INDICATORS OF THE SOURCES AND DISTRIBUTION OF NITRATE IN WATER FROM SHALLOW DOMESTIC WELLS IN AGRICULTURAL AREAS OF THE NEW JERSEY COASTAL PLAIN

by E.F. Vowinkel and R.J. Tapper

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

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
meter (m)	.3048	foot
kilometer (km)	.6214	mile
meter per kilometer		
cubic meter per day (m^3/d)	264.2	gallon per day
hectare (ha)	2.471	acre
square kilometer (km^2)	.3861	square mile
kilogram (kg)	2.205	pound
liter (L)	.2642	gallon
metric ton	1.1016	ton
degree Celsius (°C)	1.8 x °C + 32	degree Fahrenheit

mg/L = milligram per liter
µg/L = microgram per liter
meq/L = millequivalents per liter
µS/cm = microsiemens per centimeter at 25 °C
$^{o}/_{oo}$ = per mil
col/100 mL = colonies per 100 milliliters

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

Indicators of the Sources and Distribution of Nitrate in Water from Shallow Domestic Wells in Agricultural Areas of the New Jersey Coastal Plain

by E.F. Vowinkel and R.J. Tapper

ABSTRACT

Previously collected and new water-quality data from shallow wells (screened interval less than 30 meters below the land surface) in predominantly agricultural areas of the New Jersey Coastal Plain were used to determine the relation of nitrate concentrations in shallow ground water to various hydrogeologic and land-use factors in the study area. Information on land use, well construction, hydrogeology, and water quality were used to predict the conditions under which concentrations of nitrate as nitrogen in water from domestic wells in predominantly agricultural areas are most likely to be equal to or larger than the U.S. Environmental Protection Agency maximum contaminant level (MCL) of 10 milligrams per liter.

Results of the analyses of water-quality samples collected during 1980-89 from 230 shallow wells in the outcrop areas of the Kirkwood-Cohansey and Potomac-Raritan-Magothy aquifer systems were used to evaluate the regional effects of land use on shallow-ground-water quality. Results of statistical analysis indicate that concentrations of nitrate in shallow ground water are significantly different ($p = 0.001$) in agricultural areas than in undeveloped areas in both aquifer systems. Concentrations of nitrate nitrogen exceeded the MCL in water from more than 33 percent of the 60 shallow wells in agricultural areas. Concentrations of nitrate in water from shallow wells in agricultural areas increased as the percentage of agricultural land within an 800-meter-radius buffer zone of the wellhead increased ($r = 0.81$). Concentrations of nitrate in water from domestic wells in agricultural areas were similar ($p = 0.23$) to those concentrations in water from irrigation wells. These results indicate that most of the nitrate in water from domestic wells in agricultural areas results from agricultural practices rather than other sources, such as septic systems.

Water-quality samples collected from 12 shallow domestic wells in agricultural areas screened in the outcrop areas of the Kirkwood-Cohansey and Potomac-Raritan-Magothy aquifer systems were used to evaluate the local effects of hydrogeologic conditions and land-use activities on shallow-ground-water quality. Concentrations of water-quality constituents in these wells were similar among four sampling events over a 1-year span. The concentration of nitrate in water from 6 of the 12 wells exceeded the MCL. Concentrations of nitrate greater than the MCL are associated with: values of specific conductance greater than 200 microsiemens per centimeter at 25 degrees Celsius, a screened interval whose top is less than 20 meters below land surface, concentrations of dissolved oxygen greater than 6 milligrams per liter, presence of pesticides in the ground water, a distance of less than 250 meters between the wellhead and the surface-water divide, and presence of livestock near the wellhead. Ratios of stable isotopes of nitrogen in the water samples indicate that the source of nitrate in the ground water was predominantly chemical fertilizers rather than livestock wastes or effluent from septic systems.

INTRODUCTION

Contamination of ground water by agricultural chemicals, especially nitrates, is a major concern of environmental and regulatory agencies throughout the nation. Nitrate is soluble in water and is transported from its source along local and regional ground-water flow paths. Although nitrate is relatively nontoxic, in the intestines of infants it can be reduced by bacteria to nitrite and may result in the disease methemoglobinemia. Infant mortality from this disease is rare where concentrations of nitrate as nitrogen (as N) in drinking water are less than 10 mg/L; however, the incidence of mortality increases with increasing concentration (Walton, 1951). The U.S. Environmental Protection Agency (USEPA) has set a maximum contaminant level (MCL) of 10 mg/L for nitrate (as N) in water (U.S. Environmental Protection Agency, 1991). An MCL is the maximum permissible level of a contaminant in water that is delivered to any user of a public water system.

As a result of earlier studies that showed that concentrations of nitrate in ground water in agricultural areas commonly exceeded the MCL, a project was initiated by the U.S. Geological Survey (USGS) in cooperation with the New Jersey Department of Environmental Protection and Energy (NJDEPE) as part of the New Jersey Safe Drinking Water Program.

Purpose and Scope

The purpose of this report is to (1) document the seasonal variability of ground-water-quality constituents in shallow domestic wells in agricultural areas of the Coastal Plain of New Jersey; (2) describe the use of hydrogeologic, land-use, well-construction, and water-quality characteristics and constituents as indicators to predict whether the concentration of nitrate in water from a shallow domestic well in those areas will exceed the MCL; and (3) identify the predominant source(s) of nitrate in water from shallow domestic wells in agricultural areas.

Previous Investigations

In 1984, as part of its Toxic Substances Hydrology Program, the USGS began to evaluate the degradation of ground-water quality as a result of human activities. These studies were designed to test statistically the hypothesis that shallow-ground-water quality is related to human activities expressed as land use (Helsel and Ragone, 1984). Preliminary results from study areas in New York, New Jersey, Connecticut, Florida, Nebraska, and Colorado indicate that regional ground-water quality has been affected by human activities (Cain and others, 1989, p. 230).

The relation between nitrate in shallow ground water and land use in the outcrop area of the Potomac-Raritan-Magothy aquifer system in the New Jersey Coastal Plain was assessed by Barton and others (1987) and Kish and others (1988). Louis and Vowinkel (1989) evaluated the presence of agricultural chemicals in ground water in the outcrop areas of the Potomac-Raritan-Magothy aquifer system and the Kirkwood-Cohansey aquifer systems. Vowinkel (1991) reported that the relation between land use and nitrate in shallow ground water was similar between the two Coastal Plain aquifer systems; concentrations of nitrate in shallow ground water were significantly different in agricultural areas than in undeveloped areas. Water from more than 33 percent of the shallow wells in predominantly agricultural areas contained concentrations of nitrate exceeding the MCL.

Results of the USEPA's National Pesticide Survey indicate that concentrations of nitrate in ground water were equal to or greater than the MCL in 1.2 percent of the community and 2.4 percent of the rural wells nationwide. A statistical analysis of the USEPA data indicated that well depth was the only consistent predictor of nitrate concentration in ground water in community and rural wells (U.S. Environmental Protection Agency, 1992); however, because the hydrogeologic variables used in the model, such as the presence of confining units, were determined at the county scale rather than at a site or hydrogeologic-unit scale, the results of this study were limited. The USEPA findings indicate that further stratification of the data is needed to accurately test hypotheses concerning the associations among variables.

Results of a study conducted in Mercer and Burlington Counties, New Jersey (Murphy, 1992) demonstrated that the concentrations of nitrate in water from shallow drinking-water wells (screened intervals less than 30 m below the land surface) were significantly different in agricultural and residential areas than in woodland areas. Concentrations of nitrate in shallow ground water were significantly different in wells less than 15 m from a septic system than in wells farther than 15 m from a septic system; this result indicates that effluent from septic systems may have a significant effect on nitrate concentrations in water from sampled wells.

Acknowledgments

The authors thank the homeowners and farmers who allowed access to their wells for collection of water samples. Their cooperation is greatly appreciated.

DESCRIPTION OF THE STUDY AREA

The Coastal Plain physiographic province covers about 10,900 km^2 in southern New Jersey (fig. 1). The study area consists of a variety of hydrogeologic and land-use settings that can affect ground-water quality.

Hydrogeologic Setting

The Coastal Plain is underlain by a seaward-dipping wedge of unconsolidated sediments consisting of alternating layers of sand, silt, and clay of Cretaceous to Holocene age (fig. 2). The hydrogeologic framework of (Zapecza, 1989) and regional ground-water flow in (Martin, 1990) the New Jersey part of the Coastal Plain are well-documented. The Coastal Plain is separated from other physiographic provinces in New Jersey by the Fall Line, which extends from Raritan Bay in the northeast to Delaware Bay in the southwest. Two major aquifers, the Potomac-Raritan-Magothy aquifer system and the Kirkwood-Cohansey aquifer system, supply more than 90 percent of the freshwater used by the 3.2 million people living on the Coastal Plain in New Jersey. The Potomac-Raritan-Magothy aquifer system in the Cretaceous Potomac-Group, Raritan-Formation, and Magothy Formation underlies the entire Coastal Plain but crops out in a narrow 5- to 16-km-wide strip of land that comprises about 1,000 km^2 and extends from Raritan Bay to Delaware Bay. The outcrop area of the Kirkwood-Cohansey aquifer system in the Miocene Kirkwood Formation and the Cohansey Sand exceeds 7,500 km^2.

Hydrogeologic conditions in the Coastal Plain are such that shallow ground water is vulnerable to contamination from point and nonpoint sources. The land surface generally is flat; relief rarely is greater than 30 m in a drainage basin. Agricultural areas typically are in the upland parts of the drainage basin, where the soils are well-drained. Soils in agricultural areas in the northern part of the outcrop area of the Potomac-Raritan-Magothy aquifer system consist predominantly of sandy loam. In the outcrop area of the Kirkwood-Cohansey aquifer system, soils in agricultural areas consist mostly of gravelly sandy loam and loamy sand (Tedrow, 1986, pl. 1). Sandy loam- and loamy sand-type soils generally contain only small amounts of organic matter, which limits the ability of the soils to impede the movement of agricultural chemicals from the unsaturated zone to the water table.

The primary source of recharge to the aquifers in the Coastal Plain is precipitation. A long-term water budget under unstressed conditions consists of about 112 cm/yr of precipitation, 51 cm/yr of streamflow, and 61 cm/yr of evapotranspiration (Vowinkel and Foster, 1981, p. 1). Most of the ground water is discharged to surface-water bodies and only a small amount infiltrates through confining units to recharge the underlying confined aquifers (Martin, 1990, p. 45). The authors estimated from available water-level data that the median depth to the water table is about 5.8 m in the outcrop area of the Potomac-Raritan Magothy aquifer system and 3.7 m in the outcrop area of the Kirkwood-Cohansey aquifer system. The horizontal hydraulic conductivity of the unconsolidated sediments comprising the aquifer systems commonly is between 40 and 60 m/d (Martin, 1990, p. 10-12).

Shallow ground water in the Coastal Plain generally flows from upland recharge areas toward discharge areas along streams and wetlands (fig. 3). The locations of the ground-water and surface-water divides typically coincide. The direction of ground-water flow is predominantly downward near the ground-water divide, horizontal in the center of a drainage basin, and nearly vertically upward at the discharge area. In areas unstressed by ground-water withdrawals for irrigation, the water typically is older in deeper parts of the aquifer system downgradient from the ground-water divide than in shallower parts of

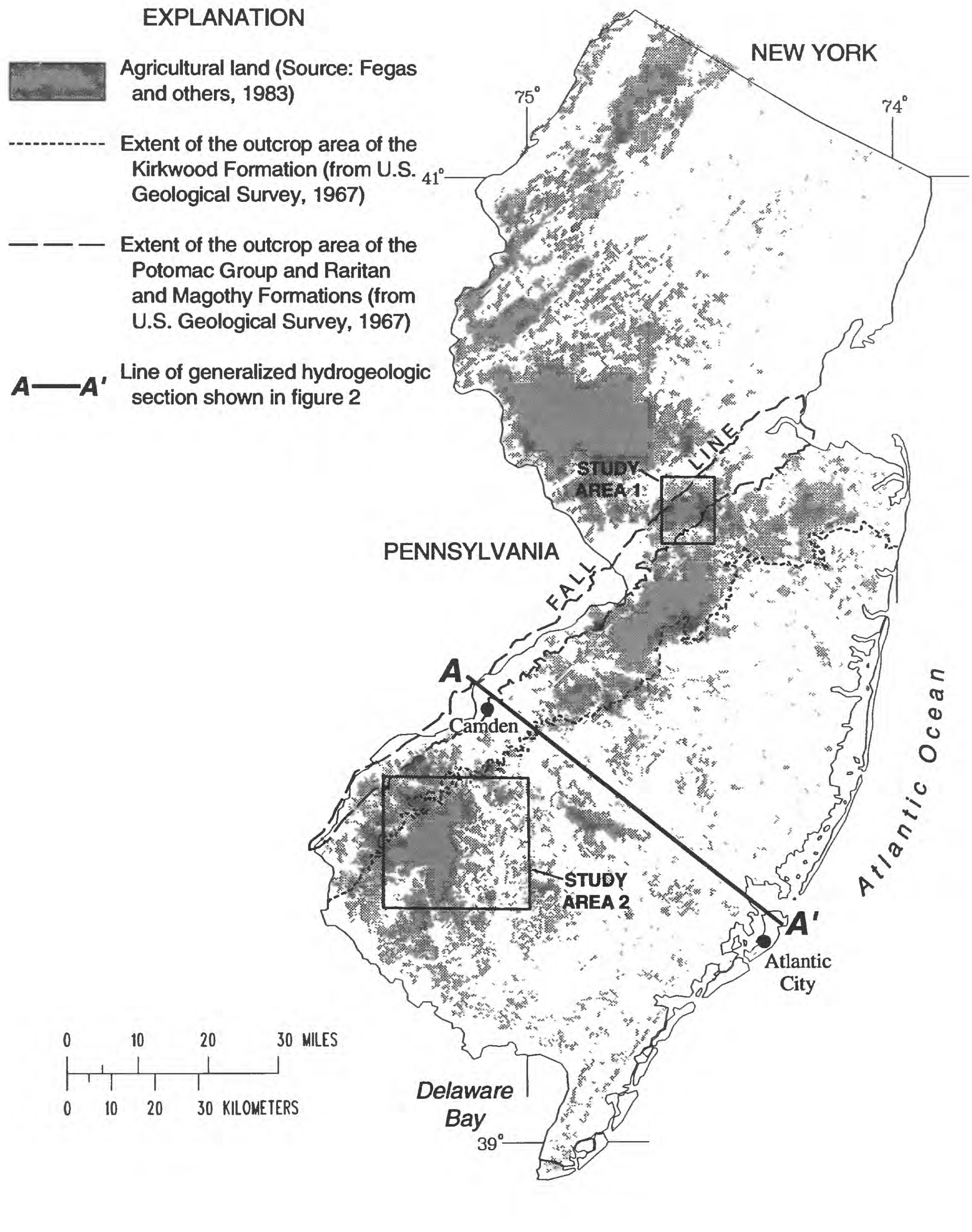

Figure 1. Location of the study areas, agricultural land, and generalized hydrogeologic section A-A'.

