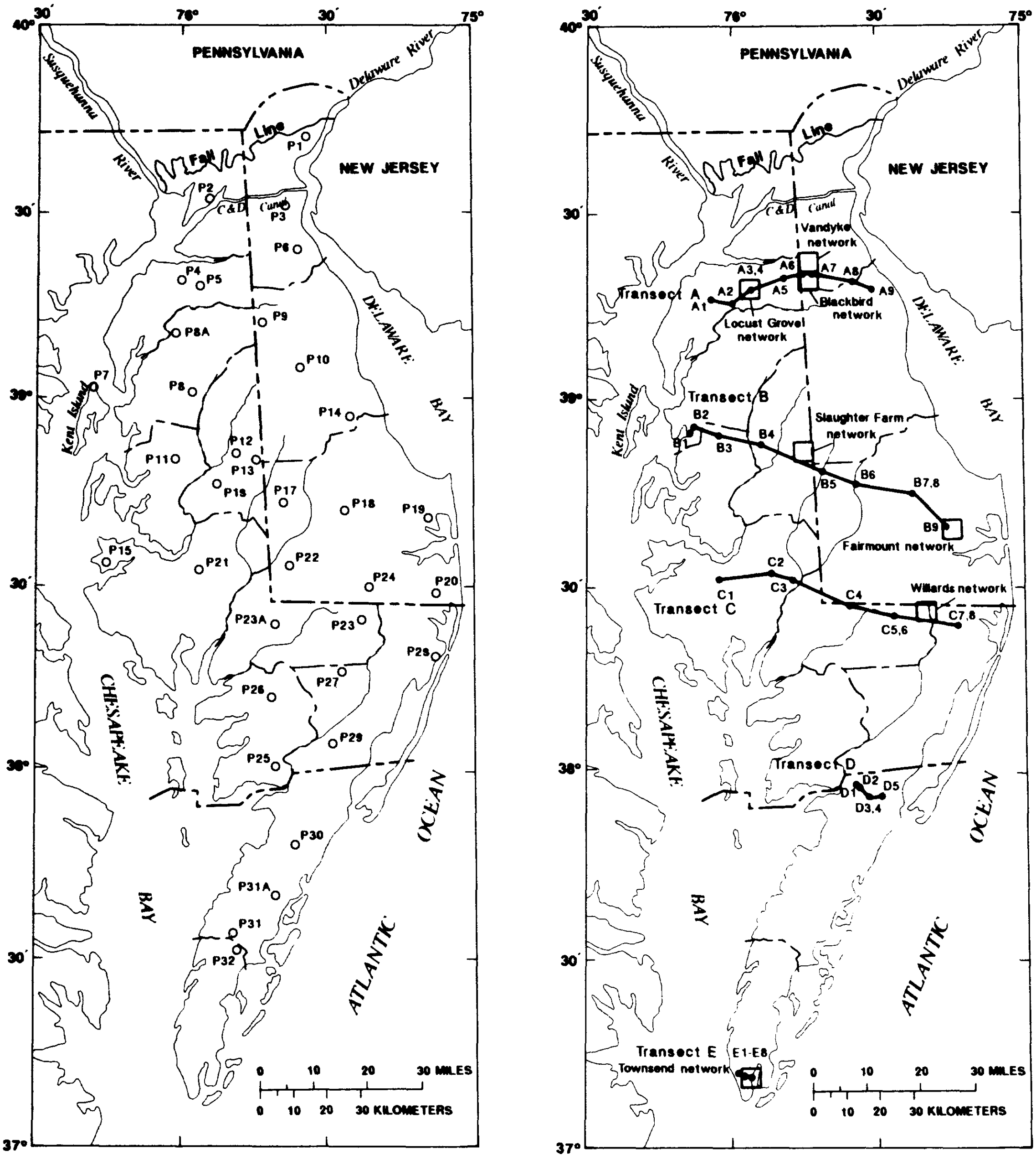
Sampling Strategy

Water samples were collected from 64 wells in the surficial aquifer in the areal network during summer 1988 (table 9; placed in the back of the report).

---

[1] Two existing wells are screened in the confined aquifers and are not included in this report.

[2] Blackbird and Slaughter Farm local-scale networks are not discussed in this report.



AREAL NETWORK

TRANSECT AND LOCAL-SCALE NETWORKS

EXPLANATION

□ GENERAL LOCATION OF WELLS IN LOCAL-SCALE NETWORK--Wells listed in tables 4 through 8 and 11 through 15

Transect B ●—●——● REGIONAL TRANSECT ACROSS THE DELMARVA PENINSULA

LOCATION OF WELLS IN REGIONAL-SCALE NETWORK SAMPLED FOR CHEMICAL ANALYSIS--More than one well is present at some locations

○ P31 Areal network-Number refers to well listed in tables 2 and 9

● B2 Transect network-Number refers to well listed in tables 3 and 10

Figure 6. Locations of wells in the areal, transect, and local-scale networks completed in the surficial aquifer in the Delmarva Peninsula.

Six of the areal-network wells were resampled during summer 1990 because of field and laboratory problems with the samples collected in 1988 (table 9). Only samples collected in summer 1990 were used in this analysis to minimize bias resulting from duplicate analyses. Water samples were collected from 39 wells in the transect network during summer 1989 (table 10; placed in the back of the report). Multiple water samples were collected from selected wells in the local-scale networks to evaluate seasonal variability in ground-water chemistry. These samples were collected before, during, and after (when possible) the growing season (tables 11-15; placed in the back of the report).

Wells were pumped to remove water that had been standing in the well casing and then sampled according to NAWQA protocols (Hardy and others, 1988). Samples were filtered through a filter with a pore size of 0.45 micrometers (represented by the term "dissolved" by the USGS). Analytical work not done in the field was done at or supervised by the USGS National Water-Quality Laboratory in Denver, Colo. Quality-assurance guidelines and protocols were followed (1) to provide accurate and representative water-quality data for each sampling network and (2) to estimate the variability in selected water-quality constituents (Jones, 1987; Hardy and others, 1988; and Koterba and others, 1990). All water-quality data are managed within the USGS National Water-Information System and a geographic information system.

Analyses of ground-water samples from the areal and transect networks include field measurements (specific conductance, pH, dissolved-oxygen concentration, and alkalinity) and laboratory determinations of concentrations of major ions, nutrients, trace metals, radiochemicals, stable isotopes, and organic compounds. Analyses of ground-water samples from local-scale well networks include field measurements and laboratory determinations of major-ion, nutrient, and trace-metal concentrations. Selection of organic constituents for analysis was customized for each local-scale well network on the basis of known or suspected pesticide use. Values for selected field measurements and concentrations of major ions, nutrients, and trace metals in water samples collected from wells in the areal, transect, and local-scale networks are listed in tables 9-15.

Additional sampling of selected wells from the regional- and local-scale networks was completed in fall and summer 1990 to assess relative ages of the ground water. Chlorofluorocarbon (CFC) dating methods (L.N. Plummer, U.S. Geological Survey, written commun., 1992) were used to estimate relative age.

Ancillary Data

Comparisons of ground-water quality are described in this report on the basis of land use, soil characteristics, aquifer composition, and hydrogeomorphic region (tables 2-8) to explain variations in selected constituents in water from the surficial aquifer. Ancillary data for individual sites (except for geologic descriptions) are alphanumerically coded and are managed and manipulated within a geographic information system and statistics package.

Land-use categories are identified at several scales because relations between water quality and land use depend on the resolution of the land-use data (Hamilton and Shedlock, 1989; Hamilton and Denver, 1990). Land-use categories at a coarse resolution were identified from land-use and land-cover data (U.S. Geological Survey, 1979a; 1979b; 1979c; 1980a; 1980b; 1980c), compiled and digitized at a scale of 1:250,000 by the National Mapping Division of the USGS (Fegeas and others, 1983). Land use at this scale was identified for areas around wells in the existing and NAWQA well networks. Minimum delineated size of agricultural and woodland areas is 40 acres; minimum delineated size of urban and residential areas is about 10 acres. Land-use categories at a finer resolution were identified for wells in the NAWQA networks from 1:24,000 topographic maps and verified field visits. Records of the predominant land use around (within 100-ft and 1/4-mi radii) and upgradient from each well are maintained.

Soil type and texture were identified from U.S. Soil Conservation Service county soil surveys. Each soil type is associated with a natural soil group, which integrates several factors that affect land-use planning (Maryland State Department of Planning, 1973), such as erodeability, runoff potential, pH, permeability, water capacity, shrink-swell potential, and depth to water table. Predominant soil type, soil texture, and natural soil group characteristics around (within 100-ft and 1/4-mi radii) and upgradient from the wells were identified for wells in the NAWQA networks.

A brief description of the lithology and approximate thickness of geologic formations at each site in the NAWQA well networks and at selected sites in the existing network is maintained in well files. Interpretations are made from lithologic and gamma logs, geology maps (Owens and Denny, 1978; 1979a; and 1984; Mixon, 1985), and a map showing lithology of drill holes on the Delmarva Peninsula (Hess, 1977).

Data Analysis

Nonparametric statistical techniques were used in the analysis of data. Nonparametric statistics involve robust techniques that generally are not sensitive to outlying or inaccurate values or to assumptions of equal variance and normality. Hypothesis tests are used to examine whether variations in data resulted from chance variability or real differences. The hypothesis tests involve a null hypothesis stating 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, a nonparametric t-test procedure involving rank-transformed data (Iman and Conover, 1983). The Mann-Whitney test is used to compare two categories of data and the Kruskal-Wallis test is used to compare more than two categories. The LOWESS (locally weighted scatterplot smoothing) line, computed from robust weighted least squares (Helsel and Hirsch, 1992), is used to assess increasing or decreasing trends in data. The Spearman test is used for nonparametric regression analysis of rank-transformed data to test for increasing or decreasing trends.

The alpha value, or level of significance, used in hypothesis and regression analyses 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 less than or equal to the alpha value, the null hypothesis is rejected. The term "significant" in this report is used strictly to describe statistical differences relative to the alpha value.

Box plots are used to graphically summarize variability in constituent concentrations. Laboratory reporting limits, where appropriate, are shown on the box plots. Maximum contaminant levels (MCL's), secondary maximum contaminant levels (SMCL's), and number of water samples in which selected constituents exceeded the levels also are shown on the box plots. MCL's have been established by the U.S. Environmental Protection Agency (USEPA) for some constituents to protect human health, and SMCL's have been set for other constituents to provide acceptable aesthetic and taste characteristics (U.S. Environmental Protection Agency, 1986a; 1986b; 1986c).

In this report, nitrate concentrations are expressed in terms of the equivalent elemental nitrogen (N) content. Nitrate concentration expressed as nitrate ion can be converted to its equivalent elemental nitrogen concentration by dividing the concentration by 4.43. For example, 44 mg/L (milligrams per liter) as nitrate (NO_3) is equivalent to about 10 mg/L as N.

NATURAL WATER CHEMISTRY IN THE SURFICIAL AQUIFER

Natural water in the surficial aquifer generally is acidic and soft, and is low in alkalinity, sodium content, and specific conductance. Natural ground-water chemistry is controlled primarily by the chemical properties of rainfall and snowmelt, mineral dissolution, biological activity and residence time in the soil zone and aquifer, and the nearby presence of saline water. The surficial aquifer primarily consists of a relatively insoluble quartz sand containing minor amounts of silicate minerals and interbedded silt and clay lenses (Denver, 1989). The major silicate minerals in the sediments that are involved in chemical reactions are the feldspars plagioclase (sodium calcium aluminum silicate) and orthoclase (potassium aluminum silicate) (table 16). Shell material, deposited in marine environments, also is involved in chemical reactions (table 16).

Weathering begins when minerals are in contact with recharge water, which enters the surficial aquifer as precipitation. Annual precipitation on the Delmarva Peninsula is about 44 in., of which about 14 in. recharges the surficial aquifer (Johnston, 1973). The chemical composition of precipitation collected at Lewes, Del., during 1978-83, and in Queenstown, Md., during 1983-87, is presented in table 17. The major components of precipitation are sulfate, chloride, sodium, and nitrogen (nitrate and ammonia). Precipitation is saturated with dissolved oxygen and carbon dioxide, and it has a low pH (between 4 and 5) and a low content of dissolved solids (about 5 to 7 mg/L)

Table 16.--Chemical reactions that commonly occur in the surficial aquifer (modified from Denver, 1989)

Incongruent dissolution reactions:

$4\ Na_{0.5}Ca_{0.5}Al_{1.5}Si_{2.5}O_8 + 6H_2CO_3 + 11H_2O$

(plagioclase feldspar)

$\rightleftharpoons\ 2Na^+ + 2Ca^{2+} + 4H_4SiO_4 + 6HCO_3^- + 3Al_2Si_2O_5(OH)_4$

(kaolinite)

$KAlSi_3O_8 + H_2CO_3 + 9/2H_2O$

(orthoclase feldspar)

$\rightleftharpoons\ K^+ + HCO_3^- + 2H_4SiO_4 + 1/2Al_2Si_2O_5(OH)_4$

(kaolinite)

Dissolution of shells:

$CaCO_3 + H^+ \rightleftharpoons Ca^{2+} + HCO_3^-$

$CaCO_3 + H_2CO_3 \rightleftharpoons Ca^{2+} + 2HCO_3^-$

Redox reactions:[1]

Nitrification: $O_2 + 1/2NH_4^+ \longrightarrow 1/2NO_3^- + H^+ + 1/2H_2O$

Iron reduction: $Fe(OH)_{3(s)} + 1\ 3/4H^+ + 1/4CH_2O \longrightarrow Fe^{2+} + 2\ 1/2H_2O + 1/4HCO_3^-$

Sulfate reduction: $1/2SO_4^{2-} + CH_2O \longrightarrow 1/2H_2S_{(g)} + HCO_3^-$

Bicarbonate depletion:

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

(H^+ from nitrification)

---

[1] Reactions listed here are mediated by bacteria.

Table 17. Average composition of precipitation at stations in Lewes, Delaware, 1978-83, and in Queenstown, Maryland, 1983-1987.

[Delaware data provided by the MAP3S Precipitation Chemistry Network; Maryland data provided by the University of Maryland Agricultural Experiment Station, Wye Research and Education Center, Queenstown, Md.; mg/L, milligrams per liter; mmol/L, millimole per liter. From Denver, 1986, p. 20]

	Concentration			
	Lewes, Del.		Queenstown, Md.	
Constituent	mg/L	mmol/L	mg/L	mmol/L
Hydrogen, H^+	0.05	0.046	0.04	0.040
Sodium, Na^+	1.2	.053	.30	.013
Ammonium, NH_4^+	.23	.013	.24	.014
Potassium, K^+	.09	.002	.03	.001
Calcium, Ca^{+2}	.13	.003	.10	.002
Magnesium, Mg^{+2}	.13	.005	.05	.002
Chloride, Cl^-	1.9	.054	.58	.016
Sulfate, SO_4^{-2}	2.1	.022	2.4	.026
Nitrate, NO_3^- as N	.27	.020	.33	.024

(Denver, 1986). The precipitation enters the soil, and subsequent evapotranspiration increases the 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 dissolved-solids content.

A weak carbonic acid solution is produced as precipitation infiltrates through the soil and reacts with silicate minerals to release silica and other ions (table 16). Dissolution of calcite in shell material releases additional calcium and bicarbonate ions (table 16).

In addition to incongruent dissolution of silicate minerals and dissolution of shells, chemical reactions include oxidation, reduction, and cation exchange. Concentrations of iron, nitrogen, sulfur, and bicarbonate are affected by oxidation and reduction (table 16). Dissolved oxygen in infiltrating precipitation is consumed, in part, by oxidation of organic matter in the soil zone. Dissolved oxygen that is not consumed in the soil zone gradually is depleted in ground water by oxidation of reduced species, such as ferrous iron, ammonium, and sulfide (table 16; Denver, 1989). Because these species are not abundant in the surficial aquifer, dissolved oxygen commonly is present in ground water throughout the extent of the aquifer. Cation-exchange reactions generally modify concentrations of calcium, magnesium, and sodium. Calcium and magnesium generally are removed from solution by cation-exchange processes and are replaced by sodium.

Definition of Natural Ground Water

Natural ground water is defined in this report as ground water that is affected minimally by human activities that elevate concentrations of nitrate and other inorganic constituents. Sources of nitrate and other inorganic constituents include agricultural and lawn fertilizers, animal wastes, and septic-tank effluent. Effects of acid precipitation, road salting, and saltwater intrusion on ground-water quality are not assessed.

Results of a study by Madison and Brunett (1984) indicate that nitrate concentrations in natural ground water are low (less than 0.2 mg/L as N) and that a threshold nitrate concentration indicative of human activities is 0.2 to 3.0 mg/L as N. A threshold concentration of 0.4 mg/L as N is used in this report to separate water samples representing natural ground water from ground water affected by human activities. This threshold was estimated from a probability distribution (Gnanadesikan, 1977; Kleiner and Graedel, 1980) of existing and NAWQA (areal and transect networks) data collected at 296 wells (fig. 7). The threshold value of 0.4 mg/L as N was interpreted qualitatively as the steepest part of the probability plot, which marks the separation of two populations of data. A total of 77 water samples with concentrations of nitrate less than 0.4 mg/L as N were considered to be unaffected by human activity; a total of 219 water samples with nitrate concentrations equal to or greater than 0.4 mg/L as N were considered to be affected by human activities.

One of the first tasks in the analysis of natural ground water was to assess whether ground water with nitrate concentrations less than 0.4 mg/L as N was actually affected by human activities but contained low or no concentrations of nitrate because of a reducing (anaerobic) environment. A reducing environment could (1) inhibit oxidation of ammonium to nitrate or (2) enhance denitrification of nitrate to nitrogen gas. Measurements of dissolved oxygen concentration could not be relied on to distinguish water samples collected in reducing environments because data were lacking, inconsistent, or imprecise. Therefore, chloride concentrations were used for further examination of the samples representing natural water quality.

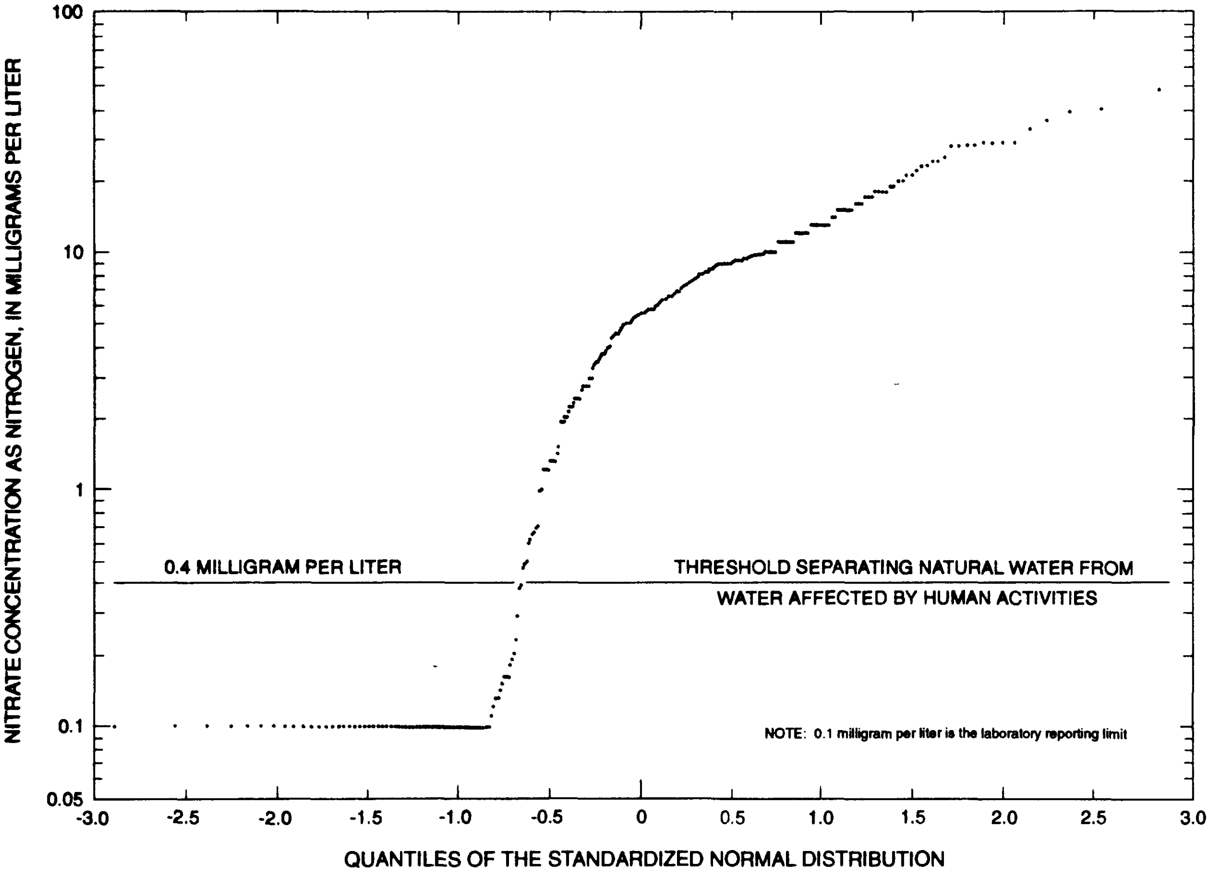


Figure 7. Probability distribution of nitrate concentrations in water collected from wells completed in the surficial aquifer in the Delmarva Peninsula, 1976-90.

Chloride, a common constituent in precipitation and in ground water affected by fertilizers and septic-tank effluent, is the only major constituent that neither reacts with other ions nor adsorbs onto mineral surfaces. Of the 77 water samples examined, 23 contained chloride concentrations near or less than what would be expected in concentrated (from evapotranspiration) precipitation (about 6 mg/L). The remaining 54 water samples contained chloride concentrations exceeding that of concentrated precipitation. Statistical analyses indicated no significant difference in concentrations and proportions of major cations and anions between the two groups. Water samples (total of 77) with nitrate concentrations less than 0.4 mg/L as N are, therefore, included in the regional analysis of natural ground water. Possible effects of reducing conditions on individual water samples are discussed in a subsequent section of the report.

A threshold value of 1.0 mg/L as N (instead of 0.4 mg/L as N) was used to assess the sensitivity of the results to the threshold value of 0.4 mg/L as N. The sensitivity assessment indicated that results generated with the higher threshold value are not significantly different. The analyses presented in this report are, therefore, not sensitive to changes within the 0.4 to 1 mg/L as N range.

Chemical Signatures of Natural Ground Water

Natural ground water is acidic. The median pH for the 77 water samples used in the regional analysis was 5.76 (fig. 8; table 18). Concentrations of dissolved constituents are low (median specific conductance of 115 µS/cm) because the surficial aquifer consists mostly of relatively insoluble quartz sand (fig. 8; table 18). In addition, the high permeability of the sediment increases ground-water-flow rates and reduces contact and reaction time between water and aquifer minerals. Specific conductance commonly is higher in areas where the surficial aquifer is anaerobic because of elevated concentrations of dissolved iron and bicarbonate from reduction of iron minerals (table 16). Specific conductance is high (7,700 µS/cm) in ground water near coastal areas where concentrations of chloride are elevated because of the presence of brackish water.

Statistical analyses of natural water for properties and major dissolved constituents are presented in figures 8-11. Maximum and minimum concentrations and 25th, 50th, and 75th quartiles are shown. The total number of samples and the number of samples that exceeded USEPA MCL's and SMCL's for drinking water also are indicated.

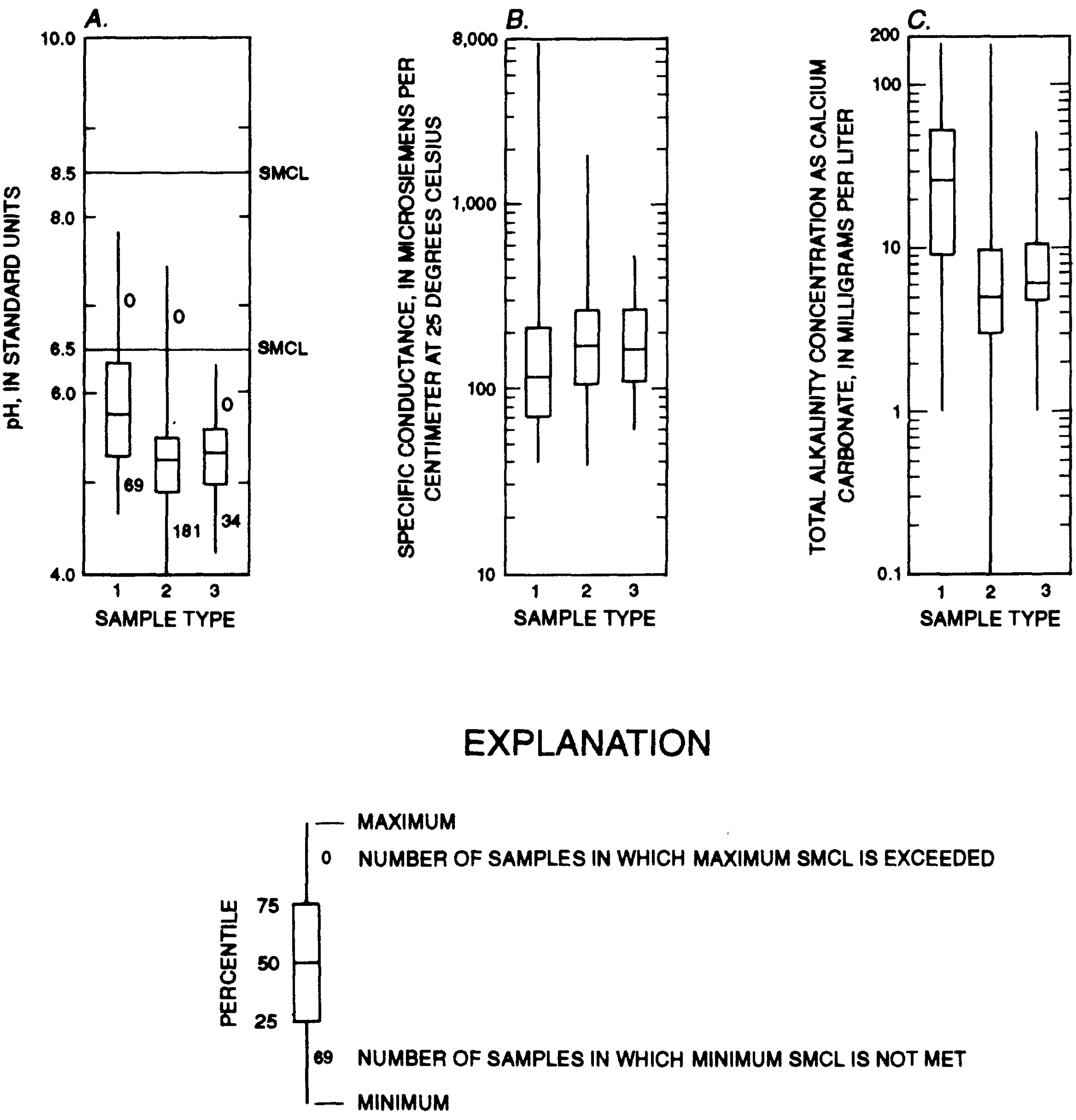
Sodium and bicarbonate generally are the dominant ions (fig. 12; table 18).[3] Concentrations of sodium generally are higher than concentrations of calcium and magnesium because divalent calcium and magnesium ions are retained preferentially on exchange sites over monovalent sodium (Denver, 1986). Concentrations of sodium and calcium usually are higher than potassium concentrations because plagioclase feldspar is more soluble than orthoclase feldspar (Denver, 1986).

Regional Variation in Chemical Signatures

Four general water types, defined on the basis of proportions of major ions, are present in the surficial aquifer in the Delmarva Peninsula because of different hydrogeology and ground-water-flow patterns within regions: calcium bicarbonate type in the northern, interior part of the peninsula; sodium bicarbonate type in the central interior part; sodium chloride type in coastal and tidal areas; and calcium sodium sulfate type in areas dominated by fine-grained sediment (fig. 13). The relation of milliequivalent concentrations of calcium, magnesium, and sodium plus potassium to milliequivalent concentrations of total cations, and milliequivalent concentrations of nitrate, sulfate, chloride, and bicarbonate to milliequivalent concentrations of total anions are shown on a quadrilinear diagram in figure 13. Water samples with milliequivalent concentrations of iron accounting for more than 10 percent of the total cation content are shown on the map but are not shown on the quadrilinear diagram. Water samples that contain elevated concentrations of iron are common in areas where fine-grained sediment is interspersed with organic material, such as in the Kent Island and Omar Formations. High concentrations of iron also are common in water samples collected from the deep part of the surficial aquifer (generally the Beaverdam Sand) where dissolved oxygen has been consumed.

---

[3] Bicarbonate is represented in this report by the total alkalinity because bicarbonate is the dominant carbonate species in most of the ground water in the Delmarva Peninsula.



SMCL	SECONDARY MAXIMUM CONTAMINANT LEVEL OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY--Maximum (8.5) and minimum (6.5) secondary maximum contaminant levels have been established for pH
	SAMPLE TYPE
1	Natural ground water (77 samples)
2	Ground water affected by agricultural activities (185 samples)
3	Ground water affected by residential activities (34 samples)

Figure 8. (A) pH, (B) specific conductance, and (C) concentrations of alkalinity in natural water and in water affected by agricultural and residential activities collected from wells completed in the surficial aquifer in the Delmarva Peninsula, 1976-90.

Table 18.--Statistical summary of the quality of natural water and water affected by agricultural activities in the surficial aquifer in the Delmarva Peninsula, 1976-90.[1]

[p-value represents Mann-Whitney statistical test[2]; number in parentheses is total number of analyses; <, less than]

Property or dissolved constituent	p-value	Median concentration, in milligrams per liter unless otherwise noted	
		Natural ground water	Water affected by agricultural activities
Properties:			
pH (standard units)	<0.001	5.76 (77)	5.25 (185)
Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	.004	115 (77)	170 (185)
Alkalinity (as calcium carbonate)	<.001	26 (77)	5.0 (185)
Dissolved constituents:			
Calcium	.001	4.8 (77)	9.0 (185)
Magnesium	<.001	1.7 (77)	5.0 (185)
Calcium plus magnesium	<.001	6.9 (77)	15 (185)
Sodium	.057	9.4 (77)	7.9 (185)
Potassium	<.001	1.1 (77)	2.6 (185)
Iron (micrograms per liter)	<.001	1,800 (77)	16 (185)
Silica	<.001	24 (77)	15 (185)
Barium (micrograms per liter)	<.001	37 (49)	120 (85)
Strontium (micrograms per liter)	<.001	57 (49)	140 (85)
Sulfate	.161	6.6 (77)	6.0 (185)
Chloride	<.001	9.1 (77)	14 (185)
Nitrate (as nitrogen)	<.001	0.1 (77)	8.2 (185)

---

[1] Analysis includes water samples collected from wells in the existing network and the NAWQA areal and transect networks. Samples affected by agriculture were determined by use of 1:250,000-scale land-use data (U.S. Geological Survey, 1979a, 1979b, 1979c, 1980a, 1980b, and 1980c).

