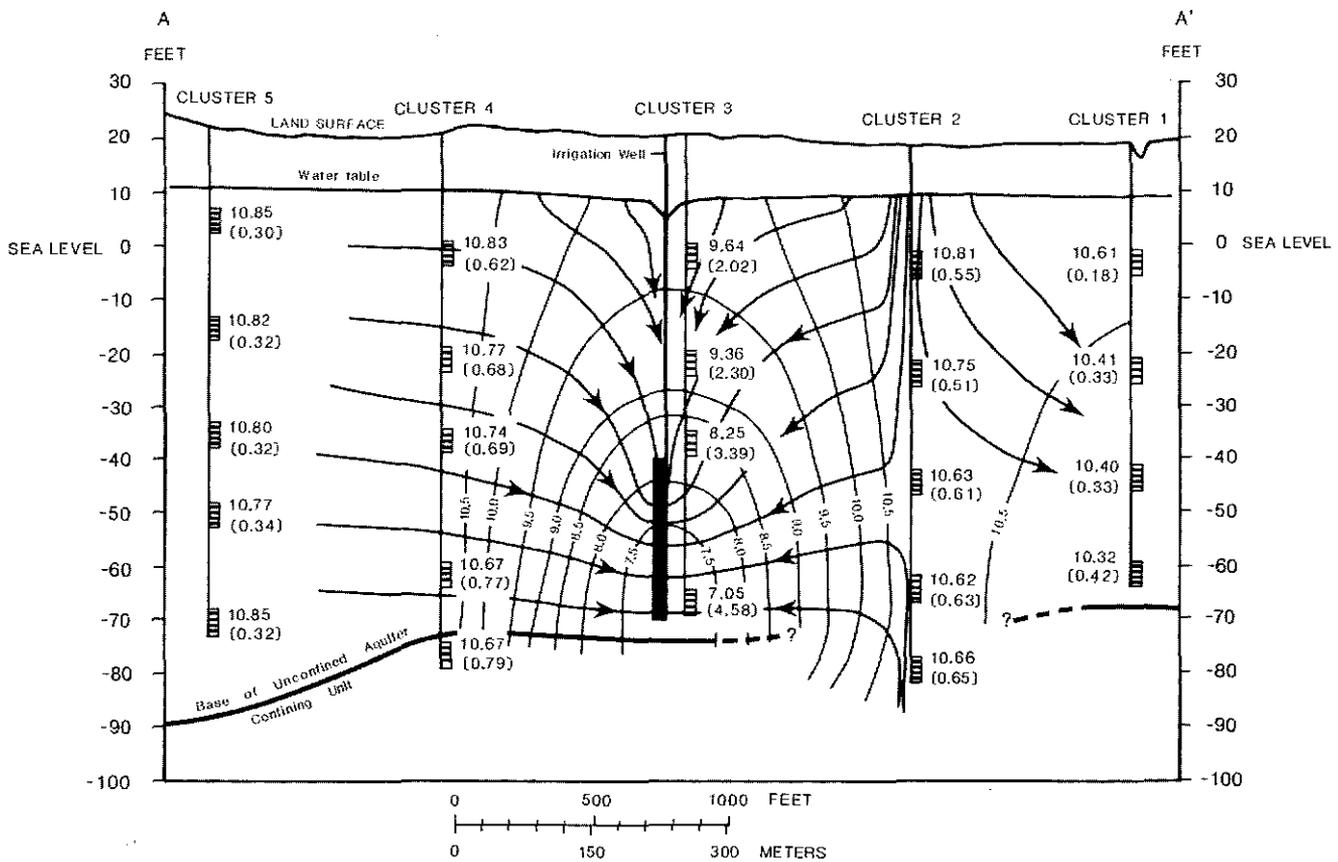


DELAWARE GEOLOGICAL SURVEY

REPORT OF INVESTIGATIONS NO. 45

EFFECTS OF AGRICULTURAL PRACTICES AND SEPTIC-SYSTEM EFFLUENT ON THE QUALITY OF WATER IN THE UNCONFINED AQUIFER IN PARTS OF EASTERN SUSSEX COUNTY, DELAWARE



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**EFFECTS OF AGRICULTURAL PRACTICES AND SEPTIC-SYSTEM EFFLUENT ON THE
QUALITY OF WATER IN THE UNCONFINED AQUIFER IN PARTS OF
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By Judith M. Denver

ABSTRACT

The unconfined aquifer is a major source of water supply in eastern Sussex County, Delaware. It also is an important source of water for surface-water bodies and deeper, confined aquifers. The aquifer consists mainly of permeable sand and gravel; its shallow water table is susceptible to contamination by nitrate and other chemical constituents associated with agricultural practices and effluent from septic systems.

Chemical analyses of ground-water samples and water levels from piezometers with screened intervals at various depths around a 220-acre irrigated field known as the Fairmount site were used to study the subsurface distribution and movement of nitrate and other fertilizer components. Land-use, soil, and aquifer characteristics at the Fairmount site are similar to large parts of eastern Sussex County. There is a direct relation between concentrations of nitrate, the dominant anion, and specific conductance in water from the Fairmount site. Therefore, specific conductance was used to estimate nitrate concentrations in water samples and to indicate the degree of agricultural influence on water chemistry.

Factors including upgradient land use, ground-water withdrawal, rates of fertilizer application, magnitude and timing of recharge, and aquifer properties affect the distribution of agricultural chemicals in the aquifer. Concentrations of nitrate as nitrogen range from less than 2 mg/L (milligrams per liter) to greater than 40 mg/L and have a median concentration greater than 10 mg/L. Although agriculture has less of an influence in deeper parts of the aquifer than in shallower parts, nitrate (as nitrogen) concentrations are as high as 29 mg/L near the base of the aquifer, 80 feet below land surface. This degree of variability indicates that a water sample from an individual well in the unconfined aquifer is not an adequate representation of overall quality.

Corn and soybeans generally are grown in alternate years at the Fairmount site. More than 200 pounds per acre of nitrogen fertilizer are applied to corn crops, and little or none is applied to grow soybeans. Consequently, variable amounts of excess nitrogen in the soil zone can be leached from the soil and percolate to the water table during the principal recharge period that begins in late fall after the growing season ends. The result is stratification of nitrogen-bearing water in the flow system.

Ground-water withdrawal for irrigation promotes movement of chemically stratified water into deeper parts of the unconfined aquifer. In parts of the aquifer not influenced significantly by ground-water pumping, land use upgradient from the Fairmount site controls much of the variability of water quality with depth.

The chemical characteristics of ground water affected by septic-system effluent were investigated in samples from 11 wells in the study area. The major dissolved chemical components of septic-system effluent are organic and ammonia nitrogen, sodium, and chloride. Other components include calcium, magnesium, potassium, sulfur, and phosphorus in lesser proportions, as well as organic compounds and components of detergents and cleaning agents. Although these chemicals were present in the water samples affected by septic-system effluent, their presence cannot be used to identify the source of water-quality problems uniquely because they also are present in manures, fertilizers, and pesticides. Differences in the proportions of dissolved constituents in ground water affected by septic-system effluent and by agricultural practices also were not distinct enough to identify sources of nitrate contamination.

The relative proportions of major dissolved constituents, expressed as percentages of the total concentration of cations or anions, are different in natural water and water affected by agricultural practices and septic-system effluent. The median percentage of bicarbonate, the predominant anion in water under natural conditions in the study area, is 43 in water unaffected by human activities and 7 in water affected by agricultural practices and septic-system effluent. The median percentages of nitrate are 65 and 54 in water affected by agricultural practices and septic-system effluent, respectively, and 25 in water under natural conditions. Sodium, the predominant cation in water under natural conditions, has a median percentage of 61 in natural water and 29 in water affected by agricultural practices and septic systems where calcium is the predominant cation.

INTRODUCTION

Background

The unconfined aquifer is a principal source of agricultural, domestic, municipal, and industrial water supply in eastern Sussex County, Delaware. It also is an important source of water for surface-water bodies and deeper confined aquifers. The area is primarily rural with resort development along the Atlantic coast. Because of development, the demand for ground water is increasing. Nitrate concentrations above the U.S. Environmental Protection Agency (EPA) drinking-water standard of 10 mg/L (milligrams per liter) as nitrogen (U.S. Environmental Protection Agency, 1986) are common in the unconfined aquifer.

The study area includes about 500 square miles of the Delmarva Peninsula (Figure 1). The boundaries are the Sussex County line to the north, the Maryland-Delaware border to the south, the Chesapeake Bay-Delaware Bay and Chesapeake Bay-Atlantic Ocean drainage divides to the west, and the Atlantic Ocean to the east. Topography is relatively flat with land surface elevations ranging from sea level near the coast to about 60 ft (feet) above sea level on the northern part of the drainage divide.

The unconfined aquifer is susceptible to contamination because the water table generally is within 15 ft of the land surface and the soils are sandy. Water in the aquifer has a naturally low dissolved-solids content and even small amounts of applied chemicals may cause major changes in ground-water quality. Agricultural fertilizers and manure, and septic-system effluent are the most widespread sources of contamination. Crop production accounts for about 50 percent of land use in eastern Sussex County (Ritter, 1986). Areas with a high density of septic tanks are most common in residential developments around Rehoboth, Indian River, and Little Assawoman bays, also known as the Inland Bays. Unsewered residential areas comprise about 9 percent of the land use in the areas draining to these bays (Ritter, 1986).

Previous studies (Miller, 1972; Robertson, 1977; Ritter and Chirnside, 1982; and Denver, 1986) have delineated the extent of ground-water contamination problems and have identified areas with potential for contamination. These assessments were made by ground-water sampling and by relating the sampling results to land uses and soil characteristics. The studies concluded that fertilizer and poultry manure are the main sources of nitrate contamination and that effluent from septic tanks also contributes nitrate to the aquifer in some unsewered residential areas. Robertson (1977) identified several areas in eastern Sussex County with mean concentrations of nitrate as nitrogen greater than 9.5 mg/L. The highest concentrations were near Indian River Bay where soils are excessively well-drained and highly permeable. Routine sampling of public water supplies by the Delaware Department of Health and Social Services also has documented elevated nitrate concentrations in eastern Sussex County.

Purpose and Scope

This report (1) adds to the existing knowledge of ground-water quality in agricultural areas by describing the vertical and horizontal distribution and movement of nitrate and other chemical constituents around an irrigated field, and (2) describes the effects of effluent from domestic septic systems on the quality of water in the unconfined aquifer. The chemistry of water affected by agricultural practices is compared to the chemistry of water affected by septic-system effluent to determine unique characteristics of each that could be used to identify sources of ground-water contamination. These affected waters are also compared to water with natural and nearly natural chemistry.

A 220-acre field with a center-pivot irrigation system and a centrally located well, referred to as the Fairmount site (Figure 1), was instrumented with 31 piezometers to study the effects of irrigation on the subsurface distribution and movement of chemicals related to agricultural practices.

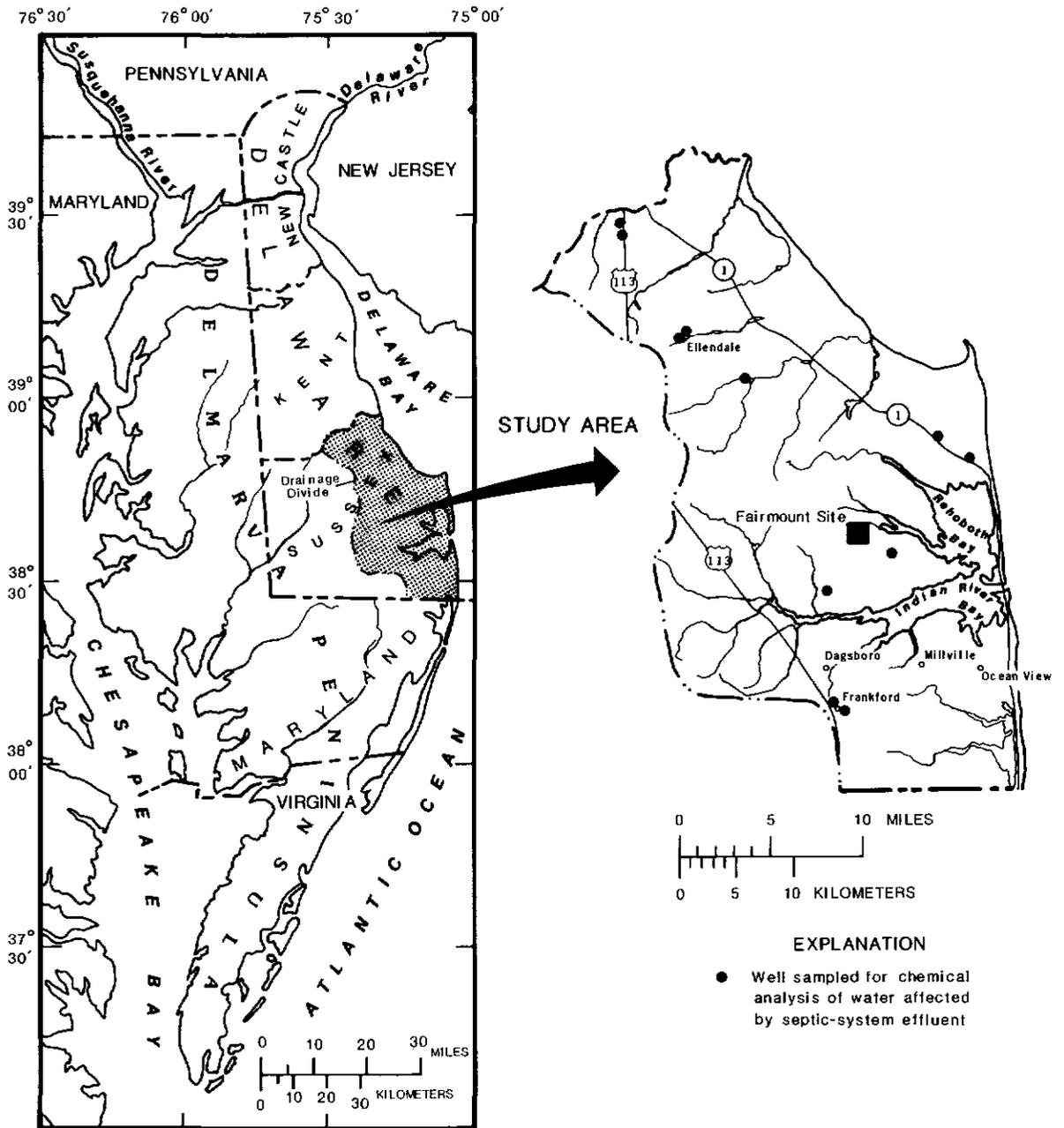


Figure 1. Location of study area, the Fairmount site, and wells sampled for chemical analysis of water affected by septic-system effluent.

This site is representative of a large part of eastern Sussex County with similar land use, soil, and aquifer characteristics. Water-level and water-quality data were collected quarterly from April 1985 through March 1987. Water-quality analysis included laboratory determination of major ions and nutrients, and field measurements for specific conductance, pH, water temperature, alkalinity, and dissolved oxygen. Continuous water-level data collected from an observation well 75 ft from the pumped well were used to relate water-level changes during pumping to water quality, and to determine periods of recharge to the aquifer. Vertical changes in water quality were studied over time at 24 of the piezometers that were arranged in 5 clusters of 4 or 5 each with screens at different vertical intervals in the aquifer ranging from 20 to 100 ft below land surface. Water quality in Phillips Branch, a small stream adjacent to the field was compared to water quality in a nearby part of the aquifer. Analysis of the data evaluates ground-water quality in relation to irrigation well pumping, the unstressed flow system, cropping and fertilization practices, soil characteristics, and recharge.

Water samples from 11 wells (Figure 1) identified as having elevated nitrate concentrations resulting from septic-system effluent were collected to evaluate the effects of the effluent on ground-water chemistry. The wells selected were located downgradient from areas with closely spaced individual septic systems where other land uses would not influence water quality. Because wells potentially affected by septic systems frequently are located adjacent to or downgradient of agricultural land, or have been developed on recently farmed areas, no additional wells could be found for sampling.

Ten additional wells with water quality affected by agricultural practices were selected (Appendix 3). Analyses from nine wells not significantly affected by agricultural practices, septic systems, or other land uses were selected as indicators of natural or nearly natural water quality (Appendix 4). Variations in water chemistry resulting from these land uses and septic-system effluent are characterized using boxplots of major-ion concentrations and relative proportions of ions.

Acknowledgments

This study was conducted under a Joint-Funded Agreement between the Delaware Geological Survey (DGS) and the U.S. Geological Survey (USGS). The staff of the DGS, under the direction of Robert R. Jordan, State Geologist, provided drilling and geophysical logging.

The Division of Public Health of the Delaware Department of Health and Social Services is thanked for allowing access to their files and helping to locate wells suitable for sampling.

Special thanks are extended to Townsend's, Inc., for allowing piezometer installation and instrumentation on their property, and to the homeowners, municipalities, and water companies who permitted their wells to be sampled.

DESCRIPTION OF EASTERN SUSSEX COUNTY

Geologic Setting

Sussex County is located on the Delmarva Peninsula, which is a part of the Atlantic Coastal Plain physiographic province. The Coastal Plain is underlain by a seaward-dipping wedge of unconsolidated to semiconsolidated marine and nonmarine sediments composed of gravel, sand, silt, and clay. The sediments range in age from Jurassic to Holocene and lie unconformably on crystalline bedrock. The sediments thicken from about 5,000 to 10,000 ft from northwest to southeast across eastern Sussex County (Benson, 1984). The stratigraphic nomenclature in this report is that of the DGS and does not necessarily follow the usage of the USGS.

The units that comprise the unconfined aquifer in most of eastern Sussex County are the Beaverdam and Omar formations of the Columbia Group of Pliocene-Pleistocene age and sand units in the Chesapeake Group of Miocene age where they subcrop the Columbia Group. Unnamed deposits of Holocene age that overlie the Columbia Group along the shores of the Delaware Bay and Atlantic Ocean also are considered to be part of the unconfined aquifer.

The Beaverdam Formation of fluvial and possibly estuarine origin (Jordan and Talley, 1976) is the primary unit of interest to this study. It generally is a medium to coarse quartz sand with variable amounts of fine sand and gravel. Thin clay-silt beds are common throughout the formation. The Beaverdam ranges from 60 to 120 ft thick in the study area (Talley and Andres, 1987).

The Omar Formation of lagoonal deposition, with features of estuaries, marshes, and beaches (Jordan, 1962), overlies the Beaverdam Formation in the southern part of the study area. It is composed of alternating beds of sand and silt and averages 45 ft thick. The silt usually contains organic matter and is fossiliferous.

The sand units of the Chesapeake Group, a marine and marginal-marine sequence that underlies the Beaverdam Formation, include the Pocomoke aquifer of the Bethany formation and the Manokin aquifer of the Manokin formation. Both the Bethany and Manokin formations are considered informal units as first proposed by Andres (1986a). The Bethany formation is the lithostratigraphic equivalent of the Pocomoke and Ocean City aquifers and their overlying, intervening, and basal confining units. The underlying Manokin formation is the lithostratigraphic equivalent of the Manokin aquifer. The thickness of the unconfined aquifer can be up to 200 ft in these areas (Denver, 1983). These units are lithologically similar to the Beaverdam Formation, and although the Chesapeake Group sand tends to be better sorted than the Beaverdam, it commonly is difficult to distinguish between them.

Holocene sediments include estuarine, lagoonal, and barrier island sequences deposited during a marine transgression (Kraft, 1971). These sediments may be up to 150 ft thick in buried stream channels (Talley and Andres, 1987).

Hydrologic Characteristics

The unconfined aquifer is a regional aquifer in eastern Sussex County. The saturated thickness of the water-bearing sand ranges from 10 to 170 ft and generally is greater than 80 ft (Andres, 1986b; Talley, 1987). The water table ranges from 1 to 20 ft below land surface and fluctuates annually from 5 to 10 ft (Andres, 1986b).

The area receives average annual precipitation of 44 in. (inches), of which approximately 14 in. recharges the unconfined aquifer. Most of the ground-water recharge occurs from mid-October to early April when evapotranspiration is at a minimum (Johnston, 1973). The unconfined aquifer generally is recharged in topographically high areas and discharges to surface-water bodies and through downward leakage into underlying aquifers of the Chesapeake Group. A small amount of ground water also transpires and evaporates. Johnston (1973) calculated that pumpage from the unconfined aquifer in Delaware represented only about 4 percent of the natural discharge. The regional ground-water divide is coincident with the western edge of the study area (Figure 1). The Inland Bays, the Delaware Bay, the Atlantic Ocean, and larger streams are major discharge areas. Small streams derive base flow from shallow, local flow systems.

Aquifer transmissivity varies locally because of lithologic changes and changes in saturated thickness. Johnston (1977) estimated that the average transmissivity of the unconfined aquifer exceeded 10,000 ft²/d (feet squared per day) in the northern part of the study area on the basis of the results of a flow-model simulation. Values of transmissivity in the part of eastern Sussex County included in the model ranged from less than 5,000 to greater than 20,000 ft²/d (Johnston, 1977). Values of storage coefficient were estimated to range from 0.11 to 0.17, with an average of 0.14 (Johnston, 1973).

The flow system in the unconfined aquifer is complex because of the dissection of the land surface by numerous streams, anisotropy of the sediments, the channeled nature of the aquifer's base, and downward flow into deeper aquifers. Johnston (1973, 1977) gives a detailed analysis of the hydrology of the unconfined aquifer.

Natural Ground-Water Chemistry

Naturally occurring concentrations of chemical constituents in water in the unconfined aquifer are low, and specific conductance of the water usually is less than 100 μ S/cm (microsiemens per centimeter at 25 degrees Celsius). The aquifer is primarily composed of relatively insoluble quartz sand and the sediments generally are highly permeable, which reduces the contact time for reactions to occur between water and aquifer materials.

The major dissolved constituents in natural water in the unconfined aquifer are derived from atmospheric precipitation and weathering of silicate minerals, principally feldspars. Sodium and bicarbonate generally are the dominant ions. Incongruent dissolution of the feldspars plagioclase and orthoclase is a primary source of sodium, as well as potassium, calcium, bicarbonate, and silicic acid. Magnesium is contributed from weathering of micas and some heavy minerals. Natural sources of sulfate and nitrate are

precipitation and organic matter. Atmospheric precipitation is the principal source of chloride in the ground water and a primary source of sodium, except in areas affected by saltwater intrusion. The chemical constituents in local precipitation and general silicate mineral dissolution reactions are presented in Tables 1 and 2, respectively.

Oxidation and reduction reactions are an important control on concentrations of certain constituents in natural water—notably iron, nitrogen, sulfur, and bicarbonate (Table 2). Dissolved oxygen in precipitation is consumed by oxidation of organic matter in the soil zone. All of the oxygen may be consumed in poorly drained soils that have high organic matter content. Dissolved oxygen not consumed by reactions with organic matter in the soil zone moves in recharge into the ground-water system where it is gradually consumed by oxidation of reduced species such as ferrous iron, ammonium, and sulfide. Oxidation and reduction reactions involving nitrogen and sulfur species are bacterially mediated.

Much of eastern Sussex County is covered by soils that are well or excessively well-drained and contain very little organic matter. This is particularly true of the soils of the Evesboro-Rumford association (Figure 2). Recharge water percolating through these soils contains relatively high concentrations of dissolved oxygen. Along the western edge and southern part of the study area, soils generally are poorly drained and have large amounts of organic matter, and the water in the aquifer is under reducing conditions (Figure 2). Dissolved iron may be elevated in these areas.

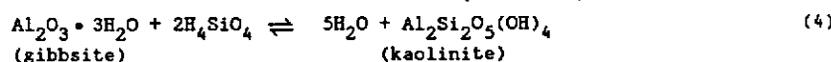
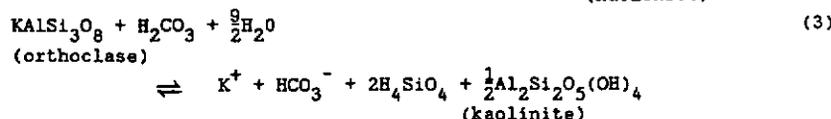
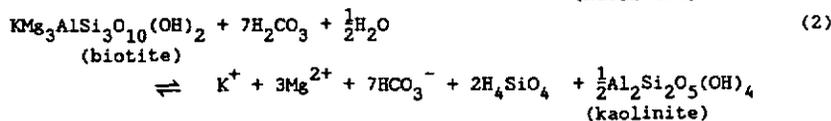
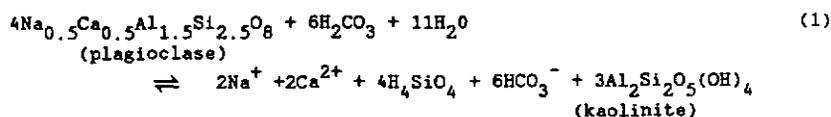
TABLE 1. Average chemical composition of precipitation from a station located in Lewes, Delaware, August 1978 through January 1983.