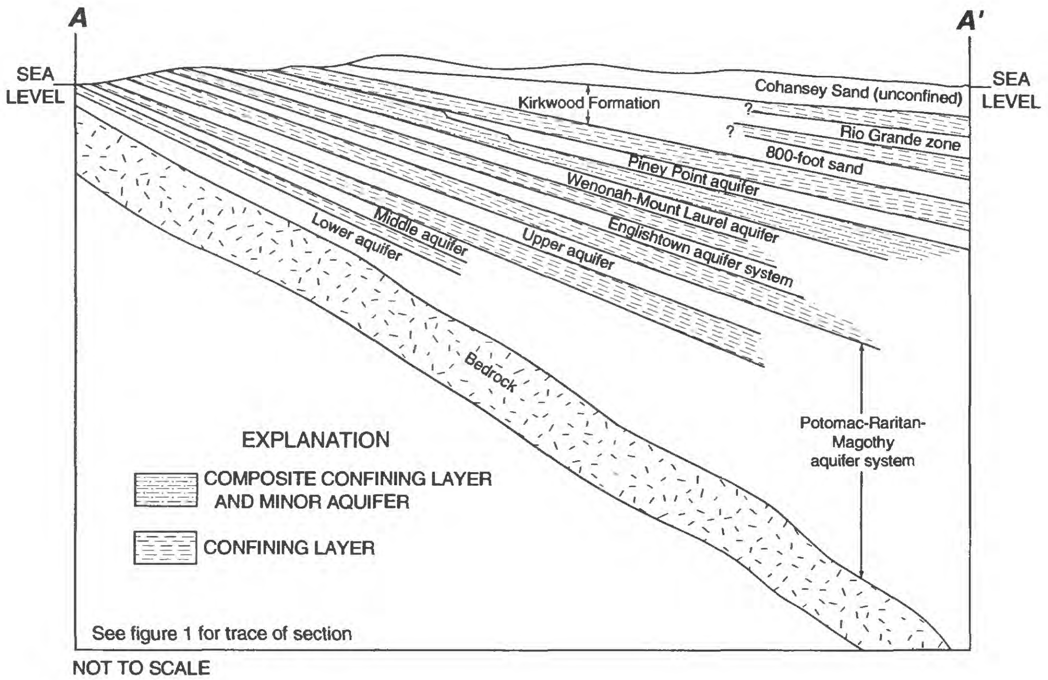

Figure 2. Generalized hydrogeologic section A-A' through the New Jersey Coastal Plain. (Modified from Eckel and Walker, 1986, p. 10.)

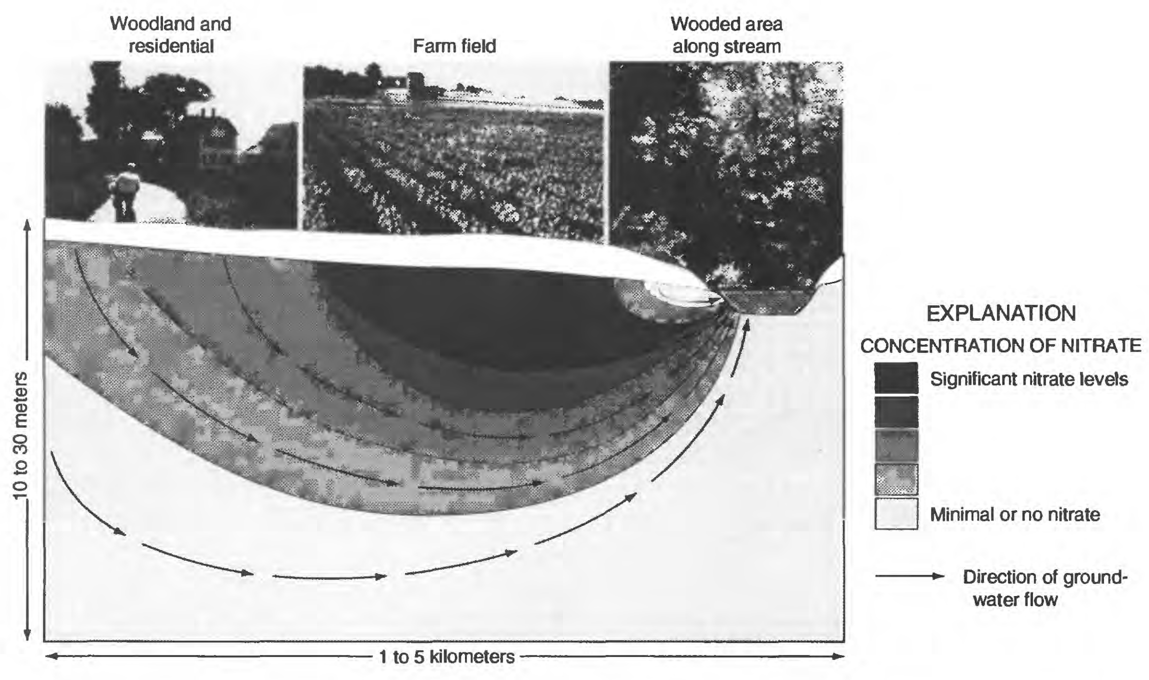

Figure 3. Generalized ground-water-flow patterns and concentrations of nitrate in agricultural areas. (Modified from Hamilton and Shedlock, 1992, p.5.)

the aquifer system near the divide. Concentrations of nitrate in ground water would be expected to decrease as the water flows downward and toward a stream because the nitrate disperses along the flow path and may be reduced by denitrifying bacteria under anaerobic conditions. Furthermore, water typically is older near ground-water-discharge areas and may be too old to have been affected by human activities at the land surface.

Agricultural Land Use and Sources of Nitrate

New Jersey is composed of a variety of land-use and land-cover types that can affect ground-water quality. Most of the Coastal Plain is undeveloped and the effects of human activities on ground-water quality in these areas are small. About 70 percent of the outcrop area of the Kirkwood-Cohansey aquifer system is pineland forests and wetlands and about 20 percent of the outcrop area of the Potomac-Raritan-Magothy aquifer system is undeveloped land. Urban land (residential and nonresidential) areas in the Coastal Plain are mostly near the Delaware and Raritan Rivers and along the Atlantic Coast.

The amount of agricultural land in New Jersey (fig. 1) has been declining steadily since the turn of the century. In 1900, almost 60 percent of the land in New Jersey was agricultural, compared to about 22 percent in the early 1970's (fig. 4), and 18 percent in 1990 (New Jersey Department of Agriculture, 1990). Although the amount of land used for agriculture has been declining, agriculture remains a large part of the State's economy. Most of the agricultural land is cropland with smaller amounts of pasture, animal feedlots, nurseries, and orchards. The crops grown are diverse; 77 types of vegetables, 10 types of fruits, and 8 grain commodities are grown in New Jersey (Louis and others, 1989). New Jersey ranks in the top five States in the country in the production of snap beans, cabbage, cranberries, and peaches (New Jersey Department of Agriculture, 1990), most of which are grown in the Coastal Plain. Other important crops in this region include soybeans, hay, wheat, barley, potatoes, sweetcorn, peppers, tomatoes, blueberries, strawberries, nursery crops, and fruit trees.

Agricultural land comprises nearly 20 percent of the outcrop areas of the Kirkwood-Cohansey and the Potomac-Raritan-Magothy aquifer systems. Possible sources of nonpoint contamination in agricultural areas include fertilizers used for plant production, pesticides used to control weeds and insects, animal wastes from feedlots, and effluent from septic systems and underground storage tanks.

Fertilizers are applied to agricultural land to increase plant productivity. In 1989, sales of about 224,000 metric tons of fertilizer were reported to the New Jersey Agricultural Statistics Service; 145,000 metric tons were for farm utilization and 79,000 metric tons were for nonfarm utilization. Nitrogen contained in mixed fertilizers was about 22,000 metric tons and sales of about 29,000 metric tons of chemical nitrogen materials were reported. Sales of about 14,000 metric tons of organic materials consisting of dried manure and sludge also were reported (New Jersey Department of Agriculture, 1990, p. 94).

Manures from livestock contain nitrogen that could potentially contaminate ground water. Generally, livestock production in New Jersey declined from 1960 to 1990 (table 1). Only the number of sheep and turkeys increased from 1970 to 1990. Because many types of livestock are raised in small, confined areas, problems commonly arise with the disposal of their wastes, runoff of manure into nearby surface-water bodies, and the leaching of nitrogen into ground water. The authors estimate that about 15,000 metric tons of nitrogen was produced in 1989 from beef, dairy, swine, and poultry wastes in New Jersey. The amount of nitrogen that leaches into ground water or surface water is not known, however.

Septic systems are the means of disposal of human wastes for about 18 percent of the population of New Jersey (Susan Lance, Rutgers University, written commun., 1992) and almost 100 percent of the population in agricultural areas of the New Jersey Coastal Plain. Nitrogen in septic-system effluent usually consists of about 75 to 80 percent ammonium and 20 to 25 percent organic nitrogen. Concentrations of total nitrogen in septic systems range from 25 to 100 mg/L. The typical annual nitrogen contribution from a family of four is estimated to be about 33 kg/yr (Hantzsche and Finnemore, 1992, p. 491). In 1987 there

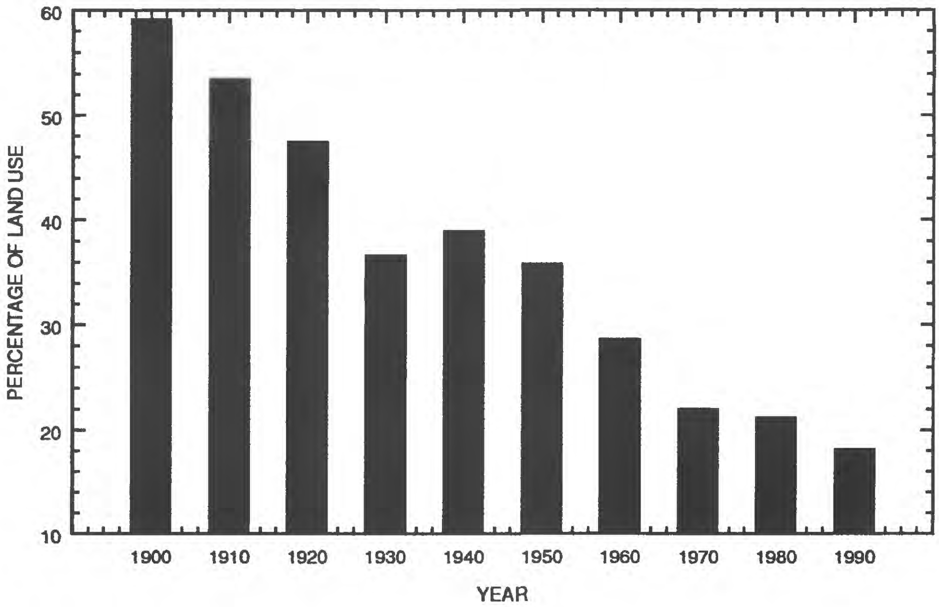

Figure 4. Percentage of New Jersey land that was agricultural, 1900-1990. (Data from New Jersey Department of Agriculture, 1990, p. 93.).

Table 1. Number of livestock, dairy, and poultry raised on New Jersey farms

[Modified from New Jersey Department of Agriculture, 1961, 1970, 1980, 1990]

Livestock type	Number of head x 1,000			
	1960	1970	1979	1989
Cattle and calves	200	132	108	75
Milk cows	140	69	41	28
Hogs and pigs	172	121	45	30
Sheep and lambs	16	8	7	15
Chickens (layers)	12,596	4,547	1,483	1,687
Turkeys	13	12	59	100

were about 9,000 farms in New Jersey. If the average farm household contains four persons, the annual load of total nitrogen from septic systems at these 9,000 farm homes is estimated to be about 300 metric tons. The estimated nitrogen load from septic systems is less than 1 percent of that reported for sales of fertilizers.

In almost all farming operations in New Jersey, both nutrients and pesticides are used to increase crop productivity. Pesticides are used to control weeds, insects, and fungi and as growth regulators. Almost 10,000 formulated pesticide products containing 400 to 500 active ingredients are registered for use in New Jersey. Pesticides are used in most agricultural areas of the Coastal Plain. Farmers reported the application of about 859 metric tons of 176 different active ingredients on farming operations in New Jersey during 1985. The applied pesticides included 358 metric tons of fungicides, 266 metric tons of herbicides, 228 metric tons of insecticides, 6 metric tons of fumigants, and about 1 metric ton of growth regulators (Louis and others, 1989, p. 198). The greatest amount of herbicides applied were alachlor, metolachlor, and atrazine. The greatest amount of insecticides applied were parathion, oil, and methomyl. Sulfur was the most commonly used fungicide.

METHODS OF DATA COLLECTION AND ANALYSIS

Information on well-location, well-construction, hydrogeologic, water-quality, and land-use characteristics were collected and stored in a geographic information system (GIS). The GIS allows for the spatial referencing of the data. Two stratified data sets were developed to test hypotheses concerning the relations of shallow-ground-water quality to hydrogeologic, well-construction, and land-use variables.

Well-Selection Criteria

The first data set, which will be called the regional data set, was developed from available data to evaluate the relation between land use and shallow-ground-water quality at a regional scale. The regional data set consists of water-quality samples collected by the USGS during 1980-89 from 233 shallow wells screened in the outcrop areas of the Potomac-Raritan-Magothy aquifer system and the Kirkwood-Cohansey aquifer system. Well-selection criteria were established to reduce sampling biases associated with hydrogeologic conditions, well-construction characteristics, and spatial autocorrelation (Vowinkel and Battaglin, 1989; Barringer and others, 1990). Because water-quality observations from sites located near each other can be spatially autocorrelated and lack independence, only wells located within the outcrop area with screened intervals less than 30 m below land surface and a minimum well-separation distance of 1,600 m were included in the data set.

The second data set, which will be called the local data set, was developed to evaluate the effects of agricultural land use on the quality of water from shallow domestic wells at the local scale and to monitor seasonal variations in ground-water quality during about a 1-year span. Water samples were collected from 12 shallow domestic wells between April 23, 1991, and April 21, 1992. Six wells are screened in the outcrop area of the Potomac-Raritan-Magothy aquifer system (Study area 1) and six of the wells are screened in the outcrop area of the Kirkwood-Cohansey aquifer system (Study area 2) (fig. 5). The screened intervals of the 12 domestic wells were less than 30 m below the land surface and were located near (less than 250 m) or downgradient from a surface-water divide. Each house near the sampled domestic well was serviced by a septic system. Livestock were raised on four of the farms, within 400 m of the domestic well, but this was not a factor in the selection process.

Water-Quality Sampling, Chemical Analyses, and Quality Control

Water-quality samples were collected by using procedures described by Wood (1976) and Wershaw and others (1983). Wells were sampled at spigots near the wellhead prior to discharging into holding tanks. Before collecting a sample, a minimum of three casing volumes of water were evacuated from the well. Pumping continued until temperature, pH, specific conductance, and dissolved-oxygen concentration was stable for at least three consecutive measurements. After stabilization, an incremental field titration for

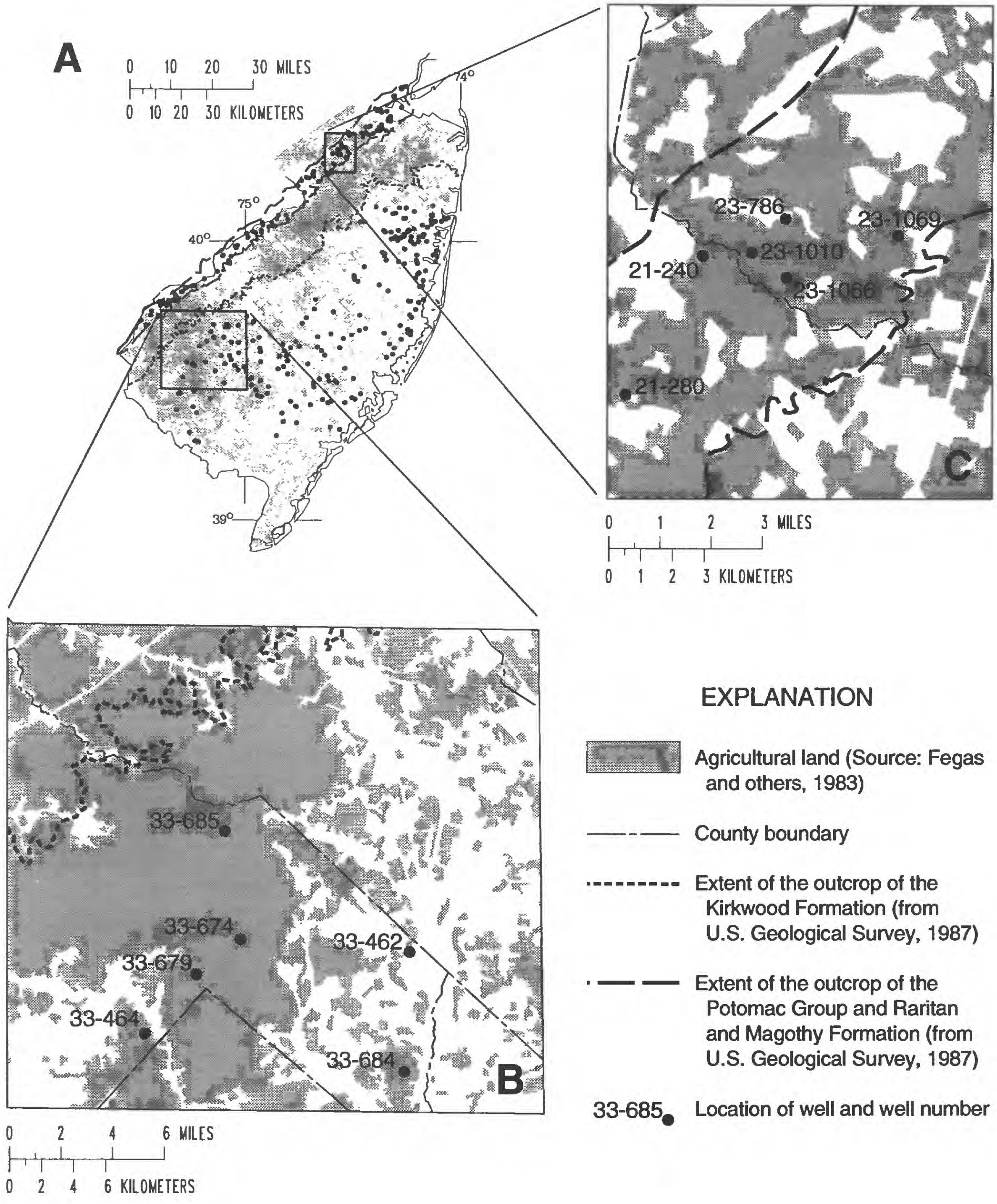

Figure 5. Locations of wells used to evaluate (A) the regional effects of land use on shallow-ground-water quality in the New Jersey Coastal Plain, (B) the local effects of agriculture on shallow ground-water quality in the outcrop area of the Kirkwood-Cohansey aquifer system, and (C) the local effects of agriculture on shallow ground-water quality in the outcrop area of the Potomac-Raritan-Magothy aquifer system.

alkalinity was performed and was followed by sample preparation, preservation, and analysis as described by Fishman and Friedman (1985) for dissolved and suspended inorganic constituents and by Wershaw and others (1983) for organic compounds. Major ion and nutrient samples were filtered in the field.

