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

Summary

A susceptibility assessment model was developed to predict the susceptibility of source water to 49 surface-water-supply intakes and 11 ground-water sources under the direct influence (GWUDI) of surface water in New Jersey to contamination by volatile organic compounds (VOCs). Susceptibility is defined by the variables that describe hydrogeologic sensitivity and potential contaminant-use intensity within the area contributing water to a surface-water source. The model was developed using water-quality data from surface-water samples collected and analyzed by the U.S. Geological Survey (USGS). Explanatory variables were selected using a percent frequency of detection relative to one-tenth of the MCL of 25 respective VOCs at 175 USGS surface-water-quality sites. The explanatory variable selected to represent hydrologic sensitivity was the conceptual variable average percent soil organic matter. Explanatory variables selected to represent potential contaminant-use intensity were percent urban land in 1995 and density of known contaminant sites, solid waste landfills, NJPDES surface- and storm-water permits, and compost facilities. Susceptibility to VOCs for the 11 GWUDI was low for 2, medium for 7, and high for 2. Of the 49 surface-water-supply intakes, the susceptibility to VOCs was low for 11, medium for 35, and high for 3 (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 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 used for 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 (**www.state.nj.us/dep/swap**).

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

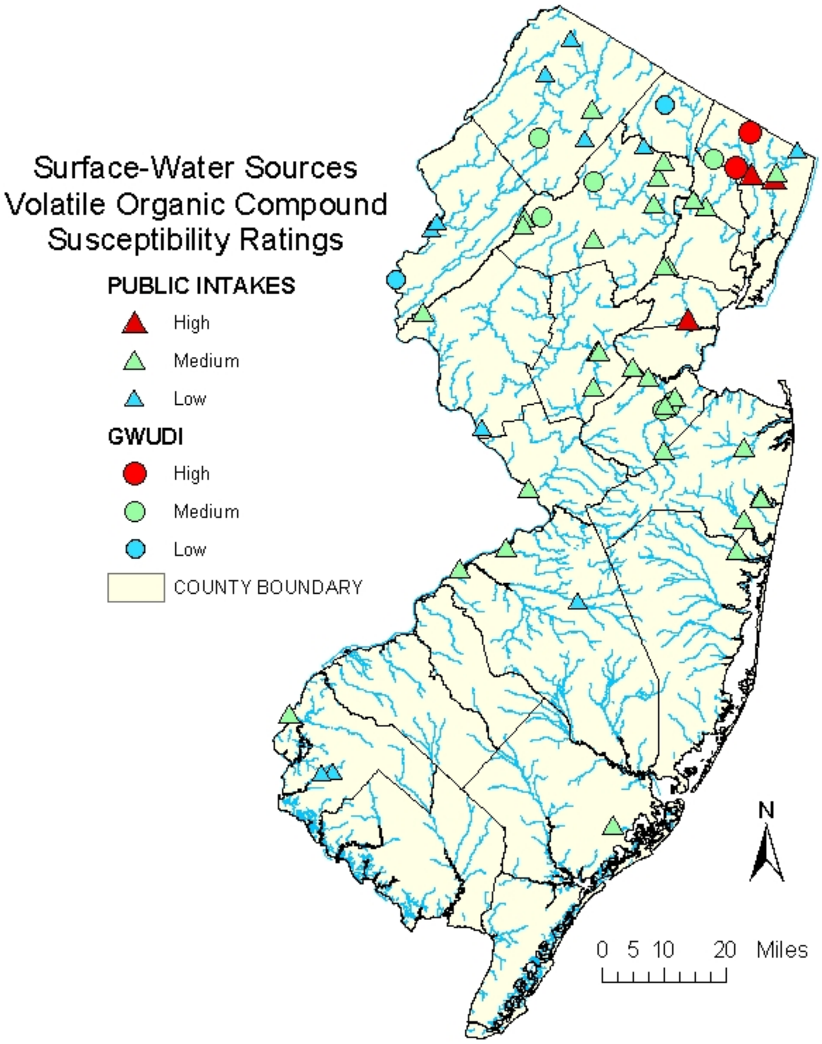

Figure 1. Susceptibility of 60 surface-water sources in New Jersey to contamination by volatile organic compounds.

