NITRATE IN THE COLUMBIA AQUIFER,
CENTRAL DELMARVA PENINSULA,
MARYLAND

By L. Joseph Bachman

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ABSTRACT

A study of nitrate in water from 604 wells tapping the Columbia aquifer on the Delmarva Peninsula in eastern Maryland was done to describe the factors that affect nitrate variability. Samples were collected from 196 randomly selected wells and analyzed for nitrogen species. Many were also analyzed for major ions. In addition, results of 313 nitrate analyses were randomly selected from county health department files. About 95 analyses of water samples collected from 1945 to 1978 were also evaluated.

The frequency distribution of the nitrate analyses is bimodal, with 25 percent of the sample ranging from 0 to about 0.42 milligrams per liter (mg/L) nitrate as nitrogen (N), and the median is about 0.1 mg/L; the rest ranges from 0.42 to 58 mg/L, and the median is about 5.9 mg/L. The overall median nitrate concentration is about 3.5 mg/L as N. Over half of the samples had nitrate concentrations of 3 mg/L as N or higher, indicating that the water in the aquifer has been affected by human activity. Nitrate-nitrogen concentrations exceeded the water-quality standard of 10 mg/L in 15 percent of the samples established by the U.S. Environmental Protection Agency.

Concentrations of nitrate nitrogen ranging from less than 1 mg/L to more than 3 mg/L were found in ground water under all land uses, soil types, and hydrogeologic environments. Median nitrate concentrations tend to decrease to the southeast where the aquifer is thicker, more likely to be confined, and has lower head gradients than to the north. Median nitrate concentrations tend to be higher at sites with urban and agricultural land uses and moderately well-drained soils. Well-drained soils are also more common in the northern part of the study area where nitrate concentrations tend to be higher. The major factors affecting nitrate concentration are the presence of a nitrogen source, hydrogeological conditions, and the soil drainage. Sites with poorly drained soils may have a lower nitrate concentration either because the soils block the entrance of nitrate into the aquifer or because the aquifer under a poorly drained soil is associated with a chemical environment that promotes denitrification.

INTRODUCTION

Background, Purpose and Scope, and Acknowledgments

NITRATE: THE MOST COMMON CONTAMINANT IN SHALLOW GROUND WATER ON THE CENTRAL DELMARVA PENINSULA

Many wells have been abandoned in the shallowest and most productive aquifer on the Delmarva Peninsula because of high nitrate concentrations in the water. This report helps define current conditions and problems by describing the hydrogeological factors associated with high nitrate concentrations.

A shallow sand called the Columbia aquifer blankets most of the Delmarva Peninsula. The Columbia is one of the most productive aquifers in the area. However, because it is commonly unconfined and is very permeable, contaminants applied to the surface of the land can easily enter the aquifer. The contaminants can enter the aquifer where it is unconfined, move to those areas where it is confined, and possibly migrate into deeper flow systems. When certain kinds of contamination occur, the law requires that the well not be used for drinking-water supply. The result could be the local abandonment of a highly productive shallow aquifer as a source of drinking water and inconvenience and possible economic hardship to the many homeowners, farmers, businesses, and municipalities who own wells that must be replaced.

Nitrate is one of the most common contaminants reported in the Columbia aquifer. It does not occur naturally in high concentrations in the aquifer. Nitrogen enters the aquifer from sources on the surface of the land such as decaying organic matter, fixed atmospheric nitrogen sewage, and organic and inorganic fertilizers. Excessive amounts of nitrate in water can cause methemoglobinemia in infants (U.S. Environmental Protection Agency, 1977, p. 107-110).[1] The presence of nitrate may also indicate the presence of other forms of contamination. Although human activities account for most of the excessive nitrate concentrations in shallow ground water, the relative contribution of the different sources in the Delmarva Peninsula is not known. Nitrate concentrations appear to be highest where a source of nitrogen is present or where the aquifer is unconfined and the soils highly permeable.

This report describes the results of an investigation of nitrate contamination in the Columbia aquifer in the Maryland part of the Central Delmarva Peninsula. The area of principal investigation, shown in figure 1, consists of Caroline, northeastern Dorchester, Wicomico, and northeastern Worcester Counties. The Columbia aquifer is the most heavily used water-supply source in this area. A number of water analyses from wells in nearby parts of Delaware were used to improve the appraisal of areal variations of nitrate. This investigation was conducted in cooperation with the Maryland Geological Survey and the Maryland Department of Health and Mental Hygiene.

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[1] *The drinking water standard set by the U.S. Environmental Protection Agency (1977, p. 107-110) is 10 milligrams per liter as nitrogen.*

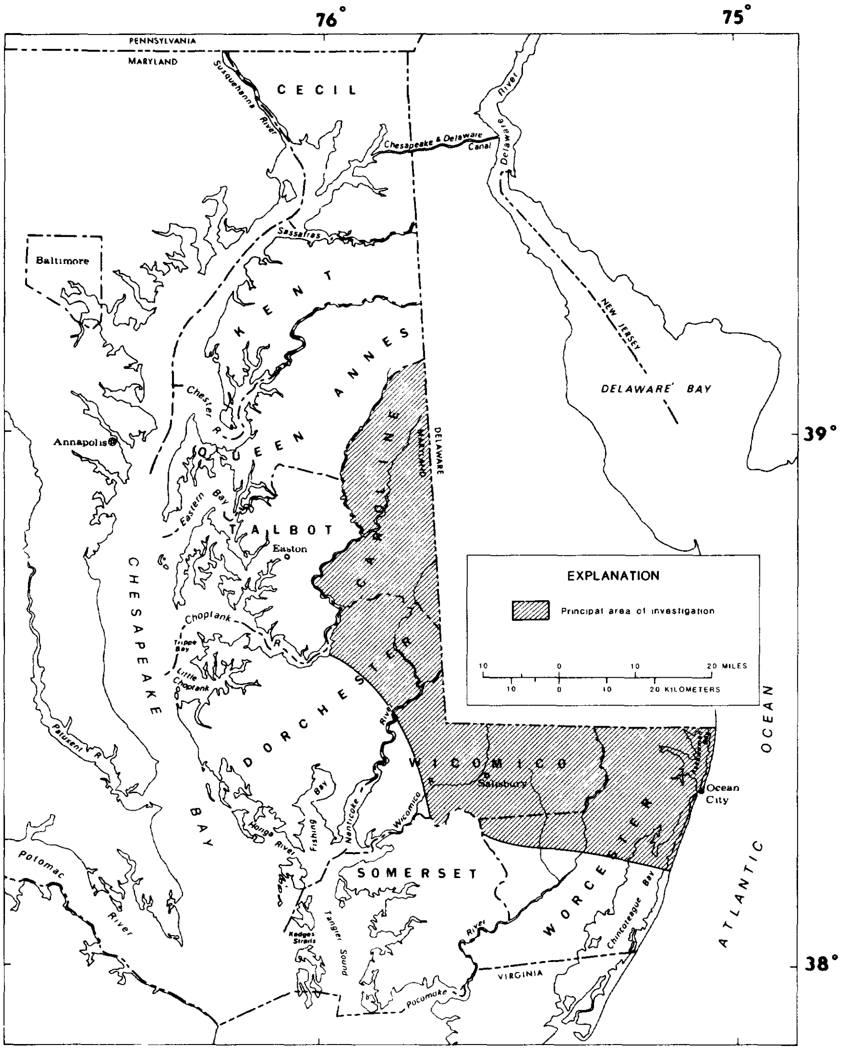


Figure 1.-- Location of study area.

The purpose of the investigation was to evaluate variation of nitrate in the water of the Columbia aquifer and relate the variation to sources of nitrate, regional trends in thickness of the aquifer, and types of flow systems within the aquifer. This was done by collecting 196 water samples from randomly selected wells, and by compiling 313 analyses from county health department records and 95 analyses collected by the U.S. Geological Survey from 1945 to 1978.

Appreciation is expressed to the following people, businesses, and agencies who assisted in the collection of data for this report: the homeowners, farmers, and businesses who allowed us to sample the water from their wells, drill test wells on their property, or both; the Health Departments of Caroline, Dorchester, Wicomico, and Worcester Counties who provided information about well permits and the results of chemical analyses of water from wells drilled in their counties; the Maryland State Highway Administration and the Maryland State Wildlife Administration who allowed us to drill test wells on state land; and the Maryland Department of Health and Mental Hygiene who provided information on well permits. Fieldwork was done by the following employees of the U.S. Geological Survey: George Zynjuk, Wayne George, George Noah, Steve Hiortdahl, and John Hilleary. They assisted the author in inventorying wells, collecting water samples for chemical analysis, conducting field analyses for pH, specific conductance, and alkalinity, and supervising test drilling.

INTRODUCTION

Data Collection

> *This report is based on chemical analyses of 604 samples of water from the Columbia aquifer. The U.S. Geological Survey, the Maryland Department of Health and Mental Hygiene, and the county health departments collected and analyzed the samples.*

This report is based on 604 chemical analyses of water samples from the Columbia aquifer. Analyses were collected and performed by the U.S. Geological Survey and the Maryland Department of Health and Mental Hygiene. The U.S. Geological Survey collected and analyzed 95 water samples from the aquifer from 1945 through 1978; the results are published in a report by Woll (1978). Since 1978, the Geological Survey has collected and analyzed 196 water samples as part of three investigations: This investigation on nitrate in the Columbia aquifer; an investigation of the hydrogeology of the Columbia aquifer in eastern Maryland (Bachman, 1984; Wilson, 1984); and an investigation of the ground-water geochemistry of the Columbia aquifer in neighboring areas of southwestern Delaware (J. Denver, U.S. Geological Survey, oral commun., 1983). Records of 313 water analyses were randomly compiled from the records of the health departments of Caroline, Dorchester, Wicomico, and Worcester Counties. The samples were collected from 1970 to 1981 by the county health departments. They were analyzed by the State Health Department Laboratory in Salisbury, Md.

The constituents analyzed depended on the purpose for which the samples were collected. Samples collected for this study were usually analyzed for at least the major ions (sodium, calcium, magnesium, bicarbonate, sulfate, and chloride), iron, and all of the nitrogen species (nitrate, nitrite, ammonia, and organic nitrogen). A number of wells have only analyses for nitrogen species or only analyses of nitrogen species and chloride. The older analyses of the Geological Survey include mostly analyses for major ions, but samples were analyzed which have analyses for only one or two constituents. The county health departments' chemical analyses usually included only nitrate.

During the Geological Survey studies since 1979, sampling techniques followed the National Handbook of Recommended Methods of Water Data Acquisition (U.S. Geological Survey, 1979). Use of these methods are intended to result in a sample of water representative of that in the aquifer both in chemical and physical characteristics. Conductivity, pH, and alkalinity were measured in the field when the sample was collected. The well was pumped until the pH of the water stabilized. All samples were filtered in the field through a filter with a pore size of 0.45 micrometers (μm); samples for analysis of nitrogen species were chilled and preserved with mercuric chloride; samples for analysis of cations were treated with 1 milliliter (ml) concentrated nitric acid per 250 ml of sample. The samples were mailed by air the day they were collected to the Central Water-Quality Laboratory of the U.S. Geological Survey in Atlanta, Ga.

Samples collected by the county health departments were field filtered, chilled, and shipped by courier to the state laboratory in Salisbury the day they were collected. There is no documentation of sample-collection methods used for the older analyses (those before 1979) done by the U.S. Geological Survey.

Chemical constituents in the water were analyzed using recognized analytical techniques. Post-1978 analyses of the U.S. Geological Survey used the techniques described by Skougstad and others (1979). The analysis of nitrate was by both the U.S. Geological Survey Laboratory and the state health department laboratory using the automated cadmium-reduction method (Skougstad and others, 1979, p. 437). The U.S. Geological Survey Central Laboratory has its own quality-assurance program; the state laboratory in Salisbury uses a quality-assurance system provided by the U.S. Environmental Protection Agency. There is no adequate documentation of the analytical techniques used in the older Geological Survey analyses, but the following publications describe the analytical techniques used by the Survey during the time indicated: 1958-70, Rainwater and Thatcher (1960); 1970-77, Brown and others (1970).

Five test wells were drilled during this study. Two to three nested well screens were placed in each hole, for a total of 14 observation wells in the Columbia aquifer and in the aquifer immediately underlying the Columbia. Lithologic logs, geophysical logs, chemical analyses of the water, and monthly water levels are available for all of these wells.

A summary of the results of the chemical analyses used in this report is found in the Supplemental Data section. More detailed information about the wells inventoried by the U.S. Geological Survey is on file at the Mid-Atlantic District Office of the Survey in Towson, Md.

INTRODUCTION

Geologic Units and Aquifers on the Coastal Plain

Table 1.--Summary of geologic units aquifer names, and water-bearing properties of the shallow sediments in the central Delmarva Peninsula

System	Series	Formation		Aquifer	Hydrogeologic Properties
Quarternary	Pleistocene	Correlative Units	Kent Island Formation		
			Parsonsburg Sand	Columbia aquifer	Sand, medium- to coarse-grained, and gravel 30 to 230 ft thick; tan, silty; reported yields from 1 to 4,000 gal/min. Clay and silt predominant in Omar Formation and Walston Silt.
			Sinepuxent Formation		
			Ironshire Formation		
			Omar Formation		
	Pliocene	Walston Silt			
		Beaverdam Sand			
		Pensauken Formation			

Tertiary	Miocene	Chesapeake Group	Yorktown and Cohansey (?) Formations	Pocomoke aquifer	Sand, gray, coarse; 0-100 ft thick; reported yields 5-650 gal/min.
				Manokin and Ocean City aquifers	Sand, gray, coarse; 0-250 ft thick; reported yields 5-1,000 gal/min.
			St. Marys Formation		
			Choptank Formation	Frederica aquifer	Sand, 0-150 ft thick; reported yields 5-200 gal/min.
				Federalsburg aquifer	Sand, fine to coarse, gray, silt and shells; 0-100 ft thick; reported yields 4-150 gal/min.
			Calvert Formation		
				Cheswold aquifer	Sand, 0-150 ft thick; yields 5-300 gal/min.
	Eocene		Piney Point Formation		
				Piney Point aquifer	Sand, green gray, glauconitic; 20-270 ft thick; reported yields 5-625 gal/min.
			Nanjemoy Formation		
	Paleocene		Aquia and Brightseat Formations	Aquia aquifer	Sand, green-gray, glauconitic; 0-250 ft thick; reported yields 4-350 gal/min.
Cretaceous	Upper Cretaceous		Monmouth Formation and older units		

Adapted from Bachman (1984), and Cushing and others (1973).

THE COLUMBIA AQUIFER THICKENS AND TENDS TO BECOME CONFINED TO THE SOUTHEAST

The thickness of the Columbia aquifer ranges from 0 to 230 feet and thickens in the southeastern part of the study area. The aquifer is mostly unconfined, but it is more likely to be partially confined to the southeast. Flow systems also tend to be deeper and flow paths longer to the southeast.

The thickness of the Columbia aquifer is highly variable, ranging from 0 to 230 feet. The aquifer tends to thicken towards the southeast (fig. 2), but paleochannels locally modify this trend. A paleochannel system has been previously described by Bachman (1984), Weigle (1972), Mack and Thomas (1972), and Hansen (1966); the trends of the paleochannels are shown in figure 2. The paleochannels are ancient stream valleys filled with permeable sand and gravel deposits. In the neighborhood of the paleochannels, the Columbia aquifer is from 40 to 130 feet thicker than it is in nearby areas without paleochannels.

Northwest of the Choptank River (fig. 2), modern rivers have cut through the base of the Columbia; to the southeast, the Columbia aquifer is thick enough that the rivers were not able to penetrate the aquifer to its base.

The Columbia aquifer is generally restricted to the inland and upland areas of the Delmarva Peninsula. The area west of the boundary of the aquifer as shown in figure 2 is underlain by the Kent Island Formation (Owens and Denny, 1979). This unit is silty and clayey and usually less than 50 feet thick. It can be sandier and thicker along the tidal rivers, but there is also a greater chance that the water in the formation is salty or brackish.

Most of the Columbia aquifer consists of a sand sheet composed of red to tan feldspathic quartz sand. Units of gray silty clay are present in this sand sheet, especially southeast of the Choptank River. Drillers commonly report thin (1 to 3 feet thick) layers of so-called clay, or silt and clay, or sand, silt, and clay at shallow depths in the northern part of the study area. Extensive sandy silt and clay units--the Omar Formation and the Walston Silt--cover the sand sheet in the southern part of the study area (fig. 2).

The Columbia aquifer is commonly unconfined, but, in places it is locally confined. This is especially true southeast of the Choptank River. Where the silt and clay layers are within the sand sheet, the aquifer is divided into confined and unconfined parts. In the areas with a surficial confining unit, as shown in figure 2, the whole aquifer is confined. In general, the confining layers within the aquifer do not appear to be very continuous and can only be traced over a few miles. The thin surficial clays reported by drillers in the northern part of the study area are hard to interpret, and it is unclear whether they are part of the Columbia aquifer or part of the soil system, and whether they actually confine ground water in the aquifer.

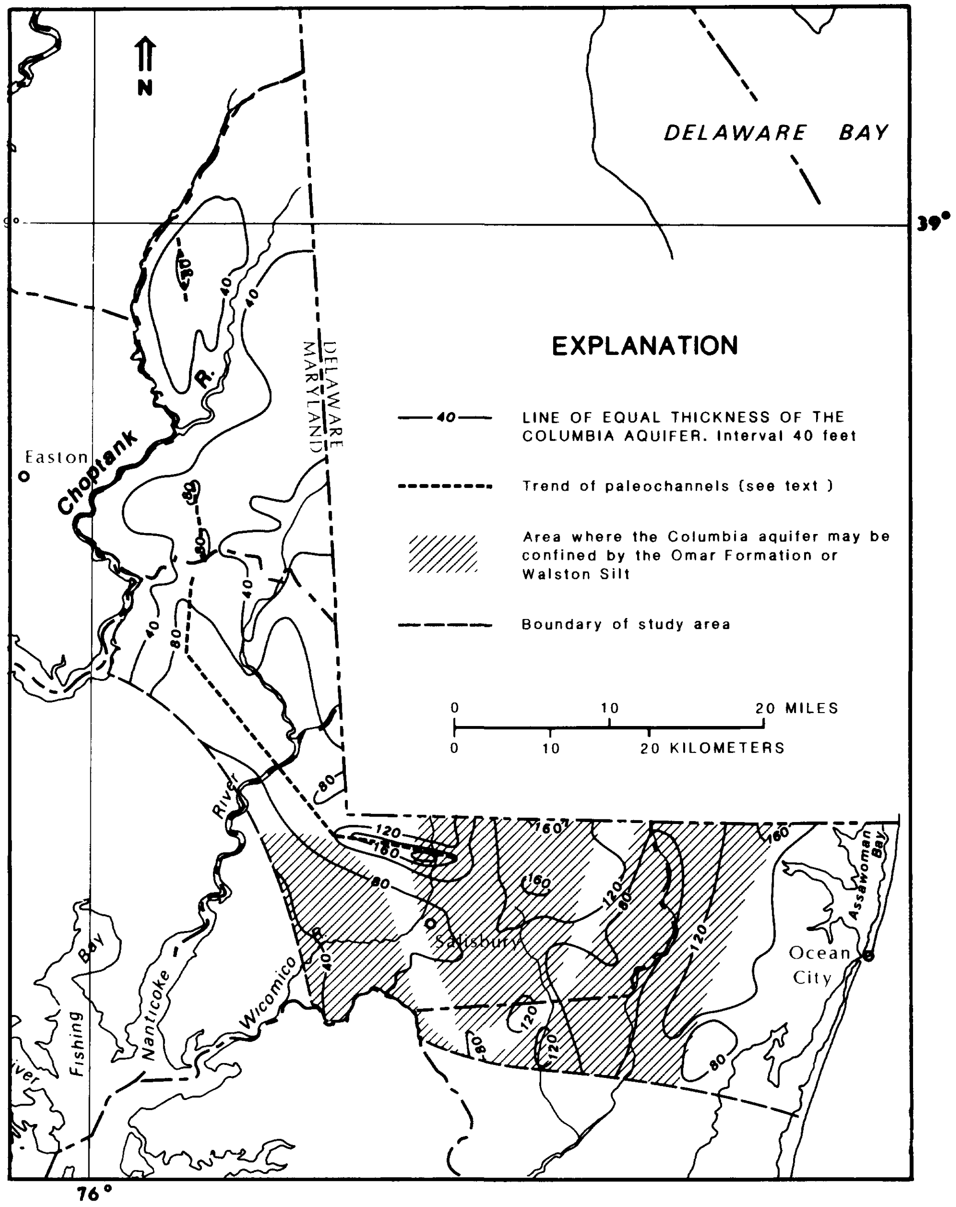


Figure 2.-- Thickness of the Columbia aquifer in the study area.