Minimum reporting levels of physical characteristics and chemical constituents measured in the field and constituents determined in the laboratory are listed in table 2. Results of the analyses are provided in appendix 2. All samples were refrigerated and all, except those to be analyzed for purgeable organic compounds, were mailed within 72 hours to the U.S. Geological Survey National Water Quality Laboratory (NWQL) in Arvada, Colorado. Samples collected for determination of purgeable organic compounds were analyzed at the USGS's New Jersey District laboratory by using a purge-and-trap gas chromatograph with a Hall detector in series with a photoionization detector (Kammer and Gibs, 1989). NWQL laboratory procedures are identified by Feltz and others (1984). Methods of sample preparation and methods of analysis for determination of dissolved and suspended inorganic constituents in and physical characteristics of water are documented by Fishman and Friedman (1985). Wershaw and others (1983) describe the procedures used for analyzing water samples for concentrations of organic carbon and pesticides.

A quality-assurance program was used to evaluate the accuracy of the water-quality data presented in this report. The internal quality-control program followed by the NWQL is documented by Friedman and Erdman (1982), Peart and Thomas (1983), and Wershaw and others (1983). The program involves analyzing a large percentage of samples to evaluate accuracy and precision. The NWQL also is checked by the USGS's Quality Assurance Program, under which standard samples are submitted for analysis and tabulated statistics on the results are reported.

The quality-assurance program developed for the local data set consisting of 12 wells included comparisons of values reported from field and laboratory measurements, cation and anion balance checks, replicate samples, field- and laboratory-blank samples, a spiked sample for pesticides, and comparison of analytical results among multiple laboratories. The median percent difference between cations and anions was less than 3 percent, and the percent difference did not exceed 8 percent in any sample. The median percent difference between measurements of pH and specific conductance made in the field and in the laboratory was less than 6 percent. Because pH and specific conductance can change during sample collection and analysis at the NWQL, field measurements are used exclusively in any statistical analyses.

Replicate samples from the local data set were collected from two wells and analytical results for all constituents were compared. Concentrations of inorganic constituents were similar between replicate samples, and pesticides were detected at similar concentrations in both samples. Duplicate samples were collected at 10 sites during the first sampling event and were submitted to two laboratories for analysis for concentrations of nitrate. One sample was sent to the NWQL and the second sample was sent to a laboratory at Heidelberg College in Tifton, Ohio, for analysis (Baker, 1990). The concentrations reported by the two laboratories were similar ($r = 0.83$).

Three samples containing deionized water were analyzed for triazine and acetanilide herbicides and carbamate insecticides. One sample was sent directly from the USGS New Jersey District's preparation room as a check of possible contamination at the NWQL. The second sample was brought into the field to a site where pesticides had been detected previously in ground-water samples. This sample was a check to determine whether sampling procedures may introduce contaminants into the water samples. No pesticides were detected in the either the field-blank or laboratory-blank water samples. These results indicate that contamination of water samples by pesticides in the field or in the laboratory was unlikely. The third deionized water sample was spiked in the New Jersey District's laboratory with known concentrations of carbamate insecticides and triazine and acetanilide herbicides. The NWQL detected all the pesticides in the sample at concentrations at or near the known concentrations.

Table 2. Physical characteristics and chemical constituents measured in the field and determined in the laboratory in water samples during each sampling event

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter, $CaCO_3$, calcium carbonate; µS/cm; microsiemens per centimeter at 25 degrees Celsius; N, nitrogen; P, phosphorous]

Water-quality characteristic or constituent	Minimum laboratory reporting level	Sampling event 1	2	3	4
Physical characteristics and constituents measured in the field					
Water temperature (°C)	0.1	Yes[1]	Yes	Yes	Yes
pH	.1	Yes	Yes	Yes	Yes
Dissolved oxygen (mg/L)	.1	Yes	Yes	Yes	Yes
Alkalinity (mg/L as $CaCO_3$)	11	Yes	Yes	Yes	Yes
Specific conductance (µS/cm)	1	Yes	Yes	Yes	Yes
Laboratory analyses					
Dissolved major ions (mg/L)	.1	Yes	No	No	No
Dissolved metals (µg/L)	variable 1 to 10	Yes	No	No	No
Dissolved nutrients (mg/L)					
Nitrate plus nitrite (as N)	.01	Yes	Yes	Yes	Yes
Nitrite (as N)	.01	Yes	Yes	Yes	Yes
Ammonia (as N)	.01	Yes	Yes	Yes	Yes
Ammonia plus organic nitrogen (as N)	.2	Yes	Yes	Yes	Yes
Orthophosphate (as P)	.01	Yes	Yes	Yes	Yes
Nitrogen $N^{15/14}$ isotope ratio (δN^{15}, in per mil)	.1	Yes	Yes	Yes	No
Bacteria (colonies per 100 milliliters)					
Fecal coliform bacteria	1	Yes	Yes	Yes	Yes
Fecal streptococci bacteria	1	Yes	Yes	Yes	Yes
Dissolved organic carbon (mg/L)	.1	Yes	No	No	No
Methylene blue active substances (MBAS) (mg/L)	.01	Yes	Yes	Yes	No
Volatile organic compounds (µg/L)	.2	Yes	No	No	No
Carbamate insecticides (µg/L)	.5	Yes	Yes	Yes	No
Triazine and acetanilide herbicides (µg/L)	.05	Yes	Yes	Yes	No

[1]A "yes" indicates that water samples were collected and analyzed for the indicated characteristic or constituent. A "no" indicates that samples were not collected for this analysis.

During the fourth sampling event, two samples containing deionized water were taken into the field to sites in agricultural areas of the New Jersey Coastal Plain where fecal streptococci bacteria had been detected previously in ground-water samples. The deionized water samples were exposed to the air to determine whether samples had been contaminated by airborne fecal streptococci bacteria. Those samples exposed to the air contained small concentrations of fecal streptococci bacteria, indicating that contamination of the samples in the field was likely. For this reason, any results relating the presence of fecal streptococci bacteria to concentrations of nitrate in ground water are used with caution.

The results of the quality-assurance program indicate that the concentrations of constituents reported by the NWQL are reasonable and that sampling procedures (except in the case of fecal streptococci bacteria) and laboratory procedures did not introduce biases in the water-quality analyses.

Quantification of Land Use Near a Well

For the regional data set used to evaluate the effects of land use on shallow-ground-water quality at a regional scale, percentages of undeveloped, agricultural, residential, and urban-nonresidential land within an 800-m-radius buffer zone centered on the wellhead were calculated from digital land-use and land-cover data obtained from the National Cartographic Information Center (Anderson and others, 1976; Fegeas and others, 1983). The buffer zone was used as a crude measure to quantify the land area surrounding a well that potentially could affect water quality. Problems associated with using land use to predict ground-water quality are discussed in Barringer and others (1990); these problems include data closure, the misclassification of land uses, and spatial autocorrelation resulting from the overlapping of buffer zones.

For the regional data set, the predominant-land-use method was used to quantify the relation between ground-water quality and land use (Vowinkel and Battaglin, 1989). In the predominant-land-use method, the land use comprising the largest areal extent within a buffer zone is assumed to have the greatest effect on the quality of water from a well. A limitation of the predominant-land-use method is that land uses within the buffer zone that are not the predominant land use are not considered to affect significantly the quality of water in the well.

For the local data set, more detailed land-use data were collected in the field at the time of sampling. Types of land-use data collected included the presence of livestock, the use of pesticides and chemical fertilizers on fields and lawns near the domestic well, the locations of agricultural plots, and the distance between the domestic well and septic system(s).

Statistical Methods

The median and interquartile range (25th and 75th percentiles) are used to evaluate the distributions and central tendencies of the water-quality-constituent concentrations. The median is reported rather than the mean because the water-quality-concentration data typically are nonnormally distributed (skewed) and are left-censored (truncated) as a result of a minimum laboratory reporting level. Concentrations below the laboratory reporting level were assigned the same value below the laboratory reporting level to distinguish them from concentrations at the reporting level. Boxplots are used to summarize graphically the characteristics of the data sets; they display the median, quartiles, spread, skewness, and presence of unusual values.

Nonparametric statistical procedures were used to test hypotheses to determine differences in water-quality concentrations among groups. When applied to nonnormal data, the power of parametric procedures is low and their results may be in error (Helsel, 1987, p. 179). Because the data typically were nonnormally distributed, correlation coefficients were determined with ranked independent and dependent variables to evaluate linear relations between variables. The Kruskal-Wallis test was used to test hypotheses about the distributions of concentrations among groups. In these statistical tests, the data are assumed to be random and independent. Because the data from each well site may be serially autocorrelated, statistical tests were conducted independently for each sampling event and the results were averaged over all the sampling events. If a test statistic met or exceeded a 0.05 significance level, the distribution of values in one group was considered significantly different from that of another group.

Multivariate statistical methods are used to identify groups of intercorrelated variables, reduce the number of variables being studied, and rewrite the data in an alternative form. Discriminant analysis, which makes use of the general linear model with nominally measured dependent variables (Johnson, 1980, p. 225-231), was used in this study to determine whether the variability in the distributions of certain water-quality, well-construction, land-use, and hydrogeologic variables are similar. The statistical model developed in this report is used to determine which variables are useful to predict whether the concentration of nitrate will be below (Group 1) or equal to or greater than (Group 2) the MCL. The independent variables were ranked prior to the discriminant analysis to avoid problems associated with nonnormally distributed values and outliers.

INDICATORS OF THE SOURCES AND DISTRIBUTION OF NITRATE IN WATER FROM SHALLOW DOMESTIC WELLS

Land-use variables describe the sources of nitrate in the environment, whereas hydrogeologic, well-construction, and water-quality variables affect the distribution of nitrate in ground water. Each variable is tested independently to determine whether a significant association with nitrate concentration exists. Groups of variables are then tested to determine which variables best describe the conditions when nitrate in shallow ground water is equal to or greater than 10 mg/L.

Factors Affecting or Related to Nitrate Concentrations

Before testing hypotheses concerning relations among hydrogeologic, well-construction, land-use, and water-quality variables, it was necessary to determine whether the time of year during which the sample was collected or the aquifer system from which the sample was collected could affect statistical results. Because sample sizes generally are small, biases that can affect the results need to be eliminated or minimized.

Sampling Event

Because agricultural chemicals are applied seasonally (mostly during spring), variability in concentrations of water-quality constituents was expected in shallow wells affected by agricultural applications of fertilizers and pesticides. To test this hypothesis, water-quality samples were collected from the 12 domestic wells on four occasions during the year. Values and concentrations reported for physical characteristics and chemical constituents measured in the field and water-quality constituents determined in the laboratory were compared for significant differences among the four sampling events (table 3). The results indicate that concentrations of most physical characteristics and constituents were similar among the four sampling events. The exceptions are that the temperature of the air and ground water and the concentration of ammonia plus organic nitrogen differed during at least one of the four sampling events. The air temperature varied as expected; median temperatures ranged from 22.5 to -1.0°C. The seasonal variability of the temperature of the ground water was significant; however, the median water temperatures during the four sampling events did not differ by more than 1 °C. Concentrations of ammonia plus organic nitrogen ($p = <0.001$) and orthophosphate ($p = 0.051$) in ground water varied among sampling events, probably because the analytical technique used at the NWQL was changed to a less sensitive technique just prior to the third sampling run (Jacob Gibs, U.S. Geological Survey, oral commun, 1991); for this reason these two constituents are not used in any of the statistical comparisons in this report.

Table 3. Physical characteristics and chemical constituents measured in the field and concentrations of water-quality constituents for 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, by sampling event.

[°C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µS/cm; microsiemens per centimeter at 25 degrees Celsius; N, nitrogen; P, phosphorous; col/100 mL, colonies per 100 milliliters; µg/L, micrograms per liter; ND, not detected; NA, not applicable. All concentrations are in mg/L except where noted]

Water-quality characteristic or constituent	Median value or concentration for sampling event				Kruskal-Wallis test p-value[1]
	1	2	3	4	
Physical characteristics and chemical constituents measured in the field					
Air temperature (°C)	22.5	27.5	-1.0	8.5	<0.0001
Water temperature (°C)	13.4	13.5	12.5	12.6	.028
pH	5.2	5.0	5.1	5.3	.763
Alkalinity ($CaCO_3$)	3.0	2.0	6.0	8.0	.839
Specific conductance (µS/cm)	191	213	187	187	.772
Dissolved oxygen	8.5	8.8	9.0	8.7	.607
Laboratory analyses					
Dissolved nutrients					
Ammonia (as N)	<.01	<.01	.05	<.01	.364
Ammonia plus organic nitrogen (as N)[2]	.45	.60	<.1	<.1	<.0001
Nitrite (as N)	<.01	<.01	<.01	<.01	.218
Nitrate (as N)	10.8	9.7	10.7	12.0	.982
Orthophosphate (as P)[2]	<.01	<.01	<.01	<.01	.051
Nitrogen $N^{15/14}$ isotope ratio (δN^{15}, in per mil)	3.7	3.3	2.9	NA	.152
Organic constituents					
Methylene blue active substances (MBAS) (mg/L)	.09	.11	.12	NA	.620
Fecal coliform (col/100 mL)	<1	<1	<1	<1	.783
Fecal streptococci (col/100 mL)	7.5	<1	<1	<1	.783
Total pesticides (µg/L)	ND	ND	ND	NA	.879
Total carbamate insecticides (µg/L)	<.5	<.5	<.5	NA	.864
Total triazine and acetanilide herbicides (µg/L)	<.05	<.05	<.05	NA	.654

[1]The Kruskal-Wallis test is used to test the hypothesis that the distributions of values or concentrations of one or more sampling events is different from those of the other events. A p-value equal to or less than 0.05 is considered significant.

[2]Results of analyses for ammonia plus organic nitrogen and orthophosphate differed between the second and third sampling event, causing the significant difference among events.

Concentrations of nitrate in ground water from the 12 domestic wells were similar ($p = 0.98$) among the four sampling events (fig. 6). Concentrations of nitrate (as N) rarely varied by more than 1 mg/L at any well. Seasonal loadings of nitrate at the land surface are not apparent in water samples from these 12 wells, probably because the nitrate is transported and dispersed along the ground-water flow path.

