RELATION OF NITRATE CONCENTRATIONS IN GROUND WATER TO WELL DEPTH, WELL USE, AND LAND USE IN FRANKLIN TOWNSHIP, GLOUCESTER COUNTY, NEW JERSEY, 1970-85

by C.L. MacLeod, T.H. Barringer, E.F. Vowinkel, and C.V. Price

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Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
ounce, fluid (fl. oz)	0.02957	liter
pint (pt)	0.4732	liter
quart (qt)	0.9464	liter
gallon (gal)	3.785	liter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Mass	
ounce, avoirdupois (oz)	28,352	milligram
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day

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.

Water-quality abbreviation: mg/L, milligrams per liter

Relation of Nitrate Concentrations in Ground Water to Well Depth, Well Use, and Land Use in Franklin Township, Gloucester County, New Jersey, 1970-85

by C.L. MacLeod, T.H. Barringer, E.F. Vowinkel, and C.V. Price

ABSTRACT

Concern about the quality of ground water, particularly nitrate concentrations, in Franklin Township, Gloucester County, New Jersey, led to a cooperative project between the U.S. Geological Survey and the Gloucester County Planning Department to develop a water-quality data base that would permit the assessment of nitrate contamination of ground water in the area. The study included an investigation of the relation of concentrations of nitrate (as nitrogen) in ground water to well depth, three categories of well use (domestic, commercial, and agricultural/irrigation), and four categories of land use (agricultural, residential, urban nonresidential, and undeveloped). Nitrate concentrations in water from 868 wells tended to decrease with depth; the largest concentrations tended to be found in water from wells screened at depths of 55 feet or less. The percentage of each land-use type within 656-foot radial buffer zones was determined for each well. Land-use-percentage data were log-ratio transformed to mitigate the problem of closure among the land-use predictors. A rank-order regression model of nitrate concentrations and land-use percentages was fitted to data from 98 shallow domestic wells. The model, which explains about 25 percent of the variance in the data, indicated that nitrate concentration increased with the percentage of developed land in a well's buffer zone. Further stratification of the data based on well use indicated that elevated nitrate concentrations were more common in water from agricultural/irrigation wells than in water from domestic or commercial wells. If concentrations of nitrate greater than 3 mg/L are considered to indicate effects of human activities on ground water, then water from about one-third of the 868 wells sampled shows these effects; however, nitrate concentrations exceeded the U.S. Environmental Protection Agency maximum contaminant level of 10 milligrams per liter in water from only 1 percent of the wells. If a more conservative estimate of 1 mg/L of nitrate is used to represent effects of human activities on ground water, then water from two-thirds of the 868 wells would be considered to be so affected. A sampling strategy in which water from a minimum of 108 wells screened at different depths and distributed among the four land-use categories is sampled yearly and analyzed for nitrate and other constituents would facilitate determination of the effects of human activities on ground-water quality over time.

INTRODUCTION

Franklin Township is a predominantly agricultural rural community in Gloucester County in southern New Jersey (fig. 1). The township is located in the New Jersey Coastal Plain in the outcrop area of the Cohansey Sand and the Kirkwood Formation. Soils developed on the gravels, sands, and silts of these geologic units tend to be nutrient-poor and require extensive fertilization for good crop yield and lawn development.

The Cohansey Sand and Kirkwood Formation comprise the unconfined Kirkwood-Cohansey aquifer system, from which Franklin Township derives its potable-water supply. Local concern about changes in ground-water quality resulting from increasing land development led the U.S. Geological Survey (USGS) to conduct a study, in cooperation with the Gloucester County Planning Department (GCPD), to develop a ground-water-quality data base for wells in Franklin Township and to evaluate the data to determine the relations among well characteristics, land use, and concentrations of nitrate as nitrogen[1].

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[1] In this report, the term "nitrate" is used to mean nitrate nitrogen--that is, nitrate expressed as the nitrogen content (N), because this constituent is represented in Federal and State drinking-water regulations.

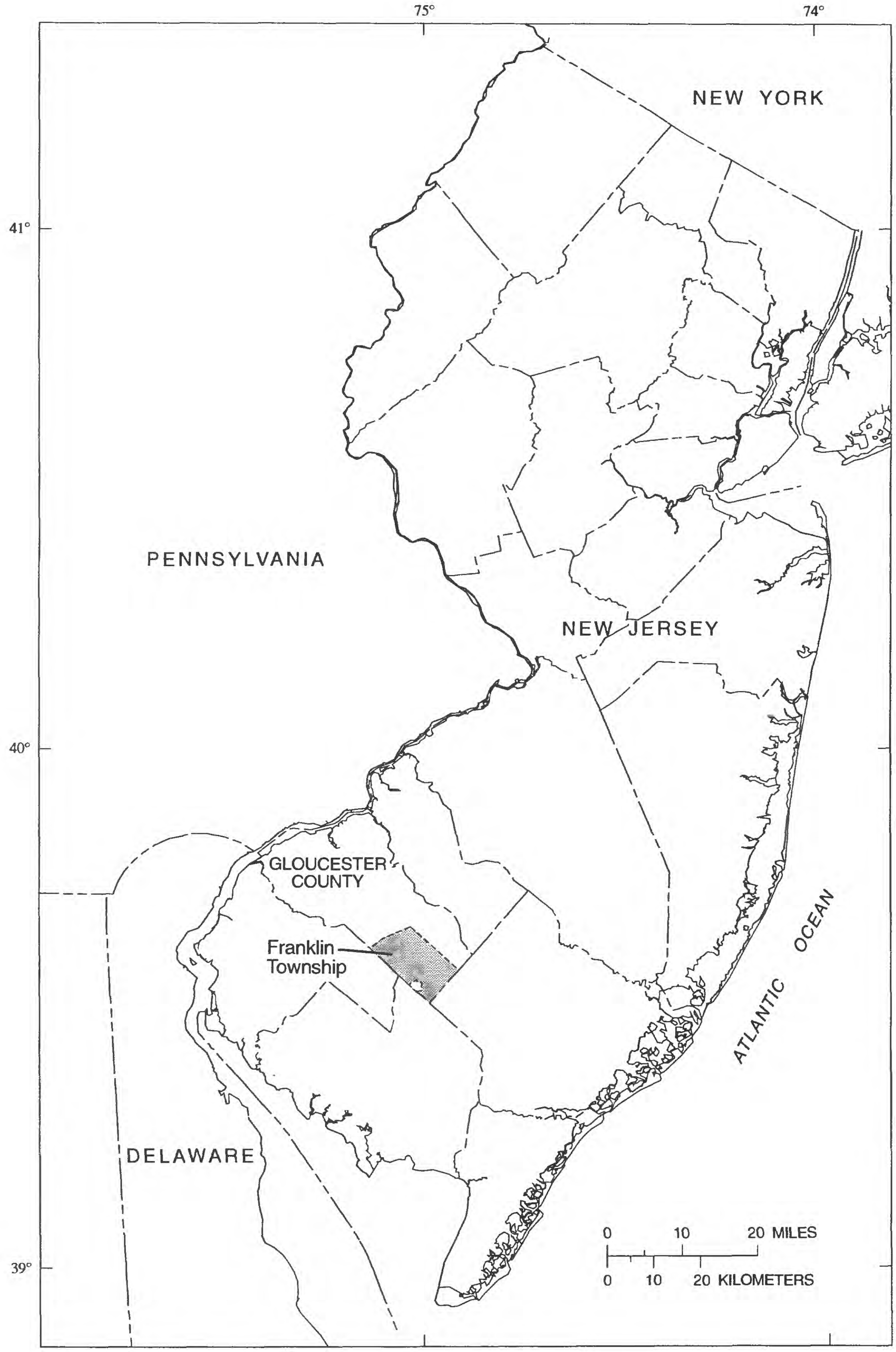

Figure 1. Location of Franklin Township, Gloucester County, New Jersey.

Purpose and Scope

This paper presents the results of a statistical analysis of the relations of well depth, well use, and land use to nitrate concentrations in ground water. The relation between nitrate concentration and well depth is discussed. The variation in nitrate concentration in water from 98 shallow wells with respect to four land-use types--residential, agricultural, undeveloped, and urban nonresidential--is documented. The variation in nitrate concentration in water from 868 wells with respect to well use--commercial, domestic, or agricultural/irrigation--also is discussed. Additionally, the relation between land-use changes during 1970-85 and nitrate concentrations in shallow wells is discussed. A well network designed to monitor any future changes in nitrate concentrations and other chemical constituents in ground water is described.