Flow systems in the Columbia aquifer are local but the areal extent and depth of the flow systems are greater, and differences in water level between recharge and discharge area are smaller to the southeast (Bachman, 1984). Water in the aquifer is derived directly from recharge by precipitation. Discharge from the aquifer is to perennial streams, tidal rivers, bays, and the ocean. There is also considerable flow between the Columbia and deeper confined aquifers. The flow systems in the Columbia aquifer are described in more detail by Bachman (1984). The thicker aquifer, larger flow systems, and smaller differences in water levels to the southeast result in larger, deeper flow systems with slower ground-water movement.

INTRODUCTION

General Water Chemistry of the Columbia Aquifer

WATER IN THE COLUMBIA AQUIFER: ACIDIC, LOW CONCENTRATION OF DISSOLVED SOLIDS, CHEMISTRY CONTROLLED BY HYDROGEOLOGY

The Columbia aquifer does not contain highly soluble minerals, and pH, alkalinity, and dissolved-solids concentrations of water in the aquifer are low. Concentrations of chemical constituents seem related to the hydrogeological characteristics of the area from which the sample is taken.

The Columbia aquifer contains little carbonate or other soluble minerals. The sand seems to have a relatively uniform mineral composition over the entire study area. In nearby parts of Delaware, feldspar content ranges from 5 to 35 percent, and total mica and other minerals range from 0 to 6 percent (Jordan, 1964, p. 55). The absence of soluble minerals is reflected in water with low pH, specific conductance and bicarbonate: median pH in water samples is 5.6; median bicarbonate concentration is 8 milligrams per liter (mg/L), and a median specific conductance is 142 micromhos per centimeter (μmho/cm). The minimum, maximum, and median concentrations of other major chemical constituents are shown in table 2. In general, the aquifer contains low concentrations of dissolved solids.

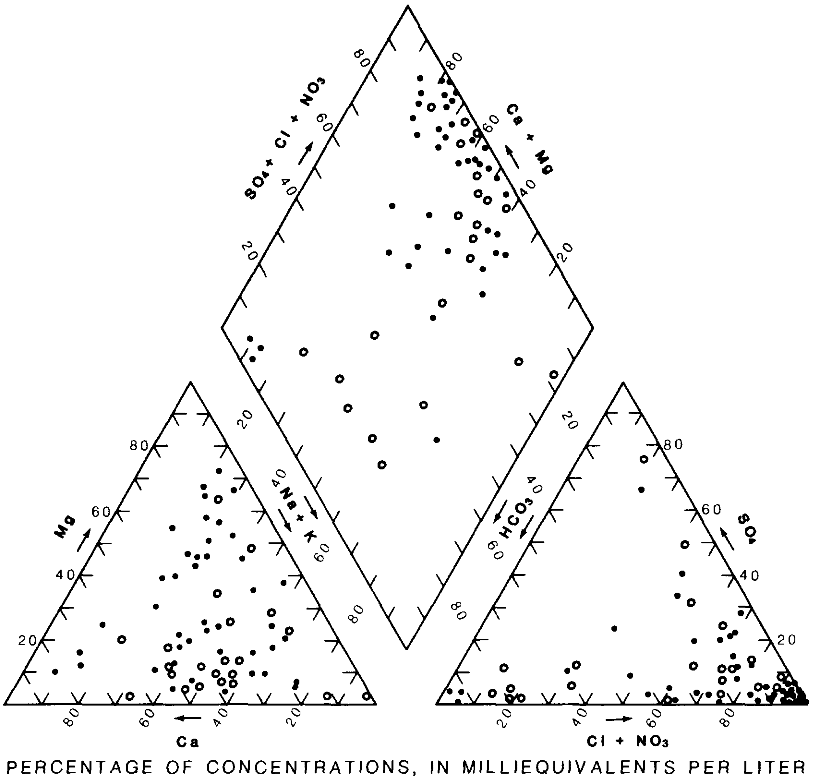
Because clay layers are less common in the northern part of the study area, potentially undesirable substances have a greater chance of entering the aquifer with recharge. For example, chloride can enter from saltwater intrusion from estuaries, bays, and the ocean, from windblown aerosols of seawater, from recharge of sewage, and from road salting in the winter. Nitrate can enter from recharge of sewage and from leaching of fertilizers.

Ground water in the southeastern part of the study area has different chemical characteristics than ground water to the north. In general, mineral dissolution is greater and reducing conditions are more common in the southeast. Clay layers may prevent the entry of pollutants into the water, but, if pollutants do enter, the larger flow paths result in a larger area of the aquifer being affected. Lower head gradients mean that pollutants will remain in the aquifer for a longer time than they will in the north.

Table 2.--Summary statistics of concentrations of selected chemical constituents in water of the Columbia aquifer

Constituent	Number of samples	Minimum	25th percentile	Median	75th percentile	Maximum
pH[1]	192	3.8	5.1	5.6	6.2	7.8
Specific conductance,[1] umho/cm	192	18	88	142	219	716
Calcium, mg/L as Ca	151	0	3.1	5.7	9.6	63
Magnesium, mg/L as Mg	168	0	1.0	2.5	5.6	20
Sodium, mg/L as Na	151	2.2	5.4	7.5	11	140
Potassium, mg/L as K	151	<0.1	1.1	2.1	3.3	31
Bicarbonate,[1] mg/L as HCO_3	89	0	4	8	22	170
Sulfate, mg/L as SO_4	151	0	1	3	9	140
Chloride, mg/L as Cl	181	1.2	6.7	9.4	15	75
Nitrate plus nitrite, mg/L as N	509	<0.01	0.2	3.5	7.8	58
Dissolved iron, mg/L as Fe	150	<0.003	0.010	0.047	0.468	14.0
Silica, mg/L as SiO_2	149	6.8	13	17	25	51

[1] Measured in the field.



EXPLANATION

- ● Analyses from sites in Caroline and Dorchester Counties
- ○ Analyses from sites in Wicomico and Worcester Counties

Figure 3.-- Comparison of relative concentrations of selected chemical constituents in the Columbia aquifer in the northern and southern parts of the study area.

The area is divided into two parts by the Nanticoke River (fig. 1). The northern part includes Caroline and Dorchester Counties, and the southeastern part includes Wicomico and Worcester Counties. A more detailed system to evaluate areal variation of chemical constituents in the aquifer will be presented in a later section. There is considerable overlap between chemical characteristics of water in the northern and southeastern parts of the study area. This is shown in the water-analysis diagram of the percentages of concentrations of major constituents (fig. 3).

In most of the samples, calcium and magnesium are the predominant cations and chloride and nitrate are the predominant anions (fig. 3). However, in the southern part of the study area, water containing sodium and potassium and bicarbonate is more common than to the north. For example, bicarbonate water (greater than 50-percent bicarbonate relative to other anions) is present in 9 percent of the samples from the northern counties, whereas it is present in 32 percent of the samples from the southern counties. Water containing mostly sodium and potassium as cations occurs in 26 percent of the northern samples, and in 50 percent of the southern samples.

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The relative increase in bicarbonate reflects both the effects of increased mineral dissolution and more common reducing conditions (Piper, 1944, p. 922; Freeze and Cherry, 1979, p. 280-282) in the two southern counties. The differences between median values of some selected constituents are shown in table 3. The statistical significance of the median values can be determined using a Kruskal-Wallis test (Conover, 1980, p. 229). The results expressed in table 3 are the probabilities that the differences between medians of a constituent are due to chance. Probabilities of less than 5 percent are commonly considered to indicate significant differences between medians. Other probabilities, such as 1 percent, 0.1 percent or 10 percent can also be used. The probability selected to indicate whether the difference is significant is up to the investigator and reflects the choice of the chance he wishes to take of saying the differences are significant when they are not. In this report, the maximum probability used to indicate significant differences is 5 percent.

The results indicate that the difference between the median values of certain constituents in the two areas is greater than would be expected strictly due to chance. The higher median values of silica and aklalinity in Wicomico and Worcester Counties may reflect the greater dissolution of quartz and feldspar in the larger, deeper flow systems in those counties. (One of the consequences of feldspar dissolution is the increase of bicarbonate. See Freeze and Cherry, 1979, p. 268-284). The higher values of dissolved iron and lower values of nitrate in the southern counties may indicate that reducing conditions are more common there.

Table 3.--Comparison of concentration of chemicl constituents in different parts of the study area

[Kruskal-Wallis test result is the percent probability that differences between the two areas are due to chance.]

Constituent	Counties				Result of Kruskal-Wallis test
	Caroline and Dorchester		Wicomico and Worcester		
	Number of samples	Median	Number of samples	Median	Probability
pH[1]	112	5.5	62	5.6	1.8
Specific conductance,[1] umho/cm	112	143	62	141	64.0
Calcium, mg/L as Ca	80	5.6	53	6.5	36.0
Magnesium, mg/L as Mg	89	3.2	62	2.1	.13
Sodium, mg/L as Na	80	5.8	53	11.0	.01
Potassium, mg/L as K	80	2.8	53	1.2	.01
Bicarbonate,[1] mg/L as HCO_3	53	5.0	33	19.0	.01
Sulfate, mg/L as SO_4	80	2.5	53	5.0	.20
Chloride, mg/L as Cl	104	9.0	58	11.0	4.8
Nitrate plus nitrite, mg/L as N	170	4.5	321	2.2	.22
Silica, mg/L as SiO_2	79	14.0	52	25.0	.01
Iron, dissolved, mg/L as Fe	79	.026	53	.190	1.26

[1] Measured in the field.

Differences in cation concentrations between the northern and southern counties are harder to evaluate. The dissolution of feldspar will yield some calcium, magnesium, sodium, and potassium, depending on the type of feldspar. However, sodium and potassium can enter the aquifer from other sources such as salt-water intrusion, or fertilizer application; thus, they could be common constituents in water in the northern counties where, presumably, feldspar dissolution is not as extensive as it is in the south. In fact, potassium concentrations are significantly higher in Caroline and Dorchester Counties than in the southern counties. Cation exchange on clays may further complicate the situation by removing some ions from solution and replacing them with others. Relative amounts of cations may then not be related to either the quality of the recharge water or the mineral dissolution that occurred before the cation exchange.

BACKGROUND INFORMATION ABOUT NITRATE

Sources of Nitrate

NITROGEN IN GROUND WATER COMES MOSTLY FROM HUMAN ACTIVITY

Nitrate rarely occurs naturally in ground water in concentrations greater than 3 mg/L as nitrogen. Greater concentrations generally are the result of applications of inorganic fertilizers, manure, and sewage to the land. Nitrogen not used by plants or fixed in the soil leaches into the ground water.

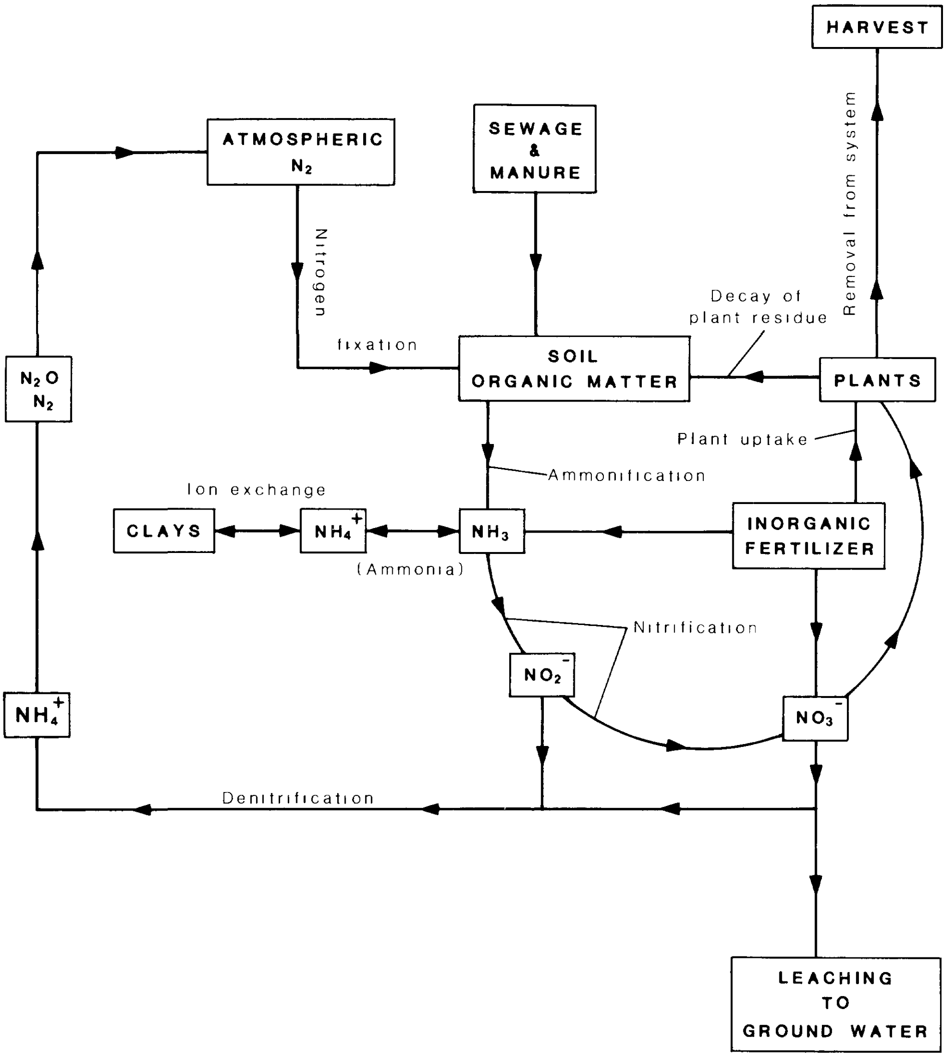
Minerals containing nitrogen are almost nonexistent in the Columbia aquifer, so dissolved nitrogen comes from sources outside the aquifer. Nitrogen enters the soil from fixation of atmospheric nitrogen by plants and bacteria, from the decay of organic matter, from rainfall, and from nitrogen applied to the land by humans and livestock.

Nitrogen follows a path of cyclical reactions in the soil, as shown in figure 4. These reactions are described in more detail in soil science textbooks, such as Buckman and Brady (1969, p. 437-462). In the presence of oxygen, the organic nitrogen compounds tend to change to inorganic forms by a process called "mineralization" by soil scientists. Mineralization actually occurs in two steps. The first, known as ammonification, results in the conversion of the organic compounds into ammonia (NH_3). The second step--nitrification---converts the ammonia to nitrite (NO_2; which is unstable) and nitrate (NO_3).

Nitrate is a stable compound, but in the presence of the proper bacteria and a reducing chemical environment, it can denitrify into nitrogen gas (N_2) or nitrous oxide (N_2O), which can leave the soil and go into the atmosphere. Nitrate is also the form of nitrogen used by plants, and so some soil nitrate is taken up by plants only to return to the soil as organic nitrogen compounds when the plants decay. Ammonia can also be temporarily absorbed on clay particles in the soil through the process of ion exchange. In many situations there is a rough balance between mineralization of organic matter in the soil and nitrate used by plants, but if more nitrogen is applied to the soil than can be used by plants or fixed on clay particles, it will eventually leach to the ground water.

Under natural conditions, concentrations of dissolved nitrogen species in ground water are low. Data collected from a number of studies on the shallow glacial aquifer on Long Island, N.Y.,--an aquifer similar to the Columbia--indicate that naturally occurring concentrations are on the order of 0.2 mg/L as N (Perlmutter and Koch, 1972; and Ragone and others, 1980). The common occurrence of much higher concentrations is due to application of nitrogen on the land by human activities.

Nitrogen applications on the Delmarva Peninsula are of three main types: Inorganic fertilizers, livestock wastes, and human wastes. Inorganic fertilizers are applied over large areas of land and are applied frequently in the study area because the sandy soils contain few natural nutrients. Livestock wastes end up on the soil as runoff from concentrated feeding operations and as fertilizer.



(Based on text from Buckman and Brady, 1969, p. 437-462)

Figure 4.-- The nitrogen cycle.

Although there are a few dairy farms in the study area, the most common type of livestock is the chicken. Thousands of broilers are grown in individual operations at most of the farms in the area. Human waste enters the soil through on-site sewage disposal systems at rural and suburban residences and from spray irrigation of municipal and industrial wastes. Sanitary landfills used for the disposal of solid wastes can also be locally important as a source of nitrate, but these do not cover extensive areas.

BACKGROUND INFORMATION ABOUT NITRATE

Factors Affecting Nitrate Concentration

GEOLOGY, SOILS, AND LAND USE ALL AFFECT THE CONCENTRATION OF NITRATE IN GROUND WATER

The study area was divided into rows based on the alignment of 5-minute quadrangles in a northeast-southwest direction to evaluate areal variation of nitrate concentration in the aquifer due to geology and soils. Soils were divided into four categories based on infiltration potential, and land uses were divided into five categories based on different sources of nitrate.

The nitrate concentration of ground water at any location in the Columbia aquifer is determined by the presence or absence of sources of nitrate, by the chemical conditions of the aquifer at that point, and by the ability of the soil and aquifer to transmit nitrogen-rich water. As mentioned previously, nitrogen leaching into the saturated zone is mostly due to human activity. The presence or absence of a nitrate source is thus closely related to the land use at the site. The infiltration potential of the soil, the geological characteristics, and the ground-water flow characteristics at the site all determine whether the nitrate can enter the aquifer, and whether it will remain there.