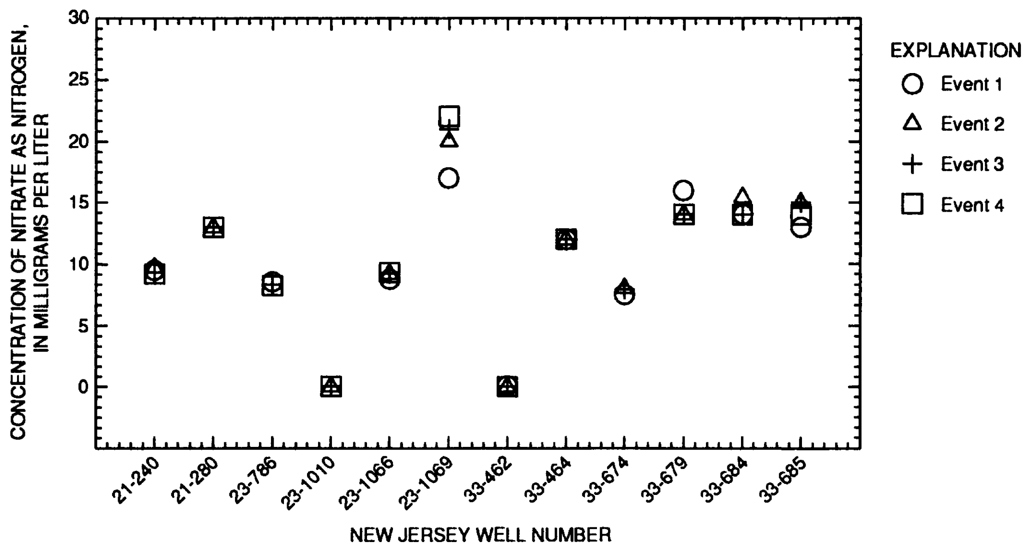

Figure 6. Distribution of concentrations of nitrate in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, by sampling event.

From these observations, several inferences are made about the quality of shallow ground water from wells with screened intervals between 16 and 30 m below the land surface: (1) concentrations of nitrate and other water-quality constituents probably do not vary seasonally; (2) sampling of wells for water-quality analyses more frequently than on a yearly cycle probably is not necessary; and (3) seasonal sampling probably does not affect statistical relations between concentrations of nitrate and other variables, such as land use.

Hydrogeologic Characteristics

Prior to determining the effects of land use on shallow-ground-water quality, the effects of hydrogeologic conditions on water quality must be considered. Water-quality characteristics and constituent concentrations are compared between the two aquifer systems and between wells located on or near the surface-water divide and those located downgradient from the divide.

Aquifer System

One of the goals of this analysis is to test the transfer value of the relations between shallow-ground-water quality and land use to other areas of similar hydrogeology and land use where water-quality data are sparse. Because only 12 sampling sites were used in the statistical analysis (6 in Study area 1 in the Potomac-Raritan-Magothy aquifer system and 6 in Study area 2 in the Kirkwood-Cohansey aquifer system), it was necessary to determine whether the values and concentrations of water-quality characteristics and constituents are similar between the two aquifer systems (table 4). If the values are

Table 4. Physical characteristics and chemical constituents measured in the field and concentrations of water-quality constituents for 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, by aquifer system

[°C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µS/cm, microsiemens per centimeter at 25 degrees Celsius; N, nitrogen; P, phosphorous; col/100 mL, colonies per 100 milliliters; µg/L, micrograms per liter; ND, not detected; NA, not applicable. All concentrations are in mg/L except where noted]

Water quality characteristic constituent	Median value or concentration for the: Study area 1 Potomac-Raritan-Magothy aquifer system	Study area 2 Kirkwood-Cohansey aquifer system	Kruskal-Wallis test p-value[1]
Physical characteristics and chemical constituents measured in the field			
Water temperature (°C)	12.4	13.7	<0.0001
pH	5.4	4.6	<.0001
Alkalinity (as $CaCO_3$)	7.5	<.1	<.0001
Specific conductance (in µS/cm)	168	211	.278
Dissolved oxygen	8.7	9.0	.373
Laboratory analyses			
Dissolved nutrients			
Ammonia (as N)	<.1	<.1	.879
Nitrite (as N)	<.01	<.01	.373
Nitrate (as N)	9.3	12	.671
Nitrogen $N^{15/14}$ isotope ratio (δN^{15}, in per mil)	2.9	3.5	.447
Organic constituents			
Dissolved organic carbon	.3	.4	.257
Methylene blue active substances (MBAS) (mg/L)	.09	.12	.356
Fecal coliform (col/100 mL)	<1	<1	.498
Fecal streptococci (col/100 mL)	<1	3	.113
Total pesticides (µg/L)	ND	ND	.741
Total carbamate insecticides (µg/L)	<.5	<.5	.583
Total triazine and acetanilide herbicides (µg/L)	<.05	<.05	.396

[1]The Kruskal-Wallis test is used to test the hypothesis that the distribution of values or concentrations in one aquifer system is different from that in the other aquifer system. A p-value equal to or less than 0.05 is considered to be significant.

similar between the two aquifer systems, then combining the data sets from both aquifer systems would not be expected to introduce biases when testing hypotheses related to the effects of other hydrogeologic, well-construction, and land-use factors on shallow-ground-water quality.

The values of some of the physical characteristics and concentrations of chemical constituents in water samples measured in the field differed between the two aquifer systems; however, the concentrations of most water-quality constituents generally were similar between the two aquifer systems. The pH and alkalinity of shallow ground water in agricultural areas were significantly lower in the outcrop area of the Kirkwood-Cohansey aquifer system than in the outcrop area of the Potomac-Raritan-Magothy aquifer system. The median pH of shallow water was about 0.5 pH units lower in the outcrop area of the Kirkwood-Cohansey aquifer system than in the outcrop area of the Potomac-Raritan-Magothy aquifer system.

The results of the statistical analysis indicate that values and concentrations of most water-quality characteristics and constituents generally are similar between the two aquifer systems. The distributions of concentrations of nitrate in shallow ground water in agricultural areas are similar ($p = 0.67$) in both aquifer systems. This result indicates that combining the data from the two aquifer systems to test hypotheses probably does not significantly affect the statistical results when comparing other variables. Also, this suggests that there is transfer value of the relations between ground-water quality and land use to other areas of similar conditions where water-quality data is scarce.

Hydrogeologic Scenario

Domestic wells used to supply drinking water to farm homes typically are located at higher elevations near the surface-water divide or at lower elevations near discharge areas such as streams or ponds. Nitrate concentrations were expected to be larger in water from domestic wells near the divide where the ground water is relatively young than in water from domestic wells near a stream where the age of the water commonly is much older.

In water from the 12 domestic wells in the local data set, the median concentration of nitrate was larger in those five wells near (less than 250 m from) the surface-water divide than in those seven wells downgradient (equal to or greater than 250 m) from the divide (table 5 and fig. 7). The median concentration of nitrate (as N) in shallow ground water in agricultural areas was 12 mg/L near the divide and 8.3 mg/L downgradient from the divide. The range of concentrations of nitrate in ground water near the surface-water divide is relatively small, partly because the ground-water flow paths are short and the water is young. The range of concentrations of nitrate in water from the wells downgradient from the divide is larger, possibly as a result of the dispersion of the nitrates along the ground-water flow path; also, in some cases, the water is too old to have been affected by nitrate sources at the land surface.

Well-Construction Characteristics

Prior to determining the effects of land use on shallow-ground-water quality, the effects of well construction on water quality must be determined. Water-quality characteristics and constituent concentrations are compared between well types and wells of different depth.

Type of Well

The type of well sampled may bias results when comparing regional water quality to land-use or other factors. Domestic wells in the outcrop area of the Potomac-Raritan-Magothy aquifer system typically are shallow and are screened in unconfined parts of the aquifer system, whereas irrigation wells typically are deeper and are screened in confined parts of the aquifer system. Domestic and irrigation wells in the Kirkwood-Cohansey aquifer system, commonly are of similar depths and generally are screened in unconfined parts of the aquifer system.

Table 5. Statistical summary of the concentrations of nitrate in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, by location of the well relative to the surface-water divide

[<, less than; ≥, equal to or greater than; m, meter]

Location of the well relative to the surface-water divide	Number of wells/samples	Concentration of nitrate as nitrogen, in milligrams per liter: 25th percentile	Median	75th percentile	Kruskal-Wallis test p-value
Downgradient (≥ 250 m)	7/28	<0.1	8.3	14	0.39
Near (<250 m)	5/20	9.3	12	14	

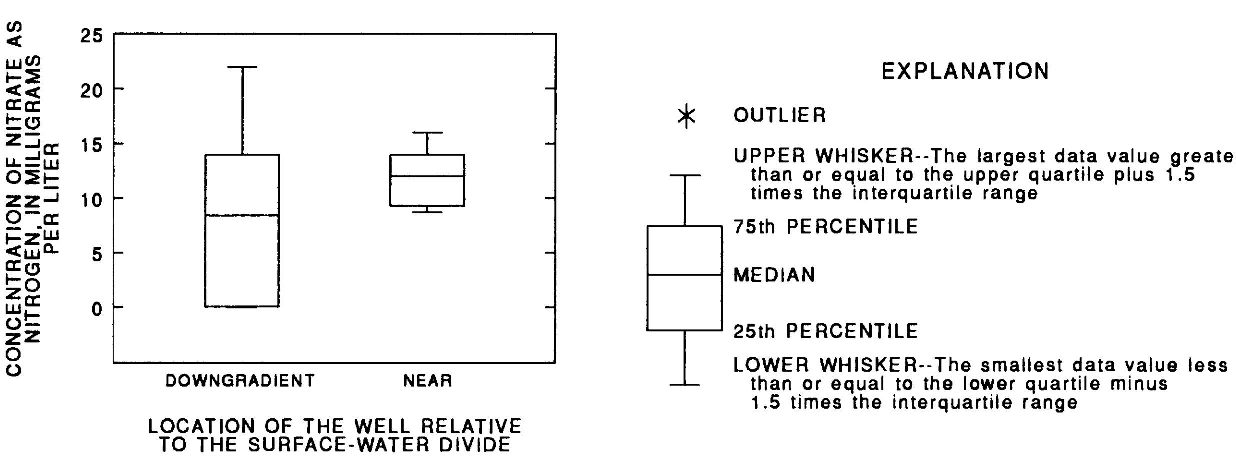

Figure 7. Distributions of concentrations of nitrate in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, by location of the well relative to the surface-water divide.

To determine whether the type of well sampled may bias statistical results, wells from the regional data set in predominantly agricultural areas with screened intervals equal to or less than 30 m below the land surface were selected to determine whether concentrations of nitrate in water are similar in samples from domestic and irrigation wells (table 6 and fig. 8). The results of the analysis indicate that the concentrations of nitrate in shallow ground water in agricultural areas are similar ($p = 0.23$) in domestic and irrigation wells. The median concentration of nitrate (as N) in shallow ground water was 8.5 mg/L in domestic wells and 9.8 mg/L in irrigation wells. The results indicate that the type of well sampled probably does not affect the relation between the concentration of nitrate in shallow ground water and the predominant land use surrounding the well. Because the concentrations of nitrate are similar in water from domestic wells and irrigation wells, it is suspected that agricultural land-use practices rather than septic systems may be the predominant source of nitrate in water from domestic wells.

Well Depth

All wells completed in the unconsolidated sediments of the New Jersey Coastal Plain have screens, and almost all wells are screened in only one aquifer. The depth of the well is defined by the depth to the top and the depth to the bottom of the screened interval below the land surface. The median depth to the bottom of the screened interval of a domestic well in the Coastal Plain of New Jersey is about 25 m. The screened lengths typically are from 1 to 10 m with a median length of about 3 m. The location of the well along the ground-water flow path and the depth of the well probably affect the concentrations of nitrate measured in water from the well. The concentration of nitrate in ground water was expected to decrease with depth in the aquifer.

In the local data set, the concentration of nitrate observed in ground water is affected by well depth. The depths to the top of the screened interval ($p = 0.189$) and the depths to the bottom of the screened interval ($p=0.108$) are shallower in wells in which the concentrations of nitrate exceeded the MCL than in wells in which the concentrations were less than the MCL (table 7 and fig. 9). The depth to the top of the screened interval typically was less than 20 m in those wells containing water with concentrations of nitrate greater than the MCL.

Other Water-Quality Characteristics and Constituents

Results of analyses of ground-water samples for physical characteristics and chemical constituents in the field and for chemical constituents in the laboratory may be useful indicators of sources of nitrate contamination in ground water and of whether the concentration of nitrate in the ground water is likely to exceed the MCL.

The physical characteristics of and chemical constituents in ground water measured in the field at the time the sample was collected were specific conductance, dissolved-oxygen concentration, pH, alkalinity, and temperature. If any of these characteristics was related to the concentration of nitrate in the ground water, it would provide a quick and inexpensive screening technique to determine whether the concentration of nitrate is large and may exceed the MCL. Results of statistical tests indicate that the values of pH, alkalinity, and temperature of the water sample are not significantly related to the concentration of nitrate, whereas the specific conductance of and the concentration of dissolved oxygen in the water sample are significantly related to the concentration of nitrate in the sample. The relation of specific conductance and dissolved-oxygen concentration to nitrate concentration are discussed later in the report.

It was expected that if the quality of water in wells in the local data set was affected by effluent from a septic system, contaminants such as fecal coliform bacteria, certain volatile organic compounds (VOC's), such as those found in household cleaners, and methylene blue active substances (MBAS), which are found in detergents, may be present in the water samples. None of the 31 VOC's analyzed for was reported at concentrations greater than the laboratory reporting level concentration of 0.2 µg/L in water samples from any of the 12 domestic wells. Fecal coliform bacteria were detected in three water samples and at a

Table 6. Statistical summary of the concentrations of nitrate in shallow ground water in predominantly agricultural areas of the New Jersey Coastal Plain, by type of well

Type of well	Number of wells/samples	Concentration of nitrate as nitrogen, in milligrams per liter: 25th percentile	Median	75th percentile	Kruskal-Wallis test p-value
Domestic	28/28	3.4	8.5	12.8	0.233
Irrigation	17/17	5.0	9.8	21.5	

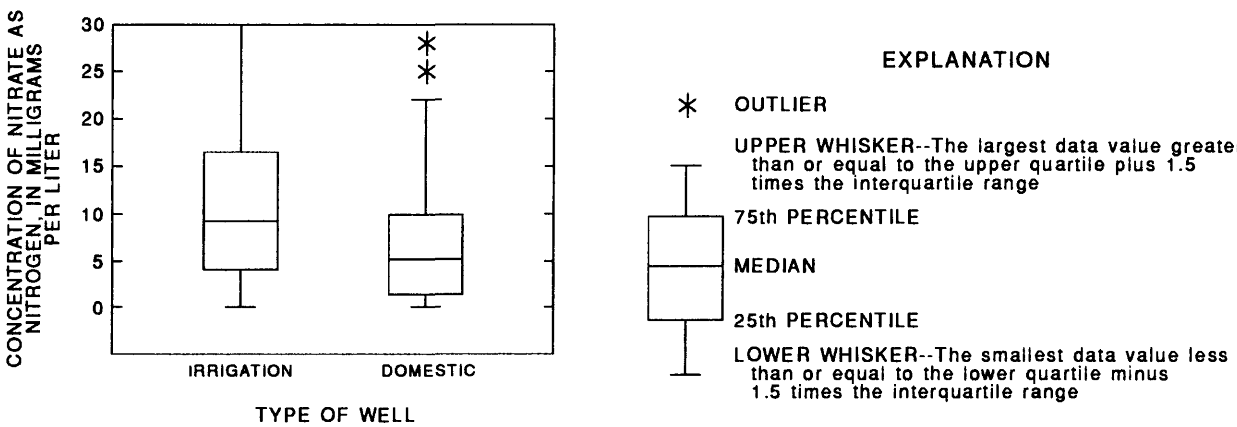

Figure 8. Distributions of concentrations of nitrate in shallow ground water in predominantly agricultural areas of the New Jersey Coastal Plain, by type of well.

