SUSCEPTIBILITY OF SOURCE WATER TO COMMUNITY AND NONCOMMUNITY SURFACE-WATER SUPPLIES AND RELATED WELLS IN NEW JERSEY TO CONTAMINATION BY PESTICIDES

Summary

A susceptibility assessment model was developed to predict the susceptibility of source water associated with 57 areas contributing water to community water-supply intakes and related wells and 3 areas contributing water to noncommunity water-supply intakes in New Jersey to contamination by pesticides. Susceptibility is defined by variables that describe hydrogeologic sensitivity and potential contaminant-use intensity within the area contributing water to the intakes and wells. The model was developed by using water-quality data from surface-water samples collected and analyzed by the U.S. Geological Survey (USGS). None of the water-quality data were from samples collected at water-supply intakes. The model was calibrated using results of analyses at 194 surface-water-quality sites for five pesticides (alachlor, atrazine, carbofuran, lindane, and simazine) for which maximum contaminant levels (MCLs) have been established. Pesticide concentrations were highest in surface-water samples from agricultural areas in the Piedmont and Coastal Plain Physiographic Provinces; these high concentrations are likely associated with agricultural practices and residential application of pesticides. Variables used to estimate susceptibility to contamination by pesticides are total pesticides application, percent soil clay, distance to agricultural land in 1995, and percent residential land in 1995. Application of the susceptibility model to 49 areas contributing water to water-supply intakes resulted in 28 (57 percent) contributing areas being rated as low, 16 (33 percent) as medium, and 5 (10 percent) as high susceptibility. Application of the susceptibility model to 11 areas contributing water to sources using ground water under the direct influence of surface water (GWUDI) resulted in 9 (82 percent) contributing areas being rated as low and 2 (18 percent) as medium susceptibility (figs. 1 and 2). Susceptibility ratings for pesticides were highest in the Piedmont and Coastal Plain Physiographic Provinces. The contributing areas of water-supply intakes rated highly susceptible to contamination by pesticides averaged more than 30 percent agricultural land.

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 surface 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 source 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 contamination, and (4) incorporate public participation and education (http://www.state.nj.us/dep/swap).

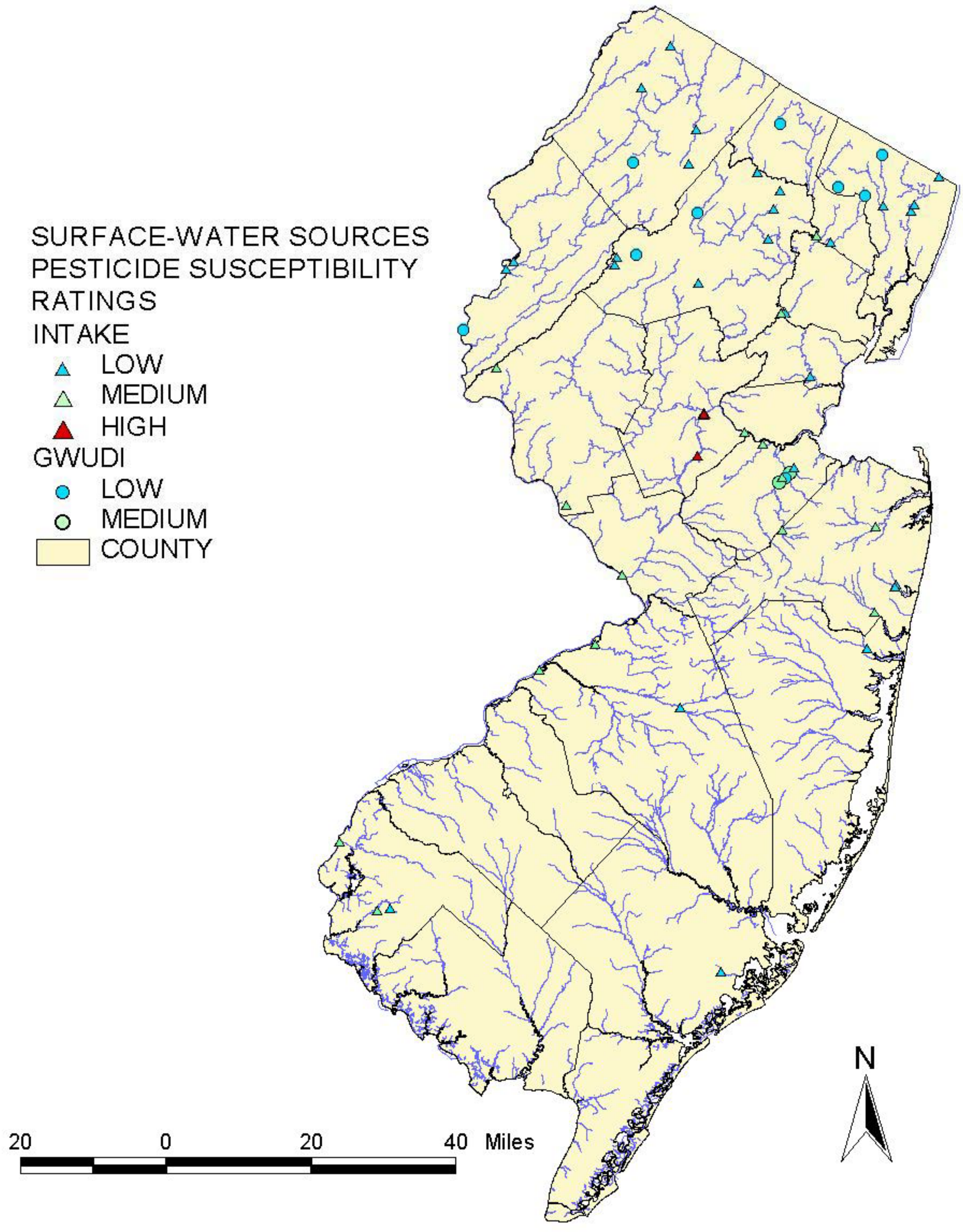

Figure 1. Susceptibility of 60 surface-water sources in New Jersey to contamination by pesticides.