The potential for nitrate contamination at any given site in the study area is best determined by a detailed ground-water investigation in the vicinity of the site. The data presented here are regional in scale, and local variations in soil permeability, aquifer lithology, and land use were not mapped. Local studies will better define the ground-water flow systems in an area of interest and determine the relationships among nitrate sources, the flow system, and wells withdrawing water from the Columbia aquifer.

The land use at each sampling site was determined when the well was inventoried. The classification is shown in table 4 and is based on the potential nitrate source for each land use. Some of the land uses, such as field crops and field crops with residence, have at least one source of nitrogen in common. Land-use information was not available for the wells from Delaware, for samples collected before 1981, and for wells sampled by the county health department.

Table 4.--Land-use categories and sources of nitrogen

Land use	Sources of nitrogen
Woods and wetlands	Natural - Fixation of atmospheric nitrogen and decay of organic matter.
Woods with residence	Fixation of atmospheric nitrogen; decay of organic matter; and infiltration of septic-tank effluent; lawn and garden fertilizer.
Field crops	Inorganic nitrogen fertilizer; non-point application of manure; natural nitrogen fixation and decay of organic matter.
Field crops with residence	Inorganic nitrogen fertilizer; non-point application of manure; natural nitrogen fixation and decay of organic matter; infiltration of septic-tank effluent.
Chickenhouses	Leaching from chicken manure.
Urban	Infiltration of septic-tank effluent; leachate from sanitary landfills; infiltration of sewage from sewage lines; lawn and garden fertilizer; dog and cat feces; natural nitrogen fixation.

The soils in the study area were grouped according to their potential for infiltration. The soil hydrologic classes shown in table 5 were determined by assigning soil series as mapped on the county soil maps (U.S. Soil Conservation Service, 1963, 1964, 1970, and 1973) into the "natural soils groups" described by the Maryland Department of State Planning (1973). The "natural soils groups" are based on texture, drainage, and parent material. The infiltration potential of the soil, which defines its soil hydrologic class, is based on soil texture and drainage and the presence of a seasonal or permanent high water table. The hydrologic characteristics for each class are also shown in table 5.

Because the geologic and hydrologic characteristics of the aquifer change from northwest to southeast, sampling sites were grouped into rows running from northeast to southwest. The sites were actually first grouped into 5-minute quadrangles, which were then aligned into the northeast-southwest direction to make the rows. The location of the 5-minute quadrangles and the rows is shown in figure 5. The quadrangles in every third row in figure 5 are shaded to show how the quadrangles were arranged into rows.

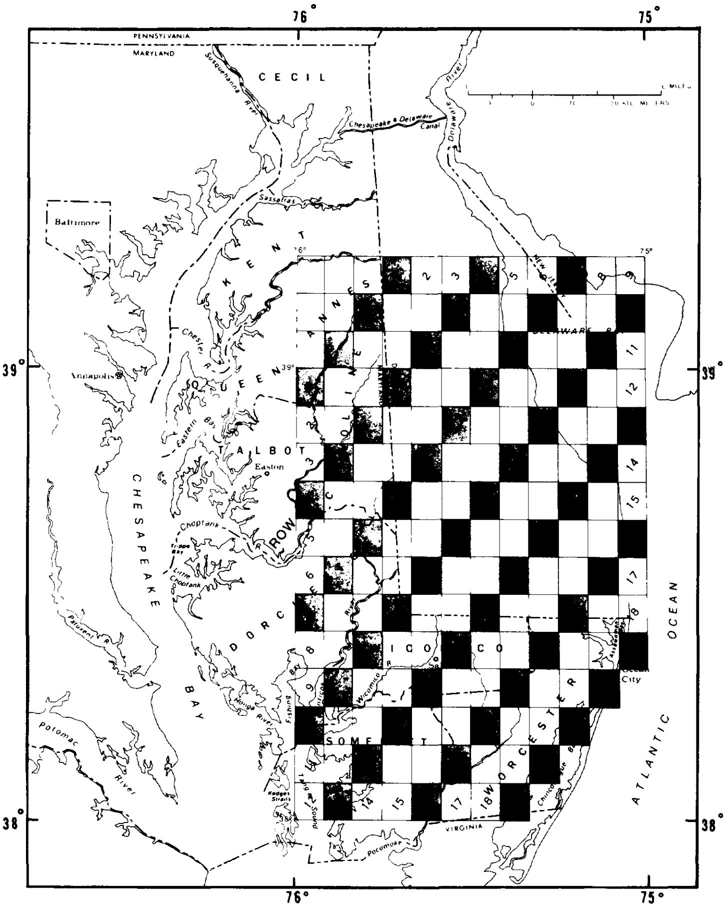


Figure 5.-- Location of 5-minute quadrangles and rows used to determine areal variation of nitrat

Table 5.--Description of soil hydrologic classes

Hydrologic soil class	Infiltration potential	Hydrologic characteristics	Natural soil groups in class[1]
A	High	Coarse texture; very well drained.	A1, A2
B	Moderate	Moderately coarse texture; well drained.	B1
C	Low	Fine texture; seasonal high water table common.	B2, B3, E1, E2, E3, G1
D	Very low	Fine to very fine texture; permanent and seasonal high water tables common.	F1, F2, F3, G2

[1] Natural soil groups are described by Maryland Department of State Planning (1973).

NITRATE IN THE COLUMBIA AQUIFER

Frequency Distribution of Sample Used in Study

OVER HALF THE WATER SAMPLES COLLECTED HAD NITRATE CONCENTRATIONS GREATER THAN 3 MG/L AS NITROGEN

Median nitrate concentrations collected during this study are significantly higher than those reported in previously published studies. Fifty-two percent of the samples collected for this study have nitrate concentrations greater than 3 mg/L as nitrogen, a figure higher than the natural concentration in ground water. The water-quality standard of 10 mg/L nitrate as N was exceeded in 15 percent of the samples compiled or collected during this study.

Nitrate analyses compiled or collected during this study are significantly higher than analyses from the Delmarva Peninsula reported in previous studies (tables 6 and 7). The analyses from the previous studies (designated "historical" in tables 6 and 7) are those reported by Woll (1978). The concentration classes in the two tables are those used by Ragone and others (1980) in their study of nitrate on Long Island, N.Y. The classes have the following significance:

- Less than 0.2 mg/L as N: This is water which has not been affected by human activity (Perlmutter and Koch, 1972).
- 0.2 to 3.0 mg/L as N: This range of concentration would represent water which may or may not be affected by human activity.
- 3.0 to 10.0 mg/L as N: Water with this range of nitrate concentration is clearly affected by human activity, but still meets the drinking water-quality standard of 10 mg/L.
- Greater than 10.0 mg/L as N: Water which exceeds the water-quality standard.

Thirty-seven percent of the historical analyses had nitrate concentrations clearly indicative of effects of human activity (table 6)--that is, concentrations greater than 3.0 mg/L—whereas, 52 percent of the combined recent Geological Survey and county health department analyses have comparable concentrations (table 7). Only 7 percent of the historical analyses had nitrate concentrations that exceed the water-quality standard of 10 mg/L, but 15 percent of the samples from this study did. The median values for nitrate analyses collected for this study (table 8) are more than twice as high as the median values for the historical analyses. The Kruskal-Wallis test indicates that there is a significant difference at the 1-percent level between median nitrate concentrations of the analyses collected for this study and the historical analyses.

The meaning of the difference between historical and current analyses is not entirely clear. There may be a trend of increasing nitrate concentrations in the Columbia aquifer related to increasing population and changes of land use in the study area. On the other hand, the difference could be due to changes in sample-collection and preservation techniques, or to changes in analytical methods. Also, none of the previous studies sampled randomly over the entire study area. Thus, there are, for example, many samples from northeastern Worcester County from the late 1960's and early 70's (Lucas, 1972; Weigle, 1974), but few or none from other parts of the study area. No chemical analyses of water from the Columbia aquifer in Caroline County were made by the U.S. Geological Survey from the mid-1950's to 1981.

[Includes analyses for nitrate and nitrate plus nitrite.]

Source of data	Nitrate - concentration class milligrams per liter as nitrogen								Total of data sources	
	Less than 0.2		0.2 - 3.0		3.0 - 10.0		More than 10.0			
	Number of analyses	Percent	Number of analyses	Percent	Number of analyses	Percent	Number of analyses	Percent	Number of analyses	Percent
U.S. Geological Survey, previous studies 1945-79	22	23	38	40	29	30	6	7	95	100
U.S. Geological Survey, this study 1981-83	56	28	35	18	68	35	37	19	196	100
Class totals	78	27	73	25	97	33	43	15	291	100

Table 6.--Comparison of frequency distributions of nitrate concentrations in data collected by the U.S. Geological Survey during this study and in data collected by the U.S. Geological Survey in previous studies

[Includes analyses for nitrate and nitrate plus nitrite.]

Source of data	Nitrate - concentration class milligrams per liter as nitrogen								Total of data sources	
	Less than 0.2		0.2 - 3.0		3.0 - 10.0		More than 10.0			
	Number of analyses	Percent	Number of analyses	Percent	Number of analyses	Percent	Number of analyses	Percent	Number of analyses	Percent
U.S. Geological Survey, this study 1981-83	56	28	35	18	68	35	37	19	196	100
Compiled from county health department records 1970-82	65	21	86	27	122	39	40	13	313	100
Class totals	121	24	121	24	190	37	77	15	509	100

Table 7.--Comparison of frequency distributions of nitrate concentrations in data collected by the U.S. Geological Survey during this study and data compiled from county health department records

[Nitrate, dissolved or nitrate plus nitrite, dissolved, in milligrams per liter (mg/L) as nitrogen]

Sample	Number of analyses	Minimum	Median	Mean	Maximum	Standard deviation
U.S. Geological Survey (pre-1979)	95	0	1.5	3.1	21.5	4.05
U.S. Geological Survey 1981-83	196	<0.01	4.3	6.0	58.1	8.05
County health department records	313	0.01	3.2	4.7	33.4	5.4
Total	604	<0.01	3.1	4.9	58.1	6.4

The Kolmogorov-Smirnov D statistic (Sokal and Rohlf, 1969) for all of these samples is significant at the 1-percent level. It is thus unlikely that these samples represent random samples from a normally distributed population.

Table 8.--Statistical summary of nitrate concentration of water from the Columbia aquifer

The distributions of recent U.S. Geological Survey and health department analyses are more comparable than are the recent and historical analyses. Nitrate exceeded 3.0 mg/L in 52 percent of the health department analyses as opposed to 54 percent in the U.S. Geological Survey analyses made after 1979. Health department analyses exceed 10.0 mg/L in 13 percent of the samples; current U.S. Geological Survey analyses exceeded 10 mg/L in 19 percent of the samples. Because of the similarities in distribution, the current U.S. Geological Survey and health department analyses were combined as one set of data for statistical analysis. This is further justified by the fact that the Kruskal-Wallis test showed no significant difference between the median of the U.S. Geological Survey analyses and the median of the health department analyses.

The sites sampled by the U.S. Geological Survey during this study were randomly selected. The analyses compiled from county health department files were also randomly selected from the files. Most of the sites were relatively new wells; indeed, the vast majority of health department analyses were made to certify that a newly constructed well met the water-quality standard.

The percentage of sites with poorly drained soils increases from the northwestern to the southeastern part of the study area. Most sites with agricultural land use tend to have fairly well drained soils; the other land uses were evenly divided by soil type.

Because a large percentage of the nitrate concentration was less than 3 mg/L, and because of the relatively few values with very high concentrations, the concentrations were converted to their logarithms to make the frequency histogram shown in figure 6. Even with this transformation, the frequency distribution shown does not resemble the classic bell-shaped curve, or normal distribution. A test for a normal distribution--the Kolomogrov-Smirnov D statistic (Sokol and Rohlf, 1969, p. 571-575)--was significant at the 1-percent level for both the original data and its logarithmic transformation. It is thus unlikely that the data are samples from a normally distributed population. For this reason, and because 78 of the analyses were below the detection limit, thus effectively reducing the scale of measurement to the ordinal scale,[1] nonparametric statistical analyses were used in this study.

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[1] *The ordinal scale of measurement is one of four fundamental scales described more fully by Stevens (1946). An ordinal scale measurement means that only the relative ranks between the observations can be described. The measurement scale controls the type of statistical analyses which can be performed on the data (Griffiths, 1967, p. 245-249; and Conover, 1980, p. 64-66.).*

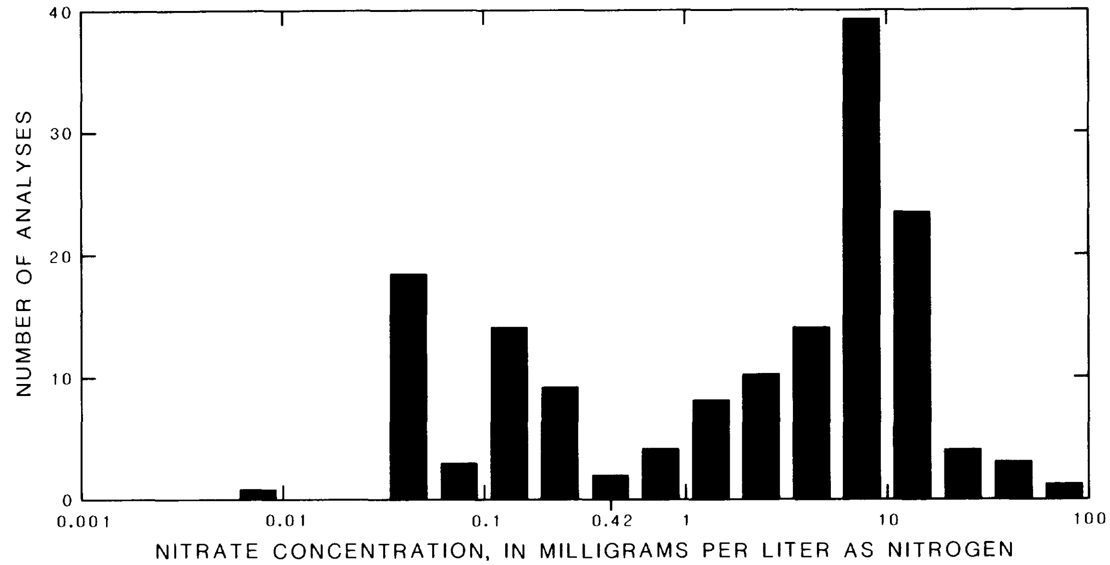


Figure 6.-- Histogram of logarithm of nitrate concentrations . (Recent (1981-1983) U.S. Geological Survey data and county health department data (1970-1982).

Figure 6 shows that the distribution of nitrate concentrations is bimodal, indicating that this distribution may be a mixture of two, possibly lognormally distributed populations (James Slack, U.S. Geological Survey, written commun., 1982). The part of the sample with the lower concentrations may represent the distribution of naturally occurring nitrate; the part with higher concentrations may represent the distribution of nitrate concentrations in water affected by human activity. The frequency class between those two distributions (indicated in fig. 6 as the class with the midpoint of 0.42 mg/L) would then represent an alternative method for dividing the sample into natural and human-affected nitrate concentrations. The part of the sample greater than 0.42 mg/L contains 364 analyses, ranges from 0.45 mg/L to 58.1 mg/L, and has a median of 5.9 mg/L. The other part of the sample ranges from 0 to 0.4 mg/L, has 145 analyses, and a median of 0.1 mg/L. Using this criteria to divide the sample rather than the classes of tables 6 and 7, a fairly large majority of the analyses are from sites which have been affected by human activity. This sample consists of analyses of the U.S. Geological Survey performed between 1981 and 1983, and analyses of the county health departments. The total sample size is 509 analyses.

NITRATE IN THE COLUMBIA AQUIFER

Relation Between Nitrate Concentration and Depth

HIGH NITRATE CONCENTRATIONS MOST COMMON IN SHALLOW WELLS

At sites with analyses of both deep and shallow ground water, nitrate concentrations tend to be higher in the shallow ground water. Nitrate concentration generally tends to decrease with increasing depth. High nitrate concentrations from deeper wells are common, however. Water from the confined aquifers below the Columbia has much lower nitrate concentrations; only about 2 percent of the wells sampled had concentrations greater than 3 mg/L as N.

Three of the five well nests were screened at two depths within the Columbia aquifer. Nitrate concentrations from these well nests are shown in table 9. In all three nests, nitrate in the shallow well has a higher concentration than nitrate in the deeper well, although the difference is not very great at the Mardela Springs site. At Fook's gravel pit, a clay layer within the Columbia aquifer at the 45- to 55-foot depth may account for the large difference between the concentrations in the deep and shallow wells. At all sites, the water-level differences between the deep and shallow screens indicate some ground-water flow from the shallow part of the aquifer to the deeper part.

Figure 7 shows a very weak inverse relationship between nitrate concentration and the depth to the top of the well screen below land surface. Concentrations of nitrate above 3.0, or even 10 mg/L as N are present in deeper wells, and concentrations of less than 3.0 mg/L as N are common in shallow wells. The presence of nitrate in high concentrations at depth is related to the presence of vertical ground-water flow, the absence of clay and silt layers, and the presence of a source of nitrate at the vicinity of the sampling site.

Table 9.--Nitrate concentrations in well nests

[See plates 1-4 for locations of wells.]

Site	Shallow well			Deep well		
	Well No.	Depth (feet)	Nitrate concentration (mg/L as N)	Well No.	Depth (feet)	Nitrate concentration (mg/L as N)
Fook's gravel pit - Hurlock	DO BG 71	48	8.0	DO BG 70	66	0.10
Mardela Springs	WI BD 70	33	0.15	WI BD 69	58	0.10
Willards	WI CH 49	42	1.2	WI CH 48	103	0.68

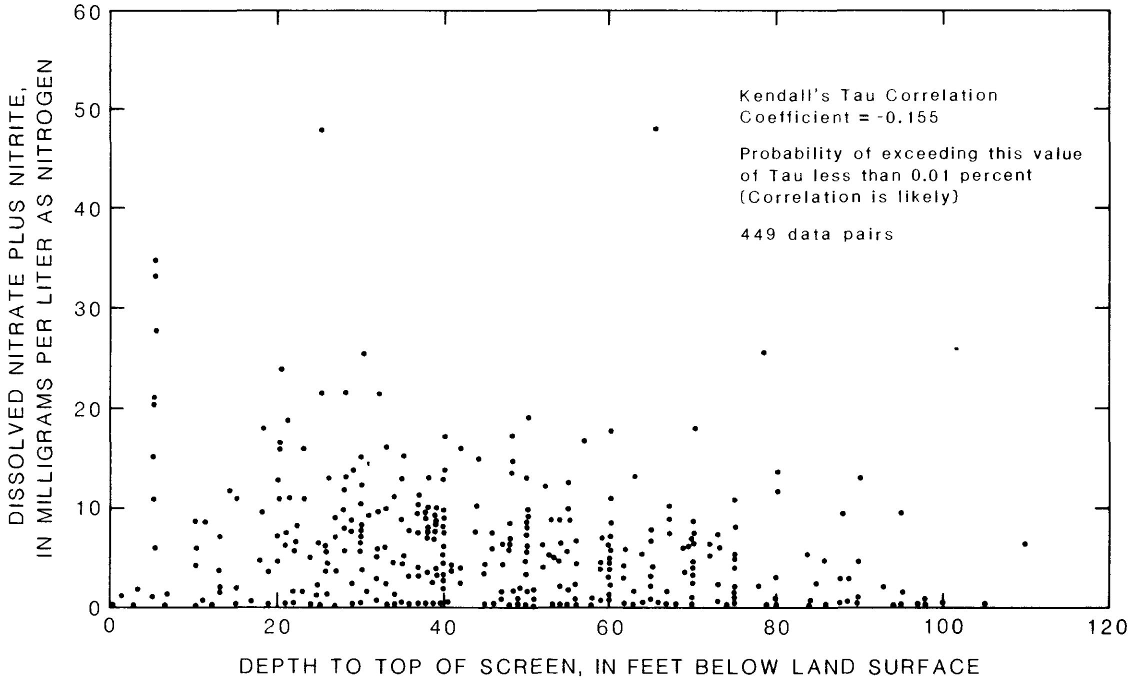


Figure 7.-- Relation between depth to top of screen and nitrate concentration. (Data from recent U.S. Geological Survey investigations and county health departments).