[Data provided by the MAP3S Precipitation Chemistry Network]

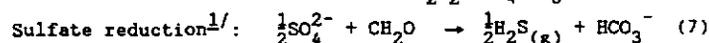
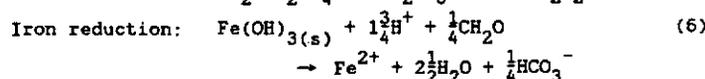
Constituent	Concentration in milligrams per liter
Hydrogen, H ⁺	0.05
Sodium, Na ⁺	1.22
Ammonium, NH ₄ ⁺	.23
Potassium, K ⁺	.09
Calcium, Ca ⁺²	.13
Magnesium, Mg ⁺²	.13
Chloride, Cl ⁻	1.93
Sulfate, SO ₄ ⁻²	2.10
Nitrate, NO ₃ ⁻	1.23
Total	7.11

TABLE 2. Chemical reactions occurring in the unconfined aquifer.

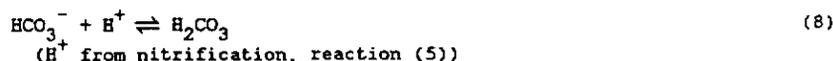
Incongruent dissolution reactions:



Redox reactions:



Bicarbonate depletion:



^{1/}Reactions are mediated by bacteria.

Cation-exchange reactions involving clay minerals also can modify water chemistry in the unconfined aquifer. The significance of these reactions varies with the type of clay minerals present and the concentration of cations in solution. Denver (1986) provides a detailed discussion of these and other reactions controlling water chemistry in the unconfined aquifer.

Agricultural Land Use

Corn and soybeans are the primary crops in eastern Sussex County. The principal agricultural practices that influence ground-water chemistry are applications of inorganic fertilizer, manure, and lime for improving crop production. The major nutrients in inorganic fertilizers are nitrogen, potassium, and phosphorus. Most of the nitrogen applied as inorganic fertilizer is in the form of ammonia compounds. Potassium is applied in the form of potassium chloride, and phosphorus usually is applied as phosphorus pentoxide. Nitrogen from manure is in the form of ammonia and organic nitrogen compounds. Poultry manure is the most common type used in eastern Sussex County. It also contains significant quantities of other major nutrients. Lime contributes calcium and magnesium for plant use and

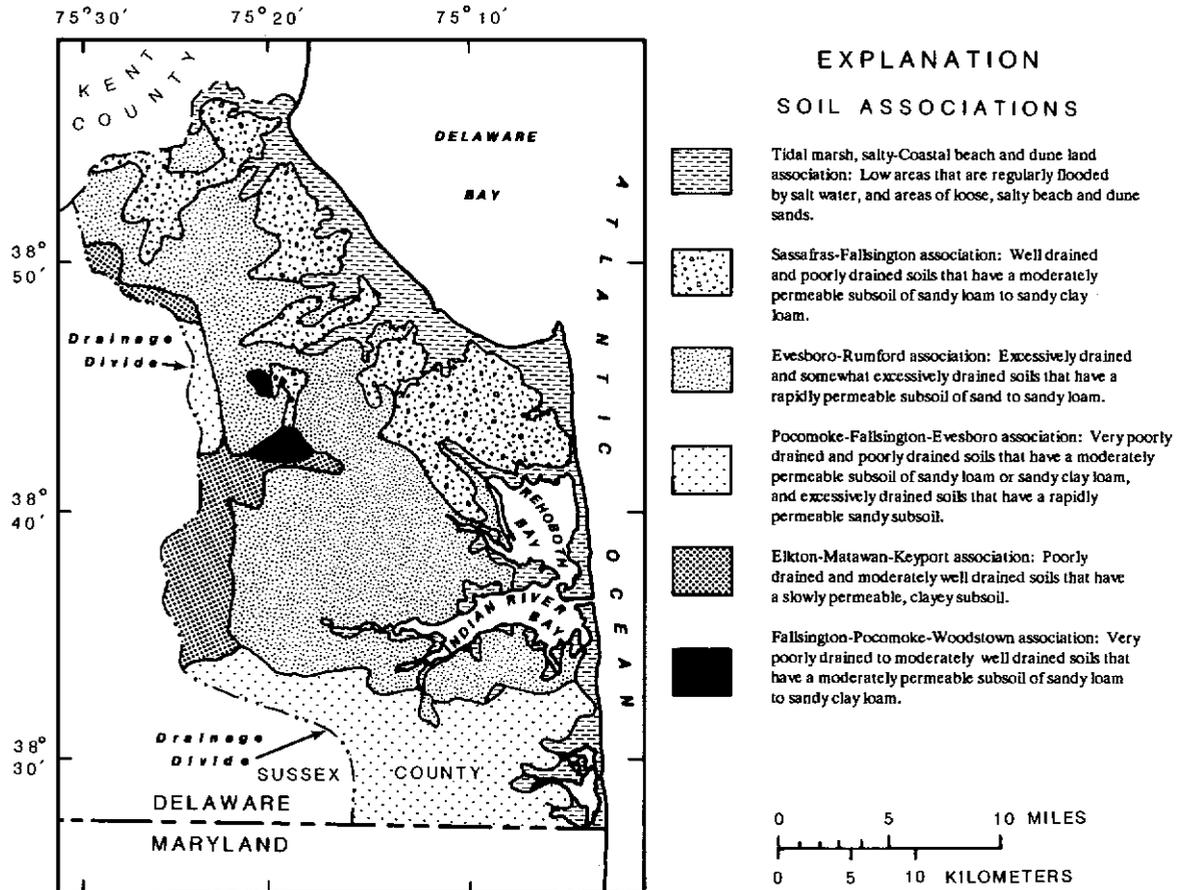


Figure 2. General distribution of soil associations in eastern Sussex County, Delaware.

bicarbonate which buffers soil acidity caused by nitrification (Denver, 1986). Other fertilizer components that may affect ground-water chemistry are sulfate and micronutrients including small amounts of iron, manganese, zinc, boron, copper, chlorine, cobalt, and molybdenum. The amounts of micronutrients present probably do not significantly influence water chemistry. Pesticides also are used to improve crop production. Their effects on ground-water quality are not considered in this study.

Approximately 100,000 acres in eastern Sussex County are used for crop production (Ritter, 1986); about 6 percent of this acreage is irrigated. Much of the agricultural land is in areas with well- or excessively well-drained soils, which frequently have a low natural organic matter content and low to moderate moisture capacity. Larger amounts of fertilizer and irrigation are needed to support crop production on these soils because fertilizers are rapidly leached from the soil zone by percolating water. These factors increase the potential for nitrate contamination in the aquifer.

Corn and soybeans are the major crops in eastern Sussex County. Nitrogen requirements for corn production are 75 to 150 lb/acre (pounds per acre) without irrigation (Harris and Williams, 1981), depending on the ability of the soil to retain nutrients. As much as 250 lb/acre of nitrogen are required for corn production on irrigated land. Nitrogen fertilizer is not required for soybean production. Most crop nitrogen requirements are met with inorganic fertilizers applied after planting and during the growing season. As a result, nitrogen supplied through spreading of poultry manure is frequently in excess of crop needs. Manure generally is applied during the nongrowing season.

Septic Systems

Residential development is concentrated along U.S. Route 113, along State Route 1 in the coastal areas, and in areas bordering Rehoboth Bay and Indian River Bay (Figure 1). Most of the towns in these areas are sewered and have centralized treatment plants that discharge to surface-water bodies. Individual septic systems are used in the towns of Frankford, Dagsboro, Millville, Ocean View, and Ellendale (Figure 1). Other areas with a high density of individual septic systems are primarily located around the Inland Bays. Many wells in these areas are screened in confined aquifers to avoid contamination by nitrates and saline water.

Effluent from septic systems discharges into tile fields or seepage beds in or just below the subsoil. Nitrogen in the effluent is in ammonia and organic forms. On the average, a septic system discharges about 7 lb of nitrogen per person per year. Of this amount, 64 percent is estimated to reach the ground-water system and the remainder is lost by volatilization (Hall, R. L., U.S. Department of Agriculture, oral commun., 1986). Most of the nitrogen from the effluent is converted to nitrate in oxidizing zones of the soil and aquifer. Components of septic-system effluent are similar to those in poultry manure. Detergents and other household chemicals also may be present in the effluent.

METHODS OF STUDY

Specific conductance, pH, alkalinity, water temperature, and dissolved oxygen were measured in the field at each well or piezometer sampled for this study. Prior to sampling, piezometers were purged using a suction pump to remove silty water. They were then pumped with a submersible pump until the field measurements stabilized and samples could be collected. For wells with permanent pumps, samples were collected upflow of any treatment systems and water was allowed to run until the field measurements stabilized. Laboratory analysis of major ions, nutrients, and selected trace constituents was conducted by the USGS laboratory in Denver, Colo. Sampling and analytical procedures used in this study are described by Skougstad and others (1979). Laboratory analysis for nitrate is actually nitrate plus nitrite as nitrogen. This is generalized as nitrate as nitrogen, or nitrate, throughout this report because nitrite is usually present in much lower concentrations than nitrate and is readily converted to nitrate; therefore, concentrations of nitrite are not reported separately.

Fairmount Site

Installation of Piezometers

Thirty-one piezometers were installed around the irrigated field at the Fairmount site (Figure 3). Each piezometer was constructed using 2-in.-inside-diameter, flush-threaded, polyvinyl chloride casing with a 5-ft-long slotted screen at the base. The piezometers bisecting the field are arranged in clusters of four or five each with screened intervals ranging from 20 to 25 ft below land surface to 97 to 103 ft below land surface (Figure 4). Each piezometer was installed in a separate hole. The piezometers installed on the perimeter of the field are between 20- and 25-ft deep. A datum was established at each piezometer, and relative land surface elevations were established to within 0.02 ft.

Data Collection

Water levels were measured bimonthly in all piezometers from April 1985 through March 1987, and at other selected times to evaluate drawdown associated with irrigation. Continuous water-level records were collected from November 1985 through May 1987 for an observation well located 75 ft from the irrigation well. The observation well is screened from 60 to 90 ft below land surface, which also is the screened interval of the irrigation well.

The schedule of field and laboratory sampling of ground water at the Fairmount site is given in Table 3. Samples from Phillips Branch were collected in June and October 1986 from an upstream and downstream site during base flow (Figure 3). A sample also was collected from the irrigation well. Results of the analyses are in Appendix 1.

Continuous records of specific conductance were collected from February through July 1987 in the 25-ft deep piezometer (Ph13-03) and the 45-ft deep piezometer (Ph13-16) in cluster 3 using USGS minimonitors. For most of the period of record, data on specific conductance agreed with field-determined values made after pumping the piezometers for sampling.

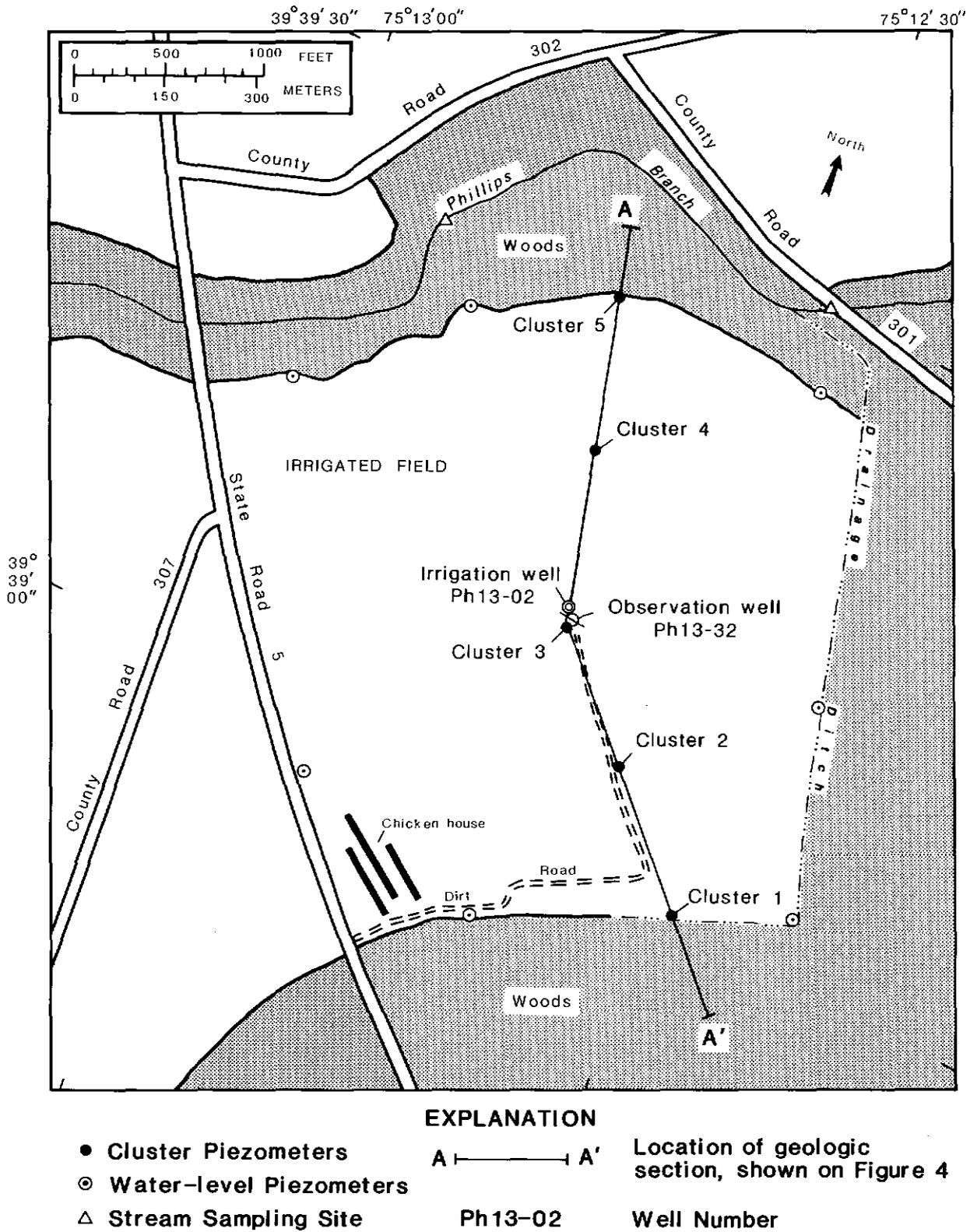


Figure 3. Fairmount site study area.

TABLE 3. Schedule of water-quality sample collection at the cluster piezometers of the Fairmount site.

[F, field analysis of specific conductance, dissolved oxygen, pH, alkalinity; L, laboratory analysis for major ions and nutrients and field parameters; ND, piezometer not developed for sampling; -, no sample collected]

Location and well number	Date							
	4,5/85	7/85	10/85	1/86	3/86	6/86	9/86	4,5/87
Cluster 1								
Ph23-10	F	F	-	F	L	F	L	F
Ph23-12	F	F	-	L	F	L	L	F
Ph23-13	F	F	-	L	F	L	L	F
Ph23-14	F	F	-	L	F	L	L	F
Cluster 2								
Ph13-04	F	F	L	L	L	L	L	F
Ph13-23	F	F	L	L	F	L	L	F
Ph13-24	F	F	L	L	F	L	L	F
Ph13-25	F	F	-	L	F	L	L	F
Ph13-26	ND	ND	ND	ND	F	L	L	F
Cluster 3								
Ph13-03	F	F	L	L	L	L	L	F
Ph13-16	F	F	L	L	F	L	L	F
Ph13-17	F	F	L	L	F	F	L	F
Ph13-18	F	F	L	L	F	F	L	F
Cluster 4								
Ph13-08	F	F	-	L	L	L	L	F
Ph13-19	F	F	-	L	F	L	L	F
Ph13-20	F	F	-	L	F	L	L	F
Ph13-21	F	F	-	L	F	L	L	F
Ph13-22	ND	ND	ND	ND	ND	ND	ND	ND
Cluster 5								
Ph13-11	ND	ND	ND	ND	ND	ND	ND	ND
Ph13-28	F	F	-	L	L	L	L	F
Ph13-13	F	F	-	L	F	L	L	F
Ph13-14	F	F	-	L	F	L	L	F
Ph13-15	ND	ND	ND	ND	ND	ND	ND	F

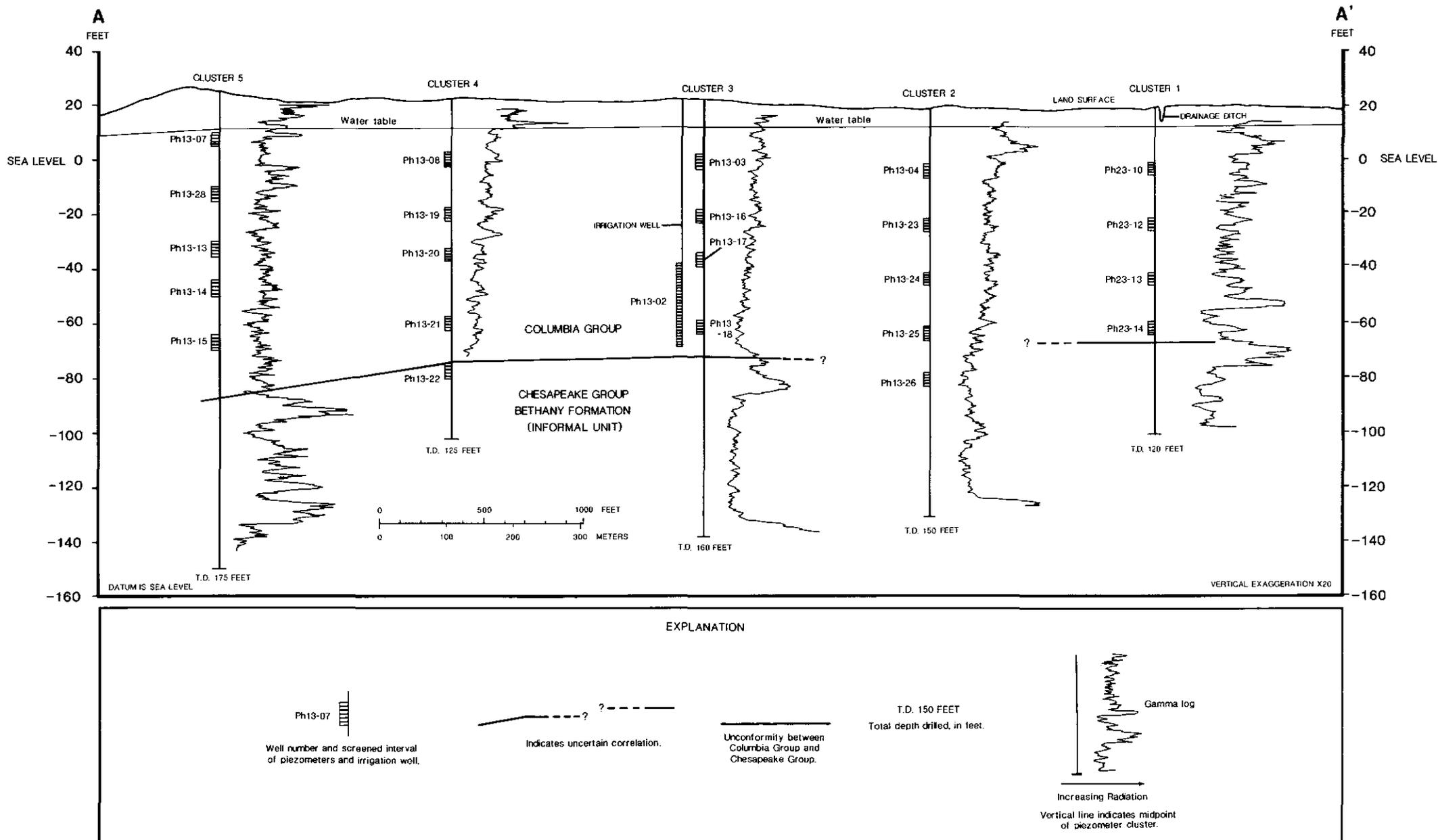


Figure 4. Section showing the configuration of geologic units and screened intervals of piezometers at the Fairmount site.

Influence of Septic-System Effluent

Only 11 wells and piezometers (Figure 1) were sampled to study the effects of septic-system effluent on ground-water chemistry as few wells could be located with nitrate contamination that could be attributed solely to septic-system effluent. Most areas with closely spaced septic tanks are adjacent to agricultural areas or occupy land formerly used for crop production. Water samples from wells were collected as near as possible to the wellhead. Three small-diameter piezometers were sampled using a peristaltic pump. Field and laboratory analytical procedures were the same as those which were used for the Fairmount site. Additionally, samples were analyzed for boron and methylene blue active substance (MBAS).

EFFECTS OF AGRICULTURAL PRACTICES ON GROUND-WATER HYDROGEOLOGY AND GEOCHEMISTRY UNDER AN IRRIGATED FIELD

Description of the Fairmount Site

The soil and aquifer characteristics and agricultural practices associated with the Fairmount site and surrounding area are typical of a large portion of eastern Sussex County. The site is a 220-acre field with a center-pivot irrigation system and a centrally located supply well (Figure 3). The irrigation system was installed in 1978. The closest surface-water feature is a perennial stream, Phillips Branch, that flows on the northern side of the field. A drainage ditch on the southern and eastern sides of the field generally is dry except in the spring. Chicken houses are in use on the southern side of the field along Route 5. Agriculture is the predominant land use upgradient from the Fairmount site.

Soils are primarily Evesboro loamy sand which is excessively drained and sandy with high permeability and generally low natural fertility (U.S. Department of Agriculture, 1974). Evesboro soils are part of the Evesboro-Rumford association (Figure 2) which is the most extensive association in eastern Sussex County. The southeastern corner of the field is covered by Woodstown soil, which is moderately well drained with moderate permeability.

The Columbia Group is 80 to 115 ft thick (Figure 4). The sediments are predominantly quartz sand and coarsen with depth. The Columbia Group is underlain by a clay layer at the top of the Bethany formation (informal unit, Andres, 1986a), except near cluster 2 (Figure 4) where no clay is present. It is not clear whether the absence of the clay is due to an erosional unconformity related to deposition of the Columbia Group or a facies change within the Bethany formation. The uppermost sand unit in the Bethany formation, part of the Pocomoke aquifer, appears to be composed of coarse sand and gravel under the southern half of the field and is siltier under the northern half (Figure 4). Areal variation in sand content is typical of this formation because of its deposition in a delta environment (Andres, 1986a).

Agricultural Practices

Corn and soybeans generally are grown in alternate years at the Fairmount site. There was corn stubble on the field when the piezometers were installed in 1985. Soybeans were planted in 1985, the first year of water-quality-data collection, and corn was grown in 1986. Table 4 summarizes the fertilization and planting schedule.

The starter fertilizer used for corn and soybeans contains some nitrogen (Table 4). No additional nitrogen was applied to soybeans, but corn received a total of 179 lb/acre through the center-pivot system during the irrigation season. Sulfur also is applied periodically through the irrigation system in the form of ammonium thiosulfate. In addition, boron was applied to corn, and both crops received applications of the micronutrients manganese and zinc through the irrigation system (Table 4).

Poultry manure is applied to the field in the winter and spring. During the period of data collection for this project, manure was applied only to the southern half of the field, and it was not considered part of the overall nutrient budget.

Soybeans, which require less water than corn, were irrigated during July and August. Corn was irrigated from planting in May through crop maturity in late August. The center-pivot system rotates completely in 48 hours. It distributes approximately 1 acre-inch of water over the field for each rotation.

Ground-Water Flow System

Flow in the unconfined aquifer generally is from west to east across the Fairmount site (Figure 5). Flow lines diverge from the ground-water divide, located west of the site, toward the major discharge area, Herring Creek. The maximum amplitude of water-table fluctuation from April 1985 through March 1987 was about 3 ft in the piezometers nearest Phillips Branch and 5 ft in the piezometers farthest from the stream.

Before the piezometers were installed, flow in the unconfined aquifer was thought to be toward Phillips Branch. This study has shown that flow paths in the aquifer, however, basically parallel Phillips Branch. Water levels indicate that Phillips Branch influences the ground-water flow system (Figure 6). At times, the elevation of the streambed is higher than the water table and the stream loses water to the aquifer (Figure 6A). The aquifer discharges to the stream when ground-water levels are higher than the streambed (Figure 6B).

Water levels measured in the cluster piezometers show similar fluctuations at different depths in the aquifer, indicating a hydraulic connection. Vertical head differences in piezometers in a particular cluster generally are on the order of a few hundredths of a foot. Head relations vary, but the head usually was highest in the shallowest part of the aquifer and decreased with depth to about 65 ft. Water-level change did not show a consistent pattern below 65 ft of depth except in cluster 5, where the head in the deepest part of the aquifer was consistently higher than the head in the shallowest part.

TABLE 4. Schedule of fertilization and planting at the Fairmount site from January 1985 through October 1986.