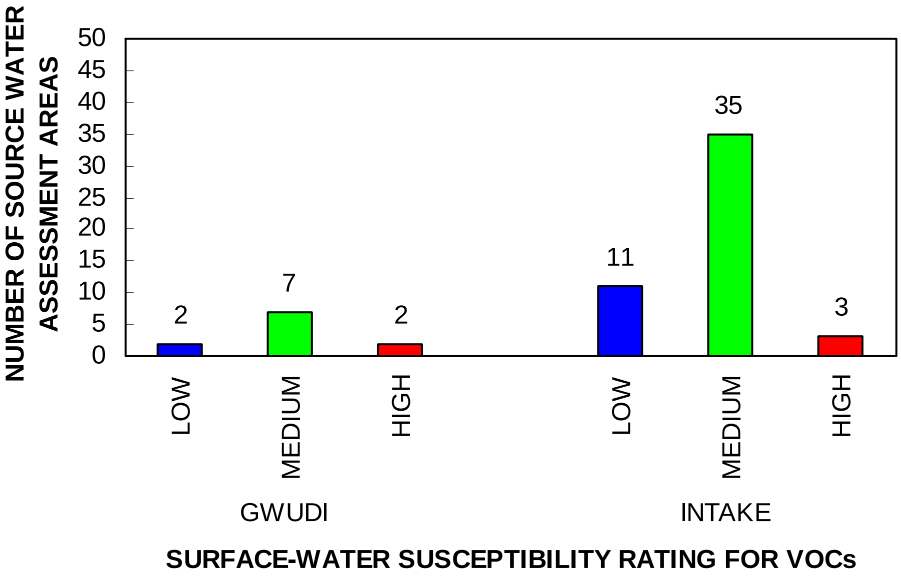

Figure 2. Number of water-supply intakes and related wells in New Jersey having low, medium, and high susceptibility to contamination by volatile organic compounds.

Background

VOCs contain organic carbon and evaporate at normal air temperature. Occurrence of VOCs in source waters is widespread. VOCs were identified as potential contaminants by 38 percent of community water systems in the United States (U.S. Environmental Protection Agency, 1997). Most VOCs are present in the environment as a result of human activity. VOCs can be found in degreasing solvents, cleaning products, fuels, paints, adhesives, refrigerants, deodorants, and petroleum-based fuels, and the production of pharmaceutical and agricultural products (Bloemen and Burn, 1993; Smith and others, 1988; Verschueren, 1983). Chloroform, used in industrial and manufacturing processes, is produced during the chlorination of drinking water. It also has been known to form naturally in soils (Hoekstra and others, 1998). Fuel hydrocarbon sources include gas stations and other transportation and storage facilities (Fetter, 1998). Compounds in fuels include benzene, toluene, ethylbenzene, and xylenes, and, recently, methyl tert-butyl ether (MTBE). Tetrachloroethylene and trichloroethylene are widely used in dry cleaning, metal degreasing, and some industrial and manufacturing processes. Fumigants applied to agricultural soils include 1,2-dichloropropane.

The sources of VOCs in surface water include urban and agricultural runoff, industrial and municipal wastewater discharge, and improper disposal and accidental leaks of petroleum products, solvents, paints, and dyes. O’Brien and others (1997) detected 50 VOCs in surface water from 42 water-quality sampling sites in New Jersey. The study showed that a greater number of VOCs were detected at sites in drainage basins with high percentages of urban land use than at sites with low percentages and concluded that this was associated with the point sources in the basin.

Definition of Susceptibility

The susceptibility of a public water supply to contamination by various 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.

Susceptibility = Hydrogeologic Sensitivity + Potential Contaminant-use Intensity

The 1999 NJDEP SWAP Plan postulated that all surface-water sources would be considered highly sensitive, but that premise has been redefined for some constituents through modeling. In some cases, documented research from existing studies and statistical methods of this study show that a sensitivity variable has a significant relation to contaminant concentrations.

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 community and noncommunity water supplies as low, medium, or high susceptibility to contamination for the groups of constituents using, as guidance, the thresholds developed by NJDEP for use in the models. 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 maximum contaminant level (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 equal to or exceed one-half of the MCL. The susceptibility ratings for the VOC group are based on a constituent susceptibility assessment model that used a calculated percent frequency of detection relative to one-tenth of the MCL of 25 respective VOCs.

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 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 coding scheme for each variable used in the models, 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. Some of the components of the analysis were subjective, especially the coding scheme of the model ratings. 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.

Development of Source Water Assessment Areas

NJDEP estimated 60 areas contributing water to surface-water sources used for drinking water in New Jersey (fig. 3); 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 that contributes to the water that flows past the intake or source. These source water assessment areas include the headwaters and tributaries and are based on 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 extremely large contributing areas, the source water assessment area is based on the time of travel to the intake or source.

NJDEP has classified approximately 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 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 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 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).

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

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

Water-Quality Data

Surface-water-quality data from June 1980 through October 2002 were obtained from the USGS NWIS database. Data for 801 surface-water-quality sites were retrieved. Analyses that were determined by older, less accurate, or less precise methods and those with high reporting levels were excluded. All water-quality data are from water samples collected by the USGS prior to treatment, unless otherwise noted. 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 for the modeling process. 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. All water-quality data were read into a relational database and a statistical software package to be used for exploratory data analysis, statistical testing, and plotting.

