SUSCEPTIBILITY OF SOURCE WATER TO COMMUNITY WATER-SUPPLY WELLS IN NEW JERSEY TO CONTAMINATION BY DISINFECTION BYPRODUCT PRECURSORS

Summary

A susceptibility assessment model was developed to predict the susceptibility of source water to community water-supply (CWS) wells in New Jersey to contamination by disinfection byproduct (DBP) precursors. Susceptibility is defined by variables that describe hydrogeologic sensitivity and potential contaminant-use intensity within the area contributing water to the wells. The model was developed using water-quality data from ground-water samples collected and analyzed by the U.S. Geological Survey (USGS). Data on DBP precursors in water from CWS wells are limited. Trihalomethane (THM) data were available for both source and incubated water collected from a network of 60 CWS wells in unconfined and confined aquifers. The concentration of THMs formed as a result of the disinfection of water supplies is known as the trihalomethane formation potential (THMFP) and is defined as the difference between the concentration measured after treatment and the concentration (if any) measured in the source water. Variables selected to estimate sensitivity in water from wells in unconfined aquifers are the hydrologic unit group and average percent soil organic matter. Both variables are conceptual. Variables selected to estimate intensity in water from wells in unconfined aquifers are area of wetland lands in 1995, a conceptual variable, and the number of potential contaminant sites. Potential contaminant sites in this model include the following: the number of New Jersey Pollutant Discharge Elimination System sites, Discharge Prevention & Countermeasures Plans & Discharge Clean-up & Removal Plans sites, Transfer Facilities, Resource Recovery Facilities, Class B Recycling Facilities, and Class C Compost Facilities. Variables selected to estimate sensitivity of water from wells in confined aquifers are the hydrologic unit group and the pH of water-quality samples. No intensity variables were selected for wells in confined aquifers because the water in confined aquifers typically is not susceptible to contamination from the land surface. Overall, of 2,237 CWS wells for which susceptibility was determined, the susceptibility to contamination by DBP precursors was low for 2 percent, medium for 76 percent, and high for 22 percent of CWS wells (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 DBP precursors, (2) presents results of application of the susceptibility model to estimate the susceptibility of source water to CWS wells to these constituents, and (3) documents the distribution of these constituents in water from CWS wells in New Jersey.