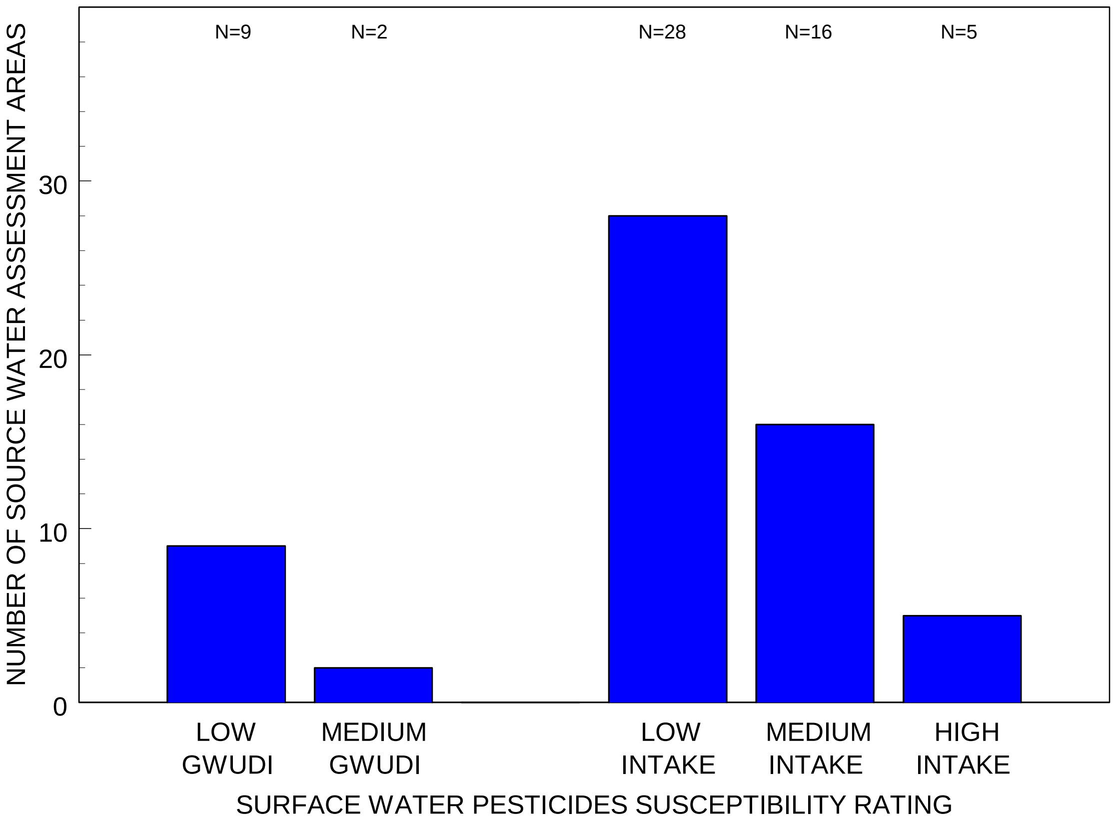

Figure 2. Number of surface-water sources in New Jersey having low, medium, and high susceptibility to contamination by pesticides.

Susceptibility assessment models were developed to rate each public surface-water source as low, medium, or high susceptibility for groups of constituents (fig. 2). This report (1) describes methods used to develop the susceptibility assessment model for pesticides, (2) presents results of application of the susceptibility model to estimate the susceptibility of source water to water-supply intakes and sources using ground water under the direct influence of surface water to these constituents, and (3) documents the distribution of these constituents in surface water in New Jersey.

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. The susceptibility assessment models were developed based on the 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 surface-water source. The 1999 NJDEP SWAP draft proposal postulated that all surface-water sources would be considered highly sensitive, but that premise has been redefined through modeling. In some cases, documented research from existing studies and statistical methods used in this study show that a sensitivity variable has a significant relation to pesticide concentrations.

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 and noncommunity water supplies as having low, medium, or high susceptibility to contamination for the groups of constituents by using, as guidance, thresholds developed by NJDEP for the purpose of creating the model. In general, the low-susceptibility category includes surface-water sources for which constituent values are not likely to equal or exceed one-tenth of the New Jersey's drinking water MCL, the medium-susceptibility category includes surface-water sources for which constituent values are not likely to equal or exceed one-half of the MCL, and the high-susceptibility category includes surface-water sources for which constituent values may equal or exceed one-half of the MCL. The susceptibility assessment ratings for the pesticide constituent group are based on a total pesticide value that was calculated by using individual pesticide concentration values. The combined value included pesticides from four major groups of pesticides--acetanilides, triazines, organochlorines, and carbamates. Acetanilides and triazines are herbicides that include some of the most commonly applied pesticides. Organochlorines and carbamates are insecticides that are used primarily for agricultural purposes. Use of several organochlorine insecticides is now restricted, but was widespread in the past.

Susceptibility Model Development

The development of the susceptibility assessment model involved several steps (Hopple and others, U.S. Geological Survey, written commun., 2003): (1) development of source water assessment areas to community and noncommunity 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 model, and (5) assessment of relations of the constituents to model variables. An independent data set was not available to verify the model. Multiple lines of evidence were used to select the final variables used in the model.

Development of Source Water Assessment Areas

NJDEP estimated 60 areas contributing water to surface-water sources used for drinking water in New Jersey; 49 are associated with surface-water intakes and 11 are associated with sources using ground water under the direct influence of surface water. For most surface-water sources, the source water assessment area includes the entire drainage area for the water that flows past the intake or source (fig. 3). These source water assessment areas include the headwaters and tributaries and are based on the areas delineated by the USGS 14-digit hydrologic unit code (HUC 14) (Ellis and Price, 1995) (http://www.state.nj.us/dep/swap). For intakes or sources with large contributing areas, the source water assessment area is based on the time-of-travel to the intake or source.

Figure 3. Example of delineated contributing area to a water-supply intake.

NJDEP has classified 55 wells as sources using ground water under the direct influence of surface water (GWUDI). Water from wells that are classified as GWUDI wells must meet specific water-quality criteria and is treated in a manner similar to that of water from surface-water intakes. To determine the susceptibility rating for these wells, NJDEP performed an integrated delineation combining the ground-water assessment area with the surface-water assessment area. The ground-water assessment area was delineated using the Combined Model/Calculated Fixed Radius Method (www.state.nj.us/dep/dsr/whpadel.pdf). The surface-water assessment area was delineated as the entire drainage area that contributes water to the well, with the 2-year time-of-travel demarcation of the ground-water assessment area determining the downstream boundary. A few GWUDI wells do not have an associated surface-water assessment area because no surface-water body is present within the 2-year ground-water time-of-travel area. In these instances, only the ground-water assessment area was used. Both the ground- and surface-water models were applied to these areas, and the higher of the two ratings was selected as the susceptibility rating for that well.

The USGS estimated the areas contributing water to 388 surface-water-quality sites in New Jersey for model development and verification. Drainage areas contributing water to a surface-water-quality site were delineated by using a GIS macro language program that determines basin area from a digital elevation model (DEM) based on a 1:24,000 scale and 30-meter resolution to contour intervals (L.J. Kauffman, U.S. Geological Survey, written commun. 2002).

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 surface-water quality within areas contributing water to surface-water sources. The variables were calculated for the source water assessment area. Sensitivity variables used in the statistical analysis include soil properties and site-specific information such as major watershed, hydrologic unit, and physiographic province. Intensity variables include land use from coverages based in 1995-97; lengths of roads, railways, and streams; the number of potential contaminant point sources; septic-tank and contaminant-site densities; and minimum distances between the surface-water source and various land uses and between the surface-water source and potential contaminant sources.

As part of its Pesticide Control Program, NJDEP periodically surveys pesticide applicators to determine the quantity of selected regulated and unregulated pesticides applied in New Jersey (Curtis Brown, New Jersey Department of Environmental Protection, written commun., 2000). The quantities of pesticides applied are reported to NJDEP by the business address of the applicator and are assumed to reflect the amount of pesticides applied within the township of the business address. These data were used to calculate the amount of five pesticides --alachlor, atrazine, carbofuran, lindane, and simazine--applied to areas that contribute water to surface-water-quality sites and intakes. The amount of each pesticide applied within townships in New Jersey was summed. The GIS was used to intersect the pesticide-application data by township within the contributing areas. Quantities of the five pesticides applied within a contributing area then were summed to determine a total pesticide application value for use in statistical testing.

Water-Quality Data

Surface-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, or less precise methods were excluded. Analyses of water from sites with known contamination problems also were not used. Sites in northern New

Jersey with more than 20 percent of the contributing area in New York State were eliminated because comparable sensitivity and intensity variables were unavailable. A statewide network of 388 USGS surface-water-quality sites was selected to develop the models. Many of these sites are part of the systematic data-collection program in the USGS New Jersey District. Some are sites in the USGS National Water Quality Assessment program and others are part of regional and local investigations. None of the water-quality data were from samples collected at water-supply intakes.