Date	Activity
1985 January	Lime broadcast on field, 1 ton per acre.
February	Potash (KCl), 60 percent red granular broadcast, 161 lb/acre.
May 14	Plant soybeans, apply liquid starter fertilizer with 14 lb/acre nitrogen, 10 lb/acre phosphorus, and 1 qt/acre 9 percent zinc.
July 10- August 17	Intermittent irrigation, with a total of 20.6 lb/acre manganese applied through the irrigation system.
October	Harvest soybeans. Lime broadcast on field, 1 ton per acre.
1986 March 11	Potash (KCl), 60 percent red granular broadcast, 150 lb/acre.
April 14-15	Plant corn, apply liquid starter fertilizer with 25 lb/acre nitrogen, 30 lb/acre phosphorus, and 1 qt/acre 9 percent zinc.
May 11- July 30	Intermittent irrigation, with a total of 179 lb/acre liquid nitrogen and 25 lb/acre sulfur applied through irrigation system. Also applied 1 qt/acre 20 percent boron, 1 qt/acre 5 percent manganese, and 1 qt/acre 9 percent zinc.
September 18-20	Harvest corn.
October 10	Lime broadcast on field, 1 ton per acre.
October 14	Plow field and plant winter wheat cover crop.

The unconfined aquifer is recharged primarily from mid-October to early April, which is the nongrowing season. Normal rainfall during this period is about 21 in., as measured from 1951 through 1980 at a station about 10 mi west of the Fairmount site (National Oceanic and Atmospheric Administration, 1987). There generally is a soil-moisture deficit during the remainder of the year, but heavy rains associated with tropical storms and thunderstorms occasionally overcome the deficit and allow water to percolate to the water table.

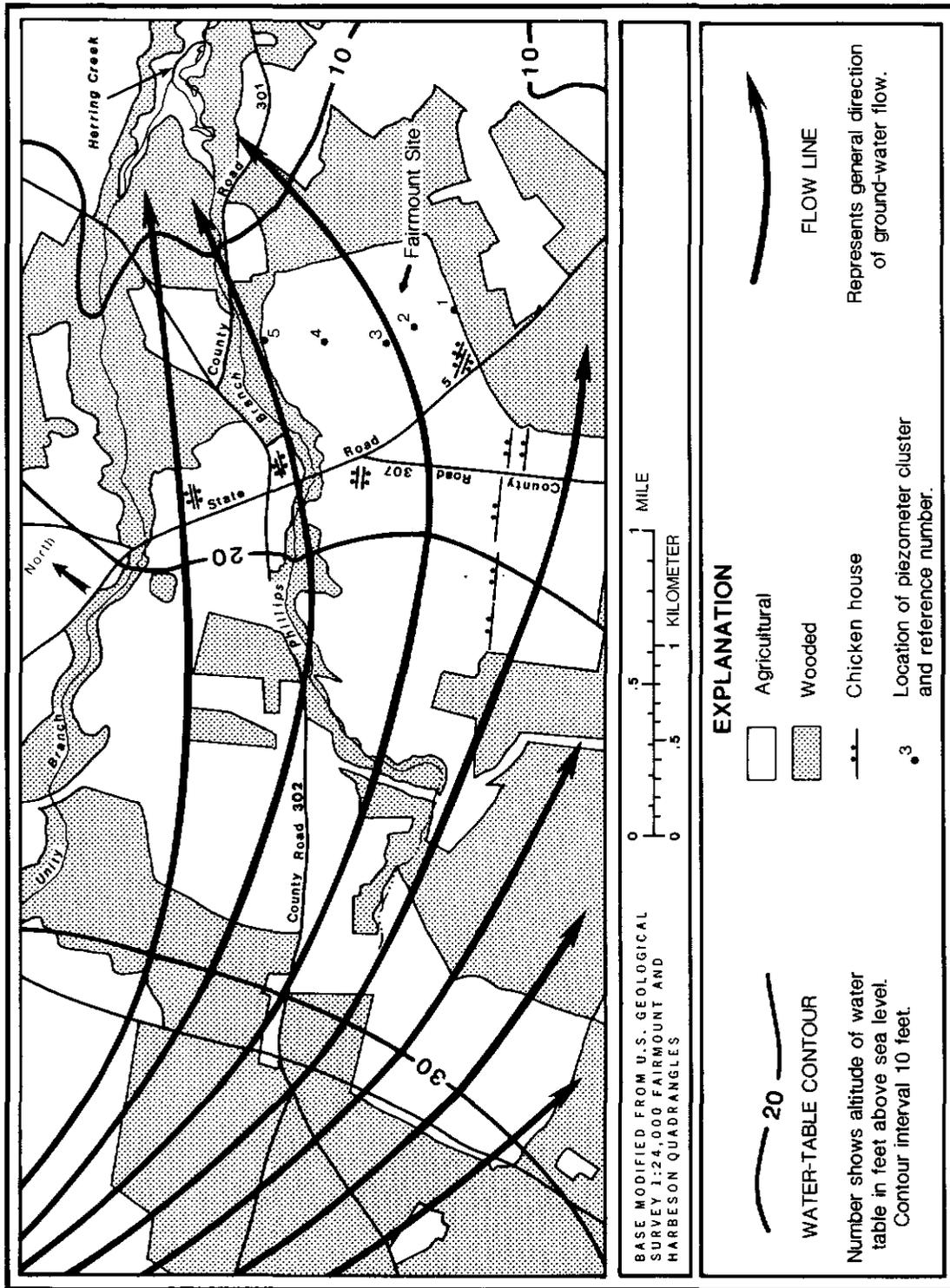


Figure 5. Land use and direction of ground-water flow in the unconfined aquifer in the area surrounding the Fairmount site. (Water-table contours modified from Adams and Boggess, 1964, and Boggess and others, 1964.)

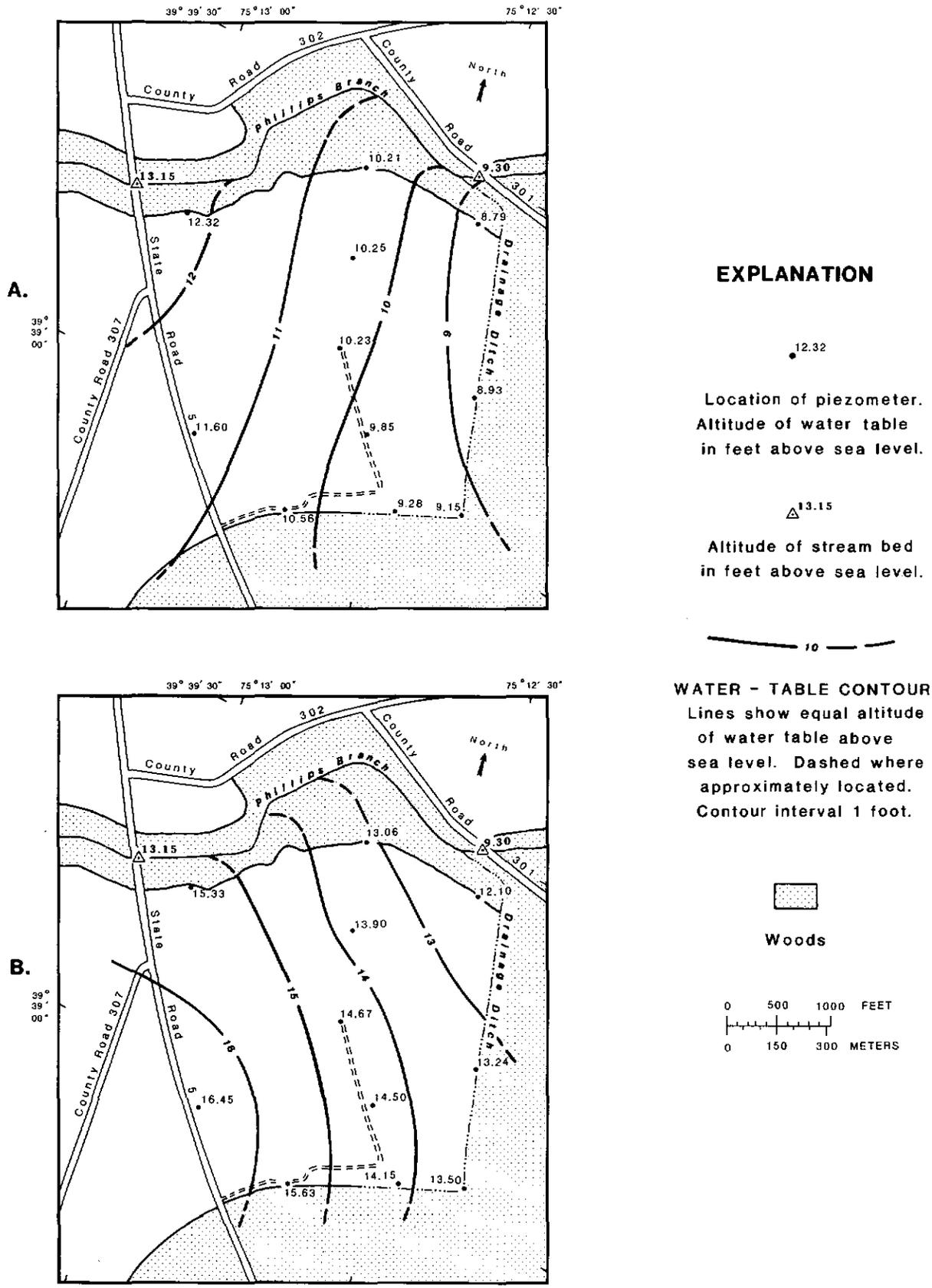


Figure 6. Altitude of the water table at the Fairmount site, (A) October 30, 1986 and (B) March 9, 1987.

Changes in ground-water levels are shown for well Ph13-32 in Figure 17. The water table rose less than 2 ft during the 1985 and 1986 water years^{1/} when precipitation during the recharge period was 64 percent and 75 percent of the normal, respectively (National Oceanic and Atmospheric Administration, 1985, 1986, 1987). Precipitation was 117 percent of the long-term (1951-80) normal during the 1987 water year recharge period, and the water table recovered more than 4 ft.

Transmissivity of the unconfined aquifer at the Fairmount site is estimated to be about 18,000 ft/d using Boulton's delayed-yield type curve for late-time data (Lohman, 1979, Plate 8). The analysis is based on water levels in well Ph13-32 recovering from drawdown caused by irrigation pumping. The irrigation well and well Ph13-32 are screened from 60 to 90 ft below land surface (essentially the bottom third of the aquifer). The storage coefficient determined is 0.16, which is within the range given by Johnston (1973) for the unconfined aquifer.

Effects of Irrigation Pumping on Ground-Water Flow

The effects of irrigation pumping on the ground-water flow system at the Fairmount site are shown in Figure 8. Near the irrigation well, there is a large component of vertical downward flow from the water table toward the screen. Water levels in well Ph13-32, located 75 ft from the irrigation well, rapidly declined about 4 ft at the onset of pumping (Figure 7). The continuous decline of the water level in well Ph13-32 during irrigation pumping (Figure 7) shows that the ground-water-flow system does not reach steady state during a 48-hour pumping period. Water levels in all piezometers declined during pumping, although the change was only a few hundredths of a foot, over a 48-hour pumping period, in the piezometers of clusters 1 and 5 because of their greater distance from the pumped well.

Water-level changes in the cluster piezometers during pumping are influenced by the anisotropy of the sediments and the discontinuous confining bed beneath cluster 2 (Figure 4). Stratification in the sediments comprising the unconfined aquifer results in a horizontal hydraulic conductivity that generally is greater than the vertical hydraulic conductivity. Most of the water derived from the pumped well is flowing horizontally toward the screened interval (Figure 8). The result is that drawdown is greater in the piezometers screened nearest the screened interval of the pumping well, from 60 to 90 ft below land surface, than in the shallower piezometers. The differences in drawdown at different depths in the aquifer are particularly emphasized in water levels from the cluster 3 piezometers adjacent to the irrigation well (Figure 8).

^{1/} A water year is the 12-month period from October 1 through September 30. It is designated by the calendar year in which it ends.

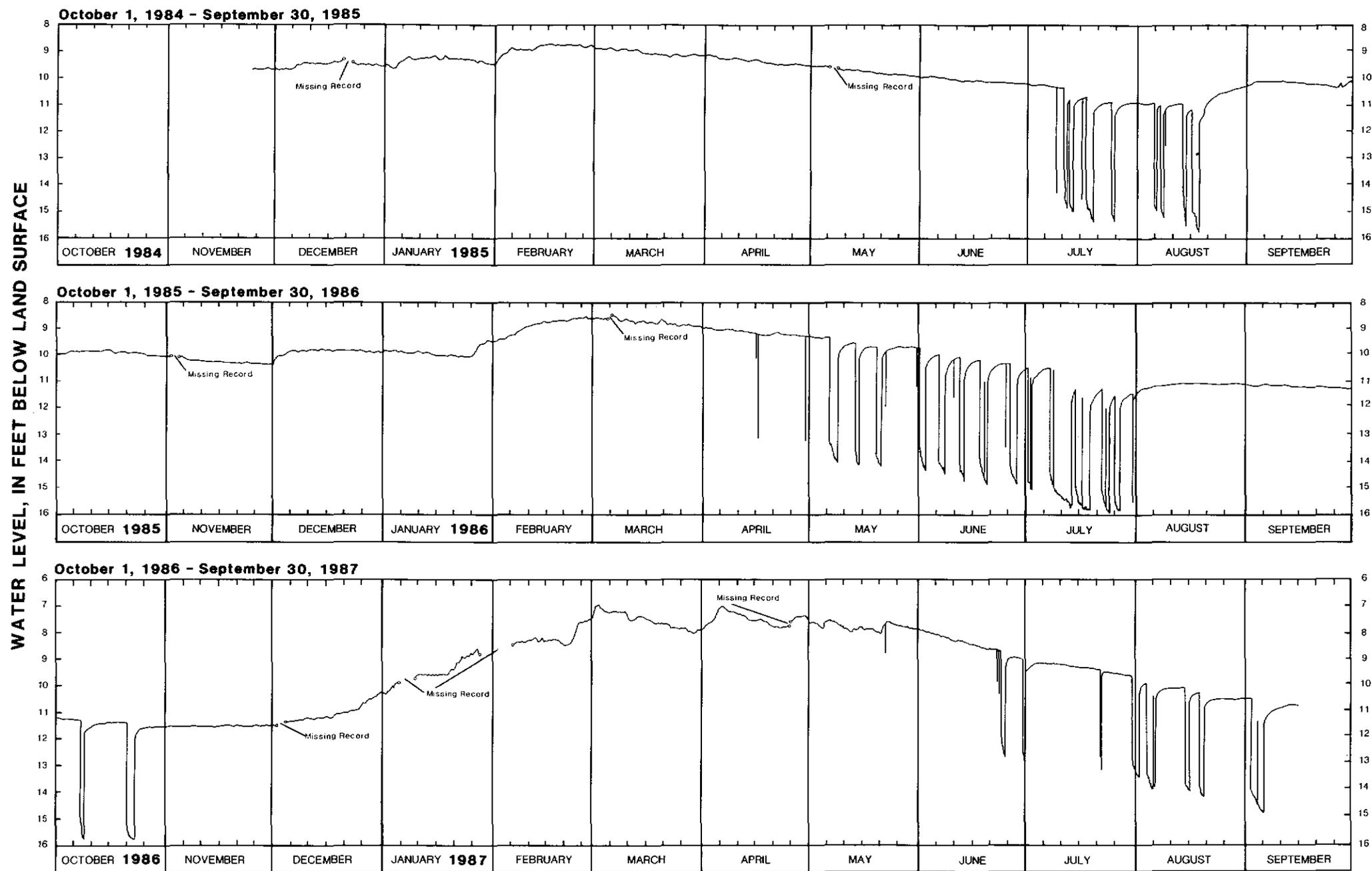


Figure 7. Water level in well Ph13-02 at the Fairmount site, November 1984 through September 1987.

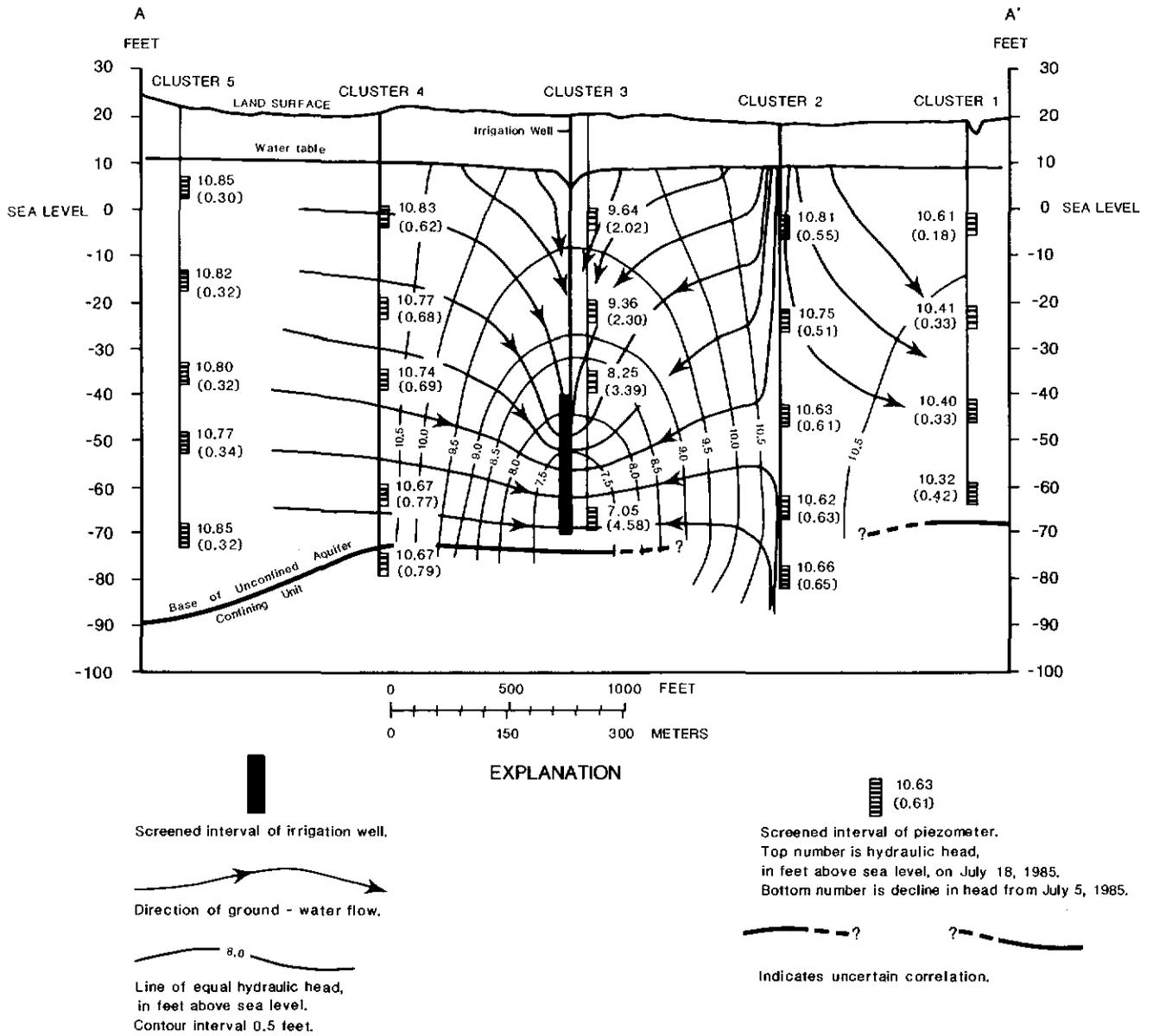


Figure 8. Flow in the unconfined aquifer at the Fairmount site after 30 hours of irrigation pumping, July 18, 1985.

Drawdown in each piezometer in cluster 2 during irrigation pumping is less than the drawdown in the corresponding piezometers in cluster 4, which are at equal distances from the irrigation well (Figure 8). Water levels apparently are influenced by an opening of unknown extent in the confining bed beneath cluster 2 that allows interconnection between the unconfined aquifer and the Pocomoke aquifer of the Chesapeake Group. The head gradient near cluster 2 indicates upward flow from the deeper sand through the opening during irrigation pumping (Figure 8). This interconnection also acts as a recharge boundary and therefore limits the effect of pumping on water levels in the piezometers of cluster 1.

Relation of Specific Conductance to Nitrate Concentrations

Nitrate is the dominant anion in oxidizing water in the unconfined aquifer where influenced by agricultural practices because of the naturally low ionic strength of the water. As a result, there is a direct correlation between nitrate concentration and specific conductance in ground water at the Fairmount site (Figure 9). The Pearson's correlation coefficient is 0.98. A value of 1.00 indicates a perfect correlation and 0.00 indicates an absence of correlation. Data for samples collected in September 1986 were used in the regression and calculation of the correlation coefficient, but data for all samples are similarly correlated (Figure 9). Because of this close correlation, specific conductance can be used to estimate nitrate concentration when laboratory analysis for nitrate was not performed. Thus, specific conductance is a general indicator of the degree of agricultural influence on ground water at the Fairmount site. Later in this report, this relation is applied to study changes in water quality over time.

Trends in Major-Ion Concentrations

Positive correlations between nitrate concentration and concentrations of other major ions related to lime and fertilizer applications, including calcium plus magnesium, chloride, potassium, and sulfate, also were observed in ground-water samples from the Fairmount site (Figures 10-12). Similar relations between nitrate concentration and concentrations of calcium plus magnesium, chloride, and potassium were observed in water samples collected from irrigation wells in western Sussex County (Denver, 1986). Alkalinity and sodium concentrations do not show a positive correlation with nitrate concentrations.

The close direct correlation between concentrations of nitrate and calcium plus magnesium in the ground water indicates substantial agricultural influence (Figure 10A). Calcium plus magnesium also correlates well with specific conductance. Because divalent cations generally have stronger adsorption affinities than monovalent cations, and the concentration of calcium plus magnesium is high relative to other cations, calcium and magnesium also probably dominate available clay-mineral exchange sites. Alkalinity produced by solution of the carbonate in lime is consumed in reactions that buffer the acidity produced by nitrification and, as a result, shows a weak negative correlation with nitrate concentration (Figure 10). In western Sussex County, alkalinity concentrations in ground water influenced by nitrification were generally less than 10 mg/L (Denver, 1986). Ground water from the Fairmount site follows this pattern.

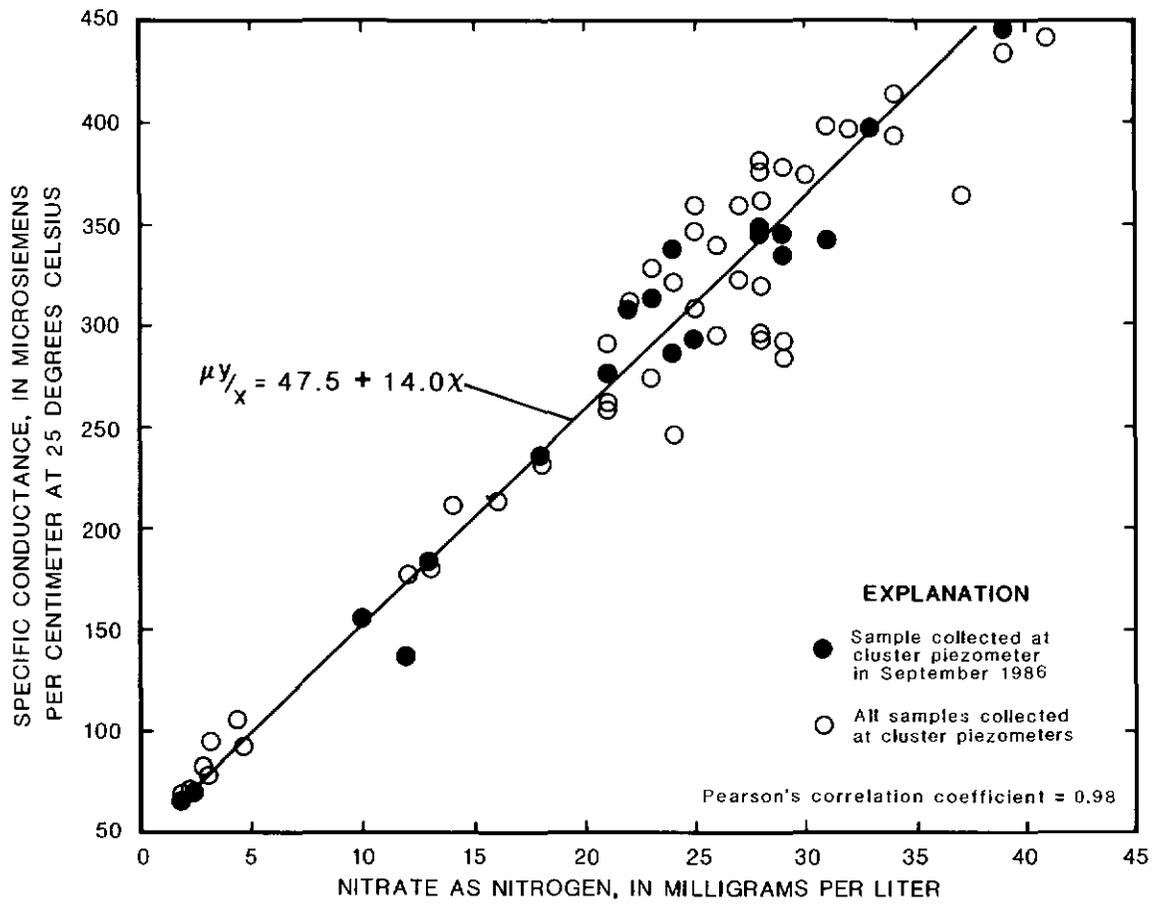


Figure 9. Relation of specific conductance to nitrate concentration for water in the unconfined aquifer at the Fairmount site.