[2] The Mann-Whitney test is a hypothesis test used to examine whether variations in data result from chance variability or real differences. The test involves a null hypothesis stating that no real difference exists between the categories. An alpha value, or level of significance, is used in the test to represent the maximum probability of rejecting the null hypothesis when it is actually true. The alpha value used in this report is 0.05. 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 between the categories.

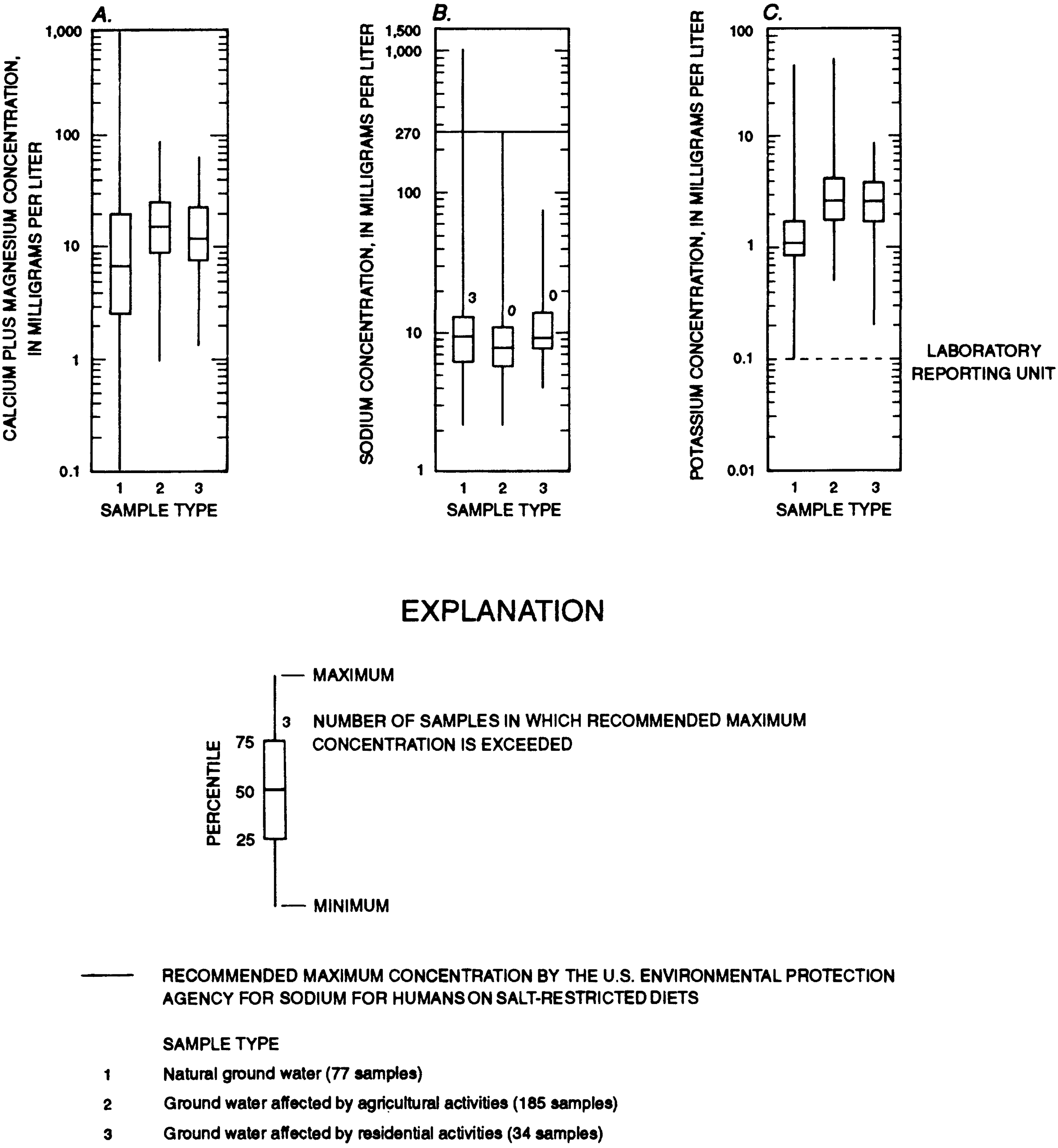


Figure 9. Concentrations of (A) calcium plus magnesium, (B) sodium, and (C) potassium in natural water and in water affected by agricultural and residential activities collected from wells completed in the surficial aquifer in the Delmarva Peninsula, 1976-90.

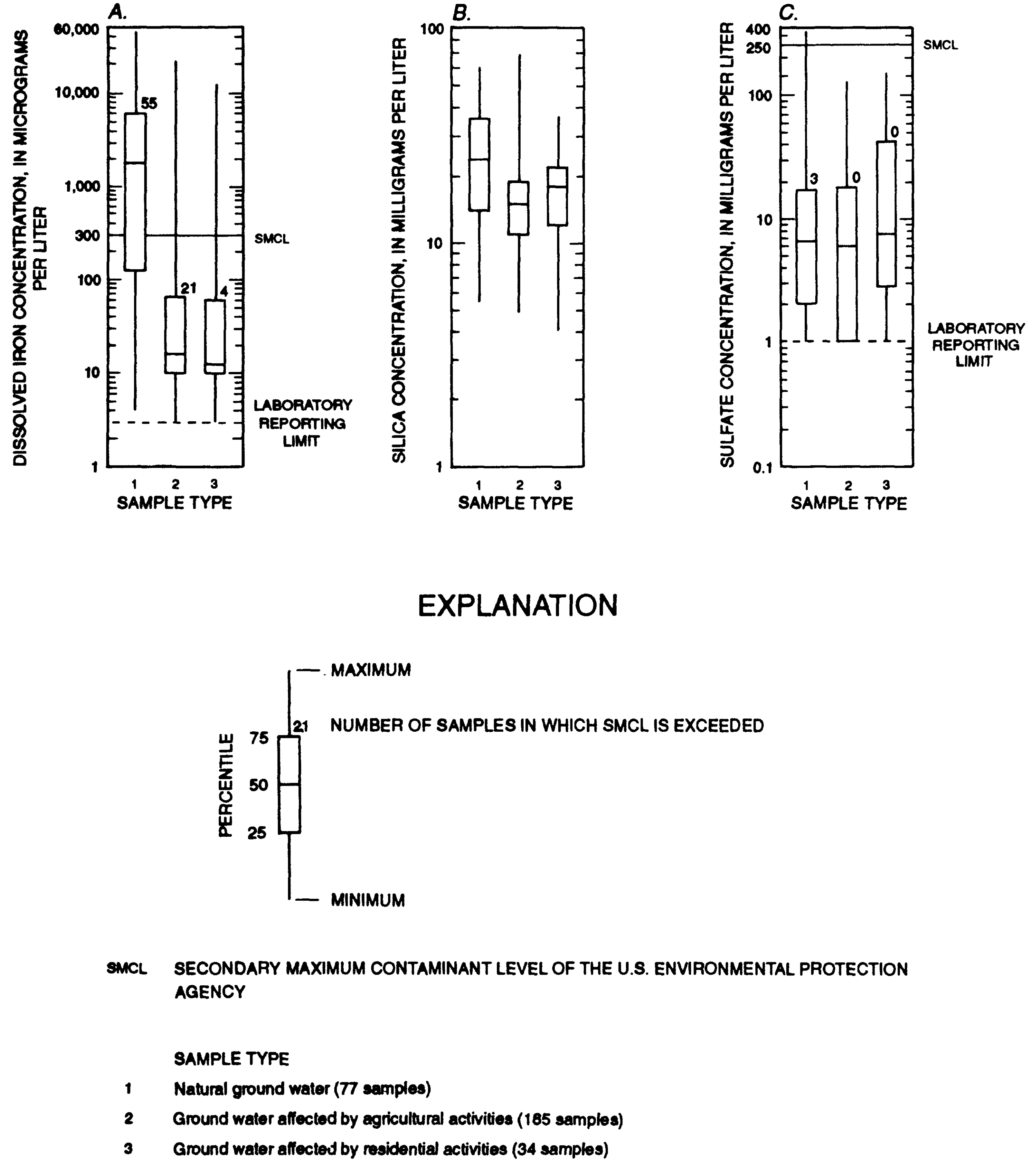
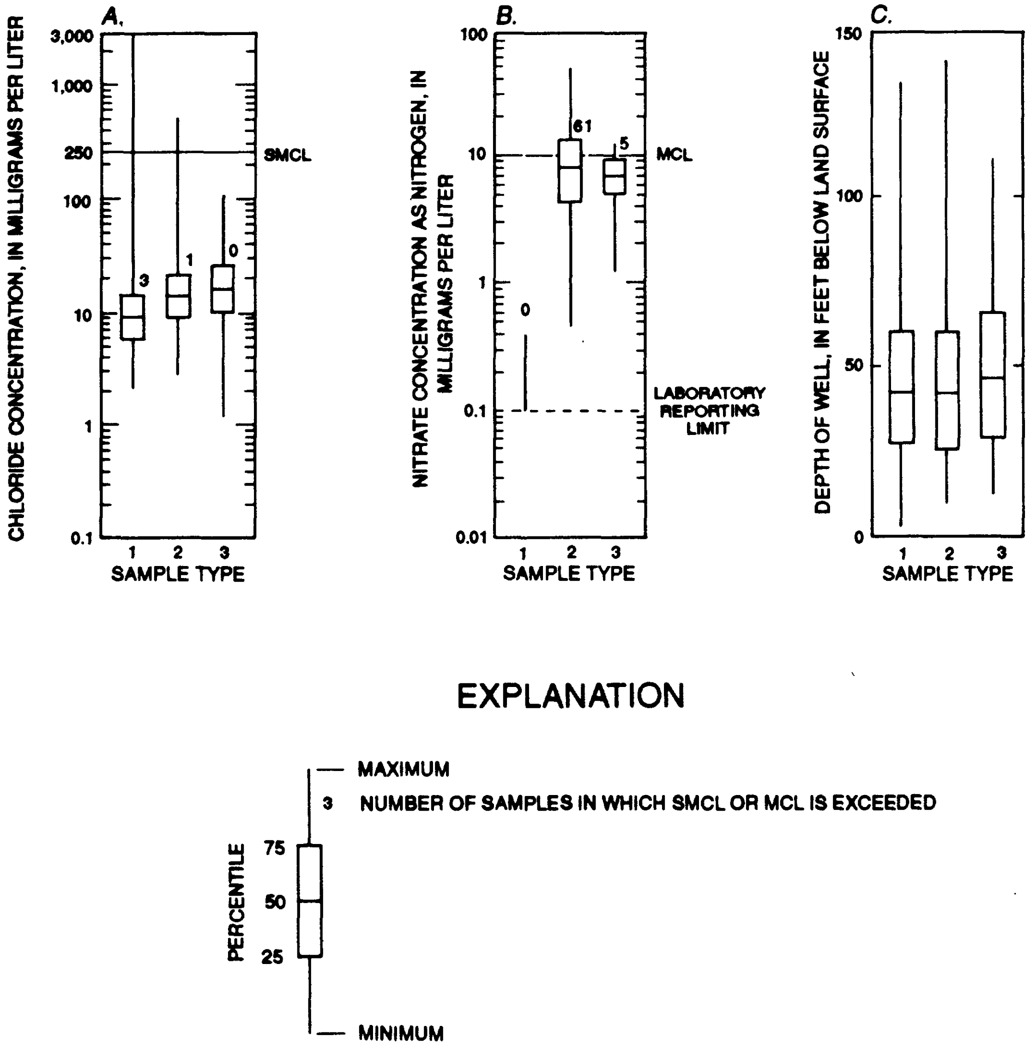


Figure 10. Concentrations of (A) dissolved iron, (B) silica, and (C) sulfate in natural water and in water affected by agricultural and residential activities collected from wells completed in the surficial aquifer in the Delmarva Peninsula, 1976-90.



MCL	MAXIMUM CONTAMINANT LEVEL OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY
SMCL	SECONDARY MAXIMUM CONTAMINANT LEVEL OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY
	SAMPLE TYPE
1	Natural ground water (77 samples)
2	Ground water affected by agricultural activities (185 samples)
3	Ground water affected by residential activities (34 samples)

Figure 11. Concentrations of (A) chloride and (B) nitrate in natural water and in water affected by agricultural and residential activities and (C) depth of wells completed in the surficial aquifer in the Delmarva Peninsula.

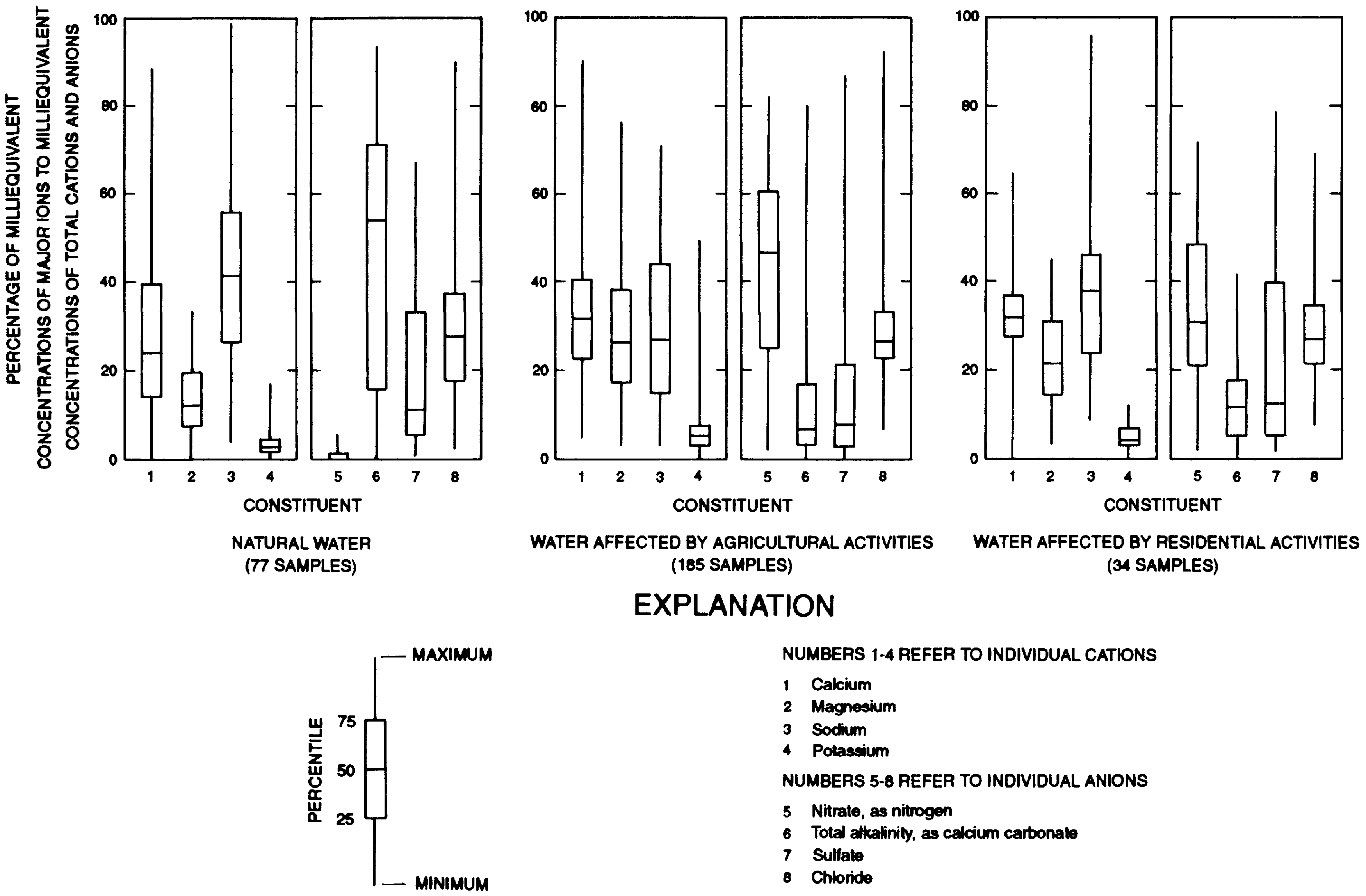


Figure 12. Proportions of milliequivalent concentrations of major ions to milliequivalent concentrations of total cations and anions in natural water and water affected by agricultural and residential activities collected from wells completed in the surficial aquifer in the Delmarva Peninsula, 1976-90.

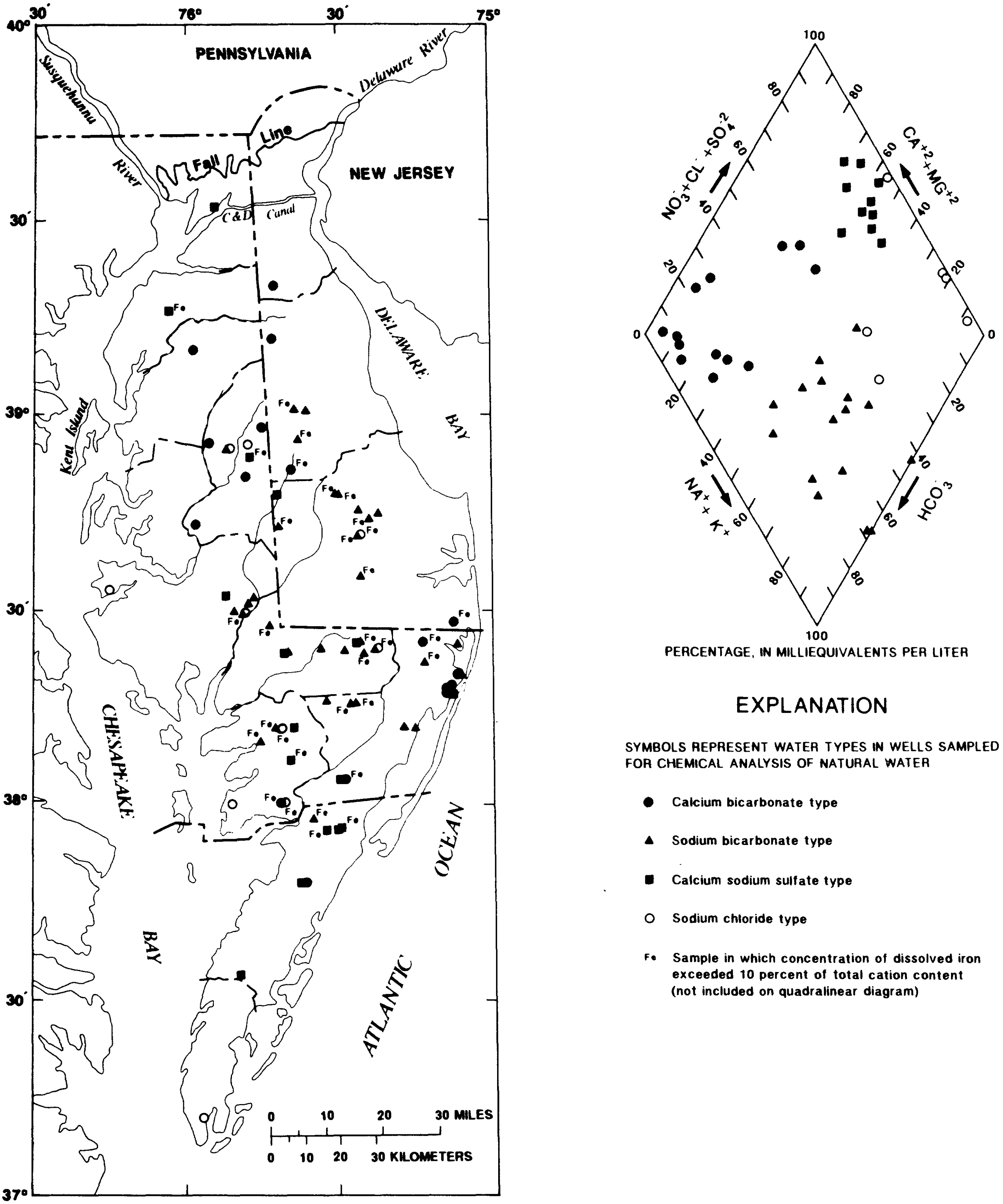


Figure 13. Water types of natural water collected from wells completed in the surficial aquifer in the Delmarva Peninsula, 1980-90.

Natural ground water predominantly is a calcium bicarbonate or sodium bicarbonate type. Natural ground water mostly is a calcium bicarbonate type in the northern part of the peninsula (fig. 13), which is underlain by the Pensauken Formation. The Pensauken Formation overlies subcrops of glauconitic sands of the Aquia Formation (fig. 2), and the two formations commonly function as one hydrologic unit. Ground water mostly is a sodium bicarbonate type in the central part of the peninsula (fig. 13), which is underlain by the Beaverdam Sand. The Beaverdam Sand primarily overlies the Choptank and Calvert Formations.

Water types in the Pensauken Formation and Beaverdam Sand are in part attributable to the composition of the reworked and underlying sediments (such as the glauconitic sands of the Aquia Formation) that make up part of the surficial aquifer. In addition to differences in the composition of these reworked and underlying sediments, other mineralogic features that differ in the two units affect water chemistry. For example, the Beaverdam Sand, primarily deposited in a shallow marine environment, has a higher percentage of clay, silt, and organic material than the Pensauken Formation, primarily deposited in a fluvial environment. The clay, silt, and organic deposits have a higher capacity for ion exchange than do sand deposits. Ground-water-flow patterns, residence times, and reaction rates also differ in the two regions. In the northern part of the peninsula, for example, the aquifer is thin, ground-water-flow paths are short, and hydraulic gradients are steep. Thus, water flows rapidly through the ground-water system. In the central and southern parts of the peninsula, the aquifer is thicker, ground-water-flow paths are longer, and hydraulic gradients are flatter. Thus, water flows relatively slowly through the ground-water system, and contact time for silicate dissolution and other chemical reactions is increased.

Ground water underlying parts of the eastern coast in Maryland and southern Delaware and Virginia commonly is a calcium bicarbonate type (fig. 13). The enriched content of calcium and bicarbonate in these areas results from abundant carbonate material in the surficial aquifer. According to Cushing and others (1973), sediments in the Virginia part of the peninsula are of marine origin and contain abundant calcareous shell material. The ground-water chemistry also is affected by clay mineralogy; the Sinepuxent Formation, which underlies much of the eastern parts of Maryland and southern Delaware, includes heavy clay assemblages that differ from the adjacent Beaverdam Sand (Owens and Denny, 1979b).

Sodium chloride-type water primarily is found in areas near tidal streams, and presumably is the result of intrusion of brackish water into the surficial aquifer near tidal reaches. Calcium sodium sulfate-type water is present in the western part of the peninsula, in southern Maryland, and in Virginia, primarily less than 30 ft below land surface where the ground water is aerobic. Silica concentrations in the calcium sodium sulfate-type water are significantly lower than those measured in natural ground water in other parts of the peninsula (Mann-Whitney test, p-value is 0.05), which indicates that the water has traveled along relatively short ground-water-flow paths and has undergone minimal silicate dissolution. The calcium sodium sulfate-type water primarily is present in estuarine environments, forested wetlands, and marshy parts of streams dominated by fine-grained sediment with moderate amounts of clay, silt, peat, and other organic matter. The sulfate probably is derived from precipitation and leaf litter that is cycled through and accumulated in organic sediments (Puckett, 1987). Calcium sulfate-type water in Virginia probably is linked to abundant organic material in clay sediments that were deposited in barrier and back-barrier environments in Pleistocene and Holocene times. In addition, sulfate is a major ion in seaspray and precipitation in a coastal environment, which includes most of the Virginia part of the peninsula.

EFFECTS OF AGRICULTURAL ACTIVITIES ON NITRATE AND OTHER INORGANIC CONSTITUENTS IN THE SURFICIAL AQUIFER

Nitrogen commonly is used for crop production and is applied mostly as anhydrous ammonia or liquid nitrogen. In the presence of dissolved oxygen, most of the nitrogen not used by plants or crops is oxidized to nitrate in the soil zone (table 16). Nitrate, which is water soluble and mobile, readily leaches from soil to ground water and moves freely through aerobic parts of the surficial aquifer with little change in concentration. In anaerobic parts of the aquifer, nitrate is not stable and generally denitrifies to nitrogen gas; thus, concentrations of nitrate generally are minimal or less than the laboratory reporting limit. In anaerobic environments, nitrogen applied as ammonia remains as ammonium ions (NH_4). Ammonium ions are not as mobile as nitrate because they are more easily adsorbed onto soil and clay minerals. Concentrations of ammonia generally are low throughout most of the ground-water system.

Previous studies have documented nitrate concentrations that are greater than natural concentrations in the surficial aquifer in the Delmarva Peninsula (Robertson, 1977 and 1979; Ritter and Chirnside, 1982; Bachman, 1984b; Denver, 1986; Hamilton and others, 1991). Nitrate concentrations primarily are elevated because of fertilizer applications, animal-waste disposal, and septic-tank effluent. Bachman (1984b) found highest nitrate concentrations in agricultural and urban areas with well-drained soils. Robertson (1979) found highest nitrate concentrations in agricultural areas, particularly near confined animal feeding operations, and lowest nitrate concentrations in woodlands. Ritter and Chirnside (1982) found low nitrate concentrations in selected low-density residential areas of Kent and Sussex Counties, Del.

Ground water in agricultural and residential areas contains elevated concentrations of inorganic constituents other than nitrate, such as calcium and magnesium from lime, potassium and chloride from potash fertilizer, and sodium and chloride from septic-tank effluent (Denver, 1989). Denver (1989) states that these additions change the relative proportions of major dissolved constituents in agricultural and residential areas in Sussex County, Del. In addition, bicarbonate, the predominant anion in natural ground water and the major anion produced by lime applications, is low in ground water affected by agricultural activities because the acidity produced during nitrification is neutralized by bicarbonate ion (table 16).

Effects of agricultural applications of inorganic fertilizers, manure, and lime on concentrations of nitrate and other inorganic constituents in water from the surficial aquifer were examined by analysis of water samples collected from wells in the existing and NAWQA areal and transect networks. Wells in agricultural areas were used in this examination. Agricultural land use was identified on the basis of 1:250,000-scale data because land-use data at a finer resolution are not available for areas surrounding most of the wells in the existing network. Detailed land-use data were used in the analysis of agricultural activities on the quality of ground water in the local-scale well networks discussed in subsequent sections of the report.

Definition of Ground Water Affected by Agriculture

"Ground water affected by agriculture" is defined in this report as ground water that contains nitrate concentrations equal to or greater than 0.4 mg/L as N and is also associated with agricultural land. Analyses for water samples collected at 185 wells in the Delmarva Peninsula were used to assess chemical signatures of ground water affected by agricultural activities. Land use surrounding 154 of the 185 wells was identified as agricultural; land use surrounding the 31 remaining wells was identified as woodlands or wetlands. Water samples collected from the 31 wells were retained in the analysis because the concentrations and proportions of major cations and anions in these samples were not significantly different from concentrations and proportions in the 154 water samples. No identified natural phenomenon in woodlands or wetlands can explain elevated concentrations of nitrate and other constituents affected by agricultural activities; these constituents probably are elevated because of upgradient agricultural land use (Hamilton and Denver, 1990). In addition, the coarse resolution of the land-use data may preclude an accurate categorization of land use (Hamilton and Shedlock, 1989).

Water samples with nitrate concentrations equal to or greater than 0.4 mg/L as N that were collected from 34 wells underlying urban or residential land were not included in the analysis of water affected by agricultural activities. Ground-water chemistry in residential areas and comparison of ground-water chemistry in residential and agricultural areas are discussed in this section of the report.

Agricultural Practices

As mentioned previously, most of the agricultural land on the Delmarva Peninsula is in soybean-corn rotation. The relative distribution of soybeans and corn is generally uniform throughout the peninsula except in Virginia, where corn rarely is grown. Soybean and corn cropping patterns, reported in annual crop reports by the U.S. Department of Agriculture, have remained stable during 1975-90 (M.T. Koterba, U.S. Geological Survey, written commun., 1992).

Application of inorganic fertilizers, lime, and manure is widespread in the production of vegetables and grains throughout the Delmarva Peninsula. The major nutrients in inorganic fertilizers are nitrogen, potassium, chloride, and phosphorus. Trace metals, including copper, zinc, manganese, molybdenum, and cobalt, are added to fertilizers as micronutrients. Most of the nitrogen applied as inorganic fertilizer is in the form of ammonia compounds. Potassium is applied in the form of potassium chloride, and phosphorus usually is applied as phosphorus pentoxide. Lime, primarily crushed dolomite, contributes calcium and magnesium for plant use and bicarbonate for buffering soil acidity caused by nitrification of ammonia to nitrate (Denver, 1989). Lime is applied to maintain a soil pH near 5.6, the optimum pH for crop production. Nitrogen from manure is in the form of ammonia and organic nitrogen compounds. Poultry manure is the most common type used in the Delmarva Peninsula because the area is one of the Nation's leading producers of chickens. The poultry industry produces about 5 tons of manure per 1,000 birds (Perkins and others, 1964). The manure is recycled in the poultry areas, spread on cropland, or disposed of locally.

The application of inorganic fertilizers and manure does not necessarily cause an increase in nitrate and inorganic constituents in ground water. When the amounts applied exceed that required by crops, or when the timing of the application allows a residue to remain in the soil for extended periods, constituents can leach with recharge from precipitation or irrigation water. The amount of nitrate that leaches to ground water depends on soil type, crop type, timing and rate of fertilizer application, and irrigation practices. More fertilizer commonly is applied on land with well-drained soils (which have a low organic-matter content and low moisture capacity) than on land with poorly drained soils. More fertilizer also is applied on irrigated land than on nonirrigated land. General rates and timing of applications of nitrogen fertilizer for selected crops commonly grown on the Delmarva Peninsula are listed in table 19. Corn crops generally require the highest nitrogen application rate. Nitrogen fertilizer is not required for soybean production (although minor amounts sometimes are applied); therefore, soybeans are not included in the table.

Chemical Signatures of Ground Water Affected by Agriculture

Nitrate concentrations ranged from 0.4 to 48 mg/L as N in 185 water samples affected by agricultural activities (fig. 11); the median was 8.2 mg/L as N. Nitrate concentrations exceeded the USEPA MCL (10 mg/L as N) in 61 (about 33 percent) of the 185 samples. Statistical analyses for properties and major dissolved constituents are presented in figures 8-11. Maximum and minimum concentrations and 25th, 50th, and 75th quartiles are shown. The total number of samples and the number of samples that exceeded USEPA MCL's and SMCL's for drinking water also are indicated.