Correlation of nitrate concentration with depth was determined using the Kendall's tau correlation coefficient, a nonparametric measure of correlation (Conover, 1980, p. 256-260). The correlation was found to be statistically significant (fig. 7), but the value of Kendall's tau is low. This further emphasizes the complex nature of nitrate occurrence in the Columbia aquifer.

Because of concern that nitrate might be entering the deeper, confined aquifers, 175 nitrate analyses of water samples were compiled from wells which tap the aquifers underlying the Columbia. The nitrate concentrations ranged from 0 to 40 mg/L as N, and the median was 0.1 mg/L as N, which is significantly lower than the median concentration in the Columbia aquifer. Only water from nine wells (or about 2 percent of the wells sampled) had concentrations above 3.0 mg/L, and only water from three wells had concentrations exceeding 10.0 mg/L. Nitrate concentrations of over 3 mg/L occurred in the underlying aquifer in Caroline, Dorchester, and Wicomico Counties. In general, conditions favoring high nitrate concentrations in the underlying aquifer are similar to those favoring high nitrate concentrations in the deeper parts of the Columbia aquifer: Presence of a significant component of vertical groundwater flow, absence of confining layers (as in a subcrop zone), and a nearby source of nitrate.

MEDIAN NITRATE CONCENTRATIONS DECREASE DOWN THE REGIONAL DIP OF THE AQUIFER

Median nitrate concentrations in the southeastern part of the study area are significantly lower than those in the northwestern part. This seems to correspond with trends of increasing aquifer thickness and with the greater abundance of poorly drained soils to the southeast.

Median nitrate concentrations are highest in ground water in the northwestern part of the study area (fig. 8). The result of the Kruskal-Wallis test indicates that the differences between row medians are statistically significant (fig. 8). The median concentration decreases sharply at row 14 (just east of Salisbury; fig. 9) to less than 1 mg/L and remains low in all rows to the southeast. This follows the regional trend of thickening of the aquifer.

Median concentrations of nitrate from wells tapping the Columbia aquifer in each 5-minute quadrangle are shown in figure 9. Plotting quadrangle medians this way eliminates the effect of large, but localized, variations while showing regional trends of nitrate concentration. Quadrangle medians generally tend to be lower south of the Maryland-Delaware State line and east of Salisbury (fig. 9). Most of the quadrangles in the southeastern part of the study area that do have median concentrations greater than 1 mg/L contain a small number of sites (commonly less than five) and may not be representative of nitrate concentration of water in the quadrangle.

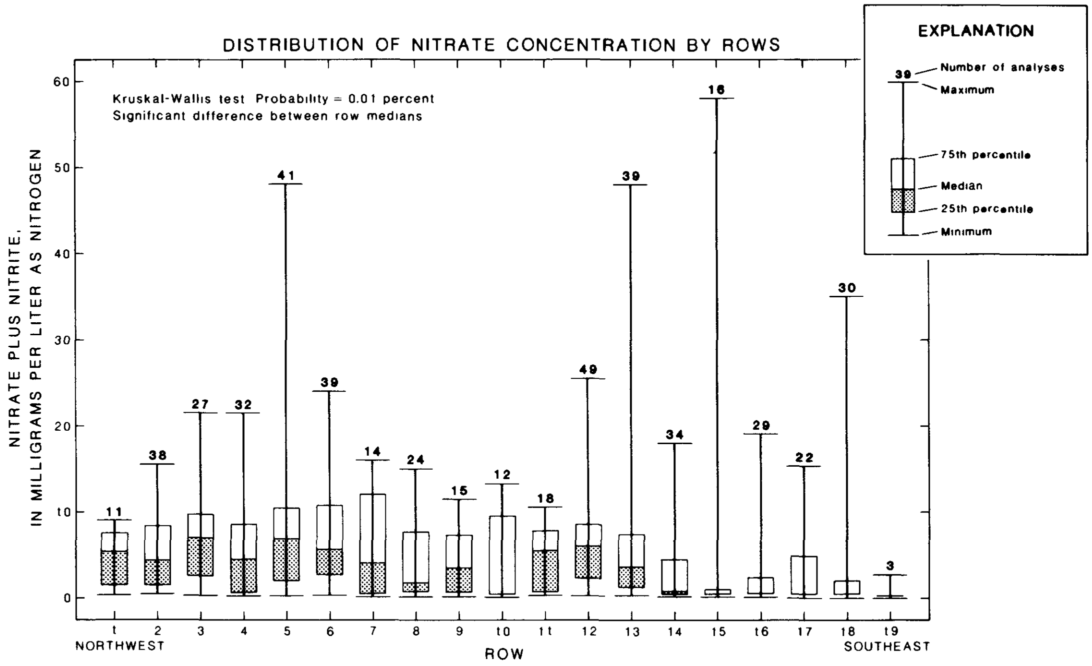


Figure 8.-- Distribution of nitrate concentration by rows.

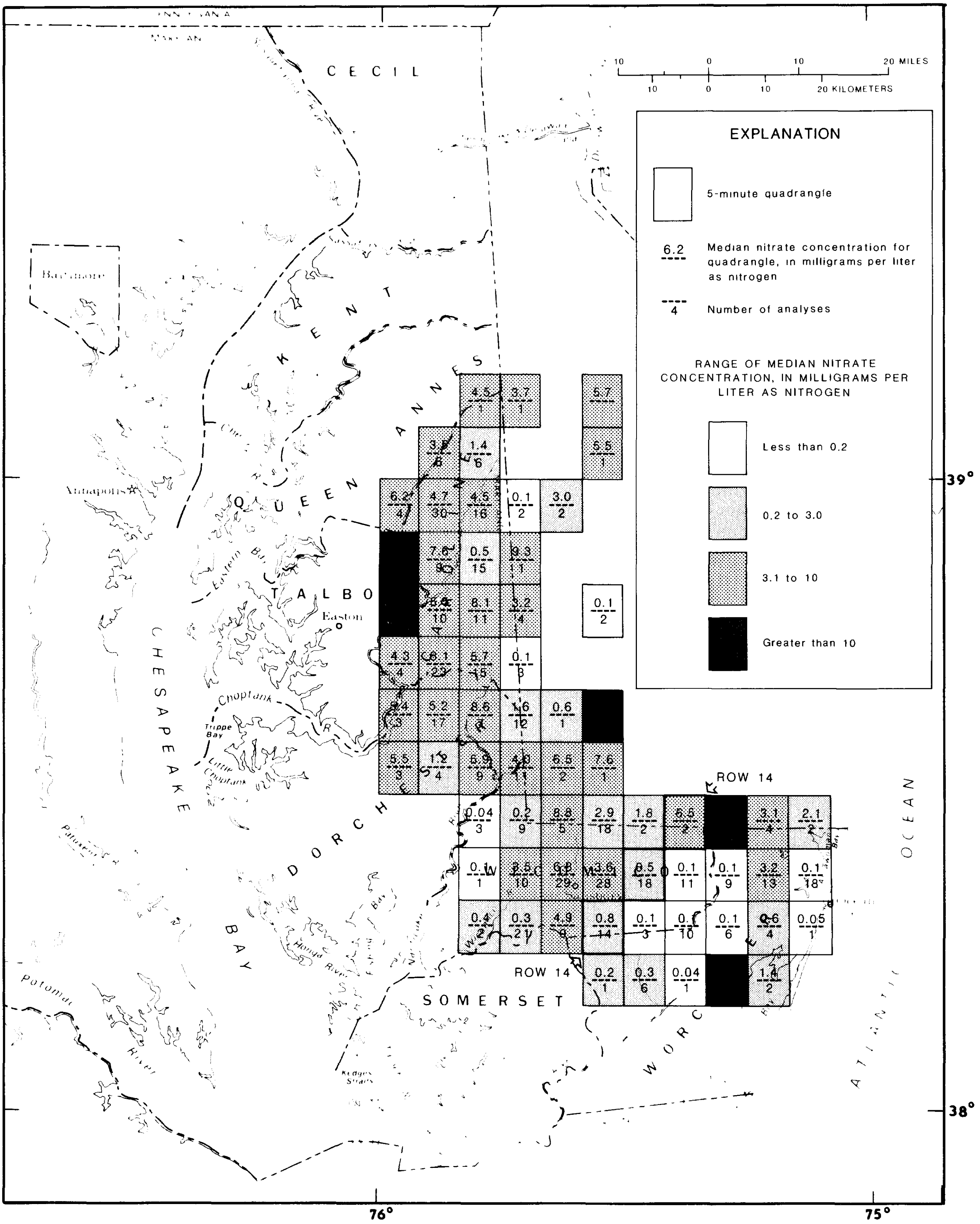


Figure 9.-- Trends of nitrate concentration in the central Delmarva Peninsula.

Nitrate concentration is also highly associated with the soil hydrologic group. Differences between soil group medians are statistically significant (fig. 10). The median nitrate concentrations of the more poorly drained type C and D soils tend to be lower than those of the type A and B soils (fig. 10). The association between nitrate concentration and rows, and between nitrate concentration and soil groups may be related to an association between row and soil groups. Maps of natural soil units and a tabulation of the units by county (Maryland Department of State Planning, 1973) indicate that type C and D soils are more common in the southeastern part of the study area. In this study, 55 percent of the sites sampled in Wicomico and Worcester Counties had type C or D soils; only 23 percent of the sites in Caroline and Dorchester Counties had those soil types. It should be emphasized that despite clear differences between median concentrations of rows and soil types, very high and very low concentrations are present in all groups (figs. 8 and 10). The best example of this is the highest single nitrate concentration recorded in this study—58.1 mg/L as N. The well from which that sample was taken (WO AE 26, table 11) is in the southeastern part of the study area (from row 15, which has a median nitrate concentration of 0.01 mg/L as N). The soil at the site is a poorly drained type D. The fact that the well is located near a chicken-house illustrates the important effect of land use on nitrate concentration, as will be explained in the next section on nitrate variation by land use.

The wide range in nitrate concentration in all rows and all soil groups reflects the overlap in ground-water conditions in the different parts of the study area as well as the effects of different land uses. In general, flow systems in the southeast tend to have more numeous and continuous confining layers, gentler slopes on the water table, and deeper and longer flow paths than flow systems in the northwest. This means that nitrate is less likely to enter the ground-water flow system. If nitrate does enter, it may be denitrified in the confined flow systems (see the following section on relation to the chemical environment), or it can be diluted by the larger flow systems. However, unconfined flow systems, shallow wells, recharge areas, and well-drained soils are present in the southeast, so if a source of nitrogen is present, ground water in the Columbia aquifer in the southeast can have high concentrations of nitrate.

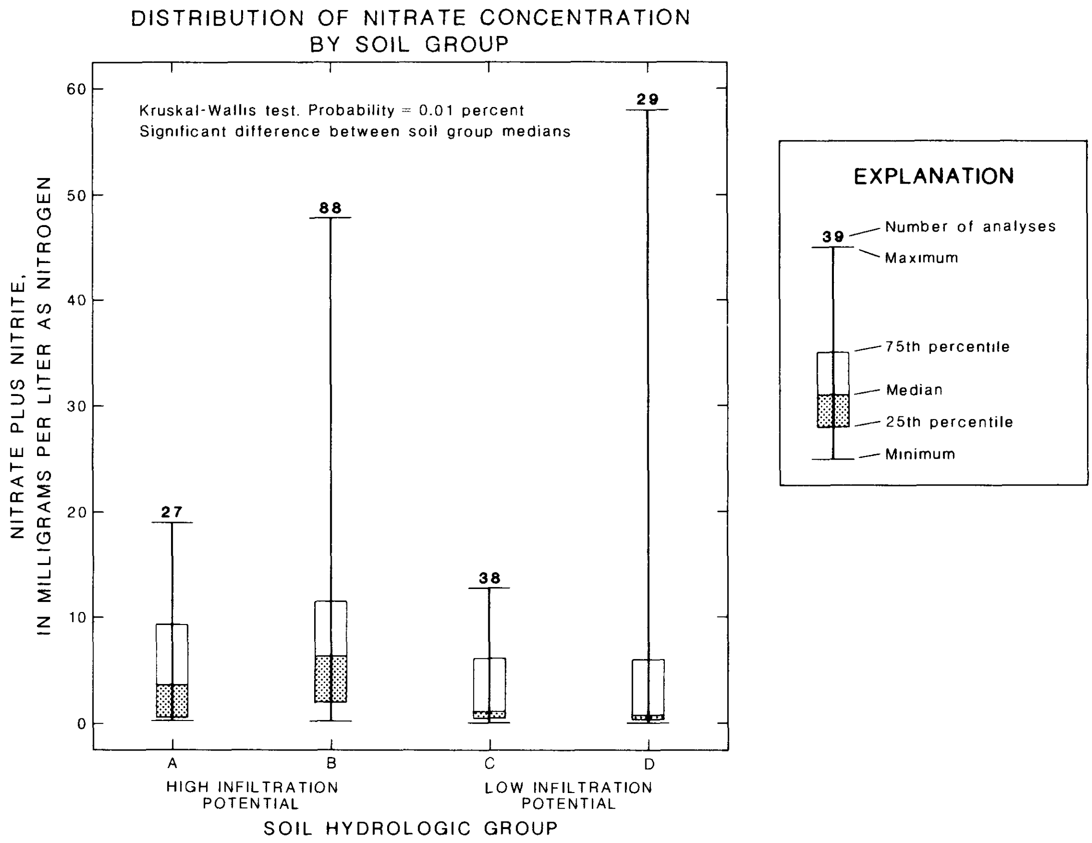


Figure 10.-- Distribution of nitrate concentration by soil hydrological group.

NITRATE IN THE COLUMBIA AQUIFER

Effect of Land Use

MEDIAN NITRATE CONCENTRATIONS ARE HIGHEST UNDER SITES WITH AGRICULTURAL OR URBAN LAND USES

Nitrate concentrations in wells tend to be highest at sites near chickenhouses. Other agricultural sites and urban sites have the next highest concentrations, and wooded sites have the lowest concentrations. Agricultural and wooded sites with on-lot sewage-disposal systems tend to have higher nitrate concentrations than sites of the same land use without a sewage system.

Nitrate concentration appears to be strongly associated with land use (fig. 11). The difference between land-use medians is statistically significant. The presence of a source of nitrogen is needed even if hydrologic conditions favor the entrance of nitrate into the aquifer.

Ground water at sites with agricultural land uses, including chickenhouses, has the highest median nitrate values. Water from wells drilled near chickenhouses has the highest median concentration, 9.7 mg/L. Sites with field crops and residences are next, followed by sites with field crops only, urban sites, and wooded sites (fig. 11). Wooded and field-crop sites with residences (and presumably on-site sewage disposal systems) have water with higher median nitrate values than sites without residences (fig. 11), although the Kruskal-Wallis test indicates a nonsignificant difference between residential and nonresidential median concentrations for sites with a woodland land use.

Because agriculture is a more widespread land use on the Delmarva Peninsula than are urban areas, agriculture is probably the larger source of nitrogen. Agricultural sources include fertilizer and leaching of manure from livestock-feeding operations. Fertilizer is spread over a large area, and affects a large part of individual flow systems. The relatively low median nitrate concentration (2.2 mg/L as N) at sites with field-crop land use (in which nearly all of the nitrogen sources are fertilizers) indicates that fertilizer use on field crops, whether inorganic or manure, probably does not result in an extremely high nitrate concentration in ground water at a site. Manure at a livestock feeding operation contains concentrated amounts of nitrogen applied to a small area overlying the aquifer. Less of the flow system is affected than is from application of fertilizer, but the water may have very high nitrate concentrations near the site of application.

Nitrogen sources from urban land uses can increase nitrate concentration in the aquifer. The largest single source is probably from septic-tank effluent in suburban areas without central sewage systems, but nitrogen can also come from leaking sewage lines and sanitary landfills. Lawn and garden fertilizers in suburban areas could also be significant sources of nitrate.

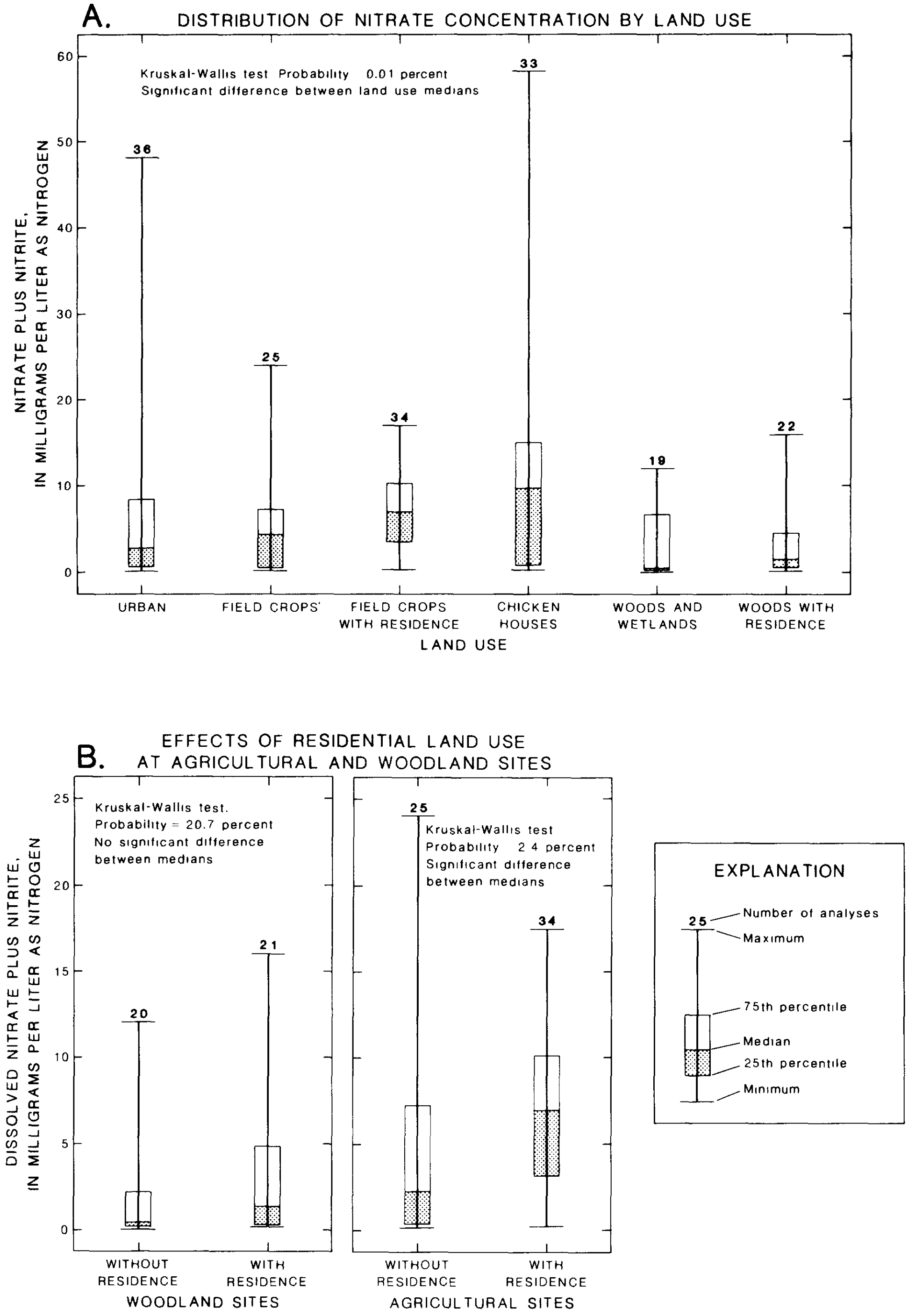


Figure 11.-- Relation between nitrate concentration and land use.