Of the 388 surface-water-quality sites delineated for the modeling process, 175 sites were used for model development. The maximum concentration measured at a surface-water-quality site was used because surface water is more variable than ground water, higher concentrations are of greater risk to human health, and selecting one sample per site avoided problems of averaging samples with Maximum Reporting Levels that may have changed over time. The number of surface-water-quality sites with VOC data, the constituents detected, and their corresponding MCLs are shown in table 1.

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.

Constituent	Standard - MCL in µg/L	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
Benzene	1[4]	178	25	8	0	3
Bromodichloromethane	[4,5]	186	11	-	-	-
Bromoform	[4,5]	183	5	-	-	-
Carbon tetrachloride	2[4]	176	0	0	0	0
Chlorobenzene	50[4]	183	10	0	0	0
Chloroform	[4,5]	186	58	-	-	-
Dibromochloromethane	[4,5]	186	5	-	-	-
1,2-Dichlorobenzene	600[4]	176	9	0	0	0
1,3-Dichlorobenzene	600[4]	176	3	0	0	0
1,4-Dichlorobenzene	75[4]	176	12	0	0	0
1,1-Dichloroethane	50[4]	186	13	0	0	0
1,2- Dichloroethane	2[4]	176	1	1	0	0
1,1-Dichloroethylene	2[4]	176	8	1	0	0
cis-1,2-dichloroethylene	70[4]	173	30	1	0	0
trans-1,2-dichloroethylene	100[4]	183	3	1	0	0
1,2-Dichloropropane	5[4]	176	0	0	0	0
Ethylbenzene	700[4]	183	15	0	0	0
Methylene chloride	3[4]	174	13	6	0	2
Methyl tertiary butyl ether (MTBE)	70[4]	173	122	4	1	0
Napthalene	300	48	25	0	0	0
Styrene	100[4]	176	6	0	0	0
1,1,2,2-Tetrachloroethane	1	51	0	0	0	0
Tetrachloroethylene (PCE)	1[4]	176	39	15	4	3
Toluene	1000[4]	185	36	0	0	0
1,2,4-Trichlorobenzene	9	48	1	0	0	0
1,1,1-Trichloroethane	30[4]	186	28	0	0	0
1,1,2-Trichloroethane	3	51	0	0	0	0
Trichloroethylene (TCE)	1[4]	176	40	14	3	6
Vinyl chloride	2[4]	176	2	0	0	1
Xylenes	1000	46	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 than the number of sites used to develop the model.

[2] Criterion 1: Concentration is at least equal to 10 percent of the standard, but is less than 50 percent of the standard.

[3] Criterion 2: Concentration is at least equal to 50 percent of the standard, but is less than the standard.

[4] 25 VOCs used for model development.

[5] MCL for total trihalomethanes is 80 µg/L, which is the sum of the concentrations of the 4 constituents.

Data Analysis

Federal and State Safe Drinking Water Regulations require routine monitoring for many VOCs at community water systems. For the purpose of modeling, NJDEP determined that concentrations greater than one-half the MCL would be of greatest concern.

Concentrations equal to or above 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 VOC model was 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 (fig. 4).

Combining VOCs, rather than modeling individual VOCs where there were a limited number of surface-water-quality sites with water-quality samples that had detections equal to or greater than one-tenth of the MCL, provided for a more robust data set from which to develop the statistical model. The maximum concentrations were mostly low at 175 sites for 25 VOCs and had to be combined to develop a meaningful statistical model. A percent frequency of detection (FOD) relative to one-tenth of the MCL of the 25 respective VOCs was calculated at each surface-water-quality site and was used to plot data and run statistical tests. The number of VOCs with concentrations equal to or greater than one-tenth of the respective MCL for each of the VOCs in the FOD group was divided by the total number of VOCs in the FOD group at each USGS surface-water-quality site and multiplied by 100 to yield a percent frequency of detection.

$$\frac{\#\,VOCs\ with\ concentrations \geq 10\%\ MCL}{\#\,VOCs\ analyzed} \times 100 = \%\ FOD$$

To apply Kruskal-Wallis tests, the 175 surface-water-quality sites were separated into two groups-- sites for which the percent FOD was zero and sites for which the percent FOD was greater than zero. Sites for which the percent FOD was zero (no VOCs were detected at equal to or greater than one-tenth of the MCL) and sites for which the percent FOD was greater than zero (at least one VOC was detected at equal to or greater than one-tenth of the MCL) are shown in figure 4.

Statistical tests and graphical procedures were used to evaluate the relation between VOCs and sensitivity and intensity variables. Univariate statistical tests were run on all variables. Univariate tests included the Kruskal-Wallis test and Spearman’s rho.