Ground water affected by agricultural activities contains significantly higher concentrations of dissolved constituents (median specific conductance was 170 μS/cm for 185 samples) than does natural ground water (median was 115 μS/cm for 77 samples) (fig. 8; table 18). Concentrations of nitrate, calcium, magnesium, potassium, and chloride are significantly higher in ground water affected by agricultural activities than in natural ground water because of applications of inorganic fertilizers, manure, and lime (figs. 9 and 11; table 18). Median concentrations of alkalinity and median pH are significantly lower because bicarbonate ion is consumed in the nitrification of ammonia (fig. 8; table 18). The dominant ions in ground water affected by agricultural activities are shown in figure 14. Natural ground-water types (fig. 13) are not readily distinguished because chemicals leached from inorganic fertilizers, manure, and lime generally dominate ground-water chemistry beneath agricultural areas.

Median concentrations of sodium and sulfate in water samples affected by agricultural activities are not significantly different from concentrations in natural ground-water samples (figs. 9 and 10; table 18). Sodium is not a major fertilizer component. Sulfate sometimes is applied through irrigation systems; however, it is not applied regionally as a major fertilizer component. Furthermore, sulfate is absorbed readily by plants and microorganisms and retained in the organic fraction of the soil (Denver, 1989).

Median concentrations of barium and strontium (trace metals in dolomitic lime) in ground water whose quality is affected by agricultural activities are significantly higher than concentrations in natural ground water (table 18). The barium probably is from barite ($BaSO_4$), an impurity in the dolomite (Denver, 1986). Some strontium can be attributed to precipitation, but most of the strontium in ground water probably results from reactions between minerals and ground water. Concentrations of strontium significantly increase with increasing calcium concentrations (p-value is 0.001),

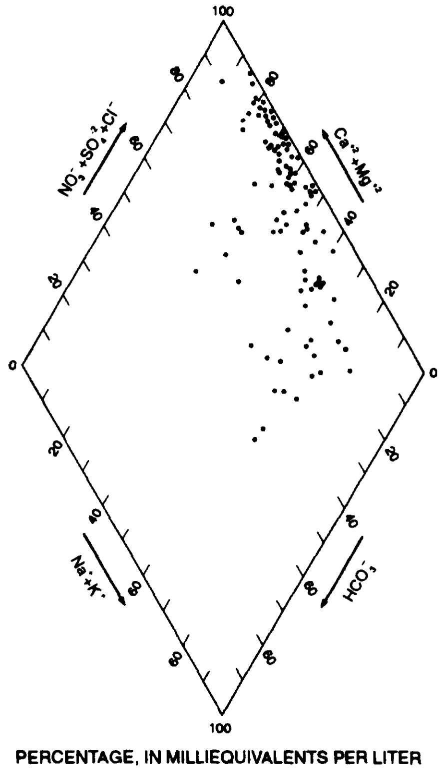
Table 19.--General rates and timing of applications of nitrogen fertilizer for selected crops on the Delmarva Peninsula[1]

[Rate, in pounds per acre]

Crop	Rate	Timing
Sweet Corn		
Fresh market	125-150	Total recommended
	40-60	Broadcast 3 weeks before plowing
	20	Hand-place with planter
	50-75	Sidedress when corn is 12 to 18 inches tall
Processing	110-130	Total recommended
	40-60	Broadcast 3 weeks before plowing
	20	Band-place with planter
	30-50	Sidedress 2 weeks after emergence
Wheat	80-125	Total recommended
	20-25	At planting
	60-100	During growing season in early to mid-March
Barley	60-100	Total recommended
	20-25	At planting
	40-80	During growing season in early to mid-March
Beans (Snap)		
	40-80	Total recommended
	20-40	Broadcast and disk-in or drill deep
	20-40	Band-place with planter
	0-20	Sidedress at prebloom stage
Cucumbers	100-125	Total recommended
	50	Broadcast and disk-in or drill deep
	25-50	Band-place with planter
	25-50	Sidedress when vines begin to run, or apply in irrigation water
Potatoes		
Sweet	50-75	Total recommended
	25	Broadcast and disk-in or drill deep
	25-50	Sidedress when vines start to run
White	150	Total recommended
	50	Broadcast and disk-in or drill deep
	100	Band-place with planter
Tomatoes		
Fresh market	80-90	Total recommended
	40-45	Broadcast and plow down
	40-45	Sidedress when first fruits are set
Processing	130	Total recommended
(Transplants	50	Broadcast and disk-in or drill deep
for multiple	50	Sidedress at first cultivation
harvests)	30	Sidedress when first fruits are 1 inch in diameter

---

[1] Rates and timing generalized from Virginia Cooperative Extension Service, 1992, and from written communication with agricultural extension agents in Delaware, Maryland, and Virginia. Rates and timing might differ throughout the peninsula, depending on soil type, climate, hydrology, and land use.



EXPLANATION

CHEMICAL ANALYSIS OF GROUND WATER AFFECTED BY AGRICULTURAL ACTIVITIES

Figure 14. Chemistry of water affected by agricultural activities collected from wells completed in the surficial aquifer in the Delmarva Peninsula, 1976-90.

which supports findings by Denver (1986) that impurities in dolomite applied to fields is a major source of strontium in ground water (fig. 15).

One assumption in the statistical comparison of natural water quality and water quality affected by agricultural activities is similarity in the vertical distribution of sampling sites because differences in well depth potentially could bias a comparison of results of two groups of data. For example, a comparison might indicate higher concentrations in one type of water than those in another type simply because the bulk of the data are from shallow wells in one type and from deep wells in the other type. Depth of well from which water samples were collected (fig. 11) introduced minimal variability in the statistical comparison of water quality in natural water and in water affected by agricultural activities; there was no significant difference between the median well depth of the two groups of data (Mann-Whitney test, p-value is 0.849).

Correlations Among Nitrate and Other Major Ions

Concentrations of nitrate in ground water affected by agricultural activities correlate significantly with specific conductance and other inorganic constituents (figs. 16 through 20; table 20). The LOWESS line, computed from robust weighted least squares (Helsel and Hirsch, 1992), is used to illustrate increasing or decreasing trends in properties or constituent concentrations with increasing nitrate concentration. Relations were tested for statistical significance by nonparametric Spearman regression analysis (table 20). Nitrate is a dominant anion in ground water affected by agricultural activities because of the naturally low ionic strength of the water (Denver, 1986 and 1989). As a result, there is a significant relation between increasing specific conductance with increasing nitrate concentration (fig. 16; table 20). Concentrations of dissolved constituents affected by applications of lime and potash fertilizers (calcium, magnesium, barium, strontium, potassium, and chloride) also increase significantly as nitrate concentrations increase (figs. 16 through 18; table 20). Alkalinity concentrations decrease as nitrate concentrations increase in part because bicarbonate ion is consumed in buffering acidity (fig. 19; table 20). The negative correlation also reflects underapplication of lime at large nitrogen loadings. Sodium is not a major fertilizer component; however, sodium in poultry manure might explain the slight increase in sodium concentration as nitrate concentrations increase (fig. 19; table 20). Sulfate concentrations neither decrease nor increase as nitrate concentrations increase (fig. 20; table 20). Most of the sulfate, which is not a major fertilizer component, is retained in the organic fraction of the soil (Denver, 1989).

Results from a study by Denver (1989) indicate similar relations in a watershed in eastern Sussex County, Del. Relations are not as strong on a regional scale (covering the entire peninsula) as on a local scale (covering eastern Sussex County, Del.) because of

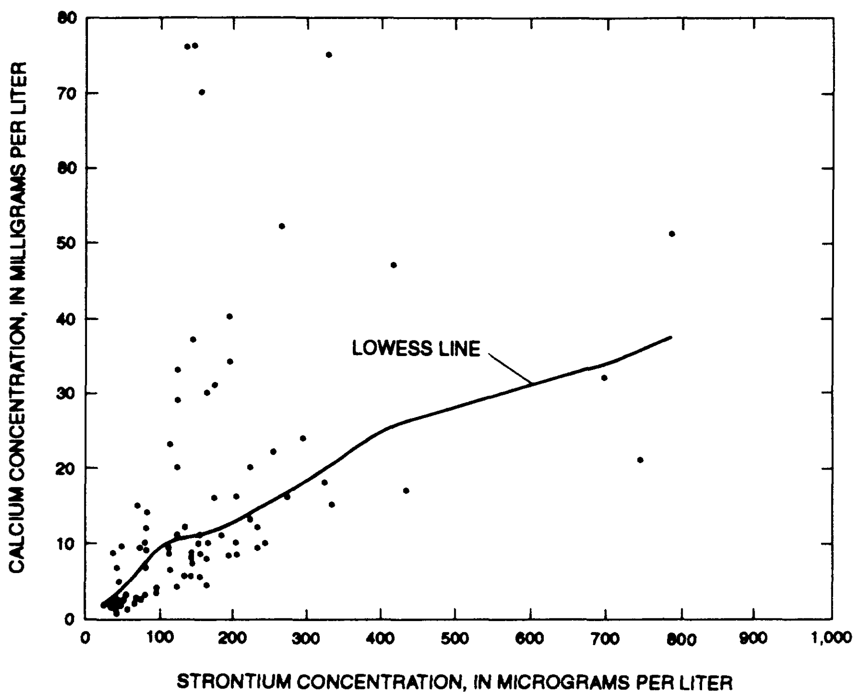


Figure 15. Relation between concentrations of strontium and calcium in water affected by agricultural activities collected from wells completed in the surficial aquifer in the Delmarva Peninsula, 1976-90.

peninsulawide variability in (1) type and rate of fertilization; (2) timing and amounts of recharge; (3) soil texture and content of organic matter; (4) heterogeneity of aquifer sediment; and (5) length of ground-water-flow paths. For example, concentrations of calcium and magnesium differ regionally because of different lithology in the northern and central parts of the peninsula (discussed in previous section of the report). Concentrations of potassium differ regionally because the ions commonly are fixed at cation-exchange sites in certain clay minerals (Denver, 1989). Concentrations of chloride differ regionally because of inputs from road salting and brackish water, and concentrations of alkalinity differ because of natural mineral and shell dissolution in the sediments. Concentrations of sodium differ regionally because of natural dissolution of feldspars.

Comparison of Ground-Water Chemistry in Agricultural and Residential Areas

Concentrations of nitrate commonly are elevated in ground water beneath residential or developed areas because of excessive applications of lawn fertilizers and the presence of septic-tank effluent (Denver, 1986). Septic-tank effluent can contain as much as 70 mg/L of nitrogen, primarily in the form of ammonia and organic nitrogen (Madison and Brunett, 1984). In aerobic conditions, nitrification can occur. Other major chemical constituents in septic-tank effluent are sodium and chloride (Denver, 1986).

Analysis of water samples whose nitrate concentrations were equal to or greater than 0.4 mg/L as N collected from 34 wells underlying urban or residential land were used to assess ground-water chemistry in residential areas. Residential land use was identified on the basis of 1:250,000-scale data because land-use data at a finer resolution are not available for areas surrounding most of the wells in the existing network.

Nitrate concentrations ranged from 1.2 to 13 mg/L as N in 34 water samples collected from wells in residential areas (fig. 11); the median was 7.1 mg/L as N. Nitrate concentrations exceeded the USEPA MCL (10 mg/L as N) in 5 (about 15 percent) of the 34 samples. Statistical analyses for properties and major dissolved constituents are presented in figures 8-11. Maximum and minimum concentrations and 25th,

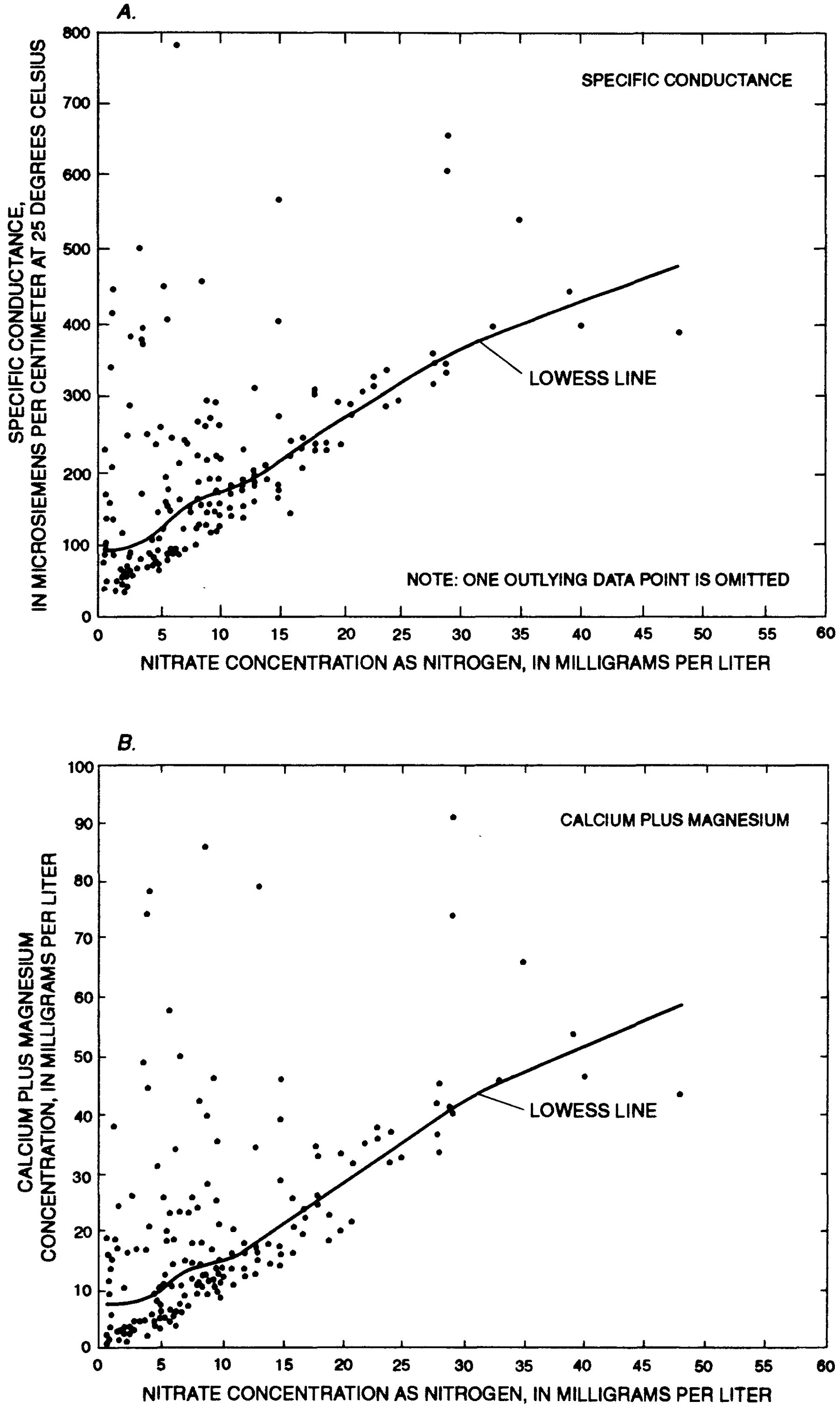


Figure 16. Relation of nitrate concentrations in water affected by agricultural activities collected from wells completed in the surficial aquifer in the Delmarva Peninsula to (A) specific conductance and (B) concentrations of calcium plus magnesium, 1976-90.

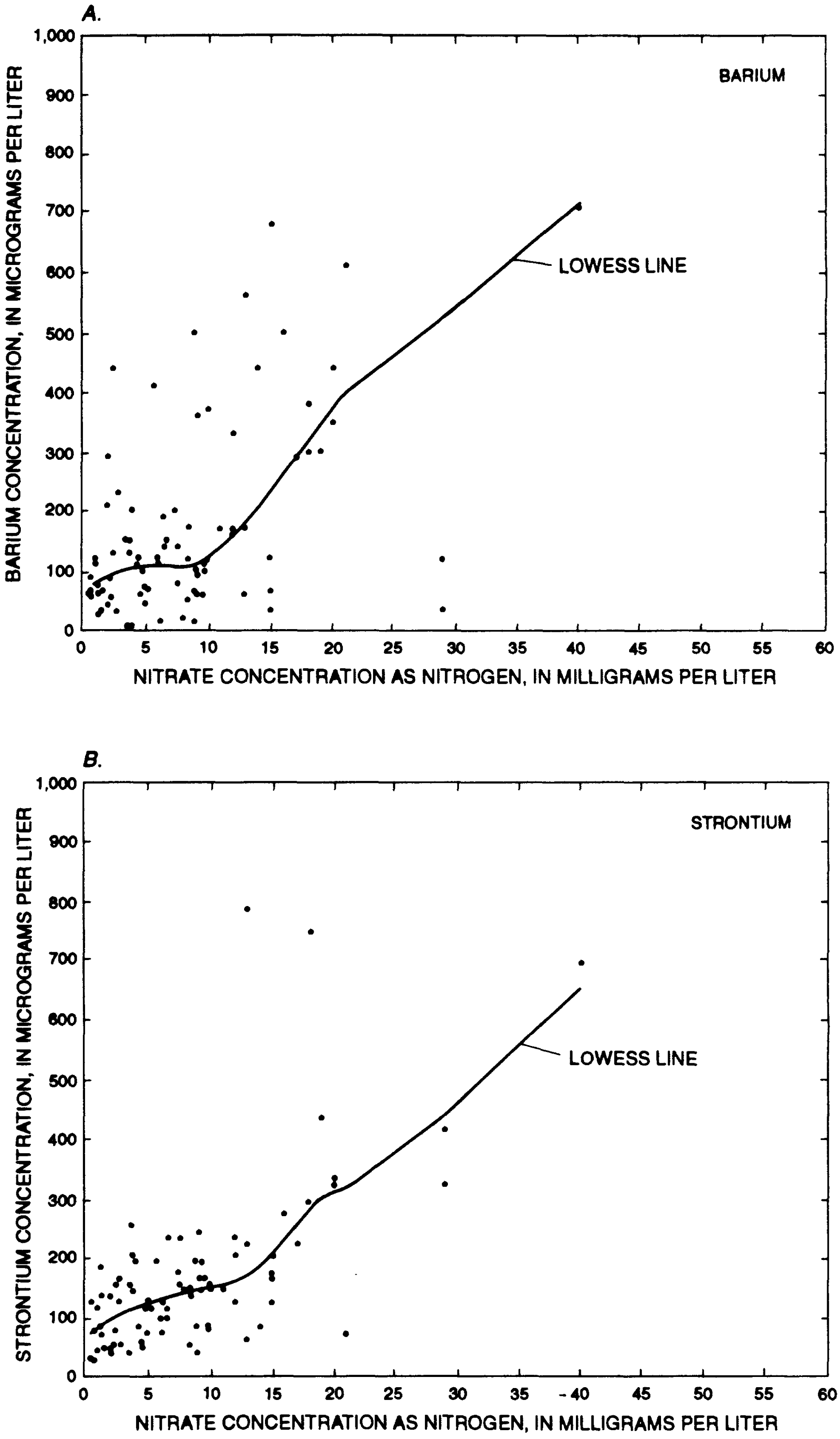
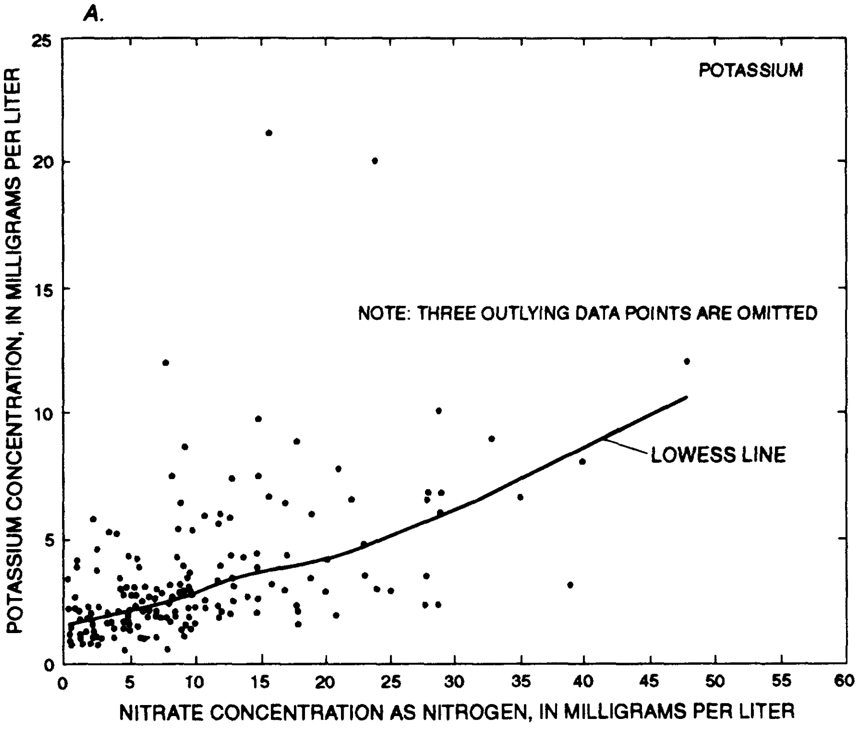


Figure 17. Relation of nitrate concentrations in water affected by agricultural activities collected from wells completed in the surficial aquifer in the Delmarva Peninsula to concentrations of (A) barium and (B) strontium, 1976-90.



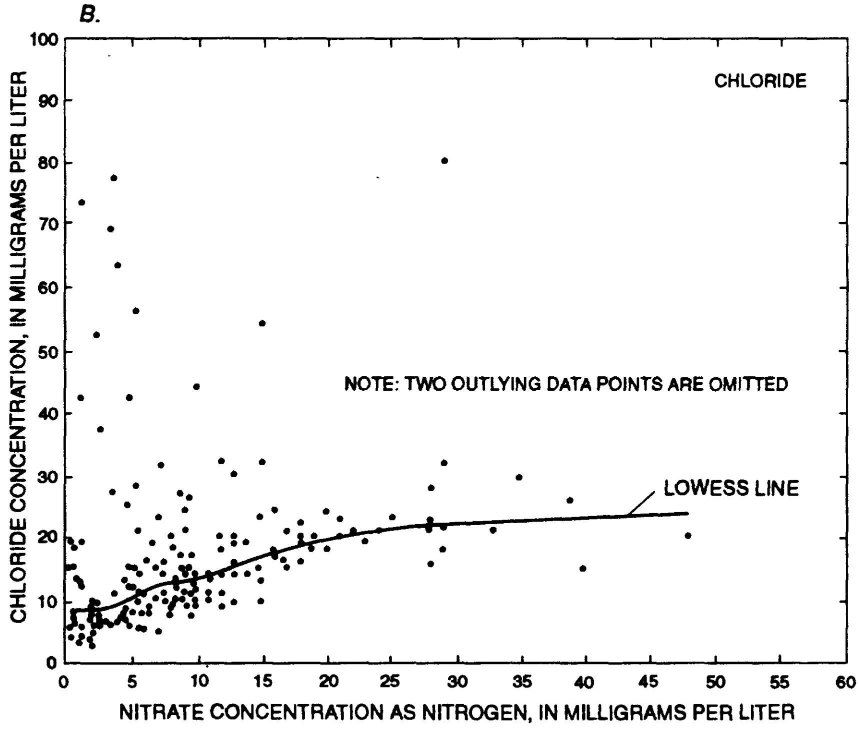


Figure 18. Relation of nitrate concentrations in water affected by agricultural activities collected from wells completed in the surficial aquifer in the Delmarva Peninsula to concentrations of (A) potassium and (B) chloride, 1976-90.

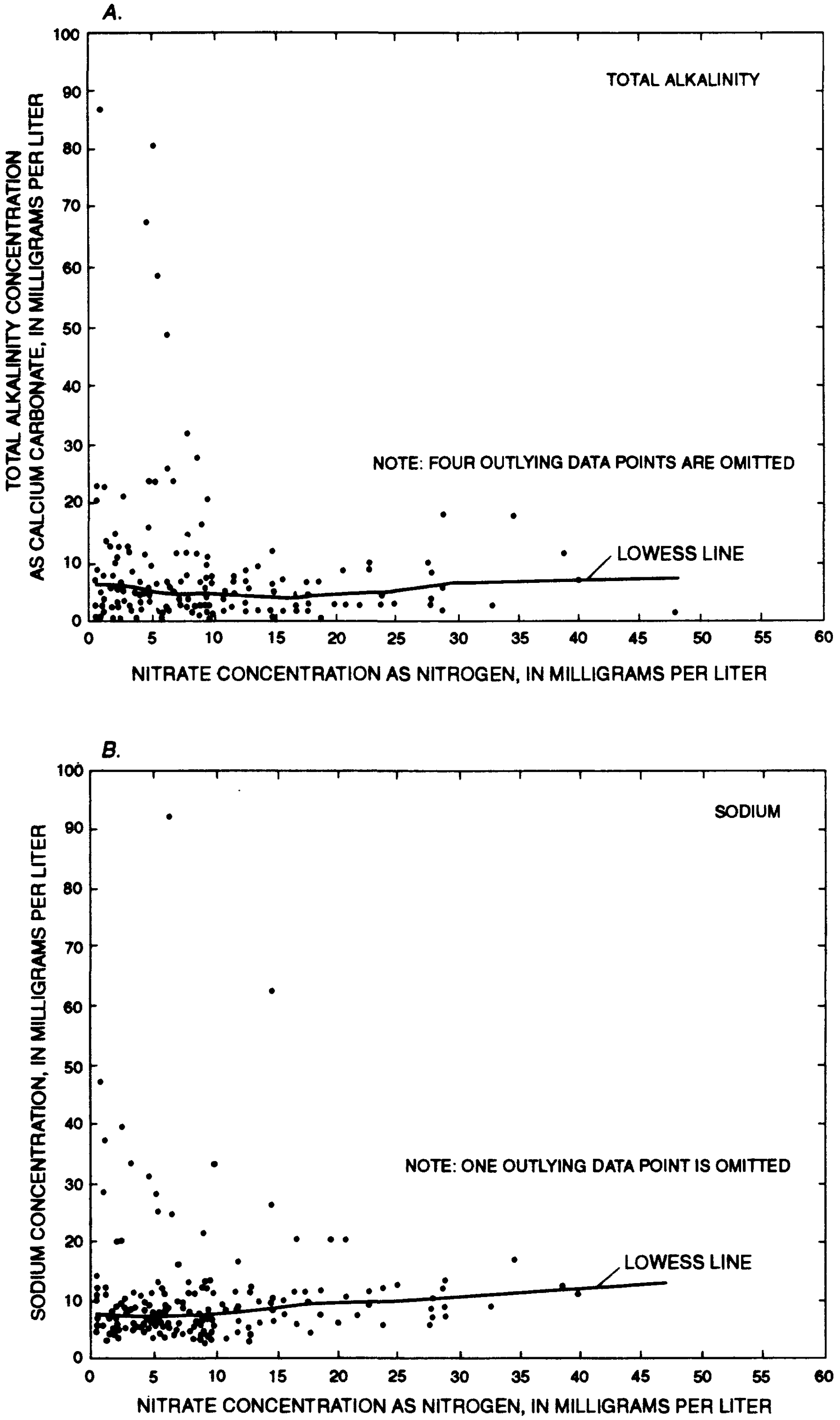


Figure 19. Relation of nitrate concentrations in water affected by agricultural activities collected from wells completed in the surficial aquifer in the Delmarva Peninsula to concentrations of (A) alkalinity and (B) sodium, 1976-90.

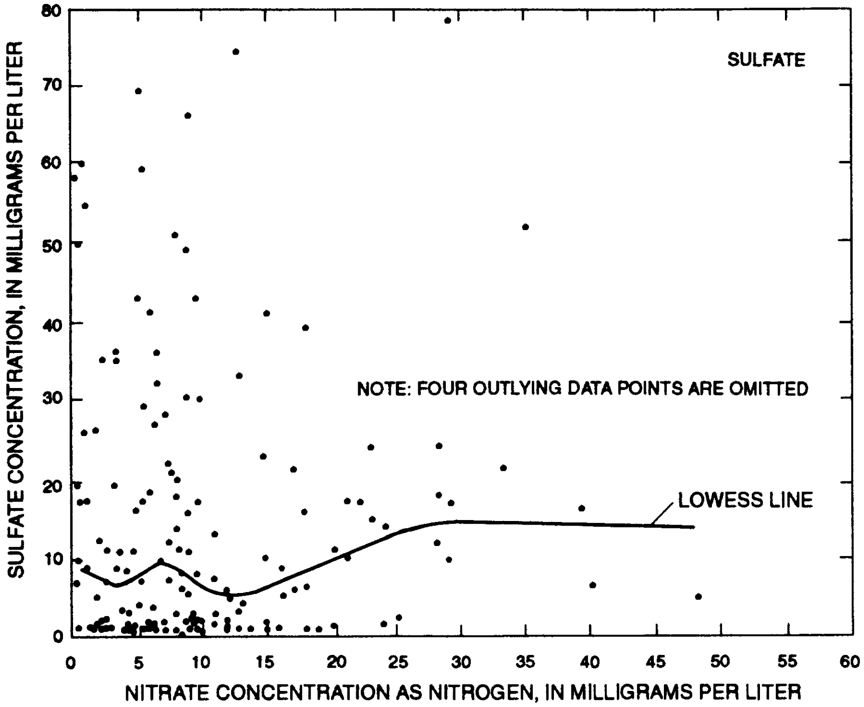


Figure 20. Relation of nitrate concentrations in water affected by agricultural activities collected from wells completed in the surficial aquifer in the Delmarva Peninsula to concentrations of sulfate, 1976-90.

50th, and 75th quartiles are shown. The total number of samples and the number of samples that exceeded USEPA MCL's and SMCL's for drinking water also are indicated.

Ground-water chemistry in residential and agricultural areas generally is similar (fig. 12; table 21) because many of the chemical constituents are common to septic-tank effluent, lawn fertilizers, manure, and inorganic agricultural fertilizers, and because lime is applied in both areas. Sodium and sulfate are the only two constituents whose concentrations differ between residential and agricultural areas. The median concentration of sodium in residential ground water was significantly higher than the median concentration in agricultural ground water (p-value = 0.009; table 21) because sodium is present in high concentrations in septic-tank effluent but is not a major fertilizer component. Sodium concentrations in septic-tank effluent reflect human consumption of salt. The differences in sodium concentrations are not statistically affected by the natural process of silicate dissolution, which generally results in increased sodium concentration. Natural silicate dissolution introduced minimal variability in the analysis; median concentrations of silica (fig. 10) and alkalinity (fig. 8) in water samples collected in agricultural and residential areas were not significantly different (table 21).

Concentrations of sulfate in residential areas are significantly higher than concentrations in agricultural areas (p-value = 0.040; table 21) probably because of oxidation of organic sulfur present in septic-tank effluent. The analysis, however, could have been statistically biased towards water samples collected from wells in areas of fine-grained sediment where sulfate concentration is elevated naturally.