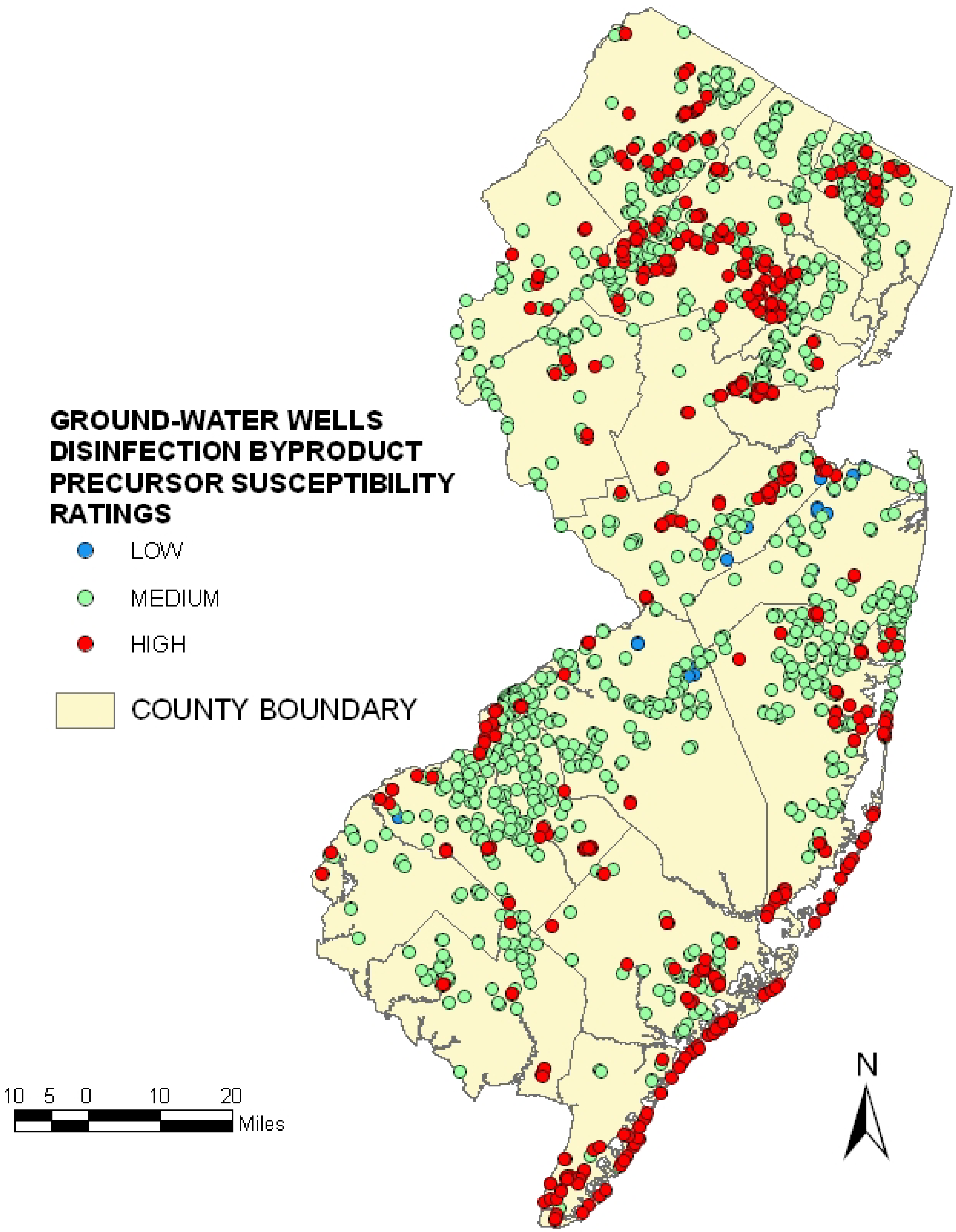

Figure 1. Susceptibility of 2,237 community water-supply wells in New Jersey to contamination by disinfection byproduct precursors.

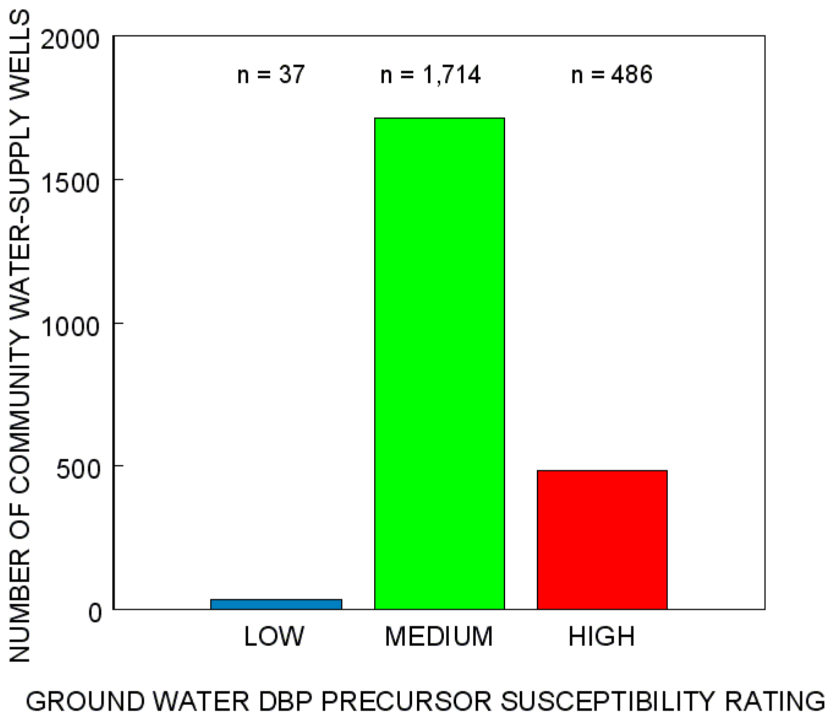

Figure 2. Number of community water-supply wells in New Jersey having low, medium, and high susceptibility to contamination by disinfection byproduct precursors.