Sites in all of the land uses, except for woodland, have median nitrate concentrations greater than either of the two "background" concentrations (0.42 or 0.2 mg/L) described previously. Median concentrations of urban and agricultural land uses show some effect of nitrogen applied on the land surface by human activity. The nitrogen may have been applied at the site, or it may have migrated to the site from a source further upgradient in the flow system. A detailed examination of the flow system near a site is needed to assess the specific sources of nitrate in the ground water.

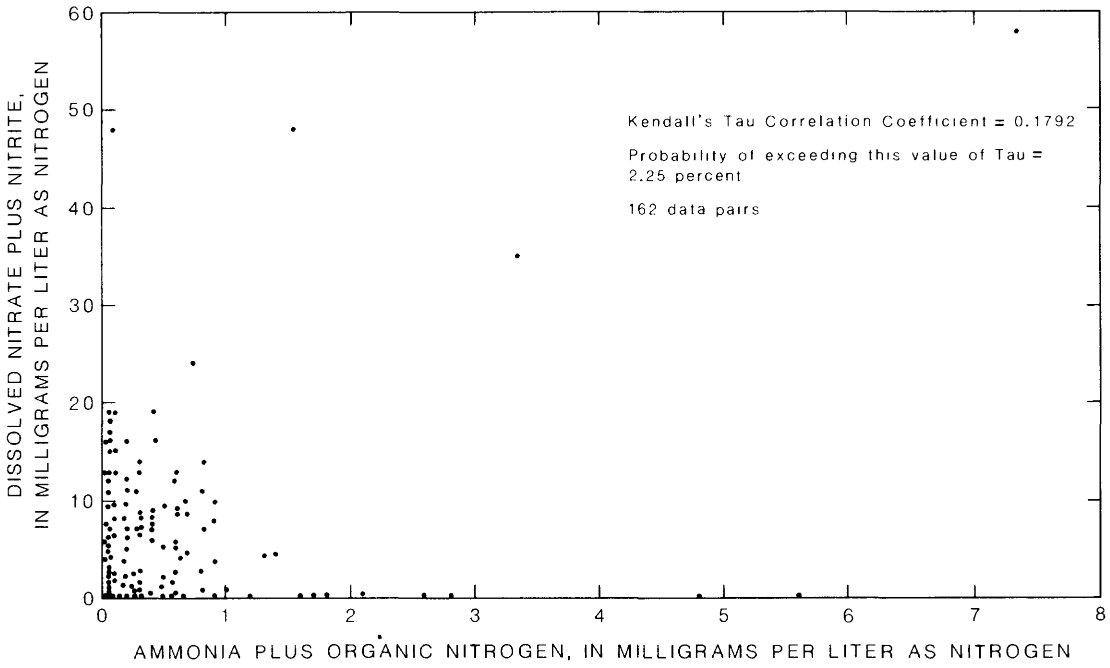
Relation to the Chemical Environment

NITRATE CONCENTRATIONS VARY INVERSELY WITH AMMONIA PLUS ORGANIC NITROGEN, DISSOLVED IRON, AND DISSOLVED SILICA CONCENTRATIONS

The concentration of nitrate in water of the Columbia aquifer varies inversely with the concentration of ammonia plus organic nitrogen, dissolved iron, and dissolved silica. Whether lower concentrations of nitrate in areas of reduced ground water are due to denitrification of nitrate, because nitrate never enters the flow systems, or because nitrate is diluted in larger, deeper flow systems, is not known. However, sites with higher concentrations of reduced nitrogen species are more likely to have poorly drained soils.

Nitrate concentrations of water samples from the Columbia aquifer appear to vary inversely with the concentrations of chemical constituents characteristic of reducing chemical environments or deep, confined flow systems (for the Columbia aquifer, deeper than about 60 feet; fig. 12). All of the constituents--ammonia plus organic nitrogen, dissolved iron, dissolved silica, and pH--have statistically significant Kendall's tau correlation coefficients with nitrate, but the scatter plots do not always show an obvious relationship. This is especially true for the plot of ammonia plus organic nitrogen and nitrate (fig. 12A), which appears almost random. The plot of nitrate and dissolved iron (fig. 12B) seems to show a hyperbolic relationship--water with low concentrations of iron seems to have a wide range of nitrate concentration, whereas water with a high iron concentration tends to have lower nitrate. The inverse relationship appears best in the plot of nitrate and dissolved silica, although nitrate concentrations are more variable at lower silica concentrations.

High concentrations of ammonia plus organic nitrogen and dissolved iron are associated with a reducing chemical environment, whereas high concentrations of dissolved silica and pH values higher than the average for the aquifer are associated with deeper flow systems and the dissolution of silicate minerals (Freeze and Cherry, 1979, p. 268-284). Thus, low nitrate concentrations in some areas may be due to the presence of a reducing environment or the fact that the well is tapping ground water from a deeper or confined flow system. If the environment is reducing, nitrate concentrations may be low because the nitrate has been denitrified to ammonia or nitrogen gas. If the flow system is confined, nitrate may be low because the entrance of nitrogen into the aquifer has been retarded by the confining layers. Deep flow systems may be low in nitrate because it has not yet arrived at the deep part of the flow system tapped by the sampling well, or the nitrate may have become diluted as it moves along the longer flow path. It is also important to remember that deep, confined flow systems are commonly associated with reducing chemical environments.

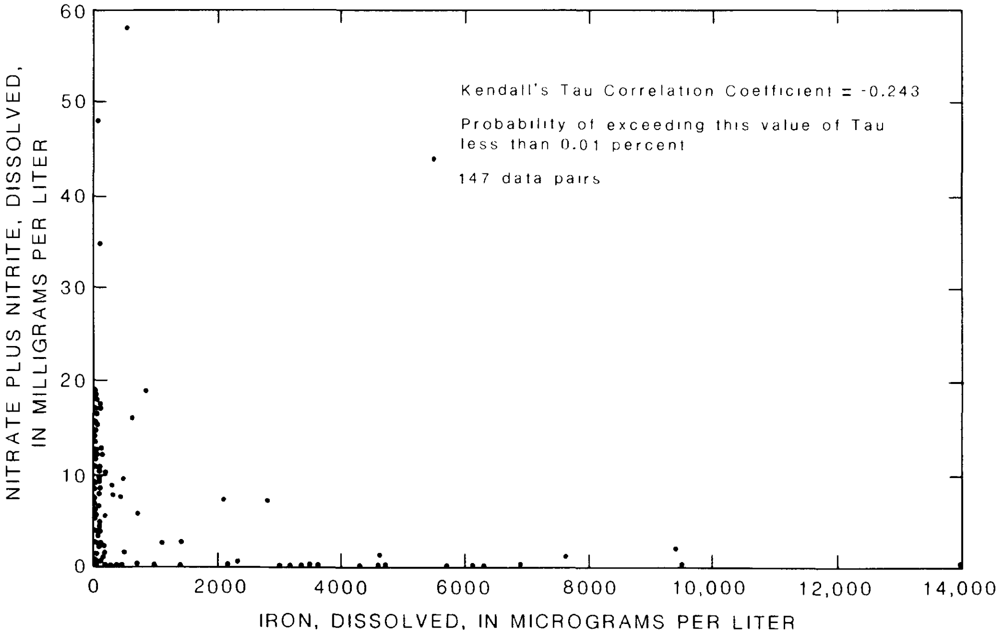


Kendall's Tau Correlation Coefficient = 0.1792

Probability of exceeding this value of Tau = 2.25 percent

162 data pairs

A. Ammonia plus organic nitrogen



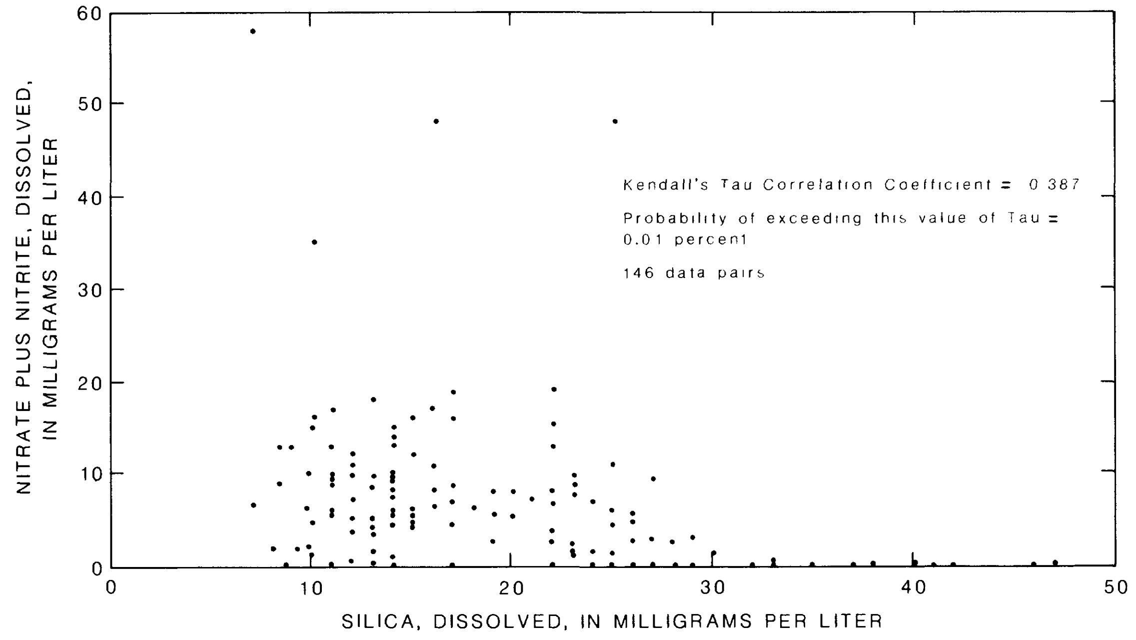
Kendall's Tau Correlation Coefficient = -0.243

Probability of exceeding this value of Tau less than 0.01 percent

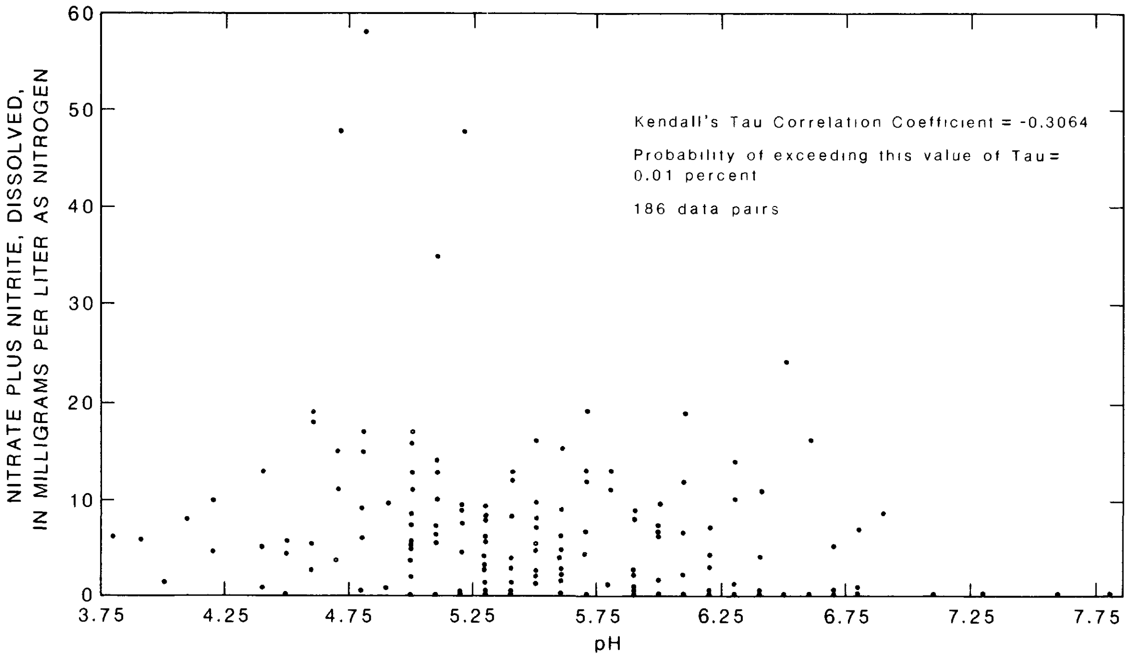
147 data pairs

B. Dissolved iron

Figure 12.-- Relation between nitrate concentration and concentration of selected chemical constituents.



C. Dissolved silica



D. pH

Nitrate concentrations tend to be lower in the southeastern part of the study area where confined flow systems and poorly drained soils are also common. Dissolved silica, iron, and ammonia plus organic nitrogen concentrations are also higher in the southern counties, which makes it difficult to determine whether low nitrate concentrations are the result of (1) denitrification of nitrate that has entered the aquifer, (2) confining layers or poorly drained soils that block the entry of nitrate into the aquifer, (3) dilution or dispersion of nitrate in the larger scale flow systems common in the southeast, or (4) a combination of some or all of these processes.

CONCLUSIONS

Hydrogeologic conditions in many parts of the Columbia aquifer on the Delmarva Peninsula tend to favor high nitrate concentrations in the water. Sites in the northwestern part of the study area are more likely to have shallow, unconfined flow systems, well-drained soils, and are likely to have higher nitrate concentrations than sites to the southeast. Nitrate concentrations are highest at agricultural and urban sites and lowest under woodlands. However, high and low nitrate concentrations are present in the aquifer under all hydrogeologic conditions and land uses.

Abundant sources of nitrogen and hydrogeologic conditions that allow nitrate to enter ground water are present on the Delmarva Peninsula. Nitrate contamination is thus a significant water-quality problem in the Columbia aquifer. Over half the water samples collected or compiled during this study have nitrate concentrations greater than the natural level of less than 1 mg/L as N. About 15 percent of the water samples exceed the water-quality standard of 10 mg/L as N.

High nitrate concentrations are present in ground water in all parts of the peninsula, under all land uses and soil types, but, in general, tend to be present in the northwestern part of the study area or at sites with shallow wells, well-drained soils, or urban and agricultural land uses. Although urban and agricultural land uses are fairly evenly distributed over the study area, well-drained soils and shallow, unconfined flow systems are more common to the northwest. In the southeast, nitrate is less likely to enter the ground water because of the numerous and extensive confining layers, and more likely to become dispersed in the longer flow paths, or be denitrified and removed from ground water in the reducing chemical environment common in the deeper flow systems. Deeper flow systems with reducing environments are also commonly confined; exactly which process occurs is not known.

Detailed local studies will be needed to determine the potential for nitrate contamination at a particular site. Measurement of water levels in wells in the local drainage basin will define the boundaries of the flow system and reveal the direction of ground-water flow. Contaminant sources, such as runoff from chickenhouses, septic tanks, fertilized fields, and sanitary landfills can be identified, as can the areas where nitrate is entering the aquifer. If the deeper aquifers underlie the Columbia aquifer with no confining layer between them, water-level measurements in the two aquifers will help determine whether nitrate will enter the deeper aquifer and how far into the aquifer it will travel.

Nitrate is a common substance in the water of the Columbia aquifer on the Delmarva Peninsula. Locating wells which may tap water with low nitrate concentration requires a knowledge of local ground-water flow systems, the types of material present in the aquifer, the soil types present near a well site, and the land uses near the well site.

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SUPPLEMENTAL DATA

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SUPPLEMENTAL DATA

The following tables (tables 10 and 11) contain the results of chemical analyses of water samples collected or compiled by the U.S. Geological Survey during the nitrate study on which this report is based. Older (pre-1980) samples collected by the U.S. Geological Survey have been previously published in Woll (1978). The U.S. Geological Survey collected no samples from the Columbia aquifer in the study area between 1978 and 1981.

Table 10 is a listing of the results of chemical analyses on water samples collected by the U.S. Geological Survey. Included are analyses of major ions, pH, conductivity, dissolved iron, silica, and, of course, the nitrogen species, dissolved nitrate plus nitrite, and ammonia plus organic nitrogen. Information about well construction is also provided. Table 11 lists the results of nitrate analyses on water samples collected by the various county health departments and analyzed by the State Health Department Laboratory in Salisbury, Md. The only information about well construction coded into the computerized data base is the depth to top of screen. The locations of the wells in tables 10 and 11 are shown on plates 1-4.

Explanation of Tables

mg/L - milligrams per liter

µg/L - micrograms per liter (= 0.001 mg/L)

µmho/cm - micromho per centimeter at 25°C

Well-Numbering System

Table 10.—Wells inventoried by the U.S. Geological Survey use the well-numbering system described in Lucas (1972) and Wilson (1984). The well number consists of a two-letter county prefix, a two-letter identifier of the 5-minute quadrangle in which the well is located, and a one- to three-digit sequence number reflecting the order in which the well was inventoried.

Table 11.--Non-inventoried wells with nitrate analyses by the health department are numbered in sequence by county. The well number consists of a two-letter county prefix, the symbol "H", which indicates that this is a non-inventoried health department well, and a one- to three-digit sequence number.

TABLE 10.-- Chemical analyses of water sampled during this investigation.