One assumption in the statistical comparison of water quality affected by agricultural and residential activities is similarity in the vertical distribution of sampling sites because differences in well depth potentially could bias a comparison of results of two groups of data. Depth of well from which water samples were collected (fig. 11) introduced minimal variability in the analysis. The difference between the median well depth in the two groups of data was not significant (Mann-Whitney test, p-value = 0.654).

Table 20.--Statistical relation between concentrations of nitrate and selected properties and ions in water affected by agricultural activities in the surficial aquifer in the Delmarva Peninsula, 1976-90.[1]

[p-value and coefficient of determination (R^2) computed by Spearman regression analysis;[2] <, less than]

Property or dissolved constituent	p-value	Coefficient of determination (R^2), in percent	Number of analyses
Properties:			
pH	0.034	-13.5	185
Specific conductance	<.001	56.0	185
Alkalinity	.018	-15.6	185
Dissolved constituents:			
Calcium	<.001	55.9	185
Magnesium	<.001	58.8	185
Calcium plus magnesium	<.001	58.9	185
Sodium	.043	12.7	185
Potassium	<.001	56.3	185
Barium	.001	34.7	85
Strontium	<.001	60.7	85
Sulfate	.360	2.7	185
Chloride	<.001	47.5	185

---

[1] Analysis includes water samples collected from wells in the existing network and the NAWQA areal and transect networks. Samples affected by agriculture were determined by use of 1:250,000-scale land-use data (U.S. Geological Survey, 1979a, 1979b, 1979c, 1980a, 1980b, 1980c).

[2] The Spearman correlation analysis is a nonparametric regression test done to examine increasing or decreasing trends in data. The test involves a null hypothesis stating that no real trend exists between categories. An alpha value, or level of significance, is used in the test to represent the maximum probability of rejecting the null hypothesis when it is actually true. The alpha value used in this report is 0.05. 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 trends are assumed to exist between the categories. The coefficient of determination (R^2) indicates the percentage of variability in the ion concentration that can be accounted for by nitrate concentration. A negative number indicates an inverse relation between categories; a positive number indicates a direct relation between categories.

Table 21.--Statistical summary of the quality of water affected by agricultural and residential activities in the surficial aquifer in the Delmarva Peninsula, 1976-1990.[1]

[p-value represents Mann-Whitney statistical test[2]; number in parentheses is total number of analyses]

		Median concentration, in milligrams per liter unless otherwise noted			
Property or dissolved constituent	p-value	Water affected by residential activities		Water affected by agricultural activities	
Properties:					
pH (standard units)	0.448	5.35	(34)	5.25	(185)
Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	.876	163	(34)	170	(185)
Alkalinity (as calcium carbonate)	.093	6.0	(34)	5.0	(185)
Dissolved constituents:					
Calcium	.716	7.8	(34)	9.0	(185)
Magnesium	.199	4.1	(34)	5.0	(185)
Calcium plus magnesium	.358	12	(34)	15	(185)
Sodium	.009	9.3	(34)	7.9	(185)
Potassium	.424	2.6	(34)	2.6	(185)
Iron (micrograms per liter)	.819	12	(34)	16	(185)
Silica	.080	18	(34)	15	(185)
Barium (micrograms per liter)	.452	110	(18)	120	(85)
Strontium (micrograms per liter)	.452	105	(18)	140	(85)
Sulfate	.040	7.5	(34)	6.0	(185)
Chloride	.427	16	(34)	14	(185)
Nitrate (as nitrogen)	.172	7.1	(34)	8.2	(185)

---

[1] Analysis includes water samples collected from wells in the existing network and the NAWQA areal and transect networks. Samples affected by agriculture were determined by use of 1:250,000-scale land-use data (U.S. Geological Survey, 1979a, 1979b, 1979c, 1980a, 1980b, 1980c).

[2] The Mann-Whitney test is a hypothesis test used to examine whether variations in data result from chance variability or real differences. The test involves a null hypothesis stating that no real difference exists between the categories. An alpha value, or level of significance, is used in the test to represent the maximum probability of rejecting the null hypothesis when it is actually true. The alpha value used in this report is 0.05. 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 between the categories.

SPATIAL DISTRIBUTION OF NITRATE AND OTHER INORGANIC CONSTITUENTS IN THE SURFICIAL AQUIFER

Results of a previous study by Hamilton and others (1991) indicate that concentrations of nitrate are elevated at all depths in the surficial aquifer but are greatest in shallow parts. Hamilton and others (1991) also suggest that nitrate concentration differs among hydrogeomorphic regions. Regional patterns, areal and vertical, were examined further by analysis of 296 water samples collected from wells in the existing and NAWQA areal and transect networks. The possible causes of the areal and vertical patterns--including ground-water flow, land use, geomorphology, soil characteristics, and aquifer composition--were assessed in five local-scale well networks in agricultural areas. Water-quality patterns observed in the local-scale well networks are presumed to be typical of water-quality patterns within three largest of the six hydrogeomorphic regions (well-drained uplands, poorly drained uplands, and the surficial confined region).

Variation With Depth

Concentrations of nitrate are elevated at all depths in the surficial aquifer (fig. 21). Although the highest concentrations were found in the shallow part of the surficial aquifer (less than 40 ft below land surface), a statistical analysis of 296 water samples collected from wells in the existing and NAWQA areal and transect networks failed to confirm that nitrate concentrations were significantly higher in the shallow part of the surficial aquifer than in the deep part. The nonparametric Spearman regression analysis indicated no significant relation between the ranks of nitrate concentration and well depth in the surficial aquifer (p-value=0.798). In addition, the relation between nitrate concentration and well depth was graphically analyzed by the LOWESS line (Helsel and Hirsch, 1992). The smooth line is generally flat and shows no increasing or decreasing trend in nitrate concentration and well depth in the surficial aquifer (fig. 21).

The lack of such a trend also is illustrated by the vertical distribution of nitrate concentrations in 185 water samples affected by agricultural activities (fig. 21). Elevated nitrate concentrations, including those that exceed the USEPA MCL for nitrate, were found in the surficial aquifer at depths greater than 80 ft below land surface. The median concentration in ground water collected from 24 wells deeper than 80 ft below land surface was 8.5 mg/L as N, and concentrations in 9 of these water samples (about 37 percent) exceeded the USEPA MCL (fig. 21).

Concentrations of nitrate are elevated in water in the deep parts of the surficial aquifer for several reasons. Ground-water-flow paths, recharged in agricultural or residential areas, commonly penetrate to the base of the surficial aquifer in the study area (Bachman, 1984; Denver, 1989 and 1991). The nitrate is not chemically reduced along the ground-water-flow paths because aerobic conditions commonly persist to the base of the surficial aquifer. In addition, nitrate is relatively conservative in aerobic conditions and concentrations remain stable.

Concentrations of nitrate below 0.4 mg/L as N also are found at all depths in the surficial aquifer. The low concentrations are along ground-water-flow paths recharged in woodlands or other nonagricultural or nonresidential areas, and in anaerobic parts of the aquifer where nitrate is not stable.

Although concentrations of nitrate are elevated in water in the deep parts of the surficial aquifer, effects of agriculture on the quality of ground water are more evident in the shallow part of the aquifer, as indicated by concentrations of other constituents affected by agricultural activities. Concentrations of calcium, magnesium, potassium, strontium, and chloride, and specific conductance decrease significantly with well depth (table 22). Concentrations of silica and pH increase with well depth (table 22) because water in the deep parts of the aquifer travels along longer flow paths than water in the shallow parts of the aquifer, and the time for silicate-mineral dissolution is correspondingly greater. Hydrogen ion is consumed in the dissolution, which raises pH.

One assumption in the statistical analyses of the distribution of constituent concentrations with well depth is independence among other possible factors affecting variability in concentrations. A possible violation of this assumption would be a relation between constituent concentration and depth to the water table. For example, nitrate can be partially or totally reduced in anaerobic water, which commonly occurs in the poorly drained regions of the peninsula where the water table is shallow (less than 10 ft below land surface). Depth to water table, therefore, can potentially bias the statistical analysis of nitrate concentrations at different well depths. The Spearman regression test

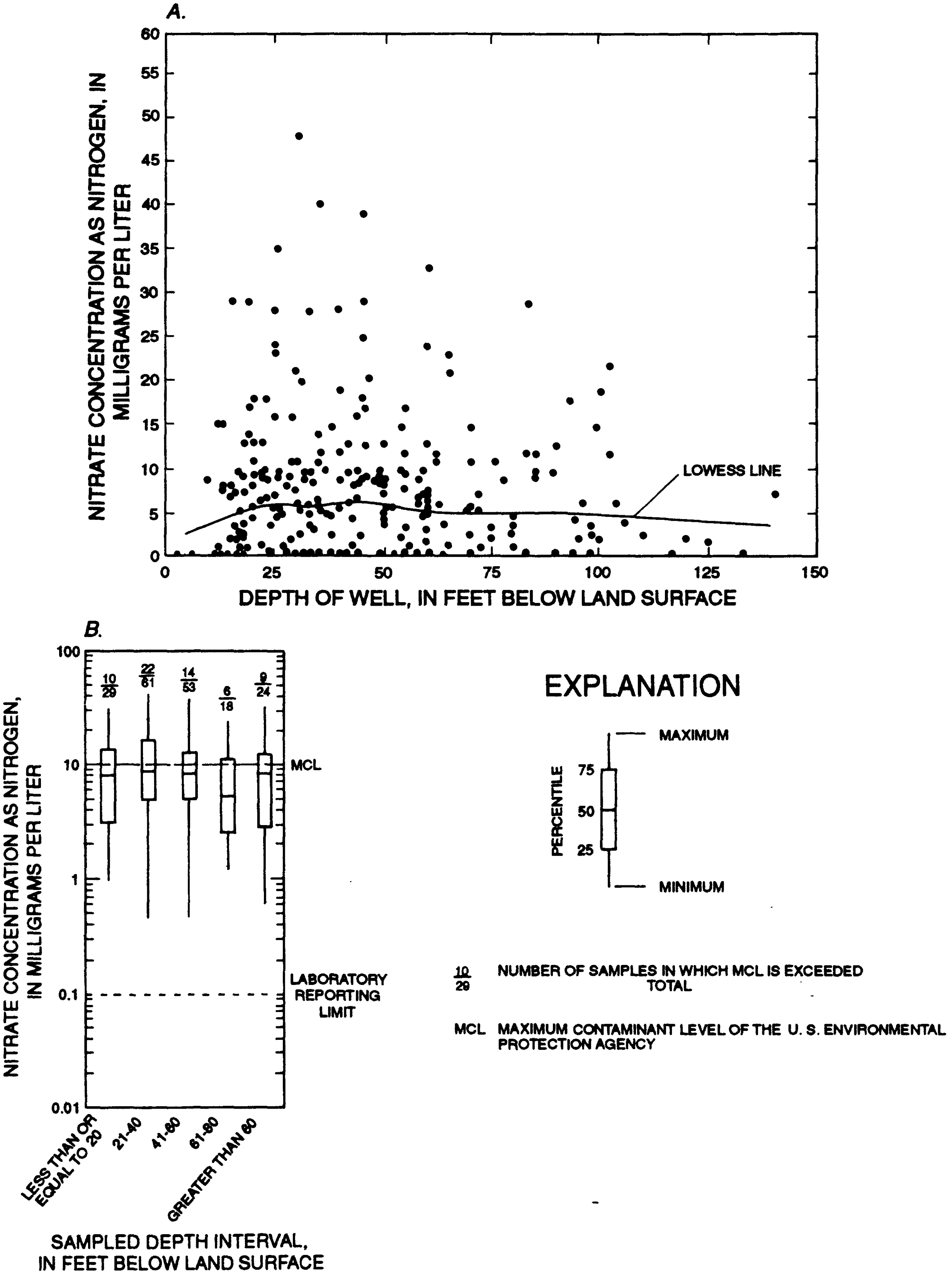


Figure 21. Nitrate concentrations and depth of wells in the surficial aquifer in the Delmarva Peninsula, 1976-90.

Table 22.--Statistical relation between depth of well and values of selected properties and ions in water affected by agricultural activities in the surficial aquifer in the Delmarva Peninsula, 1976-90.[1]

[p-value and coefficient of determination (R^2) computed by Spearman regression analysis;[2] <, less than]

Property or dissolved constituent	p-value	Coefficient of determination (R^2), in percent	Number of analyses
Properties:			
pH	0.002	23.0	185
Specific conductance	<.001	-44.9	185
Alkalinity	.802	-1.9	185
Dissolved constituents:			
Calcium	<.001	-34.5	185
Magnesium	<.001	-44.1	185
Calcium plus magnesium	<.001	-41.1	185
Sodium	.350	-6.9	185
Potassium	<.001	-29.3	185
Iron	.806	1.8	185
Silica	.002	22.6	185
Barium	.317	11.0	85
Strontium	.044	-21.9	85
Sulfate	<.001	-47.4	185
Chloride	<.001	-43.6	185
Nitrate	.463	-5.4	185

[1] Analysis includes water samples collected from wells in the existing network and the NAWQA areal and transect networks. Samples affected by agriculture were determined by use of 1:250,000-scale land-use data (U.S. Geological Survey, 1979a, 1979b, 1979c, 1980a, 1980b, 1980c).

[2] The Spearman correlation analysis is a nonparametric regression test done to examine increasing or decreasing trends in data. The test involves a null hypothesis stating that no real trend exists between categories. An alpha value, or level of significance, is used in the test to represent the maximum probability of rejecting the null hypothesis when it is actually true. The alpha value used in this report is 0.05. 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 trends are assumed to exist between the categories. The coefficient of determination (R^2) indicates the percentage of variability in the ion concentration that can be accounted for by nitrate concentration. A negative number indicates an inverse relation between categories; a positive number indicates a direct relation between categories.

indicated that nitrate concentrations increased significantly with increasing depth to the water table (p-value=0.002), which supports the assumption that depth to the water table might have been a controlling variable in the statistical analysis.

Regional Variation Among Hydrogeomorphic Regions

Hydrogeomorphic regions are characterized by related features--including surficial geology, topography, geomorphology, soil characteristics, and land use--that can impart characteristic regional water-quality patterns. For example, the surficial confined region and lowlands commonly are underlain by clay and silt deposits in the surficial aquifer and include poorly drained soils in the hydrologic soil group D[4] (table 1). The poorly drained soils correspond to a high water table; median depth to the water table at 36 sites measured during 1981-90 in the combined surficial confined region and lowlands was 5.7 ft below land surface. The poorly drained land is less conducive for farming than well-drained land; therefore, these regions have the greatest mix of woodlands with agricultural land (table 1). In contrast, the well-drained uplands are underlain by sand and gravel deposits in the surficial aquifer and are characterized by well-drained soils. The well-drained soils generally are found in areas underlain by a deeper water table than is found in areas of poorly drained soils; the water table in the well-drained uplands (median for 61 sites measured during 1976-90 was 8.9 ft below land surface) is significantly deeper than that in the combined surficial confined region and lowlands (Mann-Whitney test, p-value 0.001). The well-drained uplands provide favorable conditions for farming; therefore, this region has the lowest ratio of woodlands to agricultural land (table 1).

Hamilton and others (1991) report that the median concentrations of nitrate in ground water beneath the poorly drained lowlands, fine-grained lowlands, and the surficial confined region are significantly lower than those in ground water beneath the well-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. Regional distribution of nitrate concentrations among hydrogeomorphic regions in the surficial aquifer was examined further by analysis of additional water samples collected from 103 wells in the NAWQA areal and transect networks and water samples collected from 193 wells in the existing network. Data for the poorly drained and fine-grained lowlands were combined in this analysis because of the small number of chemical analyses for each region. Data for the inner coastal plain were eliminated from the analysis because of a limited number of chemical analyses.

This examination of data confirms results reported by Hamilton and others (1991): the median concentrations of nitrate in ground water beneath the surficial confined region (1.1 mg/L as N for 42 water samples) and poorly drained and fine-grained lowlands (0.1 mg/L as N for 30 water samples) were statistically lower (Kruskal-Wallis test, p-value 0.001) than in ground water beneath the well-drained uplands (median concentration for 125 samples was 8.9 mg/L as N) (fig. 22). In addition, this examination indicates that the median concentration of nitrate was significantly higher (p-value 0.001) in ground water beneath the well-drained uplands than in ground water beneath the poorly drained uplands (median concentration for 82 samples was 4.4 mg/L as N) (fig. 22; table 23). Concentrations of nitrate in water beneath the well-drained uplands exceeded the USEPA MCL in more samples (about 34 percent) than in water beneath the poorly drained uplands (about 20 percent), the combined surficial confined region (about 10 percent), and the lowlands (about 10 percent) (fig. 22).

Median specific conductance and concentrations of constituents affected by agricultural activities, such as calcium, magnesium, potassium, and chloride, also were significantly higher in ground water beneath the well-drained uplands than in ground water beneath the poorly drained uplands (table 23). Median pH and concentrations of iron and silica were significantly lower in water beneath the well-drained uplands than in water beneath the poorly drained uplands (table 23). Median concentrations of sodium and alkalinity were not significantly different (table 23) between the two regions. Depth of well from which water samples were collected introduced minimal variability in the statistical analysis. The median depth of wells in the

---

[4] Hydrologic soil groups are differentiated by runoff potential. Soils in Group A have the lowest runoff potential, and soils in group D have the highest runoff potential when thoroughly wetted (Maryland Department of State Planning, 1973).

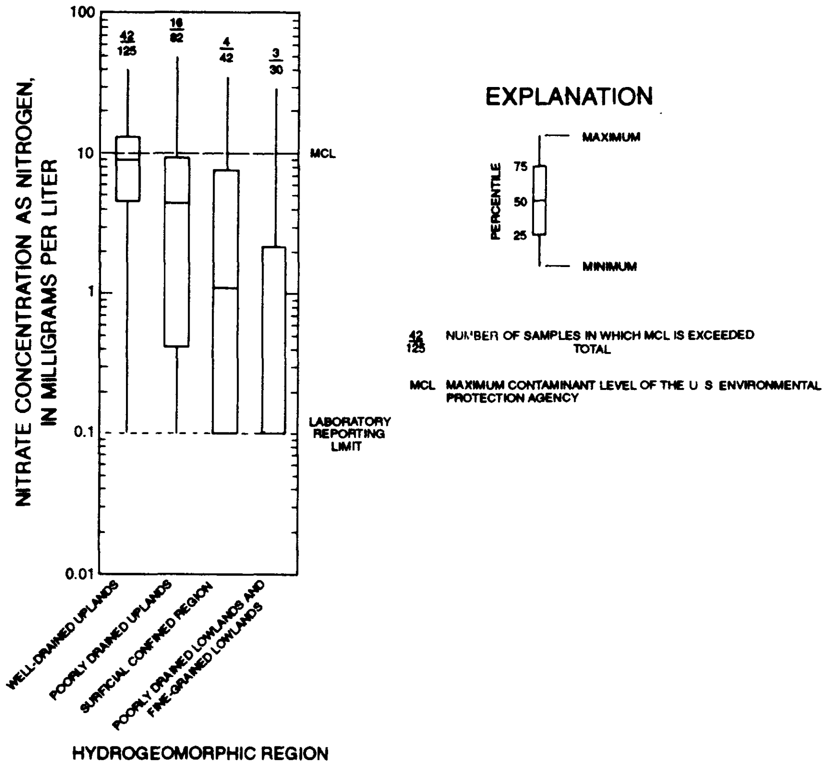


Figure 22. Nitrate concentrations in water collected from wells completed in the surficial aquifer in the Delmarva Peninsula, 1976-90, grouped by hydrogeomorphic region.

well-drained uplands was not significantly different (Mann-Whitney test, p-value = 0.290) from the median depth of wells in the poorly drained uplands.

Results were generally similar when the statistical comparison between water chemistry in the well-drained and poorly drained uplands was restricted to water samples collected from wells in agricultural areas (differences in pH and concentrations of silica and sulfate were not significant between the regions) (table 23). The statistical comparison of ground-water chemistry in the two regions is, therefore, biased minimally by a slightly higher percentage of water samples affected by agricultural activities in the well-drained uplands (about 81 percent) than in the poorly drained uplands (about 66 percent).

Local Stratification of Chemistry Within Hydrogeomorphic Regions

Water quality in the local-scale well networks was examined to assess possible causes of regional patterns of ground-water quality among different hydrogeomorphic regions and at different depths within the surficial aquifer. The hydrogeomorphic regions serve as a conceptual link between regional and local well networks and water-quality patterns. Each region is an aggregation of hundreds of watersheds with similar patterns of ground-water flow and quality. Water-quality patterns observed in the local-scale well networks are presumed to be typical of water-quality patterns within three largest of the six hydrogeomorphic regions (well-drained uplands, poorly drained uplands, and the surficial confined region). Water-quality patterns in the well-drained uplands are illustrated by the Townsend, Fairmount, and Locust Grove networks; water-quality patterns in the poorly drained uplands are illustrated by the Vandyke network; and water-quality patterns in the surficial confined region are illustrated by the Willards network.

Well-Drained Uplands

The well-drained uplands are characterized by permeable and well-drained soils and a relatively deep water table (median depth at 61 sites measured during 1976-90 was 8.9 ft below land surface). Agricultural plots are large and well drained, and woodlands are primarily confined to stream borders. Geology in the

Table 23.--Statistical summary of the quality of water in the well-drained uplands and poorly drained uplands in the surficial aquifer in the Delmarva Peninsula, 1976-90.[1]

[p-value represents Mann-Whitney statistical test;[2] number in parentheses is total number of analyses; <, less than]

Property or dissolved constituent	p-value	Median concentration, in milligrams per liter unless otherwise noted			
		Well-drained uplands		Poorly drained uplands	
ALL WATER SAMPLES					
Properties:					
pH (standard units)	0.003	5.20	(125)	5.40	(82)
Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	<.001	173	(125)	108	(82)
Alkalinity (as calcium carbonate)	.322	5.0	(124)	6.5	(82)
Dissolved constituents:					
Calcium	<.001	9.6	(125)	5.6	(82)
Magnesium	<.001	5.5	(125)	1.8	(82)
Calcium plus magnesium	<.001	16	(125)	9.0	(82)
Sodium	.603	7.3	(125)	7.3	(82)
Potassium	<.001	2.7	(125)	1.9	(82)
Iron (micrograms per liter)	<.001	12	(125)	33	(82)
Silica	.047	14	(124)	15	(82)
Sulfate	.031	6.8	(125)	3.5	(82)
Chloride	<.001	14	(125)	9.3	(82)
Nitrate (as nitrogen)	<.001	8.9	(125)	4.4	(82)
SAMPLES OF WATER AFFECTED BY AGRICULTURE[3]					
Properties:					
pH (standard units)	0.605	5.20	(101)	5.30	(54)
Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	.005	175	(101)	137	(54)
Alkalinity (as carbonate)	.350	5.0	(100)	4.5	(54)
Dissolved constituents:					
Calcium	.002	9.6	(101)	6.1	(54)
Magnesium	.002	5.7	(101)	4.6	(54)
Calcium plus magnesium	.001	16	(101)	12	(54)
Sodium	.728	7.3	(101)	7.4	(54)
Potassium	.153	2.8	(101)	2.3	(54)
Iron (micrograms per liter)	.031	12	(101)	25	(54)
Silica	.571	14	(101)	14	(54)
Sulfate	.081	6.2	(101)	2.0	(54)
Chloride	.024	15	(101)	12	(54)
Nitrate (as nitrogen)	.011	9.2	(101)	6.0	(54)

---

[1] Analysis includes water samples collected from wells in the existing network and the NAWQA areal and transect networks.

[2] The Mann-Whitney test is a hypothesis test used to examine whether variations in data result from chance variability or real differences. The test involves a null hypothesis stating that no real difference exists between the categories. An alpha value, or level of significance, is used in the test to represent the maximum probability of rejecting the null hypothesis when it is actually true. The alpha value used in this report is 0.05. 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 between the categories.

[3] Samples affected by agriculture were determined by use of 1:250,000-scale land-use data (U.S. Geological Survey, 1979a, 1979b, 1979c, 1980a, 1980b, 1980c).

well-drained uplands is nearly homogeneous; the surficial aquifer generally consists of feldspathic quartz sand and gravel with minor amounts of clay and silt.

Townsend Network

The Townsend well network encompasses approximately 1 mi^2 in southern Northampton County, Va. (figs. 6 and 23). The network consists of 16 wells, including 3 clusters (fig. 23; table 4). Water samples were collected at 14 of the 16 wells. Chemical analyses and sampling dates for samples collected at the wells are listed in table 11. Site and well-construction information for wells that were sampled for chemical analysis is listed in table 4. The wells are placed along dominant paths of ground-water flow, which generally is from the west to the east.

Land surface is flat; elevations gently decrease from 40 ft above sea level in the uplands in the western part of the well network area to 5 ft above sea level in the lowlands in the eastern part (fig. 24). Land use is agriculture, with woodlands bordering the stream to the north and the saltmarsh to the east (fig. 23; table 4). Dominant crops are soybeans, wheat, and vegetables. Soils, referred to as the "Bojac" mapping unit, are well-drained sandy loams (table 4).

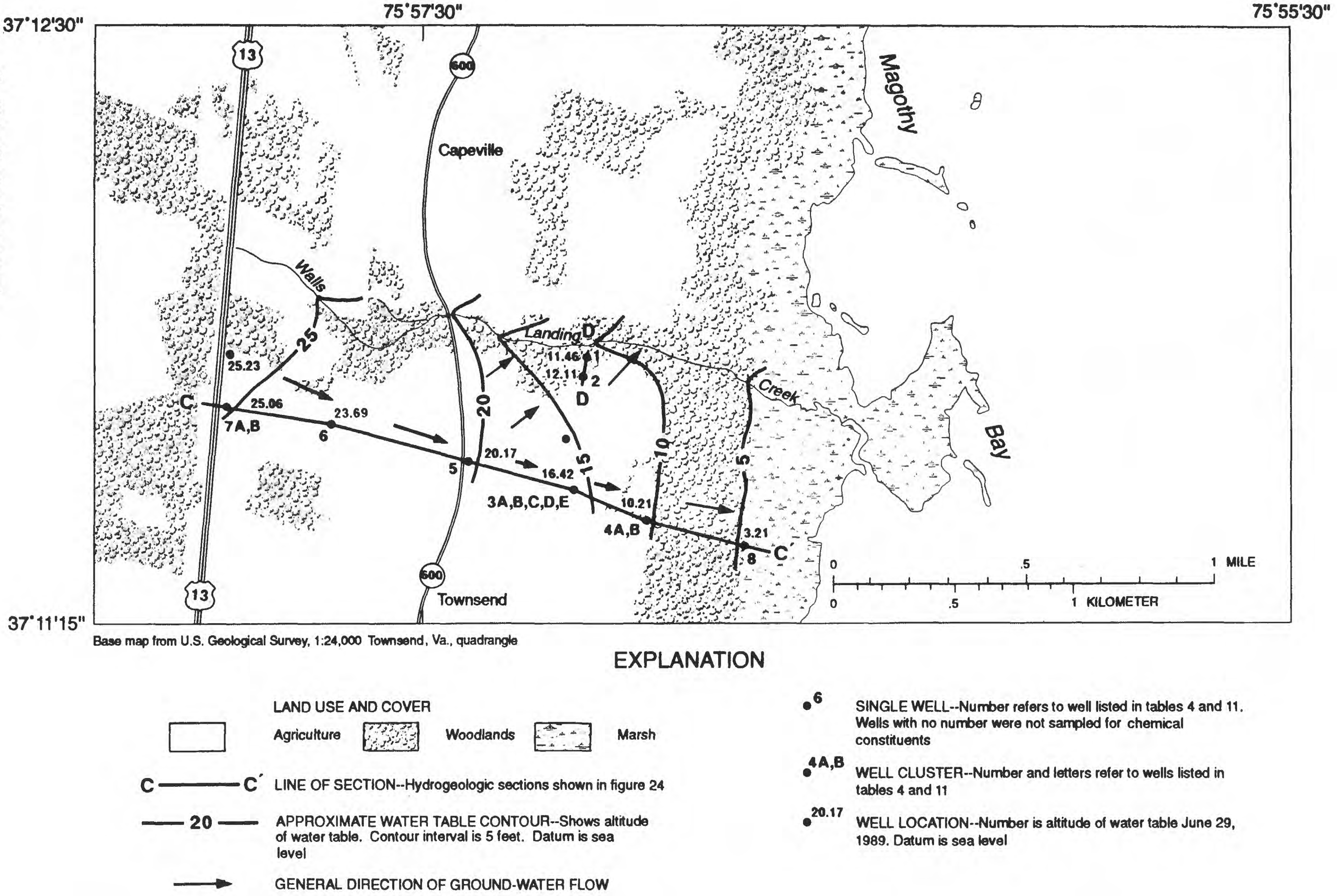
The thickness of the surficial aquifer is approximately 40 ft in the west, thinning to about 20 ft in the east. The aquifer mainly consists of permeable sand and gravel and some shells. Depth to the water table ranges from less than 1 ft below land surface adjacent to the stream and marsh to about 13 ft below land surface in the uplands.

The westernmost source of ground water is at the ground-water divide, a topographic high (approximate land-surface elevation of 40 ft) west of Route 13 (fig. 23). The vertical head difference in the western part of the well network area (a maximum of 0.25 ft at site 7) is downward, indicating ground-water recharge to the surficial and underlying confined aquifers. Ground water is recharged throughout much of the well network area. The vertical head difference in the eastern part of the well network area (a maximum of 0.10 ft at site 4) is upward, indicating ground-water discharge. The major ground-water discharge is to the woodlands adjacent to the saltwater marsh along Magothy Bay (figs. 23 and 24). Some ground water discharges through a local ground-water-flow system to Walls Landing Creek (figs. 23 and 24). This local ground-water-flow system extends from the creek through the woodlands that border the creek and into the adjacent agricultural fields, as indicated by water-level measurements and by water chemistry in the stream.

Ground water sampled 20 ft or less below land surface generally originated as precipitation in the mid- to late-1980's; water in the deeper parts (40 ft below land surface) originated in the early- to mid-1970's (L.N. Plummer, U.S. Geological Survey, written commun., 1992). Withdrawals are insignificant within the well network area, and ground-water flow and quality generally are not affected by ground-water withdrawals.

Ground water sampled in the Townsend well network generally is aerobic, and it is a calcium sulfate type containing elevated concentrations of magnesium, potassium, nitrate, and chloride (table 11). The maximum concentration of nitrate was 34 mg/L as N (well 5; table 11). Concentrations of nitrate change vertically and laterally relative to land use and position in the ground-water-flow system (fig. 24). For example, nitrate concentrations were highest in ground water 20 ft or less below land surface underlying farm fields (fig. 24), whereas nitrate concentrations were less than the laboratory reporting limit (0.1 mg/L as N) in near-surface ground water underlying woodlands or saltwater marshes (fig. 24). Elevated concentrations of nitrate in water 40 ft below land surface (wells 3C and 4B; fig. 24) indicate recharge through upgradient farmland. Nitrate concentrations were minimal or less than the laboratory reporting limit in samples collected from the deepest well (61 ft below land surface) in the network (well 3D; fig. 24 and table 11). This deep ground water generally is anaerobic (table 11), and anaerobic conditions inhibit nitrification of ammonia. The age of the water in this part of the aquifer, which originated as precipitation in the mid-1950's (L.N. Plummer, U.S. Geological Survey, written commun., 1992), reflects a relatively long travel and residence time through an overlying low-permeability clay and silt unit.