Previous Investigations

Concentrations of nitrate in ground water that exceed the U.S. Environmental Protection Agency (USEPA) and New Jersey Department of Environmental Protection (NJDEP) maximum contaminant level(MCL) of 10 mg/L (Federal Register, 1991) are common in many rural residential and agricultural communities. The primary sources of nitrate in shallow ground water are leachate from septic systems, runoff from animal feedlots, and leachate from nitrogen fertilizers. The bacterial degradation of organic nitrogen and ammonia in wastes to form nitrate is an active process in oxygenated septic systems and organic-rich natural fertilizers. Pionke and Gillmeister (1991) attribute the incidence of high nitrate concentrations in the shallow ground water of eastern Pennsylvania to misuse or overapplication of nitrogen fertilizers. In an analysis of nitrate concentrations in ground water from 85 wells on Long Island, N.Y., Perlmutter and Koch (1972) suggest that a concentration of nitrate of 1 mg/L should be considered to be the maximum naturally occurring concentration and that concentrations exceeding this value are the result of human activities. Madison and Brunett (1984), however, suggest that nitrate concentrations exceeding 3 mg/L are indicative of human inputs on the basis of an analysis of nitrate-concentration data from 124,000 wells nationwide.

Several researchers have analyzed the relation of land use to shallow-ground-water quality in New Jersey and elsewhere in the northeastern United States. Helsel and Ragone (1984) discuss the evaluation of regional ground-water quality in relation to land use. Vowinkel and Battaglin (1989a) examine methods of evaluating the relation of land use to the quality of ground water in a New Jersey Coastal Plain aquifer system. The same authors (1989b) consider various factors that can affect the evaluation of regional ground-water quality. Siwiec and Stackelberg (1989) analyze scale and data-resolution effects in determining relations between land use and ground-water quality. Hay and Battaglin (1990) study the effects of buffer size on Spearman's partial correlations between land use and shallow-ground-water quality. Barringer and others (1990) discuss problems and methods associated with relating land-use to ground-water quality. Vowinkel (1991) compares relations between shallow-ground-water quality and land use in two New Jersey Coastal Plain aquifer systems.

Acknowledgments

The authors thank the personnel of Gloucester County Planning Department for compiling well-construction, land-use, and water-quality data, and for assistance in the development of the geographic information system (GIS) data base by digitizing land-use data and well locations. In particular, Robert Scolpino, Director; Richard Westergaard, Principal Planner; and Theresa Ziegler and Garret Olin contributed substantially to this study.

DESCRIPTION OF THE STUDY AREA

The New Jersey Coastal Plain is a largely rural area consisting mostly of undeveloped and agricultural land. Urban areas are, in general, concentrated on the Atlantic Coast and along the Delaware River and are separated by vast expanses of rural land.

Land Use

Franklin Township covers about 56 mi^2. Land uses in Franklin Township are predominantly undeveloped and agricultural; a small amount of urban land also is present (figs. 2 and 3). About 62 percent of the area is undeveloped land consisting mostly of forests or wetlands. About 10 percent of the township is urban land; about 8 percent is residential and about 2 percent is commercial or industrial land. Residential areas are served almost entirely by on-site septic systems; no municipal or regional sewage-treatment plants serve the township, with the exception of a small plant operated by a private company.

About 27 percent of the township is agricultural land--mostly cropland and orchards, with smaller areas devoted to nurseries, pastures, and animal feedlots. The types of crops grown are diverse, reflecting county-wide agricultural activities. Gloucester County is the largest producer of apples, peaches, and tomatoes in the State of New Jersey; is among the top five producers of sweet potatoes, peppers, sweet corn, cabbage, and lettuce in the State; and ranks first in the State for the number of hogs and pigs raised (New Jersey Department of Agriculture, 1991, p. 38). Potential nonpoint sources of contamination in such 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.

Hydrogeologic Setting

Franklin Township is located in the Coastal Plain Physiographic Province, which is characterized by generally flat topography. 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. The hydrogeologic framework of (Zapecza, 1989) and regional ground-water flow in (Martin, 1990) the New Jersey Coastal Plain are well-documented. The Cohansey Sand, which consists mostly of coarse sand and gravel, is the major geologic unit underlying the township. In some locations the Cohansey Sand of Miocene and Pliocene age is overlain by the Bridgeton Formation of Miocene age, a highly weathered, gravelly sand. The Cohansey Sand is underlain by finer grained sand and silt of the Kirkwood Formation of Miocene age. All three units, which together comprise the Kirkwood-Cohansey aquifer system, crop out in Gloucester County. Soils in the outcrop area of the Kirkwood-Cohansey aquifer system consist mostly of gravelly sandy loam and loamy sand (Tedrow, 1986, pl. 1); these soils generally contain small amounts of organic matter. These conditions make the ground water susceptible to contamination from point and nonpoint sources at land surface.

The Kirkwood-Cohansey aquifer system is the source of almost all of the drinking water in Franklin Township. The aquifer system is generally unconfined; however, some parts are locally confined. The aquifer system is about 120 ft thick in the Franklin Township area and is underlain by the Alloway Clay Member of the Kirkwood Formation. The depth from land surface to the water table typically is between 10 and 20 ft. Ground water generally flows from the uplands toward discharge points along a stream. The direction of shallow ground-water flow is predominantly downward at the water table, particularly near the surface-water and ground-water divides, becomes more horizontal with distance from the divides, and may be horizontal or upward at the discharge areas (fig. 4).

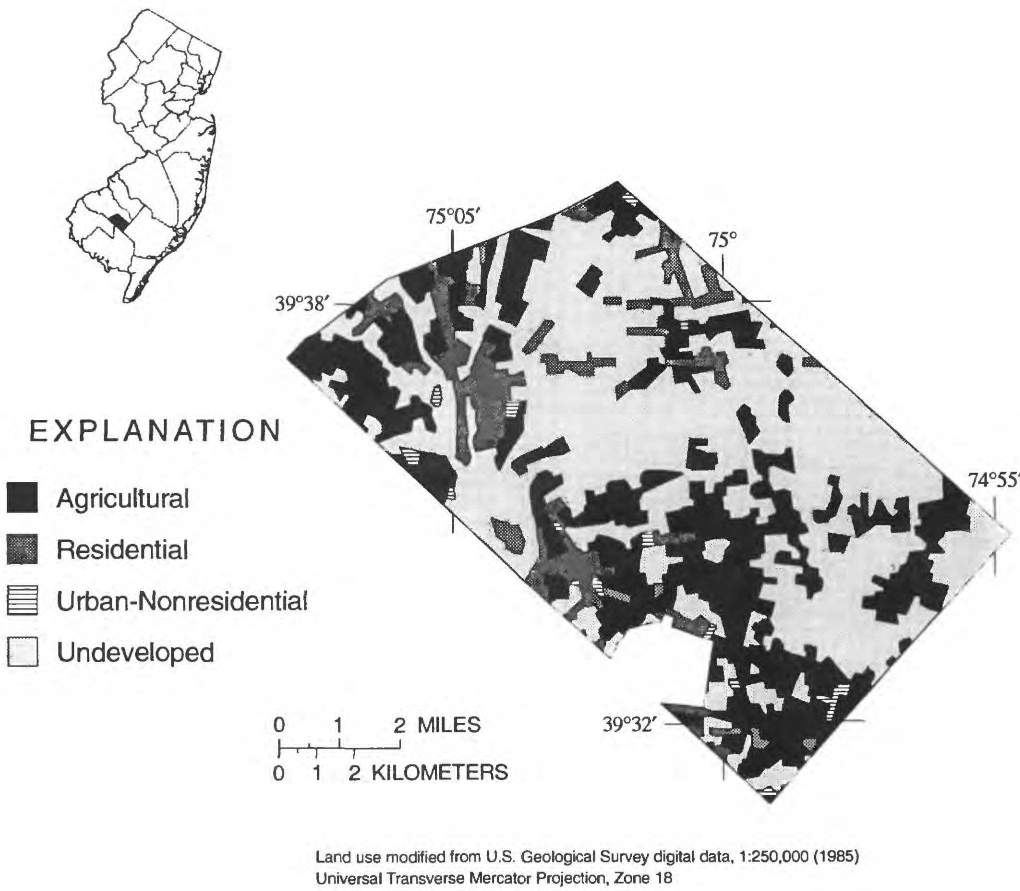

Figure 2. Land use in 1972, Franklin Township, New Jersey.

