SUSCEPTIBILITY OF SOURCE WATER TO COMMUNITY WATER SUPPLY WELLS IN NEW JERSEY TO CONTAMINATION BY NITRATE

Summary

A susceptibility assessment model was developed to predict the potential susceptibility of the source water from 2,237 community water supply (CWS) wells in New Jersey to contamination by nitrate. Susceptibility is defined by variables describing hydrogeologic sensitivity and contaminant-use intensity within the area contributing water to a well. The model was calibrated by using concentrations of nitrate in untreated water samples from 641 CWS wells collected near the wellhead by the U.S. Geological Survey (USGS). Variables used to estimate hydrogeologic sensitivity are if the well is open to a confined or unconfined aquifer and the conceptual variables depth to the top of the open interval and length of open interval. Variables used to estimate contaminant-use intensity are the percentages of agricultural land in 1986 and urban land in 1995. Results of the model indicate that 29 percent of the CWS wells are confined and not susceptible, whereas, in unconfined wells the susceptibility is low for 2 percent, medium for 22 percent, and high for 48 percent (figs. 1 and 2).

Introduction

The 1996 Amendments to the Federal Safe Drinking Water Act require all states to establish a Source Water Assessment Program (SWAP). New Jersey Department of Environmental Protection (NJDEP) elected to evaluate the susceptibility of public water systems to contamination by inorganic constituents, nutrients, volatile organic and synthetic organic compounds, pesticides, disinfection byproduct precursors, pathogens, and radionuclides. Susceptibility to contamination in ground water is a function of many factors, including contaminant presence or use in or near the water source, natural occurrence in geologic material, changes in ambient conditions related to human activities, and location of the well within the flow system. The New Jersey SWAP includes four steps: (1) delineate the source water assessment area of each ground- and surface-water source of public drinking water, (2) inventory the potential contaminant sources within the source water assessment area, (3) determine the public water system's susceptibility to contaminants, and (4) incorporate public participation and education (http://www.state.nj.us/dep/swap).

Susceptibility assessment models were developed to rate each public ground-water source as having low, medium, or high susceptibility for groups of constituents. This report (1) describes methods used to develop the susceptibility assessment model for nitrate, (2) presents results of application of the susceptibility model to estimate the susceptibility of source water to CWS wells to nitrate, and (3) documents the distribution of nitrate in water from CWS wells in New Jersey. The results of the model are intended to be a screening tool to guide water managers in decisions concerning monitoring of public sources of water.

Background

The nitrogen cycle (fig. 3) describes the movement and microbial transformation of nitrogen in the environment. Nitrogen compounds occur naturally in some geologic materials such as lignite and in soil organic matter in New Jersey, but these materials probably contribute little nitrate to ground water. Consequently, most of the nitrogen species in ground water result from point and nonpoint sources of contamination (fig. 4). Point sources are discrete identifiable points, such as municipal or industrial wastewater-treatment-plant discharges and known contamination sites.

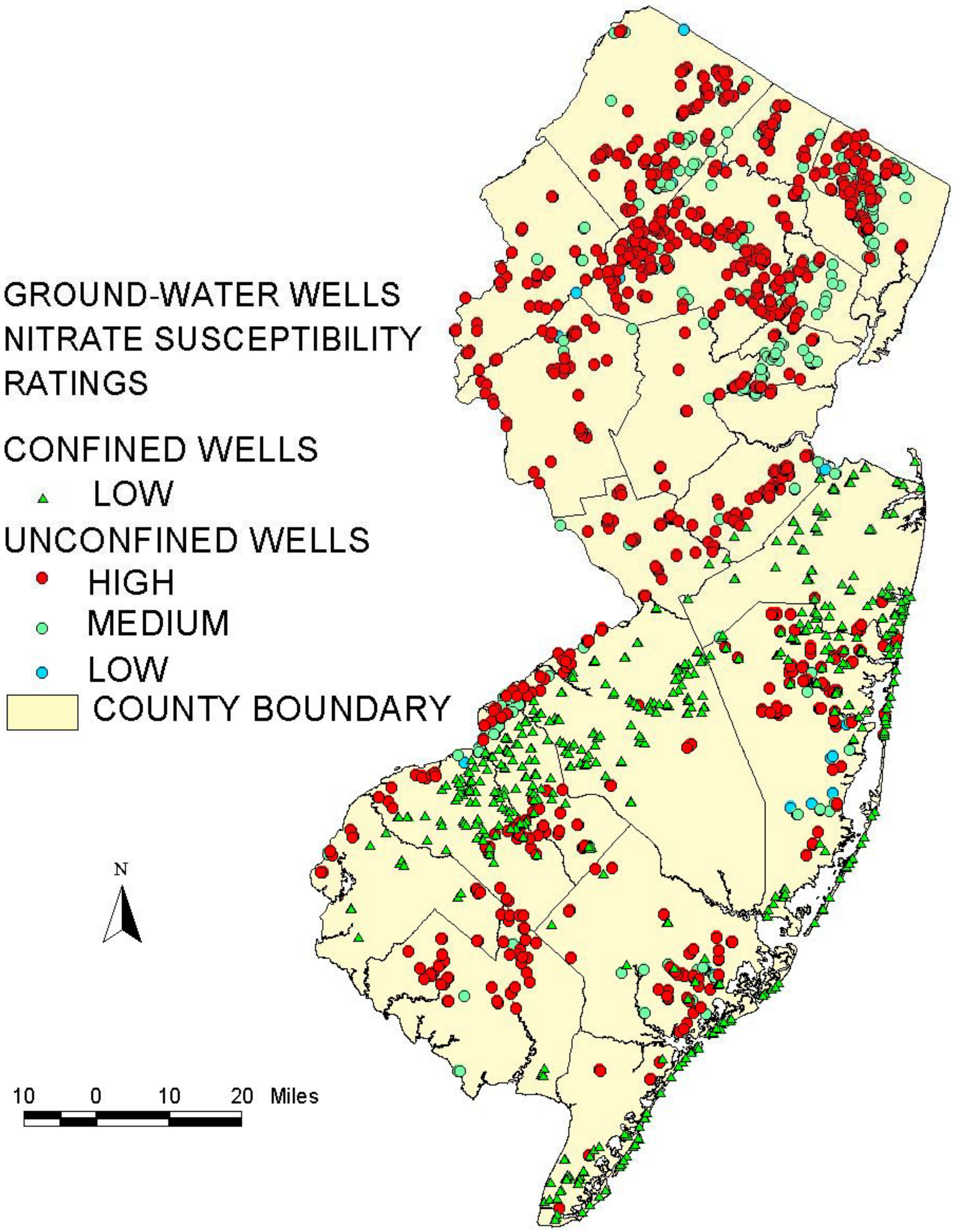

Figure 1. Susceptibility of 2,237 community water supply wells in New Jersey to contamination by nitrate.