Water chemistry at different depths within each cluster is similar where onsite and upgradient land use is the same (wells 3A, 3B, and 3C; fig. 24; table 11). Vertical differences in chemistry are found where onsite and upgradient land use differ. For example, nitrate concentrations in water samples collected from well 4A (8.9 mg/L as N) were lower than concentrations in water samples collected from well 4B (11



Base map from U.S. Geological Survey, 1:24,000 Townsend, Va., quadrangle

Figure 23. Distribution of wells and general flow directions in the surficial aquifer in the Townsend local-scale network in the Delmarva Peninsula.

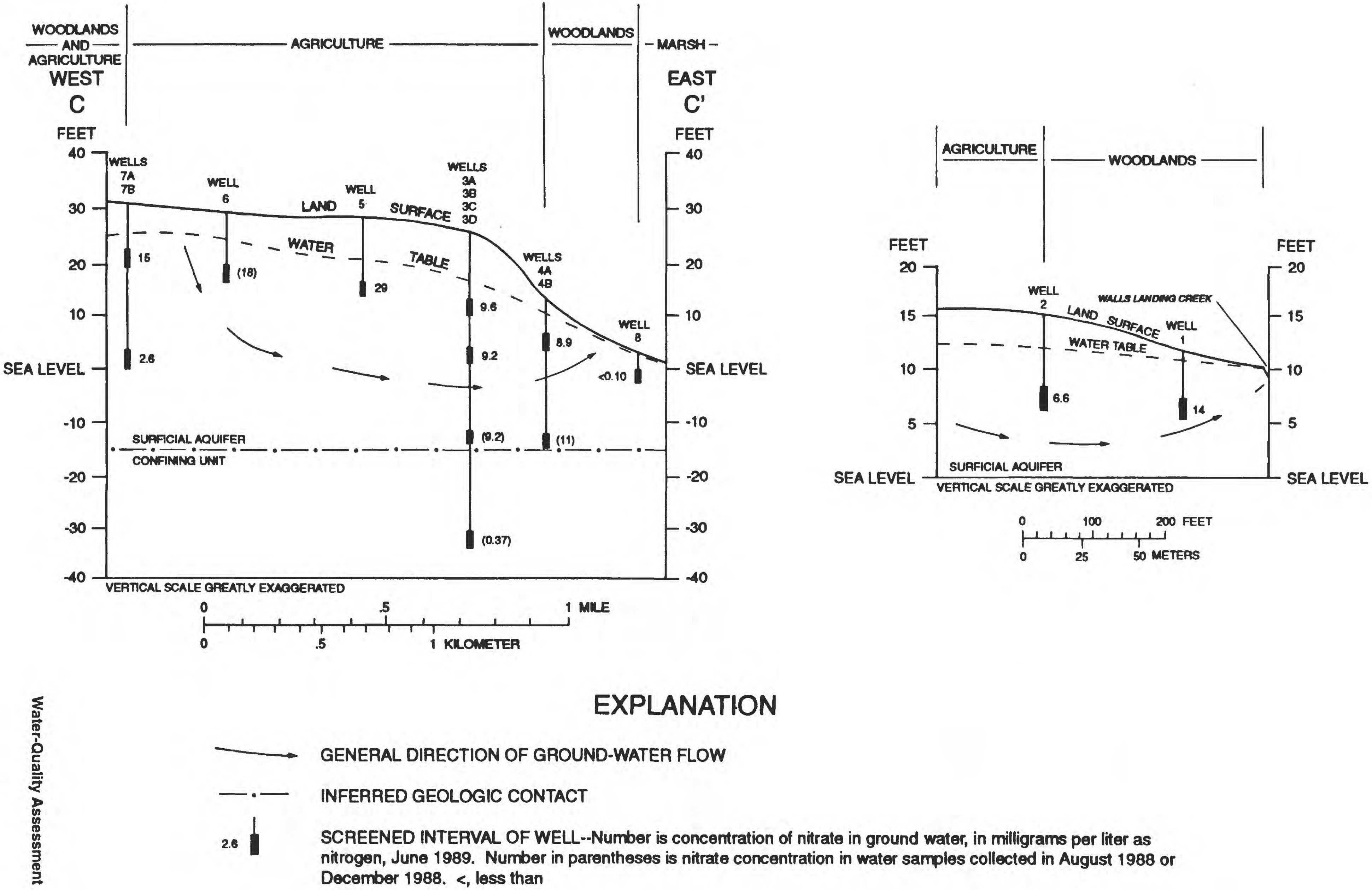


Figure 24. Vertical and lateral changes in nitrate concentration relative to land use and position in the ground-water-flow system in the surficial aquifer in the Townsend local-scale network in the Delmarva Peninsula.

mg/L as N). Well 4A draws water from less than 10 ft below land surface that recharges through onsite woods and farmland. Well 4B draws water from a deeper part of the aquifer (28 ft below land surface) that primarily recharges through upgradient farmland. Concentrations of nitrate (15 mg/L as N) and chloride (54 mg/L) in water samples collected from well 7A were higher than in samples from well 7B (2.6 mg/L as N and 37 mg/L, respectively). Well 7A draws water from about 12 ft below land surface that primarily recharges through land directly affected by highway road salt (within 100 ft of the well) and onsite farm fertilizers. Well 7B draws water from a deeper part of the aquifer (31 ft below land surface) that primarily recharges through mixed woodlands and farmland upgradient from the site. The overall result is a reduced effect of road salt and agricultural chemicals on the deep ground water.

Near-surface ground water in and near discharge areas is commonly recharged on upgradient land rather than on land around the well. Water collected from well 1, a shallow well (7 ft below land surface) in riparian woods next to Walls Landing Creek at the distal part of a local ground-water-flow system (fig. 23), contained 14 mg/L of nitrate. This water recharges through upgradient farmland rather than through onsite woodlands (fig. 24). Concentrations of silica in water samples collected from well 1 (about 13 mg/L) were higher than in samples collected from other near-surface wells (about 5 to 7 mg/L; table 11), indicating additional silicate dissolution along a longer and deeper ground-water-flow path. The water also is older (originated in the early 1970's) than water from other near-surface wells (L.N. Plummer, U.S. Geological Survey, written commun., 1992).

Chemical composition and nitrate concentrations generally were similar during all sampling periods (table 11). Exceptions include (1) variations in sodium and chloride concentrations in water samples collected from well 7A, probably because of variable inputs in the recharge from road salting; and (2) variations in nitrate concentrations in water samples collected from wells 2 and 3A, probably because of alternating cropping practices. Fields near these wells are not farmed every year. In addition, soybeans, which do not require nitrogen fertilizer, are sometimes grown. Therefore, amounts of nitrate and other dissolved constituents applied to the fields probably differ.

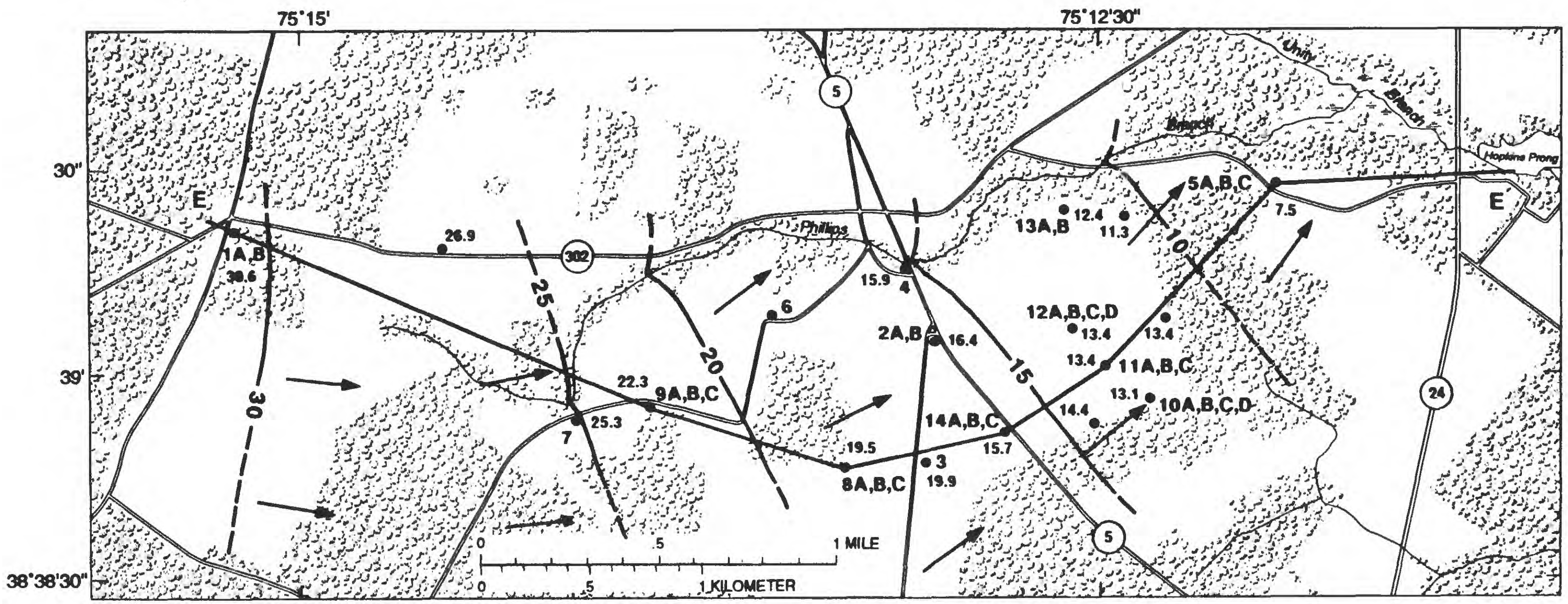
Fairmount Network

The Fairmount well network encompasses approximately 6 1/2 mi in eastern Sussex County, Del. (figs. 6 and 25). This network consists of 53 wells, many of which were installed and sampled during a previous study (Denver, 1989). Water samples were collected at 33 of the wells during the Delmarva NAWQA study (fig. 25; table 5), which included 4 individual wells and 10 clusters of 2 to 4 wells per cluster. Chemical analyses and sampling dates for samples collected at the wells are listed in table 12. Site and well-construction information for wells that were sampled for chemical analysis is listed in table 5. Individual wells within each cluster are screened at different depths in the aquifer that range from near the water table to about 100 ft below land surface. The wells are placed along dominant paths of ground-water flow, which generally is from the west to the east.

Land surface is flat; elevations gently decrease from about 40 ft above sea level in the western part of the well network area to about 10 ft above sea level in the eastern part (fig. 26). Land use primarily is agriculture. Woodlands are in the uplands and in areas adjacent to Rehoboth Bay (fig. 25). Most of the farmland is used to produce corn and soybeans to support the local poultry industry. Many of the farms include large chicken houses, and chicken manure commonly is stored in large piles and applied to fields as fertilizer. Soils are predominantly well-drained sandy loams and include the Evesboro and Rumford mapping units.

The surficial aquifer mainly consists of permeable quartz sand and gravel of the Beaverdam Formation and the sandy strata of the Bethany Formation where it is a subcrop (Andres, 1986). The thickness of the aquifer ranges from 80 to 160 ft depending on the elevation of the land surface and the confining unit. Depth to the water table ranges from less than 1 ft below land surface near discharge areas, such as the stream and bay, to 19 ft below land surface in topographic highs in the uplands.

The vertical head difference in the western part of the Fairmount network area (a maximum of 0.15 ft at site 1) is downward, indicating ground-water recharge to the surficial and confined aquifers. Ground water is recharged throughout most of the well network area. The vertical head difference in the extreme eastern part of the well network area (a maximum of 0.25 ft at site 5) is upward, indicating ground-water discharge. Ground water primarily discharges to an area



Base map from U.S. Geological Survey 1:24,000 Fairmount, Del., and Harbeson, Del., quadrangles

EXPLANATION

LAND USE AND COVER

▭	Agriculture	▨	Woodlands	▨ Marsh

E ——— E′ LINE OF SECTION--Hydrogeologic section shown in figure 26

—— 15 — — WATER-TABLE CONTOUR--Shows altitude of water table. Dashed where approximately located. Contour interval is 5 feet. Datum is sea level. Contours modified from Denver (1989, fig. 5)

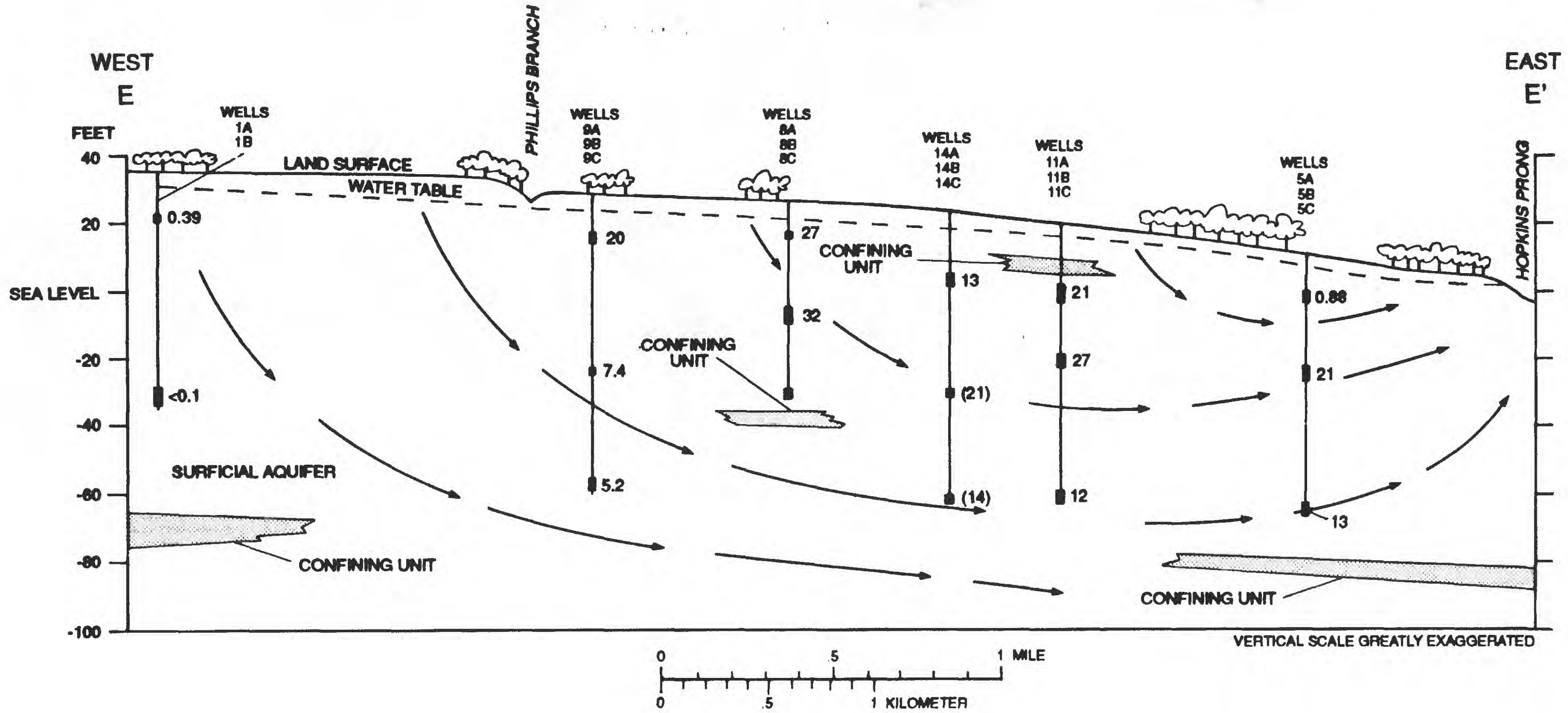
——▶ GENERAL DIRECTION OF GROUND-WATER FLOW

●6 SINGLE WELL--Number refers to well listed in tables 5 and 12. Wells with no number were not sampled for chemical constituents

●2A,B WELL CLUSTER--Number and letters refer to wells listed in tables 5 and 12

●25.3 WELL LOCATION--Number is altitude of water table July, 19, 1989. Datum is sea level

Figure 25. Distribution of wells and general flow directions in the surficial aquifer in the Fairmount local-scale network in the Delmarva Peninsula.



EXPLANATION

→ GENERAL DIRECTION OF GROUND-WATER FLOW

▮ 7.4 SCREENED INTERVAL OF WELL--Number is concentration of nitrate in ground water, in milligrams per liter as nitrogen, June 1989. Number in parentheses is nitrate concentration in water samples collected in December 1989 or January 1990. <, less than

Figure 26. Vertical and lateral changes in nitrate concentration relative to land use and position in the ground-water-flow system in the surficial aquifer in the Fairmount local-scale network in the Delmarva Peninsula.

adjacent to Rehoboth Bay. Some ground water discharges through a local ground-water-flow system to Phillips Branch (fig. 25). This local ground-water-flow system mainly is limited to the wooded riparian zone adjacent to the stream.

Ground water sampled 25 ft or less below land surface originated as precipitation in the mid-1980's; water in the deeper parts (80 ft below land surface) originated in the mid- to late-1960's (L.N. Plummer, U.S. Geological Survey, written commun., 1992). Ground-water flow and quality are affected locally by ground-water withdrawals for irrigation.

Water in the surficial aquifer is a sodium bicarbonate type under natural conditions (as represented by water samples collected in wells 1A and 1B); specific conductance was less than 60 µS/cm, and nitrate concentrations were less than 0.4 mg/L as N (table 12). Water affected by agricultural activities is a calcium magnesium nitrate type (such as represented by water samples collected in wells 8A, 9A, and 11A), dominated by nitrate because of applications of inorganic fertilizer and poultry manure and by calcium and magnesium because of applications of lime. Nitrate, which is stable in aerobic ground water, correlates positively with calcium and magnesium and other constituents affected by agricultural activities, including chloride, potassium, and sulfate (Denver, 1989). Therefore, concentrations of nitrate and calcium plus magnesium are good indicators of the effects of agricultural activities on the quality of ground water in the Fairmount network area.

Concentrations of nitrate change vertically and laterally relative to land use and position in the ground-water-flow system (fig. 26). Nitrate concentrations are highest in ground water underlying farm fields (maximum nitrate concentration was 41 mg/L as N (table 12). Ground water that is recharged through woodlands does not contain elevated concentrations of nitrate (fig. 26). For example, ground water contained concentrations of nitrate less than 0.39 mg/L as N near the upgradient end of the flow system in the western part of the well network area where the recharge area predominantly is wooded (fig. 26). Ground water with minimal nitrate concentrations (0.88 mg/L as N) overlies ground water with higher nitrate concentrations (13 and 21 mg/L as N) near the discharge area in the eastern part of the well network area (fig. 26); the near-surface ground water is recharged through soils covered with natural vegetation, and the deep ground water is recharged through soils in upgradient farmland.

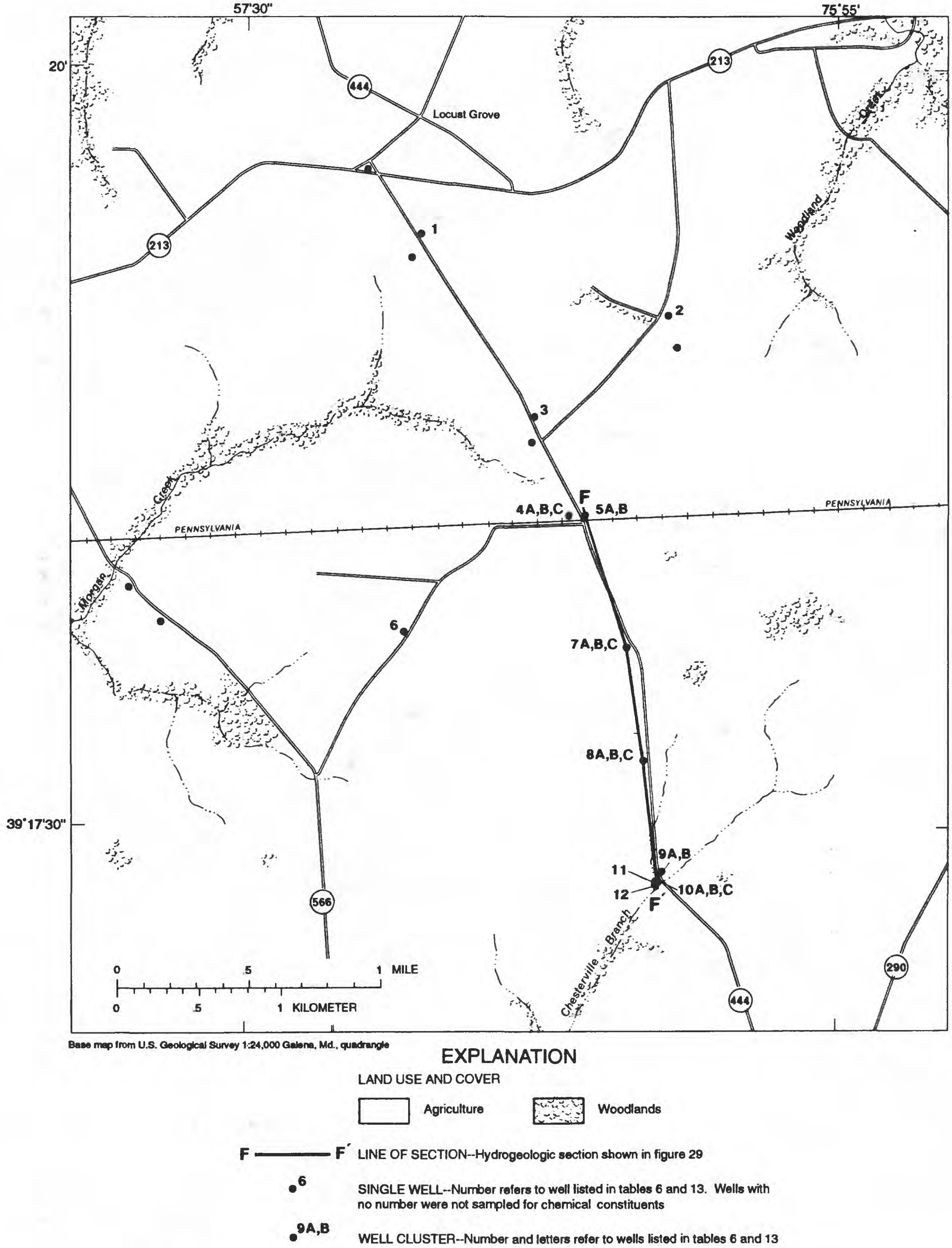
The degree of effects of agriculture on water quality was consistent throughout the period of study in water samples collected from most wells in the Fairmount network (table 12). Concentrations in some water samples collected from wells that are 15 ft below land surface or less (wells 2A, 8A, and 9A; table 12) changed temporally because of changes in chemical inputs with alternating corn and soybean cropping, changes in recharge rates, and changes in the position of the water table.

Locust Grove Network

The Locust Grove well network encompasses approximately 10 mi^2 in central Kent County, Md. (figs. 6 and 27). This network consists of 28 wells, including 12 individual shallow wells (less than or equal to 25 ft) and 6 clusters of 2 to 3 wells per cluster (fig. 27). Water samples were collected at 22 of the wells. Chemical analyses and sampling dates for samples collected at the wells are listed in table 13. Site and well-construction information for wells that were sampled for chemical analysis is listed in table 6. Individual wells within each cluster are screened at different depths in the aquifer that range in depth from 5 to 65 ft below land surface.

The well-network area primarily is agricultural. Woodlands cover less than 5 percent of the area and primarily are restricted to stream borders (fig. 27). Corn and soybeans are the major crops. The land also is used for pasture and to produce nursery stock, such as ornamental trees and bushes. Soils are predominantly well-drained to moderately well-drained silt loams and include the Matapeake and Mattapex-Matapeake-Butlertown mapping units (table 6) (U.S. Department of Agriculture, 1982). The narrow forested areas adjacent to streams are underlain by Bibb silt loam, a poorly drained flood-plain soil.

The surficial aquifer mainly consists of permeable quartz sand and gravel of the Pensauken and Aquia Formations. The surficial aquifer is underlain by less permeable silt and clay of the Monmouth Group. The thickness of the surficial aquifer ranges from about 20 ft at the northwest edge of the well network area to more than 65 ft at the southeast edge near Chesterville Branch. Depth to the water table ranges



Base map from U.S. Geological Survey 1:24,000 Galena, Md., quadrangle

Figure 27. Distribution of wells in the surficial aquifer in the Locust Grove local-scale network in the Delmarva Peninsula.

from less than 1 ft below land surface near the stream to 20 ft below land surface at the inner stream divides. Ground water flows to Morgan Creek, Woodland Creek, and Chesterville Branch (fig. 28). Withdrawals are insignificant within the well network area, and ground-water flow and quality generally are not affected by ground-water withdrawals.

Ground water in the Locust Grove network area is aerobic and nitrate is stable to the base of the surficial aquifer. All water samples collected in the well network showed affects of agricultural activities (nitrate concentrations were greater than 0.4 mg/L as N; table 13). Ground water less than 30 ft below land surface is a calcium magnesium or magnesium calcium nitrate type because of applications of inorganic fertilizers, poultry manure, and lime. Specific conductance is elevated (median of about 185 µS/cm) in this shallow ground water, and alkalinity concentration generally is less than 10 mg/L (table 13) because bicarbonate ion is consumed in buffering reactions with acid produced during nitrification of ammonia. Median concentration of nitrate in samples collected from wells less than 30 ft below land surface was about 10 mg/L as N. Only four wells yielded water that contained nitrate concentrations less than 9.7 mg/L as N (wells 4A, 6, 7A, and 11; table 13). Nitrate concentrations at these sites are low because of dilution from local recharge through the grassy buffers along county roads in the immediate vicinity of the wells.

Ground water at depths greater than 30 ft below land surface generally contains lower concentrations of nitrate (less than 10 mg/L as N) than in the shallow parts of the aquifer (fig. 29). The deep ground water also contains lower concentrations of calcium and magnesium (table 13) and a higher proportion of sodium and bicarbonate because of decreased effects of lime. Overall, effects of agricultural activities on water quality are less evident in the deep water than in water at or near the surface, as indicated by a lower specific conductance (median of about 150 µS/cm). CFC-modeled ages indicate that the deep water originated as precipitation as early as the mid-1950's and that the shallow ground water originated as precipitation as early as the mid-1970's (L.N. Plummer, U.S. Geological Survey, written commun., 1992). Farmed land in the well network area has changed minimally since about 1950, as indicated by USGS topographic maps compiled in 1953 and 1985. Therefore, differences in concentrations of nitrate and other agricultural chemicals in the shallow and deep parts of the aquifer probably result from increases in applications of inorganic fertilizers, manure, and lime, either because of changes in types of crops grown or changes in applications on a continuously grown crop.

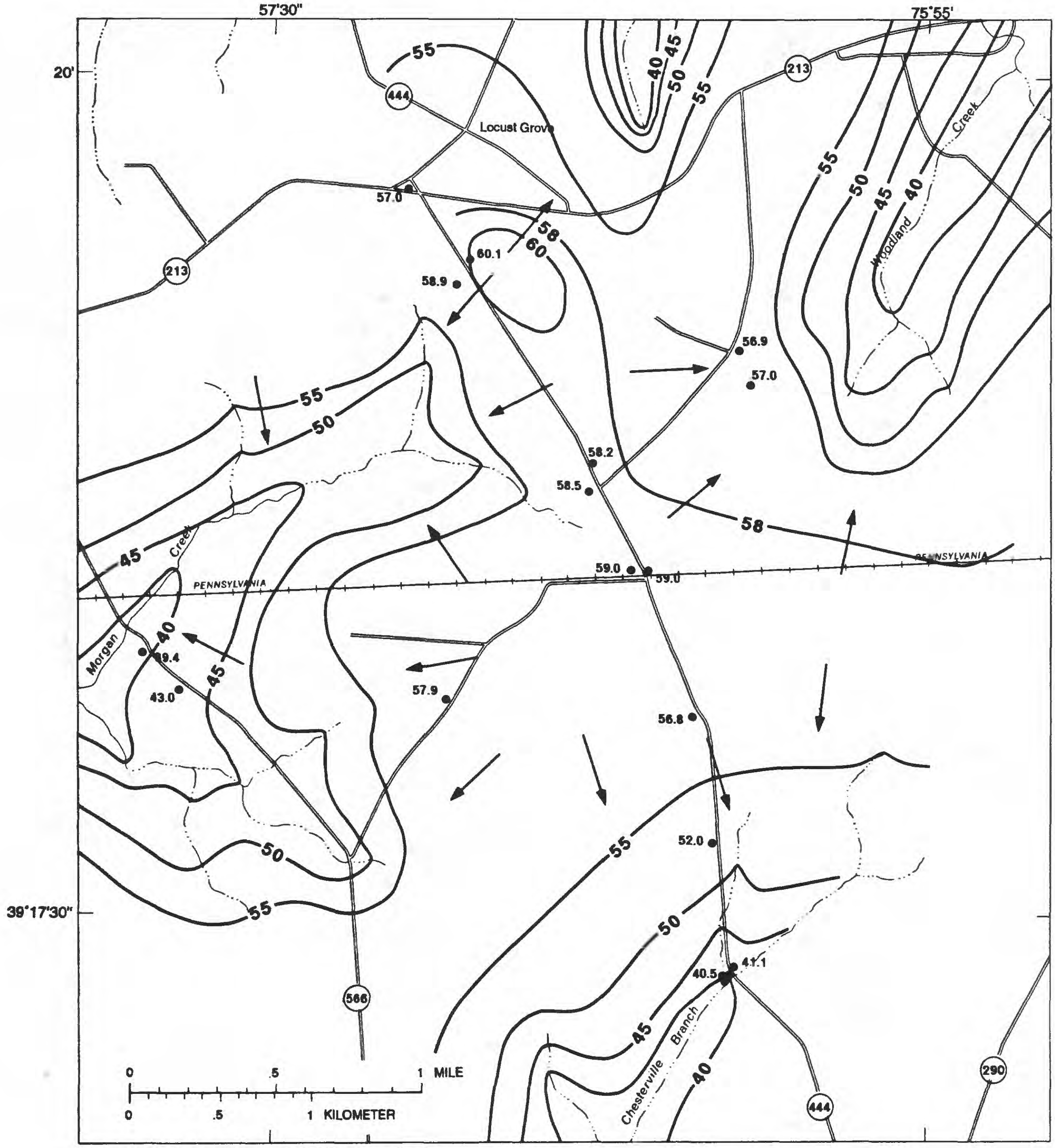
Nitrate concentrations in deep ground water are not lower than concentrations in shallow water at all locations (fig. 29). For example, ground water with nitrate concentrations of 14 and 7.6 mg/L as N at site 7 were overlain by ground water with a nitrate concentration of only 3.1 mg/L as N (fig. 29). Nitrate concentrations in the shallow ground water at this site are lower because of dilution from local recharge through the nearby grassy buffer strip along the road.