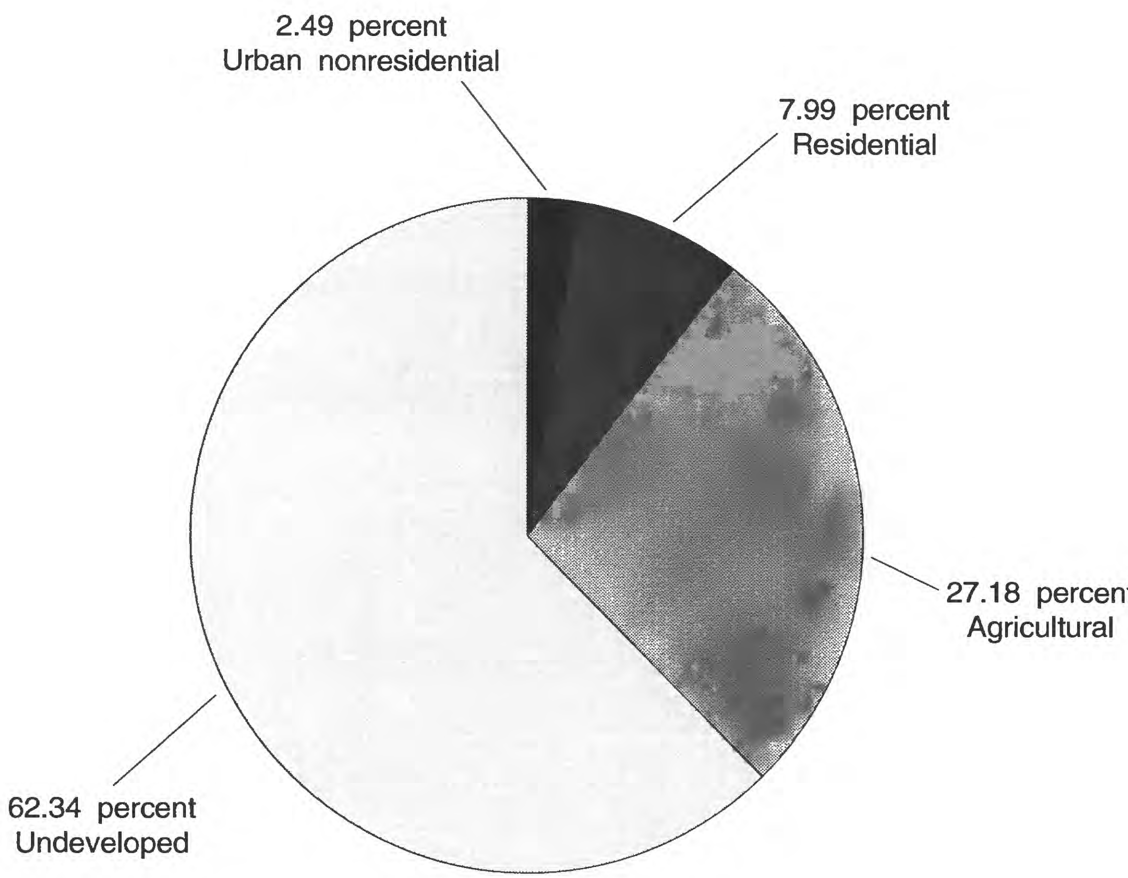

Figure 3. Distribution of land use in 1985, Franklin Township, New Jersey. [Data from land use modified from U.S. Geological Survey digital data, 1:250,000 (1985).]

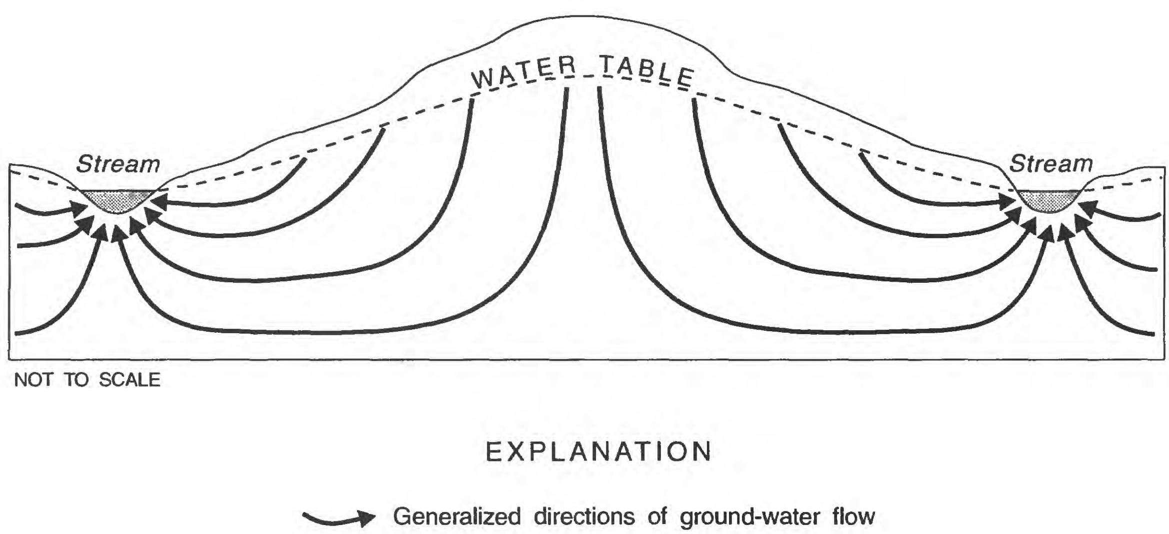

Figure 4. Diagrammatic section through a shallow part of the Kirkwood-Cohansey aquifer system, in central New Jersey, showing generalized directions of ground-water flow.

The primary source of recharge to the aquifers in the Coastal Plain is precipitation. A long-term water budget for predevelopment conditions consists of about 44 in/yr of precipitation, 20 in/yr of streamflow, and 24 in/yr of evapotranspiration (Vowinkel and Foster, 1981, p.1). Much of the ground-water recharge eventually discharges to surface-water bodies; only a small amount percolates through confining units to recharge the underlying confined aquifers (Martin, 1990, p. 45). The horizontal hydraulic conductivity of the aquifer system commonly is between 130 and 150 ft/d (Martin, 1990, p. 12). Little Ease Run is the major stream that drains the study area; in 1990 the mean annual discharge of this stream was 12.2 ft^3/s (Bauersfeld and others, 1992, p. 325).

STUDY METHODS

The methods used in data-base compilation, data conditioning, and statistical analysis are discussed in this section.

Sources of Data

Well-location, well-construction, and water-quality data used in this analysis were compiled from records of 1,606 wells submitted by well drillers to State and county regulatory agencies after the wells were completed. Well locations were plotted on 1:4,800-scale maps; each well location is accurate to within about 80 ft. Water samples collected from inside or outside house taps were analyzed at private laboratories for dissolved nitrate and pH. Some of the water samples also were analyzed for other constituents, such as dissolved solids, iron, manganese, total coliform bacteria, sulfate, chloride, and surfactants. Although some analyses, such as those for nitrate and pH, were performed on each sample, the data for iron, manganese, chloride, and sulfate were limited. The water samples were collected at the time of well construction as part of a requirement of Gloucester County for all new wells. Well records indicate that the water typically was run for 15 minutes prior to sampling.

Land-use data were obtained from the GCPD, which used aerial photographs taken in 1970 to determine land-use classifications. The land-use maps were prepared and digitized at a scale of 1:4,800 (fig. 2). The land-use-classification system used with these maps consists of 88 categories (Richard Westergaard, Gloucester County Planning Department, written commun., 1991). These land-use categories were reclassified into four generalized land-use categories--agricultural, residential, urban nonresidential, and undeveloped--for use in this study.

Data Conditioning

The initial data set consisted of 1,606 observations of nitrate concentrations in water from wells located in Franklin Township, New Jersey. Where multiple (generally two or three) observations over a 1-month period were found for a single well, the most recent observation was retained, and the remainder were deleted. In addition, where two or more of these observations for a given well differed by more than an order of magnitude, observations for that well were removed from the data set. These procedures reduced the data set to 868 observations.

For each well in the data set, land use in a circular region (buffer zone) with a radius of about 656 ft centered on the well was determined by use of a geographic information system (GIS). Percentages of four categories of land use--agricultural, residential, urban nonresidential, and undeveloped--were determined for each buffer zone. "Undefined" land use made up less than 1 percent of the land area mapped in 1970 and was no longer present in 1985; therefore, this category was not used in the analysis.