Well Number	Date of Sample (Year-month-day)	Elev. of Land Surface (ft. above sea level)	Depth of Well (feet)	Depth Drilled (feet)	Depth To Top of Screen (feet)	Field pH	Laboratory pH	Specific Conductance, field [-----µmho/cm)--]	Specific Conductance, Lab.	Carbonate Alkalinity, field, Incremental Titration [---mg/L as $CaCO_3$--]	Alkalinity, Laboratory	Bicarbonate, field (mg/L as HCO_3)
CAROLINE COUNTY												
CO AD 17	81-05-07	75.00	30	35	20	4.5	5.9	86	97	--	2.0	--
CO BC 16	82-12-08	62.00	66	75	54	6.0	6.2	122	110	15	16	18
CO BD 56	81-05-05	50.00	39	39	34	6.3	7.5	279	239	--	95	--
CO BD 56	83-01-03	50.00	39	39	39	7.1	6.9	245	215	110	111	140
CO CB 15	83-01-03	30.00	35	40	30	5.1	5.5	96	86	2.0	3.0	2.0
CO CB 16	83-01-05	45.00	3	3	2.6	7.6	7.5	300	272	140	143	170
CO CC 54	81-05-06	50.00	45	125	35	4.5	5.8	18	42	--	25	--
CO CC 55	83-01-04	50.00	70	70	59	5.7	5.6	97	83	6.0	6.0	7.0
CO CC 56	83-01-05	50.00	45	49	40	5.5	5.5	55	49	5.0	6.0	6.0
CO CC 57	83-01-05	55.00	38	61	32	5.6	5.5	87	72	7.0	6.0	9.0
CO CC 59	82-11-03	--	--	--	--	5.2	5.6	83	77	5.0	5.0	6.0
CO CC 60	82-02-10	50.00	20	55	10	6.4	6.9	460	428	--	--	--
CO CC 60	82-05-11	50.00	25	55	17	6.4	6.7	386	365	--	--	--
CO CC 63	82-02-11	58.00	26	75	11	6.8	7.1	504	444	--	--	--
CO CC 63	82-05-11	58.00	26	75	11	6.7	6.7	367	304	--	--	--
CO CC 70	81-12-21	50.00	60	--	10	4.1	6.1	100	115	--	17	19
CO CC 80	81-12-22	62.00	85	--	60	5.9	6.2	114	135	--	17	20
CO CC 84	82-05-12	50.00	46	65	39	6.7	5.9	86	91	--	--	--
CO CC 90	83-01-18	30.00	22	22	18	6.0	6.1	140	144	--	10	--
CO CC 91	82-12-07	55.00	38	38	32	5.5	5.5	91	72	5.0	6.0	6.0
CO CC 92	82-12-07	54.00	168	168	97	8.2	7.8	330	270	160	150	190
CO CC 93	82-12-07	55.00	42	42	35	5.1	5.3	200	156	1.0	2.0	2.0
CO CC 94	82-12-06	50.00	27	--	23	5.3	5.7	148	136	6.0	7.0	8.0
CO CC 95	82-12-06	55.00	33	33	27	5.3	5.6	32	34	5.0	6.0	6.0
CO CD 53	82-11-02	50.00	43	--	35	5.2	5.2	84	80	8.0	7.0	10
CO CD 54	82-11-03	50.00	45	--	31	5.2	5.7	34	30	5.0	5.0	7.0
CO CD 56	82-02-11	57.00	13	--	10	6.8	7.4	282	270	--	--	--
CO CD 58	82-11-30	60.00	58	58	48	5.6	5.6	86	76	4.0	5.0	5.0
CO CD 59	82-11-30	55.00	33	81	28	5.5	5.5	220	203	7.0	8.0	9.0
CO CD 60	82-11-30	50.00	34	34	30	7.8	7.6	300	277	140	145	170
CO CD 61	82-11-29	30.00	24	24	20	5.4	5.4	111	96	5.0	4.0	7.0
CO CE 8	82-02-23	65.00	35	69	20	6.6	6.4	331	213	--	--	--
CO CE 8	82-05-10	65.00	35	69	20	6.5	6.6	375	165	--	--	--
CO DC 139	82-12-06	55.00	55	55	48	4.8	5.5	245	226	2.0	2.0	2.0
CO DC 141	82-12-07	35.00	59	--	46	5.5	5.6	93	81	5.0	5.0	6.0
CO DC 142	82-09-30	45.00	60	60	50	5.1	5.9	85	93	4.0	3.0	5.0
CO DC 143	82-11-29	50.00	46	46	40	5.0	5.2	230	212	2.0	3.0	2.0
CO DD 48	82-02-10	45.00	35	62	20	6.0	7.1	404	350	--	--	--
CO DD 48	82-05-11	45.00	35	62	20	6.7	6.8	357	310	--	--	--
CO DD 49	82-02-22	42.00	35	45	15	7.4	--	460	--	--	--	--
CO DD 49	82-05-05	42.00	35	45	15	7.3	--	358	--	--	--	--
CO DD 53	83-01-04	55.00	19	19	15	5.9	5.7	50	35	15	13	18
CO DD 54	82-11-30	50.00	42	42	36	5.1	5.2	60	48	3.0	2.0	4.0
CO DD 56	82-11-30	50.00	44	44	38	5.1	5.3	140	130	2.0	3.0	3.0
CO DD 57	82-11-29	55.00	19	19	15	4.7	4.9	205	182	--	1.0	--
CO EC 15	82-11-02	35.00	--	--	--	4.4	4.9	225	212	.0	1.0	.0
CO EC 16	82-02-11	50.00	25	35	18	5.7	6.9	97	101	--	--	--
CO EC 16	82-05-05	50.00	25	35	18	6.2	6.4	122	115	--	--	--
CO EC 18	82-02-23	53.00	21	--	11	7.1	--	716	--	--	--	--
CO EC 25	81-05-06	58.00	28	--	18	4.2	5.9	83	96	--	25	--
CO EC 25	82-02-23	50.00	28	--	18	5.9	5.8	--	126	--	--	--
CO EC 29	82-12-15	55.00	50	50	42	5.4	5.6	68	62	4.0	5.0	5.0
CO ED 26	82-02-11	50.00	25	60	10	6.4	6.8	175	166	--	--	--
CO ED 26	82-05-05	50.00	25	60	10	6.4	6.4	235	209	--	--	--
CO ED 27	82-05-05	60.00	25	70	15	6.7	--	404	--	--	--	--
CO ED 31	83-01-04	60.00	30	30	25	4.7	4.8	390	437	--	2.0	--
CO ED 32	83-01-04	45.00	28	31	18	4.6	4.7	215	188	--	1.0	--
CO ED 33	83-01-04	50.00	30	40	25	5.8	5.6	59	49	11	13	14
CO EE 15	81-05-11	45.00	40	40	30	3.8	4.9	137	142	--	2.0	--
CO EE 15	82-11-02	45.00	40	--	30	4.6	--	240	--	--	--	--
CO EE 17	82-05-11	49.00	35	67	20	6.6	6.8	236	179	--	--	--
CO FB 27	81-05-11	30.00	30	--	22	6.4	7.9	347	341	--	180	--
CO FB 28	82-12-13	45.00	50	50	44	5.0	5.2	152	148	7.0	7.0	8.0
CO FB 29	82-12-13	45.00	29	--	21	5.0	5.3	148	127	3.0	3.0	4.0
CO FC 30	82-11-02	50.00	--	--	--	5.3	5.7	185	173	3.0	3.0	4.0
CO FC 31	82-11-02	55.00	41	--	27	5.9	6.0	215	206	10	12	13
CO FC 32	82-02-11	50.00	25	--	15	6.3	6.7	226	216	--	--	--
CO FC 33	82-12-14	40.00	62	62	52	5.7	5.9	150	139	5.0	5.0	6.0
CO FC 36	82-12-14	--	46	46	38	5.0	5.4	156	167	2.0	3.0	3.0
CO FC 37	82-12-14	50.00	55	55	50	5.9	5.9	122	107	7.0	8.0	8.0
CO FD 31	82-02-11	50.00	30	50	20	6.5	6.5	395	331	--	--	--
CO FD 31	82-05-05	50.00	30	50	20	6.6	6.7	308	286	--	--	--
CO FD 32	82-11-02	38.00	--	--	59	5.0	5.4	70	62	3.0	3.0	3.0
CO FD 34	82-12-14	35.00	29	29	23	5.0	5.4	220	195	2.0	2.0	2.0
CO FD 36	82-11-30	30.00	140	155	138	7.9	7.7	308	298	--	161	--
CO FD 37	82-11-22	30.00	40	155	38	5.6	5.8	124	128	--	9.0	--
CO FE 11	82-11-02	45.00	--	56	51	6.1	6.2	74	63	21	12	25

TABLE 10.--Chemical analyses of water sampled during this investigation.--Continued.

Sodium, Dissolved (mg/L as Na)	Potassium, Dissolved (mg/L as K)	Calcium, Dissolved (mg/L as Ca)	Magnesium, Dissolved (mg/L as Mg)	Iron, dissolved (µg/L as Fe)	Silica, dissolved (mg/L as SiO_2)	Sulfate Dissolved (mg/L as SO_4)	Chloride, Dissolved (mg/L as Cl)	Nitrogen, NO_2+NO_3 Dissolved (mg/L as N)	Nitrogen, Ammonia + Organic, Dissolved (mg/L as N)	Date of sample (year-month-day)	Well Number
CAROLINE COUNTY											
4.6	3.4	4.1	5.1	60	17	8.6	6.9	4.5	--	81-05-07	CO AD 17
12	2.5	3.7	3.1	7	14	2.0	8.8	6.3	.20	82-12-08	CO BC 16
4.1	4.8	39	3.1	4600	25	8.9	6.2	1.3	--	81-05-05	CO BD 56
3.7	1.5	38	1.5	5700	25	<5.0	2.9	.17	.40	83-01-03	CO BD 56
3.9	2.3	3.2	3.8	5	12	<5.0	6.2	7.2	.20	83-01-03	CO CB 15
6.1	2.9	38	8.4	460	51	8.0	2.9	<.10	.20	83-01-05	CO CB 16
4.9	3.1	38	9.4	37	56	4.0	1.2	<.10	<.10	82-12-08	CO CB 17
3.1	1.3	1.8	.6	160	13	.0	3.9	--	--	81-05-06	CO CC 54
7.7	1.8	5.4	1.5	83	22	<5.0	7.1	6.7	.30	83-01-04	CO CC 55
6.0	1.1	1.7	.7	<3	23	1.0	6.0	2.4	.10	83-01-05	CO CC 56
7.6	1.1	3.4	1.2	1400	19	7.0	8.0	2.7	.60	83-01-05	CO CC 57
5.9	3.0	2.1	2.5	<3	13	3.0	7.3	4.4	1.3	82-11-03	CO CC 59
--	--	--	--	--	--	--	75	.40	.60	82-02-10	CO CC 60
--	--	--	--	--	--	--	32	.15	.65	82-05-11	CO CC 60
--	--	--	--	--	--	--	37	.67	.82	82-02-11	CO CC 63
--	--	--	--	--	--	--	30	5.2	.59	82-05-11	CO CC 63
6.2	1.9	8.2	2.5	19	19	2.7	7.3	8.1	.18	81-12-21	CO CC 70
6.4	2.7	8.2	4.2	20	14	1.7	9.1	9.3	.27	81-12-22	CO CC 80
--	--	--	--	--	--	--	3.6	<.10	.24	82-05-12	CO CC 84
6.5	3.1	8.1	4.9	490	14	2.0	11	9.7	.10	83-01-18	CO CC 90
4.9	2.0	4.0	1.9	12	15	<1.0	6.1	4.9	<.10	82-12-07	CO CC 91
7.2	3.0	33	12	620	61	2.0	1.4	.14	.20	82-12-07	CO CC 92
4.8	3.0	6.5	8.7	23	14	<1.0	9.6	13	<.10	82-12-07	CO CC 93
7.3	4.8	7.6	4.5	5	10	38	5.6	1.3	.20	82-12-06	CO CC 94
2.7	1.3	.6	.7	31	11	<1.0	5.3	.17	<.10	82-12-06	CO CC 95
7.6	1.7	3.0	1.5	9	14	<1.0	8.3	4.5	1.4	82-11-02	CO CD 53
3.5	1.1	.5	.4	18	10	<1.0	5.4	<.10	.60	82-11-03	CO CD 54
--	--	--	--	--	--	--	13	7.0	.82	82-02-11	CO CD 56
5.4	2.6	3.9	2.2	18	15	<1.0	5.4	6.2	<.10	82-11-30	CO CD 58
2.2	1.9	16	9.0	27	13	17	17	9.7	.20	82-11-30	CO CD 59
8.0	2.6	35	7.5	280	41	6.0	2.2	<.10	<.10	82-11-30	CO CD 60
7.5	1.5	5.1	1.7	950	8.6	15	13	.18	<.10	82-11-29	CO CD 61
--	--	--	--	--	--	--	11	.07	5.6	82-02-23	CO CE 8
--	--	--	--	--	--	--	8.8	<.10	2.8	82-05-10	CO CE 8
5.3	3.0	9.0	14	100	11	6.0	21	17	<.10	82-12-06	CO DC 139
6.0	1.9	4.9	2.2	61	17	<1.0	5.0	7.2	<.10	82-12-07	CO DC 141
5.8	2.0	4.9	2.5	5	16	2.0	9.0	6.5	<.10	82-09-30	CO DC 142
11	4.4	17	4.9	95	16	6.0	16	17	<.10	82-11-29	CO DC 143
--	--	--	--	--	--	--	22	.14	2.0	82-02-10	CO DD 48
--	--	--	--	--	--	--	17	.12	1.6	82-05-11	CO DD 48
--	--	--	--	--	--	--	5.1	.27	.72	82-02-22	CO DD 49
--	--	--	--	--	--	--	--	.20	.38	82-05-05	CO DD 49
5.8	1.1	1.4	.3	2200	22	<5.0	4.6	.31	.30	83-01-04	CO DD 53
4.6	1.5	1.4	.8	1000	14	8.0	7.0	.16	<.10	82-11-30	CO DD 54
6.3	3.8	7.3	3.5	140	12	2.0	9.0	10	<.10	82-11-30	CO DD 56
3.1	2.8	17	5.5	--	--	17	13	11	<.10	82-11-29	CO DD 57
4.0	3.3	9.2	11	84	8.9	3.0	23	--	--	82-11-02	CO EC 15
--	--	--	--	--	--	--	8.0	4.3	.65	82-02-11	CO EC 16
--	--	--	--	--	--	--	8.8	7.3	.28	82-05-05	CO EC 16
--	--	--	--	--	--	--	--	.17	2.6	82-02-23	CO EC 18
2.6	2.7	4.5	4.4	<10	10	4.3	7.2	4.7	--	81-05-06	CO EC 25
--	--	--	--	--	--	--	8.2	6.0	2.4	82-02-23	CO EC 25
8.6	1.2	1.6	.5	<3	22	<1.0	6.8	3.9	.9	82-12-15	CO EC 29
--	--	--	--	--	--	--	9.2	4.1	.63	82-02-11	CO ED 26
--	--	--	--	--	--	--	13	11	.27	82-05-05	CO ED 26
--	--	--	--	--	--	--	--	.18	.60	82-05-05	CO ED 27
12	12	23	20	26	16	<5.0	21	48	1.5	83-01-04	CO ED 31
3.8	3.7	9.4	11	40	13	<5.0	16	18	<.10	83-01-04	CO ED 32
6.8	.9	2.8	.6	54	23	<5.0	6.0	1.1	.20	83-01-04	CO ED 33
8.1	3.4	3.1	6.3	10	9.7	1.8	12	6.3	--	81-05-11	CO EE 15
--	--	--	--	--	--	--	--	19	.10	82-11-02	CO EE 15
--	--	--	--	--	--	--	8.1	<.10	1.7	82-05-11	CO EE 17
8.0	.6	63	2.2	3200	42	5.2	8.7	.05	--	81-05-11	CO FB 27
4.0	2.9	7.7	6.9	23	14	7.0	16	7.5	.40	82-12-13	CO FB 28
4.0	3.2	6.8	5.0	4	12	<1.0	8.1	11	.20	82-12-13	CO FB 29
4.7	3.2	8.4	9.2	17	16	14	18	8.2	.30	82-11-02	CO FC 30
4.0	31	4.6	4.8	15	8.4	16	15	9.0	.40	82-11-02	CO FC 31
--	--	--	--	--	--	--	12	14	.81	82-02-11	CO FC 32
6.1	5.7	8.5	3.9	3	15	2.0	8.9	12	.20	82-12-14	CO FC 33
3.3	5.8	4.8	11	<3	8.3	3.0	16	13	.10	82-12-14	CO FC 36
7.5	2.4	7.3	2.2	20	20	<1.0	9.3	8.1	.20	82-12-14	CO FC 37
--	--	--	--	--	--	--	20	24	.71	82-02-11	CO FD 31
--	--	--	--	--	--	--	20	16	.42	82-05-05	CO FD 31
4.7	2.2	2.2	1.4	3	12	3.0	1.2	3.9	.20	82-11-02	CO FD 32
7.2	3.2	14	6.7	6	15	<1.0	18	16	<.10	82-12-14	CO FD 34
16	5.9	26	12	45	50	4.0	2.0	--	--	82-11-30	CO FD 36
9.1	1.7	6.2	3.2	300	11	3.0	11	8.9	.70	82-11-22	CO FD 37
5.5	.6	2.5	.9	4300	29	8.0	3.7	<.10	.30	82-11-02	CO FE 11

TABLE 10.-- Chemical analyses of water sampled during this investigation.--Continued.