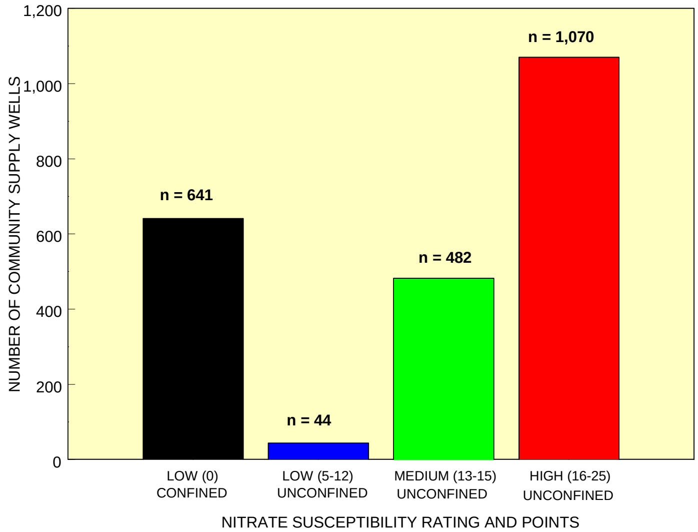

Figure 2. Number of community water supply wells by susceptibility group.

Nonpoint sources are from broad areas where the source is difficult to identify on a map. Examples of point and nonpoint sources are the atmosphere (wet and dry deposition); wildlife (birds, mammals, other); fertilizer use (residential and agricultural); domestic and farm animals, confined feedlots; septic-system wastes (residential/industrial); and leaky sewer pipes (from older piping systems).

Nitrogen species contributed by contaminant sources are either in an oxidized form like nitrate or in a reduced form, such as organic nitrogen or ammonia. The reduced forms can be oxidized to nitrite then to nitrate by soil bacteria. Nitrate is soluble and can leach into ground and surface water. In oxygenated water, nitrate tends to persist and is mobile, but in anoxic waters, it is converted to nitrous oxide or nitrogen gas by bacteria (Hem, 1989). More information on the distributions of nitrate in surface water in New Jersey and elsewhere in the United States can be found in the USGS NAWQA web site (http://water.usgs.gov/nawqa/nutrients/)

The Maximum Contaminant Level (MCL) for nitrate as nitrogen (as N) in drinking water is 10 mg/L. Routine monitoring for nitrate at all community water systems is required by State and Federal Safe Drinking Water regulations. Increased nitrate monitoring above the routine is required if the concentration exceeds 50 percent of the MCL. Concentrations equal to or above 10 percent of the MCL are considered here as an indication of an emerging problem, but health effects at this level are of less concern. Various forms of nitrogen are measured in water samples collected and analyzed by the USGS, including ammonia, ammonia plus organic nitrogen, nitrite, and nitrate plus nitrite. Because nitrite rarely is present in ground water, the nitrate plus nitrite analysis is predominantly nitrate and hereafter will be referred to as nitrate. Nitrate in ground water is mostly dissolved and does not adsorb to particles.

Definition of Susceptibility

The susceptibility of a public water supply to contamination by a variety of constituents is defined by variables that describe the hydrogeologic sensitivity of and the potential contaminant-use intensity in the area that contributes water to that source (fig. 4). The susceptibility assessment models were developed by using an equation whereby the susceptibility of the source water is equal to the sum of the values assigned to the variables that describe hydrogeologic sensitivity plus the sum of the values assigned to the variables that describe potential contaminant-use intensity within the area contributing water to a well.

Susceptibility = Hydrogeologic Sensitivity + Potential Contaminant-Use Intensity

The susceptibility models are intended to be a screening tool and are based on water-quality data in the USGS National Water Information System (NWIS) database. The objective is to rate all community water supplies as having low, medium, or high susceptibility to contamination for the groups of contaminants by using, as guidance, thresholds developed by New Jersey Department of Environmental Protection (NJDEP) for the purpose of creating the model. In general, the low-susceptibility category includes wells for which constituent values are not likely to equal or exceed one-tenth of New Jersey’s drinking-water maximum contaminant level (MCL). The medium-susceptibility category includes wells for which constituent values are not likely to equal or exceed one-half the MCL, and the high-susceptibility category includes wells for which constituent values may equal or exceed one-half the MCL.

Susceptibility Model Development

The development of the susceptibility assessment model involved several steps (J.A. Hopple and others, U.S. Geological Survey, written commun., 2003): (1) development of source water assessment areas for community water supplies; (2) building of geographic information system (GIS) and water-quality data sets, (3) exploratory data analysis using univariate and multivariate statistical techniques, and graphical procedures, (4) development of a numerical coding scheme for each variable used in the models, (5) assessment of relations of the constituents to model variables, and (6) use of an independent data set to verify the model. Multiple lines of evidence were used to select the final variables used in the models.

Development of Source Water Assessment Areas

The New Jersey Geological Survey (NJGS) estimated areas contributing water to more than 2,400 CWS wells in New Jersey and New York (fig. 5) by using the Combined Model/Calculated Fixed Radius Method. These methods use well depth, water-table gradient, water-use data, well characteristics, and aquifer properties to determine the size and shape of the contributing area. The source water assessment area for a well open to an unconfined aquifer was divided into three tiers based on the time of travel from the outside edge to the wellhead: tier 1 (2-year time of travel), tier 2 (5-year time of travel), and tier 3 (12-year time of travel) (http://www.state.nj.us/dep/njgs/whpaguide.pdf). An unconfined aquifer is a permeable water-bearing unit where the water table forms its upper boundary at the interface between unsaturated and saturated zones. The source water assessment area for a well open to a confined aquifer was defined as the area within a 50-foot radius of the well (http://www.state.nj.us/dep/njgs/whpaguide.pdf). Confined aquifers are permeable water-bearing units between hydrogeologic units with low permeability known as confining units.

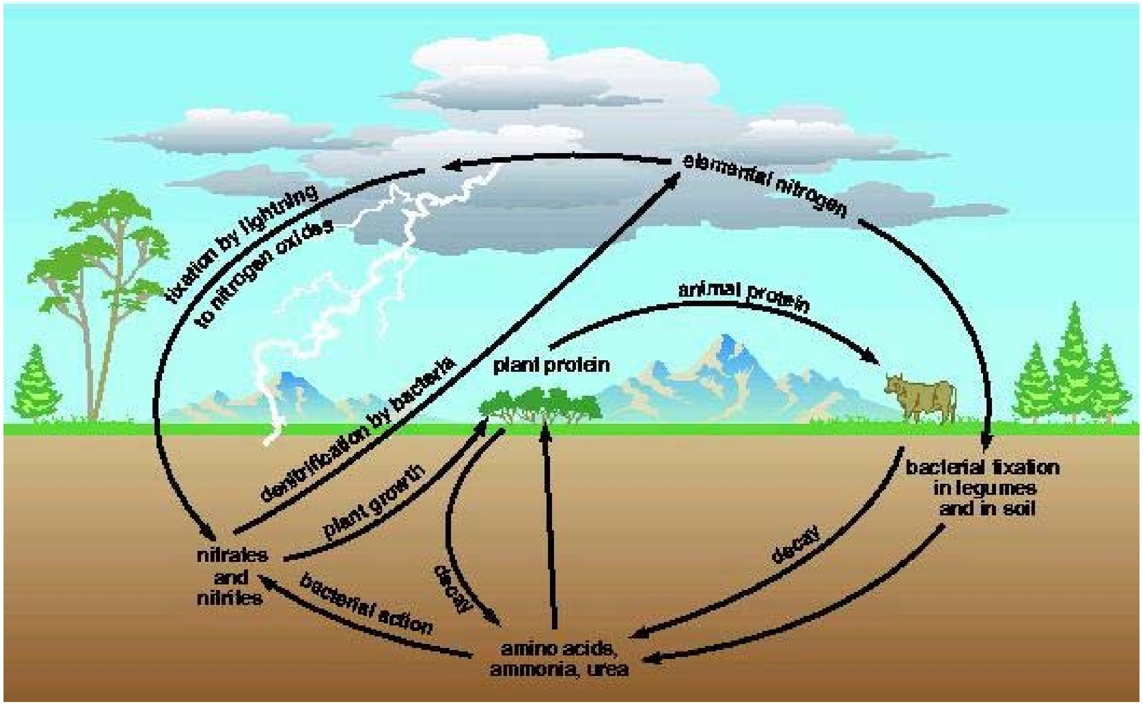

Figure 3. Schematic diagram of the nitrogen cycle.