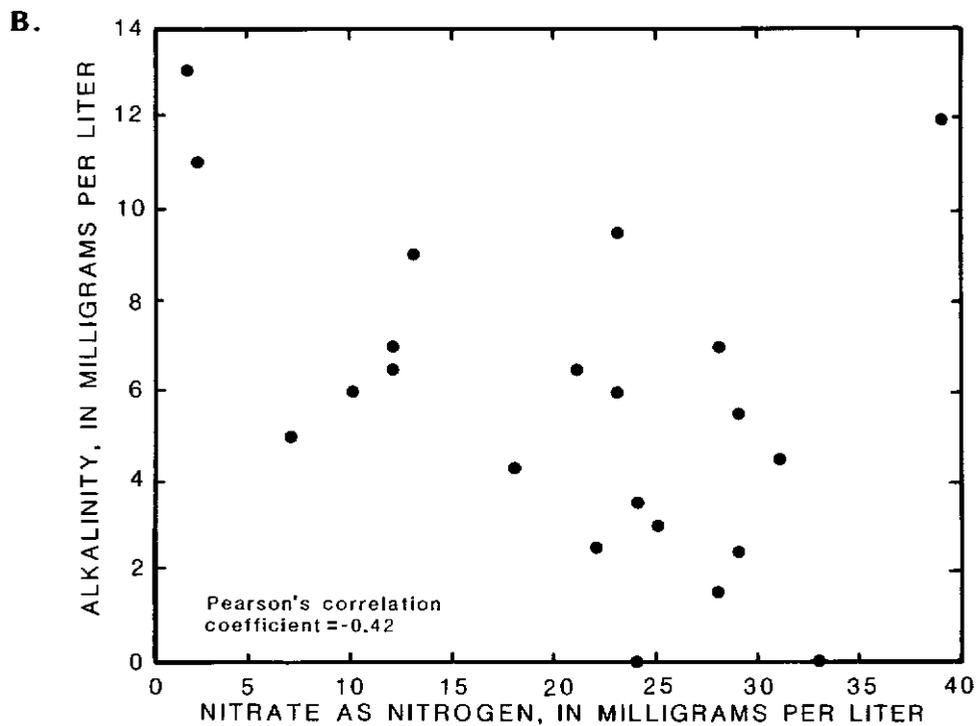
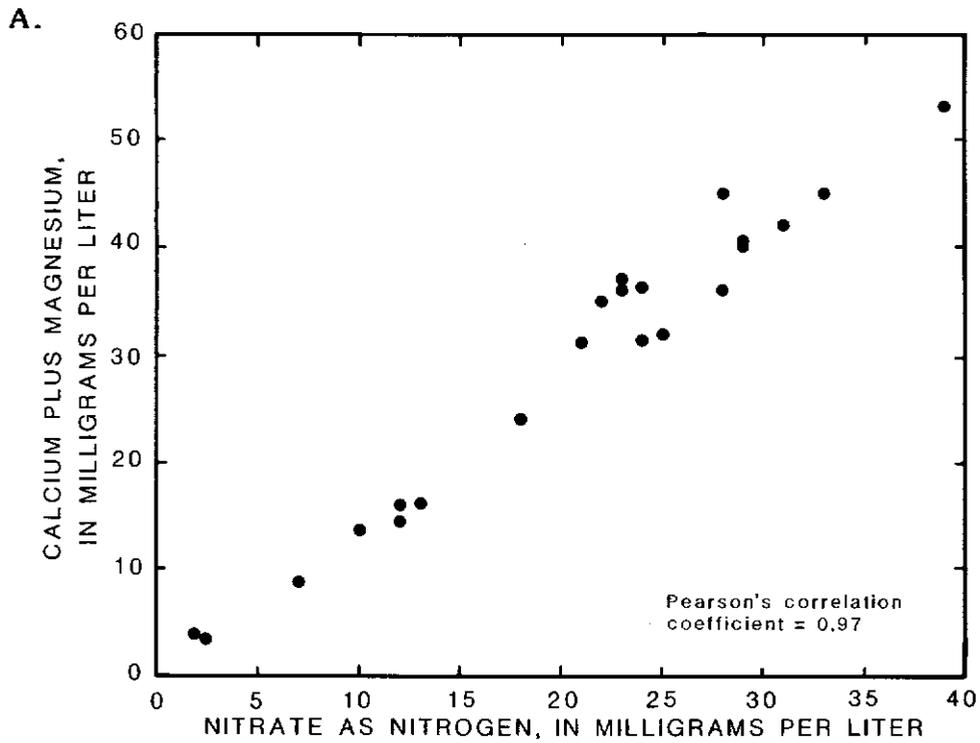


Figure 10. Relation of nitrate concentration to concentrations of (A) calcium plus magnesium and (B) alkalinity for water in the unconfined aquifer at the Fairmount site, September 1986.

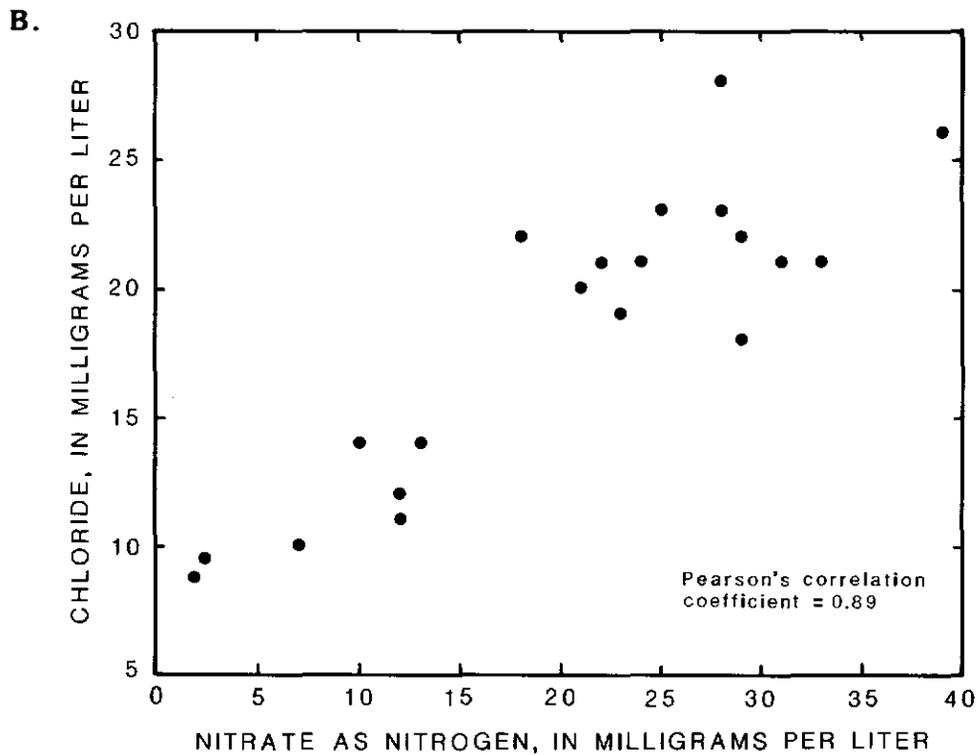
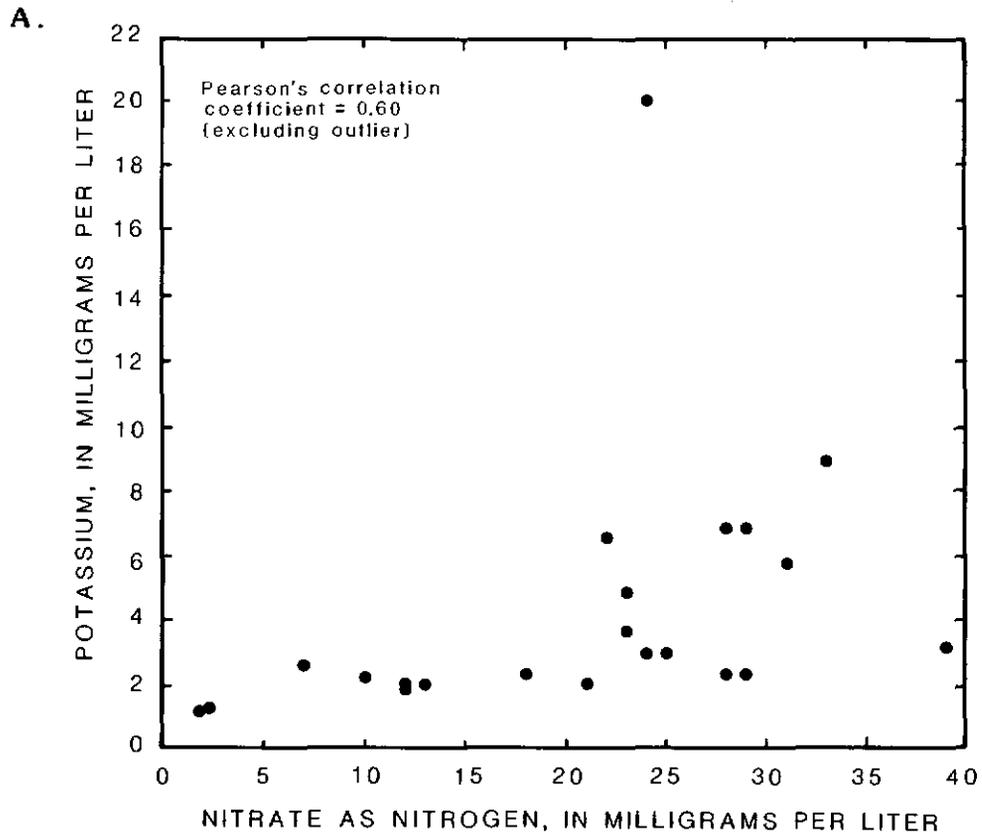


Figure 11. Relation of nitrate concentration to concentrations of (A) potassium and (B) chloride for water in the unconfined aquifer at the Fairmount site, September 1986.

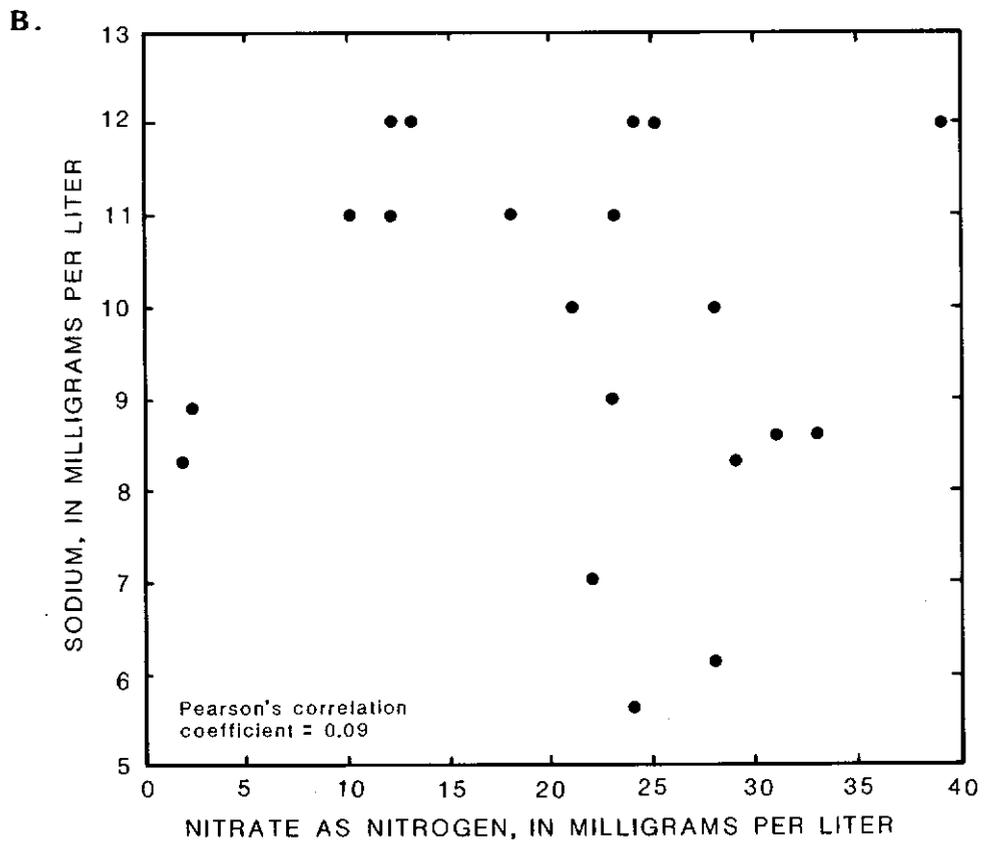
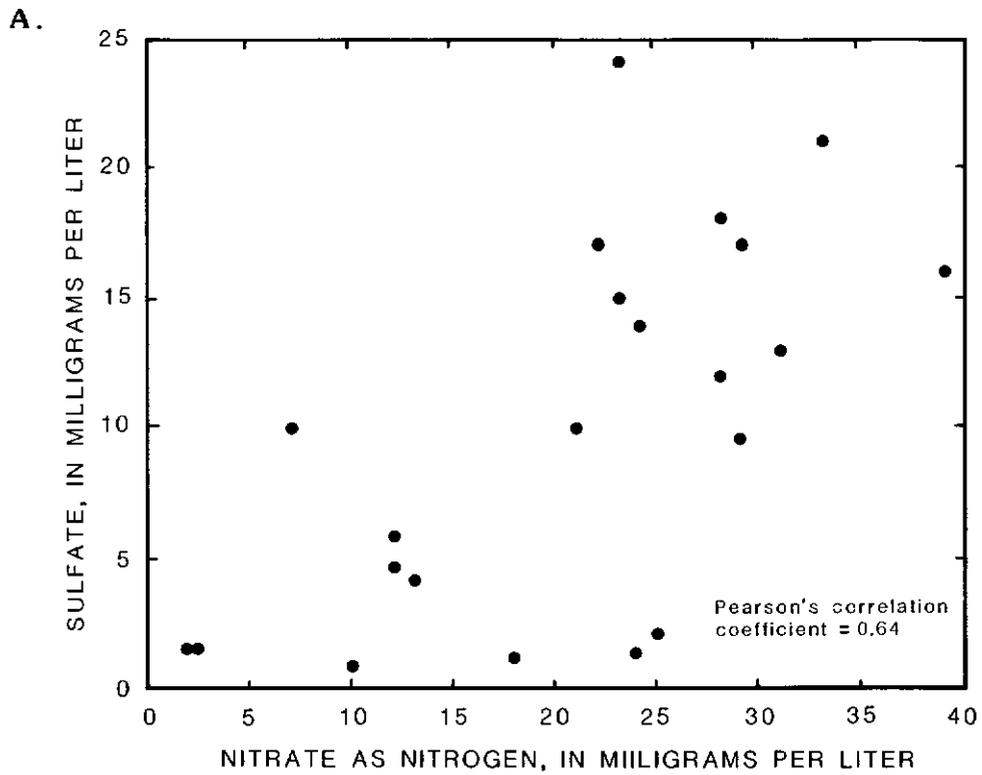


Figure 12. Relation of nitrate concentration to concentrations of (A) sulfate and (B) sodium for water in the unconfined aquifer at the Fairmount site, September 1986.

Potassium concentration generally is greater at higher nitrate concentrations (Figure 11A). However, potassium concentration is lower than concentrations of other cations, and it does not correlate closely with nitrate concentrations because potassium ions are strongly attracted to certain clay minerals and are fixed at cation-exchange sites in the clay layers. In contrast, chloride, applied in conjunction with potassium, is a nonreactive ion. Hence, chloride concentration increases more rapidly than potassium concentration for a given increase in nitrate concentration, and it is therefore more strongly correlated with nitrate (Figure 11).

Anomalously high potassium concentrations were measured in samples from the shallowest piezometer of cluster 3, Ph13-03 (shown as 20 mg/L in figure 11A). This piezometer is adjacent to the irrigation well, and, although the cause of the elevated concentrations are unknown, they may result from leaks or spills of ammonia-based fertilizer near the tank that feeds liquid fertilizer into the irrigation system. Ammonium ions and potassium ions have similar adsorption affinities, and the excess ammonium ions from spills could be occupying the exchange sites on clay usually available to potassium.

Sulfate also is applied through the irrigation system. Sulfate concentration generally increases with increasing nitrate concentration (Figure 12A), but because sulfate is absorbed by plants and microorganisms and therefore retained in the organic fraction of the soil, sulfate concentrations differ widely.

Sodium is not a major fertilizer component, although some is available from sodium chloride in poultry manure. As a result, there is no linear correlation between sodium and nitrate concentrations (Figure 12B). The sodium concentration in ground water is primarily from natural sources including dissolution of feldspars and precipitation. Sodium ions that enter the ground water at the Fairmount site are essentially conservative because of the greater adsorption affinity of calcium and magnesium on clay mineral exchange sites.

Variations in Water Chemistry

The distribution of agricultural chemicals in the unconfined aquifer is influenced by many factors including land use, irrigation, ground-water withdrawal, varying type and rate of fertilization, recharge, heterogeneity of aquifer sediments, and the texture and organic matter content of the soils. As a result of these factors, fertilizer components do not leach into ground water at uniform rates and the aquifer has zones of differing water quality. For example, nitrogen and other mobile fertilizer components that are applied in excess of crop requirements during the growing season when there is a soil-moisture deficit migrate into the aquifer with recharge after evapotranspiration declines in the fall. Heavy thunderstorms also could cause larger quantities of agricultural chemicals to leach into the aquifer. In alternate years when soybeans are grown, nitrogen is not applied during the growing season and less nitrogen is available to leach from the soil zone into the aquifer.

At the Fairmount site, ground-water flow generally is downward under natural conditions and agricultural chemicals reaching the water table are gradually carried down into the flow system. The horizontal velocity of water in the aquifer, excluding the influence of irrigation pumping, is estimated to be between 240 and 380 feet per year. This is based on a measured hydraulic gradient of 0.0013, a horizontal hydraulic conductivity of 200 feet per day, and a porosity of 25 to 40 percent. Variations in the relative amounts of clay, silt, sand, and gravel cause flow at different velocities in the aquifer. The stratification of the sediments also influences chemical stratification in the water. Irrigation pumping significantly increases the hydraulic gradient near the pumped well and, therefore, the downward movement of water and dissolved fertilizer components near the well is greater than under natural flow conditions.

Spatial Variations

Concentrations of nitrate and other ions introduced by agricultural practices vary considerably throughout the unconfined aquifer (Figures 13 and 14). However, agricultural influence is significant even near the base of the aquifer where the median nitrate concentration exceeded 10 mg/L (Figure 13A).

Although concentrations of ions introduced by agricultural practices generally are higher near the surface of the aquifer and decrease with depth, the median concentrations of nitrate (Figure 13A) and calcium plus magnesium (Figure 13B) were greater in the depth interval from 40 to 45 ft than in the interval from 20 to 25 ft. This distribution could be caused by variations in fertilizer-application rates or differences in the rate of fertilizer leaching because of the timing and amount of recharge, or both. In contrast, potassium and sulfate concentrations generally do decrease with depth (Figure 14). These ions are less mobile than nitrate, calcium, or magnesium ions because of the greater fixation of potassium on cation-exchange sites in illitic clay and absorption of sulfate by organic material in the shallow subsurface.

Concentrations of sodium and silica, and pH values generally increase with depth in the aquifer (Figure 15). Water in deep parts of the flow system is in contact with aquifer materials for a longer time than water in shallow flow systems; this increased contact time increases the opportunity for silicate-mineral dissolution, which is indicated by increased concentrations of sodium and silica. In water under natural conditions, pH increases as a result of mineral dissolution. However, nitrification produces hydrogen ions (Table 2, reaction 5) and, therefore, is probably the major control on pH at the Fairmount site because of the predominance of nitrate in the water.

Some of the variability in water chemistry with depth may result from ground-water pumping. A large component of downward flow near the irrigation well during pumping (Figure 8) promotes movement of agricultural chemicals into the aquifer. This results in increased concentrations of ions associated with agricultural practices in water nearest the pumped well. Irrigation pumping cannot be directly attributed to the distribution of agricultural chemicals related to agriculture in other parts of the aquifer because of the limited extent of pumping influence and the complexity of other factors influencing the water chemistry.

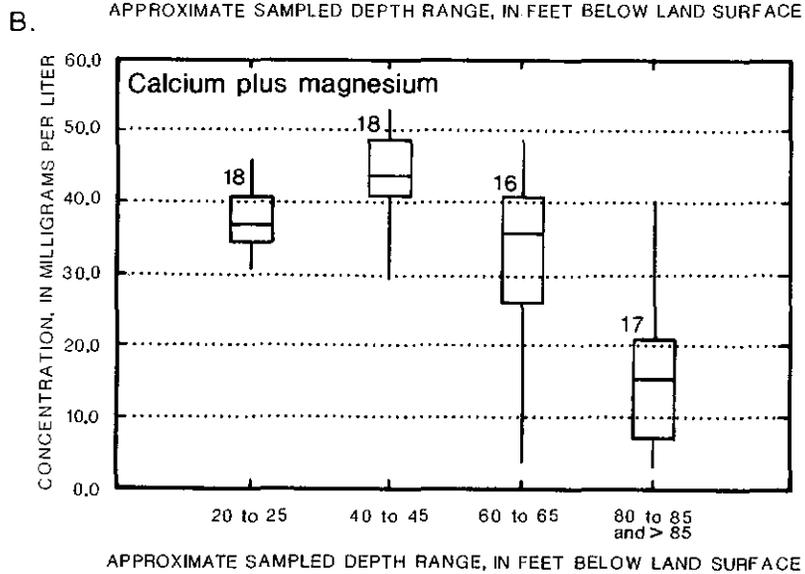
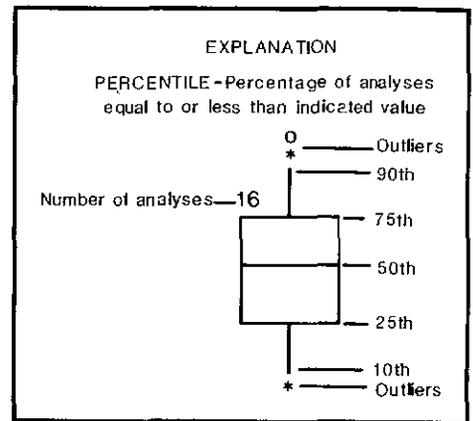
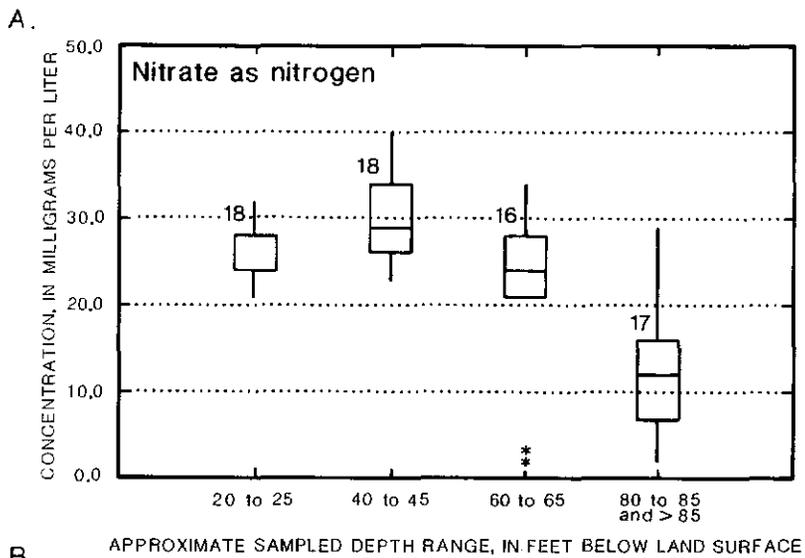


Figure 13. (A) Nitrate concentrations and (B) calcium plus magnesium concentrations for water at different depths in the unconfined aquifer at the Fairmount site.