The 868 observations were divided on the basis of well use, resulting in three data sets consisting of observations from 13 agricultural/irrigation wells, 16 commercial wells, and 837 domestic wells. (Well use was undefined for 2 of the 868 wells, which therefore were not included in the three data sets containing nitrate-concentration data sorted by well use.)

Water samples were analyzed for nitrate at several testing laboratories over a period of 8 years. To test for the possibility of a gross difference in treatment among the analyzing laboratories, the distributions of nitrate concentrations determined at different laboratories were subjected to a Kruskal-Wallis test. The results of this test indicated no statistical difference among laboratories in the data reported. The number of wells sampled more than once during a period of several years was too small to investigate the presence or absence of time trends; therefore, absence of time trends was assumed. A subset (N = 100) of the edited data was compared with the original paper records to determine the transcription-error rate. The error rate was found to be less than 5 percent.

The next step in conditioning the data set was to eliminate wells screened at depths greater than 55 ft. The presence of nitrate in elevated concentrations was assumed to be more likely in shallow ground water than in deep ground water. Therefore, because the study was conducted to evaluate effects of human activities on concentrations of nitrate in ground water, nitrate-concentration data from the deepest wells were not used in most of the subsequent analyses. Nitrate concentrations have been shown to decrease with depth in many sandy aquifers (Eccles and Bradford, 1976; Geyer and others, 1992; Goodman and others, 1992; Korom, 1992). Moreover, any correlation between land use in a well's buffer zone and the nitrate concentration in the well water might, in general, be expected to decrease with depth as a result of denitrification. Sample size also was a factor in the decision to include in the data set only observations from wells screened at a depth of 55 ft or less. The sample size would have been reduced greatly had a cutoff depth of 50 ft been used. Consequently, all wells whose screens were deeper than 55 ft were removed from the initial data set to create a subset of wells for intensive analysis. This step reduced the data set from 868 observations to 101 observations. These 101 observations consisted of data from 100 wells with defined use and 1 well whose use was undefined. Of the 100 observations, only 2 were for wells whose use was not domestic. Thus, for most subsequent analyses, these two observations were deleted, yielding a data set consisting of observations from 98 domestic wells.

The data also were tested to determine whether any relations between nitrate and other water-quality constituents could be detected. A series of regression analyses of nitrate concentrations with respect to pH and concentrations of chloride, iron, manganese, dissolved solids, and surfactants was performed. Unfortunately, these data were too limited in number to permit any useful conclusions to be drawn from the results of the regression analyses.

Data Transformations

The distribution of nitrate concentrations in the edited data set of 868 observations showed a strong right skew and was left-censored as a result of the analytic detection limit. Therefore, nonparametric techniques were used in all statistical analyses of nitrate-concentration data.

Compositional data are well-known to be subject to a closure constraint, which can lead to spurious correlations among variables. Aitchison (1986) suggested the use of an additive log-ratio transformation to mitigate closure effects. An additive log-ratio transformation was therefore applied to the buffer-zone land-use-percentage data and the resulting distributions were rank-transformed.

Correlation and Regression Analysis

A nitrate-concentration data set consisting of 852 observations was constructed by deleting observations with missing data values from the original data set of 868 wells. This data set, which included both shallow and deep wells, was analyzed to explore the distribution of nitrate concentrations within each land-use category. Bivariate scatter plots of ranked nitrate concentrations, with each of the four land uses used as predictors, were examined. Land-use percentages were log-ratio transformed, and a Spearman's correlation matrix was computed.

The data set consisting of 100 shallow wells was analyzed in the same manner, and those cases for which the correlations were significant were selected for inclusion in rank-order regression models. Because this data set included observations for only two shallow wells that were not domestic, the reduced data set of 98 shallow domestic wells was analyzed by using the same procedure.

RELATION OF NITRATE CONCENTRATIONS TO WELL DEPTH, WELL USE, AND LAND USE

The wells for which data were included in the data base were installed during 1979-89. The nitrate concentrations in water from these wells at the time of installation ranged from below detection (less than 0.2 mg/L) to 29.6 mg/L. An evaluation of nitrate concentrations in water samples from the 868 wells indicated that water from 34 percent of the wells sampled reflected the effects of human activities (nitrate concentration greater than 3 mg/L) but that water from only 1 percent of the wells contained nitrate in concentrations exceeding 10 mg/L (fig. 5). In a conservative analysis, if 1 mg/L is assumed to be the natural background nitrate concentration, the number of wells showing effects of human activities is twice as great (68 percent) (table 1).

Relation of Nitrate Concentration to Well Depth

Eccles and Bradford (1976) showed that nitrate concentrations in ground water in a sandy aquifer in California are depth-related. The results of an analysis of variations in nitrate concentration with well depth for all 868 wells indicate that nitrate concentrations in water from wells in Franklin Township tend to decrease with increasing well depth. Nitrate concentrations generally were highest in wells with depths less than or equal to 55 ft. The few high nitrate concentrations found in water from deeper wells may reflect the presence of a local long-term source of nitrate or a short flow path.

Nitrate concentrations in water from the 98 shallow domestic wells (less than 55 ft) were plotted on a map of Franklin Township (fig. 6). The data were grouped by concentration of nitrate on the basis of the definition by Madison and Brunett (1984), who identified ground water containing nitrate in concentrations greater than 3 mg/L as being affected by human activities. Concentrations ranging from greater than 0.2 to 3.0 mg/L were assumed to indicate those wells that may not be affected by human activities, whereas concentrations greater than 3.0 mg/L were assumed to indicate those wells that may be so affected. Three subsets of nitrate-concentration observations--background nitrate concentrations, nitrate concentrations showing effects of human activities but less than or equal to the MCL, and nitrate concentrations greater than the MCL are shown in figure 7. About 32 percent of the water samples from the 98 shallow domestic wells contained nitrate in concentrations between 3 and 10 mg/L; no concentrations exceeded the MCL (fig. 7).

Relation of Nitrate Concentration to Well Use

When the nitrate-concentration data are stratified according to well use, some significant differences in nitrate concentrations are noted among land-use predictors. Of the 868 wells, 16 were commercial wells, 13 were agricultural/irrigation wells, 837 were domestic wells, and use of 2 wells was undefined. Analysis of nitrate concentrations in water from wells in each of the well-use categories indicates that nitrate concentrations in water from 15 percent of the agricultural/irrigation wells and about 0.5 percent of the domestic wells exceeded the MCL of 10 mg/L; none of the commercial wells contained water with nitrate concentrations greater than the MCL (fig. 8). On the basis of Madison and Brunett's (1984) definition of

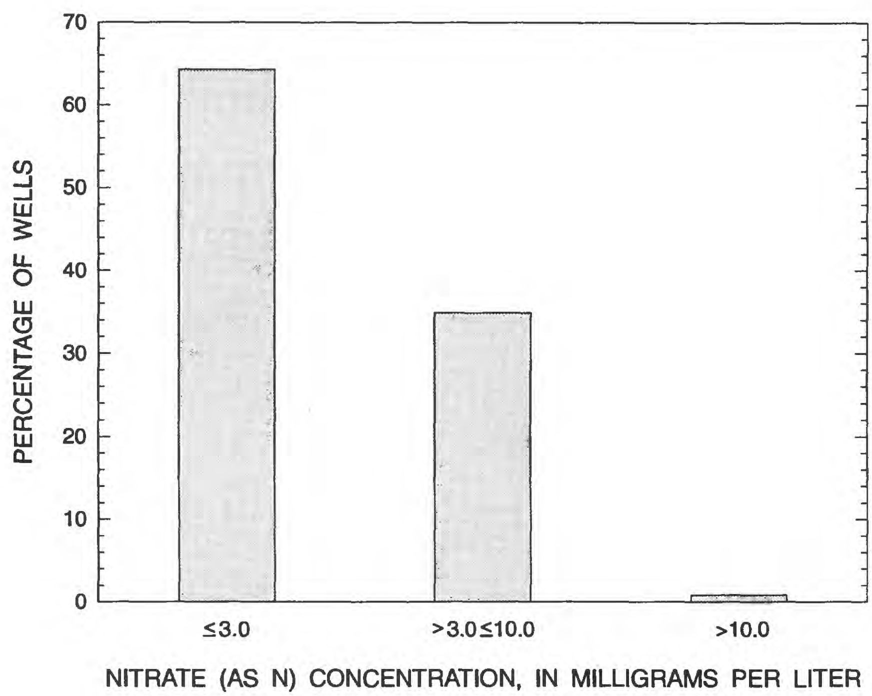

Figure 5. Nitrate concentrations in water from 868 wells in Franklin Township, New Jersey. (≤, less than or equal to; >, greater than.)