Chemistry of shallow ground water in and near discharge areas indicates that the water is recharged through upgradient land rather than through overlying land. For example, ground-water chemistry at well 11, in the forested flood plain, is affected by upward flow that discharges from the regional ground-water-flow system to Chesterville Branch. Ground water collected at this site contained 5.0 mg/L of nitrate and had a specific conductance of 71 mS/cm (table 13). Ground-water chemistry at well 11 is different from water chemistry at well 12 (table 13), even though well 12 is screened at a similar depth and is within 60 ft of well 11. Ground water collected from well 12 contained 10 mg/L of nitrate and had a specific conductance of 260 mS/cm (table 13). Water collected from well 12 is affected by ground-water flow that discharges from the local ground-water-flow system to Chesterville Branch.

The degree of agricultural effects was consistent throughout the period of study in water samples collected from most wells in the Locust Grove network (table 13). Nitrate concentrations in samples collected from the same well generally were within 1 to 2 mg/L as N (table 13).

Discussion

Ground-water chemistry in the well-drained uplands indicates that the water primarily is recharged through well-drained soils in agricultural areas. The ground water generally is aerobic and contains elevated concentrations of nitrate that commonly exceed the USEPA MCL in drinking water. Such concentrations are not limited to near-surface parts of the aquifer but also can be found at the base, as deep as 80 to 100 ft below land surface.



Base map from U.S. Geological Survey 1:24,000 Galena, Md., quadrangle

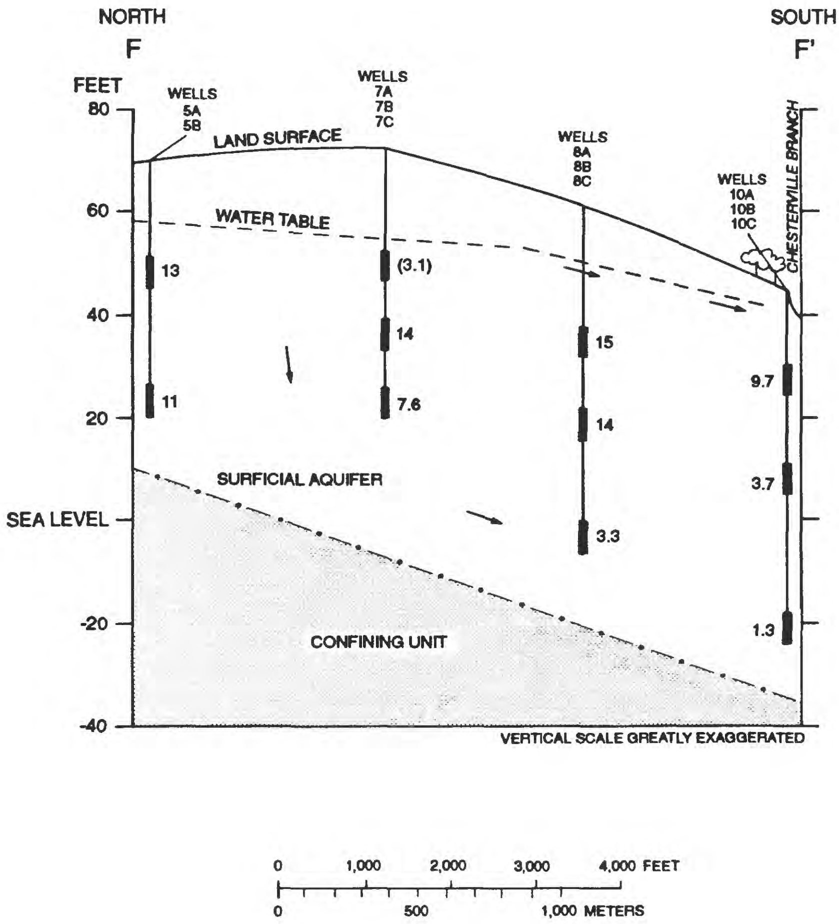
EXPLANATION

—55— APPROXIMATE WATER-TABLE CONTOUR--Shows altitude of water table. Contour interval,in feet, is variable. Datum is sea level

⟶ GENERAL DIRECTION OF GROUND-WATER FLOW

● WELL LOCATION--Number is altitude of water table, November 14, 1990. Datum is sea level. <, less than

Figure 28. General flow directions in the surficial aquifer in the Locust Grove local-scale network in the Delmarva Peninsula.



EXPLANATION

—▸ GENERAL DIRECTION OF GROUND-WATER FLOW

—·— INFERRED GEOLOGIC CONTACT

▮14 SCREENED INTERVAL OF WELL-- **Number is concentration of nitrate in ground water, in milligrams per liter as nitrogen, November 1990. Number in parentheses is nitrate concentration in water samples collected in June 1990. <, less than**

Figure 29. Vertical and lateral changes in nitrate concentration relative to the ground-water-flow system in the Locust Grove local-scale network in the Delmarva Peninsula.

Ground-water chemistry in the well-drained uplands changes vertically and laterally relative to land use and position in the ground-water-flow system. Specifically, ground water less than about 30 ft below land surface generally is recharged through overlying land within about 100 to 200 ft of a well. Nitrate concentrations are highest beneath farmland and lowest beneath woodlands and marshes. Ground-water chemistry in deep parts of the aquifer is recharged through upgradient land rather than land directly around the well. In parts of all three local-scale well networks, deep ground water containing elevated concentrations of nitrate is overlain by ground water with lower nitrate concentrations. This vertical variability of nitrate concentration is most common beneath marshes and woodlands adjacent to streams and other discharge areas. In these areas, the shallow ground water is recharged locally through soils covered with natural vegetation, and the deep ground water is recharged through soils in distant upgradient farmland.

Vertical and lateral changes in water chemistry relative to land use and position in the ground-water-flow system, observed in the three local-scale well networks, also were observed at the areal and transect sites in the well-drained uplands. For example, concentrations of nitrate were highest (measured concentrations reached a maximum of 29 mg/L as N) in near-surface parts of the aquifer directly underlying farmland (areal sites P17 S and P24 S, table 9; and transect sites KE 201, WY 103, SX 202, WR 402S, and W6, table 10). Concentrations were elevated in deep parts where upgradient land is farmed (areal sites P 8 D and P 16 D, table 9; and transect sites LG 205D, table 10). Nitrate concentrations were elevated beneath or downgradient from residential areas because of the discharge of septic-tank effluent and the application of lawn fertilizers (areal sites P 11 S and P 21 S; table 9).

Chemistry of shallow and deep water at the areal and transect sites differ where onsite and upgradient land use differ. For example, water collected from the shallow well at site P 14 predominantly was a sodium chloride type that contained elevated nitrate (table 9), indicating recharge through an onsite residential area; water collected from the deep well at site P 14 predominantly was a calcium magnesium nitrate type, indicating recharge through upgradient farmland (table 9).

Chemistry of shallow and deep water is similar at the areal and transect sites where onsite and upgradient land use is the same (such as at areal site P8A; table 9). Water chemistry also is similar at sites near discharge areas (such as at areal site P 6; table 9) where both shallow and deep ground water includes upward discharge of water that recharges through upgradient land. Water chemistry is similar at sites near recharge areas (such as at areal site P 21; table 9) where both shallow and deep ground water is recharged through onsite land.

Poorly Drained Uplands

The poorly drained uplands are in the headwaters of drainage basins containing sluggish streams that flow through poorly defined valleys with low gradients. The poorly drained uplands are marked by a hummocky topography and depressions that contain seasonal ponds most years (U.S. Department of Agriculture, 1970a). Geology in the poorly drained uplands is nearly homogeneous; the surficial aquifer generally consists of feldspathic quartz sand and gravel with minor amounts of clay and silt. The water table generally is shallow; median depth to the water table at 35 sites measured during 1981-90 was 6.7 ft below land surface.

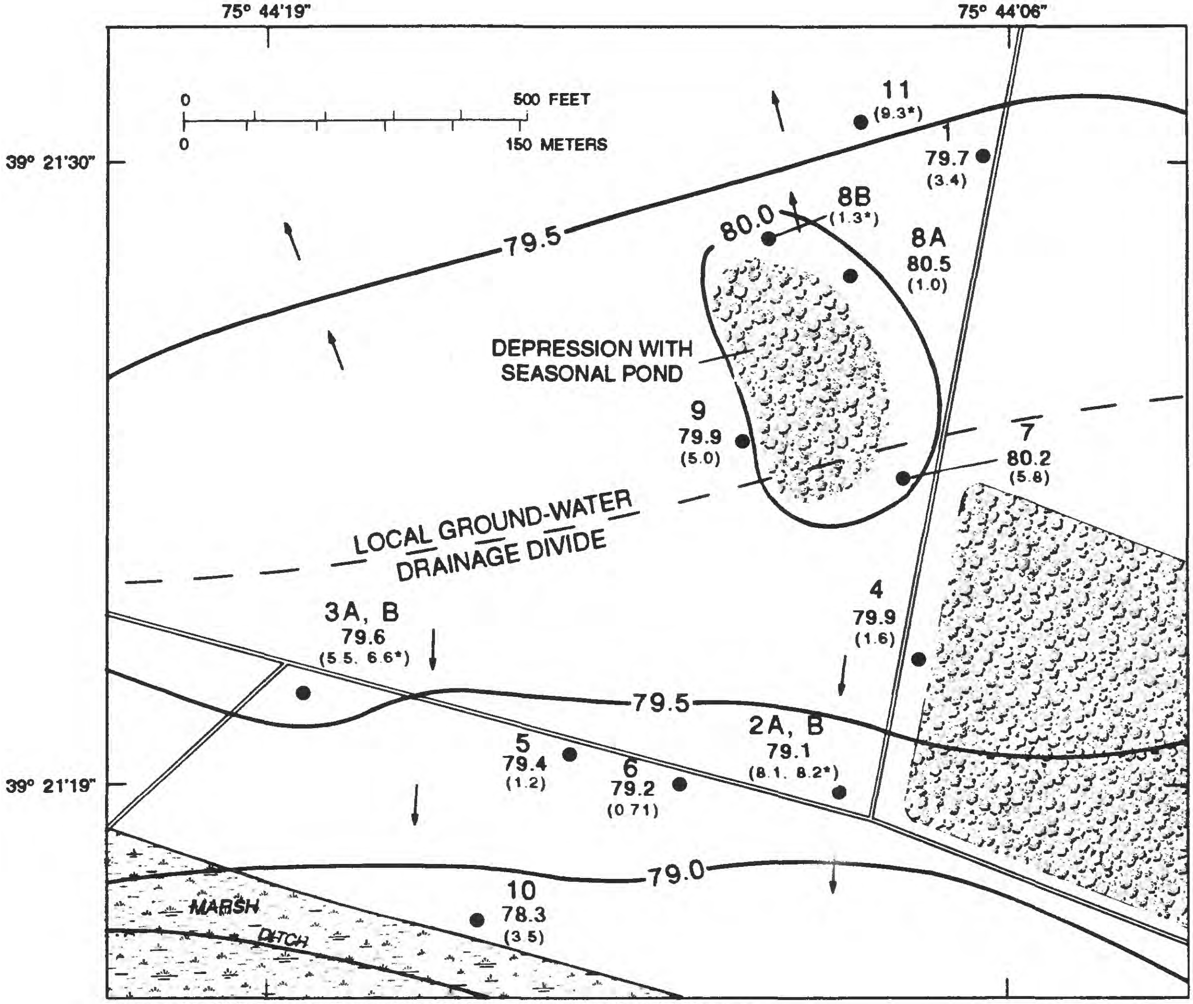
Vandyke Network

The Vandyke network encompasses less than 1 mi^2 (approximately 35 acres) in southwest New Castle County, Del. (figs. 6 and 30). This network consists of 14 wells (fig. 30; table 7). Water samples were collected at each of the 14 wells. Site and well-construction information, chemical analyses, and sampling dates are listed in tables 7 and 14. Most of the wells are screened less than 5 ft below the water table and range in depth from 11 to 23 ft below land surface. Deeper wells, ranging from 25 to 30 ft below land surface, were installed adjacent to the shallow wells at three locations (fig. 30; table 14).

The well-network area primarily includes an agricultural field with a wooded depression containing a seasonal pond (fig. 30). Corn and soybeans are grown in the field. Topography is hummocky with gentle relief; land-surface elevation ranges from about 90 ft in the field to about 79 ft in the depression. Higher elevations in the well network area are underlain by medium- to coarse-textured, well-drained, sandy loams (referred to as the "Sassafras" mapping unit) and are farmed. Low flats and depressions are underlain by poorly drained sandy loams (referred to as the "Pocomoke" mapping unit) and are wooded.

The surficial aquifer primarily consists of medium- to coarse-grained quartz sand and gravel of the Pensauken Formation, with minor amounts of clay and silt. The thickness of the aquifer ranges from about 30 to 40 ft. Sand grains typically are stained with limonite (iron hydroxide), and limonite crusts are common, particularly at the base of the unit. Cores from a boring on the edge of the pond included 3 ft of dark gray, organic-rich sediments at the surface containing progressively more oxidized sand with depth. The aquifer uncomformably overlies a 40-ft-thick clay and silt unit of the Chesapeake Group.

Ground-water-flow paths are short and localized at the Vandyke site. A local drainage divide, determined on the basis of water levels and topographic and geomorphic features, trends approximately southwest to northeast through the area (fig. 30). Directions of ground-water flow temporally vary, particularly around the depression. During dry periods, the water



Base map from U.S. Geological Survey 1:24,000 Clayton, Del. quadrangle and field surveys

EXPLANATION

☐ Agriculture ▨ Woodlands ▤ Marsh

— 79.0 — APPROXIMATE WATER-TABLE CONTOUR--Shows altitude of water table. Contour interval is 0.5 feet. Datum is sea level. Location of ground-water drainage divide based on water levels and topographic and geomorphic features

→ GENERAL DIRECTION OF GROUND-WATER FLOW

9
79.9 ●
(5.0) SINGLE WELL--Numbers refer to well listed in tables 7 and 14 and altitude of water table June 14, 1989. Datum is sea level. Number in parentheses is concentration of nitrate in ground water, in milligrams per liter as nitrogen, June 1989. Number with asterisk is nitrate concentration in water samples collected in January 1990

3A, B
79.6 ●
(5.5, 6.6*) WELL CLUSTER--Number and letters refer to wells listed in tables 7 and 14. Number is altitude of water table, June 14, 1989. Datum is sea level. Number in parentheses is concentration of nitrate in ground water, in milligrams per liter as nitrogen, June 1989. Number with asterisk is nitrate concentration in water samples collected in January 1990

Figure 30. Nitrate concentrations and general flow directions in the surficial aquifer in the Vandyke local-scale network in the Delmarva Peninsula.

table is below the base of the depression and is flat, sloping gradually away from the divide towards the headwaters of local streams. When the water table rises and intersects the depression, an ephemeral pond is formed, and the water-table gradient increases. When the water table drops, it mounds around the pond because of slow infiltration through the fine-grained sediments, and the pond recharges the aquifer. The water table does not follow topography and commonly is higher near the depression than elsewhere.

Water in the surficial aquifer under natural conditions is a sodium bicarbonate type (as represented by water samples collected in well 8B); specific conductance was 59 µS/cm (table 14). Although ground water collected at this site exhibited nearly natural water chemistry, it contained 1.3 mg/L of nitrate (fig. 30; table 14), indicating some effects of agriculture but not enough to dominate its natural composition.

Most of the water samples collected from wells in the Vandyke network and analyzed for water quality showed effects of agricultural activities; however, none of the nitrate concentrations exceeded the USEPA MCL for drinking water (fig. 30; table 14). The maximum concentration was 9.4 mg/L as N (table 14). Both aerobic and anaerobic conditions affect concentrations of nitrate and other constituents in ground water in the Vandyke network area. Ground water that is recharged through well-drained soils in the agricultural field is aerobic and generally is a calcium magnesium nitrate type (sites 2, 3, and 11; table 14). Ground water that is recharged through poorly drained soils (primarily in the pond area) is anaerobic. In the anaerobic ground water, calcium and magnesium are the dominant cations because of applications of lime, but chloride or bicarbonate are the dominant anions instead of nitrate because nitrate formation is inhibited. In general, the concentration of dissolved iron in the anaerobic water is higher than in the aerobic water (table 14). Substantial concentrations of nitrate and dissolved iron commonly were present in water samples collected in the Vandyke network (wells 6, 7, 8A, and 9; table 14) because the wells, particularly around the pond, draw water from aerobic and anaerobic parts of the aquifer.

Sodium and chloride concentrations in ground water were sometimes elevated along the shoulder of County Road 47 and around the pond probably because of road salting (table 14). Sulfate concentrations also were elevated near County Road 47, although the source of sulfate is unknown. The water in these wells recharges through the grassy shoulder and is affected by runoff from the road and agricultural chemicals.

Water chemistry was consistent throughout the period of study in water samples collected from most wells in the Vandyke network (table 14) with the exception of well 9 on the perimeter of the pond area. Nitrate concentrations in ground water collected from well 9 ranged from less than 0.1 mg/L as N (the laboratory reporting limit) to 5.0 mg/L as N. Ground water collected from this well represents a mix of water from aerobic and anaerobic parts of the aquifer. The mixture changes as redox conditions vary over time. In addition, the mixture changes with seasonal variations in rainfall; during wet periods, the pond extends beyond the well site into the well-drained agricultural field.

Discussion

Nitrate concentrations in ground water in the Vandyke network area generally are lower than those measured in the networks in the well-drained uplands because of several factors. First, ground water in the Vandyke network commonly is a mix of aerobic water (which recharges through well-drained soils in farmland) with anaerobic water (which recharges through poorly drained woodlands). The overall result is a reduced effect of agricultural chemicals on ground-water chemistry. The abundant mix of woodlands with farmland and the mix of well-drained sediment with poorly drained sediment in the Vandyke network area results from the poorly incised and hummocky topography typical of the poorly drained uplands. Second, soils in the Vandyke network area have a greater organic content and a greater percentage of silt and clay than soils in the networks in the well-drained uplands. The silt, clay, and organic matter can inhibit leaching and transport of fertilizers from the soil zone. Finally, agricultural practices are different in the Vandyke network area, particularly regarding the use of poultry manure (poultry manure is not applied in the area of the Vandyke well network).

Ground-water chemistry in the area of the Vandyke network and other areas in the poorly drained uplands changes vertically and laterally relative to land use and position in the ground-water-flow system. Similar to ground water in the well-drained uplands, nitrate concentrations in near-surface ground water generally is recharged through overlying land, and nitrate concentrations in deep ground water is recharged through more distant upgradient land.

Surficial Confined Region

The surficial confined region of the peninsula is characterized by complex and heterogeneous hydrogeology. The surficial aquifer consists of the Beaverdam Sand and the Parsonsburg Sand separated in places by discontinuous clay and silt deposits of the Walston Silt, Omar Formation, and Kent Island Formation. Soils generally are poorly drained (table 1). Ground-water flow is complex in this area. Flow paths are short (thousands of feet) and highly localized in the Parsonsburg Sand and longer (several miles) in the Beaverdam Sand. The water table is shallow; median depth to the water table at 36 sites measured during 1981-90 was 5.7 ft below land surface.

Willards Network

The Willards well network encompasses approximately 28 mi^2 in eastern Wicomico Country, Md. (figs. 6 and 31). This network includes 15 wells that are distributed among 8 sites (fig. 31). The network includes one shallow well in the Beaverdam Sand and seven clusters of two wells per cluster. A shallow well is screened near the base of the Parsonsburg Sand and a deep well is screened in the upper 10 to 20 ft of the Beaverdam Sand at six of the seven clusters. The shallow well is in the alluvium at the remaining cluster. Water samples were collected at 11 of the wells in the Willards network. Chemical analyses and sampling dates for samples collected at the wells are listed in table 15. Site and well-construction information for wells that were sampled for chemical analysis is listed in table 8.

The well network area includes interspersed agricultural land and woodlands (fig. 32). Most of the farmland is used to produce soybeans and corn. Many of the farms include large chicken houses, and chicken manure commonly is stored in large piles and applied to fields as fertilizer. Woodlands primarily are in interfluves between ditches and streams and in low-lying areas that fringe Green Run and Pocomoke River. Soils in the Willards network area are poorly drained, sandy or silty loams and include the Pocomoke and Fallsington mapping units (table 8) (U.S. Department of Agriculture, 1970b). Some well-drained sandy soils, including the Galestown and Evesboro mapping units, are along sand ridges.

The surficial aquifer consists of the Beaverdam Sand at its base, overlain by 10 to 30 ft of clay and silt of the Walston Silt in the western part of the well network area, and 10 to 25 ft of clay, silt, peat, and sand of the Omar Formation in the eastern part of the well network area (fig. 31). The Walston Silt, Omar Formation, and Beaverdam Sand are overlain by 10 to 25 ft of the Parsonsburg Sand. Alluvium deposits form the flood plains of Green Run and Pocomoke River. These deposits are 10 to 20 ft thick and include sand, peat, clay, and gravel (Owens and Denny, 1979a).

Land-surface elevations decrease from about 75 ft above sea level west of Route 353 in the western part of the well network area to about 25 ft above sea level near the Pocomoke River (fig. 31). Ground-water flow in the Parsonsburg Sand does not parallel the regional topographic gradient from west to east but is affected locally by agricultural ditches and small streams (fig. 31). The Parsonsburg Sand is recharged by precipitation throughout most of the area. CFC-modeled ages indicate that water in the Parsonsburg Sand originated as precipitation in the mid- to late 1970's (L.N. Plummer, U.S. Geological Survey, written commun., 1992).

Ground-water flow in the Beaverdam Sand generally follows the regional west to east topographic gradient; water levels in the Beaverdam Sand range from 50 ft above sea level in the western part of the Willards network area to about 30 ft above sea level in the eastern part of the well network area (fig. 31). The westernmost source of ground water to the Beaverdam Sand is the Parsonsburg divide at the topographic high. CFC-modeled ages indicate that some of the water in the Beaverdam Sand is about 50 years old, originating as early as the mid-1940's (L.N. Plummer, U.S. Geological Survey, written commun., 1992).

Ground water recharges the Beaverdam Sand by downward leakage from the Parsonsburg Sand throughout most of the well network area, as indicated by downward vertical water-level gradients (fig. 31). The silt and clay of the Walston Silt and Omar Formation inhibit, but do not prevent, vertical flow between the Parsonsburg Sand and Beaverdam Sand. In areas where the Walston Silt and Omar Formation are thin or absent (west of cluster 5; fig. 31) and where the Omar Formation is sandy (cluster 6; fig. 31), the hydraulic connection between the Parsonsburg Sand and Beaverdam Sand is increased. Ground-water recharge to the Beaverdam Sand is increased in the areas of increased hydraulic connection. Ground water discharges from the Beaverdam Sand into the Pocomoke River (about 25 ft above sea level) and near other

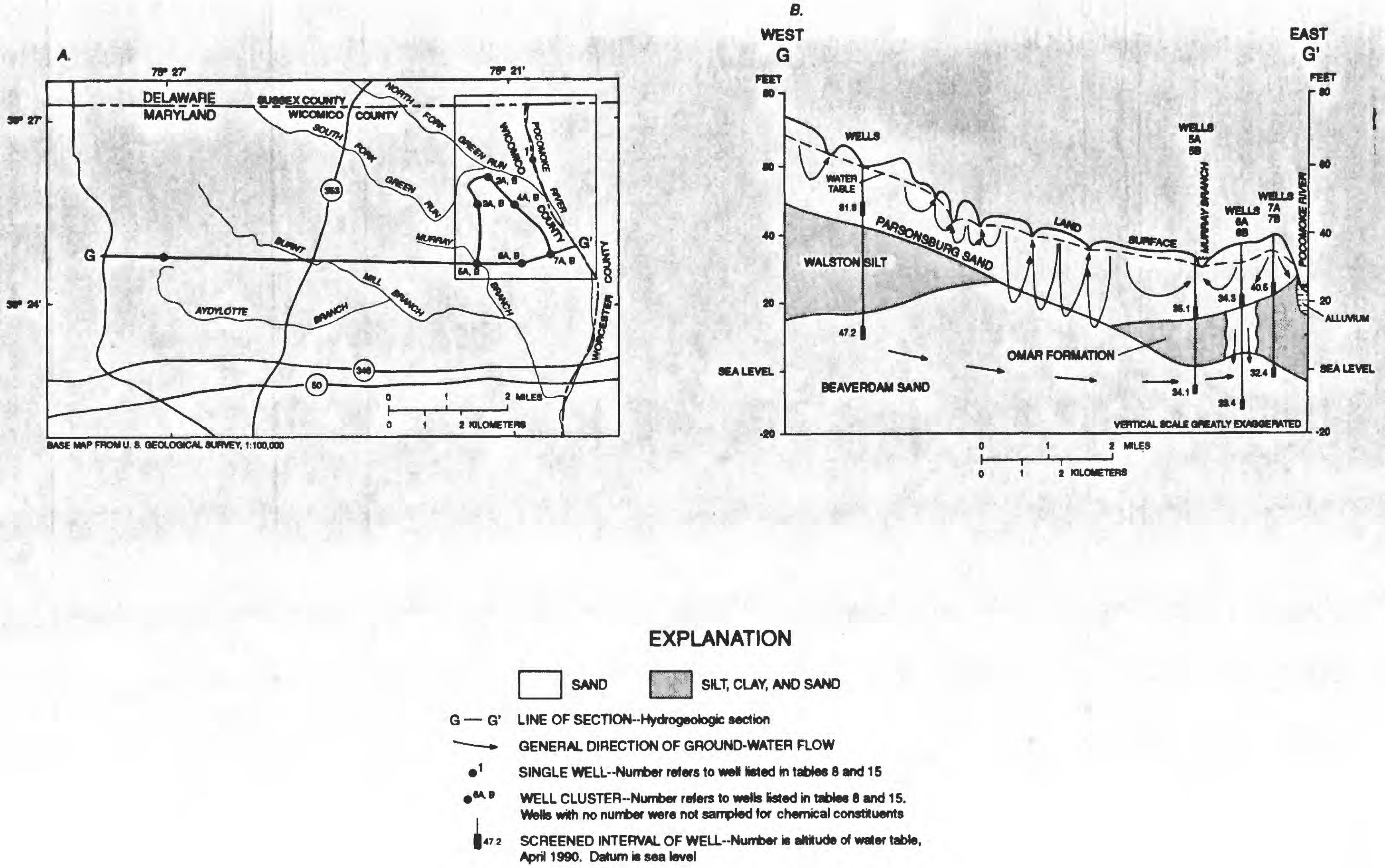
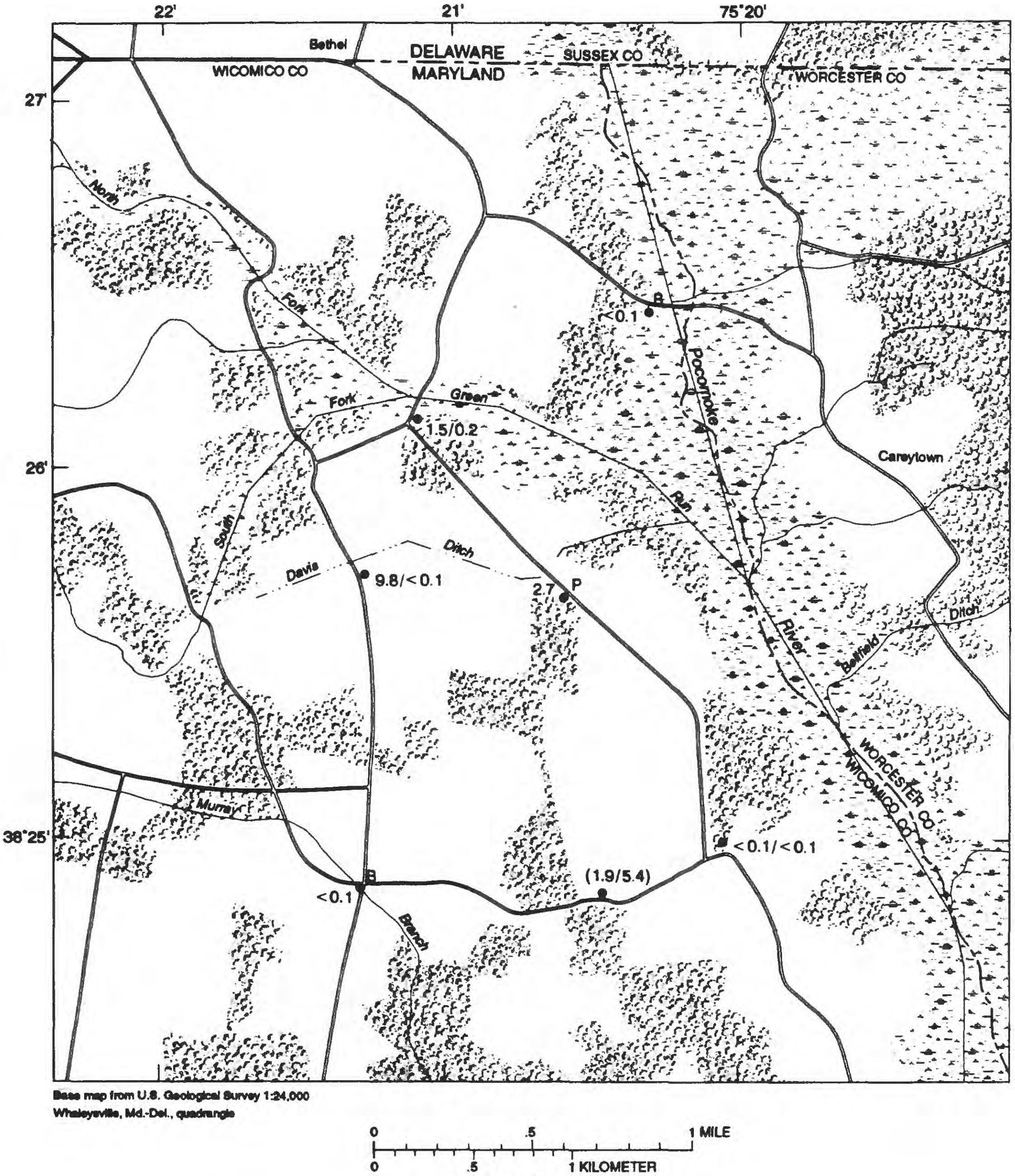


Figure 31. (A) Distribution of wells in and (B) hydrogeologic section of the surficial aquifer in the Willards local-scale network in the Delmarva Peninsula.