Table 7. Statistical summary of the depths to the top of the screened interval for 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the maximum contaminant level for nitrate

Concentration of nitrate as nitrogen, in milligrams per liter	Number of wells/samples	Depth to the top of the screened interval, in meters below the land surface			Kruskal-Wallis test p-value
		25th percentile	Median	75th percentile	
Less than 10	6/24	18.3	21.5	23.2	0.189
10 or greater	6/24	14.6	17.8	19.2	

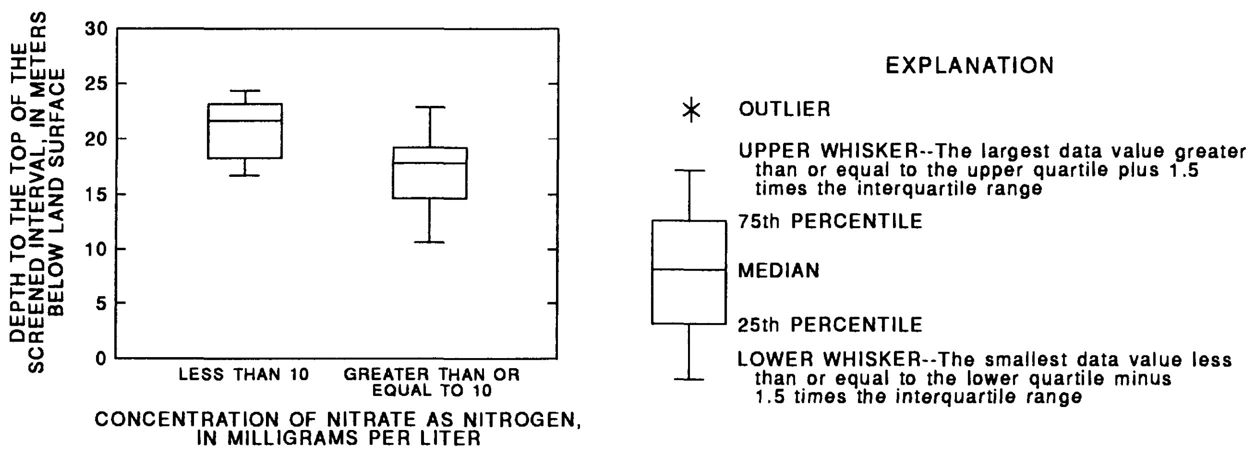

Figure 9. Distributions of the depths to the top of the screened interval of 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the maximum contaminant level for nitrate.

maximum concentration of 3 col/100 mL; all of these samples contained concentrations of nitrate (as N) greater than 10 mg/L. Because VOC's and fecal coliform bacteria generally are not present in water samples from the local data set, these results indicate that the effect of the septic systems on the quality of water in, and concentrations of nitrate in samples from, the wells was minor, probably because none of the septic systems was located upgradient from the well.

Specific Conductance

Specific conductance is a measure of the conductance of water of a unit length and unit cross section at a specified temperature; it is reported in units of μS/cm (microsiemens per centimeter at 25° Celsius). Specific-conductance values provide an indication of the concentration of total ions in solution. A significant positive relation between the values of specific conductance and the concentration of nitrate in the ground-water samples was expected because the nitrate ions contribute to the specific conductance of the water.

In water samples from the local data set, the values of specific conductance were significantly different ($p = 0.005$) in water from wells in which the concentration of nitrate exceeded the MCL than in water from wells in which the concentration of nitrate was less than the MCL (table 8 and fig. 10). In all cases except one, the specific conductance of the water sample was greater than 200 μS/cm when the concentration of nitrate exceeded the MCL. The correlation coefficient between the ranked concentrations of nitrate and specific conductance is 0.82. These results indicate that specific conductance increases as the concentrations of nitrate and other ions such as chloride, sulfate, calcium, and magnesium increase. Nitrate ions commonly constitute a large percentage of the ions contributing to the specific conductance of ground water in agricultural areas.

Dissolved Oxygen

The concentration of dissolved oxygen in ground water can provide an indication of whether the ground water was recently in contact with the atmosphere and whether oxygen has been consumed as a result of geochemical or microbiological reactions with inorganic and organic substances in the subsurface. When oxygen is present in ground water, ammonia in the system usually is converted to nitrate by nitrifying bacteria. Conversely, if dissolved oxygen is absent in ground water, anaerobic denitrifying bacteria can reduce the nitrate in the ground water.

In the regional data set, concentrations of dissolved oxygen in shallow ground water in agricultural areas typically were greater than 3 mg/L; the median concentration of dissolved oxygen in shallow ground water was 8.4 mg/L in the Potomac-Raritan Magothy aquifer system and 7.4 mg/L in the Kirkwood-Cohansey aquifer system. Because shallow ground water in agricultural areas typically contains dissolved oxygen, the predominant form of nitrogen in the ground water is nitrate.

In the local data set, the concentration of dissolved oxygen in water from shallow wells was larger ($p = 0.26$) in wells where the concentration of nitrate exceeded the MCL than in wells where the concentration of nitrate was less than the MCL (table 9 and fig. 11). The concentration of dissolved oxygen in ground water was larger than 6 mg/L in water from wells containing water with a concentration of nitrate greater than the MCL. Concentrations of dissolved oxygen are typically less than 1 mg/L in water from wells near discharge areas. A positive correlation between the ranked concentrations of nitrate and dissolved oxygen in ground water was observed ($r = 0.81$).

Table 8. Statistical summary of values of specific conductance of water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the maximum contaminant level for nitrate

Concentration of nitrate as nitrogen, in milligrams per liter	Number of wells/samples	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius: 25th percentile	Median	75th percentile	Kruskal-Wallis test p-value
Less than 10	6/23	153	162	165	0.005
10 or greater	6/24	218	295	387	

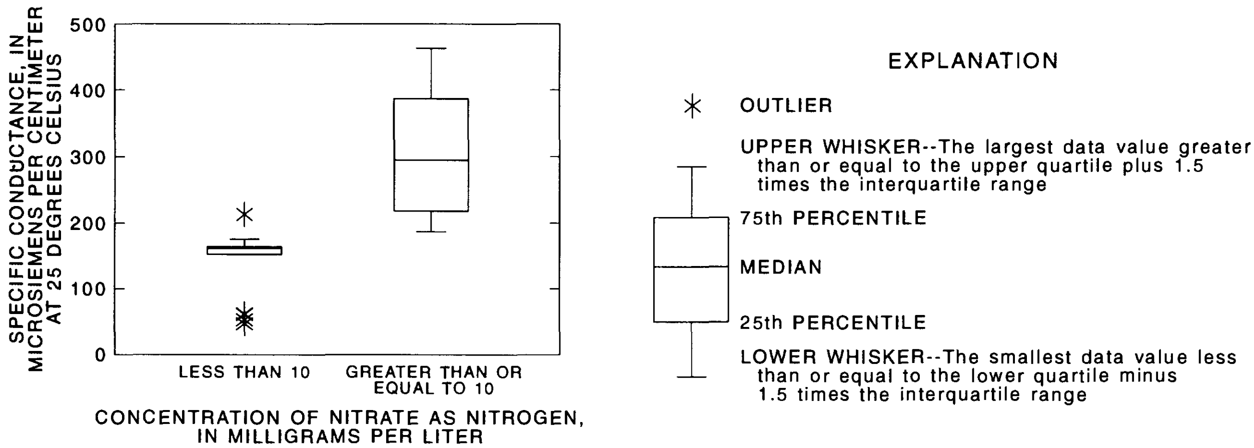

Figure 10. Distributions of values of specific conductance of water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the maximum contaminant level for nitrate.

Table 9. Statistical summary of concentration of dissolved oxygen in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the maximum contaminant level for nitrate

Concentration of nitrate as nitrogen, in milligrams per liter	Number of wells/samples	Concentration of dissolved oxygen, in milligrams per liter			Kruskal-Wallis test p-value
		25th percentile	Median	75th percentile	
Less than 10	6/23	0.2	8.6	9.1	0.26
10 or greater	6/23	8.0	9.0	9.7	

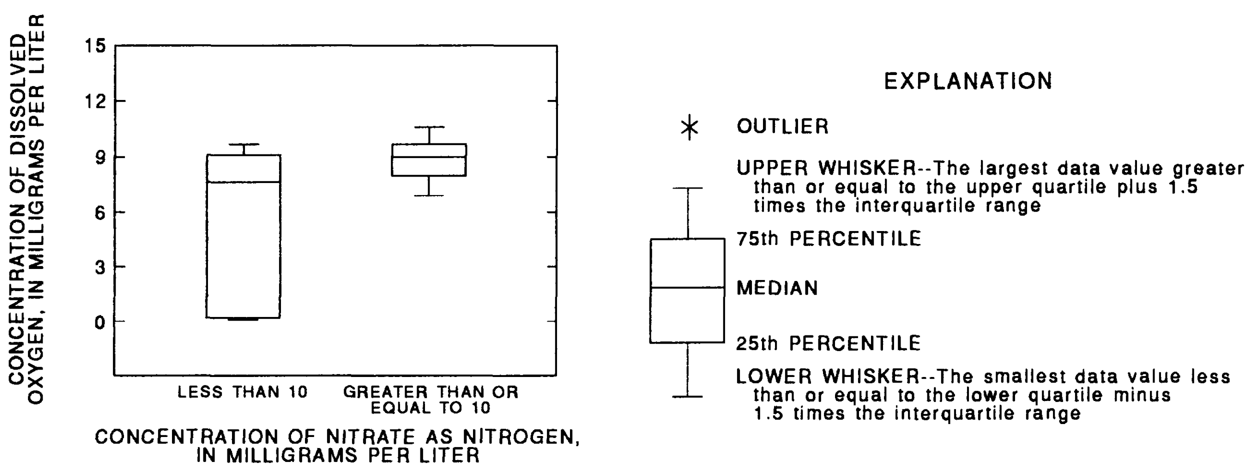

Figure 11. Distributions of concentrations of dissolved oxygen in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the maximum contaminant level for nitrate.

Stable Isotopes of Nitrogen

Ratios of stable isotopes of nitrogen can be used to determine possible sources of nitrate contamination in water. The isotopic composition of N_2 (nitrogen) in a water sample is expressed in terms of its δN^{15} value where

$$\delta N^{15} ({}^{o}/_{oo}) = [(R_{sample} - R_{standard}) / R_{standard}] \times 10^{3}.$$

In the common practice for stable-isotope notation, R, is defined as the atomic N^{15}/N^{14} ratio. Because the isotopic concentration is considered to be globally uniform, the standard is the ratio for atmospheric N_2 (Heaton, 1986). Most fertilizers used for agricultural purposes are processed by means of the Haber process, which incorporates atmospheric nitrogen. The isotopic signature of atmospheric N_2 is 0.0 δN^{15} ${}^{o}/_{oo}$.

A δN^{15} value for a water sample from -2 to 7 ${}^{o}/_{oo}$ indicates that the source is from commercial fertilizers, whereas a value from 10 to 23 ${}^{o}/_{oo}$ indicates that the source is from animal wastes (Tyler Coplen, U.S. Geological Survey, written commun., 1990). Kreitler and others (1978) demonstrated a relation between land use and ${}^{d}N^{15}$ values for shallow ground water on Long Island, New York. The δN^{15} values for water from the upper glacial aquifer were isotopically lighter where the land was predominantly agricultural than where the land was predominantly suburban and serviced by septic systems or sewers. The authors suggest that chemical fertilizers are the predominant source of nitrogen in ground water in agricultural areas and human wastes from septic systems are the primary source of nitrogen in ground water in the residential areas on Long Island.

δN^{15} values for the local set ranged from 1.5 to 6.3 ${}^{o}/_{oo}$; these are below the range of δN^{15} values in water containing nitrogen solely from animal sources. The δN^{15} values indicate that the nitrogen is isotopically heavier ($p = 0.06$) in water from wells that contained a concentration of nitrate greater than the MCL (table 10 and fig. 12) than in water from wells that contained a concentration of nitrate less than the MCL. The δN^{15} values for the water samples from wells in areas where livestock were present were similar ($p = 0.19$) to those from wells located in areas where livestock were absent. These results indicate that the predominant source of nitrate in samples in the local data set was probably chemical fertilizers rather than livestock wastes or effluent from septic systems.

Pesticides

Results of statistical analyses of constituent concentration data from the regional data set indicate a significant relation between the concentration of nitrate and the presence of pesticides in shallow ground water in agricultural areas (Louis and Vowinkel, 1989). Pesticides were detected in water from 33 percent of the 81 sampled wells; pesticides were detected in 43 percent of the irrigation wells, 29 percent of the domestic wells, and 10 percent of the public supply wells. The frequency with which the concentrations of one or more pesticides in water were above the laboratory reporting level was similar for the domestic and irrigation wells. The concentrations of nitrate were significantly different ($p = 0.004$) in water samples from the 27 wells where pesticides were present than those from the 54 wells where pesticides were absent.

Samples collected from wells in the local data set during the first three sampling events were analyzed for triazine and acetanilide herbicides and carbamate insecticides (app. 2F and 2G). Atrazine, alachlor, metolachlor, metribuzin, and carbofuran were the most frequently reported pesticides in ground water. Concentrations of one or more pesticides were above the minimum reporting level in water from four wells during all three sampling events and in water from a fifth well during only one sampling event.

Table 10. Statistical summary of values of δN^{15} in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the maximum contaminant level for nitrate

Concentration of nitrate as nitrogen, in milligrams per liter	Number of wells/samples	Nitrogen $N^{15/14}$ isotope ratio (δN^{15}, in per mil) 25th percentile	Median	75th percentile	Kruskal-Wallis test p-value
Less than 10	6/15	2.0	2.6	3.2	0.06
10 or greater	6/18	3.2	3.8	4.5	

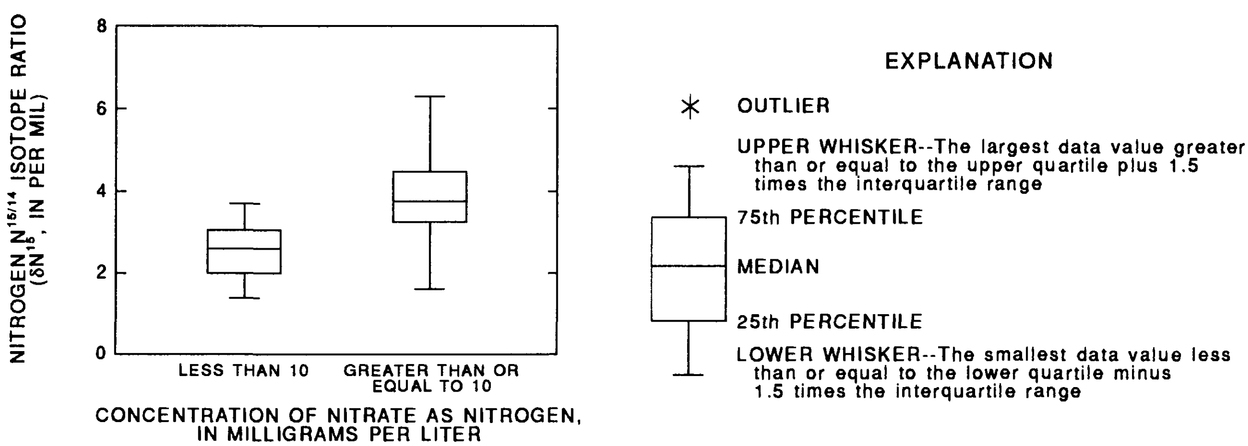

Figure 12. Distributions of values of δN^{15} in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the maximum contaminant level for nitrate.

A significant relation between nitrate concentration and the presence of one or more pesticides in ground water was observed (table 11 and fig. 13). The concentrations of nitrate in the water samples were significantly different in wells with water that contained pesticides than in wells with water that did not contain pesticides ($p = 0.022$). In all but one of the samples that contained a pesticide, the concentration of nitrate was above the MCL.

Land-Use Activities

The concentrations of nitrate in water from shallow wells previously was shown to be significantly related to land use at the regional scale (Vowinkel, 1991). Detailed land-use information near the 12 domestic wells was collected to evaluate the effects of the presence of livestock, septic systems, and land uses surrounding the well on the water quality.