The maximum concentration determined at each site for each pesticide was selected to represent the site because (1) human-health risk was assumed to increase with concentration and (2) selecting one sample per site avoided problems of averaging concentrations of constituents with different method reporting limits. For the 388 sites in the statewide network, sufficient data on only five pesticides with MCLs--alachlor, atrazine, carbofuran, lindane, and simazine--were available to run all the statistical tests that were needed. Results of analyses for all five pesticides were available for 194 surface-water-quality sites. Many of the pesticides in surface-water samples were detected at low concentrations (less than 1 µg/L); however, synergistic health effects at these concentrations may be a concern. Because of this concern, a cumulative (total) pesticide value related to the corresponding MCL was calculated for the five pesticides (fig. 4). The number of surface-water-quality sites with pesticides data, the constituents detected, and their corresponding MCLs are shown in table 1.

The concentration of each of the five pesticides was normalized to the MCL in order to weight each constituent equally relative to the MCL, so that values could be added to determine a total pesticide value. The total pesticide value then was used in statistical tests to determine relations between the value and other variables. Normalizing gives a common basis, relative to the MCL, so that values can be added and statistics can be run on an equal level. For example, a value of 1 µg/L of lindane and a value of 1 µg/L of carbofuran should not have the same weight (level of concern) because their MCLs are so different (0.2 and 40 µg/L, respectively). By normalizing the concentration of each constituent, the values become 1/0.2 x 100 = 500 and 1/40 x 100 = 2.5 percent of MCL. Therefore, the total pesticide value was calculated as follows:

$$\frac{\text{Constituent Concentration, in micrograms per liter}}{\text{Maximum Contaminant Level}} \times 100 = \text{Constituent Concentration, in percent of Maximum Contamination Level}$$

$$\text{Total Pesticide Concentration} = \sum \text{5 Constituent Concentrations, in percent of Maximum Contamination Level}$$

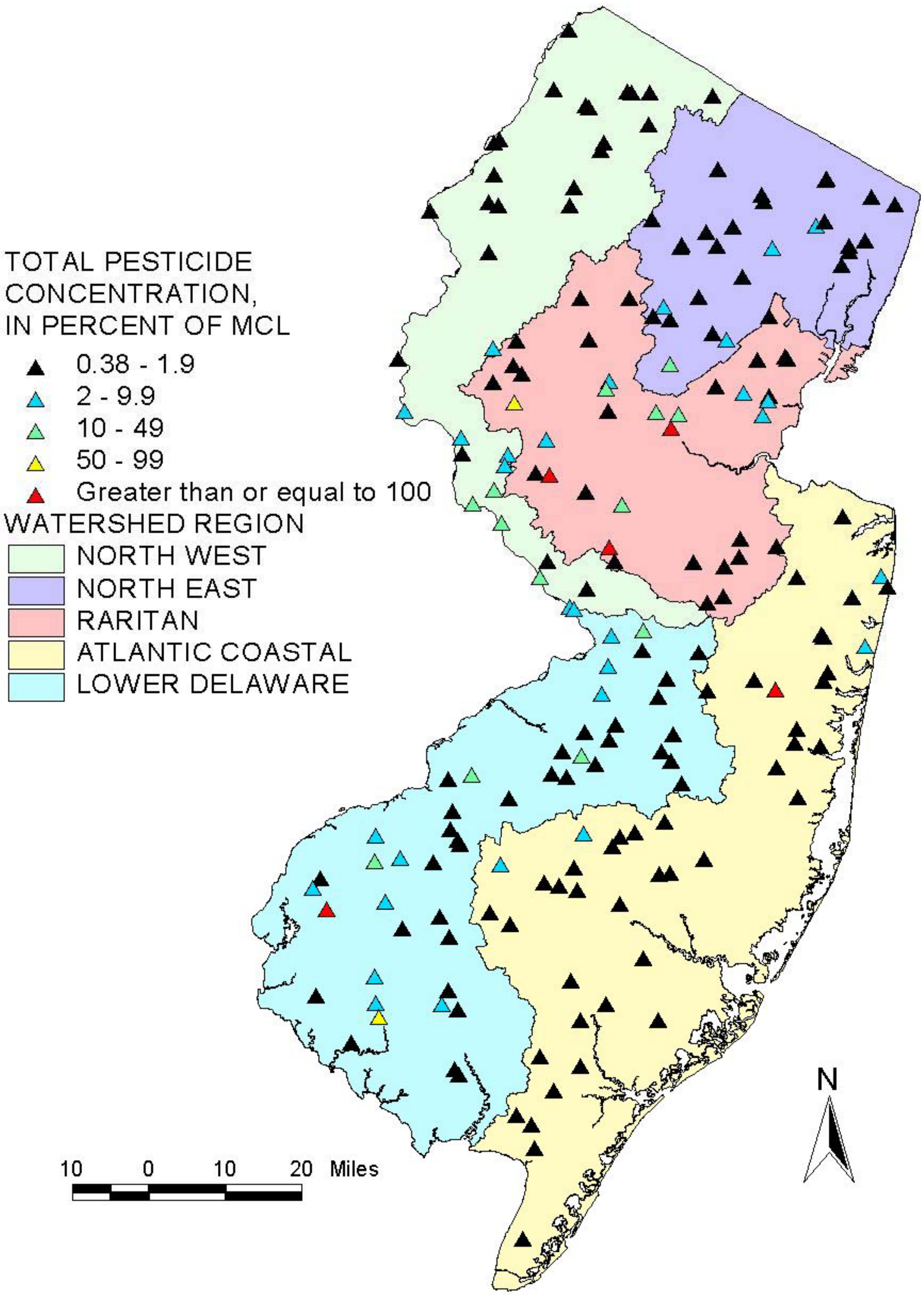

Figure 4. Total concentration of five pesticides (alachlor, atrazine, carbofuran, lindane, and simazine) at 194 surface-water-quality sites used for model development.

Table 1. Number of sites at which selected constituents in samples from surface-water-quality sites met or exceeded selected criteria related to the MCL, and frequency of detection							
Constituent	Standard, in micrograms per liter	Number of sites for which data are available[1]	Number of sites at which constituent was detected	Number of sites at which concentration meets criterion 1[2]	Number of sites at which concentration meets criterion 2[3]	Number of sites at which concentration equals or exceeds standard	Frequency of detection[4]
2,4,5-TP (Silvex), filtered	50	8	0	0	0	0	0
2,4,5-TP (Silvex), unfiltered	50	3	0	0	0	0	0
2,4-D, filtered	70	12	8	0	0	0	0.67
2,4-D, unfiltered	70	3	2	0	0	0	0.67
Alachlor, filtered	2	194	44	2	2	1	0.23
Aldicarb, filtered	3	10	1	0	0	0	0.10
Aldicarb sulfone, filtered	3	12	0	0	0	0	0
Aldicarb sulfoxide, filtered	4	12	0	0	0	0	0
Atrazine, filtered	3	194	179	8	1	5	0.92
Carbofuran, filtered	40	194	17	0	0	0	0.09
Carbofuran, filtered	40	12	1	0	0	0	0.08
Chlordane, unfiltered	0.5	18	0	0	0	0	0
cis-Chlordane, unfiltered	2	1	0	0	0	0	0
trans-Chlordane, unfiltered	2	1	0	0	0	0	0
Dinoseb, filtered	7	12	0	0	0	0	0
Endrin, unfiltered	2	18	0	0	0	0	0
Heptachlor, unfiltered	0.4	18	0	0	0	0	0
Heptachlor epoxide, unfiltered	0.2	18	0	0	0	0	0
Lindane, filtered	0.2	194	4	0	0	0	0.02
Lindane, unfiltered	0.2	18	0	0	0	0	0
Methoxychlor, unfiltered	40	18	0	0	0	0	0
Oxamyl, filtered	200	12	0	0	0	0	0
Picloram, filtered	500	12	0	0	0	0	0
Simazine, filtered	4	194	122	2	1	0	0.63
Toxaphene, unfiltered	3	18	0	0	0	0	0

[1] Number of sites represents 388 surface-water-quality sites with estimated contributing areas in the NWIS database for constituents with primary standards and may be different from the number of sites used to develop the model.
[2] Criterion 1: Concentration is at least equal to one-tenth of the standard, but is less than one-half of the standard.
[3] Criterion 2: Concentration is at least equal to one-half of the standard, but is less than the standard.
[4] Number of sites at which constituent was detected divided by number of sites for which data are available.