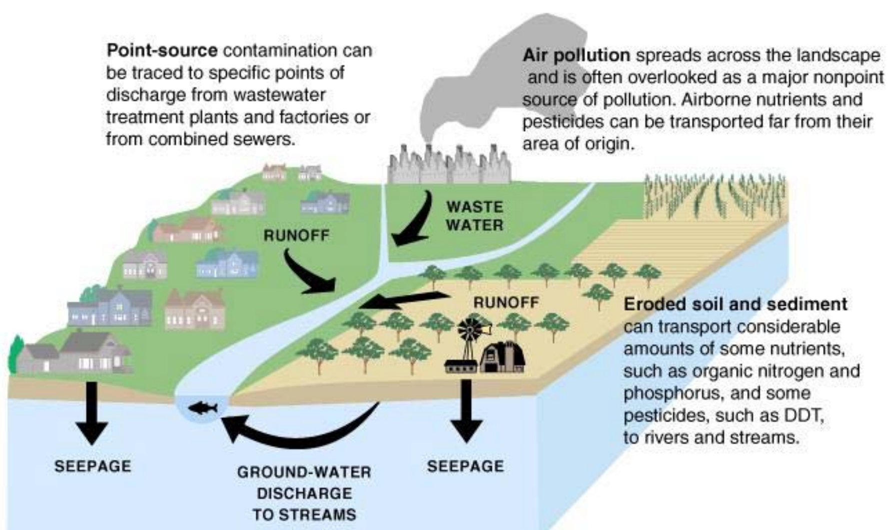

Figure 4. Schematic diagram showing point and nonpoint sources of contamination and how they can affect ground- and surface-water quality**.**

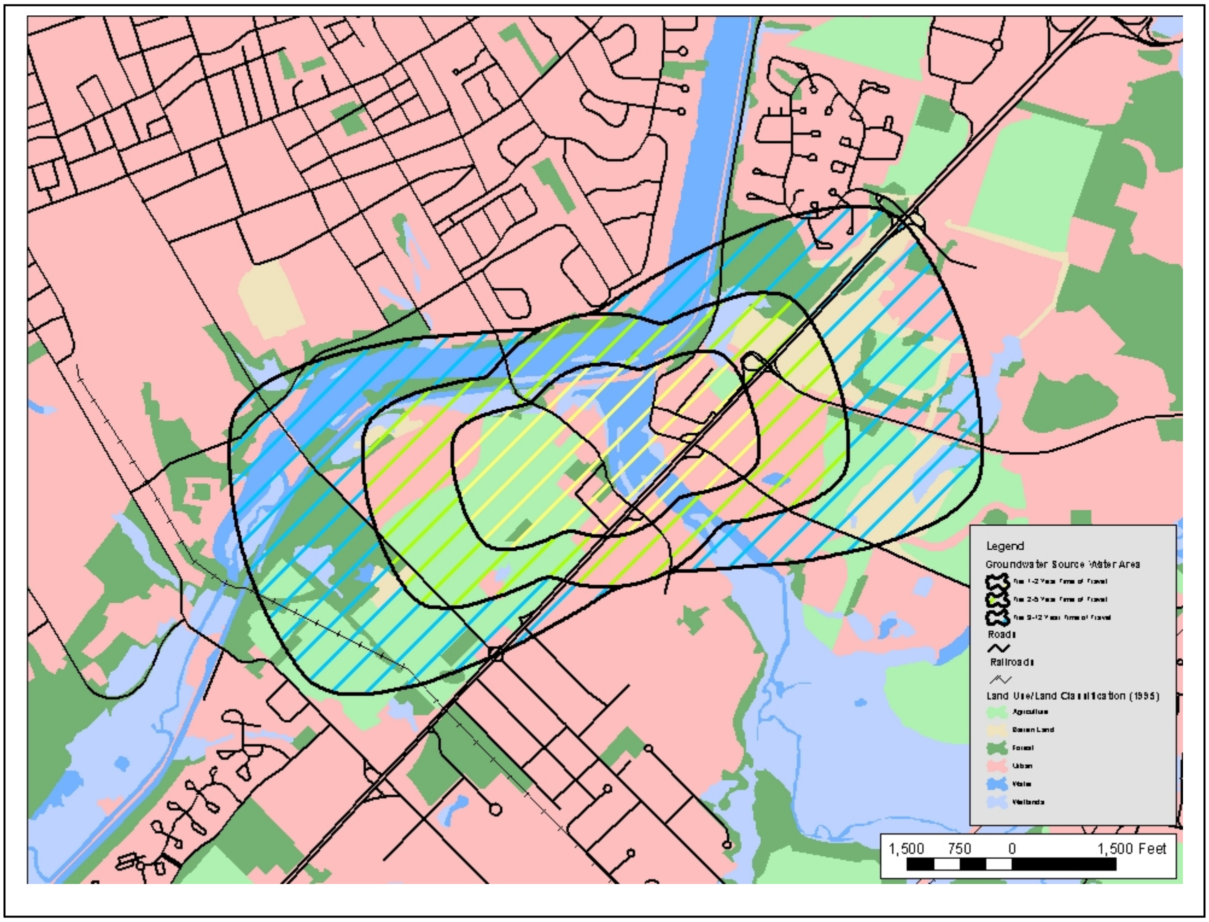

Figure 5. Example of delineated contributing area to a community water-supply well showing time of travel (TOT), land use, roads, and railroads.

Development of Data Sets

Data sets were developed for the GIS and water-quality data to assess the variables used to develop the susceptibility models. A relational database was used to store and manipulate water-quality, hydrogeologic-sensitivity, and intensity variables.

GIS

A GIS was used to quantify hydrogeologic-sensitivity and potential contaminant-use variables that may affect ground-water quality within areas contributing water to wells. The variables were calculated for each of the three ground-water tiers and for the entire source water assessment areas for wells open to unconfined aquifers. The variables were calculated for the entire source water assessment area for wells open to confined aquifers. Sensitivity variables used in the statistical analysis include soil properties, aquifer properties, physiographic province, and well-construction characteristics. Intensity variables include land use from coverages based in the early 1970’s, 1986, and 1995-97; lengths of roads, railways, and streams; the number of potential contaminant sources; septic-tank, population, and contaminant-site densities; and minimum distances of the well to the various land uses and to potential contaminant sources.