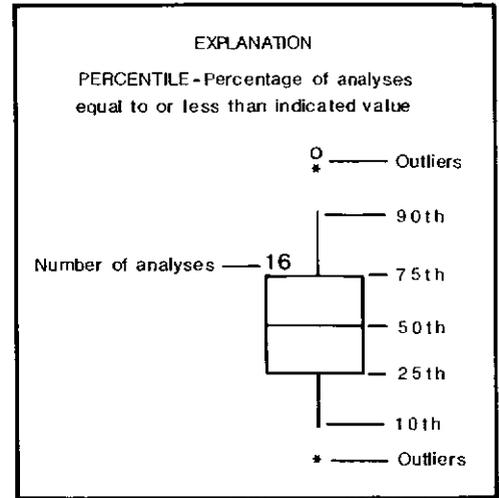
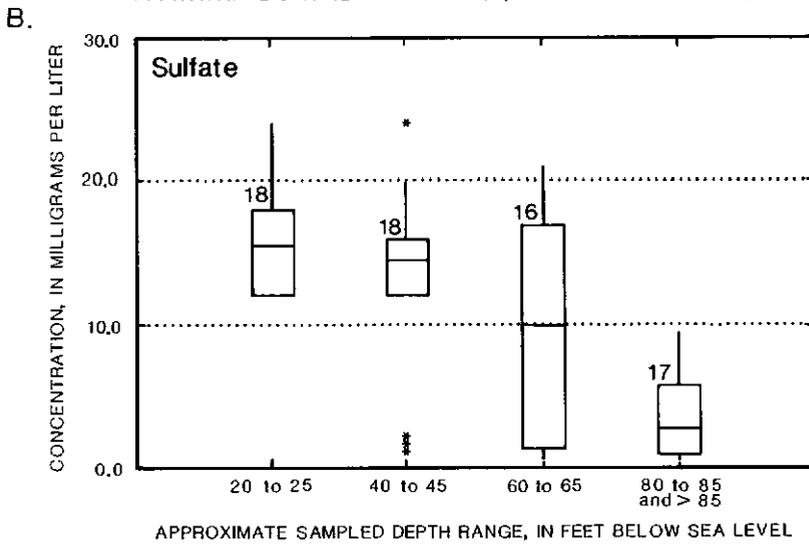
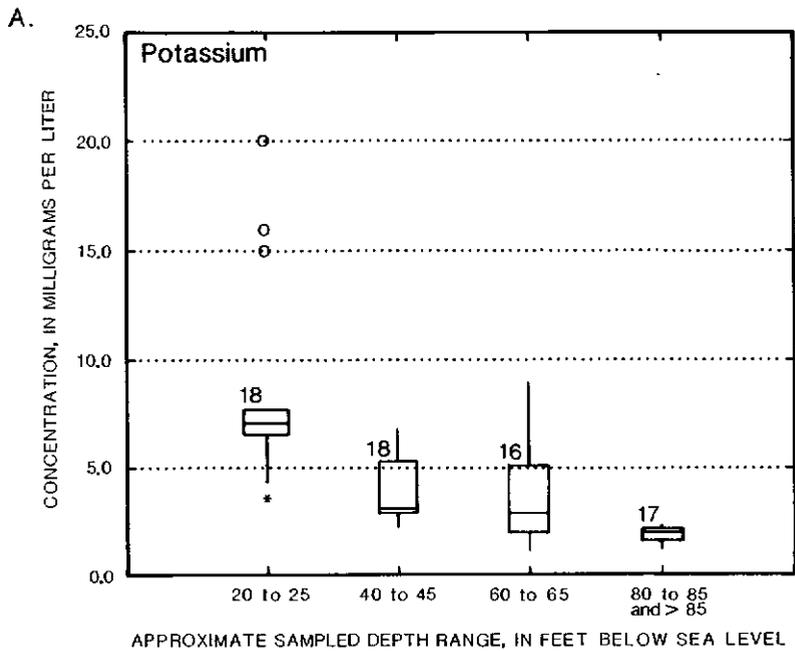


Figure 14. (A) Potassium concentrations and (B) sulfate concentrations for water at different depths in the unconfined aquifer at the Fairmount site.

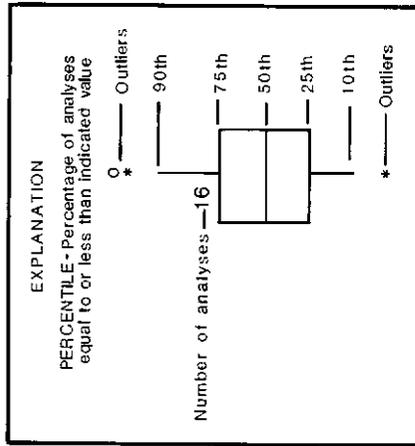
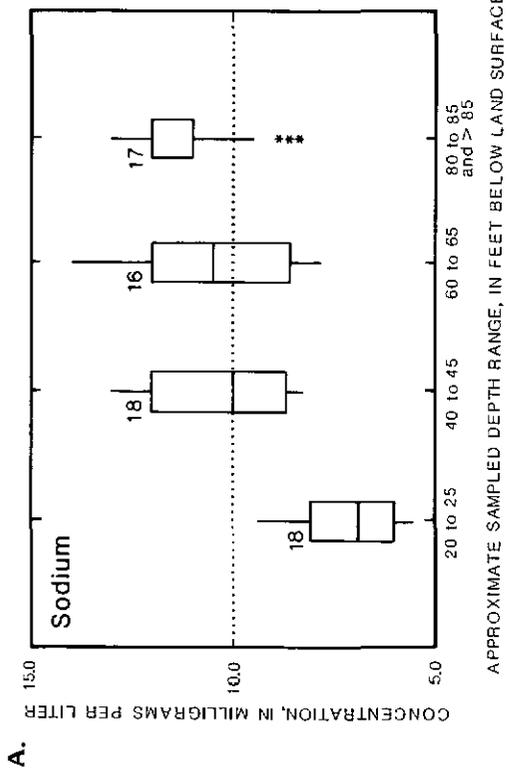
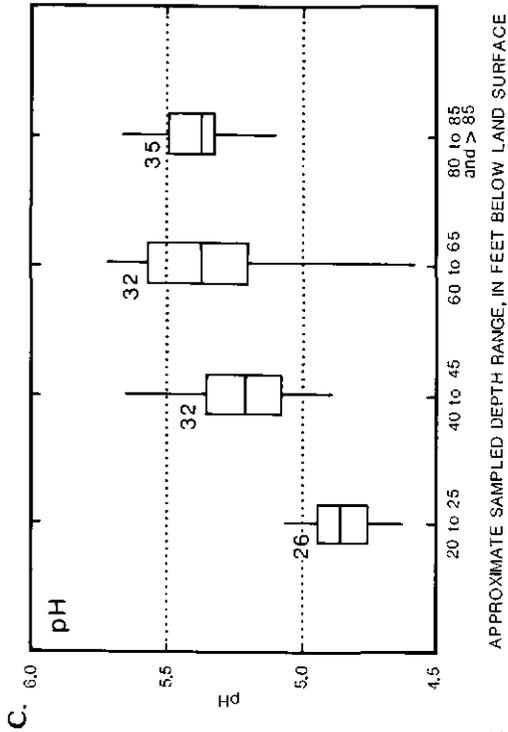


Figure 15. (A) Sodium concentrations, (B) silica concentrations, and (C) pH for water at different depths in the unconfined aquifer at the Fairmount site.

The degree of agricultural influence in the unconfined aquifer is quite variable across the Fairmount site. Nitrate concentrations ranged from less than 2 mg/L to greater than 40 mg/L. A profile of Stiff diagrams representing the net concentration of major ions resulting from agriculture illustrates these variations (Figure 16). Concentrations of ions in water from the two deepest piezometers in cluster 5 were very similar and did not reflect agricultural influence. The water in these piezometers was assumed to represent natural water. The profile was produced by subtracting the concentrations of ions in natural water from these piezometers from concentrations of ions in water from the other piezometers.

Water from the piezometers in cluster 1 is affected significantly by agricultural practices. Nitrate concentration in water from the deepest piezometer was 29 mg/L in September 1986. In contrast, below a 40-ft depth, water from piezometers in cluster 5 does not appear to be affected by agricultural practices. Neither cluster is significantly affected by irrigation pumping and the chemical variability between them is attributed primarily to land uses directly upgradient from the field. Regional groundwater-flow directions and upgradient land uses are shown in Figure 5.

Agriculture is the predominant land use upgradient from the Fairmount site. In addition, several large chicken houses were previously located upgradient of cluster 1 (Figure 5). Except for the existing chicken houses on the southwestern corner of the Fairmount site, the other chicken houses have been removed and the land area has been converted to crop production. Previous storage and spreading of manure probably still influences groundwater quality, and contributes to the agricultural effects on the aquifer near cluster 1. In contrast, the degree of agricultural influence in water from the two deepest piezometers of cluster 2 is much less than in the adjacent deep piezometer in cluster 1 (Figure 16). Upward flow of water from the Pocomoke aquifer through the break in the confining bed during irrigation pumping (Figure 8) apparently influences water quality in these piezometers.

The wooded area adjacent to Phillips Branch immediately upgradient from the area near cluster 5 apparently influences water quality in the deeper parts of the aquifer. Water samples from Phillips Branch did not show characteristics of agricultural influence, but were very similar to those from deeper piezometers in cluster 5 (Appendix 1).

Some chemical processes in the unconfined aquifer are shown by the Stiff diagrams in Figure 16. Under natural conditions, bicarbonate usually is the major anion in the unconfined aquifer. However, bicarbonate concentrations in several samples are below those in natural water because of reaction with acid produced by nitrification. Bicarbonate produced by solution of lime also has been depleted in the buffering reactions.

The proportion of calcium plus magnesium to nitrate is relatively constant in water from the Fairmount site (Figure 10A). The proportion of calcium to magnesium, however, is not constant (Figure 16). This distribution probably results from cation exchange between calcium and magnesium, but this cannot be quantified further without information on clay mineralogy and the type and quantities of exchangeable cations in the clay.

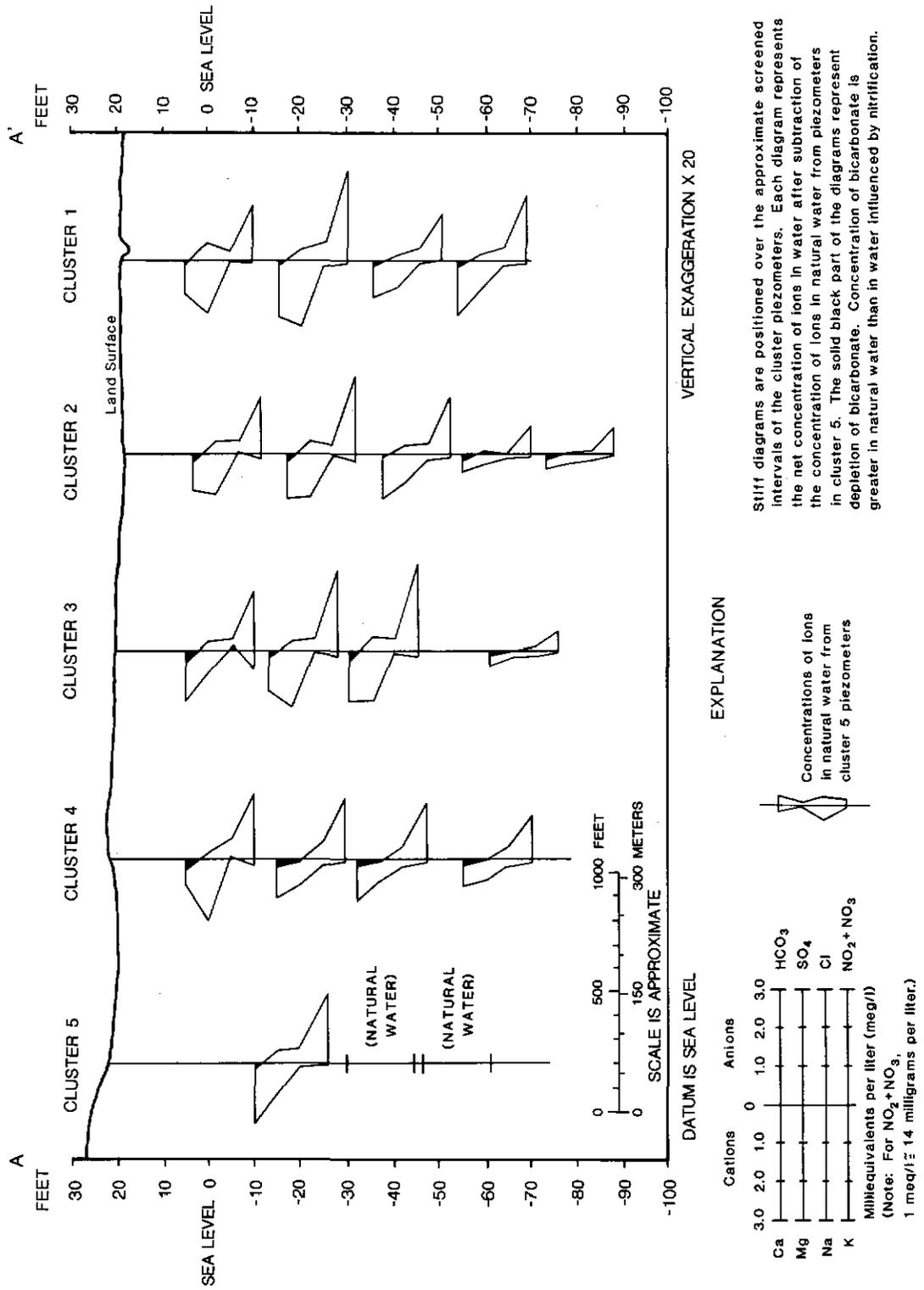


Figure 16. Concentrations of major ions resulting from agricultural fertilizers in water from the cluster piezometers at the Fairmount site, September 1987.

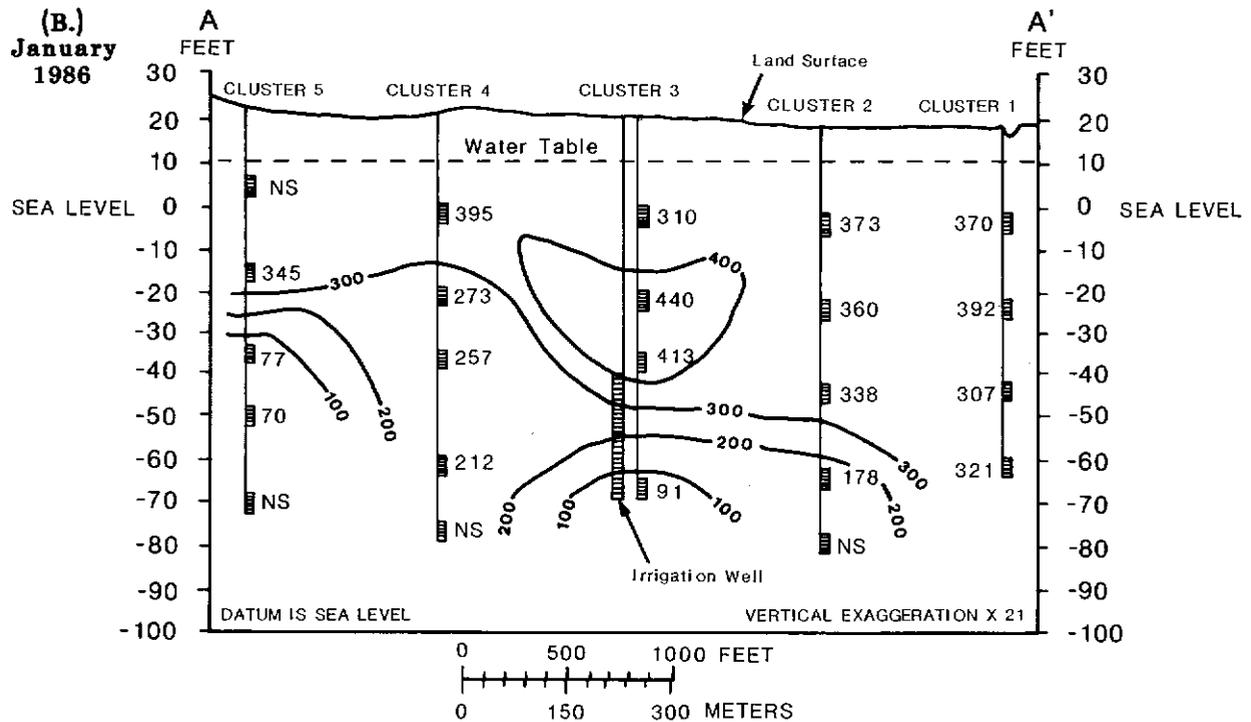
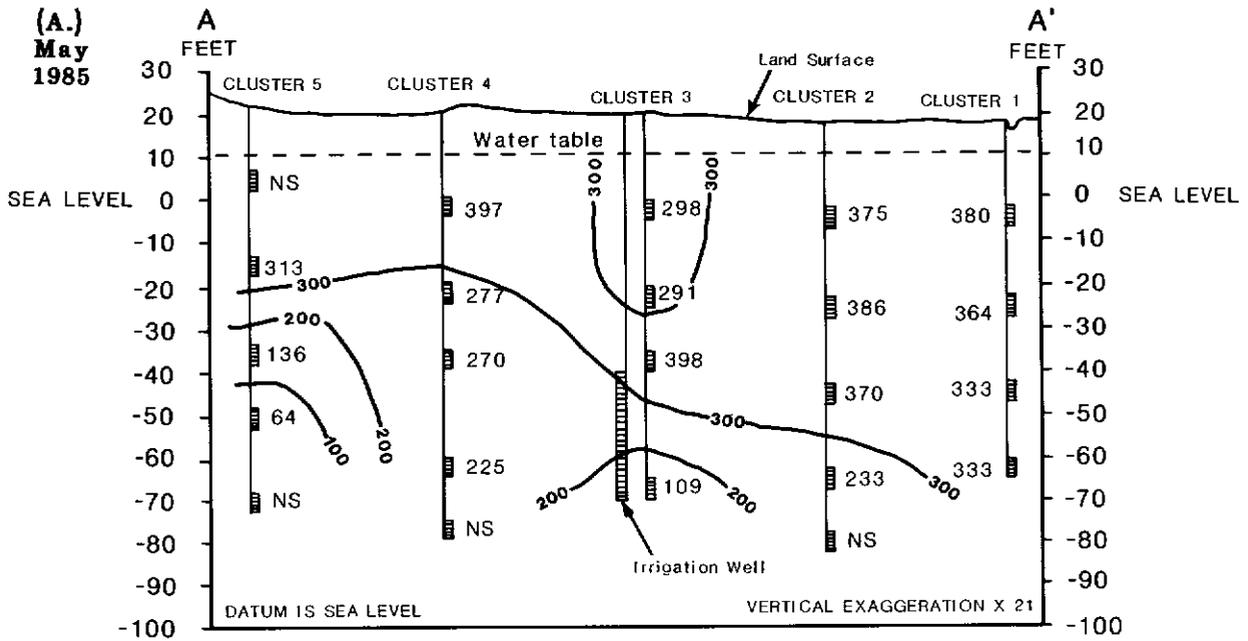
Temporal Variations

Specific conductance is used to indicate temporal changes in water quality because of its close relation to concentrations of nitrate (Figure 9). Spatial variability in specific conductance is shown for four time periods from May 1985 through September 1986 (Figures 17 and 18). Changes in specific conductance in water from individual piezometers varied from 6 $\mu\text{S}/\text{cm}$ to greater than 80 $\mu\text{S}/\text{cm}$. Differences in specific conductance with depth in a particular cluster were greater than 300 $\mu\text{S}/\text{cm}$ in some instances. This degree of variability indicates that a water sample from an individual well in the unconfined aquifer is not an adequate representation of overall quality in the aquifer. Specific conductance of water from the irrigation well (Figure 18B) represents a mixture of water over a larger depth interval of the aquifer and is a better indicator of average water quality.

There is no regular pattern of change in specific conductance over time at different depths because of the complexity of the flow system, the influence of irrigation, and the chemical variability of water recharging the aquifer. Several changes in specific conductance in water from the piezometers of cluster 3 appear to reflect the effects of irrigation pumping (Figures 17 and 18). For example, the increase in specific conductance from May 1985 to January 1986 in the three piezometers screened shallower than the irrigation well shows that higher-conductivity water has been drawn toward the well during the 1985 irrigation season.

Temporal changes in specific conductance were recorded continuously from February 1986 through March 1987 in the 25- and 45-ft-deep piezometers of cluster 3, Ph13-03 and Ph13-16, respectively (Figure 19). These data were verified by periodic field measurements and therefore are believed to accurately represent water-quality conditions over time. Temporal variations in water quality can be related to the movement of water with different degrees of agricultural influence into deeper parts of the flow system by irrigation pumping and by recharge.

When the continuous monitors were first installed, the specific conductance of water in piezometer Ph13-03 was lower than that in piezometer Ph13-16. During the 1986 irrigation season, the lower-conductivity water was drawn deeper into the aquifer with each pumping cycle and the specific conductance of water in piezometer Ph13-16 gradually decreased (Figure 19). As the irrigation season progressed, from May through July 1986, the specific conductance of water in piezometer Ph13-16 began to resemble the specific conductance of the water initially in Ph13-03, the shallower piezometer. Specific conductance changed rapidly with water-level changes associated with irrigation pumping. In piezometer Ph13-03, specific conductance increased when the irrigation well was pumping, implying that water in the aquifer above the screened interval had a higher conductivity. The change in specific conductance was less dramatic than that in piezometer Ph13-16, but drawdown was also relatively less than in piezometer Ph13-16 (Figure 8).



EXPLANATION

 235
SCREENED INTERVAL
Number is specific conductance in microsiemens per centimeter at 25 degrees Celsius.
NS means not sampled.

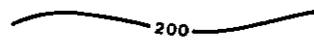
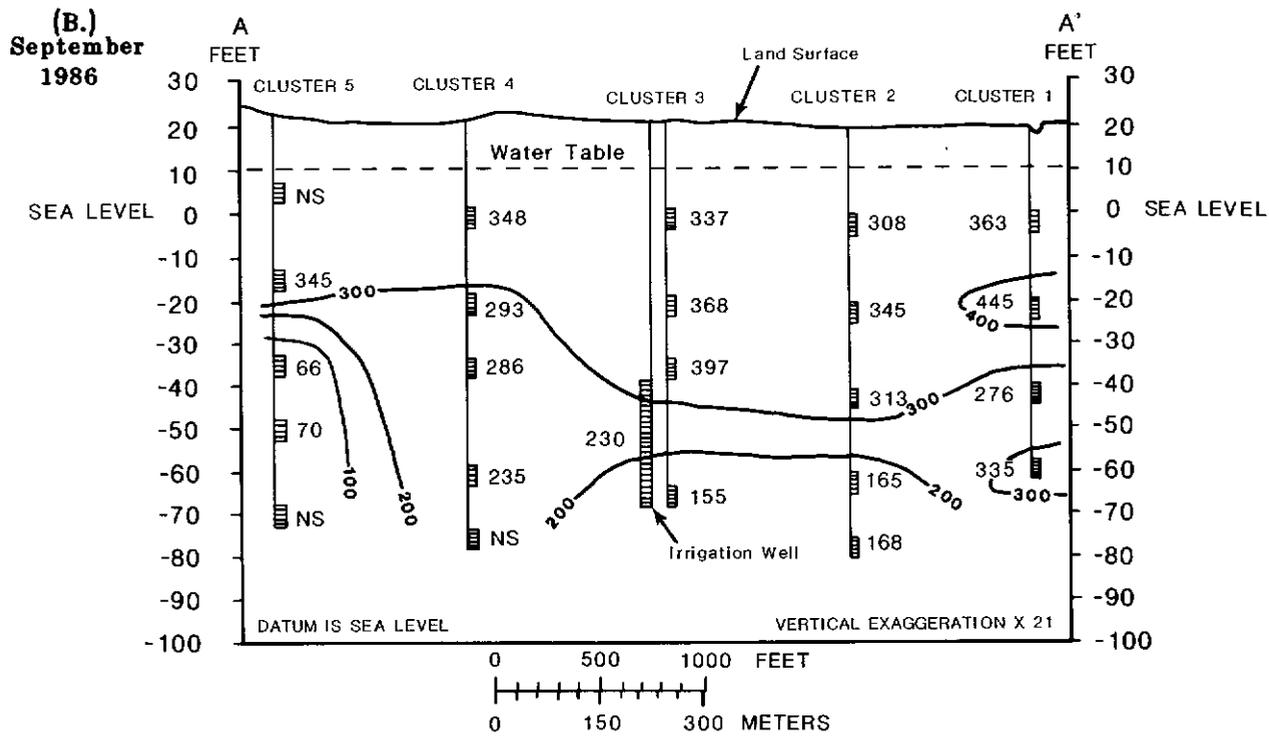
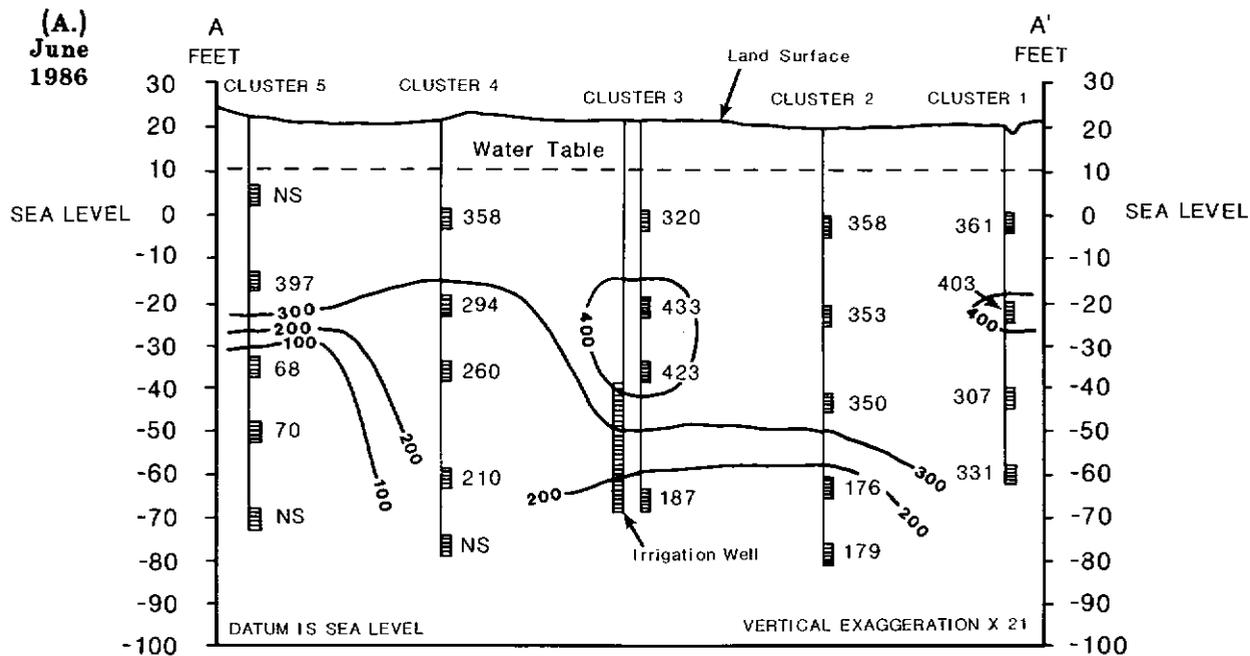
 200
SPECIFIC CONDUCTANCE CONTOUR
Shows specific conductance in microsiemens at 25 degrees Celsius. ($\mu\text{S}/\text{cm}$).
Contour interval 100 $\mu\text{S}/\text{cm}$.