Well Number	Date of Sample (Year-month-day)	Elev. of Land Surface (ft. above sea level)	Depth of Well, (feet)	Depth Drilled (feet)	Depth To Top of Screen (feet)	Field pH	Laboratory pH	Specific Conductance, field [----µmho/cm----]	Specific Conductance, Lab. [----µmho/cm----]	Carbonate Alkalinity, field, Incremental Titration [--mg/L as $CACO_3$---]	Alkalinity, Laboratory [--mg/L as $CACO_3$---]	Bicarbonate, field (mg/L as HCO_3)
					DORCHESTER COUNTY							
DO AG 7	83-01-19	25.00	35	35	29	5.1	5.3	188	167	4.0	2.0	5.0
DO AG 8	81-05-06	30.00	55'	--	38	6.1	7.0	179	177	--	21	--
DO AG 8	82-02-10	30.00	55	--	38	5.2	6.6	124	153	--	--	--
DO AG 10	82-02-11	15.00	30	--	10	6.4	6.3	342	275	--	--	--
DO AG 10	82-05-04	15.00	30	--	10	6.6	6.5	347	240	--	--	--
DO AG 11	82-11-16	45.00	54	54	44	4.8	4.9	160	173	2.0	1.0	2.0
DO AH 7	83-01-19	50.00	52	52	46	5.3	5.4	77	66	3.0	2.0	4.0
DO AH 8	82-11-16	50.00	45	50	35	5.2	5.4	142	126	3.0	3.0	4.0
DO AH 9	82-11-16	35.00	37	37	32	5.0	4.9	144	128	2.0	1.0	2.0
DO BF 40	82-11-15	25.00	50	50	40	5.0	4.2	260	228	3.0	<1.0	4.0
DO BG 63	81-05-07	40.00	46	46	40	3.9	5.6	122	127	--	1.0	--
DO BG 63	83-01-19	40.00	46	46	40	4.8	5.3	142	129	--	2.0	--
DO BG 65	81-05-07	44.00	110	--	93	4.5	7.0	25	38	--	7.0	--
DO BG 65	82-02-11	44.00	110	110	93	5.6	6.0	30	31	--	--	--
DO BG 65	82-05-04	44.00	110	110	93	5.6	6.2	26	26	--	--	--
DO BG 66	82-02-23	48.00	62	75	52	7.1	6.3	207	112	--	--	--
DO BG 66	82-05-04	48.00	62	75	52	6.2	6.2	62	56	--	--	--
DO BG 69	82-11-23	30.00	162	175	160	7.8	7.8	252	245	--	127	--
DO BG 70	82-11-23	30.00	68	175	66	6.3	6.5	115	112	--	42	--
DO BG 71	82-11-23	30.00	50	175	48	5.4	5.9	106	113	--	7.0	--
DO BH 14	83-01-19	25.00	95	95	85	6.1	6.0	61	57	11	11	13
DO BH 15	82-02-22	50.00	21	105	10	6.6	--	238	--	--	--	--
DO BH 15	82-05-04	50.00	21	105	10	6.1	6.3	159	163	--	--	--
DO BH 16	82-11-16	30.00	50	58	40	5.4	5.4	190	174	2.0	2.0	2.0
DO BH 17	82-11-17	40.00	44	43	33	5.0	4.8	140	238	3.0	2.0	4.0
DO BI 12	81-05-12	27.00	80	80	70	4.4	6.5	25	38	--	20	--
DO BI 12	83-01-18	27.00	80	80	70	5.5	5.7	35	31	--	5.0	--
DO BI 14	83-01-18	25.00	--	71	50	4.8	5.4	33	31	--	7.0	--
DO BI 17	82-11-17	30.00	49	51	39	5.5	5.6	118	104	2.0	2.0	2.0
DO CF 34	82-02-22	25.00	35	77	28	5.1	--	123	--	--	--	--
DO CF 34	82-05-04	25.00	35	77	28	6.3	6.4	104	85	--	--	--
DO CG 32	81-08-25	10.00	15	--	12	5.3	6.3	136	88	--	17	--
DO CG 43	82-11-17	45.00	100	100	60	5.9	5.9	37	30	3.0	3.0	4.0
DO CG 44	82-11-17	40.00	55	55	52	5.4	5.4	230	206	2.0	3.0	2.0
DO CH 28	81-05-12	25.00	70	70	60	5.0	7.1	64	84	--	34	--
DO CH 29	83-01-19	25.00	54	60	44	6.3	5.5	188	121	--	2.0	33
DO CH 37	83-01-19	35.00	33	33	26	4.8	4.9	145	140	--	<1.0	--
DO CI 6	83-01-18	19.00	49	49	39	4.9	5.5	140	137	--	3.0	--
DO DH 13	81-08-25	5.00	17	--	12	5.9	7.2	6840	6520	--	80	--
DO DH 20	81-08-24	10.00	12	--	7.0	4.0	4.2	423	438	--	<1.0	--
DO DH 21	81-08-24	10.00	30	--	25	5.2	--	591	--	--	--	--
DO DH 25	81-08-25	10.00	55	--	48	5.6	6.9	105	80	--	24	--

TABLE 10.--Chemical analyses of water sampled during this investigation.--Continued.

Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Calcium dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Iron, dis-solved (μg/L as Fe)	Silica, Dis-solved (mg/L as SiO_2)	Sulfate dis-solved (mg/L as SO_4)	Chlo-ride, dis-solved (mg/L as Cl)	Nitro-gen, NO_2+NO_3 dis-solved (mg/L as N)	Nitro-gen, Am-monia + Organic Dis. (mg/L as N)	Date of Sample (Year-month-day)	Well number
					DORCHESTER COUNTY						
9.5	4.3	8.2	6.0	8	14	<1.0	14	14	.30	83-01-19	DO AG 7
3.8	5.1	8.1	6.2	50	7.1	6.6	12	6.7	--	81-05-06	DO AG 8
--	--	--	--	--	--	--	9.0	9.0	.40	82-02-10	DO AG 8
--	--	--	--	--	--	--	8.2	.18	1.6	82-02-11	DO AG 10
--	--	--	--	--	--	--	9.1	<.10	.91	82-05-04	DO AG 10
7.4	4.4	9.5	6.1	24	9.9	2.0	15	15	<.10	82-11-16	DO AG 11
4.4	2.8	2.6	2.1	10	11	<1.0	5.6	5.7	.60	83-01-19	DO AH 7
7.4	3.2	7.1	3.9	29	13	2.0	15	8.9	.30	82-11-16	DO AH 8
6.5	2.1	4.7	5.6	28	13	16	15	5.0	.20	82-11-16	DO AH 9
3.4	4.3	15	10	170	12	43	15	5.2	.60	82-11-15	DO BF 40
4.2	3.5	3.7	6.3	<10	11	.0	13	5.9	--	81-05-07	DO BG 63
4.3	4.0	4.2	7.3	8	11	1.0	14	9.2	.60	83-01-19	DO BG 63
2.9	2.1	1.0	.3	10	9.3	.1	2.8	2.1	--	81-05-07	DO BG 65
--	--	--	--	--	--	--	3.2	2.0	.50	82-02-11	DO BG 65
--	--	--	--	--	--	--	2.8	--	--	82-05-04	DO BG 65
--	--	--	--	--	--	--	8.0	.06	4.8	82-02-23	DO BG 66
--	--	--	--	--	--	--	5.3	2.5	.26	82-05-04	DO BG 66
7.4	1.7	26	12	65	56	7.0	3.3	--	--	82-11-23	DO BG 69
7.6	2.1	10	2.7	3500	33	9.0	3.5	--	--	82-11-23	DO BG 70
6.3	3.4	7.6	2.5	19	14	27	7.1	--	--	82-11-23	DO BG 71
7.0	1.3	2.3	.7	4	23	1.0	5.2	2.2	<.10	83-01-19	DO BH 14
--	--	--	--	--	--	--	13	8.6	.82	82-02-22	DO BH 15
--	--	--	--	--	--	--	14	12	.58	82-05-04	DO BH 15
4.5	3.5	7.0	10	21	11	1.0	19	13	.30	82-11-16	DO BH 16
7.1	21	11	4.9	600	10	5.0	24	16	.20	82-11-17	DO BH 17
4.6	1.3	.9	.4	<10	14	.8	4.5	.88	--	81-05-12	DO BI 12
4.1	1.5	1.0	.4	8	13	1.0	3.5	1.6	<.10	83-01-18	DO BI 12
4.2	1.4	.9	.4	11	12	1.0	5.3	.59	<.10	83-01-18	DO BI 14
6.5	3.0	5.3	3.5	7	11	<1.0	7.7	9.8	<.10	82-11-17	DO BI 17
--	--	--	--	--	--	--	10	.11	.97	82-02-22	DO CF 34
--	--	--	--	--	--	--	7.4	<.10	.32	82-05-04	DO CF 34
13	.9	1.7	1.0	190	26	2.1	12	.05	.51	81-08-25	DO CG 32
3.2	2.0	1.0	.2	190	9.8	2.0	2.8	2.2	.20	82-11-17	DO CG 43
8.3	6.0	6.9	11	53	12	<1.0	32	12	<.10	82-11-17	DO CG 44
20	.1	<.1	<.1	80	27	6.5	5.8	<.01	--	81-05-12	DO CH 28
3.2	3.8	5.7	6.4	180	9.7	1.0	10	10	.90	83-01-19	DO CH 29
3.7	4.0	9.8	4.5	720	15	18	11	6.0	.40	83-01-19	DO CH 37
3.9	3.5	5.8	7.4	10	11	1.0	15	9.5	.20	83-01-18	DO CI 6
1100	44	52	130	790	9.8	330	2100	.05	.55	81-08-25	DO DH 13
15	2.4	26	19	520	30	140	29	1.5	.57	81-08-24	DO DH 20
--	--	--	--	--	--	--	--	.04	.31	81-08-24	DO DH 21
13	1.1	1.5	.8	100	26	1.6	7.3	.04	.15	81-08-25	DO DH 25

TABLE 10.-- Chemical analyses of water sampled during this investigation.--Continued.

Well Number	Date of Sample (Year-month-day)	Elev. of Land Surface (ft. above sea level)	Depth of Well, (feet)	Depth Drilled (feet)	Depth To Top of Screen (feet)	Field pH	Laboratory pH	Specific Conductance, field	Specific Conductance, Lab.	Carbonate Alkalinity, field, incremental titration	Alkalinity, Laboratory	Bicarbonate, field (mg/L as HCO_3)
								[----µmho/cm----]		[--mg/L as $CaCO_3$---]		
WICOMICO COUNTY												
WI BD 68	82-11-29	25.00	100	220	98	6.4	6.2	67	67	--	24	--
WI BD 69	82-11-29	25.00	60	220	58	6.5	6.2	59	59	--	14	--
WI BD 70	82-11-29	25.00	35	230	33	6.4	6.2	88	77	--	3.0	--
WI BF 64	81-05-12	52.00	98	--	88	4.6	6.8	48	60	--	18	--
WI BF 64	82-10-19	50.00	98	98	88	5.3	5.7	62	69	6.6	7.0	8.0
WI BF 65	82-10-19	50.00	49	49	39	5.3	5.2	142	138	5.0	5.0	6.0
WI BF 66	82-10-20	50.00	55	55	55	5.2	5.5	146	150	6.0	6.0	7.0
WI BF 67	82-10-20	50.00	70	70	60	5.4	5.5	84	86	11	13	13
WI BF 69	81-05-13	43.00	84	140	64	5.6	7.1	115	110	--	41	--
WI BF 69	82-02-23	43.00	84	140	64	7.6	7.4	156	99	--	--	--
WI BF 69	82-05-03	43.00	84	140	64	6.7	6.6	103	83	--	--	--
WI BF 70	81-05-13	43.00	30	30	15	5.0	6.0	140	125	--	1.0	--
WI BF 70	82-02-23	43.00	30	30	15	6.1	5.8	230	173	--	--	--
WI BF 70	82-05-03	43.00	30	30	15	5.9	6.1	141	139	--	--	--
WI CD 67	82-10-12	45.00	60	--	50	5.3	6.1	68	84	12	13	15
WI CD 67	81-05-13	7.00	55	65	--	5.1	7.1	104	133	--	27	--
WI CE 233	82-10-25	25.00	69	80	64	5.5	5.7	110	112	7.0	8.0	9.0
WI CE 234	82-10-26	30.00	58	58	48	6.0	6.0	127	128	11	12	13
WI CE 235	82-10-26	25.00	60	83	50	5.7	5.7	220	212	9.0	10	11
WI CE 236	82-10-27	15.00	72	85	67	5.5	8.2	158	153	16	12	19
WI CE 239	82-10-13	10.00	55	--	50	--	--	--	--	--	--	21
WI CE 240	82-10-12	50.00	80	80	60	4.6	5.6	86	100	--	2.0	--
WI CF 84	82-10-18	50.00	61	61	53	6.9	7.0	403	399	26	118	32
WI CF 186	82-10-19	43.00	99	110	89	6.2	6.3	105	113	46	45	56
WI CF 187	82-10-26	50.00	59	59	54	5.6	5.7	76	86	7.0	12	9.0
WI CF 192	82-10-13	43.00	81	--	65	5.2	5.1	313	315	6.0	7.0	8.0
WI CG 53	81-05-13	60.00	98	98	88	5.6	6.8	141	109	--	38	--
WI CG 56	83-01-05	60.00	--	60	50	5.7	5.9	97	91	36	37	44
WI CH 45	83-01-05	40.00	--	75	--	5.3	5.6	79	82	--	7.0	--
WI CH 47	82-11-17	42.00	149	149	147	6.6	6.3	212	132	--	56	--
WI CH 47	83-07-06	42.00	149	149	147	6.6	--	232	--	--	--	--
WI CH 48	83-07-06	42.00	105	149	103	6.6	--	226	--	--	--	--
WI CH 49	82-11-17	42.00	44	149	42	6.3	6.3	119	102	--	30	--
WI CH 49	83-07-06	42.00	44	149	42	6.2	--	117	--	--	--	--
WI DC 32	83-01-05	5.00	--	110	100	6.8	6.9	583	516	--	166	--
WI DE 72	81-05-13	30.00	58	58	53	5.0	6.8	189	231	--	27	--
WI DE 72	82-10-26	30.00	58	58	53	5.5	5.6	243	234	19	21	23
WI DE 75	82-05-04	45.00	--	95	--	5.0	6.8	118	105	--	--	--
WI DG 13	83-01-05	45.00	--	60	50	6.2	5.9	151	73	65	17	80

TABLE 10.--Chemical analyses of water sampled during this investigation.--Continued.

Sodium, Dis- solved (mg/L as Na)	Potas- sium, Dis- solved (mg/L as K)	Calcium Dis- solved (mg/L as Ca)	Magne- sium, Dis- solved (mg/L as Mg)	Iron, Dis- solved (µg/L as Fe)	Silica, Dis- solved (mg/L as SiO_2	sulfate Dis- solved (mg/L as SO_4	Chlo- ride, Dis- solved (mg/L as Cl	Nitro- gen, NO_2+NO_3 Dis- solved (mg/L as N	Nitro- gen, Am- monia + Organic Dis. (mg/L as N	Date of Sample (Year- month- day	Well Number
WICOMICO COUNTY											
9.9	1.3	2.9	1.2	1900	25	6.0	5.9	.16	.20	82-11-29	WI BD 68
6.7	.9	1.9	.6	6100	24	2.0	5.2	<.10	<.10	82-11-29	WI BD 69
5.5	.7	2.1	.8	14000	26	7.0	8.3	.15	.10	82-11-29	WI BD 70
7.2	1.3	2.1	.5	10	27	1.1	6.0	2.8	--	81-05-12	WI BF 64
8.0	1.0	2.4	.5	65	26	2.0	6.1	2.7	<.10	82-10-19	WI BF 64
12	1.5	8.7	1.6	17	27	3.0	9.1	9.4	<.10	82-10-19	WI BF 65
13	2.2	8.0	1.5	4	23	8.0	11	9.6	.50	82-10-20	WI BF 66
10	.8	2.7	.4	4	28	11	7.2	2.7	.30	82-10-20	WI BF 67
8.9	1.5	6.5	2.7	6300	24	6.5	5.0	.17	--	81-05-13	WI BF 69
--	--	--	--	--	--	--	5.0	.05	1.7	82-02-23	WI BF 69
--	--	--	--	--	--	--	4.5	<.10	.29	82-05-03	WI BF 69
13	2.3	4.6	2.2	9400	8.0	11	25	2.0	--	81-05-13	WI BF 70
--	--	--	--	--	--	--	24	.14	1.8	82-02-23	WI BF 70
--	--	--	--	--	--	--	23	.64	.26	82-05-03	WI BF 70
8.3	1.1	4.2	.7	<3	29	<1.0	6.3	3.2	<.10	82-10-12	WI CD 67
12	1.7	6.5	1.7	200	26	4.0	9.8	5.4	--	81-05-13	WI CD 67
9.4	1.7	6.5	1.3	21	26	5.0	12	5.3	.50	82-10-25	WI CE 233
9.9	1.2	9.6	1.6	<3	22	5.0	12	6.8	.40	82-10-26	WI CE 234
8.1	1.6	22	4.2	37	22	23	11	13	.60	82-10-26	WI CE 235
14	2.6	8.0	2.5	2100	21	2.0	19	7.3	.20	82-10-27	WI CE 236
--	--	--	--	--	--	--	--	1.9	1.3	82-10-13	WI CE 239
.9	3.1	5.0	1.2	3	14	1.0	9.6	5.7	<.10	82-10-12	WI CE 240
72	3.6	9.2	2.0	22	17	12	25	8.6	.60	82-10-18	WI CF 84
20	.6	3.5	1.0	720	40	2.0	6.5	.39	<.10	82-10-19	WI CF 186
9.3	.6	4.4	.7	<3	25	<1.0	8.7	4.7	.70	82-10-26	WI CF 187
16	2.8	30	4.4	4	25	4.0	14	48	<.10	82-10-13	WI CF 192
11	.8	4.8	1.5	14000	46	6.7	6.9	.02	--	81-05-13	WI CG 53
15	1.2	3.6	.8	31	24	<1.0	6.9	.13	.40	83-01-05	WI CG 56
8.4	.9	1.8	.7	4700	33	7.0	10	.18	.60	83-01-05	WI CH 45
12	1.7	11	3.4	27000	32	4.0	6.7	--	--	82-11-17	WI CH 47
--	--	--	--	--	--	--	--	.10	1.1	83-07-06	WI CH 47
--	--	--	--	--	--	--	--	.10	1.2	83-07-06	WI CH 48
8.4	1.4	9.6	1.4	4300	33	9.0	9.5	--	--	82-11-17	WI CH 49
--	--	--	--	--	--	--	--	.12	1.7	83-07-06	WI CH 49
140	.3	.0	<.0	65	--	15	60	.12	.30	83-01-05	WI DC 32
26	3.7	14	3.7	100	26	6.5	33	4.9	--	81-05-13	WI DE 72
21	3.1	14	3.9	48	23	10	30	9.0	.90	82-10-26	WI DE 72
--	--	--	--	--	--	--	6.9	<.10	.56	82-05-04	WI DE 75
7.6	1.1	2.0	.7	28000	25	3.0	6.4	.11	.20	83-01-05	WI DG 13

TABLE 10.-- Chemical analyses of water sampled during this investigation.--Continued.

Well Number	Date of Sample (Year-month-day)	Elev. of Land Surface (ft. above sea level)	Depth of Well, (feet)	Depth Drilled (feet)	Depth To Top of Screen (feet)	Field pH	Laboratory pH	Specific conductance, field	Specific conductance, Lab.	Carbonate Alkalinity, field, Incremental Titration	Alkalinity Laboratory	Bicarbonate, field (mg/L as HCO_3)
								[——µmho/cm	——]	[——mg/L as $CaCO_3$	——]	
WORCESTER COUNTY												
WO AE 26	82-12-14	35.00	50	50	45	4.8	4.4	589	564	8.0	<1.0	7.0
WO AF 29	81-05-14	15.00	80	80	60	4.4	6.4	109	123	--	24	--
WO AF 30	82-12-07	22.00	220	223	218	5.9	5.7	80	70	--	14	--
WO AF 31	82-12-07	22.00	145	223	143	6.3	5.9	85	70	--	17	--
WO AF 32	82-12-07	22.00	65	223	63	5.4	5.3	417	397	--	2.0	--
WO AG 17	82-12-14	20.00	40	40	35	5.3	--	118	--	--	--	--
WO BE 32	83-01-04	35.00	55	55	50	4.9	4.9	168	155	4.0	<1.0	5.0
WO BF 67	82-12-15	--	--	--	--	6.0	5.9	97	89	29	19	35
WO BF 68	82-12-14	35.00	--	--	--	5.8	5.7	329	314	26	14	32
WO BF 69	82-12-15	--	--	--	--	6.3	6.3	185	155	--	62	--
WO BF 70	82-12-14	10.00	50	50	5.0	5.6	5.7	195	187	9.0	8.0	11
WO BG 50	81-05-13	10.00	80	80	70	6.7	7.9	211	218	--	110	--
WO BG 51	81-05-13	20.00	90	90	80	5.4	7.2	86	101	--	25	--
WO BG 52	82-10-05	5.00	--	43	38	6.4	6.5	199	202	81	69	98
WO CA 3	83-01-05	45.00	30	30	20	5.0	5.2	148	144	3.0	2.0	4.0
WO CB 10	83-01-05	55.00	35	35	30	5.9	6.2	95	89	42	41	51
WO CD 21	83-01-03	20.00	43	43	38	5.5	5.5	161	158	6.0	4.0	7.0
WO CD 22	82-12-15	25.00	65	65	40	5.7	5.7	284	267		8.0	--
WO CD 23	82-12-15	35.00	35	35	29	6.2	5.9	72	59	23	13	28
WO CE 30	82-12-15	30.00	38	38	33	6.4	6.2	177	161	120	31	150
WO CF 52	82-12-15	25.00	25	25	5.0	5.5	5.5	64	104	20	10	24
WO CG 45	81-05-12	60.00	94	94	84	6.3	7.6	190	187	--	75	--
WO DB 4	83-01-04	25.00	40	40	6.4	6.1	5.7	102	76	34	24	41
WO DC 29	83-01-04	35.00	65	65	50	6.0	6.1	240	217	18	12	22
WO DC 30	83-01-04	40.00	60	60	50	6.0	5.9	62	58	--	13	--
WO DE 36	83-01-03	10.00	25	25	5.0	5.1	6.0	544	528	32	18	39
WO DE 37	83-01-03	20.00	67	67	47	5.6	5.6	84	79	11	12	14
WO DE 38	83-01-03	35.00	60	60	55	5.2	5.9	145	147	28	29	34
WO DE 46	81-05-13	10.00	64	64	54	5.2	6.8	112	130	--	24	--
WO DF 3	82-12-14	--	--	--	--	5.9	5.6	272	256	20	20	24

TABLE 10.--Chemical analyses of water sampled during this investigation.--Continued.