Table 1. Percentage of wells yielding water containing nitrate-nitrogen concentrations in each of three concentration ranges, Franklin Township, New Jersey

Nitrate-nitrogen concentration, in milligrams per liter	Percentage			
	All wells (N = 868)	Domestic wells (N = 837)	Agricultural wells (N = 13)	Commercial wells (N = 16)
Less than or equal to 1.0*	32.03	32.38	7.69	31.25
Greater than 1.0 and less than or equal to 10.0	67.17	67.03	76.92	68.75
Greater than 10.0	.81	.60	15.38	.00

*One milligram per liter or less is assumed to represent natural background concentration of nitrate in ground water.

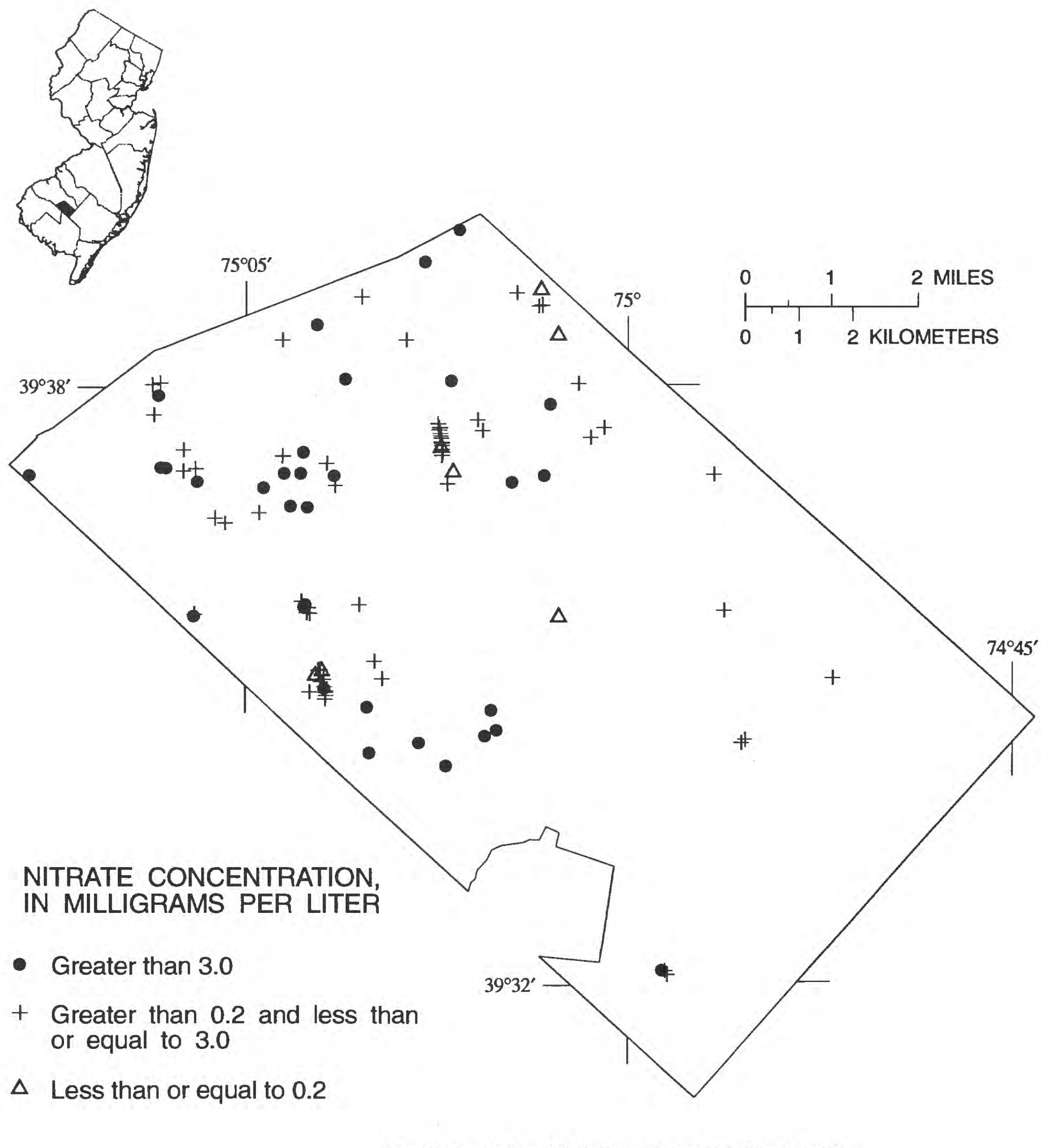

Figure 6. Areal distribution of nitrate concentrations in water from 98 shallow domestic wells in Franklin Township, New Jersey.

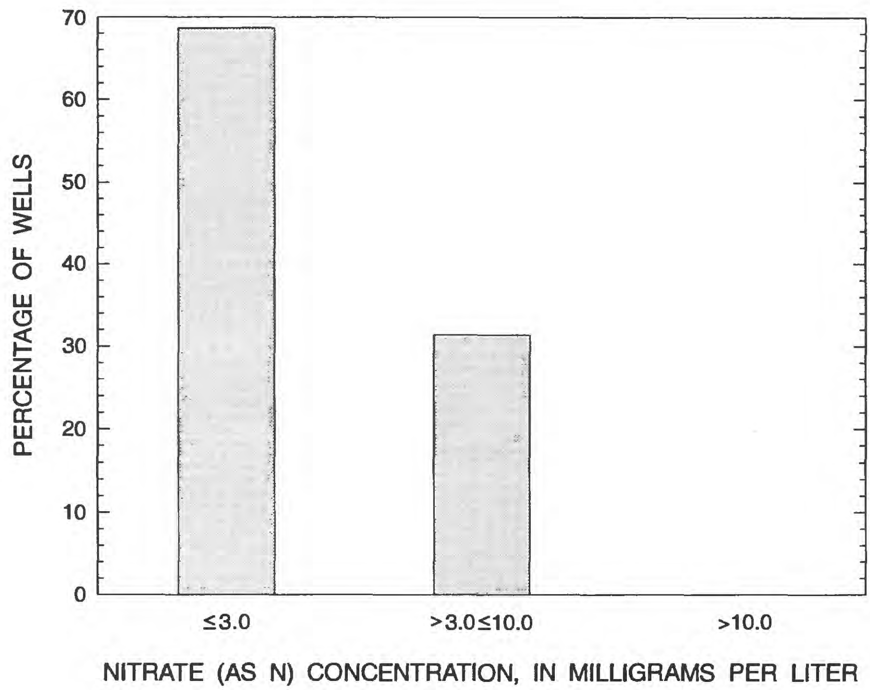

Figure 7. Nitrate concentrations in water from 98 shallow domestic wells in Franklin Township, New Jersey. (≤, less than or equal to; >, greater than.)