The Kruskal-Wallis test was used to determine whether distributions of hydrogeologic sensitivity or contaminant-use intensity variables differed between surface-water-quality sites where VOCs in the group selected for model development were either not detected or detected, but concentrations were less than one-tenth of the respective MCL, and surface-water-quality sites where one or more VOCs in the group selected for model development were detected at equal to or greater than one-tenth of the respective MCL (table 2). The Kruskal-Wallis test is a nonparametric statistical method and is calculated by performing a one-way analysis of variance on the ranks of a data set (Iman and Conover, 1983). 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 concentration of each modeled constituent and all hydrogeologic sensitivity, potential contaminant-use intensity, and many water-quality variables. Scatter plots of each variable in relation to the modeled constituent 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 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. 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 was not supported by scientific investigations, (3) the variable did not show a graphical relation to the constituent (4) the variable was found to have a similar relation to the constituent as another variable.

Table 2. Results of univariate statistical tests for explanatory variables used in the VOC model.

Variable	Kruskal-Wallis Score	P-value	Conceptual Variable
Average percent soil organic matter	-	[1]	Yes[2]
Percent urban land 1995	20.6384	0.0000	No
Density of Known Contaminant Sites, Solid Waste Landfills, NJPDES Surface and Storm Water Permits, and Compost Facilities	37.8225	0.0000	No

[1] Not significant at the alpha <0.05 level.

[2] This conceptual variable improves the model, shows a graphical relation, and is supported by previous scientific investigations.

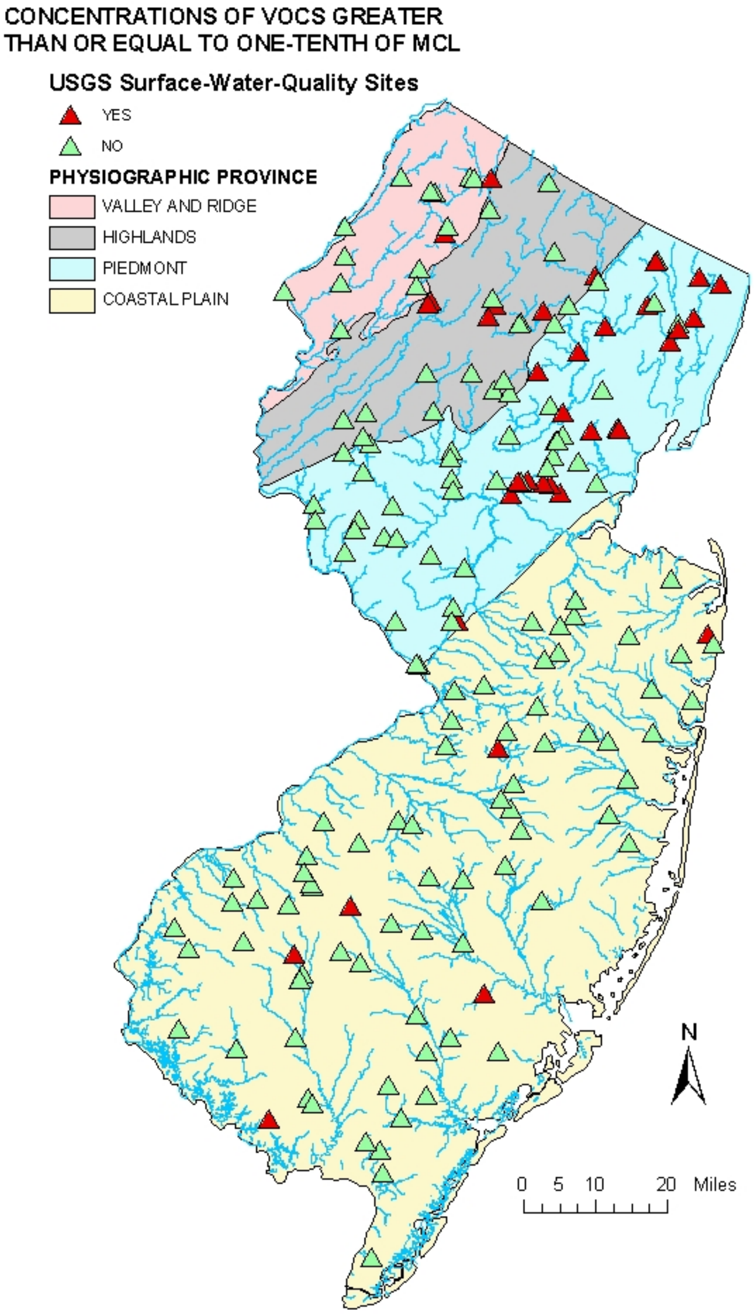

Figure 4. Distribution of VOCs detected at concentrations equal to or greater than one-tenth of the MCL of the respective VOC at 175 USGS surface-water-quality sites in New Jersey used for development of the VOC model (Yes - at least one VOC detected at equal to or greater than one-tenth of the MCL, No – No VOCs detected at equal to or greater than one-tenth of the MCL).