Figure 17. Specific conductance for water from the cluster piezometers at the Fairmount site, (A) May 1985 and (B) January 1986.



EXPLANATION

235
SCREENED INTERVAL
Number is specific conductance in microsiemens per centimeter at 25 degrees Celsius.
NS means not sampled.

200
SPECIFIC CONDUCTANCE CONTOUR
Shows specific conductance in microsiemens at 25 degrees Celsius. ($\mu\text{S}/\text{cm}$).
Contour interval 100 $\mu\text{S}/\text{cm}$.

Figure 18. Specific conductance for water from the cluster piezometers at the Fairmount site, (A) June 1986 and (B) September 1986.

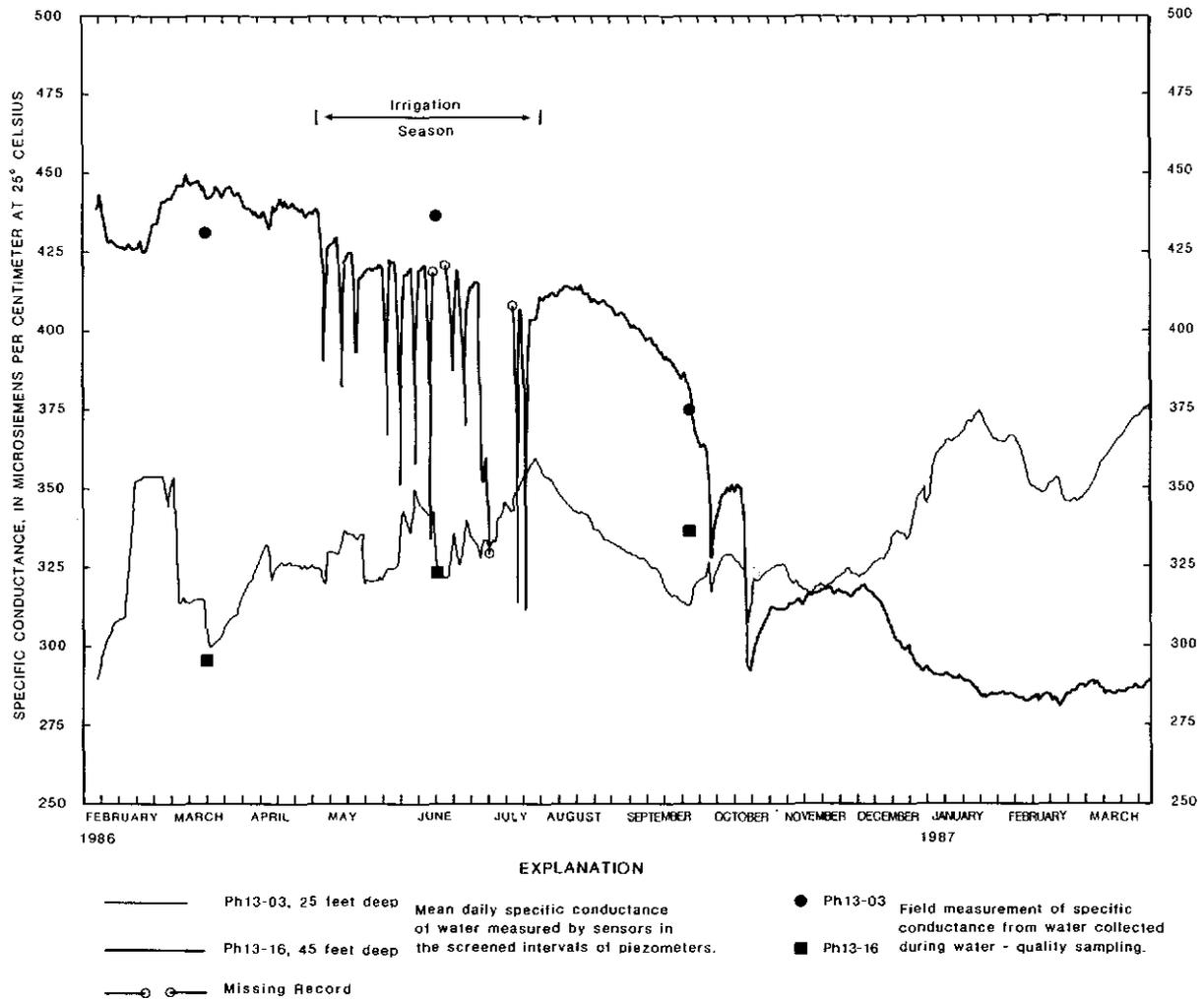


Figure 19. Specific conductance of water from piezometers Ph13-03 and Ph13-16, February 1986 through March 1987.

During December 1986 through March 1987, water levels in the unconfined aquifer near cluster 3 (Figure 7) recovered about 4 ft. Water with higher specific conductance migrated deeper into the aquifer and the specific conductance in piezometer Ph13-03 increased (Figure 19). The specific conductance of water in piezometer Ph13-16 decreased over the same period as lower-conductivity water moved into that zone of the aquifer. Both of these water-quality trends are consistent with downward flow during irrigation pumping. Water with the lowest specific conductance, about 290 $\mu\text{S}/\text{cm}$, which corresponds to greater than 20 mg/L of nitrate as nitrogen, still is affected significantly by agriculture.

EFFECTS OF SEPTIC-SYSTEM EFFLUENT ON GROUND-WATER CHEMISTRY

Organic and ammonia nitrogen, sodium, and chloride are the major chemical components of septic-system effluent. Other minor components include calcium, magnesium, potassium, sulfur, and phosphorus, as well as organic compounds and components of detergents and cleansing agents.

Concentrations of organic and ammonia nitrogen range from 8 to 35 mg/L and from 12 to 50 mg/L as nitrogen, respectively, in average domestic septic-system effluent (Eastburn and Ritter, [1985]). In aerobic soils, most of the nitrogen is converted to nitrate by the nitrification process. Under anaerobic conditions, ammonia is the dominant nitrogen species.

Sodium and chloride are major components of septic-system effluent because of salt in the human diet. Both of these components and nitrate, under aerobic conditions, do not react significantly with aquifer materials and are relatively mobile in ground water. Concentrations of nitrate, sodium, and chloride above background levels could indicate contamination by septic-system effluent. However, manure spreading also may be a source of these constituents.

Boron and phosphorus have been used to identify septic-system effluent in ground water (Le Blanc, 1982). Because boron and phosphorus are also used as fertilizers, the source of contamination could not be distinguished based on the presence of these ions in areas with both septic system and agricultural land uses. Boron is relatively mobile in oxidized ground water, but phosphorus forms complexes with other ions and is fixed by silicate clay and hydrous oxides of iron, manganese, and aluminum. Concentrations of phosphorus in water from the unconfined aquifer are usually below the detection limit.

Detergents are manmade chemicals and their presence in ground water may be used as an indicator of wastewater presence. Prior to 1964, the most common surfactant in detergents was alkyl benzene sulfonate (ABS), which is not biodegradable (LeBlanc, 1982). To reduce the detrimental environmental effects of detergents, ABS was replaced by the biodegradable surfactant linear alkyl sulfonate (LAS). Concentrations of both surfactants in water are measured by the MBAS (methylene blue active substances) method which does not distinguish between them. Surfactants are also used in manufacturing of some pesticides and, therefore, MBAS may also be present in water affected by agricultural practices.

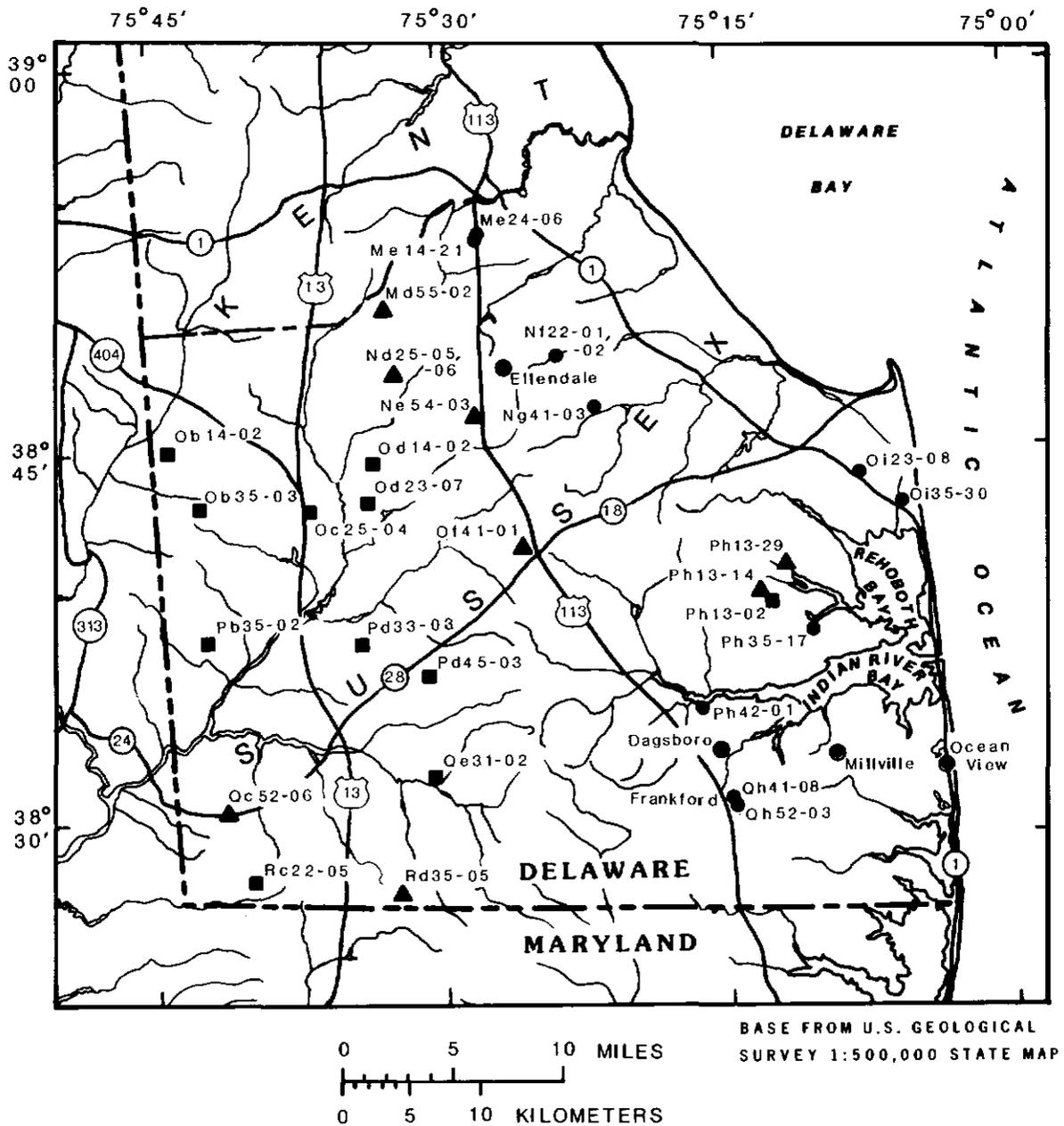
The principal components of septic-system effluent are common to agricultural chemicals and manures, and levels of these components above background concentrations do not necessarily indicate contamination by domestic wastewater. As a result, previous workers in the study area (Ritter and Chirnside, 1982; Robertson, 1977) identified areas with ground-water contamination from septic systems primarily on the basis of local land use. This also was the general procedure used in this study to initially select wells with known or suspected elevated nitrate concentrations resulting from septic-system effluent. The wells sampled in this study are shown in Figure 20. Six of the wells sampled (Me24-06, Me14-21, Oi35-30, Oi23-08, Qh41-08, and Qh52-03) are in residential areas; four (Nf22-01, Nf22-02, Ng41-03, and Ph35-17) are supply wells for mobile-home parks located in wooded areas; and one (Ph42-01) is a supply well located downgradient of a mobile-home park with individual septic systems in a predominantly agricultural area. Chemical analyses of water from these wells (Appendix 2) show elevated concentrations of ions associated with septic-system effluent. However, because these are not unique to septic-system effluent, the source cannot be positively identified.

COMPARISON OF NATURAL WATER CHEMISTRY AND CHEMISTRY OF WATER AFFECTED BY SEPTIC-SYSTEM EFFLUENT AND AGRICULTURAL PRACTICES

One of the objectives of this study was to identify unique chemical characteristics of water affected by septic-system effluent to help differentiate between sources of nitrate in the unconfined aquifer. Although the chemical composition of septic-system effluent and agricultural leachate is similar, the proportions of the components entering the aquifer from the different sources would be expected to differ because the amounts and forms of chemicals in each are not the same.

Appendices 2 and 3 show analyses of ground water affected by septic-system effluent and agricultural practices. Analysis of water from the irrigation well at the Fairmount site, Ph13-02, is included in Appendix 2. Appendix 4 presents data from wells with natural and nearly natural water quality. Even though water with nearly natural water quality may be slightly affected by human activities, nitrate concentrations are less than 3 mg/L, and nitrification is not a dominant chemical process affecting water chemistry. Figure 20 shows the location of wells in each of these tables. Comparisons are shown by boxplots of the specific conductance (Figure 21) and by the median relative percentages of major ions in the water samples (Table 5).

Water affected by septic-system effluent has a higher median specific conductance (172 $\mu\text{S}/\text{cm}$) than water affected by agricultural practices (134 $\mu\text{S}/\text{cm}$) (Figure 21A). Both are considerably higher than the conductivity of natural water, which has a median value of 60 $\mu\text{S}/\text{cm}$. Most of the samples from agricultural areas are from irrigation wells that generally are deeper than the wells affected by septic-system effluent, and specific conductance is generally less in deep parts of the aquifer than in shallow parts. Irrigation wells generally have longer screened intervals than the wells affected by septic-system effluent, which probably accounts for the wider range of ion concentrations in water from agricultural areas than water affected by septic-system effluent.



EXPLANATION

- | | |
|---------|--|
| Ph42-01 | Well Number |
| ● | Water influenced by septic-system effluent. |
| ■ | Water influenced by agricultural activities. |
| ▲ | Water under natural and nearly natural conditions. |

Figure 20. Location of wells sampled with water affected by septic-system effluent, agricultural fertilizers, and in water under natural and nearly natural conditions in the unconfined aquifer.

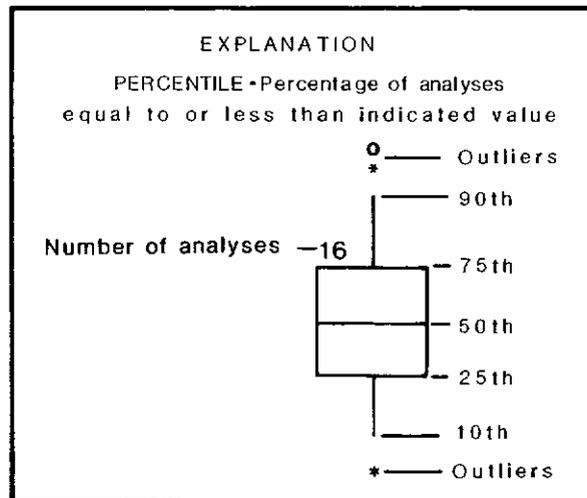
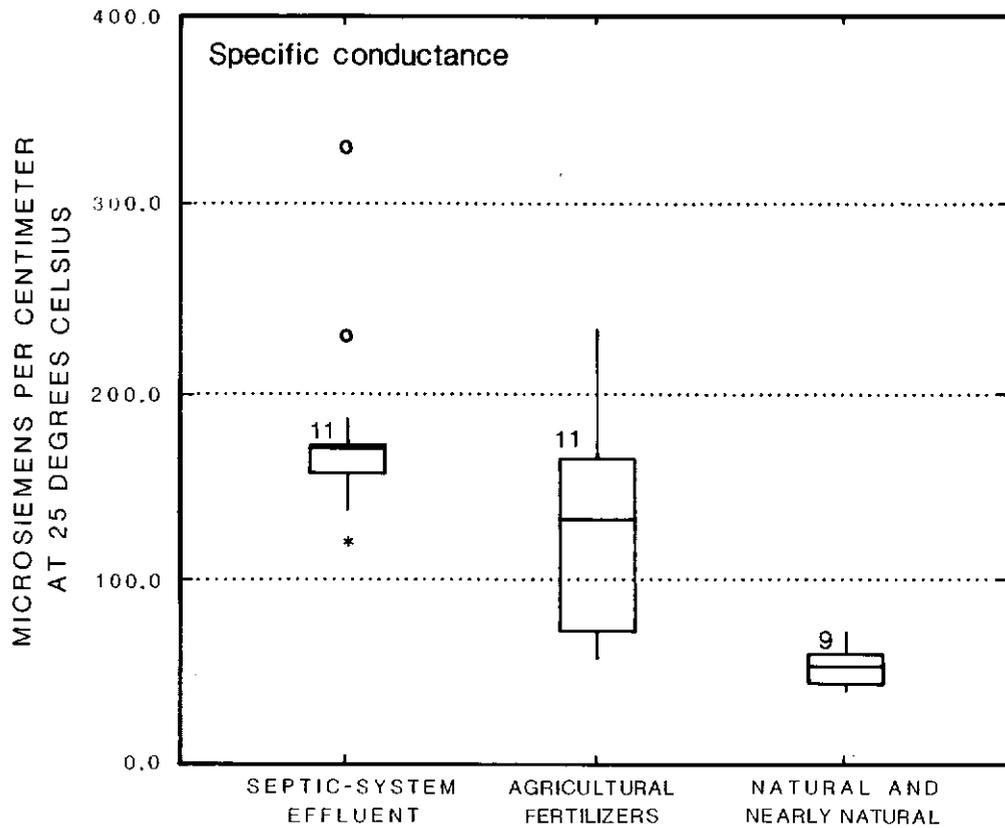


Figure 21. Comparisons of specific conductance in water from the unconfined aquifer affected by septic-system effluent, agricultural fertilizers, and in water under natural and nearly natural conditions.

TABLE 5. Percentages of major ions in water from the unconfined aquifer under natural and nearly natural conditions, affected by septic-system effluent and agricultural practices.

[Percentages of reacting values are calculated from milliequivalents per liter of each constituent]

Constituent	Natural and nearly natural			Septic-system effluent			Agricultural practices		
	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum
Calcium, Ca ⁺²	25	28	11	39	60	7	31.5	41	20
Magnesium, Mg ⁺²	9	27	5	25	62	18	25	38	11
Sodium, Na ⁺	61	65	45	29	46	8	28.5	61	20
Potassium, K ⁺	6	11	3	5	8	3	6.5	10	3
Chloride, Cl ⁻	37	44	23	26	37	7	25	33	21
Sulfate, SO ₄ ⁻²	4	15	1	9	62	1	1	7	0
Alkalinity, HCO ₃ ⁻	43	66	25	7	52	0	7	18	2
Nitrite plus nitrate NO ₂ ⁻ + NO ₃ ⁻	25	37	0	54	75	6	65	68	51

The most significant difference between water affected by septic-system effluent and water affected by agricultural practices is the relative proportion of nitrate to other anions. The median percentage of nitrate was 65 in samples from agricultural areas and 54 in areas affected by septic systems (Table 5). The Kruskal-Wallis test and Fisher's least significant difference procedure indicate these differences are statistically significant at $\alpha = 0.05$.

Sulfate is the only other major ion that shows a significant difference in concentration depending on its source (Table 5). Higher proportions of sulfate in water affected by septic systems than in water affected by agricultural practices and natural water probably result from oxidation of organic sulfur in the effluent.

Bicarbonate, the primary contributor to alkalinity, is the major anion in natural water. Alkalinity concentrations and proportions (Table 5) are similar in water affected by the septic systems and agricultural practices. Both are considerably lower than concentrations in natural water because bicarbonate is consumed in reactions with acid produced during nitrification (Table 2). Values of pH are affected similarly (Appendices 2, 3, and 4).

Concentrations of sodium, chloride, calcium, magnesium, and potassium in water affected by septic-system effluent and agriculture are elevated above those in the natural and nearly natural water samples, but they are not significantly different from each other (Appendices 2, 3, and 4). Sodium is the major cation in water under natural and nearly natural conditions, whereas calcium predominates in water affected by septic-system effluent and agricultural practices (Table 5).

Concentrations of MBAS range from 0.03 to 0.15 mg/L in water affected by septic-system effluent (Appendix 2). Analysis of MBAS was available only for water from 3 wells with natural quality, but the MBAS concentrations in these wells range from 0.03 to 0.04 mg/L. Thus, MBAS is slightly elevated in water affected by septic-system effluent. Water from 3 piezometers affected by agricultural practices at the Fairmount site also was analyzed for MBAS (Appendix 3). Concentrations of MBAS were 0.13 mg/L, 0.21 mg/L, and 0.23 mg/L. The source of MBAS in water affected by agricultural practices probably is surfactants in pesticides.

In summary, comparison of water affected by septic-system effluent to water affected by agricultural chemicals shows different proportions of nitrate and sulfate. Neither these nor other ions, however, show differences in proportions that are distinct enough to allow determination of nitrate source based on major-ion concentrations for an individual water sample.

SUMMARY AND CONCLUSIONS

This report describes the distribution and movement of nitrate and other chemical constituents in ground water under an irrigated field, and identifies the effects of domestic septic-system effluent on the quality of ground water. The chemistry of water affected by agricultural practices is compared to the chemistry of water affected by septic-system effluent to look for unique characteristics of each that could be used to identify sources of ground-water contamination. Both types of water also are compared to water with natural and nearly natural chemistry.

Nitrate and other chemical constituents from anthropogenic sources significantly affect the chemical character of water in the unconfined aquifer because of the naturally low concentrations of dissolved ions (specific conductance is generally less than 100 $\mu\text{S}/\text{cm}$). Fertilizer and manure applied to cropland are the major sources of nitrate. Approximately 50 percent of the land (about 100,000 acres) in eastern Sussex County is used for crop production; about 6 percent of this acreage is irrigated. Effluent from domestic septic systems is another significant source of nitrate in the unconfined aquifer in unsewered residential areas, which occupy about 9 percent of the land in eastern Sussex County.

Thirty-one piezometers were installed in an irrigated field, referred to as the Fairmount site, to study the distribution and movement of nitrate and other chemical constituents related to fertilizer and manure applications. Soil and aquifer characteristics at the Fairmount site are typical of a large portion of eastern Sussex County. Clusters of 4 or 5 piezometers each were installed from north to south across the field; the central cluster was located about 75 ft from the irrigation well. The piezometers in each cluster were screened at different vertical intervals ranging from 20 to 100 ft below land surface. Water levels and water-quality data were collected from April 1985 through March 1987.

Nitrate is the dominant anion in water affected by agricultural practices, and there is a close correlation between nitrate concentrations and specific conductance in water samples from the Fairmount site. Specific conductance can be used to estimate nitrate concentration, and it is a good indicator of the degree of agricultural influence. Nitrate concentrations also correlate positively with concentrations of other major ions associated with fertilizer application including calcium plus magnesium, potassium, chloride, and sulfate. Bicarbonate, produced by solution of lime, is consumed in buffering reactions with acid that is produced during nitrification, and, as a result, there is a weak negative correlation between concentrations of bicarbonate and nitrate.