Presence of Livestock

Because livestock are kept in small areas, nitrogen compounds derived from their wastes typically are a source of large concentrations of nitrate in ground water in agricultural areas. Livestock are raised at 4 of 12 sites at which ground water was sampled. It was suspected that the concentration of nitrate in water from shallow domestic wells would be larger at farms where livestock were present within 400 m of the wellhead than in water from the domestic wells where livestock were absent.

In water samples in the local data set, the concentrations of nitrate were similar ($p = 0.74$) between the four sites where livestock were present and the eight sites where livestock were absent (table 12 and fig. 14). The distributions of concentrations of nitrate in ground water in both groups show considerable overlap. Both groups contain samples with concentrations of nitrate greater than the MCL; however, the smallest concentrations of nitrate in water samples are not associated with wells near livestock. These results indicate that nitrogen loads from fertilizers alone and loads from fertilizers and farm-animal wastes can cause concentrations of nitrate in ground water to exceed the MCL.

Distance of the Wellhead from the Septic System

A field evaluation of the location(s) and distance(s) of the septic system(s) and the domestic well relative to the probable direction of ground-water flow was conducted for each of the 12-domestic well sites in the local data set. During the well-selection process, no wells were found that were directly downgradient from a septic system. The lateral distance between the well and the septic system was estimated in the field. The direction of ground-water flow was estimated by observing the locations of the highest elevation (surface-water divide) and the lowest elevation (discharge area). The five wells near the surface-water divide probably were the only wells that could be affected by effluent from a septic system because the elevations of the septic system and the wellhead at these five sites were similar.

If effluent from septic systems affects the concentration of nitrate in water from the wells in the local data set, a negative relation between the distance of the wellhead from the septic system and the nitrate concentration would be expected. Additionally, the distance would be expected to be shorter for those wells containing water with nitrate in concentrations equal to or greater than the MCL than for those containing water with nitrate concentrations less than the MCL. A low positive correlation between the ranked distance and ranked nitrate concentration ($r = 0.13$) was determined. The distributions of the distances from the well to the septic system are similar ($p = 0.41$) for wells containing water with nitrate concentrations equal to or greater than the MCL and those wells containing water with nitrate concentrations less than the MCL (table 13 and fig. 15). These results indicate that the distance between the septic system and the domestic well is not related to the concentration of nitrate in water from the wells in this data set.

Table 11. Statistical summary of concentrations of nitrate in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, by the presence of pesticides in the water samples

Presence of pesticides in water sample	Number of wells/samples	Concentration of nitrate as nitrogen, in milligrams per liter			Kruskal-Wallis test p value
		25th percentile	Median	75th percentile	
Absent	7/23	0.1	8.5	12	0.022
Present	5/13	7.9	10.7	14	

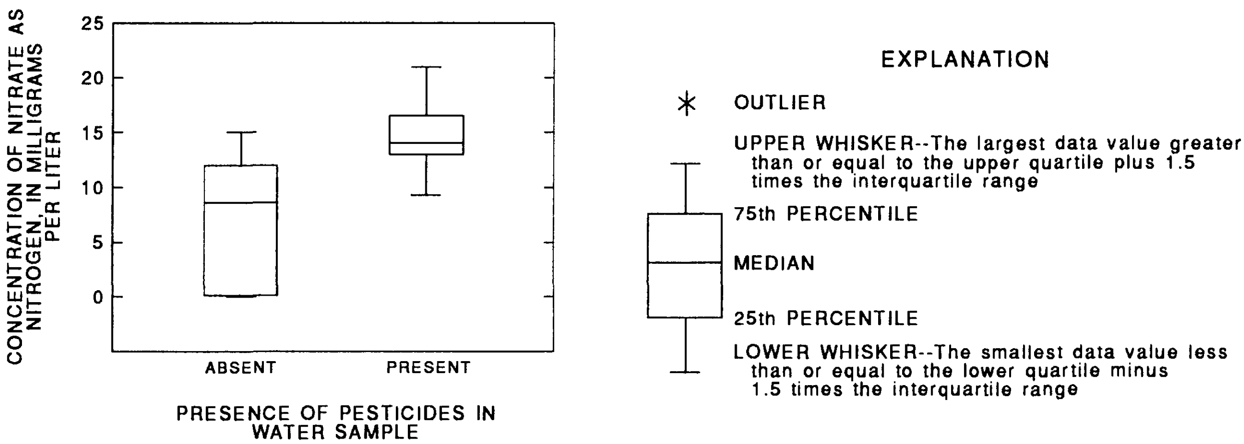

Figure 13. Distributions of concentrations of nitrate in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the presence of pesticides in the water samples.

Table 12. Statistical summary of the distributions of concentrations of nitrate in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, by the presence of livestock near the wellhead

Presence of livestock near wellhead	Number of wells/samples	Concentration of nitrate as nitrogen, in milligrams per liter: 25th percentile	Median	75th percentile	Kruskal-Wallis test p value
Absent	8/32	2.1	9.3	14	0.74
Present	4/16	9.0	12.5	13.8	

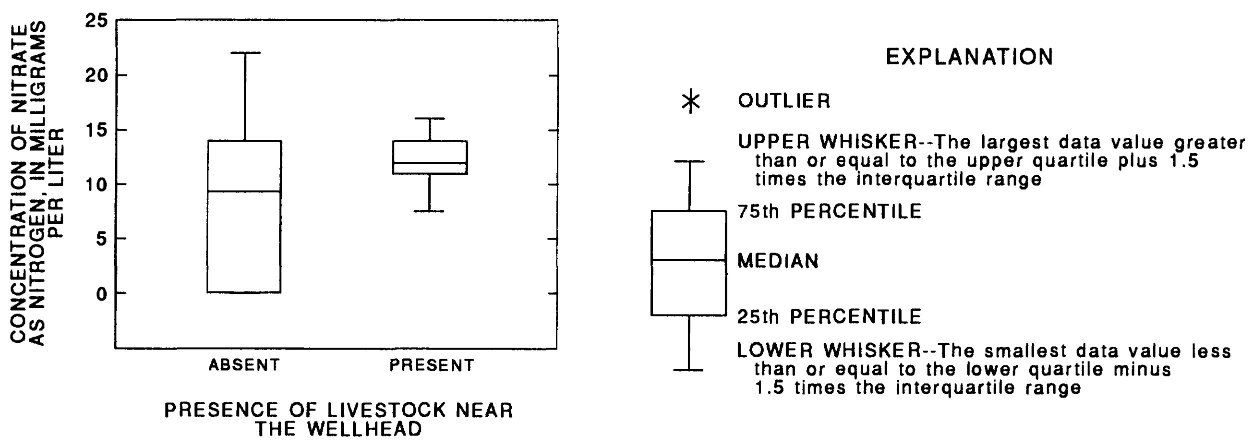

Figure 14. Distributions of concentrations of nitrate in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the presence of livestock near the wellhead.

Table 13. Statistical summary of the distances between the wellhead and the septic system for 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the maximum contaminant level for nitrate

Concentration of nitrate as nitrogen, in milligrams per liter	Number of wells/samples	Distance between well and septic system, in meters			Kruskal-Wallis test p value
		25th percentile	Median	75th percentile	
Less than 10	6/24	18	30	49	0.41
10 or greater	6/24	17	26	28	

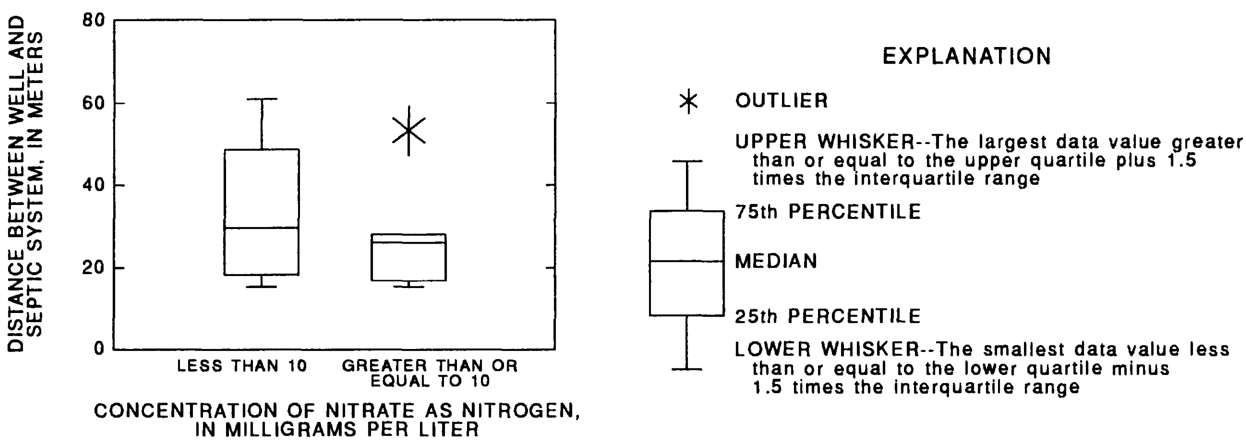

Figure 15. Distributions of distances between the wellhead and the septic system for 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain, relative to the maximum contaminant level for nitrate.

Predominant Land Use Surrounding the Wellhead

Natural sources of nitrate in ground water in undeveloped areas are limited, although nitrate can be transported from agricultural and urban areas through atmospheric deposition and ground-water and surface-water flow. In agricultural areas, sources of nitrate to ground water include septic systems, crop fertilizers, and manure from stock and poultry farms. Nitrate concentrations were expected to be smallest in ground water beneath undeveloped areas because human sources of nitrate are scarce, whereas the largest concentrations of nitrate were expected beneath agricultural land as a result of the presence of multiple sources and the high intensity of nitrate use.

The relation between the concentration of nitrate in shallow ground water and land use for each aquifer system was tested by using data sets with a minimum well-separation distance of 1,600 m and the predominant land use within an 800-m-radius buffer zone of the wellhead (table 14). Nitrate concentrations in shallow ground water in undeveloped areas were smaller than concentrations in agricultural areas; the median nitrate (as N) concentration in undeveloped areas was less than the laboratory reporting level of 0.1 mg/L for both aquifer systems.

Nitrate in shallow ground water in agricultural areas comprises about 75 percent of the total nitrogen concentrations in ground water in the outcrop area of the Potomac-Raritan-Magothy aquifer system and about 90 percent of the total nitrogen concentrations in ground water in the outcrop area of the Kirkwood-Cohansey aquifer system (table 15). Nitrate is predominant over ammonia in part because the ground water in agricultural areas typically contains oxygen, and ammonia is converted to nitrate by microorganisms.

The distributions of concentrations of nitrate in shallow ground water in agricultural areas are similar in both aquifer systems (fig. 16). The median concentrations of nitrate (as N) in shallow ground water from agricultural areas in the outcrop areas of the Kirkwood-Cohansey aquifer system and the Potomac-Raritan-Magothy aquifer system were 7.2 mg/L and 8.5 mg/L respectively; concentrations exceeded the MCL in water from more than 33 percent of the wells in both aquifer systems.

Concentrations of nitrate in shallow ground water were expected to increase as the percentage of agricultural land near a well increased. A positive correlation ($r = 0.81$) was determined between the ranked concentration of nitrate in water from shallow domestic wells and the ranked percentage of agricultural land within 800-m-radius buffer zones of the wellheads (fig. 17). Domestic wells surrounded by more than 50 percent agricultural land have a greater chance of being contaminated by sources of nitrates from agricultural practices that are upgradient from the well. In water from wells surrounded by less than 50 percent agricultural land, the concentration of nitrate (as N) was typically between 3 and 10 mg/L but rarely exceeded 10 mg/L. Elevated concentrations of nitrate in water from shallow domestic wells where agriculture is less than 50 percent of the land use near the well may result from (1) the transport of nitrates in ground water from agricultural areas that are upgradient from the well, (2) the transport of wastes from septic systems near the well, (3) the use of lawn fertilizers, and (4) the conversion of previously agricultural land surrounding the well to other land uses since the early 1970's, when the land-use data used in the analysis were collected. The fourth scenario is likely because much of the agricultural land in New Jersey was converted to other land uses from the 1940's to the 1970's.

Multivariate Statistical Model to Predict Nitrate Concentrations

Discriminant analysis was used to determine those variables (table 16) that best describe the presence of nitrate in water samples from shallow domestic wells in agricultural areas in the local data set. Several combinations of variables were used to predict into which of two groups the water samples would fall: (1) nitrate concentration is less than the MCL, or (2) nitrate concentration is equal to or greater than the MCL. Some variables are better predictors of nitrate concentrations in Group 1, whereas other variables are better predictors of nitrate concentrations in Group 2. For example, the presence or absence of livestock predicted correctly 86.4 percent of the observations in Group 1 but only 50 percent of the observations in Group 2.

Table 14. Statistical summary of concentrations of nitrate in shallow ground water in the New Jersey Coastal Plain, by predominant land use

[<, less than the laboratory reporting level]

			Concentration of nitrate as nitrogen, in milligrams per liter			
Aquifer system outcrop area	Predominant land use	Number of wells/samples	25th percentile	Median	75th percentile	Kruskal-Wallis test p value
Kirkwood-Cohansey	Undeveloped	99/99	<0.1	<0.1	0.7	0.001
	Agricultural	36/36	4.1	7.2	14.8	
Potomac-Raritan-Magothy	Undeveloped	15/15	<.1	.1	1.2	<.001
	Agricultural	24/24	1.2	8.5	12.8	

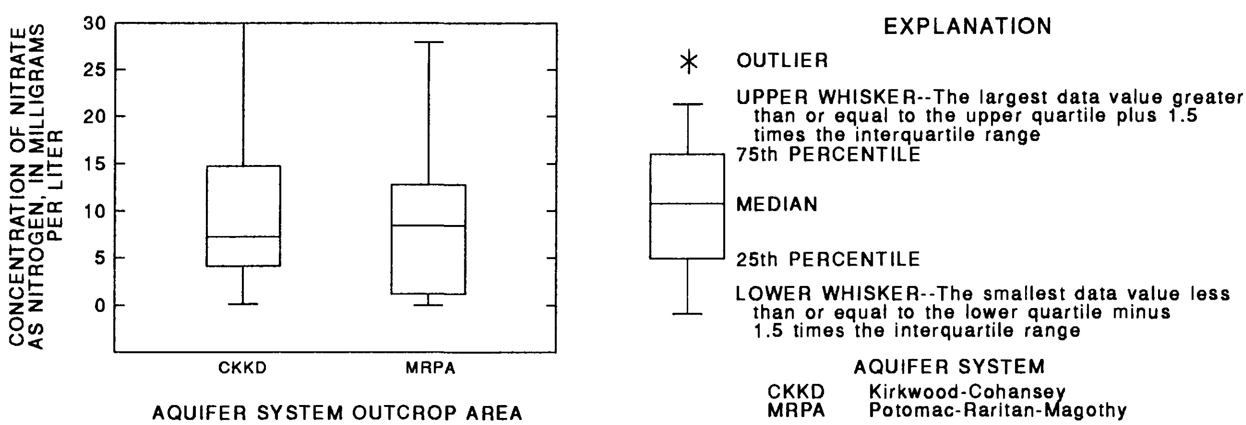

Figure 16. Distributions of concentrations of nitrate in shallow ground water in predominantly agricultural areas of the New Jersey Coastal Plain, by aquifer system.