Rating Scheme

A scoring method was developed for the VOC model that gave a maximum of 3 points to each conceptual and statistically significant variable used in the model (table 3). Relations observed in scatter plots of the variable as a function of the percent frequency of detection, and distributions in boxplots (fig. 5) were used as the starting point for devising the code.

As an example, when percent urban land in 1995 was statistically related (Kruskal-Wallis score of 20.6384 and p-value of 0.000) to the VOC percent FOD and the percent urban land for a USGS surface-water-quality site was greater than zero and less than or equal to 10 percent, a score of 1 was assigned. As the percentage of urban land increases, the score increases.

Table 3. Susceptibility rating scheme for VOCs in water from surface-water-quality sites. VOC Rating: 0-4 Low, 5-6 Medium, 7-8 High

	Sensitivity Points				**Conceptual Variable**
Variable		1	2	3	
Average percent soil organic matter		>8	>1.5 - ≤8	≤1.5	Yes[1]
	Intensity Points				
Variable	0	1	2	3	
Percent urban land 1995	0	>0 - ≤10	>10 - ≤70	>70	No
Density of Known Contaminant Sites, Solid Waste Landfills, NJPDES Surface and Storm Water Permits, and Compost Facilities		≤5.5	>5.5		No

[1] This conceptual variable improves the model, shows a graphical relation, and is supported by previous scientific investigations.