Water-Quality Data

Ground-water-quality data from June 1980 through October 2002 were obtained from the USGS NWIS database. Data were imported into a relational database and a statistical software package used for exploratory data analysis, statistical testing, and plotting. All water-quality data are from water samples collected by the USGS prior to treatment, unless otherwise noted. Analyses that were determined by older, less accurate, less precise methods were excluded. Analyses with known contamination problems also were not used.

Three data sets consisting of wells sampled for nitrate were used in the modeling process: (1) a subset of all 641 CWS wells (fig. 6), and (2) a subset of 421 unconfined CWS wells. The most recent concentration measured at each well was used because (1) the sample reflects more recent conditions, (2) the sample probably was analyzed using a method with the lowest minimum reporting level (MRL) and greatest precision, and (3) selecting one sample avoided problems of averaging samples with different MRLs. A third data set of 220 confined Coastal Plain wells was developed because it was determined previously that contamination of water from human activities at the land surface was unlikely to affect confined wells in the Coastal Plain (Vowinkel, 1998, and Storck and others, 1997) except in cases where the casing has been breached and contaminants move along the annulus of the well.

Data Analysis

Federal and State Safe Drinking Water Regulations require routine monitoring for many nitrate at community water systems. For the purpose of modeling, NJDEP determined that concentrations greater than one-half of the MCL would be of greatest concern. Concentrations equal to or greater than one-tenth of the MCL also are considered in this report as an indication of an emerging problem, but health effects at this level are of less concern. The nitrate models were developed to determine the variables that best describe the presence or absence of constituents in source waters at concentrations equal to or greater than one-tenth of the MCL.

Statistical tests were used to determine those variables that best describe the presence or absence of nitrate in source waters at 5 and 1 mg/L. The size of the Kruskal-Wallis test statistic and corresponding p-value are used as a measure of the strength of differences between the groups. Spearman's rho, the nonparametric equivalent of a correlation coefficient, was used to evaluate linear trends between ranked explanatory and response variables because environmental variables rarely are normally distributed (Helsel and Hirsch, 2002). Correlation coefficients were calculated between the nitrate value and all hydrogeologic-sensitivity and intensity variables, and many water-quality variables. Scatter plots of each variable in relation to the total pesticide value were generated to confirm the results of statistical tests. Boxplots were used to compare the distributions of variables among groups.

In some cases, variables thought to be a good predictor of contamination did not produce a significant univariate statistical relation. In this report, conceptual variables are variables with possible graphical relations for which results of univariate statistical tests were not significant but that have been shown in a previous scientific investigation to be related to the concentrations of a constituent. Conceptual variables also are variables for which results of univariate statistical tests were or were not significant but that improve the model and may represent a surrogate for other unidentified variables associated with the concentration of a constituent, although no evidence was found in previous investigations of a relation. Conceptual variables that did not produce significant univariate statistical relations may, however, produce a significant relation when used with other variables in multivariate statistical tests. Selected sensitivity and intensity

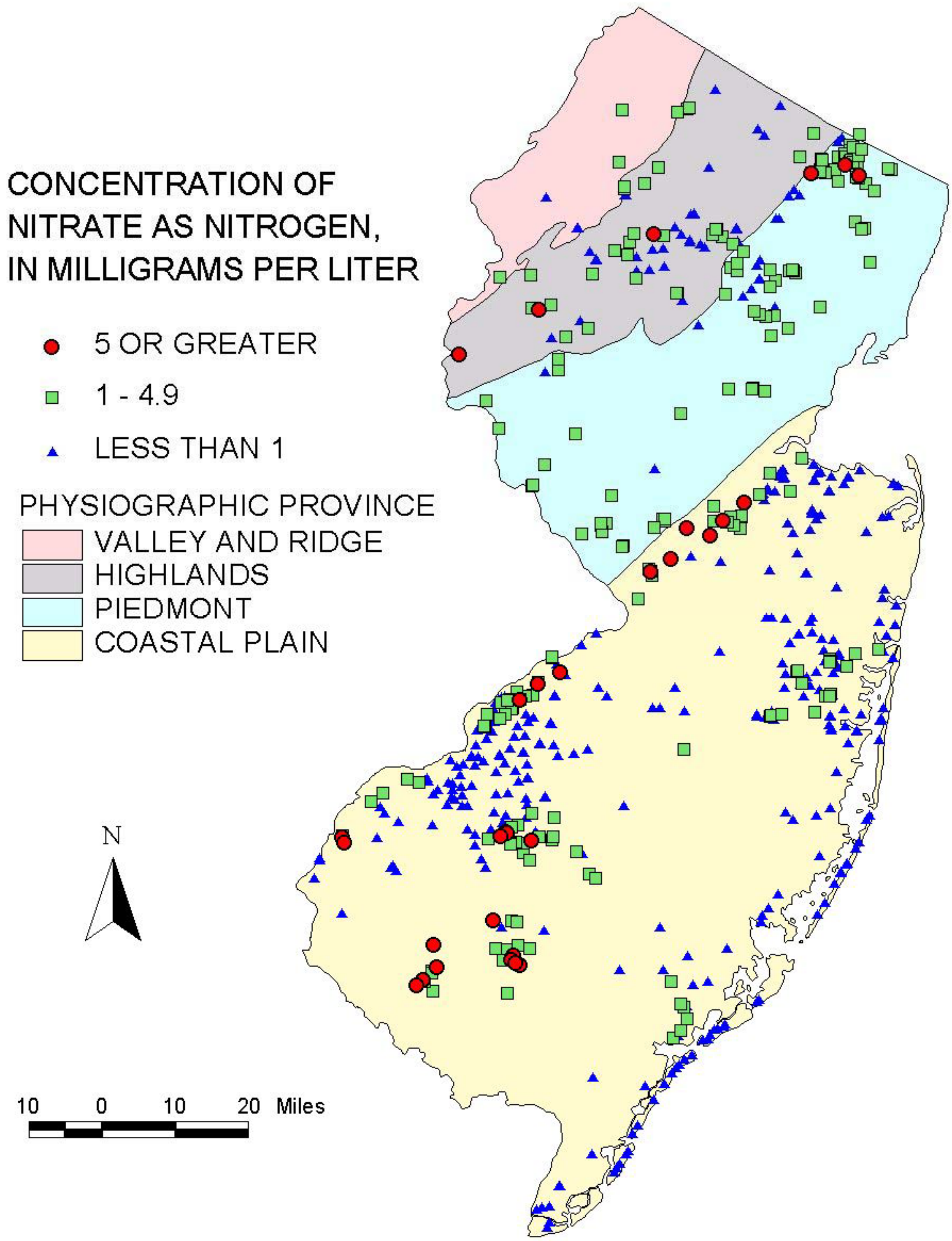

Figure 6. Nitrate concentrations in water from 641 community water supply wells sampled by the U.S. Geological Survey and used for model development.

variables that were either conceptually or significantly related to the presence or absence of a particular constituent were tested for covariance by using Principal Components Analysis. Logistic regression analysis was used to determine the best combination of variables to predict the presence or absence of a constituent at a given concentration. Variables were included in the susceptibility models only if there was a physical basis or explanation for their inclusion, plots showed an apparent graphical relation, or they improved the results of the model.