Base map from U.S. Geological Survey 1:24,000
Whaleyville, Md.-Del., quadrangle

EXPLANATION

LAND USE AND COVER

☐ Agriculture ▨ Woodlands ▤ Marsh

WELL LOCATIONS--

<0.1●B Number is concentration of nitrate in ground water, in milligrams per liter as nitrogen, June 1990. B, refers to well completed in Beaverdam Sand; P, refers to well completed in Parsonsburg Sand. <, less than

(1.9/5.4) Numbers are concentrations of nitrate in ground water, in milligrams per liter as nitrogen, June 1990. First number refers to well completed in Parsonsburg Sand or alluvium. Second number refers to well completed in Beaverdam Sand. Numbers in parentheses refer to nitrate concentrations in water samples collected in March 1991. <, less than

Figure 32. Nitrate concentrations in the surficial aquifer in the Willards local-scale network in the Delmarva Peninsula.

streams where the water-level gradient is upward, such as at site 2, which is about 500 ft from Green Run (fig. 31). The water table near site 6 is depressed slightly because of the combined effects of recharge to the aquifer and increased vertical leakage to the Beaverdam Sand through the sandy sediments of the Omar Formation (fig. 31).

Ground-water chemistry in the Parsonsburg Sand is mixed. The water contains low concentrations of dissolved iron (less than 100 mg/L in water samples from three of the four wells) and low concentrations of silica (less than 10 mg/L; table 15). Although nitrate commonly is present, ranging from less than 0.1 mg/L as N (the laboratory reporting limit) to 9.8 mg/L as N (table 15), it does not dominate the chemistry. Water in the Parsonsburg Sand reflects the chemistry of precipitation and minimal silicate dissolution along short and local ground-water-flow paths.

Concentrations of nitrate change laterally relative to land use in the Parsonsburg Sand (fig. 32). Nitrate concentrations were highest (9.8 mg/L as N) in water samples collected from well 3A in an agricultural field consisting of a well-drained loamy sand (fig. 32; table 15). Nitrate concentrations were lower (2.7 mg/L as N) in samples collected from well 4A in an area between woodlands and farmland consisting of a poorly drained sandy loam (fig. 32; table 15). In addition to nitrate, water samples from well 4A also contained elevated concentrations of dissolved iron (940 mg/L) and low concentrations of dissolved oxygen (0.3 mg/L) (table 15), representing a mix of anaerobic water (recharged through the woodlands) and aerobic water (recharged through the farmland). Concentrations of nitrate were less than the laboratory reporting limit (0.1 mg/L as N) in water samples collected from well 7A (fig. 32), the only well in the Parsonsburg Sand where nitrate was not reported. Water samples collected from well 7A had a low pH (4.3) and contained an elevated concentration of ammonia (3.4 mg/L as N) and a substantial concentration of dissolved oxygen (4.1 mg/L) (table 15). The presence of ammonia in aerobic ground water indicates that the ammonia source is nearby because nitrification to nitrate did not occur. The ammonia probably results from applications of manure generated from chicken houses within 300 ft of the well.

Water in the Beaverdam Sand generally is a mixed-cation bicarbonate type, with concentrations of dissolved iron generally greater than 1,000 mg/L (table 15). Concentrations of silica in the Beaverdam Sand (generally greater than 30 mg/L) are higher than those in the Parsonsburg Sand (table 15). Water sampled from well 6B did not contain elevated concentrations of iron (less than 100 mg/L) or elevated concentrations of silica (less than 10 mg/L; table 15) and the water originated more recently (mid-1970's) than water in other parts of the Beaverdam Sand. Ground-water chemistry and age in the Beaverdam Sand at site 6 resemble that of the overlying Parsonsburg Sand because of increased recharge through the sandy facies of the Omar Formation (fig. 31). Chemistry of water collected from well 2A, a near-surface well that taps alluvium adjacent to Green Run, contained 61,000 mg/L of iron and 44 mg/L of silica (table 15). The iron and silica concentrations, in combination with water levels, indicate that ground water discharges from the underlying Beaverdam Sand into the alluvium.

Nitrate concentrations in the Beaverdam Sand generally were less than the laboratory reporting limit (0.1 mg/L as N; fig. 32; table 15). Elevated concentrations of dissolved iron and low dissolved oxygen (table 15) indicate that these waters are reducing; nitrate is not stable. Water samples collected from well 6B were the only samples from the Beaverdam Sand that contained elevated concentrations of nitrate (ranging from 2.0 to 5.4 mg/L as N; table 15). Nitrate concentrations were elevated at site 6 in the Beaverdam Sand because of the direct hydrologic connection to the overlying Parsonsburg Sand through the sandy Omar Formation. The predominant form of nitrogen in the Beaverdam Sand is either ammonia or organic nitrogen. Sources of this nitrogen are difficult to distinguish because of the complex geology and ground-water flow.

The chemical composition of ground water was consistent in samples collected from wells in the Willards network throughout the period of study (table 15).

Discussion

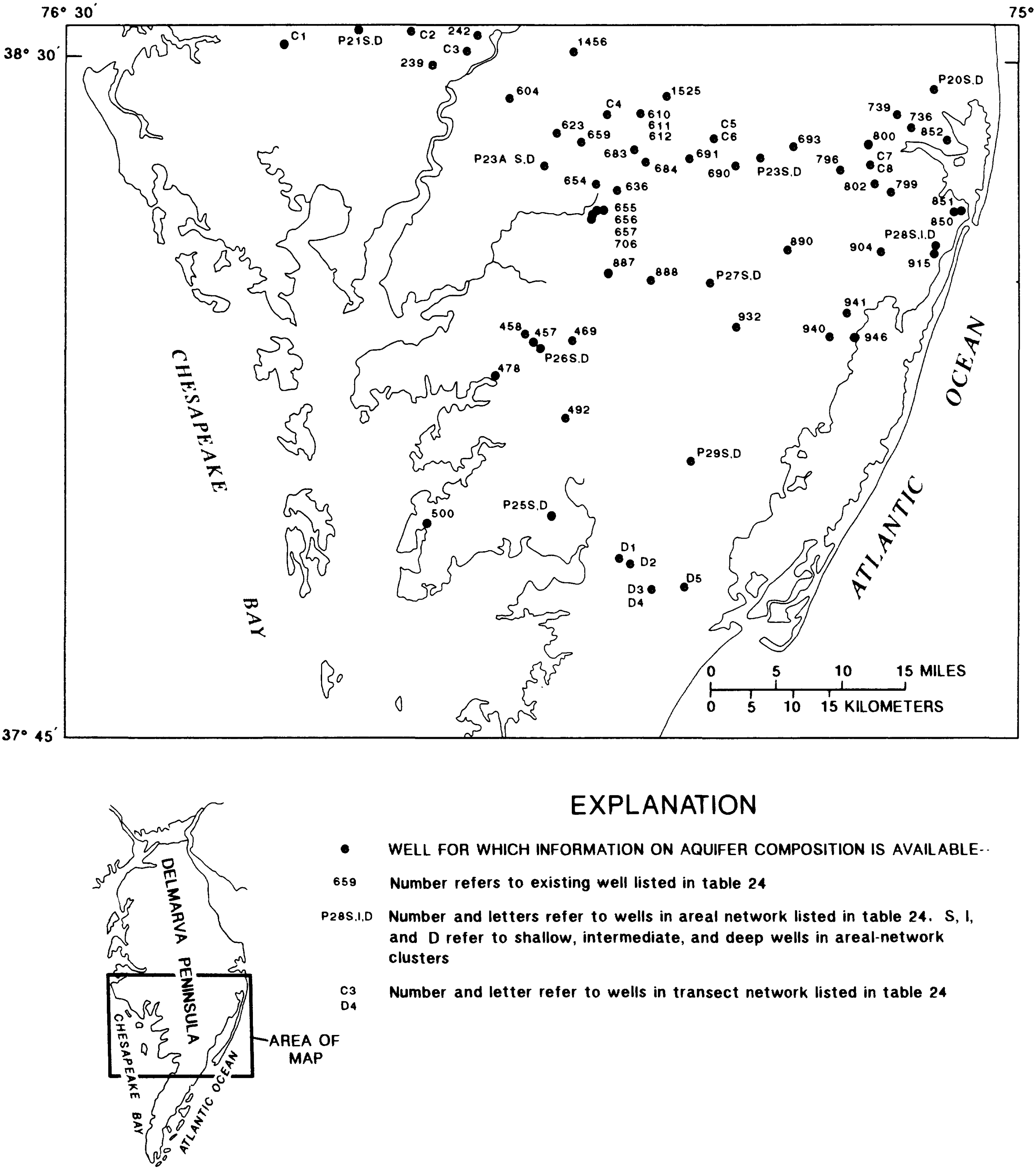
Analysis of ground-water quality in the Willards network indicates that aquifer composition, and specifically, the complex and heterogenous geology, affects nitrate concentrations in ground water in the surficial confined region. The relation between nitrate concentration and aquifer composition was examined further with regional data. The analysis was not limited to water samples collected from wells in the surficial confined region, but included water samples from wells throughout the central part of the peninsula where the surficial aquifer is composed of several geologic formations, such as in the lowlands underlain by the Kent Island Formation (fig. 3). Data included water samples collected at the areal and transect networks, and data collected at existing wells for which information on geology is available (fig. 33; table 24).

The regional data are consistent with data collected from wells in the Willards network area; concentrations of nitrate primarily are elevated in areas where the composition of surficial aquifer is sandy, such as where the Beaverdam Sand composes the entire aquifer, or where the Parsonsburg Sand, Ironshire Formation, or sandy parts of the Omar or Kent Island Formations overlie the Beaverdam Sand (table 24). In general, the ground water is aerobic in the sandy deposits, and nitrification of ammonia can occur. Concentrations of nitrate are low in areas underlain by silt and clay deposits, such as those in the Walston Silt, and Omar and Kent Island Formations.

Nitrate concentrations are low in areas underlain by the Walston Silt and Omar and Kent Island Formations for several reasons. First, anaerobic or nearly anaerobic ground water in the Beaverdam Sand underlying the clay and silt deposits inhibits nitrification of ammonia and promotes denitrification of nitrate. The reducing environment is reflected by a significantly lower median concentration of dissolved oxygen (Kruskal-Wallis test, p-value < 0.001) and significantly higher median concentration of dissolved ammonia (Kruskal-Wallis test, p-value <0.001) in water beneath the surficial confined region than in water beneath the well-drained and poorly drained uplands. Second, clay and silt sediments have abundant exchange sites for ammonia adsorption, which reduces the amount of nitrogen available to move to the water table. Third, the minimally permeable clay and silt deposits inhibit downward flow from the Parsonsburg Sand to the Beaverdam Sand, and, therefore, inhibit downward movement of fertilizers to the water table. Finally, ground water in the Beaverdam Sand underlying this part of the peninsula is relatively old because of the slow rate of flow through clay and silt sediments. Some of the ground water in the Beaverdam Sand underlying this part of the peninsula originated as precipitation in the 1940's (L.N. Plummer, U.S. Geological Survey, written commun., 1992). Ground water in the Beaverdam Sand might, therefore, be affected minimally by agricultural activities because the water entered the aquifer before applications of fertilizers that began on the peninsula around 1940. The median concentration of silica in water in the surficial confined region was significantly higher (Kruskal-Wallis test, p-value < 0.001) than median concentrations in water in the uplands, which indicates additional silicate dissolution along long and deep ground-water-flow paths in the surficial confined region.

A small number of water samples collected from wells in the regional networks in areas overlain by clay and silt deposits contained detectable nitrate concentrations; however, these concentrations generally were less than 2.0 mg/L as N (table 24). Nitrate concentrations were greater than 2.0 mg/L as N in selected samples collected in areas overlain by clay and silt deposits from parts of the aquifer that (1) contain oxygen-rich recharge and near-surface thin strata of nitrate-rich water; (2) are downgradient from sandy parts of the aquifer where the water recharged; or (3) contain thin, highly eroded, discontinuous clay lenses that are interspersed with local sandy conduits (table 24).

The local stratification, areal and vertical, of nitrate concentrations in water in the surficial confined region depends significantly on land use, in combination with aquifer composition. Concentrations of nitrate are elevated in agricultural or residential areas where the surficial aquifer consists of sandy deposits (such as in the Parsonsburg Sand). In agricultural or residential areas underlain by clay and silt deposits and anaerobic water, effects of human activities are less evident than they are in aerobic ground water. For example, concentrations of nitrate were less than the laboratory reporting limit in water samples collected from areal well P25 S (table 9) and transect wells KE 404 and DO 404 (table 10), which are located in intense agricultural areas, probably because of reducing environments. Concentrations of dissolved oxygen were generally less than 0.5 mg/L, and concentrations of dissolved iron were generally greater than 1,000 µg/L (tables 9 and 10); such concentrations are typical of a reducing environment and low-nitrate water.



EXPLANATION

●	WELL FOR WHICH INFORMATION ON AQUIFER COMPOSITION IS AVAILABLE--
659	Number refers to existing well listed in table 24
P28S,I,D	Number and letters refer to wells in areal network listed in table 24. S, I, and D refer to shallow, intermediate, and deep wells in areal-network clusters
C3 D4	Number and letter refer to wells in transect network listed in table 24

Figure 33. Distribution of wells completed in the surficial aquifer in the central part of the Delmarva Peninsula for which information on aquifer composition is available.

Table 24.--General description of aquifer composition at selected wells in the central part of the Delmarva Peninsula, grouped by well network and presented in order of increasing nitrate concentration.[1]

[N, nitrogen; mg/L, milligrams per liter; ft, feet; BLS, below land surface; <, less than]

Map number	USGS number	Latitude (degrees, minutes, and seconds)	Longitude (degrees, minutes, and seconds)	Depth of well (ft BLS)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Description of aquifer composition
					EXISTING WELL NETWORK	
239	DO Cg 32	38 30 03	75 50 48	15	<0.10	Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam Sand
242	DO Ch 28	38 32 06	75 47 03	70	<.10	Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam Sand
457	SO Be 87	38 11 54	75 42 29	60	<.10	Clay, silt, and fine sand of the Kent Island Formation (30 ft) overlying the Beaverdam Sand
469	SO Bf 20	38 12 01	75 39 19	27	<.10	Parsonsburg Sand (2 ft) and clayey part of Omar Formation (10 ft) overlying the Beaverdam Sand
478	SO Cd 45	38 09 40	75 45 45	65	<.10	Clay, silt, and fine sand of the Kent Island Formation (30 ft) overlying the Beaverdam Sand
492	SO Cf 20	38 07 01	75 39 47	35	<.10	Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam Sand
500	SO Dc 6	38 00 05	75 51 07	55	<.10	Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam Sand
604	WI Bd 69	38 27 48	75 44 12	60	<.10	Parsonsburg Sand (15 ft) overlying the Beaverdam Sand

---

[1] The remaining pages of table 24 are stored on disk.

SUMMARY AND CONCLUSIONS

Agricultural applications of inorganic fertilizers, manure, and lime affect concentrations of nitrate and other inorganic constituents in water from the surficial aquifer in the Delmarva Peninsula. The chemistry of ground water affected by agricultural activities differs from natural ground-water chemistry. Concentrations of nitrate and other inorganic constituents affected by agricultural activities, such as calcium and magnesium from applications of lime and chloride and potassium from applications of potash fertilizers, differ areally and with depth in the surficial aquifer.

More than 200 wells were installed in the surficial aquifer in the Delmarva Peninsula to study natural ground-water chemistry and the effects of agriculture on ground-water chemistry. The wells are part of (1) a regional-scale network, which provides a broad geographic description of constituent concentrations and identifies the regional extent of ground-water problems and contamination, and (2) local-scale networks, which identify cause-and-effect relations between ground-water quality and natural and human factors. Water-quality data collected at 193 sites in the surficial aquifer by the USGS before the NAWQA study also are included in the analysis.

The chemical character of natural water (minimally affected by human activities) in the surficial aquifer is controlled primarily by the chemical properties of precipitation, in combination with mineral dissolution and biological activity in the aquifer. Like precipitation, natural ground water is moderately acidic (pH of about 5.8). Concentrations of dissolved constituents are low (indicated by a median specific conductance value of 115 mS/cm) because the surficial aquifer consists mostly of relatively insoluble quartz sand. In addition, the high permeability of the sediment increases ground-water-flow rates and reduces contact and reaction time between water and aquifer minerals.

The kinds and concentrations of ions in natural ground water are variable in the peninsula because of differing lithology and hydrology. Sodium and bicarbonate generally are the dominant ions, particularly in the central interior part of the peninsula where the surficial aquifer consists mostly of the Beaverdam Sand. Calcium bicarbonate-type water typically is present in the northern interior part of the peninsula, where the surficial aquifer consists of the Pensauken Formation; sodium chloride-type water is present along the coastal and tidal parts of the peninsula; and, calcium sodium sulfate-type water is present in areas of the peninsula where fine-grained sediment commonly is interspersed with abundant organic material.

Nitrate, derived from nitrification of ammonia in inorganic fertilizers and manure, is the dominant anion in agricultural areas. Concentrations of nitrate in 185 water samples collected in agricultural areas ranged from 0.4 to 48 mg/L as N, with a median concentration of 8.2 mg/L as N. Nitrate concentrations exceeded the USEPA MCL of 10 mg/L as N in about 33 percent of the 185 water samples.

Ground water in agricultural areas contains significantly higher concentrations of dissolved constituents (indicated by a median specific conductance value of 170 mS/cm) than natural ground water. Concentrations of calcium and magnesium are significantly higher in ground water affected by agricultural activities than in natural water because of liming of soils, and concentrations of potassium and chloride are significantly higher because of applications of potash used to supplement the nitrogen-based fertilizers. Alkalinity concentrations commonly are lower because bicarbonate ion is consumed in buffering reactions with acid produced during nitrification of ammonia.

Effects of agricultural activities on the quality of ground water are not limited to the near-surface parts of the aquifer underlying farm fields but are common at or near the base of the aquifer, 80 to 100 ft below land surface. The median concentration of nitrate in agricultural areas in water collected from 24 wells deeper than 80 ft below land surface was 8.5 mg/L as N, and concentrations in 9 of these water samples exceeded the USEPA MCL.

Concentrations of nitrate and other inorganic constituents in water from the surficial aquifer differ among hydrogeomorphic regions of the Delmarva Peninsula. Hydrogeomorphic regions are characterized by related features--including surficial geology, topography, geomorphology, soil characteristics, and land use-that can impart characteristic regional water-quality patterns. Six hydrogeomorphic regions are delineated on the peninsula--well-drained uplands, poorly drained uplands, poorly drained lowlands, fine-grained lowlands, the surficial confined region, and the inner coastal plain. Beaches, tidal marshes, tidal lagoons, and barrier islands, were not evaluated and were classified as "other areas."

Median concentrations of nitrate in water beneath the surficial confined region (1.1 mg/L as N), and beneath the fine-grained and poorly drained lowlands (about 0.1 mg/L as N) are significantly lower than concentrations in water in the well-drained uplands (about 8.9 mg/L as N). The surficial aquifer underlying the surficial confined region and lowlands commonly contains abundant fine sand, clay, silt, peat, and other organic matter of the Walston Silt and Omar and Kent Island Formations. Nitrate concentrations are low in areas underlain by the Walston Silt and Omar and Kent Island Formations for several reasons. First, anaerobic or nearly anaerobic ground water in the Beaverdam Sand underlying the clay and silt deposits inhibits nitrification of ammonia and promotes denitrification of nitrate. Second, clay and silt sediments have abundant exchange sites for ammonia adsorption, which reduces the amount of nitrogen available to move to the water table. Third, the minimally permeable clay and silt deposits inhibit downward flow, and, therefore, inhibit leaching and transport of fertilizers to the water table. Finally, ground water in the Beaverdam Sand underlying this part of the peninsula is relatively old (recharged as early as the 1940's) because of the slow rate of flow through clay and silt sediments, and might predate the use of fertilizers that began on the peninsula around 1940. In general, concentrations of nitrate in water beneath the surficial confined region and lowlands are elevated only in areas where the composition of surficial aquifer is sandy, such as in areas where the Beaverdam Sand composes the entire aquifer, or where the Parsonsburg Sand or the Ironshire Formation or sandy parts of the Omar or Kent Island Formations overlie the Beaverdam Sand. The ground water generally is aerobic in the sandy deposits and nitrification can occur.

Nitrate concentrations commonly are elevated in the well-drained and poorly drained uplands. The sandy soils and aquifer sediments are more permeable in the uplands than in the surficial confined region and lowlands, which allows nitrate and other constituents to move readily to the water table and flow through the surficial aquifer. Although the median nitrate concentration in the poorly drained uplands is greater than in the surficial confined region and lowlands, the median concentration of nitrate in the poorly drained uplands (4.4 mg/L as N) is significantly lower than in the well-drained uplands (8.9 mg/L as N). Ground water in the poorly drained uplands contains significantly lower concentrations of dissolved constituents (indicated by a median specific conductance value of 108 µS/cm) than those in the well-drained uplands (indicated by a median specific conductance value of 173 µS/cm). Concentrations of calcium, magnesium, potassium, and chloride also are significantly lower in the poorly drained uplands than those measured in the well-drained uplands. Nitrate concentrations exceeded the USEPA MCL for drinking water in more water samples collected in the well-drained uplands (about 34 percent) than in samples collected in the poorly drained uplands (about 20 percent).

Ground-water chemistry in the poorly drained uplands differs from that in the well-drained uplands partly because of different topography and geomorphology. The poorly drained uplands generally contain sluggish streams that flow through low-gradient, poorly incised valleys. The poorly drained uplands are in the headwaters of drainage basins that are marked by a hummocky and undulating topography. Higher land-surface elevations in the poorly drained uplands are underlain by medium- to coarse-textured, well-drained, sandy loams and are farmed. The low flats and depressions are underlain by poorly drained sandy loams and are wooded. Ground-water chemistry in the poorly drained uplands represents a mix of aerobic water that is recharged through the well-drained soils in farmland with anaerobic water that is recharged through poorly drained soils in woodlands. The overall result is a reduced effect of agricultural activities on ground-water chemistry. In contrast, the well-drained uplands are underlain by well-drained soils (generally sandy loams) and sediment that are deeply incised by stream valleys. Agricultural plots are large, and woodlands are confined primarily to stream borders. Ground-water chemistry in the well-drained uplands mostly reflects aerobic water that is recharged through farmland. As a result, agricultural activities have a greater effect on ground-water chemistry in the well-drained uplands than in the poorly drained uplands.

Nitrate concentrations are variable locally depending on ground-water flow and land use. In near-surface ground water (less than 30 ft below land surface), nitrate concentrations generally reflect recharge through overlying land within about 100 to 200 ft of a well. Nitrate concentrations are highest beneath farmland and lowest beneath woodlands and marshes.

Nitrate concentrations are elevated in near-surface ground water beneath residential areas because of septic-tank effluent and lawn fertilizers. Concentrations of nitrate are elevated in deep ground water because of recharge through distant agricultural or residential land rather than through agricultural or residential land directly around the well. In some areas of the Delmarva Peninsula, deep ground water containing elevated nitrate concentrations is overlain by ground water with lower nitrate concentrations. This vertical variability of nitrate concentration is most common beneath marshes and woodlands adjacent to streams and other discharge areas. In these areas, the near-surface ground water is recharged through soils covered with natural vegetation, and the deep ground water is recharged through soils in distant agricultural or residential areas.

Aquifer composition, in combination with ground-water flow and land use, affects the local stratification of nitrate in water beneath the surficial confined region and lowlands. Nitrate concentrations commonly are elevated beneath agricultural or residential areas where the surficial aquifer consists of the Beaverdam Sand, Parsonsburg Sand, Ironshire Formation, or sandy parts of the Omar or Kent Island Formations. Nitrate concentrations are minimal or less than the laboratory reporting limit beneath agricultural or residential areas that are underlain by fine sand, clay, silt, peat, and other organic matter.

REFERENCES CITED

Andres, A.S., 1986, Stratigraphy and depositional history of the Post-Choptank Chesapeake Group: Delaware Geological Survey Report of Investigations 42, 39 p.

Bachman, L.J., 1984a, The Columbia aquifer of the Eastern Shore of Maryland, part 1--hydrogeology: Maryland Geological Survey Report of Investigations 40, 34 p.

____ 1984b, Nitrate in the Columbia aquifer, central Delmarva Peninsula, Maryland: U.S. Geological Survey Water-Resources Investigations Report 84-4322, 51 p.

Cushing, E.M., Kantrowitz, I.H., and Taylor, K.R., 1973, Water resources of the Delmarva Peninsula: U.S. Geological Survey Professional Paper 822, 58 p.

Denny, C.S., Owens, J.P., Sirkin, L.A., and Rubin, Meyer, 1979, The Parsonsburg Sand in the central Delmarva Peninsula, Maryland and Delaware: U.S. Geological Survey Professional Paper 1067-B, 16 p.

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

____ 1989, Effects of agricultural practices and septic-system effluent on the quality of water in the unconfined aquifer in parts of eastern Sussex County, Delaware: Delaware Geological Survey Report of Investigations 45, 66 p.

____ 1991, Ground-water-sampling network to study agrochemical effects on water quality in the unconfined aquifer, southeastern Delaware, in Nash, R.G., and Leslie, A.R., eds., Ground water residue sampling design: American Chemical Society Symposium Series 465, p. 139-149.

Fegeas, R.G., Claire, R.W., and others, 1983, Land use and land cover digital data: U.S. Geological Survey Circular 895-E, 21 p.

Gnanadesikan, Ramanathan, 1977, Methods for statistical data analysis of multivariate observations: New York, John Wiley and Sons, 100 p.

Hamilton, P.A. and Denver, J.M., 1990, Effects of land use and ground-water flow on shallow ground-water quality, Delmarva Peninsula, Delaware, Maryland, and Virginia: Ground Water, v. 28, no. 5, p. 789.

Hamilton, P.A. and Shedlock, R.J., 1989, Relations between land use and nitrate concentrations in shallow ground water, Delmarva Peninsula: U.S. Geological Survey Yearbook, Fiscal Year 1989, p. 38-41.

Hamilton, P.A., Shedlock, R.J., and Phillips, P.J., 1991, Ground-water quality assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia--analysis of available water-quality data through 1987: U.S. Geological Survey Water-Supply Paper 2355-B, 65 p.

Hansen, H.J. III, 1966, Pleistocene stratigraphy of the Salisbury area, Maryland, and its relationship to the lower Eastern Shore--a subsurface approach: Maryland Geological Survey Report of Investigations 2, 56 p.

____ 1981, Stratigraphic discussion in support of a major unconformity separating the Columbia Group from the underlying Upper Miocene aquifer complex in eastern Maryland: Southeastern Geology, v. 22, no. 3, p. 123-138.

Hardy, M.A., Leahy, P.A., Alley, W.M., 1988, Well installation and documentation, and ground-water sampling protocols for the pilot National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 89-396, 36 p.

Harsh, J.F., and Laczniak, R.J., 1990, Conceptualization and analysis of the ground-water-flow system in the Coastal Plain of Virginia and adjacent parts of Maryland and North Carolina: U.S. Geological Survey Professional Paper 1404-F, 100 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: New York, Elsevier, 484 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water, 3d ed.: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hess, K.M, 1977, Drill-hole logs and location map of surface and shallow subsurface materials, central and southern Delmarva Peninsula, Maryland, Delaware, and Virginia: U.S. Geological Survey, Miscellaneous Field Studies Map MF-899, scale 1:250,000, 2 sheets.

Hirsch, R.M., Alley, W.M., and Wilber, W.G., 1988, Concepts for a National Water-Quality Assessment Program: U.S. Geological Survey Circular 1021, 42 p.

Iman, R.L., and Conover, W.J., 1983, A modern approach to statistics: New York, John Wiley and Sons, 497 p.

Johnston, R.H., 1973, Hydrology of the Columbia (Pleistocene) deposits of Delaware--an appraisal of the regional water-table aquifer: Delaware Geological Survey Bulletin 14, 78 p.

Jones, B.E., 1987, Quality control manual of the U.S. Geological Survey's National Water-Quality Laboratory: U.S. Geological Survey Open-File Report 87-457, 36 p.

Jordan, R.R., 1962, Stratigraphy of the sedimentary rocks of Delaware: Delaware Geological Survey Bulletin 9, 51 p.

____ 1964, Columbia (Pleistocene) sediments of Delaware: Delaware Geological Survey Bulletin 12, 69 p.

Kleiner, Baat and Graedel, T.E., 1980. Exploratory data analysis in the geophysical sciences: Reviews of Geophysics and Space Physics, v. 18, p. 699-717.

Koterba, M.T., Shedlock, R.J., Bachman, L.J., and Phillips, P.J., 1990, Regional and targeted ground-water-quality networks in the Delmarva Peninsula *in* Nash, R.G., and Leslie, A.R., eds., Ground-water residue sampling design: American Chemical Society Symposium Series 465, p. 110-138.

Madison, R.J., and Brunett, J.O., 1984, Overview of the occurrence of nitrate in ground water of the United States, in U.S. Geological Survey, National water summary 1984--hydrologic events, selected water-quality trends, and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, p. 93-105.

Maryland State Department of Planning, 1973, Natural soils groups: Maryland State Department of Planning Publication 199, 153 p.

Mixon, R.B., 1985, Stratigraphic and geomorphic framework of uppermost Cenozoic deposits in the southern Delmarva Peninsula, Virginia and Maryland: U.S. Geological Survey Professional Paper 1067-G, 53 p.

Owens, J.P., and Denny, C.S., 1978, Geologic map of Worcester County: Maryland Geological Survey, scale 1:62,500.

____ 1979a, Geologic map of Wicomico County: Maryland Geological Survey, scale 1:62,500.

____ 1979b, Upper Cenozoic deposits of the central Delmarva Peninsula, Maryland and Delaware: U.S. Geological Survey Professional Paper 1067-A, 28 p.

____ 1984, Geologic map of Somerset County: Maryland Geological Survey, scale 1:62,500.

Owens, J.P., and Minard, J.P., 1979, Upper Cenozoic sediments of the Lower Delaware Valley and the northern Delmarva Peninsula, New Jersey, Pennsylvania, Delaware, and Maryland: U.S. Geological Survey Professional Paper 1067-D, 47 p.

Perkins, H.F., Parker, M.B., and Walker, M.M., 1964, Chicken manure--its production, composition, and use as fertilizer: Georgia Agriculture Experiment Station Bulletin No. 123: Athens, Ga., University of Georgia, 22 p.

Perlmutter, M.M., and Koch, Ellis, 1972, Preliminary hydrogeologic appraisal of nitrate in ground water and streams, southern Nassau County, Long Island, New York, in Geological Survey Research, 1972: U.S. Geological Survey Professional Paper 800-B, p. B225-B235.

Puckett, L.J., 1987, The influence of forest canopies on the chemical quality of water and the hydrologic cycle *in* Averett, R.C., and McKnight, D.M., eds., Chemical quality of water and the hydrologic cycle: Chelsea, Mich., Lewis Publishers, p. 3-22.