Data Analysis

Federal and State Safe Drinking Water Regulations require routine monitoring for many pesticides at surface-water intakes every 3 years. 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. For these reasons, models were developed to determine the variables that best describe the presence or absence of constituents in source waters at a concentration equal to or greater than one-tenth of the MCL.

Statistical tests and graphical procedures were used to evaluate the relation between total pesticide concentrations, in percent of MCL, and sensitivity and intensity variables. Univariate statistical tests were run on all variables. Variables included sensitivity, intensity, water quality, and site-related characteristics such as water region. Univariate tests included the Kruskal-Wallis test and Spearman's rho rank correlation (Table 2). Differences between median values of grouped data also were compared.

Table 2. Results of univariate statistical tests for explanatory variables used in the total pesticides model					
	Kruskal-Wallis rank test		Spearman's rank correlation		
Variable	Kruskal-Wallis score	p-value	Spearman's rho	p-value	Conceptual variable
Average percent soil clay	38.88	0.000	0.296	0.000	No
Total pesticide application (lbs)	23.47	0.000	0.326	0.000	No
Distance to agricultural land, 1995 (feet)	6.21	0.013	-0.145	0.058	No
Percent residential land, 1995	1.41	0.235	0.316	0.000	No

The Kruskal-Wallis test was used to determine whether distributions of hydrogeologic-sensitivity or potential contaminant-use intensity variables differed between sites where the total pesticide concentration was either less than one-tenth of the MCL or greater than or equal to one-tenth of the MCL. 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 total pesticide 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.

Results of univariate statistical tests (Spearman's rho and Kruskal-Wallis) and graphs (scatter plots and boxplots) were used to identify potential predictors of contamination at selected concentration levels relative to the MCL. 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 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.

Rating Scheme

A scoring method was developed for the pesticide model that gave a maximum of 5 points to each variable used in the model for surface-water-quality sites (table 3). In some cases, the scoring interval was based on a weighting scheme relative to the strength of the statistical relation. The maximum number of points was given to variables that appeared to work best statistically (both univariate and multivariate tests) and that graphically approached a linear relation. If, for example, when the average percent soil clay was statistically related (a positive Spearman's correlation, Kruskal Wallis score of 40.25, and p-value of 0.000) to the concentration of pesticides and the percent soil clay within the contributing area for a surface-water site was large, a score of 5 was assigned. When the percent soil clay was small for a site, a score of 0 was assigned. Fewer points were given to variables that were less significant statistically, that had lower correlation coefficients, that appeared graphically to be grouped, or that did not show changes over the entire range of values. Relations observed in the graphs presented in this report were used as the starting point for devising the numerical code.

Table 3. Susceptibility rating scheme for pesticides in water from community and noncommunity water-supply intakes and related wells

Surface Water Total Pesticide Model

Pesticide Rating: 0-6.5 LOW, 7-9.5 MEDIUM, 10-12 HIGH

	Sensitivity Points—Surface-Water Sites						
Variable	0	1	2	3	4	5	Conceptual variable
Average percent soil clay	0-5	>5-10	>10-14	>14-17	>17-20	>20	No

	Intensity Points—Surface-Water Sites						
Variable	0	0.5	1	1.5	2	2.5	
Total pesticide application (lbs)	0-20	>20-100	>100-200	>200-500	>500-1,500	>1,500	No
Percent residential land, 1995	0-2.5	>2.5-5	>5-10	>10-15	>15-20	>20	No
Distance to agricultural land, 1995 (ft)	>10,000		>1,000-10,000		0-1,000		No

Relation of Pesticides in Surface Water to Susceptibility Variables

Relations between concentrations of pesticides in water from surface-water-quality sites and various hydrogeologic sensitivity and potential contaminant-use intensity variables were investigated to select the variables that best predict the susceptibility of surface-water sources in New Jersey to contamination by pesticides. The model was calibrated by using results of analyses for five pesticides with MCLs--alachlor, atrazine, carbofuran, lindane, and simazine. The remaining 19 pesticides with primary standards were not included in the model for various reasons. Several pesticides are not routinely measured by the USGS and no results of analyses were available for surface-water-quality sites in New Jersey. These include dalapon, diquat, endothal, and glyphosate. Several other pesticides were not detected in surface-water samples. These include 2,4,5-TP (silvex), aldicarb sulfone, aldicarb solfoxide, chlordane, dinoseb, endrin, heptachlor, heptachlor epoxide, methoxychlor, oxamyl, picloram, and toxaphene. Aldicarb, 2,4-D, and hexachlorobenzene had insufficient data to be included in the model.

Pesticides are chemical substances and biological agents used to control weeds, insects, fungi, rodents, bacteria, and other pests. They have been widely dispersed in the environment by human activities. Common sources of pesticides found in surface water include land applications (fig. 5) in both agricultural and nonagricultural settings (nonpoint source), past land uses, and facilities that manufacture and distribute pesticides (point source). Several pesticides and their metabolites, including atrazine, simazine, and 2,4-D (a herbicide used on turf and grains), are frequently detected in low concentrations in surface-water samples.

Pesticide use has substantially increased agricultural productivity. In 1991, 76 percent of pesticides sold in the United States were used for agricultural purposes; industry and government accounted for 18 percent, and residential use represented 6 percent of the total use. About 1.1 billion pounds are used annually in the United States (Ware, 1994). In New Jersey, about 1.6 million pounds were applied in 2000 by licensed applicators (Curtis Brown, New Jersey Department of Environmental Protection, written commun., 2000).

Typically, the highest concentrations and greatest frequency of detection of pesticides are found in agricultural areas (Reiser and O`Brien, 1999). The frequency of detection and concentration of pesticides found in water samples are determined partly by the physical and chemical properties of the pesticides. Water solubility and the ability to adsorb to soil particles appear to be the two main physical properties that influence the presence of pesticides in surface water (Reiser and O`Brien, 1999). Application rates, the occurrence of rainfall soon after application, and other factors also may play a substantial role in movement of pesticides from areas where they are applied to streams or ground water. Pesticides can accumulate in soils that are rich in organic matter and clay (fig. 6). Concentrations of atrazine exceeded the MCL of 3 µg/L (micrograms per liter) at 5 of 194 surface-water-quality sites. Concentrations of alachlor exceeded the MCL of 2 µg/L at 1 of 194 surface-water-quality sites. Concentrations of carbofuran, lindane, and simazine were less than their respective MCLs at all 194 surface-water-quality sites.

Alachlor, an herbicide used to control annual grasses and broadleaf weeds is commonly applied to corn, sorghum, and soybeans. The second most widely used herbicide, alachlor, is broken down by bacterial action and sunlight. It does not readily adsorb to soils and may evaporate or be transported to surface and ground water. After alachlor enters the ground-water system, it slowly degrades (http://www.epa.gov/safewater/dwh/c-soc/alachlor.html). Alachlor was frequently detected in samples from streams in agricultural areas of the Piedmont and Coastal Plain Physiographic Provinces. The maximum concentration of alachlor exceeded the 2 µg/L MCL at one site in the Raritan Water Region.