Some variables that proved to be statistically significant were not used in the model. Some possible reasons for exclusion were (1) the variable was not a known source of the constituent modeled, (2) use of the variable in the model was not supported by scientific investigations, (3) the variable did not show a graphical relation to the constituent, or (4) the variable was found to have a similar relation to the constituent as another variable. Also, problems exist related to closure when percentages are used in statistical analyses. Results of statistical analyses that include percentages are used with caution. Since all surface-water-quality sites were used in the statistical analysis, overlapping buffers could bias results because of double accounting of land uses (Barringer and others, 1990).

Relation of Nitrate in Ground Water to Susceptibility Variables

Results of graphical and univariate and multivariate statistical analyses indicate that concentrations of nitrate in water from CWS wells are related to various hydrogeologic-sensitivity variables, including aquifer type and well-construction characteristics (fig. 7). Concentrations of nitrate as N (as nitrogen) in filtered water from 641 CWS wells (fig. 1) were equal to or exceeded 10 mg/L in 2 wells, 5 mg/L in 30 wells, and 1 mg/L in 239 wells. Concentrations differ among aquifer types (fig. 8). Nitrate generally is present in water from unconfined Coastal Plain, bedrock, and glacial wells but exceeded 1 mg/L in only 1 of 224 confined Coastal Plain (fig. 8) wells. The water probably is too old (centuries to millennia) to have been affected by human activities, and because dissolved oxygen is absent. As a result of these findings, wells screened in confined Coastal Plain aquifers are considered not sensitive to contamination by nitrate from human activities at the land surface. Land uses above a confined well usually are not a source of contamination to water from the well.

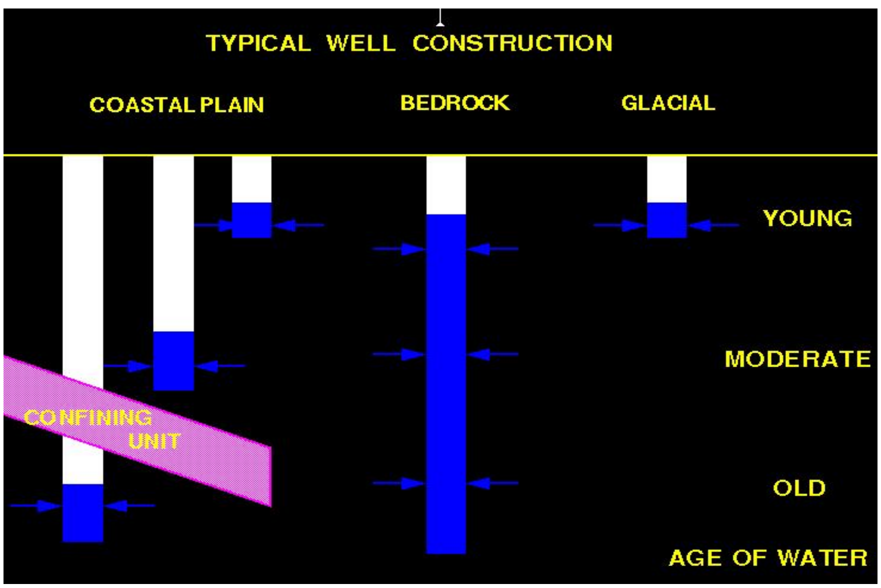

Figure 7. Schematic diagram of relation of aquifer type to well construction characteristics and age of water.

The age of water from the time the water recharged at the land surface is on the order of years for young, decades for moderate, and centuries to millennia for old water.

Arrow indicated direction of ground-water flow.

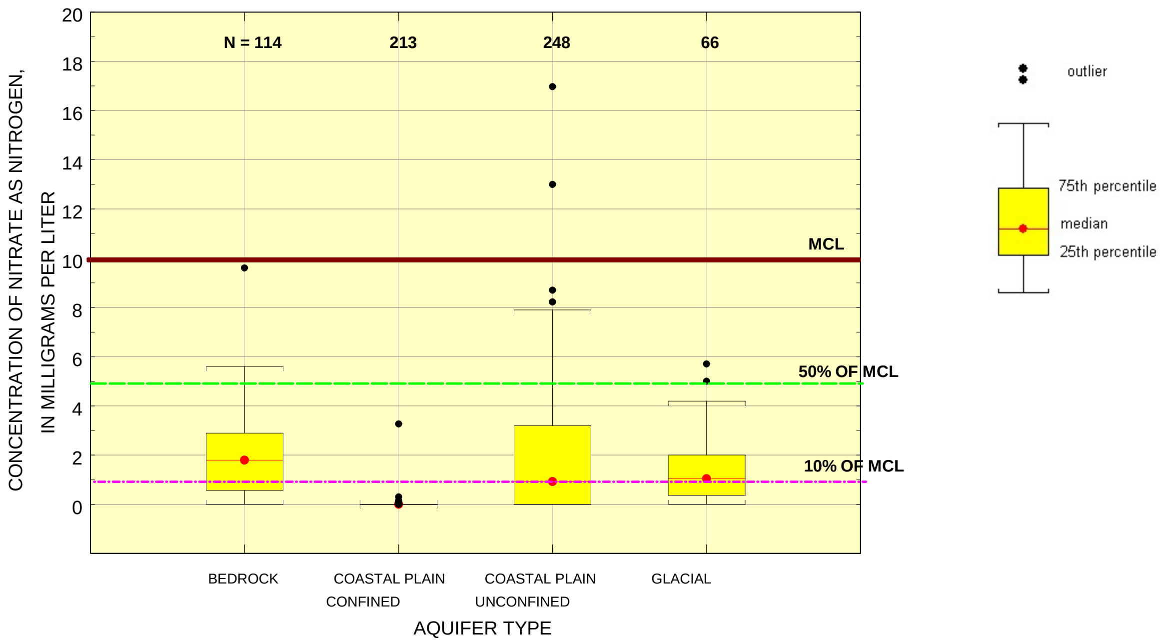

Figure 8. Distributions of nitrate in water from Community Water Supply wells by aquifer type. (MCL; Maximum Contaminant Level, %, percent)