Table 15. Mean ratio of concentrations of dissolved-nitrogen species to concentrations of all dissolved nitrogen in water from shallow wells in predominantly agricultural areas of the New Jersey Coastal Plain, in the regional data set

[<, less than]

Aquifer system outcrop area	Number of wells/samples	Nitrogen species			
		Nitrate	Nitrite	Ammonia	Organic nitrogen
Kirkwood-Cohansey	24/24	88.9	<0.1	0.9	10.3
Potomac-Raritan-Magothy	23/23	74.4	<.1	8.5	17.1

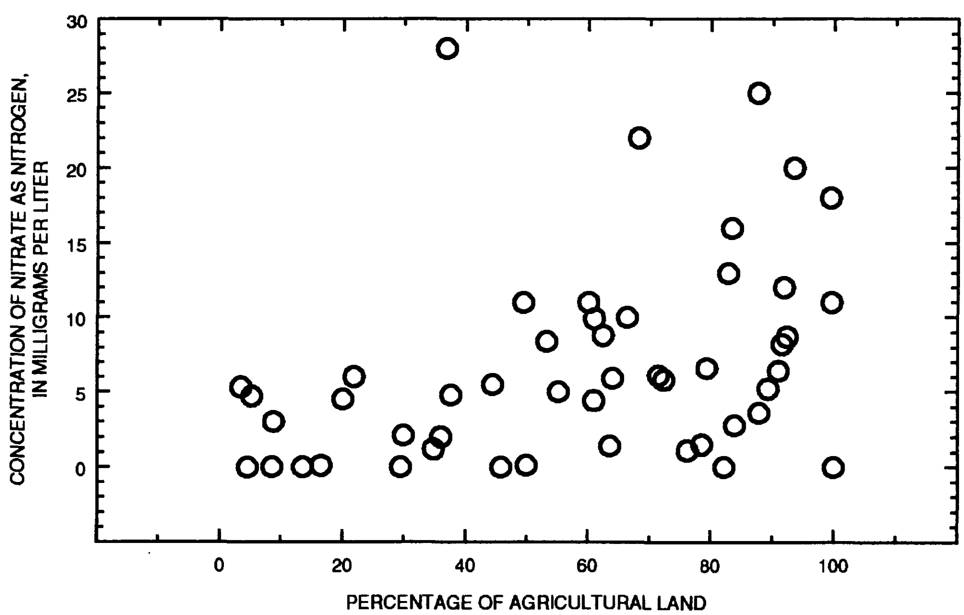

Figure 17. Relation between concentrations of nitrate in water from shallow domestic wells and the percentage of agricultural land within 800-meter-radius buffer zones of the wellhead.

Data sets for the independent and dependent variables listed in table 16 were complete for a total of 46 samples; nitrate concentrations were below the MCL in 22 of the samples and were equal to or greater than the MCL in 24. Specific conductance was the single best discriminator between nitrate concentrations below and above the MCL; it was able to predict correctly more than 90 percent of the nitrate concentrations in Group 1 and Group 2. The variables δN^{15} value, depth to the bottom of the screened interval, and presence or absence of pesticides were able to correctly predict whether the concentration of nitrate was in Group 1 or Group 2 more than 70 percent of the time.

The variables specific conductance, presence or absence of pesticides, presence or absence of livestock, and concentration of dissolved oxygen were able to predict correctly 100 percent of nitrate concentrations in both Group 1 and Group 2 (table 17). Because specific conductance explained about 95.5 percent of the nitrate concentrations in either Group 1 or Group 2, little predictive information is gained by including the other variables. When the variable specific conductance was excluded, the best model for predicting nitrate concentrations in Groups 1 and 2 combined included the variables depth to the top of the screened interval, the presence or absence of pesticides, and the presence or absence of livestock. This model correctly predicted nitrate concentrations in 90.9 percent of the samples in Groups 1 and 2.

In general, the model results indicate that the conditions that best describe those domestic wells in agricultural areas containing water with concentrations of nitrate equal to or greater than the MCL (Group 2) are associated with: specific conductance greater than 200 mg/L, top of the screened interval less than 20 m below the land surface, concentration of dissolved oxygen greater than 6 mg/L, presence of pesticides in the water sample, a distance of less than 250 m between the wellhead and the surface-water divide, and presence of livestock near the wellhead.

SUMMARY AND CONCLUSIONS

Previously collected and new water-quality data from shallow wells (screened interval less than 30 m below the land surface) in predominantly agricultural areas of the New Jersey Coastal Plain were used to determine the relation of nitrate concentrations in shallow ground water to various hydrogeologic and land-use factors in the study area. Information on land use, well construction, hydrogeology, and water quality were used to predict the conditions under which concentrations of nitrate as nitrogen in water from domestic wells in predominantly agricultural areas are most likely to be equal to or larger than the USEPA MCL of 10 mg/L.

Results of the analyses of water-quality samples collected during 1980-89 from 230 shallow wells in the outcrop areas of the Kirkwood-Cohansey and Potomac-Raritan-Magothy aquifer systems were used to evaluate the regional effects of land use on shallow-ground-water quality. Results of statistical analysis indicate that concentrations of nitrate in shallow ground water are significantly different ($p = 0.001$) in agricultural areas than in undeveloped areas in both aquifer systems. Concentrations of nitrate nitrogen exceeded the MCL in water from more than 33 percent of the 60 shallow wells in agricultural areas. Concentrations of nitrate in water from shallow wells in agricultural areas increased as the percentage of agricultural land within an 800-meter-radius buffer zone of the wellhead increased ($r = 0.81$). Concentrations of nitrate in water from domestic wells in agricultural areas were similar ($p = 0.23$) to those concentrations in water from irrigation wells. These results indicate that most of the nitrate in water from domestic wells in agricultural areas is derived from agricultural practices rather than from other sources, such as septic systems.

Water-quality samples collected from 12 shallow domestic wells in agricultural areas screened in the outcrop areas of the Kirkwood-Cohansey and Potomac-Raritan-Magothy aquifer systems were used to evaluate the local effects of hydrogeologic conditions and land-use activities on shallow ground-water quality. Concentrations of water-quality constituents in these wells were similar among four sampling events over a 1-year span. The concentration of nitrate in water from 6 of the 12 wells exceeded the MCL. Concentrations of nitrate greater than the MCL are associated with the following characteristics: values of specific conductance greater than 200 µS/cm, a screened interval whose top is less than 20 m below land surface, concentrations of dissolved oxygen greater than 6 mg/L, the presence of pesticides in the ground water, a distance of less than 250 m between the wellhead and the surface-water divide, and presence of livestock near the wellhead. Ratios of stable isotopes of nitrogen in the water samples indicate that the source of nitrate in the ground water was predominantly chemical fertilizers rather than livestock wastes or effluent from septic systems.

Table 16. Capability of single variables to predict the relation of the concentration of nitrate in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain to the maximum contaminant level for nitrate

[<, less than; ≥, equal to or greater than; MCL, U.S. Environmental Protection Agency's Maximum Contaminant Level]

		Percent correctly predicted		
Variable	Variable-weighting or transformation method	Group 1 (<MCL)	Group 2 (≥MCL)	Both groups
Water quality				
pH	ranked	54.5	62.5	58.7
Specific conductance	ranked	95.5	95.5	95.5
Dissolved oxygen	ranked	50.0	56.5	53.3
δN^{15} value	ranked	78.6	83.3	81.3
Pesticides	present (1) or absent (2)	72.7	75.0	73.9
Well-construction characteristics				
Depth of screened interval				
Top of screen	ranked	68.2	70.8	69.6
Bottom of screen	ranked	81.8	70.8	76.1
Hydrogeologic characteristics				
Hydrogeologic scenario	near (1) or downgradient (2) from the surface-water divide	63.6	50.0	54.2
Distance to surface-water divide	base10 log	50.0	50.0	50.0
Distance to nearest stream	base10 log	50.0	50.0	50.0
Land-use conditions				
Livestock	present (1) or absent (2)	86.4	50.0	67.4
Distance to septic tank	base 10 log	63.6	66.7	65.2

Table 17. Capability of multiple variables to predict the relation of the concentration of nitrate in water from 12 shallow domestic wells in agricultural areas of the New Jersey Coastal Plain to the maximum contaminant level for nitrate

[<, less than; ≥, equal to or greater than; MCL, U.S. Environmental Protection Agency's Maximum Contaminant Level]

		Percent correctly predicted		
Discriminant analysis run number	Variables used in analysis	Group 1 (<MCL)	Group 2 (≥MCL)	Both groups
1	Specific conductance, depth to top of screen, presence of livestock	95.5	91.7	93.5
2	Specific conductance, presence of pesticides, presence of livestock, dissolved-oxygen concentration	100	100	100
3	Depth to top of screen, presence of pesticides, presence of livestock	86.4	100	90.9
4	Presence of pesticides, ratio of nitrogen isotopes, depth to bottom of screen	92.9	83.3	87.5

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Appendix 1. Well-construction characteristics of 12 domestic wells in agricultural areas of the New Jersey Coastal Plain

[--, information not available; ls, land surface; sl, sea level; MM-DD-YY, month-day-year; min, minute]

New Jersey well number[1]	Date of construction (MM-DD-YY)	Primary use of water[2]	Altitude of land surface above sl (meters)	Depth to top of open interval below ls (meters)	Depth to bottom of open interval below ls (meters)	Discharge rate (liters/min)	Date of discharge and water-level measurement (MM-DD-YY)	Depth to static water level below ls (meters)	Depth to pumping water level below ls (meters)	Aquifer code[3]
				Potomac-Raritan-Magothy aquifer system						
21-240	10-03-76	H	25.9	21.6	23.2	132	10-03-76	10.7	16.8	211MRPAM
21-280	--	H	27.4	--	24.4	--	--	--	--	211MRPA
23-786	11-20-79	H	30.5	16.8	19.2	246	11-20-79	2.1	16.7	211MRPAM
23-1010	09-01-76	H	18.3	22.2	24.1	57	09-01-67	2.1	18.3	211MRPAM
23-1066	01-25-85	H	27.4	24.4	27.4	68	01-07-85	13.7	--	211MRPAM
23-1069	08-00-65	H	32.0	18.6	19.5	227	08-00-65	4.0	7.6	211MRPAU
				Kirkwood-Cohansey aquifer system						
33-462	05-01-85	H	29.0	18.3	21.3	--	--	--	--	121CKKD
33-464	11-22-74	H	35.1	14.6	17.7	--	--	--	--	121CKKD
33-674	11-05-83	H	44.2	21.3	24.4	--	--	--	--	121CKKD
33-679	01-05-87	H	42.7	17.1	20.1	--	--	--	--	121CKKD
33-684	11-15-84	H	32.0	19.2	21.3	--	--	--	--	121CKKD
33-685	- -52	H	42.7	--	12.2	--	--	--	--	121CKKD

[1]Locations of wells shown in figure 5. The New Jersey well number consists of a two-digit county code followed by a consecutive number assigned to that well. The county codes are as follows: 21, Mercer; 23, Middlesex; and 33, Salem.

[2]H, domestic.

[3]Aquifer codes: 121CKKD, Cohansey Sand and Kirkwood Formation, undifferentiated;
211MRPA, Potomac-Raritan-Magothy aquifer system, undifferentiated;
211MRPAM, Potomac-Raritan-Magothy aquifer system, middle aquifer;
211MRPAU, Potomac-Raritan-Magothy aquifer system, upper aquifer.

Appendix 2. Results of water-quality analyses of samples from 12 domestic wells in agricultural areas of the New Jersey Coastal Plain

A. Physical characteristics and chemical constituents measured in the field

[MM-DD-YY, month-day-year; <, less than; °C, degrees Celsius; mg/L, milligrams per liter; μS/cm, microsiemens per centimeter at 25 degress Celsius; -- analysis not performed; $CaCO_3$, calcium carbonate]

New Jersey well number	Date sampled (MM-DD-YY)	Air temperature (°C)	Water temperature (°C)	pH (standard units)	Alkalinity (mg/L as $CaCO_3$)	Specific conductance (μS/cm)	Dissolved oxygen (mg/L)
			Potomac-Raritan-Magothy aquifer system				
21-240	05-01-91	24.5	12.6	5.5	6	163	8.9
	08-13-91	28.0	12.9	5.5	6	214	9.7
	12-19-91	-5.0	11.2	5.5	10	176	9.3
	02-11-92	8.0	11.2	5.7	10	162	8.7
21-280	04-30-91	24.0	12.6	5.5	9	268	6.9
	09-05-91	22.0	12.6	4.8	--	264	7.3
	12-17-91	-3.0	12.0	5.5	14	273	7.6
	03-10-92	--	12.2	5.3	10	260	7.2
23-786	05-01-91	23.0	13.1	5.0	3	162	8.6
	08-14-91	28.0	13.5	5.0	2	200	8.8
	12-19-91	0.0	12.3	5.0	--	164	9.4
	03-11-92	--	12.6	4.9	--	155	8.7
23-1010	04-30-91	16.0	12.2	7.9	69	158	0.2
	08-15-91	25.0	13.0	7.8	68	164	.2
	12-16-91	-1.0	12.3	7.7	64	165	.1
	03-10-92	--	12.5	7.8	72	153	.1
23-1066	05-02-91	17.0	12.3	5.4	3	152	9.1
	08-15-91	27.0	13.5	5.4	4	162	8.8
	12-16-91	-2.0	11.7	5.5	12	170	9.5
	03-11-92	--	11.5	5.3	--	161	9.1
23-1069	05-08-91	19.0	12.8	5.1	3	360	8.3
	08-13-91	30.5	13.3	5.0	2	463	8.6
	12-17-91	-6.0	11.9	5.1	2	371	8.6
	02-11-92	--	11.8	5.3	6	390	8.8
			Kirkwood-Cohansey aquifer system				
33-462	04-24-91	22.0	13.8	4.5	<1	47	.3
	08-22-91	--	14.0	4.5	<1	62	.2
	12-23-91	--	12.9	4.5	<1	61	.2
	02-19-92	--	13.9	4.5	<1	53	.1
33-464	04-24-91	13.8	13.8	5.2	3	218	9.0
	09-04-91	--	13.7	4.5	<1	220	9.8
	12-09-91	20.0	13.7	5.1	--	210	10.2
	02-19-92	--	13.2	5.1	--	203	9.3
33-674	04-26-91	27.0	14.2	4.6	<1	163	5.9
	08-21-91	--	13.8	4.6	<1	176	6.7
	12-12-91	--	12.6	4.6	<1	164	6.3
33-679	04-23-91	23.0	13.7	4.9	2	412	9.1
	08-21-91	--	12.8	4.9	--	418	10.6
	12-12-91	14.5	13.0	5.0	--	396	9.7
	02-20-92	--	13.0	5.0	--	415	9.0
	04-21-92	23.5	13.7	5.0	--	406	
33-684	04-26-91	31.0	14.2	4.4	<1	222	9.2
	08-22-91	--	14.9	4.4	<1	211	10.3
	12-10-91	13.5	13.0	4.4	<1	197	10.1
	04-21-92	--	13.6	4.5	<1	187	--
33-685	04-23-91	20.5	13.9	5.7	11	377	8.0
	08-20-91	--	14.3	5.7	13	348	9.0
	12-09-91	--	14.6	5.8	--	335	8.3
	02-20-92	9.0	13.7	5.8	--	317	7.7
	04-21-92	--	14.0	5.9	--	287	--

Appendix 2. Results of water-quality analyses of samples from 12 domestic wells in agricultural areas of the New Jersey Coastal Plain

B. Dissolved major ions

[All concentrations in milligrams per liter; <, less than; MM-DD-YY, month-day-year]

New Jersey well number	Date sampled (MM-DD-YY)	Constituent								
		Dis-solved solids	Calcium	Magnesium	Sodium	Potassium	Silica	Chloride	Sulfate	Fluoride
		Potomac-Raritan-Magothy aquifer system								
21-240	05-01-91	117	12	2.8	9.8	2.7	14	19	0.2	<0.1
21-280	04-30-91	177	23	8	8.4	3.2	16	26	16	<.1
23-786	05-01-91	113	11	4.1	6	2.8	9.1	21	.2	<.1
23-1010	04-30-91	113	14	3.3	11	2.0	43	5.4	2.7	.2
23-1066	05-02-91	82	9.9	3.4	10	2.2	15	17	.2	<.1
23-1069	05-08-91	167	23	15	7.8	7.9	11	26	38	<.1
		Kirkwood-Cohansey aquifer system								
33-462	04-24-91	44	.74	.49	2	1.1	18	<.1	9.5	<.1
33-464	04-24-91	109	8.4	13	3.1	3.3	9.5	22	3.3	<.1
33-674	04-26-91	84	9.3	3.7	7.6	1.5	12	20	7.8	<.1
33-679	04-23-91	220	32	20	4.7	1.6	12	18	62	<.1
33-684	04-26-91	133	16	5.2	2.8	3.6	7	21	.5	<.1
33-685	04-23-91	238	28	24	5.9	2.0	10	26	80	<.1

Appendix 2. Results of water-quality analyses of samples from 12 domestic wells in agricultural areas of the New Jersey Coastal Plain