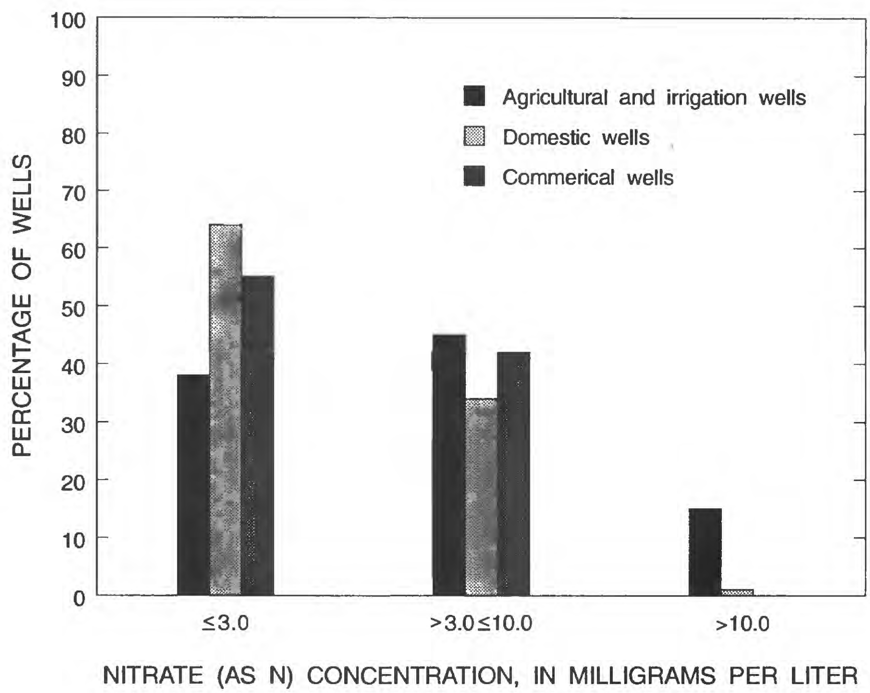

Figure 8. Distribution of nitrate concentrations in water from 13 agricultural and irrigation wells, 837 domestic wells, and 16 commerical wells, Franklin Township, New Jersey. (≤, less than or equal to; >, greater than.)

water affected by human activities, about 45 percent of the agricultural wells, 34 percent of the domestic wells, and 42 percent of the commercial wells yielded water with nitrate concentrations less than or equal to the MCL, but greater than 3 mg/L. This analysis shows that about 60 percent of the agricultural/irrigation wells yielded water that is affected by human activities, whereas only about 35 percent of the domestic wells and about 42 percent of the commercial wells yielded affected water. About one-third of the entire data set of nitrate-concentration observations from 868 wells were indicative of water that is affected by human activities. By using the definition of Perlmutter and Koch (1972)--that is, that water containing greater than 1 mg/L nitrate represents effects of human activities--a more conservative estimate is obtained as shown in table 1. The conservative estimate shows that about 92 percent of the agricultural wells yielded water affected by human activities, whereas about 67 percent of the domestic wells and about 69 percent of the commercial wells yielded affected water. By using the conservative estimate, about two-thirds of the 868 wells yielded water with nitrate concentrations indicative of human activities. The conservative estimate is likely to be more realistic for water from the Kirkwood-Cohansey aquifer system, which in undeveloped areas commonly contains nitrate in concentrations less than 1 mg/L. Further evaluation of nitrate-concentration data and well-use data indicates that elevated (>1.0 mg/L) nitrate concentrations were found in water from nearly all the agricultural/irrigation wells, regardless of well depth. Median nitrate concentrations grouped by well use are shown in table 2.

Analysis of nitrate concentrations in water from domestic wells required further stratification by well depth; wells deeper than 55 ft were again omitted from the data base, resulting in the analysis of nitrate concentrations in water from 98 domestic wells with log-ratio-transformed land-use data. Figure 9 shows the resultant correlation matrix for this analysis. Nitrate concentration is found to be positively correlated with agricultural land use. The negative correlation between nitrate concentration and undeveloped land use is shown by regression analysis to account for about 30 percent of the variance in nitrate concentrations in Franklin Township.

Relation of Nitrate Concentration to Land Use

Land use in Franklin Township in 1970 and 1985 is shown in table 3. These data show that the percentage of undeveloped and agricultural land decreased during this period and that the percentage of residential land increased by about 55 percent. Because the nitrate-concentration data were collected during 1975-89, and no individual well was monitored continually over the 14-year period, analysis of the effects of land-use change on nitrate concentrations was not possible.

Nitrate concentrations in the data set used in this study are not strongly correlated with land use (fig. 10). Because the data set consists of initial nitrate concentrations at the time of well installation, it may be biased toward the previous land use and not yet show the effects of the current land use. Ranked nitrate concentration is negatively correlated with ranked amount of undeveloped land (log-ratio transformed) in a well's buffer zone--that is, as the amount of undeveloped land in a buffer zone increases, the nitrate concentration in the well water tends to decrease (fig. 11). The t-ratio statistic (-10.1) indicates a strong relation. Regression analysis performed on ranked nitrate-concentration and log-ratio-transformed land-use data for shallow domestic wells does not indicate a strong relation between nitrate concentration and undeveloped land use, however (fig. 12a); the adjusted R-square statistic (0.286) indicates that this land-use model accounts for only about 25 percent of the variation in nitrate concentration found in water from the shallow domestic wells in Franklin Township. If the land-use categories agricultural, residential, and urban nonresidential are lumped into one "developed" category, nitrate concentrations tend to increase with increasing development. The relation with agricultural land use is weaker (t=2.85), although nitrate concentration does tend to increase with increasing percentage of agricultural land within a well's buffer zone (fig. 12b). In this case, the adjusted R-square statistic (0.067) indicates that this relation accounts for less than 10 percent of the variation in nitrate concentrations. The data do indicate, however, that although

Table 2. Median nitrate-nitrogen concentrations in water from wells in Franklin Township, New Jersey, grouped by well use

Well use	Number of wells	Median nitrate-nitrogen concentration, in milligrams per liter
Domestic	837	1.90
Agricultural/irrigation	13	3.40
Commercial	16	2.75

	Rank of nitrate concentration	Rank of LRAT percentage of agricultural land use	Rank of LRAT percentage of residential land use	Rank of LRAT percentage of urban nonresidential land use	Rank of LRAT percentage of undeveloped land use
Rank of nitrate concentration	1				
Rank of LRAT percentage of agricultural land use	.300*	1			
Rank of LRAT percentage of residential land use	-.237*	-.544*	1		
Rank of LRAT percentage of urban nonresidential land use	-.071	-.385*	-.147	1	
Rank of LRAT percentage of undeveloped land use	-.536*	-.650*	.344*	.110	1

* Significant at $p = 0.05$; $\omega.025 = -0.199$

Figure 9. Spearman's rank-correlation matrix for nitrate-nitrogen concentrations and log-ratio-transformed (LRAT) land-use-percentage data for 98 shallow domestic wells, Franklin Township, New Jersey.

Table 3. Area in each of five land-use categories in 1970 and 1985, Franklin Township, New Jersey

Land use	Area, in square miles	
	1970	1985
Undefined	0.1	0.0
Agricultural	16.1	15.3
Residential	2.9	4.5
Urban nonresidential	1.1	1.4
Undeveloped	36.1	35.1