Atrazine, an herbicide used to control broadleaf and grassy weeds, is commonly applied to corn and soybeans. It is the most widely used herbicide. Microbial activity and certain chemicals can break it down, particularly in alkaline soils. Atrazine may adsorb to some soil particles but tends to move to surface and ground water (http://www.epa.gov/safewater/dwh/c-soc/atrazine.html). Atrazine is the most frequently detected pesticide with a MCL in New Jersey. It was detected at least once in samples from 92 percent of surface-water-quality sites with analyses (179 of 194 sites). Atrazine was detected in all physiographic provinces and water regions. The maximum concentration of atrazine exceeded the 3-µg/L MCL at five sites in the Raritan, Lower Delaware, and Atlantic Coastal Water Regions. The highest concentrations were found in agricultural areas.

Carbofuran, an insecticide used to control beetles, nematodes, and rootworms, is used on alfalfa, rice, turf, and grapes and was previously used on corn. Microbial activity and certain chemicals can break it down, particularly in alkaline soils. Carbofuran may adsorb to soil organic matter but may migrate to ground water in sandy soils (http://www.epa.gov/safewater/dwh/c-soc/carbofuran.html). Carbofuran was frequently detected in samples from streams in the Coastal Plain Physiographic Province and occasionally detected in the Piedmont. Concentrations of carbofuran did not exceed one-tenth of the 40-µg/L MCL at any of the 194 sites with data.

Lindane, an insecticide used to treat wood-inhabiting beetles, seeds, and fleas and lice on pets and livestock, is applied to fruit and nut trees, vegetables, timber, and ornamentals. Its use has been restricted since 1983. Microbial activity and certain chemicals can break it down. Lindane may evaporate or be transported to surface and ground water (http://www.epa.gov/safewater/dwh/c-soc/lindane.html). Lindane was rarely detected in samples from streams in the Coastal Plain and Piedmont Physiographic Provinces (4 of 194). Concentrations of lindane did not exceed one-tenth of the 0.2-µg/L MCL at any of the 194 sites with data.

Simazine, an herbicide used to control broadleaf and grassy weeds, is used on corn, row crops, and fruit. Simazine is unlikely to adsorb to soil and may migrate to surface and ground water. It may persist for a few months to a few years (http://www.epa.gov/safewater/dwh/c-soc/simazine.html). Simazine was frequently detected in all physiographic provinces and water regions. Concentrations of simazine occasionally exceeded one-tenth of the 4-µg/L MCL (at 3 of 194 sites with data).

The highest concentrations and the greatest frequency of detection of pesticides in surface water in New Jersey were found in the Piedmont Physiographic Province and are associated with agricultural activities (fig. 7). However, pesticides also were frequently detected in the Coastal Plain Physiographic Province, particularly in the Lower Delaware Water Region (fig. 4). Residential application may be an additional contribution of pesticides to surface water (fig. 8). Total pesticide concentration, in percent of the MCL, was equal to or exceeded 100 percent of the MCL at 5 of 194 sites and was equal to or exceeded 10 percent of the MCL at 20 of 194 sites.

The variable selected to represent hydrogeologic sensitivity of surface water to contamination by pesticides was average percent soil clay. Variables selected to represent potential contaminant-use intensity to contamination of surface water by pesticides were total pesticide application, distance to agricultural land in 1995, and percent residential land in 1995. Of the 194 surface-water-quality sites used for model development, 129 were rated as having low susceptibility, 57 were rated as having medium susceptibility, and 8 were rated as having high susceptibility (figs. 9 and 10).

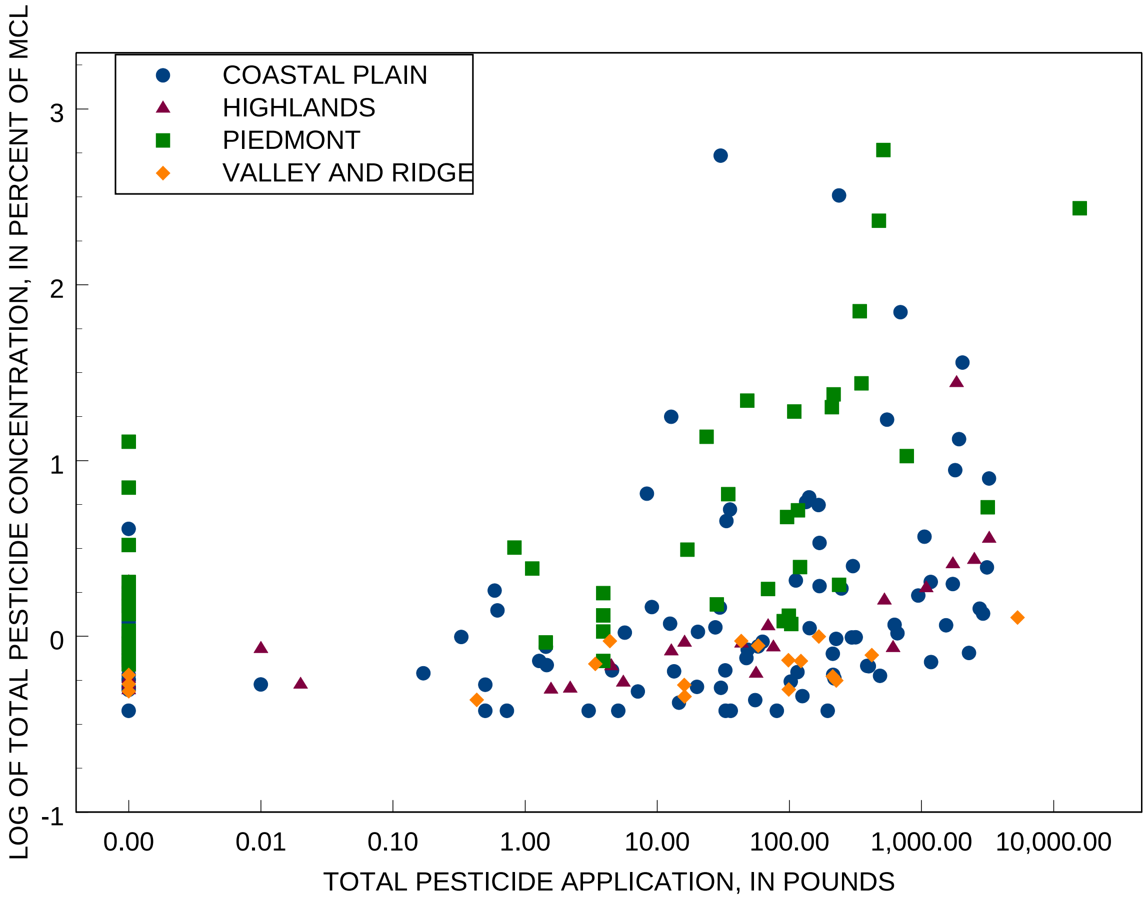

Figure 5. Relation of total pesticide concentration to total pesticide application, by physiographic province, for 194 surface-water-quality sites in New Jersey.