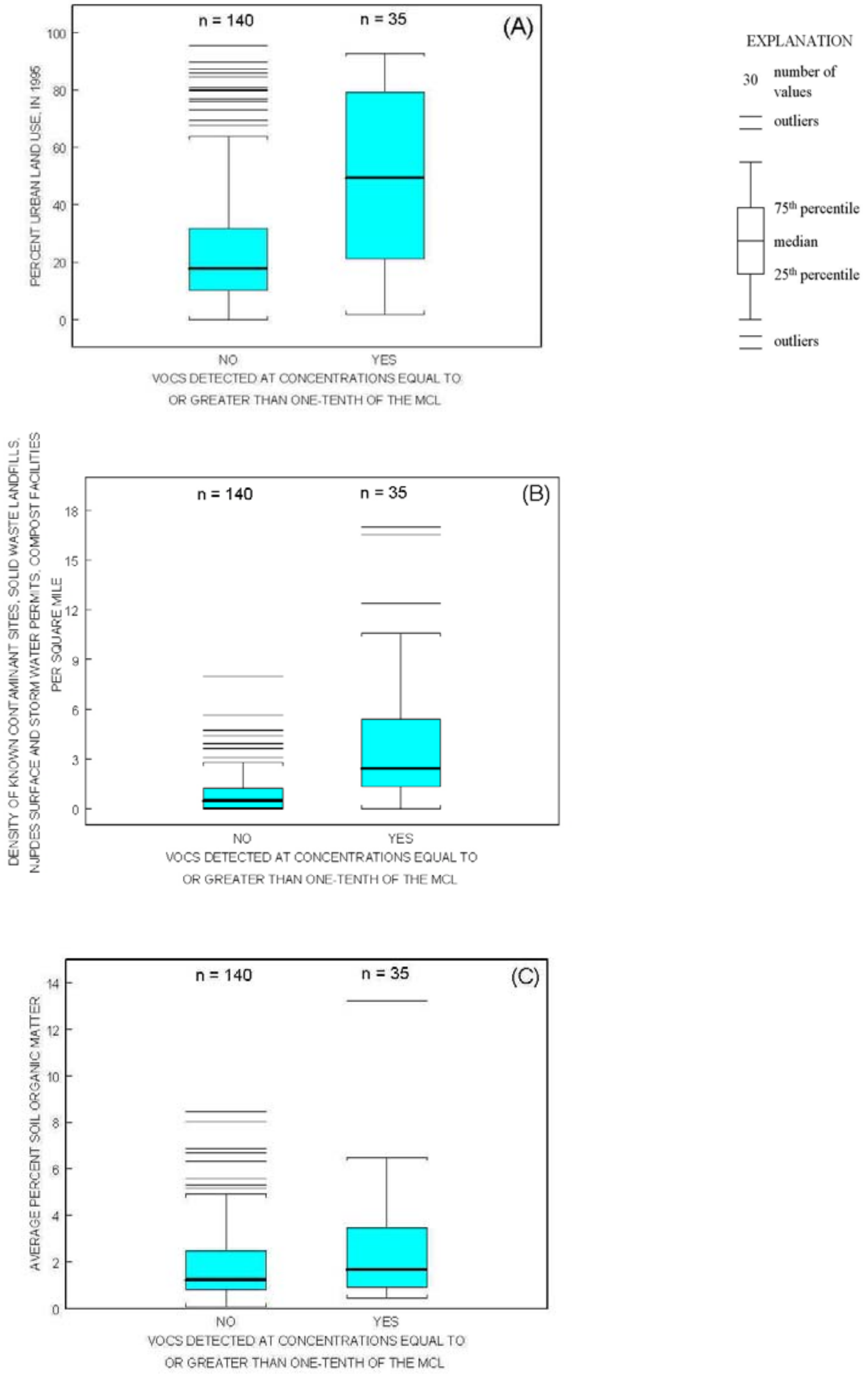

Figure 5. Distribution of (A) percent urban land in 1995, (B) density of known contaminant sites, solid waste landfills, NJPDES surface- and storm-water permits, and compost facilities, (C) percent average soil organic matter for samples in which one or more VOCs were or were not detected at concentrations equal to or greater than one-tenth of the MCL of the respective VOC for 175 USGS surface-water-quality sites in New Jersey.

Relation of VOCs in Surface Water to Susceptibility Variables

The model was developed to investigate relations between VOC concentrations at USGS surface-water-quality sites and various hydrogeologic sensitivity and potential contaminant-use intensity variables. Most surface-water-quality sites had insufficient VOC data to develop individual meaningful statistical models (table 1). Data on carbon tetrachloride, 1,2-dichloropropane, 1,1,2,2 tetrachloroethane, 1,1,2 trichloroethane, and total xylenes are highly censored (no reported detections). Only 10 of the 26 regulated VOCs have data that exceed one-tenth of the MCL, and 6 of the 10 have data that exceed one-half of the MCL. Maximum benzene concentrations exceeded the MCL at less than 2% of sampled sites. Maximum methylene chloride concentrations exceeded the MCL at approximately 1% of sampled sites. Maximum tetrachloroethylene concentrations exceeded the MCL at 1.7% of sampled sites. Maximum trichloroethylene concentrations exceeded the MCL at 3.4% of sampled sites, and maximum vinyl chloride concentrations exceeded the MCL at less than 1% of sampled sites.

In order to determine variables for the VOC model, as with any susceptibility assessment model, knowledge of the occurrence and use of the constituent must be incorporated into the process. In concept, the VOC model should contain variables that include urban sources because existing studies conducted in New Jersey link the presence of VOCs to urban land use (O’Brien and others, 1997). Sensitivity variables should be considered because VOCs can be affected by soil and water properties.

Results of Kruskal-Wallis univariate statistics for variables used in the VOC model are shown in table 2. The susceptibility ratings for VOCs are influenced mainly by the intensity variables of the model because most sources of VOCs are anthropogenic. Intensity variables that showed a correlation with VOC data were percent urban land use (1995) and density of known contaminant sites, solid waste landfills, NJPDES surface- and storm-water permits, and compost facilities per square mile. The boxplot of percent urban land use (1995) in relation to percent frequency of detection for VOCs shows a substantial difference in the medians of the group with one or more detected VOCs and the group with no detects (fig. 5a). The boxplot of density of known contaminant sites, solid waste landfills, NJPDES surface- and storm-water permits, and compost facilities per square mile in relation to percent frequency of detection for VOCs also shows a difference in the medians of the same two groups (fig. 5b). The sensitivity variable for the VOC model is average percent soil organic matter. It is used as a conceptual variable. VOCs tend to sorb to soil organic matter (United States Environmental Protection Agency, 1993). The boxplot of average percent soil organic matter in relation to percent frequency of detection of VOCs shows a slight difference in the medians between the two groups (fig. 5c). The final VOC model included the intensity variables percent urban land in 1995, density of known contaminant sites, solid waste landfills, NJPDES surface- and storm-water permits, and compost facilities per square mile, and the sensitivity variable average percent soil organic matter. The VOC model applied to 175 sites rate 39 sites as low susceptibility, 117 sites as medium susceptibility, and 19 sites as high susceptibility to contamination by VOCs (figs. 6 and 7). The boxplot of the VOC susceptibility relative to the percent FOD is shown in figure 7; only 4 surface-water-quality sites out of 39 rated as low susceptibility had a percent FOD greater than zero and less than 5 percent and, 19 surface-water-quality sites out of 117 rated as medium susceptibility had a percent FOD greater than zero and less than 10 percent. The distribution of the susceptibility scores for 175 surface-water-quality sites across New Jersey shows that most of the sites in the high susceptibility group are located in the Piedmont Physiographic Province and one is in the Coastal Plain (fig. 6). All sites rated as high susceptibility have greater than 67% urban land use, and 78% of the sites rated as high susceptibility have greater than 75% urban land use.