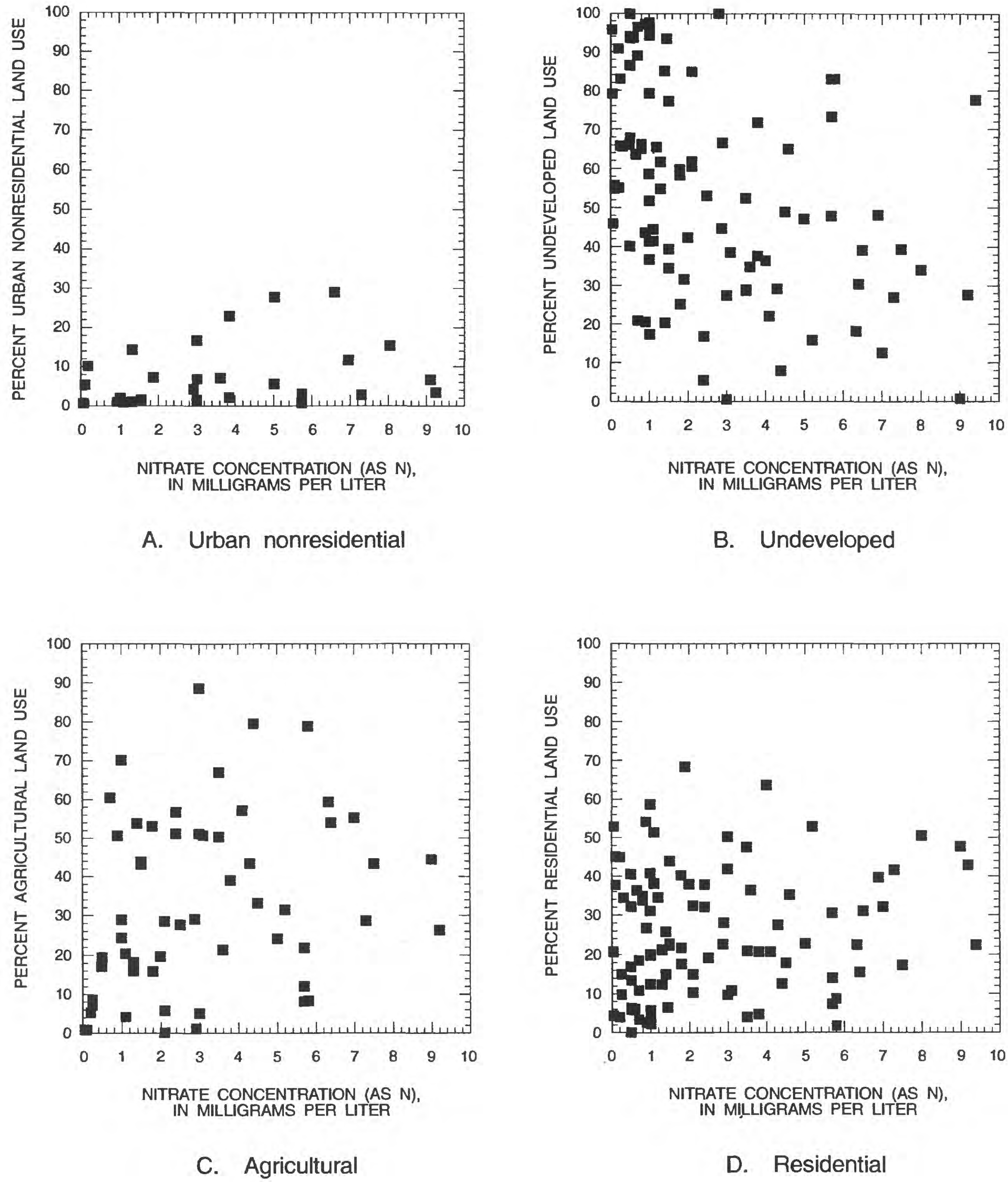

Figure 10. Relation of nitrate concentration in ground water to percentage of each four land-use categories in the buffer zone of the well, Franklin Township, New Jersey.

	Rank of nitrate concentration	Rank of LRAT percentage of agricultural land use	Rank of LRAT percentage of residential land use	Rank of LRAT percentage of urban nonresidential land use	Rank of LRAT percentage of undeveloped land use
Rank of nitrate concentration	1				
Rank of LRAT percentage of agricultural land use	.142	1			
Rank of LRAT percentage of residential land use	-.122	-.520*	1		
Rank of LRAT percentage of urban nonresidential land use	.103	-.486*	-.109	1	
Rank of LRAT percentage of undeveloped land use	-.329	-.536*	.411	-.164	1

* Significant at $p = 0.05$; $\omega.025 = -0.197$

Figure 11. Spearman's rank-correlation matrix for nitrate-nitrogen concentrations and log-ratio-transformed (LRAT) land-use-percentage data for 852 shallow domestic wells, Franklin Township, New Jersey. (From original data set of 868 wells with missing values deleted.)

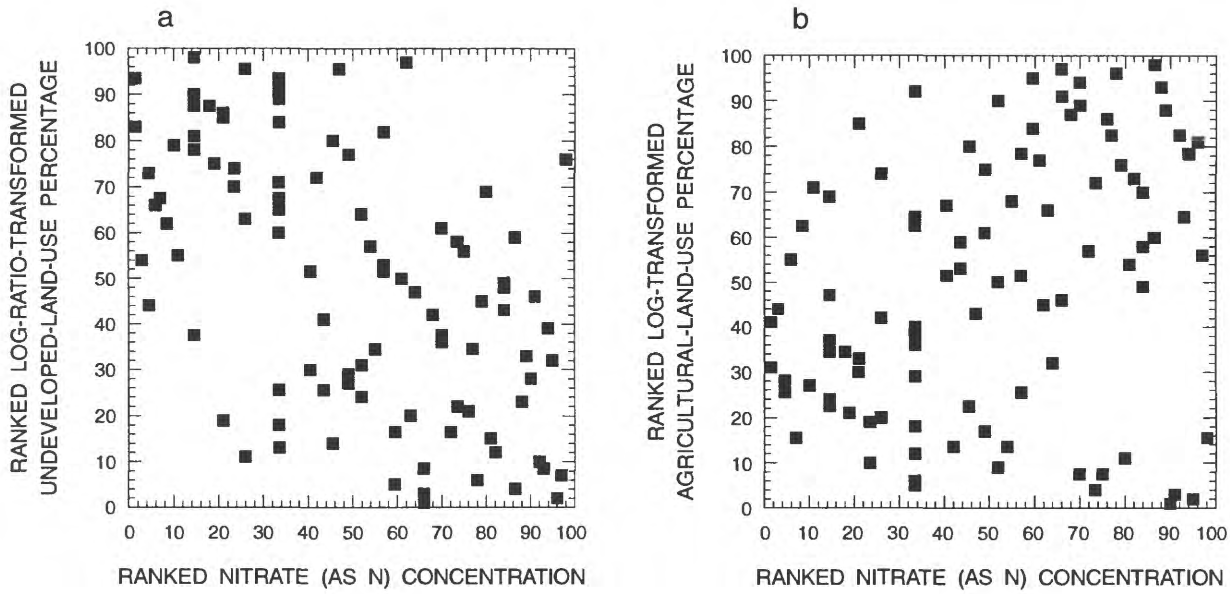

Figure 12. Ranked nitrate concentration in water from 98 shallow domestic wells as a function of (a) log-ratio-transformed undeveloped-land-use percentage, and (b) log-ratio-transformed agricultural-land-use percentage, Franklin Township, New Jersey.

no individual land-use category is strongly related to nitrate concentrations in ground water, water underlying undeveloped land contains nitrate in lower concentrations than water underlying developed land. Nevertheless, although the statistical analysis was inconclusive, a qualitative analysis of median nitrate concentrations within a predominant-land-use buffer zone shows the median nitrate concentration in water underlying undeveloped land to be about 1.0 mg/L, and that in water underlying developed land to be about 3.3 mg/L (fig. 13). Thus, the relation between increasing nitrate concentrations and land development is apparent on a qualitative basis.

By using the definition of background nitrate concentration of less than or equal to 3 mg/L (Madison and Brunett, 1984), water underlying undeveloped land could be considered to be unaffected by human activities. If the more conservative definition (less than or equal to 1 mg/L) of Perlmutter and Koch (1972) is used, then nitrate concentrations in water underlying undeveloped land are approximately twice the background concentrations, and significant inputs related to human activities are indicated (see table 1). Other water-quality data for the area indicate more strongly the presence of nitrate related to human activities. The USGS data base included observations for 23 wells in or near Franklin Township from which water has been analyzed for water-quality constituents, including nitrate, in the past (J.L. Barringer, U.S. Geological Survey, oral commun., 1992; Lacombe and Rosman, in press). Analysis of nitrate concentrations in water from these wells as a function of land-use category shows a clear difference between nitrate concentrations in water from developed and undeveloped areas (fig. 14). Seventeen percent of the samples from the 23 wells contained nitrate in concentrations exceeding 10 mg/L. These data indicate that residential and agricultural land uses, in particular, have affected nitrate concentrations in ground water. Vowinkel (1991), in a statistical study of ground-water quality for two Coastal Plain aquifers, showed that nitrate concentrations in water from the Kirkwood-Cohansey aquifer system were higher in agricultural areas than in other land-use areas.

GROUND-WATER-QUALITY MONITORING NETWORK

Because the data used in this study were limited and were not collected specifically for a statistical analysis of water-quality trends, only a preliminary analysis was possible. In order to monitor more effectively the effect of land development on ground-water quality, the data base used in this study could be used as a basis for an annual or biannual sampling strategy. If a subset of wells for which water-quality observations currently are available were monitored consistently, analysis of the relation between changes in ground-water quality and changes in land use would be possible. Additional wells for which the data base currently contains no observations could be added to the network as needed. The design of a gridded ground-water-quality monitoring network is outlined below.

The wells included in the network ideally would be installed in one of the four land-use categories (agricultural, residential, urban nonresidential, and undeveloped) and would be divided equally among them. Ideally, these wells would be screened in shallow, intermediate, and deep zones of the aquifer. Table 4 provides examples of the number of monitoring wells by land-use category and depth for two well-separation distances.

Periodic sampling and analysis for nitrate and other water-quality constituents would provide data that would permit an assessment of the effects of development on water quality with time. Although nitrate concentration is an indicator of human activities, analyses of other water-quality constituents also would be useful in examining the effects of specific land-use practices.