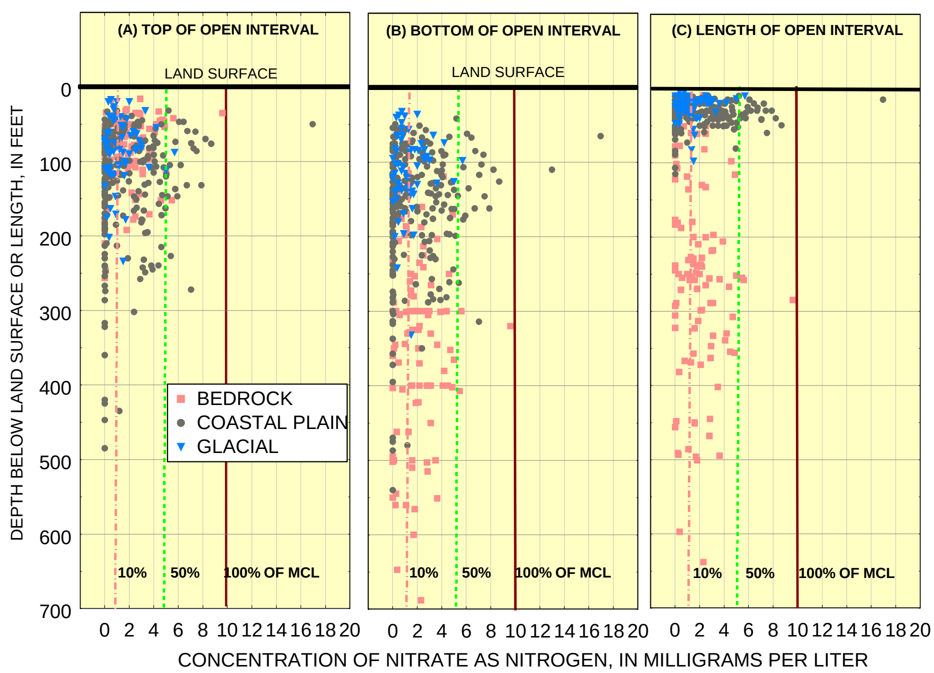

Figure 9. Relation of concentration of nitrate to well construction characteristics by aquifer type in unconfined Community Water Supply wells: (A) top of open interval, (B) bottom of open interval, and (C) length of open interval. (MCL, Maximum Contaminant Level; %, percent)

Concentrations of nitrate in water from unconfined CWS wells are related to well-construction characteristics (table 1 and fig. 9). Glacial wells are typically less than 200 feet deep with short open intervals. Bedrock wells typically have short depths to top of open intervals, but the length of open intervals is often several hundred feet. The largest concentrations of nitrate are in water from wells that have a depth to the top of the open interval less than 100 feet below land surface (fig. 9A) and a length of open interval of less than 50 feet. The concentration of nitrate as N is greater than 5 mg/L in only six wells with a depth to top of open interval greater than 100 feet and a bottom of open interval less than 200 feet below land surface (fig. 9B) Only two wells with a length of open interval greater than 200 feet contain nitrate as N greater than 5 mg/L (fig. 9C).

Results of graphical, univariate, and multivariate statistical analyses indicate that concentrations of nitrate in water from unconfined CWS wells are significantly related to the predominant land-use type and percentage of land use within the source water assessment area (fig. 10), including developed (fig. 10A), agricultural (fig. 10B), and urban land uses (fig. 10C). Most CWS wells are in predominantly urban areas. A smaller number are in predominantly agricultural, forested and wetlands areas. Land-use change also may have an affect on the statistical relations. The relative strength of significance of each variable differs at the 1- and 5-mg/L cutoff level (table 1). Developed land use is the sum of urban and agricultural land uses—areas that typically are sources of nitrate from human activities. Undeveloped land is the sum of forested land and wetlands—areas that typically are not sources of nitrate in the environment. The predominant land use within the source water assessment areas is the single land use with the largest percentage within the area.

Concentrations of nitrate tend to increase as the percentage of developed land (fig. 10A) increases probably because the use of nitrogen increases, and, because there is less undeveloped land with lower nitrogen use to dilute the nitrate from agricultural and urban sources. Concentrations are less than 1 mg/L where developed land use is less than 20 percent, indicating that atmospheric sources of nitrate to ground water are probably less than 1 mg/L in undeveloped areas. The nitrate deposited from the atmosphere is probably used by plants or sorbed by organic matter in forests and wetlands. Atmospheric sources to ground water could be more significant in urban areas where local nitrogen sources may be present and less vegetation is available to uptake nitrogen. Concentrations exceeded 5 mg/L at only six sites where less than 70 percent of the area is developed land use, and concentrations frequently exceed 5 mg/L where the percent developed land use accounts for greater than 70 percent.

Concentrations of nitrate as N are most significantly related to the percentage of agricultural land use in 1986 especially at the 5-mg/L cutoff level, and tend to increase as the percentage of agricultural land use increases (fig. 10B), probably because nitrogen is used in agricultural areas more than in most urban areas. Several wells were in predominantly agricultural areas in 1986 but are now in predominantly urban land areas because housing developments have replaced some agricultural land since the mid-1980’s. If the more current 1995 land use is used, then the agricultural effect on water quality may be underrepresented.

Concentrations of nitrate tend to increase as the percentage of urban land use increases (fig. 10C). Some larger nitrate values at low percentages of urban land use probably result from the effects of agricultural land uses, and not urban uses. The concentrations of nitrate tend to level off at percentages greater than 50 percent of urban land use probably because these areas usually are sewered and the nitrogen is transported to sewage treatment facilities, and then to streams. Areas that are less than 50 percent urban land use are often served by septic systems where the nitrogen is treated on site and ammonia is oxidized to nitrate in oxygenated ground water.