Factors that influence the distribution of agricultural chemicals in the unconfined aquifer include ground-water withdrawal, land use, irrigation, variable rates and timing of fertilization, timing and intensity of recharge, heterogeneity of aquifer sediments, and the texture and organic matter content of the soils. Concentrations of nitrate as nitrogen ranged from less than 2 mg/L to greater than 40 mg/L (with a median concentration greater than 10 mg/L) in water samples from the cluster piezometers at the Fairmount site, indicating a large spatial variation in agricultural influence. Although nitrate concentrations were normally lowest in samples from the deepest piezometers in each cluster, concentrations as high as 29 mg/L indicate that agricultural influence is significant near the base of the aquifer.

Land use upgradient from the Fairmount site controls much of the variation in water quality with depth. Land upgradient from cluster 5, on the northern side of the site, is primarily wooded. Water samples from Phillips Branch, which flows through the woods adjacent to cluster 5, had concentrations of nitrate as nitrogen below 2 mg/L and were very similar in quality to water samples from the deeper cluster 5 piezometers. In contrast, water samples from a cluster 1 piezometer screened near the base of the aquifer, on the southern side of the site, had the highest nitrate concentrations measured near the base of the aquifer at the Fairmount site. Corn and soybean production is the major upgradient land use, and older maps also show several large chicken houses in the area which have been removed. Nitrogen leached from manure piles and spreading of manure probably contributes significantly to the elevated nitrate concentrations at depth in the aquifer.

Variable leaching of chemicals into the aquifer results in widely differing zones of water quality which change over time. The range in specific conductance of water from individual piezometers ranged from 6 $\mu\text{S}/\text{cm}$ to greater than 80 $\mu\text{S}/\text{cm}$ over the period of study. In a single sampling period, the specific conductance in water samples from a single cluster differed by more than 300 $\mu\text{S}/\text{cm}$ at different depths. This indicates that a water sample from an individual well in the unconfined aquifer is not an adequate representation of overall quality in the aquifer.

Recharge to the unconfined aquifer generally occurs after evapotranspiration declines in the fall and continues until the growing season begins in the spring. Different amounts of nitrate that have accumulated in the soil zone over the growing season during corn production, for which over 200 lb/acre of nitrogen fertilizer is applied, are available to leach into the aquifer than from soybean production, which receives little or no nitrogen

fertilizer. As a result, water of variable quality reaches the water table and stratification of nitrate-bearing water occurs. This stratification is shown by temporal changes in specific conductance in water from two shallow piezometers nearest to the irrigation well where downward flow is greatest during irrigation pumping. Because of the complexity of factors that influence nutrient leaching and movement in the aquifer, there is no clearly defined pattern in areal water-quality trends in samples from the cluster piezometers as a result of irrigation.

The major components in septic-system effluent are organic and ammonia nitrogen, sodium, and chloride. Other minor components include calcium, magnesium, potassium, sulfur, and phosphorus, as well as organic compounds and components of detergents and cleansing agents. Concentrations of these components were elevated above background levels in the water samples collected from 11 wells that were assumed to be affected by septic-system effluent. However, these components also are common in agricultural applications of manures, fertilizers, and pesticides. As a result, sources of water-quality problems cannot be based on the presence of these components in ground water in eastern Sussex County. The proportions of major ions in ground water from different land uses were also not distinct enough to identify sources of nitrate contamination.

Concentrations of chemicals associated with agricultural practices and septic-system effluent tend to mask the natural chemistry of the water because ionic concentrations in water under natural conditions are low. Alkalinity (as bicarbonate) constitutes a median of 7 percent of the major anions in water affected by agricultural practices and septic-system effluent as opposed to 43 percent in water with natural and nearly natural water quality under oxidizing conditions. The median percentages of nitrate are 65 and 54 in water affected by agricultural practices and septic-system effluent, respectively, and 25 percent in water with natural and nearly natural water quality. The predominant cation in natural water is sodium, with a median of 61 percent. In water affected by agricultural practices or septic-system effluent, the median is about 29 percent for sodium, and calcium is the major cation.

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APPENDICES

APPENDIX 1. Well records and chemical analyses of ground water and surface water at the Fairmount site.

[$\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; <, less than; mg/L, milligrams per liter; $\mu\text{g/L}$, micrograms per liter; ft, feet; min, minutes; WH WAT, whole water; --, no analysis]

DGS WELL NUMBER	DATE	DEPTH TO TOP OF SAMPLE INTER- VAL (ft)	DEPTH TO BOT- TOM OF SAMPLE INTER- VAL (ft)	ELEVATION OF LAND SURFACE DATUM (ft above sea level)	PUMP OR FLOW PERIOD PRIOR TO SAM- PLING (min)	TEMPER- ATURE WATER (deg C)	SPE- CIFIC CON- DUCT- ANCE ($\mu\text{S/cm}$)	OXYGEN, DIS- SOLVED (mg/L)	pH (stand- ard units)
CLUSTER 1									
Ph23-10	04-23-85	20	25	19.09	35	12.0	380	0.4	4.86
	07-18-85	20	25	19.09	30	14.0	378	0.1	4.99
	03-17-86	20	25	19.09	25	14.0	377	--	4.79
	06-17-86	20	25	19.09	30	13.0	361	0.2	4.92
	09-23-86	20	25	19.09	30	15.5	327	0	4.87
Ph23-12	04-23-85	40	45	19.00	45	13.0	364	5.2	5.23
	07-18-85	40	45	19	30	14.5	403	3.4	5.43
	01-09-86	40	45	19	20	15.0	392	--	5.26
	03-17-86	40	45	19	30	15.0	348	--	5.17
	06-17-86	40	45	19	35	14.0	363	2.1	5.35
	09-23-86	40	45	19	30	14.0	445	2.9	5.25
Ph23-13	04-22-85	60	65	19.19	55	13.5	333	5.5	5.22
	07-18-85	60	65	19.19	40	14.5	333	5.0	5.64
	01-09-86	60	65	19.19	25	14.5	307	--	5.43
	03-17-86	60	65	19.19	40	15.0	269	--	5.39
	06-17-86	60	65	19.19	45	14.0	245	5.6	5.56
	09-23-86	60	65	19.19	25	14.0	276	6.2	5.55
Ph23-14	04-22-85	78	83	19.24	75	14.0	333	3.4	5.35
	07-18-85	78	83	19.24	55	14.5	337	2.3	5.33
	03-17-86	78	83	19.24	50	14.5	278	--	5.19
	01-09-86	78	83	19.24	--	14.5	321	--	5.40
	06-17-86	78	83	19.24	45	14.0	283	2.4	5.30
	09-23-86	78	83	19.24	50	14.0	335	2.5	5.40
CLUSTER 2									
Ph13-04	05-16-85	20	25	19.28	30	14.0	375	10.0	4.86
	07-23-85	20	25	19.28	25	14.0	357	10.4	4.96
	10-22-85	20	25	19.28	25	14.5	369	9.6	5.00
	01-13-86	20	25	19.28	30	16.0	373	--	5.00
	03-19-86	20	25	19.28	40	15.0	375	--	4.95
	06-17-86	20	25	19.28	55	14.0	295	10.3	5.00
	09-30-86	20	25	19.28	25	16.0	308	--	4.90
	Ph13-23	05-16-85	40	45	19.34	45	14.5	386	9.8
07-23-85		40	45	19.34	40	15.0	367	10.5	4.93
10-22-85		40	45	19.34	35	14.0	365	9.5	5.00
01-13-86		40	45	19.34	30	15.5	360	--	5.00
03-19-86		40	45	19.34	25	15.5	351	--	4.92
06-17-86		40	45	19.34	30	14.5	291	8.6	5.00
09-30-86		40	45	19.34	30	16.0	345	--	5.00
Ph13-24	05-20-85	60	65	19.32	45	15.0	370	7.2	5.40
	07-23-85	60	65	19.32	45	15.0	365	7.8	5.51
	10-22-85	60	65	19.32	40	14.0	342	6.9	5.60
	01-13-86	60	65	19.32	30	15.0	338	--	5.60
	03-19-86	60	65	19.32	35	15.0	339	--	5.47
	06-17-86	60	65	19.32	40	14.5	292	7.0	5.50
	09-30-86	60	65	19.32	25	15.0	313	--	5.60
Ph13-25	05-20-85	80	85	19.33	60	15.0	233	8.1	5.33
	07-23-85	80	85	19.33	60	14.5	224	8.2	5.52
	01-13-86	80	85	19.33	45	17.5	178	--	5.40
	03-19-86	80	85	19.33	45	17.5	165	--	5.27
	06-18-86	80	85	19.33	45	14.5	176	1.6	5.70
	09-23-86	80	85	19.33	35	15.0	136	6.7	5.50
Ph13-26	09-23-86	97	102	19.04	35	14.5	137	6.7	5.40
	06-18-86	97	102	19.04	35	14.0	179	6.6	5.60
	09-01-87	97	102	19.04	20	15.5	222	6.2	5.35

APPENDIX 1. Well records and chemical analyses of ground water and surface water at the Fairmount site--Continued.

DGS WELL NUMBER	pH LAB (stand- ard units)	ALKA- LINITY WE WAT TOTAL FIELD (mg/L as CaCO3)	ALKA- LINITY LAB (mg/L as CaCO3)	NITRO- GEN, AMMONIA DIS- SOLVED (mg/L as N)	NITRO GEN, AM- MONIA + ORGANIC DIS- SOLVED (mg/L as N)	NITRO- GEN, NO2+NO3 DIS- SOLVED (mg/L as N)	PHOS- PHORUS, DIS- SOLVED (mg/L as P)	HARD- NESS (mg/L as CaCO3)	CALCIUM DIS- SOLVED (mg/L as Ca)
CLUSTER 1									
Ph23-10	--	9	--	--	--	--	--	--	--
	--	10	--	--	--	--	--	--	--
	5.10	6	8.0	<0.010	1.3	29.0	<0.010	140	23
	5.20	8	9.0	0.020	0.60	28.0	<0.010	130	22
Ph23-12	5.10	6	9.0	0.020	0.40	23.0	<0.010	120	20
	--	13	--	--	--	--	--	--	--
	--	13	--	--	--	--	--	--	--
	5.60	14	11	0.010	1.9	34.0	<0.010	150	30
Ph23-13	--	12	--	--	--	--	--	--	--
	5.50	11	13	0.020	0.40	37.0	<0.010	160	32
	5.50	12	--	<0.010	0.40	39.0	<0.010	170	32
	--	7	--	--	--	--	--	--	--
Ph23-14	--	7	--	--	--	--	--	--	--
	5.90	7	6.0	0.010	1.3	25.0	<0.010	110	27
	5.80	7	9.0	0.020	0.30	24.0	<0.010	110	25
	5.80	8	9.0	0.020	0.40	21.0	<0.010	92	22
Ph23-14	--	9	--	--	--	--	--	--	--
	--	6	--	--	--	--	--	--	--
	5.90	5	4.0	0.010	0.80	27.0	<0.010	110	30
	5.27	4	5.0	<0.010	0.30	29.0	<0.010	120	31
5.60	6	6.0	0.010	<0.20	29.0	<0.010	120	31	
CLUSTER 2									
Ph13-04	--	1	--	--	--	--	--	--	--
	--	2	--	--	--	--	--	--	--
	5.20	2	3.0	--	--	28.0	--	130	27
	5.50	3	<1.0	<0.010	1.0	30.0	<0.010	140	29
	5.40	3	<3.0	<0.010	1.1	28.0	0.020	130	26
	5.30	2	3.0	0.020	0.40	28.0	<0.010	130	26
5.20	3	--	<0.010	1.5	22.0	<0.010	110	22	
Ph13-23	--	1	--	--	--	--	--	--	--
	--	2	--	--	--	--	--	--	--
	5.20	3	4.0	--	--	28.0	--	130	28
	5.60	2	1.0	<0.010	0.80	28.0	<0.010	130	29
	--	2	--	--	--	--	--	--	--
	5.30	2	3.0	0.020	0.40	29.0	<0.010	130	27
5.30	2	--	0.020	1.7	29.0	<0.010	120	26	
Ph13-24	--	8	--	--	--	--	--	--	--
	--	8	--	--	--	--	--	--	--
	5.70	8	9.0	--	--	24.0	--	120	29
	6.00	8	7.0	0.010	1.1	26.0	<0.010	120	29
	--	8	--	--	--	--	--	--	--
	5.80	8	9.0	0.020	0.40	28.0	<0.010	120	30
5.90	10	10	<0.010	0.80	23.0	0.010	110	26	
Ph13-25	--	6	--	--	--	--	--	--	--
	--	6	--	--	--	--	--	--	--
	6.10	7	4.0	0.010	0.60	13.0	<0.010	49	13
	--	5	--	--	--	--	--	--	--
5.80	7	7.0	<0.010	1.3	12.0	<0.010	49	13	
5.80	7	7.0	<0.010	0.50	12.0	0.010	46	12	
Ph13-26	6.00	7	7.0	0.020	0.50	12.0	0.010	41	11
	5.80	7	7.0	0.010	0.40	13.0	<0.010	48	13
	5.80	6	--	<0.010	1.9	16.0	--	61	16

APPENDIX 1. Well records and chemical analyses of ground water and surface water at the Fairmount site--Continued.

DGS WELL NUMBER	MAGNE- SIUM, DIS- SOLVED (mg/L as Mg)	SODIUM, DIS- SOLVED (mg/L as Na)	POTAS- SIUM, DIS- SOLVED (mg/L as K)	CHLO- RIDE, DIS- SOLVED (mg/L as Cl)	SULFATE DIS- SOLVED (mg/L as SO4)	SILICA, DIS- SOLVED (mg/L as SiO2)	BORON, DIS- SOLVED (µg/L as B)	IRON, DIS- SOLVED (µg/L as Fe)	METHY- LENE BLUE ACTIVE SUB- STANCE (mg/L)
CLUSTER 1									
Ph23-10	--	--	--	--	--	--	--	--	--
	20	9.4	4.3	22	18	11	--	91	--
	19	9.0	3.5	21	24	11	--	4	--
	17	9.0	3.6	19	24	12	--	10	--
Ph23-12	--	--	--	--	--	--	--	--	--
	19	12	2.9	20	12	17	--	86	--
	20	13	3.1	25	17	18	--	6	--
	21	12	3.1	26	16	17	--	12	--
Ph23-13	--	--	--	--	--	--	--	--	--
	11	10	2.0	20	8.9	17	--	86	--
	11	11	2.1	19	9.9	17	--	<3	--
	9.1	10	2.0	20	10	17	--	9	--
Ph23-14	--	--	--	--	--	--	--	--	--
	8.8	12	2.3	27	7.6	19	--	26	--
	9.3	12	2.2	20	9.1	19	--	5	--
	9.4	12	2.3	22	9.6	19	--	16	--
CLUSTER 2									
Ph13-04	--	--	--	--	--	--	--	--	--
	16	8.1	7.0	28	16	16	--	<3	--
	17	8.2	7.1	31	12	18	--	64	--
	16	8.1	7.2	27	15	16	--	40	--
	15	7.6	6.7	24	18	17	--	4	--
	13	7.0	6.5	21	17	17	--	7	--
Ph13-23	--	--	--	--	--	--	--	--	--
	15	8.7	6.7	20	15	15	--	5	--
	15	8.5	6.4	26	12	16	--	62	--
	14	8.6	6.8	18	20	16	--	<3	--
	14	8.3	6.8	18	17	16	<10	11	0.23
Ph13-24	--	--	--	--	--	--	--	--	--
	11	12	4.3	24	16	17	--	4	--
	11	11	4.7	26	12	17	--	25	--
	11	12	5.1	21	17	18	--	<3	--
	9.9	11	4.8	19	15	18	--	5	--
Ph13-25	--	--	--	--	--	--	--	--	--
	3.9	11	1.9	14	6.4	18	--	84	--
	4.1	11	1.9	10	5.8	19	--	<3	--
	3.8	11	1.9	11	5.9	18	--	10	--
Ph13-26	3.3	12	2.0	12	4.7	18	--	8	--
	3.8	12	2.0	12	5.5	19	--	<3	--
	5.1	12	2.3	16	3.0	19	<10	6	--

APPENDIX 1. Well records and chemical analyses of ground water and surface water at the Fairmount site--Continued.

DGS WELL NUMBER	DATE	DEPTH TO TOP OF SAMPLE INTER- VAL (ft)	DEPTH TO BOT- TOM OF SAMPLE INTER- VAL (ft)	ELEVATION OF LAND SURFACE DATUM (ft above sea level)	PUMP OR FLOW PERIOD PRIOR TO SAM- PLING (min)	TEMPER- ATURE WATER (deg C)	SPE- CIFIC CON- DUCT- ANCE (μ S/cm)	OXYGEN, DIS- SOLVED (mg/L)	pH (stand- ard units)
CLUSTER 3									
Ph13-03	05-16-85	20	25	22.40	30	14.0	298	10.4	4.72
	07-10-85	20	25	22.40	25	14.5	291	10.5	4.73
	10-21-85	20	25	22.40	25	15.0	302	8.4	4.87
	01-21-86	20	25	22.40	20	17.0	310	--	5.00
	03-21-86	20	25	22.40	40	14.5	290	--	5.07
	06-20-86	20	25	22.40	30	13.5	320	9.2	4.80
	09-30-86	20	25	22.40	25	17.5	337	--	4.76
Ph13-16	05-16-85	40	45	22.47	55	15.0	291	9.5	5.14
	07-10-85	40	45	22.47	30	15.0	314	10.1	5.12
	10-21-85	40	45	22.47	45	13.5	420	10.5	5.30
	01-21-86	40	45	22.47	35	17.0	440	--	5.37
	03-21-86	40	45	22.47	30	16.0	422	--	5.29
	06-20-86	40	45	22.47	30	14.0	433	9.3	5.09
	09-30-86	40	45	22.47	30	16.0	342	8.5	5.22
Ph13-17	05-16-85	55	60	22.51	70	15.0	398	6.4	5.27
	07-10-85	55	60	22.51	55	15.0	372	6.6	5.03
	10-21-85	55	60	22.51	40	14.0	403	5.7	4.73
	01-21-86	55	60	22.51	35	20.0	413	--	4.90
	03-21-86	55	60	22.51	35	19.0	401	--	4.75
	06-20-86	55	60	22.51	40	15.0	423	6.0	4.60
	09-30-86	55	60	22.51	40	16.5	397	--	4.70
Ph13-18	05-08-85	80	85	22.54	60	15.0	109	7.0	5.47
	07-10-85	80	85	22.54	50	14.5	104	6.2	5.38
	10-21-85	80	85	22.54	45	14.0	113	6.2	5.70
	01-16-86	80	85	22.54	30	15.5	91	--	5.70
	03-21-86	80	85	22.54	35	15.0	90	--	5.58
	06-20-86	80	85	22.54	30	14.5	187	6.4	5.35
	09-30-86	80	85	22.54	30	15.5	155	--	5.40
CLUSTER 4									
Ph13-08	05-02-85	20	25	23.31	40	13.0	397	11.7	4.68
	07-22-85	20	25	23.31	35	15.0	394	10.0	4.74
	01-17-86	20	25	23.31	20	17.5	395	--	4.80
	03-18-86	20	25	23.31	35	16.5	380	--	4.76
	06-19-86	20	25	23.31	30	13.5	358	9.4	4.63
	09-22-86	20	25	23.31	20	15.0	348	8.9	4.78
Ph13-19	05-02-85	40	45	23.33	60	13.5	277	10.5	5.01
	07-22-85	40	45	23.33	45	15.0	274	8.9	5.14
	01-17-86	40	45	23.33	40	16.5	273	--	5.30
	03-18-86	40	45	23.33	45	16.5	295	--	5.22
	06-19-86	40	45	23.33	35	14.5	294	8.5	5.14
	09-22-86	40	45	23.33	30	14.5	293	8.6	5.30
Ph13-20	04-30-85	55	60	23.38	55	15.0	270	9.7	5.38
	07-22-85	55	60	23.38	50	15.0	270	8.5	5.34
	01-17-86	55	60	23.38	30	16.0	257	--	5.34
	03-18-86	55	60	23.38	45	15.5	254	--	5.20
	06-19-86	55	60	23.38	30	14.5	260	7.7	5.20
	09-22-86	55	60	23.38	30	14.5	286	8.0	5.30
Ph13-21	05-02-85	80	85	22.17	105	13.0	225	10.3	5.38
	07-22-85	80	85	22.17	55	15.0	228	9.0	5.50
	01-17-86	80	85	22.17	30	15.5	212	--	5.45
	03-18-86	80	85	22.17	35	15.5	187	--	5.28
	06-19-86	80	85	22.17	25	14.5	210	7.6	5.33
	09-22-86	80	85	22.17	25	14.5	235	8.4	5.40

APPENDIX 1. Well records and chemical analyses of ground water and surface water at the Fairmount site--Continued.

DGS WELL NUMBER	pH LAB (stand- ard units)	ALKA- LITY WH WAT TOTAL FIELD (mg/L as CaCO3)	ALKA- LITY LAB (mg/L as CaCO3)	NITRO- GEN, AMMONIA DIS- SOLVED (mg/L as N)	NITRO- GEN, AM- MONIA + ORGANIC DIS- SOLVED (mg/L as N)	NITRO- GEN, NO2+NO3 DIS- SOLVED (mg/L as N)	PHOS- PHORUS, DIS- SOLVED (mg/L as P)	HARD- NESS (mg/L as CaCO3)	CALCIUM DIS- SOLVED (mg/L as Ca)
CLUSTER 3									
Ph13-03	--	1	--	--	--	--	--	--	--
	--	1	--	--	--	--	--	--	--
	5.10	2	2.0	--	--	24.0	--	94	27
	5.40	2	1.0	0.010	0.90	22.0	<0.010	94	27
	5.40	2	<3.0	<0.010	1.6	21.0	0.050	88	25
	5.40	2	3.0	0.070	0.70	24.0	0.060	97	28
4.90	0	3.0	0.010	1.3	24.0	0.700	100	29	
Ph13-16	--	3	--	--	--	--	--	--	--
	--	4	--	--	--	--	--	--	--
	5.60	3	4.0	--	--	37.0	--	160	29
	6.30	4	3.0	0.010	1.4	41.0	<0.010	160	28
	--	3	--	--	--	--	--	--	--
	5.70	2	4.0	0.020	0.80	39.0	<0.010	160	28
5.50	5	5.0	0.010	1.4	31.0	0.030	130	24	
Ph13-17	--	5	--	--	--	--	--	--	--
	--	3	--	--	--	--	--	--	--
	5.00	1	2.0	--	--	34.0	--	150	30
	5.50	1	<1.0	0.010	1.1	34.0	<0.010	150	30
	--	1	--	--	--	--	--	--	--
	5.10	0	3.0	0.020	0.80	33.0	<0.010	140	29
Ph13-18	--	9	--	--	--	--	--	--	--
	--	7	--	--	--	--	--	--	--
	5.80	8	9.0	--	--	6.70	--	20	6.1
	6.10	9	8.0	0.010	0.60	4.60	<0.010	14	4.4
	--	9	--	--	--	--	--	--	--
	5.80	6	8.0	0.020	0.80	10.0	<0.010	38	11
CLUSTER 4									
Ph13-08	--	1	--	--	--	--	--	--	--
	--	1	--	--	--	--	--	--	--
	5.20	3	<1.0	0.020	0.90	32.0	<0.010	150	19
	5.20	1	<3.0	<0.010	1.2	28.0	<0.010	140	17
	5.20	0	3.0	0.010	0.60	27.0	<0.010	130	16
4.90	2	3.0	<0.010	0.60	28.0	<0.010	120	16	
Ph13-19	--	3	--	--	--	--	--	--	--
	--	3	--	--	--	--	--	--	--
	5.80	3	3.0	<0.010	0.70	23.0	<0.010	87	21
	--	3	--	--	--	--	--	--	--
5.80	3	5.0	<0.010	0.40	26.0	<0.010	89	21	
5.60	3	--	<0.010	0.30	25.0	<0.010	94	23	
Ph13-20	--	6	--	--	--	--	--	--	--
	--	7	--	--	--	--	--	--	--
	5.80	4	4.0	0.010	0.90	21.0	<0.010	75	20
	--	5	--	--	--	--	--	--	--
	5.70	5	6.0	<0.010	0.50	21.0	<0.010	72	19
5.60	4	5.0	0.020	0.50	24.0	<0.010	90	24	
Ph13-21	--	5	--	--	--	--	--	--	--
	--	5	--	--	--	--	--	--	--
	5.90	5	4.0	0.010	0.60	16.0	<0.010	63	15
	--	5	--	--	--	--	--	--	--
	5.80	4	6.0	0.020	0.50	14.0	<0.010	59	14
5.60	4	5.0	0.020	0.60	18.0	<0.010	71	17	

APPENDIX 1. Well records and chemical analyses of ground water and surface water at the Fairmount site--Continued.