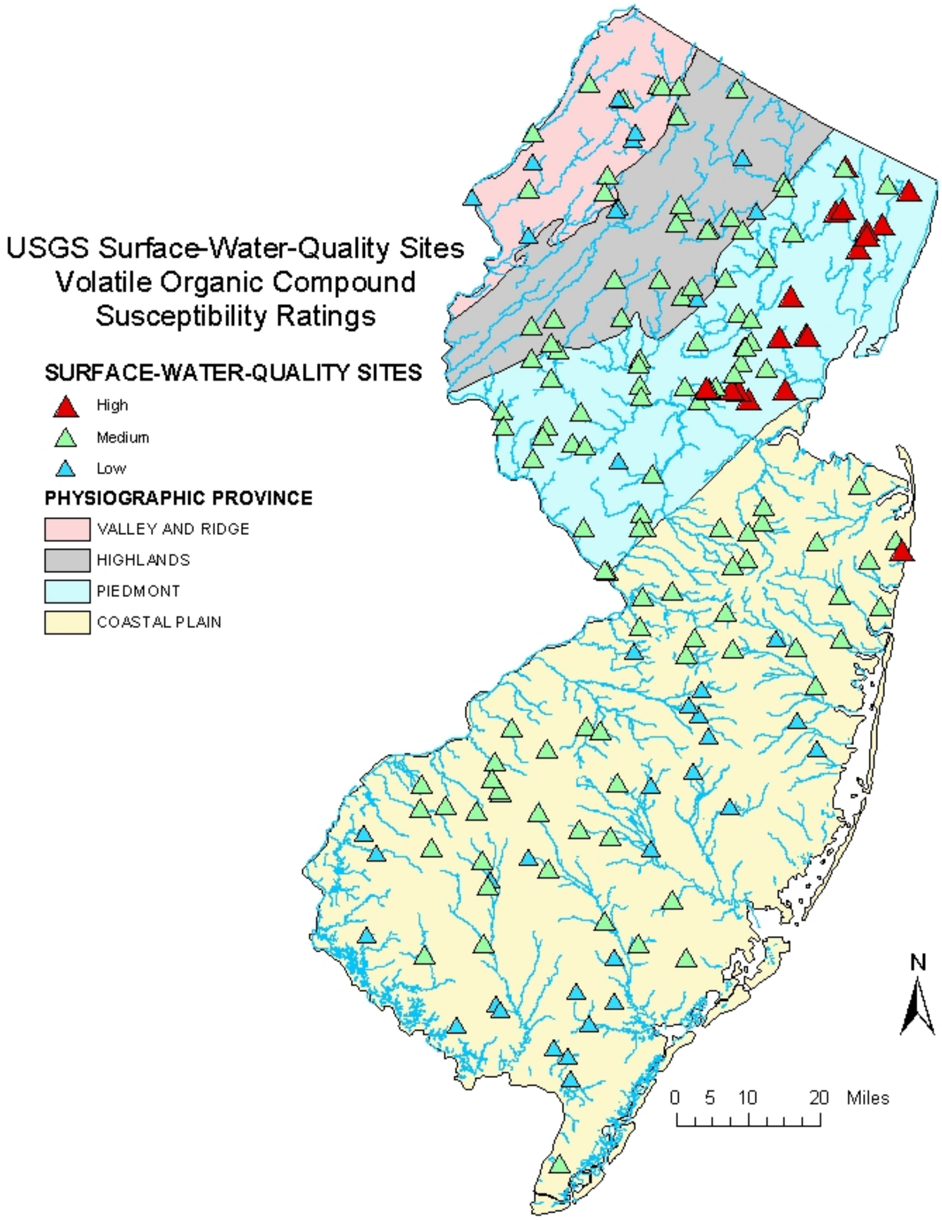

Figure 6. Susceptibility of 175 USGS surface-water-quality sites in New Jersey to contamination by volatile organic compounds.