Rasmussen, W.C., and Slaughter, T.H., 1955, The ground-water resources of Somerset, Wicomico, and Worcester Counties: Maryland Department of Geology, Mines and Water Resources, Bulletin 16, 469 p.

Ritter, W.F., and Chirnside, A.E., 1982, Ground-water quality in selected areas of Kent and Sussex Counties, Delaware: Newark, Del., University of Delaware Agricultural Engineering Department, 229 p.

Robertson, F.N., 1977, The quality and potential problems of the ground water in coastal Sussex County, Delaware: Newark, Del., University of Delaware Water Resources Center, 58 p.

____ 1979, Evaluation of nitrate in the ground water in the Delaware Coastal Plain: Ground Water, v. 17, no. 4, p. 328-337.

Spoljaric, Nened, and Woodruff, K.D., 1970, Geology, hydrology and geophysics of Columbia sediments in the Middletown-Odessa area, Delaware: Delaware Geological Survey Bulletin 13, 156 p.

U.S. Bureau of the Census, 1986, Current population reports, local population estimates, South--1984 population and 1983 per-capita income estimates for counties and incorporated places: U.S. Department of Commerce Series P-26, No. 84-S-SC, 117 p.

U.S. Department of Agriculture, 1970a, Soil survey for New Castle County, Delaware: Soil Conservation Service, 97 p.

____ 1970b, Soil survey of Wicomico County, Maryland: Soil Conservation Service, 90 p.

____ 1982, Soil survey of Kent County, Maryland: Soil Conservation Service, 125 p.

U.S. Environmental Protection Agency, 1986a, Maximum contaminant levels (subpart B of part 141, national primary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, parts 100-149, rev. July 1, 1986: U.S. Environmental Protection Agency, p. 524-528.

____ 1986b, Quality criteria for water: U.S. Environmental Protection Agency.

____ 1986c, Secondary maximum contaminant levels (sec. 143.3 of part 143, national secondary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, parts 100-149, rev. July 1, 1986: U.S. Environmental Protection Agency, p. 587-590.

U.S. Geological Survey, 1979a, Land use and land cover, 1972-73, Eastville, Virginia; North Carolina; Maryland: U.S. Geological Survey Land-Use Map Series, Map L-58, scale 1:250,000.

____ 1979b, Land use and land cover, 1972, Wilmington, Delaware; New Jersey; Pennsylvania; Maryland: U.S. Geological Survey Land-Use Map Series, Map L-38, scale 1:250,000.

____ 1979c, Land use and land cover, 1973, Salisbury, Maryland; Delaware; New Jersey; Virginia: U.S. Geological Survey Land-Use Map Series, Map L-65, scale 1:250,000.

____ 1980a, Land use and land cover, 1972, Washington, D.C.; Maryland; Virginia: U.S. Geological Survey Land-Use Map Series, Map L-201, scale 1:250,000.

____ 1980b, Land use and land cover, 1973, Richmond, Virginia; Maryland: U.S. Geological Survey Land-Use Map Series, Map L-140, scale 1:250,000.

____ 1980c, Land use and land cover, 1974-76, Baltimore, Maryland; Pennsylvania; Virginia; West Virginia: U.S. Geological Survey Land-Use Map Series, Map L-113, scale 1:250,000.

Virginia Cooperative Extension Service, 1992, Commercial Vegetable Production Recommendations: Blacksburg Virginia, Virginia Polytechnic Institute and State University, 100 p.

Table 2.--Site information for wells in the areal network that are completed in the surficial aquifer and that were sampled for chemical analysis.[1]

[USGS, U.S. Geological Survey; NAWQA, National Water-Quality Assessment; ft, feet; BLS, below land surface; ---, no data; latitude and longitude are in degrees, minutes, and seconds]

Well number	Map number	USGS number	Latitude	Longitude	Altitude of land surface (ft)	Depth of well (ft BLS)	Depth to top of sample interval (ft BLS)	Depth to bottom of sample interval (ft BLS)	Status of well
P 1 S	P1	Cd31-19	39 42 24	75 34 05	68	75	72	75	NAWQA
P 2 S	P2	CE Ce 81	39 32 23	75 53 47	85	70	65	68	NAWQA
P 3 S	P3	Ec42-15	39 31 22	75 38 32	53	38	---	---	Existing
P 4 S	P4	KE Bd 42	39 19 27	76 00 03	75	27	24	27	NAWQA
P 5 S	P5	KE Be 47	39 18 32	75 56 08	66	24	21	24	NAWQA
P 5 D	P5	KE Be 46	39 18 32	75 56 08	64	50	40	50	NAWQA
P 6 S	P6	Gc14-02	39 24 14	75 36 09	10	16	13	16	NAWQA
P 6 D	P6	Gc14-03	39 24 14	75 36 10	12	80	60	80	Existing
P 7 D	P7	QA Db 40	39 02 17	76 18 14	20	35	25	35	Existing
P 8 S	P8	QA Df 55	39 01 26	75 57 54	58	26	23	26	NAWQA
P 8 D	P8	QA Df 54	39 01 26	75 57 54	58	42	36	42	Existing
P8A S	P8A	QA Be 20	39 10 42	76 01 17	20	22	19	21	NAWQA
P8A D	P8A	QA Be 19	39 10 42	76 01 17	20	44	41	44	NAWQA
P 9 S	P9	Ib32-05	39 12 33	75 43 31	65	30	27	30	NAWQA
P10 S	P10	Jc55-02	39 05 03	75 35 43	62	15	12	15	NAWQA
P10 D	P10	Jc55-03	39 05 03	75 35 40	62	30	25	30	Existing
P11 S	P11	TA Be 84	38 50 23	76 01 26	68	18	15	18	NAWQA
P11 D	P11	TA Be 83	38 50 23	76 01 26	68	37	30	37	Existing
P12 S	P12	CO Dd 61	38 51 14	75 48 52	10	10	8	10	NAWQA
P12 D	P12	CO Dd 60	38 51 14	75 48 52	10	16	13	16	NAWQA

---

[1] The remaining pages of table 2 are stored on disk.

Table 3.--Site information for wells in the transect network that are completed in the surficial aquifer and that were sampled for chemical analysis.[1]

[USGS, U.S. Geological Survey; NAWQA, National Water-Quality Assessment; ft, feet; BLS, below land surface; ---, no data; latitude and longitude are in degrees, minutes, and seconds]

Well number	Map number	USGS number	Latitude	Longitude	Altitude of land surface (ft)	Depth of well (ft BLS)	Depth to top of sample interval (ft BLS)	Depth to bottom of sample interval (ft BLS)	Status of well
				TRANSECT A					
KE 404	A1	KE Bd 39	39 16 45	76 03 50	75	38	35	38	NAWQA
KE 405	A2	KE Be 65	39 16 08	75 59 43	49	22	19	22	NAWQA
LG 205D	A3	KE BE-52	39 18 10	75 55 58	74	36	33	36	NAWQA
LG 305	A4	KE BE-53	39 18 03	75 55 52	75	50	47	50	NAWQA
KE 201	A5	KE Bg 36	39 19 57	75 49 06	62	31	28	31	NAWQA
NC103	A6	Ga55-01	39 20 54	75 45 34	82	17	14	17	NAWQA
NC 102	A7	Gb52-03	39 20 48	75 43 03	74	33	28	33	NAWQA
NC110	A8	Hd11-03	39 19 11	75 34 52	12	22	19	22	NAWQA
NC105	A9	Hd14-01	39 18 04	75 30 51	15	28	25	28	NAWQA
				TRANSECT B					
WY 103	B1	QA Fd 03	38 54 56	76 09 03	15	19	16	19	NAWQA
QA 402	B2	QA Ed 39	38 55 55	76 07 54	60	26	23	26	NAWQA
TA 101	B3	TA Be 85	38 54 40	76 02 44	45	23	20	23	NAWQA
CA 102	B4	CO Dc 146	38 53 02	75 54 01	45	20	17	20	NAWQA
SX 301	B5	Nb24-03	38 48 37	75 41 52	38	13	11	13	NAWQA
SX 202	B6	Nd41-04	38 46 30	75 34 51	45	20	17	20	NAWQA
SX 204	B7	Of12-01	38 44 58	75 23 06	48	31	28	31	NAWQA
SX 304	B8	Of12-02	38 44 58	75 23 06	48	18	15	18	NAWQA
SX 205	B9	Pg14-01	38 39 39	75 16 38	41	23	20	23	NAWQA

---

[1] The remaining pages of table 3 are stored on disk.

Table 4.–Site information for wells in the Townsend local-scale network that are completed in the surficial aquifer and that were sampled for chemical analysis.[1]

[USGS, U.S. Geological Survey; NAWQA, National Water-Quality Assessment; ft, feet; BLS, below land surface; ---, no data; latitude and longitude are in degrees, minutes, and seconds]

USGS number	Map number	Latitude	Longitude	Altitude of land surface (ft)	Depth of well (ft BLS)	Depth to top of sample interval (ft BLS)	Depth to bottom of sample interval (ft BLS)	Status of well
63F 25	1	37 11 45	75 56 59	12	7	4	7	NAWQA
63F 26	2	37 11 43	75 56 58	15	9	6	9	NAWQA
63F 28	3A	37 11 25	75 57 02	27	17	14	17	NAWQA
63F 44	3B	37 11 25	75 57 02	27	26	23	26	NAWQA
63F 45	3C	37 11 25	75 57 02	27	41	38	41	NAWQA
63F 46	3D	37 11 25	75 57 02	27	61	58	61	NAWQA
63F 28	3E	37 11 25	75 57 02	27	17	14	17	NAWQA
63F 29	4A	37 11 21	75 56 50	13	9	6	9	NAWQA
63F 47	4B	37 11 21	75 56 50	13	28	25	28	NAWQA
63F 30	5	37 11 28	75 57 21	29	15	12	15	NAWQA
63F 32	6	37 11 36	75 57 48	29	12	9	12	NAWQA
63F 31	7A	37 11 36	75 58 02	32	12	9	12	NAWQA
63F 48	7B	37 11 36	75 58 02	31	31	28	31	NAWQA
63F 40	8	37 11 18	75 56 35	4	7	4	7	NAWQA

---

[1] The remaining pages of table 4 are stored on disk.

Table 5.--Site information for wells in the Fairmount local-scale network that are completed in the surficial aquifer and that were sampled for chemical analysis.[1]

[USGS, U.S. Geological Survey; NAWQA, National Water-Quality Assessment; ft, feet; BLS, below land surface; ---, no data; latitude and longitude are in degrees, minutes, and seconds]

USGS number	Map number	Latitude	Longitude	Altitude of land surface (ft)	Depth of well (ft BLS)	Depth to top of sample interval (ft BLS)	Depth to bottom of sample interval (ft BLS)	Status of well
Pg15-03	1A	38 39 21	75 15 15	35	15	12	15	NAWQA
Pg15-02	1B	38 39 21	75 15 15	34	69	66	69	NAWQA
Ph12-06	2A	38 39 06	75 13 03	32	23	20	23	NAWQA
Ph12-05	2B	38 39 06	75 13 03	32	68	65	68	NAWQA
Ph12-08	3	38 39 08	75 13 35	33	20	17	20	NAWQA
Ph12-09	4	38 39 15	75 13 08	25	17	14	17	NAWQA
Ph13-30	5A	38 39 39	75 12 01	11	15	12	15	NAWQA
Ph13-31	5B	38 39 39	75 12 01	11	39	34	39	NAWQA
Ph13-29	5C	38 39 39	75 12 01	11	78	75	78	NAWQA
Ph21-07	6	38 38 53	75 14 12	31	15	12	15	NAWQA
Ph22-08	7	38 38 34	75 13 05	25	18	15	18	NAWQA
Ph22-10	8A	38 38 45	75 13 21	27	13	10	13	NAWQA
Ph22-13	8B	38 38 45	75 13 21	27	36	31	36	NAWQA
Ph22-09	8C	38 38 45	75 13 21	26	63	55	63	NAWQA
Ph22-12	9A	38 38 55	75 13 57	29	15	12	15	NAWQA
Ph22-11	9B	38 38 55	75 13 57	29	54	51	54	NAWQA
Ph22-15	9C	38 38 55	75 13 57	28	88	83	88	NAWQA
Ph23-10	10A	38 38 54	75 12 20	19	25	20	25	NAWQA
Ph23-12	10B	38 38 54	75 12 20	19	45	40	45	NAWQA
Ph23-13	10C	38 38 54	75 12 20	19	65	60	65	NAWQA

---

[1] The remaining pages of table 5 are stored on disk.

Table 6.--Site information for wells in the Locust Grove local-scale network that are completed in the surficial aquifer and that were sampled for chemical analysis.[1]

[USGS, U.S. Geological Survey; NAWQA, National Water-Quality Assessment; ft, feet; BLS, below land surface; ---, no data; latitude and longitude are in degrees, minutes, and seconds]

USGS number	Map number	Latitude	Longitude	Altitude of land surface (ft)	Depth of well (ft BLS)	Depth to top of sample interval (ft BLS)	Depth to bottom of sample interval (ft BLS)	Status of well
KE Be 49	1	39 19 23	75 56 43	74	25	22	25	NAWQA
KE Be 51	2	39 18 51	75 55 44	70	27	24	27	NAWQA
KE Be 50	3	39 18 51	75 56 18	70	22	20	22	NAWQA
KE Be 167	4A	39 18 38	75 56 09	66	18	15	18	NAWQA
KE Be 166	4B	39 18 38	75 56 09	66	28	25	28	NAWQA
KE Be 165	4C	39 18 38	75 56 09	66	48	45	48	NAWQA
KE Be 59	5A	39 18 32	75 56 08	71	26	23	26	NAWQA
KE Be 164	5B	39 18 32	75 56 08	71	48	45	48	NAWQA
KE Be 60	6	39 18 11	75 56 49	78	26	24	26	NAWQA
KE Be 53	7A	39 18 10	75 55 58	75	22	20	22	NAWQA
KE Be 52	7B	39 18 10	75 55 58	75	36	33	36	NAWQA
KE Be 61	7C	39 18 03	75 55 52	75	50	47	50	NAWQA
KE Be 62	8A	39 17 42	75 55 48	61	25	22	25	NAWQA
KE Be 163	8B	39 17 42	75 55 48	61	43	40	43	NAWQA
KE Be 162	8C	39 17 42	75 55 48	61	67	64	67	NAWQA
KE Be 64	9A	39 17 21	75 55 45	45	16	13	16	NAWQA
KE Be 63	9B	39 17 21	75 55 45	45	39	36	39	NAWQA
KE Be 161	10A	39 17 20	75 55 46	45	19	16	19	NAWQA
KE Be 160	10B	39 17 20	75 55 46	45	38	35	38	NAWQA
KE Be 159	10C	39 17 20	75 55 46	45	68	65	68	NAWQA
KE Be 169	11	39 17 19	75 55 47	39	5	2	5	NAWQA
KE Be 170	12	39 17 20	75 55 47	40	6	3	6	NAWQA

---

[1] The remaining pages of table 6 are stored on disk.

Table 7.--Site information for wells in the Vandyke local-scale network that are completed in the surficial aquifer and that were sampled for chemical analysis.[1]

[USGS, U.S. Geological Survey; NAWQA, National Water-Quality Assessment; ft, feet; BLS, below land surface; ---, no data; latitude and longitude are in degrees, minutes, and seconds]

USGS number	Map number	Latitude	Longitude	Altitude of land surface (ft)	Depth of well (ft BLS)	Depth to top of sample interval (ft BLS)	Depth to bottom of sample interval (ft BLS)	Status of well
Gb42-03	1	39 21 31	75 44 08	85	23	20	23	NAWQA
Gb41-12	2A	39 21 20	75 44 10	81	18	15	18	NAWQA
Gb41-23	2B	39 21 20	75 44 10	80	30	27	30	NAWQA
Gb41-09	3A	39 21 20	75 44 19	84	15	12	15	NAWQA
Gb41-22	3B	39 21 20	75 44 19	80	25	20	25	NAWQA
Gb41-08	4	39 21 23	75 44 08	81	11	8	11	NAWQA
Gb41-10	5	39 21 20	75 44 15	83	15	12	15	NAWQA
Gb41-11	6	39 21 19	75 44 13	80	13	10	13	NAWQA
Gb41-19	7	39 21 25	75 44 08	81	11	8	11	NAWQA
Gb41-20	8A	39 21 28	75 44 12	80	11	9	11	NAWQA
Gb41-24	8B	39 21 28	75 44 12	80	30	27	30	NAWQA
Gb41-21	9	39 21 27	75 44 14	81	11	9	11	NAWQA
Gb41-17	10	39 21 17	75 44 17	78	9	6	9	NAWQA
Gb41-25	11	39 21 29	75 44 10	80	13	10	13	NAWQA

[1] The remaining pages of table 7 are stored on disk.

Table 8.--Site information for wells in the Willards local-scale network that are completed in the surficial aquifer and that were sampled for chemical analysis.[1]

[USGS, U.S. Geological Survey; NAWQA, National Water-Quality Assessment; ft, feet; BLS, below land surface; ---, no data; latitude and longitude are in degrees, minutes, and seconds]

USGS number	Map number	Latitude	Longitude	Altitude of land surface (ft)	Depth of well (ft BLS)	Depth to top of sample interval (ft BLS)	Depth to bottom of sample interval (ft BLS)	Status of well
WI Bh 11	1	38 26 26	75 20 18	37	34	31	34	NAWQA
WI Bh 8	2A	38 26 09	75 21 05	38	13	11	13	NAWQA
WI Bh 9	2B	38 26 09	75 21 05	38	41	38	41	NAWQA
WI Bh 4	3A	38 25 43	75 21 22	40	12	10	12	NAWQA
WI Bh 5	3B	38 25 43	75 21 22	40	33	30	33	NAWQA
WI Bh 2	4A	38 25 11	75 20 36	38	11	9	11	NAWQA
WI Ch 55	5B	38 24 51	75 21 19	38	45	42	45	NAWQA
WI Ch 56	6A	38 24 52	75 20 29	40	17	15	17	NAWQA
WI Ch 57	6B	38 24 52	75 20 29	40	50	47	50	NAWQA
WI Ch 52	7A	38 24 59	75 20 03	40	19	17	19	NAWQA
WI Ch 53	7B	38 24 59	75 20 03	40	48	45	48	NAWQA

---

[1] The remaining pages of table 8 are stored on disk.

Table 9.--Chemical analyses of water collected from wells in the areal network that are completed in the surficial aquifer, 1988-90.[1]

[uS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than]

Well number	Map number	USGS number	Specific conductance field (uS/cm)	pH field (standard units)	Oxygen, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
P 1 S	P1	Cd31-19	128	5.02	6.1	7.5	3.4	9.3	1.3
P 2 S	P2	CE Ce 81	47	5.03	8.1	2.6	1.9	3.8	.90
P 3 S	P3	Ec42-15	275	5.97	10	16	12	6.1	2.0
P 4 S	P4	KE Bd 42	235	6.80	5.7	23	7.7	9.0	2.9
P 5 S	P5	KE Be 47	373	5.11	7.3	22	22	11	1.7
P 5 D	P5	KE Be 46	127	4.59	10	9.6	2.7	5.1	2.7
P 6 S	P6	Gc14-02	380	7.42	2.4	70	3.2	5.8	1.7
P 6 D	P6	Gc14-03	396	7.34	1.4	76	1.6	5.4	1.5
P 7 D	P7	QA Db 40	506	4.23	.6	4.6	7.1	77	1.1
P 8 S	P8	QA Df 55	173	5.31	7.1	9.1	4.2	13	1.3
P 8 D	P8	QA Df 54	138	5.55	7.8	10	4.9	12	1.4
P8A S	P8A	QA Be 20	194	4.14	6.7	1.2	11	2.6	4.3
P8A D	P8A	QA Be 19	459	6.58	.4	76	9.1	3.5	1.9
P 9 S	P9	Ib32-05	192	7.58	.4	34	.41	3.5	.90
P10 S	P10	Jc55-02	114	4.45	9.4	5.6	4.9	3.9	2.3
P10 D	P10	Jc55-03	180	5.11	5.1	8.9	4.5	14	2.5
P11 S	P11	TA Be 84	188	5.04	3.8	7.2	3.9	21	1.2
P11 D	P11	TA Be 83	259	4.95	5.5	8.7	3.1	33	1.6
P12 S	P12	CO Dd 61	230	6.01	1.0	19	9.0	8.4	6.8
P12 D	P12	CO Dd 60	267	4.95	.7	16	9.3	7.5	3.7

---

[1] The remaining pages of table 9 are stored on disk.

Table 10.--Chemical analyses of water collected from wells in the transect network that are completed in the surficial aquifer, 1989.[1]

[uS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than]

Well number	Map number	USGS number	Specific conductance field (uS/cm)	pH field (standard units)	Oxygen, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
TRANSECT A									
KE 404	A1	KE Bd 39	68	4.9	0.6	1.1	1.2	3.7	3.3
KE 405	A2	KE Be 65	133	5.7	5.6	12	5.0	3.2	1.8
LG 205D	A3	KE BE 52	172	4.9	8.7	11	6.7	4.4	3.3
LG 305	A4	KE Be 53	128	5.1	9.5	8.8	2.6	5.8	2.9
KE 201	A5	KE Bg 36	295	4.8	7.1	18	15	6.1	2.9
NC103	A6	Ga55-01	122	5.4	6.9	8.7	3.6	5.5	2.2
NC 102	A7	Gb52-03	103	6.1	5.2	8.1	2.9	7.2	1.7
NC110	A8	Hd11-03	218	4.6	7.5	10	11	4.6	5.4
NC105	A9	Hd14-01	229	4.0	.4	11	7.8	14	1.2
TRANSECT B									
WY 103	B1	QA Fd 03	658	4.0	5.2	47	26	13	5.9
QA 402	B2	QA Ed 39	107	4.6	6.7	5.0	3.2	7.0	1.6
TA 101	B3	TA Be 85	162	4.6	7.4	12	11	4.1	2.1
CA 102	B4	CO Dc 146	181	5.4	8.8	8.3	12	3.2	2.5
SX 301	B5	Nb24-03	44	5.2	7.2	2.5	1.2	3.3	.70
SX 202	B6	Nd41-04	310	5.2	7.9	24	8.4	4.4	8.8
SX 204	B7	Of12-01	49	5.7	6.8	2.5	.60	5.0	2.0
SX 304	B8	Of12-02	249	4.9	6.4	11	5.1	20	5.8
SX 205	B9	Pg14-01	261	4.3	8.0	14	14	3.5	4.2

---

[1] The remaining pages of table 10 are stored on disk.

Table 11.--Chemical analyses of water collected from wells in the Townsend local-scale network that are completed in the surficial aquifer.[1]

[uS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than]

Well number	Map number	USGS number	Specific con-ductance field (uS/cm)	pH field (stan-dard units)	Oxygen, dis-solved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
November 1990									
63F 25	1	460	6.40	3.8	49		19	12	1.8
63F 26	2	305	5.60	3.6	33		5.6	8.1	7.4
63F 49	3E	635	5.50	8.6	---		---	---	---
63F 44	3B	300	5.50	8.5	---		---	---	---
63F 45	3C	430	6.50	5.0	---		---	---	---
63F 46	3D	330	5.80	.3	---		---	---	---
63F 29	4A	298	5.70	4.9	---		---	---	---
63F 47	4B	478	5.30	5.5	---		---	---	---
June 1990									
63F 25	1	475	6.29	6.3	52		19	12	1.6
63F 26	2	245	5.35	5.4	28		4.7	5.9	5.0
June 1989									
63F 28	3A	293	5.08	7.6	30		5.0	8.5	8.6
63F 44	3B	272	5.43	7.8	40		5.7	6.3	6.4
63F 46	3D	---	---	---	52		3.4	10	1.8
63F 29	4A	295	5.55	3.5	34		5.5	6.7	5.4
63F 30	5	610	5.48	7.6	75		15	7.3	10
63F 31	7A	405	5.41	5.3	31		7.6	26	7.5
63F 48	7B	289	6.00	2.0	20		5.9	20	3.8
63F 40	8	4,020	5.95	.2	67		100	870	20

---

[1] The remaining pages of table 11 are stored on disk.

Table 12.--Chemical analyses of water collected from wells in the Fairmount local-scale network that are completed in the surficial aquifer.[1]

[uS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than]

Well number	Map number	USGS number	Specific conductance field (uS/cm)	pH field (standard units)	Oxygen, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
January 1990									
Ph12-06	2A	103	5.10	8.8		3.0	4.3	4.5	4.1
Ph12-05	2B	113	5.40	8.4		---	---	---	---
Ph13-30	5A	92	5.10	3.0		---	---	---	---
Ph13-31	5B	251	5.50	8.4		---	---	---	---
Ph13-29	5C	79	5.70	5.0		---	---	---	---
Ph21-07	6	108	4.90	10.0		---	---	---	---
Ph22-10	8A	346	4.90	10.3		---	---	---	---
Ph22-13	8B	460	5.00	3.9		---	---	---	---
Ph22-12	9A	434	4.40	5.1		16.0	23.0	12.0	7.0
Ph22-11	9B	169	5.10	8.0		---	---	---	---
Ph22-15	9C	118	5.60	7.4		---	---	---	---
Ph23-10	10A	389	4.90	.5		---	---	---	---
Ph23-12	10B	370	5.40	7.0		---	---	---	---
Ph23-13	10C	271	5.80	7.2		---	---	---	---
Ph23-14	10D	353	5.50	3.5		---	---	---	---
Ph13-04	11A	359	4.70	9.5		---	---	---	---
Ph13-23	11B	377	4.90	9.7		---	---	---	---
Ph13-16	12B	308	5.40	9.8		17	15	8.1	4.2
Ph13-17	12C	324	5.00	7.1		---	---	---	---
Ph13-18	12D	176	5.60	5.0		---	---	---	---

---

[1] The remaining pages of table 12 are stored on disk.

Table 13.--Chemical analyses of water collected from wells in the Locust Grove local-scale network that are completed in the surficial aquifer.[1]

[uS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than]

Well number	Map number	USGS number	Specific con-ductance field (uS/cm)	pH field (stan-dard units)	Oxygen, dis-solved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
March 1991									
KE Be 52	7B	197	5.00	10.0	11	8.3	4.6	2.7	
KE Be 61	7C	106	5.10	11.4	7.4	2.3	5.1	2.4	
KE Be 62	8A	246	5.60	9.0	17	12	3.7	2.4	
KE Be 163	8B	161	5.00	10.8	7.4	6.3	7.5	4.0	
KE Be 162	8C	53	5.30	10.4	3.6	.89	3.4	1.5	
KE Be 161	10A	136	5.00	9.4	11	3.6	5.4	3.5	
KE Be 160	10B	57	5.30	10.0	3.4	1.0	4.1	1.8	
KE Be 159	10C	219	7.10	1.6	42	.74	2.9	1.8	
KE Be 169	11	71	5.20	8.7	3.9	1.6	4.4	1.9	
KE Be 170	12	260	6.10	3.2	17	16	4.1	2.0	
November 1990									
KE Be 167	4A	188	5.10	10.1	6.4	10	5.6	2.5	
KE Be 166	4B	229	4.90	10.4	14	10	4.0	3.7	
KE Be 165	4C	231	5.00	10.7	19	4.5	9.6	2.9	
KE Be 59	5A	276	5.90	7.6	20	14	7.5	2.7	
KE Be 164	5B	146	5.50	9.2	12	3.8	4.6	2.8	

---

[1] The remaining pages of table 13 are stored on disk.

Table 14.--Chemical analyses of water collected from wells in the Vandyke local-scale network that are completed in the surficial aquifer.[1]

[uS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than]

Well number	Map number	USGS number	Specific con- ductance field (uS/cm)	pH field (stan- dard units)	Oxygen, dis- solved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
January 1990									
Gb42-03	1	92	5.00	4.3	3.4	2.8	5.6	1.3	
Gb41-12	2A	220	5.60	---	---	---	---	---	
Gb41-23	2B	120	5.60	9.1	8.8	3.9	4.9	.90	
Gb41-09	3A	230	5.70	9.3	---	---	---	---	
Gb41-22	3B	114	5.50	9.6	7.0	3.5	5.5	1.5	
Gb41-10	5	154	5.20	9.3	---	---	---	---	
Gb41-11	6	234	6.10	5.4	---	---	---	---	
Gb41-20	8A	135	5.50	.4	---	---	---	---	
Gb41-24	8B	59	5.50	.0	2.5	.92	7.2	1.2	
Gb41-21	9	91	5.40	.5	6.4	3.1	2.8	1.7	
Gb41-25	11	137	4.60	10.4	4.8	4.6	9.8	1.5	
June 1989									
Gb42-03	1	97	4.80	8.4	4.0	3.1	5.9	1.1	
Gb41-12	2A	196	5.50	8.3	14	9.2	4.4	1.3	
Gb41-09	3A	175	5.60	7.3	10	8.9	4.6	2.4	
Gb41-08	4	121	5.10	5.1	7.2	3.3	5.7	4.8	
Gb41-10	5	166	5.30	6.5	8.0	8.9	3.3	3.7	

---

[1] The remaining pages of table 14 are stored on disk.

Table 15.--Chemical analyses of water collected from wells in the Willards local-scale network that are completed in the surficial aquifer.[1]

[uS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than]

Well number	Map number	USGS number	Specific con-ductance field (uS/cm)	pH field (stan-dard units)	Oxygen, dis-solved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
March 1991									
WI Bh 11	1	154	6.10	0.2		10	1.3	9.4	1.4
WI Bh 4	3A	128	5.20	.4		9.9	3.8	2.2	6.6
WI Bh 5	3B	82	5.60	.6		3.0	1.2	7.8	1.6
WI Ch 56	6A	196	4.80	2.0		13	7.0	9.9	1.8
WI Ch 57	6B	320	5.20	.3		19	13	20	2.8
November 1990									
WI Bh 11	1	145	6.10	.1		9.0	1.2	9.4	1.2
WI Ch 56	6A	163	5.30	.0		9.9	5.5	9.5	2.3
WI Ch 57	6B	315	5.60	.1		19	14	20	2.8
June 1990									
WI Bh 11	1	135	6.00	.4		9.8	1.5	8.4	1.3
WI Bh 8	2A	284	6.00	.0		6.7	3.5	5.3	1.9
WI Bh 9	2B	158	6.30	.0		4.7	1.7	8.8	.90
WI Bh 4	3A	125	5.10	.3		10	3.9	2.6	6.9
WI Bh 5	3B	88	5.60	.4		2.7	1.1	10	1.8
WI Bh 2	4A	170	5.70	.3		19	6.6	2.8	1.7
WI Ch 55	5B	155	6.20	.4		5.6	1.6	10	1.7
WI Ch 57	6B	258	5.50	.5		18	12	19	3.1
WI Ch 52	7A	146	4.30	4.1		12	3.6	6.3	1.8
WI Ch 53	7B	309	7.00	.4		53	2.2	6.5	.90

---

[1] The remaining pages of table 15 are stored on disk.