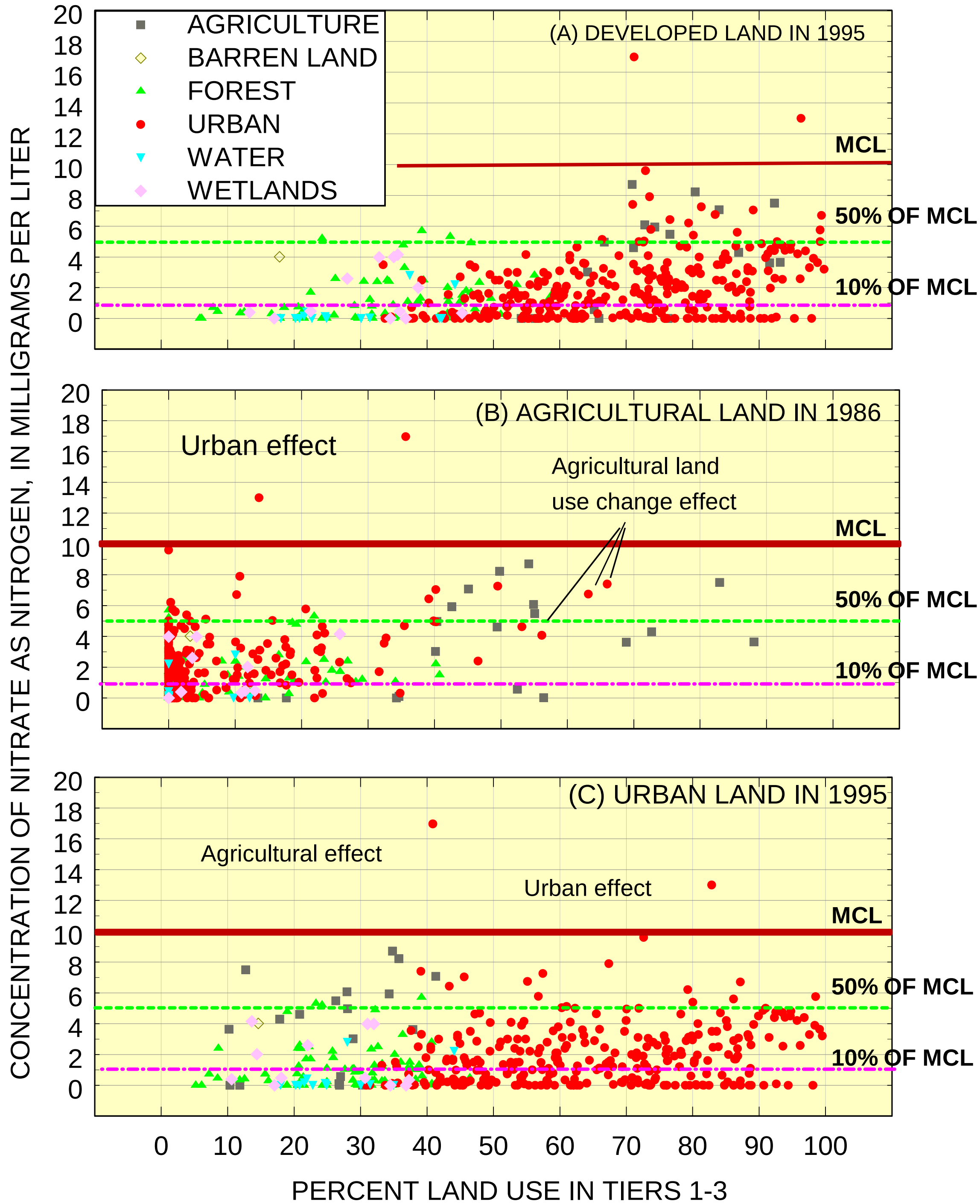

Figure 10. Relation of concentration of nitrate in unconfined Community Water Supply wells to percent: (A) developed land in 1995 in tiers 1-3, (B) agricultural land in 1986 in tiers 1-3, and (C) urban land in 1995 in tiers 1-3, by predominant land use in 1995 in the source water assessment area. (MCL, Maximum Contaminant Level; %, percent).

Results of univariate statistical tests at the 1-mg/L cutoff level indicate that the relation of the occurrence of nitrate and land use is stronger for all three tiers than for tier 1 alone for developed, agricultural, and urban land uses. The relation is strongest for developed land use, followed by agricultural and urban land use, indicating that the effects of agricultural and urban land use are additive.

Results of univariate statistical tests at the 5-mg/L-cutoff level indicate that relation of the occurrence of nitrate and land use is stronger for all three tiers than for tier 1 alone for agricultural and developed land uses possibly because agricultural land use is more prevalent in the outer tiers than in tier 1. The relation is strongest for agricultural land followed by developed land and is not significant for urban land because nitrate rarely exceeds 5 mg/L in urban areas; the relation is stronger for agricultural land use in 1986 than in 1995 or 1970.

Table 1. Results of univariate statistical tests showing the relation of hydrogeologic and land use variables to the presence or absence of nitrate in Community Water Supply wells at 1-mg/L and 5-mg/L cutoff levels.

[<, less than]

	1-mg/L cutoff level			5-mg/L cutoff level		
	Kruskal-Wallis rank test			Kruskal-Wallis rank test		
Variable[1]	Kruskal-Wallis score	p-value	Con-ceptual variable	Kruskal-Wallis score	p-value	Con-ceptual variable
Well screened in confined or unconfined aquifer	188.59	<0.001	No	16.46	<0.001	No
Depth to top of open interval, in feet	11.12	0.0012	No	0.05	0.830[2]	Yes
Length of open interval, in feet	3.79	0.052	No	0.29	0.590	Yes[3]
Percent developed land use in 1995, Tiers 1-3	51.24	<0.001	No	18.91	<0.001	No
Percent urban land use in 1995, Tiers 1-3	18.83	<0.001	No	0.02	0.883[2]	Yes[3]
Percent agricultural land use in 1986, Tiers 1-3	33.51	<0.001	No	27.06	<0.001	No

[1]Only the 421 wells open to unconfined aquifers were tested for hydrogeologic sensitivity and potential land-use variables.
[2] Not significant at the alpha 0.05 level.
[3] This conceptual variable shows a graphical relation, improves the model, and is supported by scientific investigations.

Results of multivariate statistical tests at the 5-mg/L cutoff level indicate that the relation of occurrence of nitrate and land use is strongest using percentages of agricultural land use in 1986 in tiers 1-3 (fig. 10B) and urban land use in 1995 in tiers 1-3 (fig. 10C). Concentrations of nitrate as N above 5 mg/L in water from unconfined CWS wells are related more significantly to agricultural land use in 1986 than to agricultural land use in 1995 possibly because ground water moves slowly and previous land uses may be the source of contamination rather than current land uses. Nitrate is usually below 5 mg/L even in areas where the urban land use is greater than 50 percent (fig. 10C). This may result because residential wastewater and nitrogen compounds are removed from the area by sewers, treated, and discharged to streams in more urbanized areas rather than discharged locally to ground water by septic systems, as they are in less urban areas.

Rating Scheme

A scoring method was developed that assigned every variable a value from 0 to 5 (table 2). The graphs and results of statistical tests presented in this report were used as the starting point for devising the numerical code. First, if a well is screened in a confined aquifer (more than 1 mile downdip from the outcrop area of the aquifer from which water is withdrawn), then the well was given zero sensitivity and zero intensity points because the water from the well has a small chance of being affected by contamination at the land surface above the well or from sources upgradient. No other hydrogeologic sensitivity or potential contaminant-use intensity variables are calculated for these confined wells because they would have no effect on the concentration of nitrate in the water from the well.

For wells in unconfined aquifers, depth to the top of open interval and length of open interval were selected to characterize the vertical extent of contamination. The depth to top of the open interval is an indication of the minimum vertical distance that the nitrate from land surface would have to travel to enter a well. The length of open interval is a way to describe the thickness of the aquifer that needs to be contaminated at that concentration or a measure of the possible dilution of higher concentrations by mixing deeper, older and probably less contaminated ground water with shallower, younger, and probably more contaminated ground water. Adequate top of open interval, well depth, and length of open interval data were not available for 300 of the 2,237 CWS wells. NJDEP decided that these wells be given the largest sensitivity scores for depth to top of open interval and length of open interval. For the remaining unconfined wells, as depth to top of open interval and length of open interval increased, the points attributed to the well decreased.

If a land-use percentage (agricultural or urban) was equal to zero within the source water assessment area then a score of zero was assigned, and the resultant nitrate concentration should then be zero if that were the only source of contamination. The value assigned to the percentage of land use increases as the percentage of land use increases based on the relation observed in the graph. A score of 5 was assigned to percentages of a land use likely to have concentrations of nitrate as N equal to or greater than 5 mg/L.

Table 2. Susceptibility coding scheme for nitrates in water from Public Community Water Supply wells. [>, greater than; ≥, greater than or equal to; <less than]

Point range for susceptibility groups: Confined low,0; Unconfined low, 5 to12, unconfined medium, 13 to15, unconfined high; 16 to 25-

	Hydrogeologic Sensitivity Points					
Hydrogeologic sensitivity variable[1]	0	1	2	3	4	5
Confined (Yes or No)	Yes	--	--	--	--	No
Depth to top of open interval, in feet (Conceptual)	≥400	<400	<300	<200	<100	<50
Length of open interval, in feet (Conceptual)	≥200	<200	<100	<50	<20	<10
	Contaminant-use intensity Points					
Potential contaminant-use intensity variable[1]	0	1	2	3	4	5
Percent urban land in 1995 in tiers 1-3	0	>0-9	≥10-19	≥20-29	≥30-49	≥50
Percent agricultural land in 1986 in tiers 1-3	0	>0-4	≥5-9	≥10-19	≥20-29	≥30

[1]Only unconfined wells are rated by other hydrologic sensitivity variables or potential contaminant-use intensity variables.