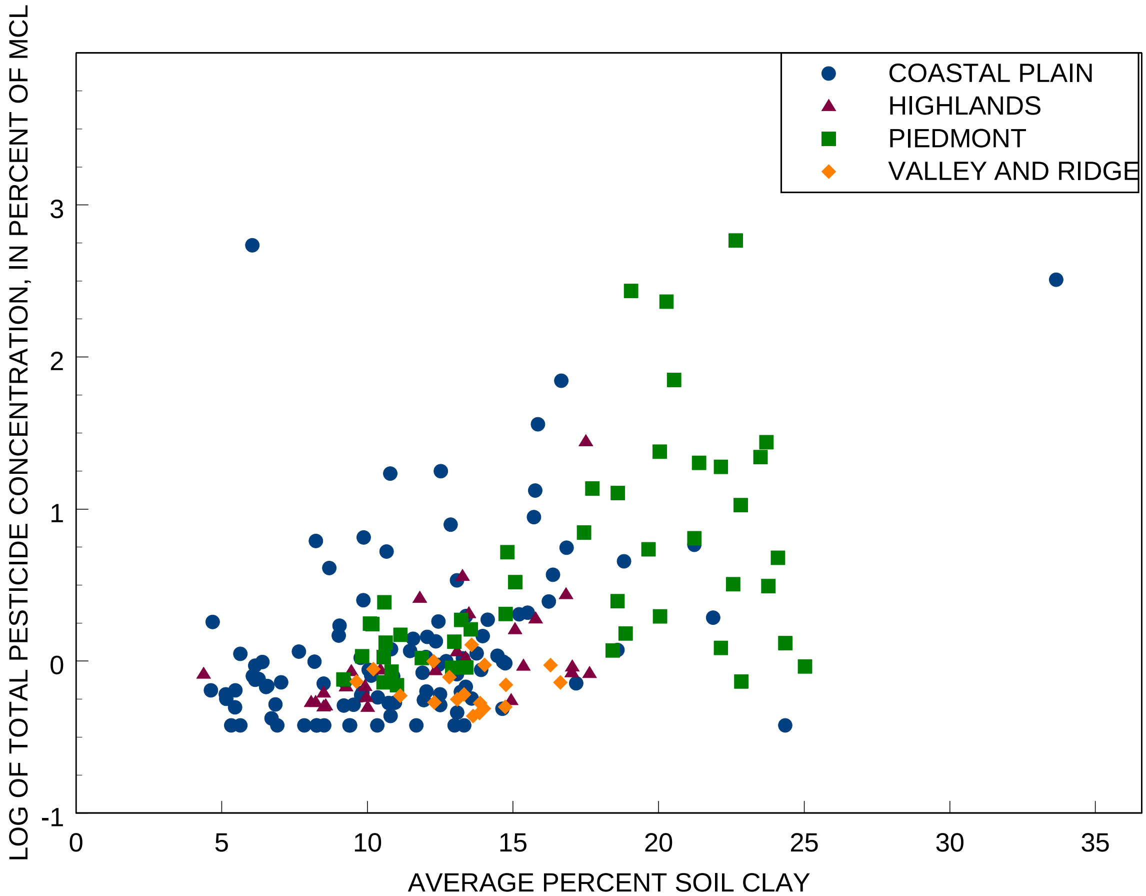

Figure 6. Relation of total pesticide concentration to average percent soil clay, by physiographic province, for 194 surface-water-quality sites in New Jersey.

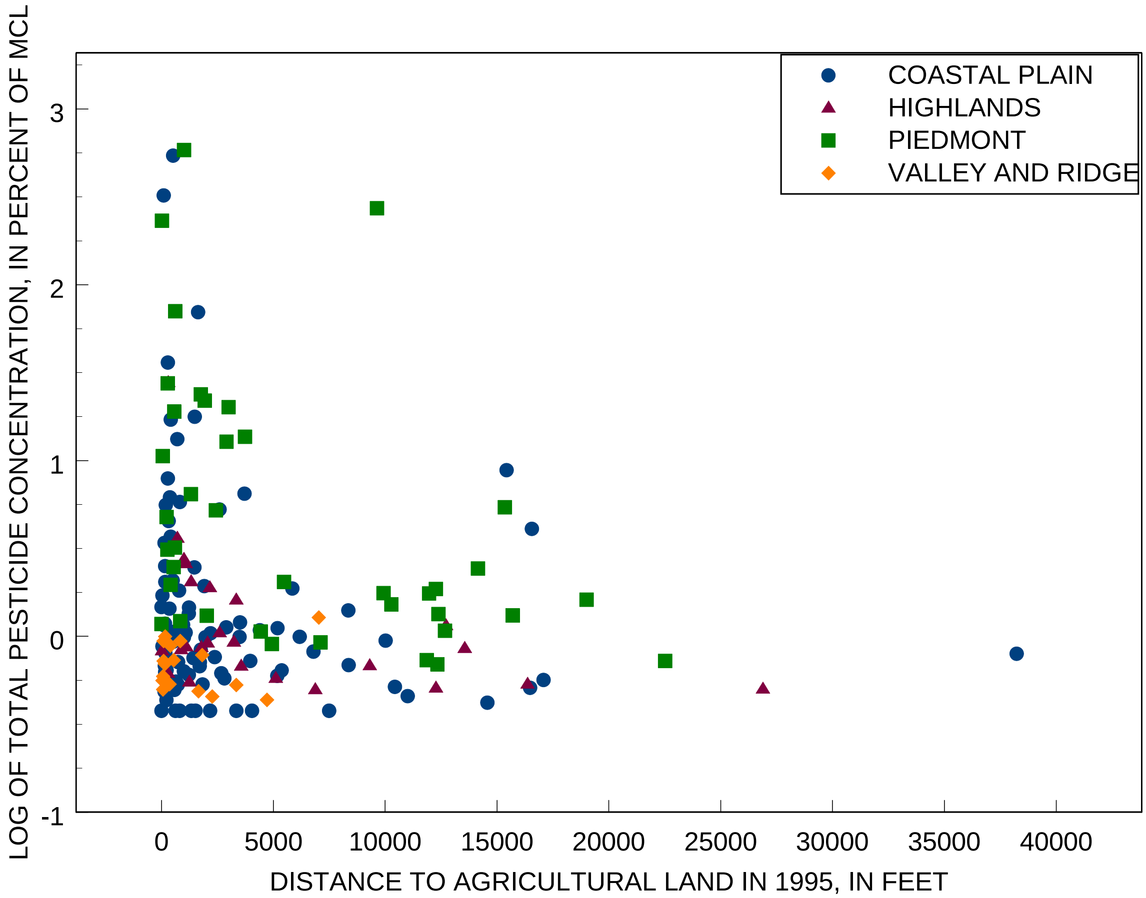

Figure 7. Relation of total pesticide concentration to distance to agricultural land in 1995, by physiographic province, for 194 surface-water-quality sites in New Jersey.