Sodium, Dis-solved (mg/L as Na)	Potas-sium, Dis-solved (mg/L as K)	Calcium Dis-solved (mg/L as Ca)	Magne-sium, Dis-solved (mg/L as Mg)	Iron, Dis-solved (µg/L as Fe)	Silica, Dis-solved (mg/L as SiO_2)	Sulfate Dis-solved (mg/L as SO_4)	Chlo-ride, Dis-solved (mg/L as Cl S	Nitro-gen, NO_2+NO_3 Dis-solved (mg/L as N	Nitro-gen, Am-monia + Organic Dis. (mg/L as N	Date of Sample (Year-month-day)	Well Number
WORCESTER COUNTY											
11	27	29	6.5	490	6.8	22	25	--	--	82-12-14	WO AE 26
11	3.1	3.2	4.0	<10	13	1.3	12	5.0	--	81-05-14	WO AF 29
7.5	1.1	2.8	.9	7100	23	3.0	8.8	<.10	.40	82-12-07	WO AF 30
7.0	1.0	3.1	.9	8600	21	2.0	7.8	<.10	.30	82-12-07	WO AF 31
28	4.1	29	8.2	7600	23	110	42	1.2	.50	82-12-07	WO AF 32
--	--	--	--	--	--	--	--	--	--	82-12-14	WO AG 17
6.6	3.4	9.8	6.0	2300	12	50	7.1	.65	1.0	83-01-04	WO BE 32
13	.7	3.1	.9	3000	37	3.0	11	<.10	.10	82-12-15	WO BF 67
66	.2	.0	1.3	3	25	44	28	11	<.10	82-12-14	WO BF 68
11	1.0	16	2.1	9500	47	5.0	9.4	.20	2.1	82-12-15	WO BF 69
14	1.6	11	3.5	58	22	4.0	13	--	--	82-12-14	WO BF 70
13	.9	24	4.5	990	40	.4	10	<.01	--	81-05-13	WO BG 50
11	1.1	4.9	2.0	300	42	.7	9.0	.04	--	81-05-13	WO BG 51
18	3.1	11	4.1	3	25	4.0	13	<.10	.40	82-10-05	WO BG 52
8.4	5.9	6.5	3.9	95	16	3.0	11	11	.80	83-01-05	WO CA 3
11	1.0	5.1	2.1	300	51	2.0	5.2	<.10	.60	83-01-05	WO CB 10
11	1.8	10	4.2	290	22	20	8.9	8.2	.40	83-01-03	WO CD 21
20	2.1	15	8.3	800	22	10	22	--	--	82-12-15	WO CD 22
9.7	.6	2.0	1.0	4600	28	4.0	8.5	--	--	82-12-15	WO CD 23
16	.9	9.3	3.9	4700	41	19	14	--	--	82-12-15	WO CE 30
13	.8	3.9	1.9	31	23	9.0	15	--	--	82-12-15	WO CF 52
11	.8	19	4.4	3400	42	1.8	11	.05	--	81-05-12	WO CG 45
9.7	.9	4.3	1.3	6900	40	<5.0	11	.17	1.2	83-01-04	WO DB 4
16	1.1	17	5.8	2800	24	28	23	7.2	.40	83-01-04	WO DC 29
7.8	.7	3.5	.8	<3	23	<5.0	6.6	1.6	.10	83-01-04	WO DC 30
17	6.6	49	16	34	10	52	30	35	3.3	83-01-03	WO DE 36
12	1.2	2.2	1.0	190	24	<5.0	9.7	1.5	.30	83-01-03	WO DE 37
35	<.1	.0	<.0	<3	32	16	14	.15	.30	83-01-03	WO DE 38
15	1.5	5.5	1.7	10	38	3.7	13	.18	--	81-05-13	WO DE 46
29	1.1	7.5	7.3	1100	22	19	43	2.6	.80	82-12-14	WO DF 3

Table 11.--Nitrate analyses of water samples from the Columbia aquifer collected by the county health departments

(Analyses performed by the Maryland Department of
Health and Mental Hygiene Laboratory
in Salisbury, Md.)

Well No.	Date of collection	Depth to top of screen (feet)	Dissolved nitrate plus nitrite (mg/L as N)
CAROLINE COUNTY			
CO H2	10/06/79	22	1.5
CO H7	3/31/81	37	11
CO H10	2/04/80	20	0.4
CO H12	7/14/80	26	1.3
CO H13	7/28/80	21	7.5
CO H14	-	22	0.5
CO H16	12/02/79	20	0.9
CO H17	1/29/79	26	4.4
CO H18	1/29/79	19	<.2
CO H20	-	35	-
CO H21	3/21/79	31	1.4
CO H23	5/08/79	21	<.2
CO H31	-	19	3.5
CO H32	10/29/79	27	7.0
CO H36	12/15/80	23	1.2
CO H38	11/17/80	26	13
CO H39	1/19/81	32	21
CO H40	2/10/81	33	2.5
CO H41	3/23/81	27	3.5
CO H42	3/23/81	27	8.9
CO H53	10/29/80	28	5.6
CO H56	4/20/81	28	13
CO H57	11/18/80	37	.4
CO H61	1/12/81	34	4.3
CO H62	1/19/81	31	9.3
CO H64	1/21/80	30	3.3
CO H65	1/24/79	30	26
CO H66	8/14/79	29	2.5
CO H67	6/12/79	22	5.8
CO H68	4/20/81	30	10
CO H69	11/17/80	36	7.7
CO H70	11/24/80	29	7.6
CO H76	4/07/81	30	12
CO H79	5/12/80	59	4.3
CO H80	6/24/80	56	2.0
CO H81	11/05/80	38	9.3
CO H82	-	28	22
CO H84	-	40	<.2
CO H85	-	34	<.2
CO H86	1/11/78	23	11
CO H87	-	24	-
CO H89	4/27/81	52	4.0
CO H92	1/29/79	26	5.4
CO H101	4/14/81	40	3.1
CO H102	4/06/81	30	8.1
CO H103	4/14/81	20	17
CO H106	10/15/7-	32	5.9
CO H109	1/14/80	40	9.5
CO H110	1/28/80	26	4.4
CO H111	1/22/80	39	8.9
CO H112	1/28/80	48	5.7
CO H114	4/29/80	35	16
CO H115	6/17/80	41	4.2
CO H116	7/21/80	30	3.5
CO H117	7/28/80	40	8.7
CO H118	8/11/80	40	4.1
CO H120	10/27/80	39	4.1
CO H121	11/17/80	26	6.0
CO H124	12/01/80	38	3.3
CO H125	9/15/80	34	11
CO H126	1/26/81	28	7.8
CO H127	2/23/81	21	6.2
CO H128	3/03/81	24	5.1
CO H131	4/07/80	51	6.0
CO H137	10/29/80	32	9.7
CO H139	10/03/76	11	8.6
CO H141	10/21/80	37	9.6
CO H144	10/24/78	52	6.0
CO H150	1/16/80	35	5.1
CO H152	-	35	15
CO H153	2/27/79	21	19
CO H162	11/19/80	25	22
CO H164	11/24/80	20	7.3
CO H173	5/20/80	30	11
CO H177	10/20/80	32	2.9
DORCHESTER COUNTY			
DO H1A	2/19/81	65	3.9
DO H1	5/03/77	-	8.0
DO H4	2/28/79	47	1.4
DO H7	6/20/79	49	1.5
DO H7	7/12/79	49	1.8
DO H10	7/09/79	40	.7
DO H11	8/14/79	39	7.5
DO H14	4/28/75	40	14
DO H15	8/09/76	25	6.3
DO H16	3/23/81	13	1.5

Table 11.--Nitrate analyses of water samples from the Columbia aquifer collected by the county health departments--Continued.

Well No.	Date of collection	Depth to top of screen (feet)	Dissolved nitrate plus nitrite (mg/L as N)
DO H18	1/16/80	50	9.5
DO H20	9/18/80	45	4.0
DO H21	9/29/80		.9
DO H22	10/29/80	54	8.6
DO H24	7/28/80	49	7.2
DO H25	4/21/80	45	3.3
DO H26	12/05/78	40	9.1
DO H27	11/08/79	84	5.2
DO H29	4/22/75	45	.05
DO H30	7/19/77	51	1.8
DO H33	1/16/80	40	.6
DO H35	3/19/79	48	15
DO H35	8/20/79	48	13
DO H36	1/22/81	50	5.7
DO H41	9/23/74	47	4.0
DO H42	9/13/79	237	8.4
DO H43	8/26/75	50	4.6
DO H45	10/19/76	25	2.2
DO H46	9/08/75	26	3.4
DO H51	6/02/75	30	5.5
DO H54	8/27/76	37	11
DO H55	9/16/75	50	3.0
DO H59	6/13/78	40	5.4
DO H61	6/20/79	49	1.5
DO H61	7/12/79	49	1.8
DO H68	6/21/77	55	1.6
DO H71	3/15/77	60	.4
DO H72	10/13/76	40	7.6
DO H74	10/17/79	40	1.8
DO H75	8/09/76	73	5.9
DO H76	1/03/77	28	12
DO H77	9/06/78	24	.15
DO H79	6/06/77	79	<.2
DO H80	12/07/76	38	.23
DO H81	4/05/77	-	7.6
WICOMICO COUNTY			
WI H1	12/28/78	25	<.2
WI H2	2/01/78	14	12
WI H3	8/19/78	49	<.2
WI H4	3/06/78	55	13
WI H5	6/30/78	32	.7
WI H6	3/28/78	67	1.6
WI H7	6/05/78	13	1.9
WI H8	10/25/78	39	<.2
WI H9	2/15/78	75	3.8
WI H10	7/26/78	27	0.0
WI H11	1/18/79	55	8.6
WI H12	4/18/79	39	<.2
WI H13	7/30/79	60	5.5
WI H14	7/09/79	57	<.2
WI H15	7/12/79	65	3.0
WI H16	7/12/79	55	<.2
WI H17	8/30/79	70	4.4
WI H18	9/14/79	90	13
WI H19	3/27/79	60	3.7
WI H20	2/02/79	39	3.3
WI H22	2/05/81	90	<.2
WI H23	8/29/80	95	9.2
WI H24	8/11/80	70	4.2
WI H25	3/12/81	62	<.2
WI H26	9/16/80	59	.5
WI H27	6/01/81	40	<.2
WI H28	8/18/80	40	.4
WI H29	10/16/80	50	5.4
WI H30	5/13/81	37	3.6
WI H31	4/29/81	72	5.3
WI H32	2/11/81	50	1.3
WI H33	1/27/81	75	7.9
WI H34	2/04/81	74	<.2
WI H35	6/30/81	90	<.2
WI H36	6/29/81	75	4.8
WI H37	5/14/81	66	.4
WI H38	6/29/81	67	8.8
WI H39	5/18/81	73	.5
WI H40	3/11/81	69	3.5
WI H41	2/11/81	70	3.7
WI H42	5/27/81	90	.7
WI H43	1/14/81	73	2.2
WI H44	4/09/81	70	2.3
WI H45	1/20/81	49	1.1
WI H46	10/14/80	75	3.6
WI H47	3/11/81	62	<.2
WI H48	1/27/81	63	13
WI H49	1/21/81	95	1.2
WI H50	12/09/80	75	5.1
WI H51	5/20/81	65	6.7

Table 11.--Nitrate analyses of water samples from the Columbia aquifer collected by the county health departments--Continued.

Well No.	Date of collection	Depth to top of screen (feet)	Dissolved nitrate plus nitrite (mg/L as N)
WI H52	11/21/80	80	3.0
WI H53	4/22/81	70	6.2
WI H55	4/22/81	70	7.2
WI H56	5/18/81	22	8.3
WI H57	7/03/80	70	18
WI H58	8/07/81	50	8.7
WI H59	5/18/81	35	.4
WI H60	2/25/81	40	7.6
WI H61	9/24/79	53	.2
WI H62	5/10/79	38	7.1
WI H64	2/26/79	80	14
WI H65	8/20/79	22	6.5
WI H66	11/19/79	30	<.2
WI H67	1/10/79	37	7.2
WI H68	3/15/79	39	2.3
WI H69	7/19/79	3	1.7
WI H70	4/10/78	41	3.6
WI H71	2/24/81	70	6.7
WI H72	6/02/81	-	6.0
WI H74	7/07/81	80	12
WI H75	5/05/81	70	8.7
WI H76	6/16/81	73	7.1
WI H77	2/02/81	60	2.6
WI H78	1/28/81	95	9.6
WI H80	11/17/80	60	6.8
WI H81	4/21/81	98	<.2
WI H82	7/09/80	62	<.2
WI H83	10/24/78	20	.21
WI H85	8/23/78	37	.3
WI H87	5/02/78	45	.04
WI H89	10/04/78	56	.13
WI H90	9/13/78	57	17
WI H92	2/06/79	55	5.6
WI H93	7/17/79	50	6.9
WI H94	5/24/79	60	18
WI H95	5/01/79	75	11
WI H96	10/09/79	50	8.3
WI H97	5/09/78	70	.3
WI H98	10/23/80	98	.5
WI H99	8/04/80	1	1.0
WI H100	8/26/80	75	.5
WI H101	11/21/80	65	.6
WI H102	7/23/80	90	4.4
WI H103	11/24/80	90	.7
WI H104	6/04/81	72	6.1
WI H105	8/26/80	75	.5
WI H106	9/09/80	-	.9
WI H107	4/24/80	60	6.2
WI H108	9/02/80	80	.6
WI H109	7/24/80	-	5.2
WI H111	6/26/80	65	1.9
WI H112	9/09/80	65	7.8
WI H113	9/09/80	62	4.2
WI H114	8/14/80	60	11
WI H115	11/13/80	36	3.1
WI H116	7/11/80	67	<.2
WI H117	7/11/80	62	<.2
WI H118	6/09/81	75	.6
WI H119	9/11/80	70	.6
WI H121	7/23/80	68	<.2
WI H125	3/05/81	78	2.1
WI H127	10/28/80	62	5.6
WI H128	4/07/81	60	8.2
WI H129	11/21/80	75	1.2
WI H130	6/24/81	75	1.9
WI H131	1/21/81	75	.7
WI H134	12/09/80	88	9.2
WI H135	4/27/81	62	4.2
WI H136	2/05/81	63	13
WI H138	3/11/81	62	<.2
WI H139	4/23/81	85	<.2
WI H140	3/12/81	75	<.2
WI H143	7/02/81	-	.9
WI H145	7/07/81	63	<.2
WI H146	12/17/79	10	6.0
WI H147	3/20/80	35	<.2
WI H150	9/09/80	75	.7
WI H151	7/19/80	80	.4
WI H154	10/14/80	55	.6
WI H156	3/04/80	78	26
WI H157	6/03/80	37	<.2
WI H161	6/02/80	37	<.2
WI H162	7/29/80	75	.6
WI H164	7/09/80	75	1.7
WI H165	8/29/80	58	0.5
WI H166	9/09/80	69	5.9

Table 11.--Nitrate analyses of water samples from the Columbia aquifer collected by the county health departments--Continued.

Well No.	Date of collection	Depth to top of screen (feet)	Dissolved nitrate plus nitrite (mg/L as N)
WORCESTER COUNTY			
WO H1	9/21/78	47	6.3
WO H2	5/06/81	56	<.2
WO H4	6/11/79	67	<.2
WO H5	7/23/76	46	.01
WO H6	8/13/79	58	<.2
WO H7	4/01/81	45	<.2
WO H8	1/10/80	54	1.8
WO H10	10/24/79	50	<.2
WO H11	9/10/79	105	<.2
WO H12	12/14/78	67	10
WO H13	11/02/79	58	<.2
WO H14	10/29/80	5	11
WO H15	8/19/81	86	4.4
WO H16	3/18/75	70	3.2
WO H17	12/07/72	88	.4
WO H18	8/11/80	66	<.2
WO H19	7/21/81	51	.4
WO H20	10/04/77	55	.1
WO H21	12/17/80	98	.6
WO H21	1/05/81	98	.5
WO H22	1/31/79	80	<.2
WO H23	12/07/78	5	6.0
WO H24	5/25/78	5	-
WO H25	4/29/81	42	2.4
WO H26	3/09/81	40	8.3
WO H27	2/17/81	38	<.2
WO H28	4/07/80	100	<.2
WO H29	10/04/79	86	<.2
WO H30	1/07/80	97	<.2
WO H31	10/04/79	0	<.2
WO H32	6/17/80	94	<.2
WO H33	10/25/78	95	.17
WO H34	8/06/79	-	3.9
WO H35	3/18/75	88	.2
WO H36	4/21/81	63	<.2
WO H37	3/16/71	62	2.8
WO H38	10/10/78	90	.25
WO H39	10/17/78	90	<.2
WO H40	1/19/81	89	2.6
WO H41	8/13/79	68	<.2
WO H42	5/01/75	100	<.2
WO H43	3/18/75	88	.15
WO H44	6/13/72	37	.04
WO H45	10/14/77	40	.45
WO H46	3/31/81	110	6.3
WO H48	4/24/78	90	.56
WO H49	8/19/81	70	.6
WO H50	4/01/81	95	<.2
WO H51	2/27/81	42	-
WO H52	2/22/73	25	.05
WO H54	9/09/81	47	.5
WO H55	11/27/79	75	<.2
WO H56	2/23/73	50	-
WO H57	9/08/76	98	.17
WO H58	1/30/79	65	<.2
WO H59	7/23/75	40	.08
WO H60	5/06/80	5	28
WO H60	6/25/80	5	33
WO H60	7/28/80	5	20
WO H60	8/05/80	5	21