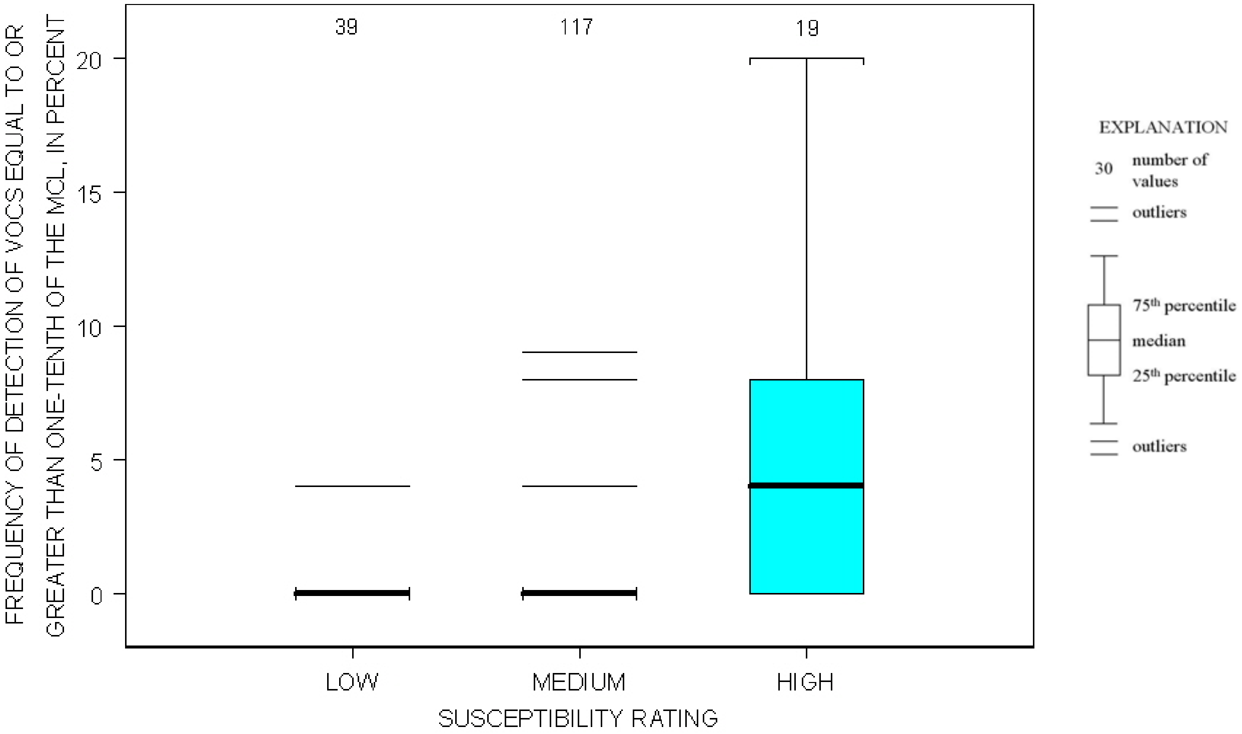

Figure 7. Results of VOC susceptibility assessment model for 175 USGS surface-water-quality sites in New Jersey showing distribution of percent frequency of detection relative to one-tenth of the MCL of the respective VOC by susceptibility rating.

Susceptibility of Surface-Water Sources

The rating schemes created during the VOC model development were applied to the sensitivity and intensity variables of each GWUDI and surface-water intake. The sensitivity and intensity variable scores were added to yield a susceptibility assessment rating at a source for VOCs. The rating is designated as low, medium, or high susceptibility to contamination in relation to one-tenth of, one-half of, and the maximum contaminant level. Application of the VOC model estimated 2 GWUDI as having low susceptibility, 7 GWUDI as having medium susceptibility, 2 GWUDI as high susceptibility, 11 intakes as low susceptibility, 35 intakes as having medium susceptibility, and 3 intakes as having high susceptibility to contamination by VOCs (figs. 1 and 2).

The range of urban land use for the high susceptibility group was 79 to 96 percent. The medium susceptibility group had a range of 9 to 67 percent urban land use; with only 19 percent of the sites having greater than 49 percent urban land use. The range of urban land use for the low susceptibility group was 1 to 54 percent; with 92 percent of the sites having less than 9 percent urban land use. Sixty percent of the high susceptibility group had 5 to 7 known contaminant sites, solid waste landfills, NJPDES surface- and storm-water permits, and compost facilities per square mile. Ninety-eight percent of the medium and low groups had less than 3 known contaminant sites, solid waste landfills, NJPDES surface- and storm-water permits, and compost facilities per square mile. The range of average percent soil organic matter was 0.36 to 3.21 for the low group, 0.3 to 3.38 for the medium group with 11.28 at one site, and 0.6 to 0.89 for the high group.

Discussion

There are several limitations to the susceptibility assessment models. These models should be used only as screening tools to assess the potential susceptibility of a surface-water source to contamination from regulated constituents. 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. Significant susceptibility factors can change with time and additional water-quality data can be used in the future to update the models.

Statistics were run on grouped constituent values and at a level below the threshold of concern of the NJDEP and may not produce the same results as statistics that were run for a higher level. For VOCs 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 and have no detections in the samples if the constituent does not originate from human activities or natural sources within the assessment area.

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

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