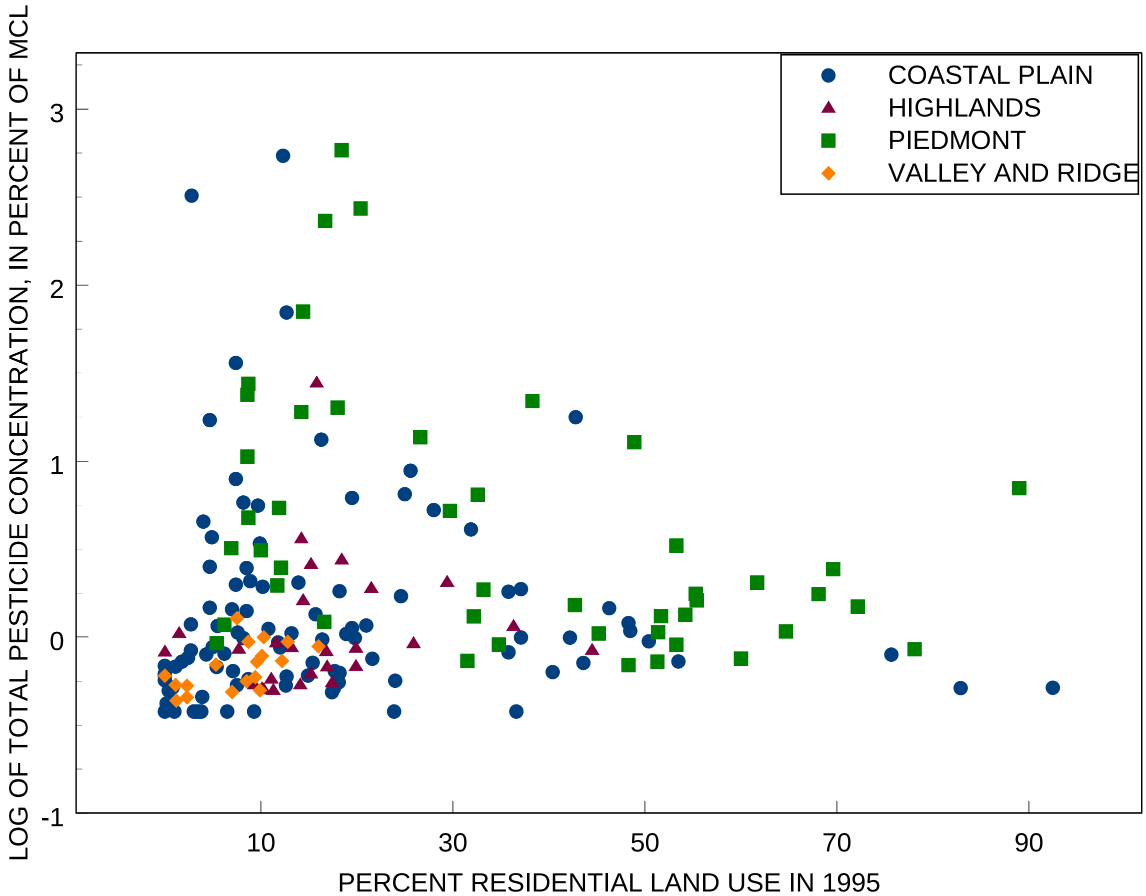

Figure 8. Relation of total pesticide concentration to percent residential land in 1995, by physiographic province, for 194 surface-water-quality sites in New Jersey.

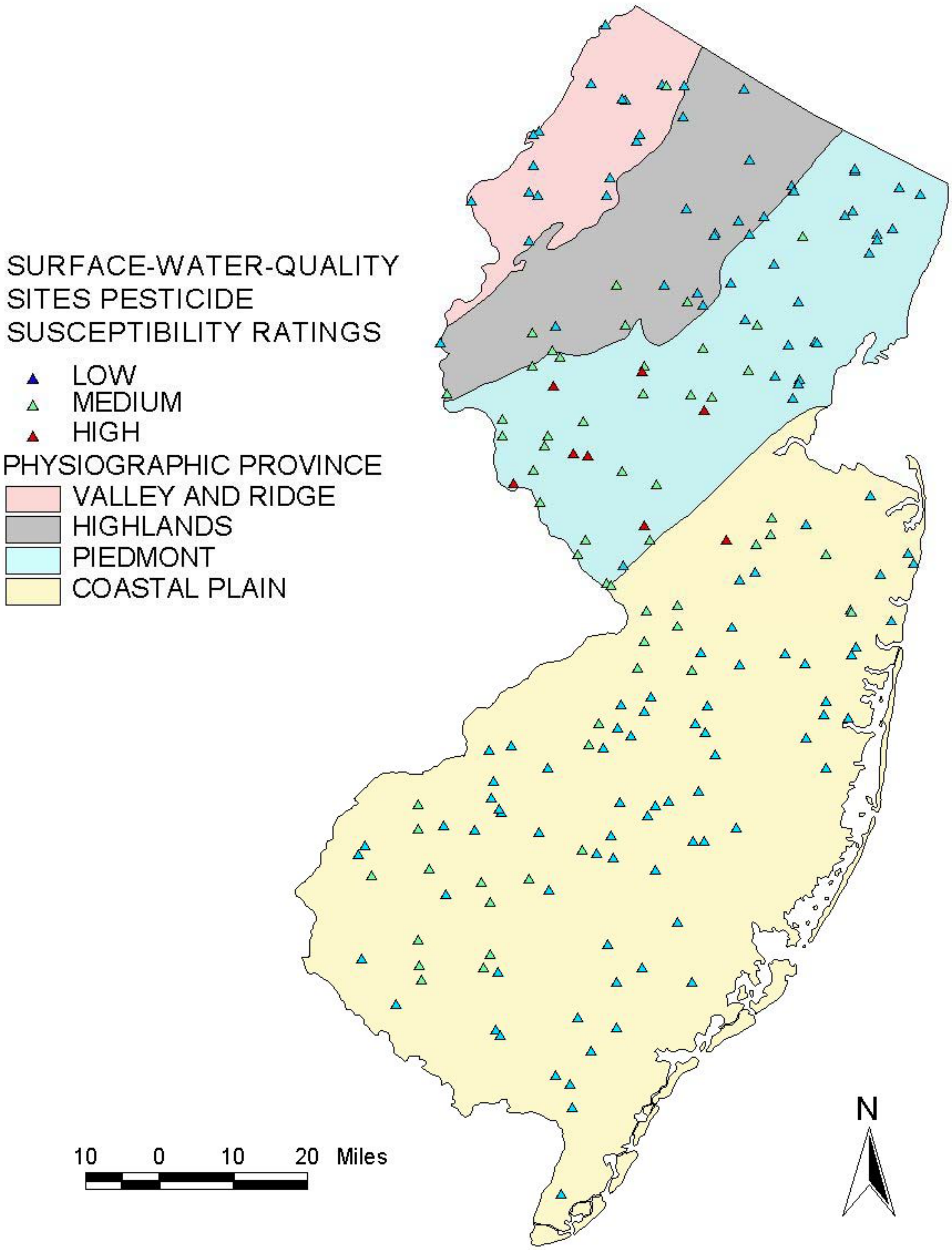

Figure 9. Susceptibility of 194 surface-water-quality sites in New Jersey used for model development to contamination by pesticides.