DGS WELL NUMBER	MAGNE- SIUM, DIS- SOLVED (mg/L as Mg)	SODIUM, DIS- SOLVED (mg/L as Na)	POTAS- SIUM, DIS- SOLVED (mg/L as K)	CHLO- RIDE, DIS- SOLVED (mg/L as Cl)	SULFATE DIS- SOLVED (mg/L as SO4)	SILICA, DIS- SOLVED (mg/L as SiO2)	BORON, DIS- SOLVED (µg/L as B)	IRON, DIS- SOLVED (µg/L as Fe)	METHY- LENE BLUE ACTIVE SUBSTANCE (mg/L)
CLUSTER 3									
Ph13-03	--	--	--	--	--	--	--	--	--
	6.4	5.9	16	18	18	9.6	--	<3	--
	6.5	6.0	16	17	15	10	--	110	--
	6.1	5.5	16	17	16	9.3	--	57	--
	6.5	5.5	15	18	19	8.8	--	5	--
	7.2	5.6	20	21	14	9.5	--	21	--
Ph13-16	--	--	--	--	--	--	--	--	--
	22	9.5	5.0	26	14	16	--	4	--
	22	9.3	5.1	28	13	17	--	73	--
	--	--	--	--	--	--	--	--	--
	21	9.3	5.3	23	15	16	--	<3	--
	18	8.6	5.7	21	13	16	--	10	--
Ph13-17	--	--	--	--	--	--	--	--	--
	18	8.6	7.5	24	20	17	--	34	--
	19	8.5	6.7	24	17	17	--	420	--
	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--
	16	8.6	8.9	21	21	18	--	17	--
Ph13-18	--	--	--	--	--	--	--	--	--
	1.2	13	1.6	13	1.1	17	--	6	--
	0.80	11	1.5	10	1.0	19	--	25	--
	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--
	2.5	11	2.2	14	0.9	18	--	9	--
CLUSTER 4									
Ph13-08	--	--	--	--	--	--	--	--	--
	25	6.9	7.7	34	12	17	--	190	--
	23	6.6	7.3	34	12	15	--	130	--
	21	6.3	6.6	32	12	16	--	10	--
	20	6.1	6.8	28	12	16	--	16	--
Ph13-19	--	--	--	--	--	--	--	--	--
	8.5	13	3.0	23	1.5	18	--	84	--
	--	--	--	--	--	--	--	--	--
	8.9	12	3.0	23	1.9	17	--	8	--
	8.9	12	2.9	23	2.2	18	--	<3	0,21
Ph13-20	--	--	--	--	--	--	--	--	--
	6.1	14	2.9	22	0.9	18	--	29	--
	--	--	--	--	--	--	--	--	--
	6.0	13	2.8	22	0.7	17	--	4	--
	7.3	12	2.9	21	1.4	17	--	12	--
Ph13-21	--	--	--	--	--	--	--	--	--
	6.3	11	2.3	21	3.0	17	--	36	--
	--	--	--	--	--	--	--	--	--
	5.8	9.5	2.2	17	0.5	17	--	31	--
	6.9	11	2.3	22	1.2	17	--	5	--

APPENDIX 1. Well records and chemical analyses of ground water and surface water at the Fairmount site--Continued.

DGS WELL NUMBER	DATE	DEPTH TO TOP OF SAMPLE INTER- VAL (ft)	DEPTH TO BOT- TOM OF SAMPLE INTER- VAL (ft)	ELEVATION OF LAND SURFACE DATUM (ft above sea level)	PUMP OR FLOW PERIOD PRIOR TO SAM- PLING (min)	TEMPER- ATURE WATER (deg C)	SPE- CIFIC CON- DUCT- ANCE (μ S/cm)	OKYGEN, DIS- SOLVED (mg/L)	pH (stand- ard units)
CLUSTER 5									
Ph13-28	04-30-85	35	40	25.13	75	15.0	313	11.2	5.53
	07-19-85	35	40	25.13	40	15.5	332	9.8	5.63
	01-16-86	35	40	25.13	30	11.5	345	--	5.60
	03-20-86	35	40	25.13	35	15.5	358	--	5.67
	06-19-86	35	40	25.13	50	15.0	397	8.3	5.60
	09-22-86	35	40	25.13	35	15.0	345	8.4	5.67
Ph13-13	04-30-85	55	60	25.04	50	15.0	136	8.2	5.29
	07-19-85	55	60	25.04	55	15.5	73	6.8	5.59
	01-16-86	55	60	25.04	30	16.0	77	--	5.60
	03-20-86	55	60	25.04	35	15.5	69	--	5.59
	06-19-86	55	60	25.04	30	15.0	68	5.2	5.74
	09-22-86	55	60	25.04	30	14.5	66	5.3	5.60
Ph13-14	04-23-85	70	75	25.08	45	14.0	64	7.6	5.48
	07-19-85	70	75	25.08	60	15.0	64	6.8	5.58
	01-16-86	70	75	25.08	30	16.0	70	--	5.70
	03-20-86	70	75	25.08	40	15.5	69	--	5.54
	06-19-86	70	75	25.08	30	15.0	70	5.2	5.13
	09-22-86	70	75	25.08	30	14.5	70	5.5	5.60
	09-01-87	70	75	25.08	--	--	65	--	5.65
Ph13-02	10-22-86	63	93	22.31	1380	15.0	230	--	5.58
Ph13-32	09-18-86	50	90	22.17	35	14.5	183	9.0	5.60
PHILLIPS B AT FAIRMOUNT, DE	06-19-86	--	--	--	--	15.0	68	5.2	5.70
	10-30-86	--	--	--	--	16.0	81	--	6.00
PHILLIPS B NR FAIRMOUNT, DE	06-18-86	--	--	--	--	20.0	104	--	6.80
	10-30-86	--	--	--	--	16.0	93	--	5.83

APPENDIX 1. Well records and chemical analyses of ground water and surface water at the Fairmount site--Continued.

DGS WELL NUMBER	pH LAB (stand- ard units)	ALKA- LINITY WE WAT TOTAL FIELD mg/L as CaCO3	ALKA- LINITY LAB (mg/L as CaCO3)	NITRO- GEN, AMMONIA DIS- SOLVED (mg/L as N)	NITRO- GEN, AM- MONIA + ORGANIC DIS- SOLVED (mg/L as N)	NITRO- GEN, NO2+NO3 DIS- SOLVED (mg/L as N)	PHOS- PHORUS, DIS- SOLVED (mg/L as P)	HARD- NESS (mg/L as CaCO3)	CALCIUM DIS- SOLVED (mg/L as Ca)
CLUSTER 5									
Ph13-28	--	8	--	--	--	--	--	--	--
	--	9	--	--	--	--	--	--	--
	5.10	8	7.0	0.010	1.0	25.0	<0.010	130	33
	6.00	8	9.0	<0.010	1.1	25.0	<0.010	130	34
	5.00	10	9.0	<0.010	0.30	31.0	<0.010	150	39
	5.90	7	10	0.010	<0.20	28.0	<0.010	130	35
Ph13-13	--	6	--	--	--	--	--	--	--
	--	11	--	--	--	--	--	--	--
	6.20	10	9.0	0.020	0.90	3.00	<0.010	14	4.2
	--	11	--	--	--	--	--	--	--
	6.20	11	12	0.020	<0.20	1.80	0.010	11	3.1
	6.10	13	--	<0.010	1.3	1.90	<0.010	10	3.2
Ph13-14	--	11	--	--	--	--	--	--	--
	--	10	--	--	--	--	--	--	--
	6.20	9	9.0	0.030	0.50	2.10	<0.010	10	2.8
	--	10	--	--	--	--	--	--	--
	6.20	10	11	<0.010	<0.20	2.20	<0.010	9	2.7
	6.10	11	--	0.010	0.30	2.40	<0.010	9	2.8
	--	--	--	--	--	--	--	--	--
Ph13-02	6.00	6	7.0	<0.010	0.80	18.0	0.010	77	17
Ph13-32	6.10	9	--	0.020	0.70	13.0	0.010	48	11
PHILLIPS B AT FAIRMOUNT, DE	6.20	11	12	<0.020	<0.20	1.80	<0.010	11	3.1
	6.70	12	13	<0.010	0.20	2.80	<0.010	19	4.9
PHILLIPS B NR FAIRMOUNT, DE	6.90	--	12	0.040	0.60	4.30	0.020	24	5.8
	6.90	12	14	0.030	0.30	3.10	<0.010	21	5.3

APPENDIX 1. Well records and chemical analyses of ground water and surface water at the Fairmount site--Continued.

DGS WELL NUMBER	MAGNE- SIUM, DIS- SOLVED (mg/L as Mg)	SODIUM, DIS- SOLVED (mg/L as Na)	POTAS- SIUM, DIS- SOLVED (mg/L as K)	CHLO- RIDE, DIS- SOLVED (mg/L as Cl)	SULFATE DIS- SOLVED (mg/L as SO4)	SILICA, DIS- SOLVED (mg/L as SiO2)	BORON, DIS- SOLVED (µg/L as B)	IRON, DIS- SOLVED (µg/L as Fe)	METHY- LENE BLUE ACTIVE SUB- STANCE (mg/L)
CLUSTER 5									
Ph13-28	--	--	--	--	--	--	--	--	--
	11	11	2.5	25	14	20	--	38	--
	10	10	2.6	25	16	19	--	30	--
	12	10	2.5	27	24	19	--	6	--
	10	10	2.3	23	18	20	--	14	--
Ph13-13	--	--	--	--	--	--	--	--	--
	0.90	7.9	1.4	9.1	1.0	21	--	29	--
	0.69	8.1	1.2	8.6	0.8	21	--	5	--
	0.57	8.3	1.2	8.8	1.6	21	--	5	0.03
Ph13-14	--	--	--	--	--	--	--	--	--
	0.70	8.7	1.3	8.5	1.1	22	--	22	--
	0.66	8.5	1.2	8.7	0.8	21	--	12	--
	0.59	8.9	1.3	9.5	1.6	21	--	13	0.04
	--	--	--	--	--	--	--	--	--
Ph13-02	8.4	11	2.2	19	6.2	18	--	11	--
Ph13-32	5.0	12	2.0	14	4.2	18	<10	<3	0.13
PHILLIPS B AT FAIRMOUNT, DE	0.69	8.1	1.2	8.6	0.8	21	--	<5	--
	1.7	7.9	2.0	9.1	5.9	21	--	16	--
PHILLIPS B NR FAIRMOUNT, DE	2.2	8.7	1.4	8.1	3.8	20	--	19	--
	1.9	7.9	1.8	9.6	6.7	21	--	45	--

APPENDIX 2. Chemical analyses of water from wells affected by septic-system effluent.

[$\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; <, less than; >, greater than; mg/L, milligrams per liter; $\mu\text{g/L}$, micrograms per liter; ft, feet; min, minutes; WH WAT = whole water; --, no analysis; E, estimated]

DGS WELL NUMBER	DATE	DEPTH TO TOP OF SAMPLE INTER-VAL (ft)	DEPTH TO BOT-TOM OF SAMPLE INTER-VAL (ft)	DEPTH OF HOLE, TOTAL (ft)	ELEVATION OF LAND SURFACE DATUM (ft above sea level)	PUMP OR FLOW PERIOD PRIOR TO SAMP-LING (min)	TEMPER-ATURE WATER (deg C)	SPE-CIFIC CON-DUCT-ANCE ($\mu\text{S/cm}$)	OXYGEN, DIS-SOLVED (mg/L)	pH (stand-ard units)
Me24-06	11-19-86	39	59	59	33.0	60	14.5	174	8.0	4.86
Me14-21	03-27-87	--	--	--	20.0	30	16.0	175	8.0	5.21
Nf22-01	11-19-86	56	76	81	42.0	20	14.5	138	--	5.08
Nf22-02	11-19-86	--	70	--	42.0	20	15.0	172	--	5.15
Ng41-03	07-01-86	--	80	--	5.0	>20	21.0	170	8.2	5.24
Oi23-08	11-19-86	82	102	102	25.0	20	13.5	187	--	5.50
Oi35-30	07-01-86	25	35	35	20.0	>15	15.0	330	1.9	5.80
Ph35-17	09-18-86	--	15	20	22.0	20	24.0	121	--	5.30
Ph42-01	03-12-85	68	78	80	E25.0	>30	13.0	168	8.0	5.40
Qh41-08	04-14-87	11	13	15	30.0	45	12.0	231	0.4	4.53
Qh52-03	04-14-87	9.0	11	15	30.0	35	12.5	159	5.0	5.80

DGS WELL NUMBER	PH LAB (stand-ard units)	ALKA-LINITY WH WAT TOTAL (mg/L as CaCO3)	ALKA-LINITY LAB (mg/L as CaCO3)	NITRO-GEN, AMMONIA DIS-SOLVED (mg/L as N)	NITRO-GEN, AM-MONIA + ORGANIC DIS-SOLVED (mg/L as N)	NITRO-GEN, NO2+NO3 DIS-SOLVED (mg/L as N)	PHOS-PHORUS, DIS-SOLVED (mg/L as P)	HARD-NESS (mg/L as CaCO3)	CALCIUM DIS-SOLVED (mg/L as Ca)
Me24-06	5.40	2	5.0	<0.010	0.40	10.0	<0.010	47	8.8
Me14-21	5.47	--	5.0	<0.010	0.80	11.0	0.010	51	12
Nf22-01	5.80	3	5.0	<0.010	1.3	11.0	<0.010	38	11
Nf22-02	6.10	3	5.0	<0.010	0.70	15.0	<0.010	48	14
Ng41-03	5.50	4	5.0	0.030	0.60	11.0	<0.010	47	11
Oi23-08	5.90	7	8.0	<0.010	0.50	12.0	<0.010	38	8.8
Oi35-30	6.30	31	28	0.770	1.3	11.0	0.030	90	22
Ph35-17	6.00	5	--	0.810	1.8	7.00	0.030	34	1.3
Ph42-01	5.70	7	8.0	--	--	9.00	--	46	13
Qh41-08	5.10	0	6.0	0.070	0.90	1.60	<0.010	49	12
Qh52-03	6.30	--	40	<0.010	1.0	3.70	0.010	64	18

DGS WELL NUMBER	MAGNE-SIUM, DIS-SOLVED (mg/L as Mg)	SODIUM, DIS-SOLVED (mg/L as Na)	POTAS-SIUM, DIS-SOLVED (mg/L as K)	CHLO-RIDE, DIS-SOLVED (mg/L as Cl)	SULFATE DIS-SOLVED (mg/L as SO4)	SILICA, DIS-SOLVED (mg/L as SiO2)	BORON, DIS-SOLVED ($\mu\text{g/L}$ as B)	IRON, DIS-SOLVED ($\mu\text{g/L}$ as Fe)	METH-YLENE BLUE ACTIVE SUB-STANCE (mg/L)
Me24-06	6.0	9.2	4.0	18	5.8	15	<10	7	0.11
Me14-21	5.1	7.2	5.2	18	2.8	15	<10	19	0.11
Nf22-01	2.6	7.9	2.3	10	1.6	16	10	3	0.11
Nf22-02	3.1	9.7	2.6	10	0.7	16	<10	25	0.14
Ng41-03	4.7	9.1	2.5	13	7.6	16	<10	65	0.11
Oi23-08	3.9	16	2.2	18	1.4	14	<10	10	0.11
Oi35-30	8.6	20	5.2	25	41	17	40	15	0.15
Ph35-17	7.4	5.0	2.6	10	10	12	10	380	0.09
Ph42-01	3.2	10	1.5	13	0.4	22	--	6	--
Qh41-08	4.6	21	2.8	21	55	14	20	240	0.03
Qh52-03	4.6	2.6	4.5	3.6	18	5.3	20	6	0.03

APPENDIX 3. Chemical analyses of water from wells affected by agricultural practices.

(μ S/cm, microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; <, less than; >, greater than; mg/L, milligrams per liter; μ g/L, micrograms per liter; ft, feet; min, minutes; WE WAT = whole water; --, no analysis)

DGS WELL NUMBER	DATE	DEPTH TO TOP OF SAMPLE INTERVAL (ft)	DEPTH TO BOTTOM OF SAMPLE INTERVAL (ft)	DEPTH OF HOLE, TOTAL (ft)	ELEVATION OF LAND SURFACE DATUM (ft above sea level)	PUMP OR FLOW PERIOD PRIOR TO SAMPLING (min)	TEMPERATURE WATER (deg C)	SPECIFIC CONDUCTANCE (μ S/cm)	OXYGEN DIS-SOLVED (mg/L)
Ob14-02	07-14-83	40	80	80	51.0	>60	15.0	71	7.5
Ob35-03	08-15-83	59	72	90	48.0	55	17.0	64	5.5
Oc25-04	09-13-82	56	96	96	45.0	>60	16.0	86	11.2
Od23-07	07-14-83	69	99	99	41.0	>60	14.0	180	9.0
Pb35-02	08-24-82	33	89	91	30.0	>60	15.5	123	9.2
Pd33-03	10-04-83	42	47	82	35.0	95	19.5	235	4.8
Pd45-03	09-09-82	50	100	101	40.0	>60	14.5	226	11.9
Ph13-02	10-22-86	63	93	93	22.0	1380	15.0	230	--
Qe31-02	07-15-83	23	83	83	35.0	>60	16.0	134	8.7
Rc22-05	09-16-83	40	45	45	44.0	80	15.0	166	4.1

DGS WELL NUMBER	pH (stand-ard units)	pH LAB (stand-ard units)	ALKA-LINITY WE WAT TOTAL FIELD (mg/L as CaCO3)	ALKA-LINITY LAB (mg/L as CaCO3)	NITRO-NITRO-GEN AMMONIA DIS-SOLVED (mg/L as N)	GEN, AM-MONIA+ ORGANIC DIS-SOLVED (mg/L as N)	NITRO-GEN, NOW+NO3 DIS-SOLVED (mg/L as N)	PHOS-PHORUS, DIS-SOLVED (mg/L as P)
Ob14-02	5.60	4.90	5	5.0	<0.010	<0.10	5.00	0.020
Ob35-03	5.60	5.00	6	6.0	0.050	0.20	5.50	0.040
Oc25-04	6.00	6.30	7	7.0	0.110	1.3	6.50	0.020
Od23-07	5.00	4.80	2	3.0	0.060	<0.10	15.0	0.020
Pb35-02	4.20	6.00	1	4.0	0.670	1.2	10.0	0.010
Pd33-03	5.20	5.20	3	7.0	0.010	<0.10	20.0	<0.010
Pd45-03	6.10	5.90	7	6.0	0.040	0.30	19.0	<0.010
Ph13-02	5.58	6.00	6	7.0	<0.010	0.80	18.0	0.010
Qe31-02	5.20	5.50	3	3.0	<0.010	<0.10	12.0	0.030
Rc22-05	4.90	4.90	2	6.0	0.010	0.30	14.0	0.010

DGS WELL NUMBER	HARD-NESS (mg/L) as CaCO3	CALCIUM DIS-SOLVED (mg/L as Ca)	MAGNE-SIUM, DIS-SOLVED (mg/L as Mg)	SODIUM DIS-SOLVED (mg/L as Na)	POTAS-SIUM, DIS-SOLVED (mg/L as K)	CHLO-RIDE, DIS-SOLVED (mg/L as Cl)	SILICA DIS-SOLVED (mg/L as SiO2)	IRON DIS-SOLVED (μ /L as Fe)
Ob14-02	10	2.4	1.0	6.4	2.0	8.1	19	<3
Ob35-03	10	2.5	0.83	8.9	2.2	4.9	19	13
Oc25-04	18	4.1	1.8	8.5	3.1	8.8	18	48
Od23-07	47	7.9	6.5	8.8	3.9	13	11	<3
Pb35-02	35	5.6	5.0	5.7	2.8	9.3	14	27
Pd33-03	58	15	4.8	20	4.1	18	18	35
Pd45-03	65	17	5.3	11	3.4	18	17	<3
Ph13-02	77	17	8.4	11	2.2	19	18	11
Qe31-02	38	9.4	3.5	7.9	2.3	11	14	9
Rc22-05	50	10	5.9	7.8	4.0	16	14	14

APPENDIX 4. Chemical analyses of water from wells with natural and nearly natural water quality.

[μ S/cm, microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; <, less than; >, greater than; mg/L, milligrams per liter; μ g/L, micrograms per liter; ft, feet; min, minutes; WE WAT = whole water]

DGS WELL NUMBER	DATE	DEPTH TO TOP OF SAMPLE INTERVAL (ft)	DEPTH TO BOTTOM OF SAMPLE INTERVAL (ft)	DEPTH OF HOLE, TOTAL (ft)	ELEVATION OF LAND SURFACE DATUM (ft above sea level)	PUMP OR FLOW PERIOD PRIOR TO SAMPLING (min)	TEMPERATURE WATER (deg C)	SPECIFIC CONDUCTANCE (μ S/cm)	OXYGEN, DIS-SOLVED (mg/L)	pH (standard units)
Md55-02	09-09-83	40	50	50	56.0	30	15.0	40	3.4	5.80
Nd25-05	10-18-83	49	54	54	50.0	45	17.5	56	3.6	5.90
Nd25-06	01-07-83	38	43	43	50.0	85	14.0	50	1.6	5.90
Ne54-03	03-14-83	72	82	E165	50.0	110	13.5	39	2.6	5.60
Ph13-29	04-14-87	--	45	45	6.0	15	15.0	66	--	5.02
Of41-01	02-09-83	97	117	120	48.0	30	15.5	59	3.1	6.00
Ph13-14	01-16-86	70	75	--	18.0	30	16.0	70	--	5.70
Qc52-06	09-08-82	60	120	120	42.0	>60	14.5	43	7.4	5.40
Rd35-05	07-29-83	29	99	99	55.0	>60	15.5	53	7.2	5.50

DGS WELL NUMBER	pH LAB (standard units)	ALKALINITY WH WAT TOTAL mg/L as CaCO3	ALKALINITY LAB (mg/L as CaCO3)	NITROGEN, AMMONIA DIS-SOLVED (mg/L as N)	NITROGEN, AMMONIA + ORGANIC DIS-SOLVED (mg/L as N)	NITROGEN, NO2+NO3 DIS-SOLVED (mg/L as N)	PHOSPHORUS, DIS-SOLVED (mg/L as P)	HARDNESS (mg/L as CaCO3)	CALCIUM DIS-SOLVED (mg/L as Ca)
Md55-02	5.10	13	16	<0.010	--	--	<0.010	6	2.0
Nd25-05	5.70	10	14	<0.010	0.20	2.30	<0.010	8	2.5
Nd25-06	5.80	13	14	0.050	0.20	1.20	0.010	7	2.2
Ne54-03	5.30	10	9.0	<0.010	<0.10	<0.100	<0.010	4	1.2
Ph13-29	6.10	9	11	<0.010	0.50	2.80	0.010	11	3.3
Of41-01	5.80	15	12	<0.010	0.50	1.80	<0.010	10	2.8
Ph13-14	6.20	9	9.0	0.030	0.50	2.10	<0.010	10	2.8
Qc52-06	5.90	15	9.0	0.020	0.70	2.40	<0.010	11	2.6
Rd35-05	5.50	6	7.0	<0.010	0.10	1.90	0.050	8	0.98

DGS WELL NUMBER	MAGNESIUM, DIS-SOLVED (mg/L as mg)	SODIUM, DIS-SOLVED (mg/L as Na)	POTASSIUM, DIS-SOLVED (mg/L as K)	CHLORIDE, DIS-SOLVED (mg/L as Cl)	SULFATE, DIS-SOLVED (mg/L as SO4)	SILICA, DIS-SOLVED (mg/L as SiO2)	BORON, DIS-SOLVED (mg/L as B)	IRON, DIS-SOLVED (mg/L as Fe)	METHYLENE BLUE ACTIVE SUBSTANCE (mg/L)
Md55-02	0.22	5.4	0.40	4.2	0.6	30	--	37	--
Nd25-05	0.45	7.2	0.90	4.7	0.4	23	--	16	--
Nd25-06	0.34	6.8	0.80	4.1	<1.0	24	--	<3	--
Ne54-03	0.35	4.4	1.2	5.0	0.9	14	--	300	--
Ph13-29	0.66	8.9	1.3	11	0.4	21	<10	5	0.01
Of41-01	0.59	6.7	1.3	5.8	<5.0	28	--	67	--
Ph13-14	0.70	8.7	1.3	8.5	1.1	22	--	22	--
Qc52-06	0.97	4.8	1.6	6.0	2.0	16	--	<3	--
Rd35-05	1.4	5.0	1.8	7.3	0.4	14	--	<3	--

APPENDIX 5

CONVERSION FACTORS AND ABBREVIATIONS

For those readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted using the following factors:

<u>Multiply inch-pound unit</u>	<u>by</u>	<u>To obtain metric unit</u>
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft ² /d)	0.0929	meter squared per day (m ² /d)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square mile (mi ²)	2.590	square kilometer (km ²)
acre	0.4047	hectare (ha)
acre-inch	1.028	cubic centimeter (cm ³)
pound (lb)	0.4536	kilogram (kg)
pound per acre (lb/acre)	1.12	kilogram per hectare (kg/ha)
quart per acre (qt/acre)	2.338	liter per hectare (L/ha)
ton per acre	2.242	metric ton per hectare

Chemical concentration, water temperature, and specific conductance are given in metric units. Chemical concentration is expressed in milligrams per liter (mg/L), micrograms per liter (μg/L), or milliequivalents per liter (meq/L). Water temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the following equation:

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

Specific conductance is expressed in microsiemens per centimeter (μS/cm) at 25 degrees Celsius.

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