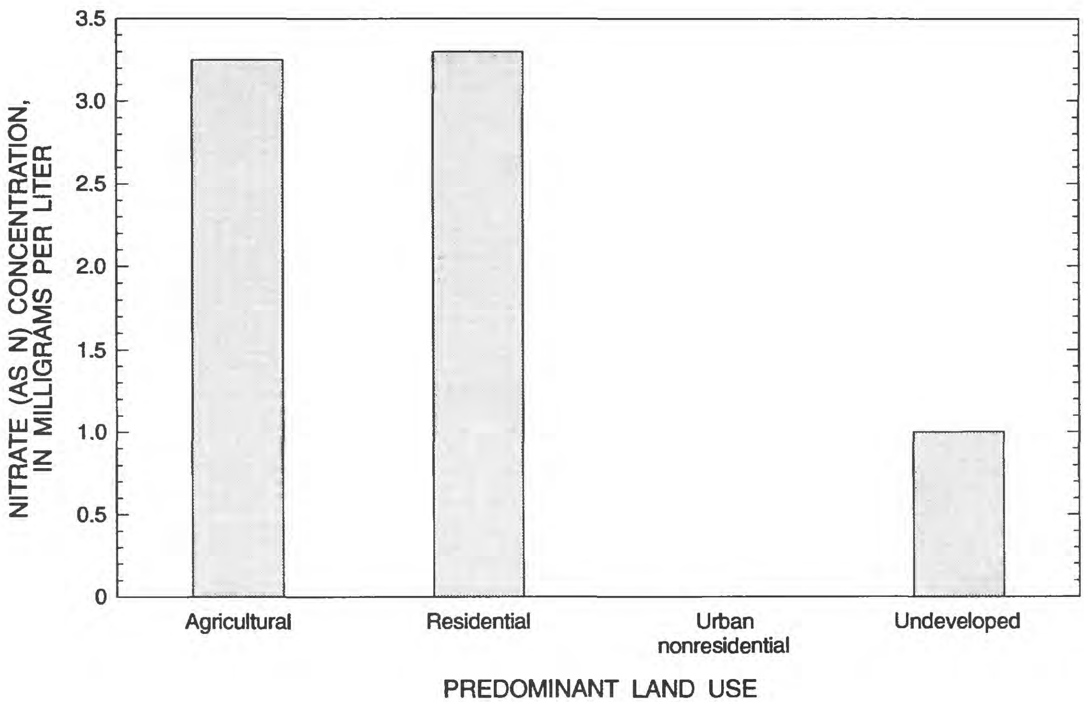

Figure 13. Median nitrate concentrations in water from wells in predominantly agricultural, residential, urban nonresidential, and undeveloped land-use areas, Franklin Township, New Jersey.

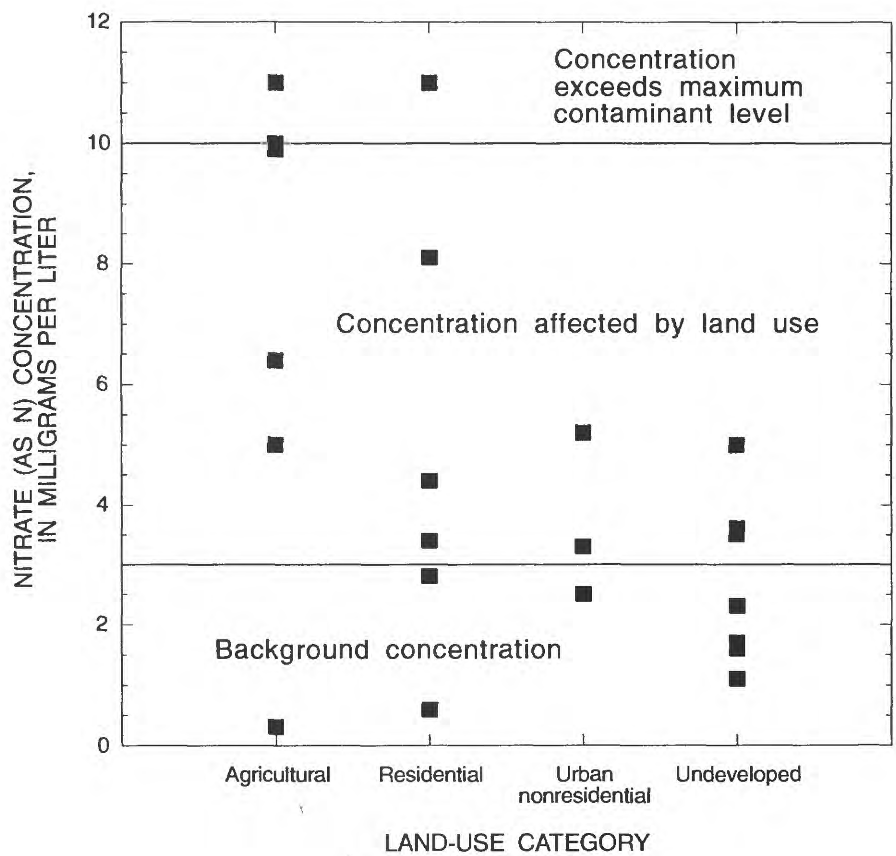

Figure 14. Nitrate concentrations in water from 23 wells in Gloucester County, New Jersey, grouped by land-use category.

Table 4. Ideal number of wells required for two separation distances for a gridded water-quality monitoring network in Franklin Township, New Jersey

Separation distance between wells (feet)	Minimum number of wells	Number of wells in each land-use category[1]	Number of wells of each well use[2]	Number of wells in each well-depth category[3]
656	432	108	36	12
1,312	108	27	9	3

[1]Agricultural, residential, urban nonresidential, and undeveloped

[2]Domestic, agricultural/irrigation, and commercial

[3]Shallow (0-55 feet), medium (56-100 feet), and deep (greater than 100 feet)

SUMMARY AND CONCLUSIONS

A data base consisting of nitrate-concentration and well-construction data from 1,606 wells in Franklin Township, Gloucester County, New Jersey, was compiled by the U.S. Geological Survey in cooperation with the Gloucester County Planning Department. The data base was used to test the relations of nitrate concentration in ground water to well depth, well use, and land use. Analysis of these data showed that nitrate concentrations in water from one-third of the 868 wells are indicative of sources of nitrate that are related to human activities, if nitrate concentrations greater than 3 mg/L are taken to represent effects of human activities. Two-thirds of the wells yielded water affected by human activities if 1 mg/L is considered to be the background concentration of nitrate, however. Nitrate concentrations in water from only 1 percent of the 868 wells in the edited data base exceeded the U.S. Environmental Protection Agency maximum contaminant level of 10 mg/L. Well depth and well use were used to stratify the data set in order to fully test the relation between nitrate concentration and land use. Deep wells generally contain older water than shallow wells; nitrate concentrations are lower and the water quality is more likely to be representative of past, rather than present, land use. Statistical analysis of nitrate concentrations in water from 98 shallow domestic wells, screened at depths of 55 feet or less, located in areas of agricultural, residential, urban nonresidential, and undeveloped land use indicates that nitrate concentrations tend to decrease as the percentage of undeveloped land within a 656-ft radius of a well decreases. A weak statistical relation was found between nitrate concentration and agricultural land use; however, U.S. Geological Survey ground-water-quality data for 23 wells in agricultural areas in Franklin Township and the vicinity indicate a slightly stronger link between agricultural land use and elevated nitrate concentrations. The lack of strong correlation between nitrate concentration and land use shown in the Franklin Township data set (868 wells) may be a function of a bias toward previous land use; the data set was compiled from nitrate data collected at the time of well installation.

The original data set (868 wells) was stratified according to well use. By using nitrate concentrations of 3 mg/L and the conservative 1 mg/L as cut-off points between water affected by human activities and background levels, water from the majority of agricultural/irrigation wells in both cases (60 and 92 percent, respectively) was found to be affected, whereas about 42 and 69 percent, respectively, of commercial wells and about 35 and 67 percent, respectively, of domestic wells yielded water affected by human activities.

Overall, although statistical relations developed for the Franklin Township data generally were not strong, the median nitrate concentration of water underlying undeveloped land was found be about 1.0 mg/L, whereas that in water underlying developed land was about 3.3 mg/L. Therefore, a relation exists between elevated nitrate concentrations in ground water and land development.

Continued monitoring of the effects of land development on ground-water quality over time could be done by sampling many of the same wells used in this study for nitrate concentrations. For a well-designed statistical analysis, such a sampling network ideally would include equal numbers of wells of different well-use type, screened in shallow, intermediate, and deep zones of the aquifer, and located equally in four different land uses--agricultural, residential, urban nonresidential, and undeveloped.

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