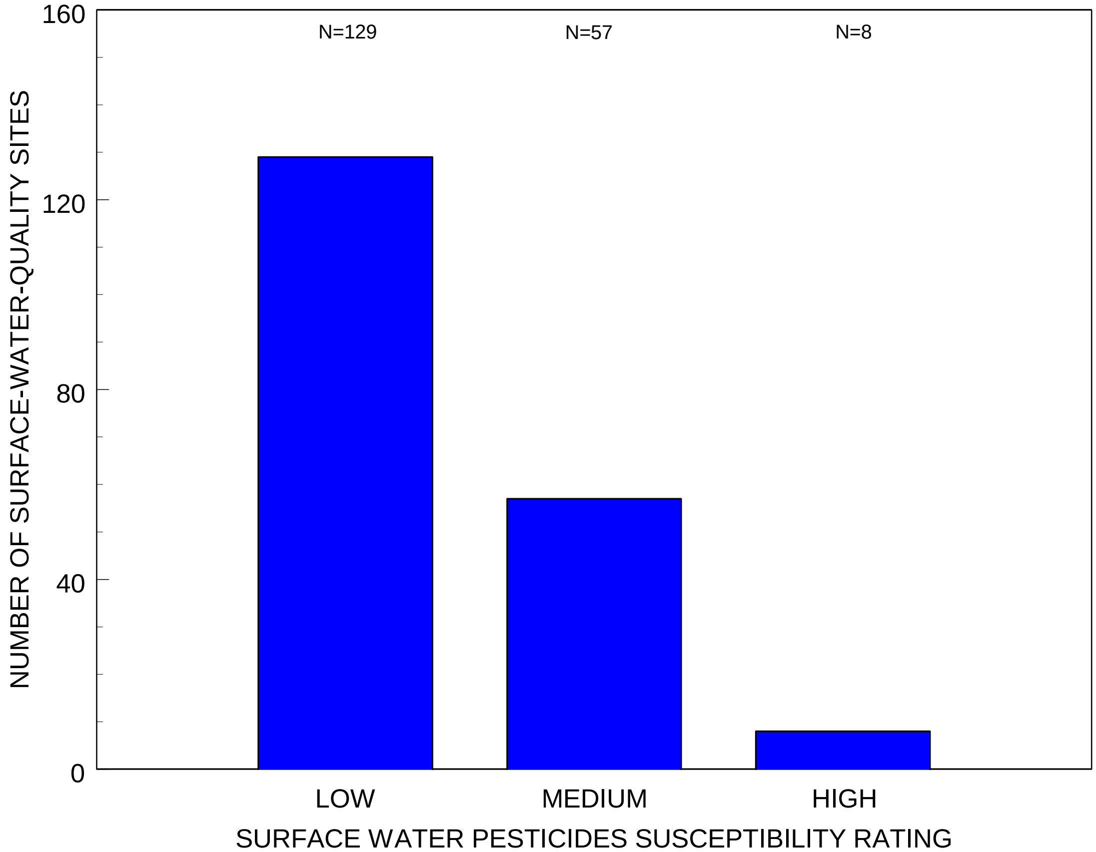

Figure 10. Number of surface-water-quality sites in New Jersey used for model development having low, medium, and high susceptibility to contamination by pesticides.

Susceptibility of Surface-Water Sources

The results of the susceptibility assessment model indicate that as sensitivity and intensity increase, the concentrations of pesticides increase (fig. 11). The numerical rating scheme created during model development was applied to the sensitivity and intensity variables for each water-supply intake. Of the 60 source water assessment areas associated with intakes and related wells to which the model was applied, the susceptibility to contamination by pesticides was low for 37, medium for 18, and high for 5 (figs. 1 and 2). All five intakes in the high susceptibility group are in the Raritan Water Region and in the Piedmont Physiographic Province.

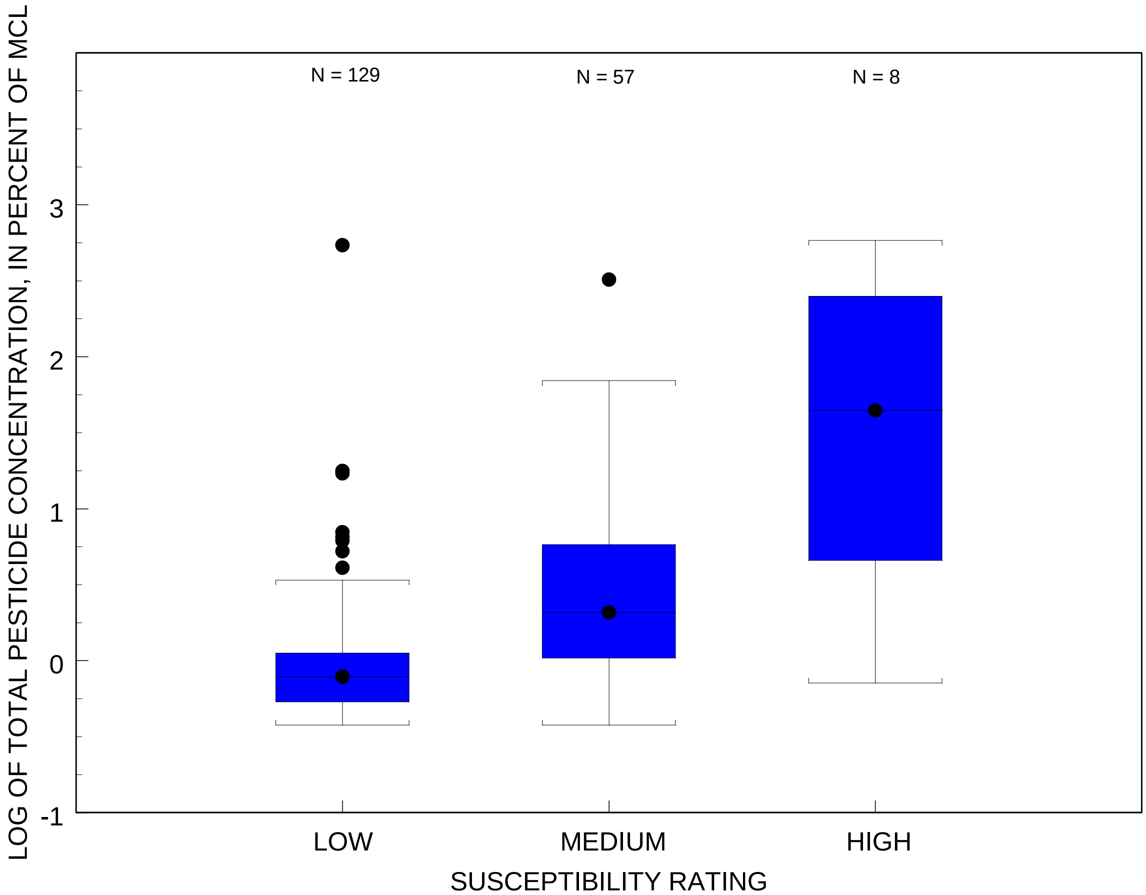

Figure 11. Results of the total pesticide susceptibility assessment model for 194 surface-water-quality sites in New Jersey showing distribution of total pesticide concentration by susceptibility rating.

Discussion

Several limitations to the susceptibility assessment models should be noted. These models should only be used as screening tools to identify potential contamination problems. The maximum concentrations in samples from a surface-water site were used in the analysis to develop models and do not take into account fluctuations in concentrations that may occur. Some of the components of the analysis were subjective, especially the coding scheme used for the susceptibility assessment model. Problems may exist in the interpretation of data at a local scale and projecting to statewide scales. Using different scales for various GIS layers could bias statistical results and land-use changes could cause spurious relations. The method used to determine source water assessment areas for intakes with large contributing areas that represent times of travel of water to the intake is inexact, and produces only estimates of the areas that may affect the water quality at the intake.

Statistics were run on a grouped pesticide value and at a level below the threshold of concern of the NJDEP and may not produce the same results as statistics that were run on individual pesticides at a higher level. For most pesticides with primary standards, statistics could not be run at one-half the MCL because few, if any, of the constituents were detected at this level.

The susceptibility rating represents a combination of both sensitivity and intensity, and in some cases may be inconsistent with the results of water-quality analyses. For example, a source may be highly susceptible to contamination by pesticides and have no detections in the samples if the pesticides are not applied within the contributing area.

Only 5 of 24 pesticides had sufficient data to run statistics. Pesticides used in the total calculation represent four major groups of pesticides--acetanilides (alachlor), triazines (atrazine and simazine), organochlorines (lindane), and carbamates (carbofuran). Major groups of pesticides not represented include organophosphorus and chlorophenoxy acid.

The database, GIS coverages, statistical analysis, and susceptibility assessment models can be used by scientists and water managers to help determine effects of hydrogeology and land use on the quality of water of public supplies. The relations between water quality and susceptibility variables shown in figures, graphs, and tables can be used in determining and evaluating monitoring requirements for water purveyors to ensure public health.

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