C. Dissolved trace elements

[All concentrations in micrograms per liter; <, less than; MM-DD-YY, month-day-year]

New Jersey well number	Date sampled (MM-DD-YY)	Constituent									
		Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead
		Potomac-Raritan-Magothy aquifer system									
21-240	05-01-91	<1	180	0.6	<10	<1	<5	<3	20	12	2
21-280	04-30-91	<1	320	<.5	<10	<1	<5	<3	20	13	3
23-786	05-01-91	<1	250	.6	<10	2	<5	<3	20	<3	1
23-1010	04-30-91	<1	48	<.5	50	<1	<5	<3	<10	410	<1
23-1066	05-02-91	<1	19	<.5	<10	<1	<5	<3	40	<3	3
23-1069	05-08-91	<1	65	3	<10	1	<5	10	130	150	9
		Kirkwood-Cohansey aquifer system									
33-462	04-24-91	<1	15	<.5	<10	<1	<5	<3	<10	780	<1
33-464	04-24-91	<1	100	<.5	20	<1	<5	6	60	18	3
33-674	04-26-91	<1	52	<.5	<10	<1	<5	3	30	210	1
33-679	04-23-91	<1	61	<.5	10	<1	<5	<3	20	41	7
33-684	04-26-91	<1	110	1	10	<1	<5	7	20	8	3
33-685	04-23-91	<1	47	<.5	10	<1	<5	<3	<10	6	2

New Jersey well number	Date sampled (MM-DD-YY)	Constituent								
		Lithium	Manganese	Mercury	Molybdenum	Nickel	Silver	Strontium	Vanadium	Zinc
		Potomac-Raritan-Magothy aquifer system								
21-240	05-01-91	<4	9	0.1	<10	<10	<1	160	<6	12
21-280	04-30-91	<4	19	.2	<10	<10	<1	350	<6	26
23-786	05-01-91	<4	18	.3	<10	<10	<1	130	<6	23
23-1010	04-30-91	4	280	.2	<10	<10	<1	140	<6	4
23-1066	05-02-91	<4	7	.1	<10	<10	<1	130	<6	12
23-1069	05-08-91	4	310	.2	<10	<10	<1	210	<6	60
		Kirkwood-Cohansey aquifer system								
33-462	04-24-91	<4	9	.2	<10	<10	<1	8	<6	16
30-464	04-24-91	<4	19	.2	<10	<10	<1	140	<6	5
33-674	04-26-91	<4	15	.2	<10	<10	<1	26	<6	42
33-679	04-23-91	<4	20	.3	<10	<10	<1	200	<6	31
33-684	04-26-91	<4	36	.2	<10	<10	<1	62	<6	12
33-685	04-23-91	<4	54	.2	<10	<10	<1	290	<6	26

Appendix 2. Results of water-quality analyses of samples from 12 domestic wells in agricultural areas of the New Jersey Coastal Plain

D. Dissolved nutrients and nitrogen isotope ratios

[All concentrations in milligrams per liter, except where noted; <, less than; --, no sample collected; MM-DD-YY, month-day-year]

New Jersey well number	Date sampled (MM-DD-YY)	Constituent: Ammonia as nitrogen	Nitrite as nitrogen	Ammonia plus organic nitrogen as nitrogen	Nitrite plus nitrate as nitrogen	Ortho-phosphate	Nitrogen$^{15/14}$ isotope ratio (dn^{15}, in per mil)
		Potomac-Raritan-Magothy aquifer system					
21-240	05-01-91	<0.01	<0.01	0.4	9.5	<0.01	2.6
	08-13-91	.01	<.01	.6	9.7	<.01	2.7
	12-19-91	.01	<.01	<.2	9.3	<.01	1.7
	02-11-92	<.01	<.01	<.2	9.2	<.01	--
21-280	04-30-91	--	--	--	--	--	6.3
	09-05-91	<.01	<.01	.7	13	<.01	5.5
	12-17-91	<.01	<.01	<.2	13	.01	5.8
	03-10-92	.02	<.01	<.2	13	<.01	--
23-786	05-01-91	<.01	<.01	.4	8.5	<.01	3.7
	08-14-91	--	--	--	--	--	3.3
	12-19-91	<.01	<.01	<.2	8.3	<.01	2.4
	03-11-92	.02	<.01	<.2	8.2	<.01	--
23-1010	04-30-91	--	--	--	--	--	3.0
	08-15-91	.52	<.01	.6	<.05	.08	2.0
	12-16-91	.53	<.01	.5	.06	.08	1.4
	03-10-92	.52	<.01	.5	<.05	.08	--
23-1066	05-02-91	<.01	<.01	.5	8.7	<.01	2.6
	08-15-91	.02	<.01	.5	9.2	<.01	2.5
	12-16-91	<.01	<.01	<.2	9.2	.01	2.0
	03-11-92	.02	<.01	<.2	9.3	<.01	--
23-1069	05-08-91	<.01	<.01	.8	17	<.01	3.7
	08-13-91	<.01	<.01	.7	20	<.01	4.7
	12-17-91	<.01	.01	<.2	21	.01	3.5
	02-11-92	<.01	<.01	<.2	22	<.01	--
		Kirkwood-Cohansey aquifer system					
33-462	04-24-91	.03	.05	<.2	.09	<.01	--
	08-22-91	<.01	<.01	<.2	<.05	<.01	--
	12-23-91	.02	<.01	<.2	<.05	.01	--
	02-19-92	<.01	<.01	<.2	<.05	<.01	--
33-464	04-24-91	.02	.06	.4	12	<.01	2.6
	09-04-91	<.01	<.01	.5	12	<.01	1.9
	12-09-91	<.01	<.01	<.2	12	<.01	1.6
	02-19-92	.01	<.01	<.2	12	<.01	--
33-674	04-26-91	<.01	<.01	1	7.5	<.01	3.6
	08-21-91	<.01	<.01	.6	8.0	<.01	3.2
	12-12-91	.02	<.01	<.2	7.9	<.01	2.9
33-679	04-23-91	<.01	<.01	.6	16	<.01	4.4
	08-21-91	<.01	<.01	.6	14	<.01	3.8
	12-12-91	.02	.01	<.2	14	<.01	3.7
	02-20-92	.01	<.01	<.2	14	<.01	--
	04-21-92	<.01	<.01	<.2	14	<.01	--
33-684	04-26-91	<.01	<.01	.7	14	<.01	4.0
	08-22-91	<.01	<.01	.7	15	<.01	3.9
	12-10-91	.01	<.01	<.2	14	<.01	3.1
	04-21-92	<.01	<.01	<.2	14	<.01	--
33-685	04-23-91	<.01	<.01	.4	13	<.01	4.2
	08-20-91	.04	<.01	.6	15	<.01	3.3
	12-09-91	<.01	<.01	<.2	15	<.01	3.5
	02-20-92	.021	<.01	<.2	14	<.01	--
	04-21-92	<.01	<.01	<.2	13	<.01	--

Appendix 2. Results of water-quality analyses of samples from 12 domestic wells in agricultural areas of the New Jersey Coastal Plain

E. Dissolved organic carbon, methylene blue active substances, fecal coliform, and fecal streptococci

[mg/L, milligrams per liter; mL, milliters; <, less than; K, nonideal colony count; --, no sample collected; MM-DD-YY, month-day-year]

New Jersey well number	Date sampled (MM-DD-YY)	Dissolved organic carbon (mg/L)	Methylene blue active substances (mg/L)	Fecal coliform (colonies per 100 mL)	Fecal streptococci (colonies per 100 mL)
		Potomac-Raritan-Magothy aquifer system			
21-240	05-01-91	0.2	0.08	<1	3 K
	08-13-91	--	.08	<1	1 K
	12-19-91	--	.09	<1	<1
	02-11-92	--	--	<1	<1
21-280	04-30-91	.6	.12	<1	41
	09-05-91	--	.11	<1	76 K
	12-17-91	--	.14	<1	20 K
	03-10-92	--	--	<1	<1
23-786	05-01-91	.3	.08	<1	9 K
	08-14-91	--	.06	<1	<1
	12-19-91	--	.11	<1	<1
	03-11-92	--	--	<1	<1
23-1010	04-30-91	.3	.01	<1	38
	08-15-91	--	<.01	<1	<1
	12-16-91	--	.01	<1	<1
	03-10-92	--	--	<1	<1
23-1066	05-02-91	.2	.08	<1	1 K
	08-15-91	--	.08	<1	<1
	12-16-91	--	.09	<1	<1
	03-11-92	--	--	<1	<1
23-1069	05-08-91	.8	.16	<1	15 K
	08-13-91	--	.16	<1	<1
	12-17-91	--	.18	<1	<1
	02-11-92	--	--	1 K	1 K
		Kirkwood-Cohansey aquifer system			
33-462	04-24-91	.3	<.01	<1	6 K
	08-22-91	--	.01	<1	1 K
	12-23-91	--	<.01	<1	<1
	02-19-92	--	--	<1	<1
33-464	04-24-91	--	.11	3 K	3 K
	09-04-91	--	.11	<1	<1
	12-09-91	--	.12	<1	3 K
	02-19-92	--	--	<1	<1
33-674	04-26-91	.3	.07	<1	1 K
	08-21-91	--	.13	<1	81 K
	12-12-91	--	.14	<1	16 K
33-679	04-23-91	.8	.12	<1	6 K
	08-21-91	--	.14	<1	37 K
	12-12-91	--	.08	<1	<1
	02-20-92	--	--	--	--
	04-21-92	--	--	<1	2 K
33-684	04-26-91	.4	.14	<1	54
	08-22-91	--	.13	<1	<1
	12-10-91	--	.14	<1	<1
	04-21-92	--	--	<1	<1
33-685	04-23-91	.8	.10	<1	28 K
	08-20-91	--	.15	<1	110
	12-09-91	--	.14	2 K	36
	02-20-92	--	--	--	--
	04-21-92	--	--	<1	3 K

Appendi 2. Results of water-quality analyses of samples from 12 domestic wells in agricultural areas of the New Jersey Coastal Plain

F. Total triazine and acetanilide herbicides

[All concentrations in micrograms per liter; <, less than; MM-DD-YY, month-day-year]

New Jersey well number	Date sampled (MM-DD-YY)	Triazine herbicides									Acetenilide herbicides		
		Ame-tryne	Atra-zine	Atrazine, desethyl	Atrazine, deiso-propyl	Cyana-zine	Prome-tone	Prome-tryne	Propa-azine	Sima-zine	Ala-chlor	Metol-achlor	Metri-buzin
						Potomac-Raritan-Magothy aquifer system							
21-240	05-01-91	<0.05	<0.05	<0.05	<0.05	<0.2	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	08-13-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	12-19-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	.09	<.05
21-280	04-30-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	8.8	<.05	<.05
	09-05-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	8.0	<.05	<.05
	12-17-91	.5	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	8.0	<.05	<.05
23-786	05-01-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	08-14-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	12-19-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
23-1010	04-30-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	08-15-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	12-16-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
23-1066	05-02-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	08-15-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	12-16-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
23-1069	05-08-91	<.05	<.05	.08	<.05	<.2	<.05	<.05	<.05	<.05	<.05	.25	.22
	08-13-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	.19	<.05
	12-17-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	.14	.17	.08
						Kirkwood-Cohansey aquifer system							
33-462	04-24-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	8-22-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	12-23-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
33-464	04-24-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	09-04-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	12-09-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
33-674	04-26-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	08-21-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	12-12-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
33-679	04-23-91	<.05	<.05	.20	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	08-21-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	12-12-91	<.05	<.05	.22	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
33-684	04-26-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	08-22-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	12-10-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	<.05	<.05	<.05
33-685	04-23-91	<.05	.44	.19	.48	<.2	<.05	<.05	<.05	<.05	.07	<.05	<.05
	08-20-91	<.05	<.05	<.05	<.05	<.2	<.05	<.05	<.05	<.05	.18	<.05	<.05
	12-09-91	<.05	.54	.46	.92	<.2	<.05	<.05	<.05	<.05	.18	.09	<.05

Appendix 2. Results of water-quality analyses of samples from 12 domestic wells in agricultural areas of the New Jersey Coastal Plain

G. Total carbamate insecticides

[All concentrations in micrograms per liter; <, less than; MM-DD-YY, month-day-year]

		Insecticide									
New Jersey well number	Date sampled (MM-DD-YY)	Aldi-carb	Aldi-carb aul-phone	Aldi-carb sulfox-ide	Carb-ayl	Carbo-furan	3-hydroxy carbo-furan	Metho-myl	1-Naph-thol	Oxymyl	Propham
					Potomac-Raritan-Magothy aquifer system						
21-240	05-01-91	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	08-13-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	12-19-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
21-280	04-30-91	<.5	<.5	<.5	<.5	1.5	<.5	2.1	<.5	<.5	<.5
	09-05-91	<.5	<.5	<.5	<.5	2.1	<.5	4.2	<.5	<.5	<.5
	12-17-91	<.5	<.5	<.5	<.5	5.8	<.5	5.6	<.5	<.5	<.5
23-786	05-01-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	08-14-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	12-19-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
23-1010	04-30-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	08-15-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	12-16-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
23-1066	05-02-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	08-15-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	12-16-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
23-1069	05-08-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	08-13-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	12-17 91	<.5	.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
					Kirkwood-Cohansey aquifer system						
33-462	04-24-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	08-22-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	12-23-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
33-464	04-24-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	09-04-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	12-09-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
33-674	04-26-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	08-21-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	12-12-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
33-679	04-23-91	<.5	<.5	<.5	<.5	1.8	<.5	<.5	<.5	<.5	<.5
	08-21-91	<.5	<.5	<.5	<.5	2.6	<.5	<.5	<.5	<.5	<.5
	12-12-91	<.5	<.5	<.5	<.5	2.1	<.5	<.5	<.5	<.5	<.5
33-684	04-26-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	08-22-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	12-10-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
33-685	04-23-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	08-20-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
	12-09-91	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5

Appendix 2. Results of water-quality analyses of samples from 12 domestic wells in agricultural areas of the New Jersey Coastal Plain

H. Volatile organic compounds

[All concentrations in micrograms per liter; <, less than; MM-DD-YY, month-day-year]

New Jersey well number	Date sampled (MM-DD-YY)	Benzene	Bromoform	Bromomethane	Carbon-tetrachloride	Chlorobenzene	Bromodichloromethane	Chloroethane	2-Chloroethylvinylether	Chloroform	Dibromochloromethane	1,1-Dichloroethene
					Potomac-Raritan-Magothy aquifer system							
21-240	05-01-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
21-280	04-30-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-786	05-01-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-1010	04-30-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-1066	05-02-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-1069	05-08-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
					Kirkwood-Cohansey aquifer system							
33-462	04-24-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-464	04-24-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-674	04-26-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-679	04-23-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-684	04-26-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-685	04-23-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

New Jersey well number	Date sampled (MM-DD-YY)	1,2-Dichloroethane	1,1-Dichloroethylene	cis-1,2-Dichloroethylene	trans-1,2-Dichloroethyene	Chloromethane	1,2-Dichloropropane	trans-1,3-Dichloropropene	Ethylbenzene	Methylene chloride	1,1,2,2-Tetrachloroethane	Tetrachloroethylene
					Potomac-Raritan-Magothy aquifer system							
21-240	05-01-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
21-280	04-30-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-786	05-01-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-1010	04-30-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-1066	05-02-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-1069	05-08-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
					Kirkwood-Cohansey aquifer system							
33-462	04-24-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-464	04-24-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-674	04-26-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-679	04-23-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-684	04-26-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-685	04-23-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

New Jersey well number	Date sampled (MM-DD-YY)	Toluene	1,1,1-Trichloroethane	1,1,2-Trichloroethane	Vinyl chloride	1,2-Dichlorobenzene	1,3-Dichlorobenzene	1,4-Dichloropropene	cis 1,3-Dichloropropene	trans-1,3-Dichloropropene
					Potomac-Raritan-Magothy aquifer system					
21-240	05-01-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
21-280	04-30-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-786	05-01-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-1010	04-30-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-1066	05-02-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23-1069	05-08-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
					Kirkwood-Cohansey aquifer system					
33-462	04-24-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-464	04-24-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-674	04-26-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-679	04-23-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-684	04-26-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
33-685	04-23-91	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2