Susceptibility of Community Water Supply Wells

The results of the numerical rating model indicate that as the sensitivity and contaminant-use intensity increase, concentrations of nitrate as N increase and the more likely it is that the concentration of nitrate in water from the well will be greater than 5 mg/L (fig. 11). The strongest predictor of nitrate concentration in water from a CWS well is whether the well is unconfined or unconfined. Those wells in the confined susceptibility group are not likely to contain nitrate above 0.1 mg/L. Well-construction characteristics play a lesser but important role in the distribution of concentration of nitrate in water from an unconfined CWS well. The largest concentrations of nitrate are in wells with shallow depths to top of open intervals that also have short open intervals. The largest concentrations of nitrate in water from CWS wells occur where more than 70 percent of the area contributing water to the well is urban and agricultural land use. Agricultural land use is a significant source of nitrate to wells containing nitrate concentrations as N in excess of 5 mg/L. Contaminant-use intensity was generally more important in discriminating nitrate concentrations than were hydrogeologic sensitivity factors in unconfined wells.

Concentrations of nitrate as N in water samples from the CWS wells in the confined group were less than 0.2 mg/L except for two wells (fig. 11). The distributions of concentrations of nitrate in water from CWS wells in the high susceptibility groups are larger those in than the other groups. The high susceptibility wells usually contained more than 70 percent agricultural and urban land use in 1995 in the source water assessment area and have a depth to top of open interval of less than 100 feet below land surface and a length of open interval of less than 50 feet.

Discussion

The statistical analysis and numerical rating models developed by the USGS as part of the SWAP project will provide guidance to scientists and managers at the NJDEP as they determine impacts of hydrogeology and land use on the quality of source waters to public community supply wells. The relations shown in figures, graphs, and tables will be useful in determining monitoring requirements for water purveyors to ensure public health.

There are several limitations to these models that should be noted. Because well construction data were unavailable for over 300 wells, these wells were given the maximum scores for depth to the top of open interval and length of open interval; this automatically puts a well near the high susceptibility group. These models should be used only as screening tools for potential contamination problems. Most recent concentrations were used in the analysis, and concentrations could have been higher in the water from the well. Some of the components of the analysis were subjective especially for the coding scheme for the numerical rating model. Projecting the interpretation of water-quality data at a local scale to a statewide scale is difficult. The use of different scales for various GIS data layers could bias statistical results, and land-use changes may cause spurious relations. The methods used to determine source water assessment areas for wells and tiers representing times of travel of water to the well are inexact, and produce only estimates of the actual contributing areas and the length of time water is in transit before it reaches the well.

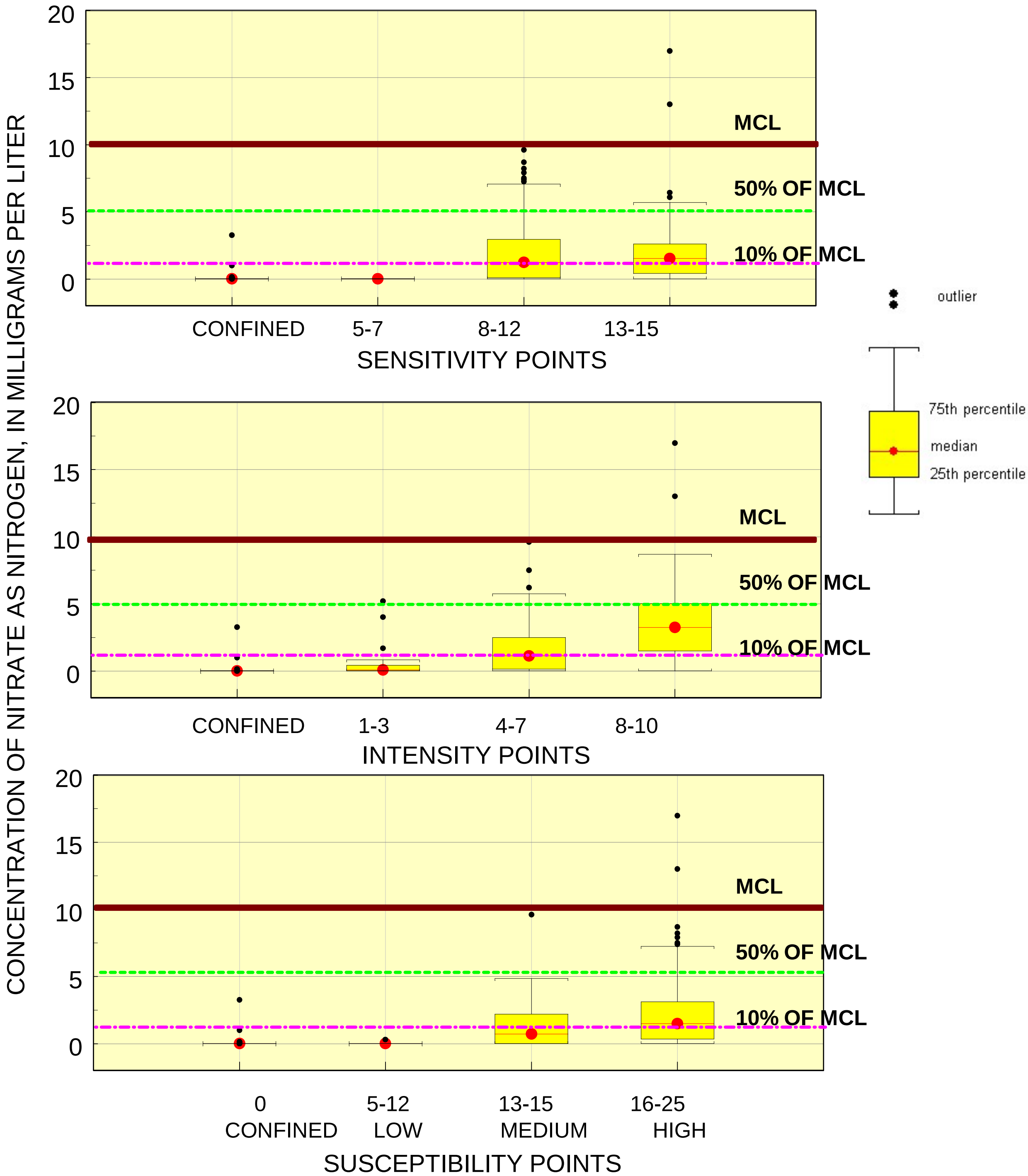

Figure 11. Distribution of concentrations of nitrate in water from Community Water Supply wells sampled by the USGS, by (A) sensitivity, (B) intensity, and (C) susceptibility points. (MCL, Maximum Contaminant Level)

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