Background

DBPs are formed when disinfectants, such as chlorine compounds, react with organic and inorganic compounds naturally present in raw water. Formation of DBPs was first attributed to the use of chlorine in drinking water in 1974 (Rook, 1974). These compounds are formed when organic matter in the water reacts with the chlorine (NaOCl) used to disinfect the water used for public supply against water-borne organisms, such as coliform bacteria. The major chemical species formed by the chlorination are trihalomethanes (THMs), haloacetic acids, haloacetonitriles, and chloral hydrate. The group designated as total THMs is the sum of the concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

Natural organic matter was found to be an important component of the organic material that reacted to form DBPs (Stevens and others, 1976). Some compounds that occur as DBPs in water supplies may occur naturally, or as a result of human activities such as where septic-system effluent containing both chlorine and organic compounds drains to surface-water bodies or percolates to ground water. DBP compounds tend to form within the water-supply system. Consequently, water containing high concentrations of organic compounds has a greater potential for DBP formation when chlorinated than does water with low concentrations of organic compounds. The susceptibility of public water supplies needs to be considered in light of water entering the system that already contains

DBPs and water entering the system that contains compounds that promote the formation of DBPs. DBP precursors include dissolved organic carbon (DOC) and bromide. The precursor DOC contains several different forms of carbon. When DOC is fractionated, its components, hydrophobic acids and hydrophilic acids are isolated. Hydrophobic acids are composed of humic and fulvic acids; these contain aromatic compounds that are thought to be the primary contributing factor to the formation of THMs (Amy and others, 1990; Reckhow and others, 1990; Owen and others, 1993). The hydrophilic acid fraction contains fewer aromatic compounds than does the hydrophobic acid fraction (Fujii and others, 1998). Organic substances absorb ultraviolet radiation; thus, ultraviolet absorbance measurements at 254 nanometers (UV-254) can show a relation to concentrations of organic compounds. UV-254 measurements tend to increase as the amount of aromaticity of DOC increases. UV-254 is an indicator of the potential for precursor DOC to form DBPs. Specific UV-254 is UV-254 normalized (divided by the DOC concentration) and is used to estimate the percentage of aromatic structure of DOC (Rook, 1974, Reckhow and others, 1990).

New regulations adopted by United States Environmental Protection Agency (USEPA) as part of the Disinfection By-Products Rule, increased the requirements for water purveyors to collect detailed information on both source waters and treated waters. The Disinfection By-Products Rule, which sets maximum contaminant levels (MCLs) for total THMs, haloacetic acids, bromate, and chlorite, and maximum residual disinfection concentrations for chlorine, chloramines, and chlorine dioxide went into effect in 1998 (United States Environmental Protection Agency, 1998). Stage 1 of the Disinfection By-Products Rule lowered the MCL for total THMs from 100 μg/L (micrograms per liter or parts per billion) to 80 μg/L and established the MCL for haloacetic acids at 60 μg/L.

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 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 constituents using, as guidance, the thresholds developed by NJDEP for use in the models. In general, the low-susceptibility category includes wells for which constituent concentrations 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 concentrations are not likely to equal or exceed one-half the MCL, and the high-susceptibility category includes wells for which constituent concentrations may equal or exceed one-half the MCL. The susceptibility rating for the DBP precursor indicator constituent group is based on the results of a susceptibility assessment model developed for THFMP at 60 sites.

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 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. 3) 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.

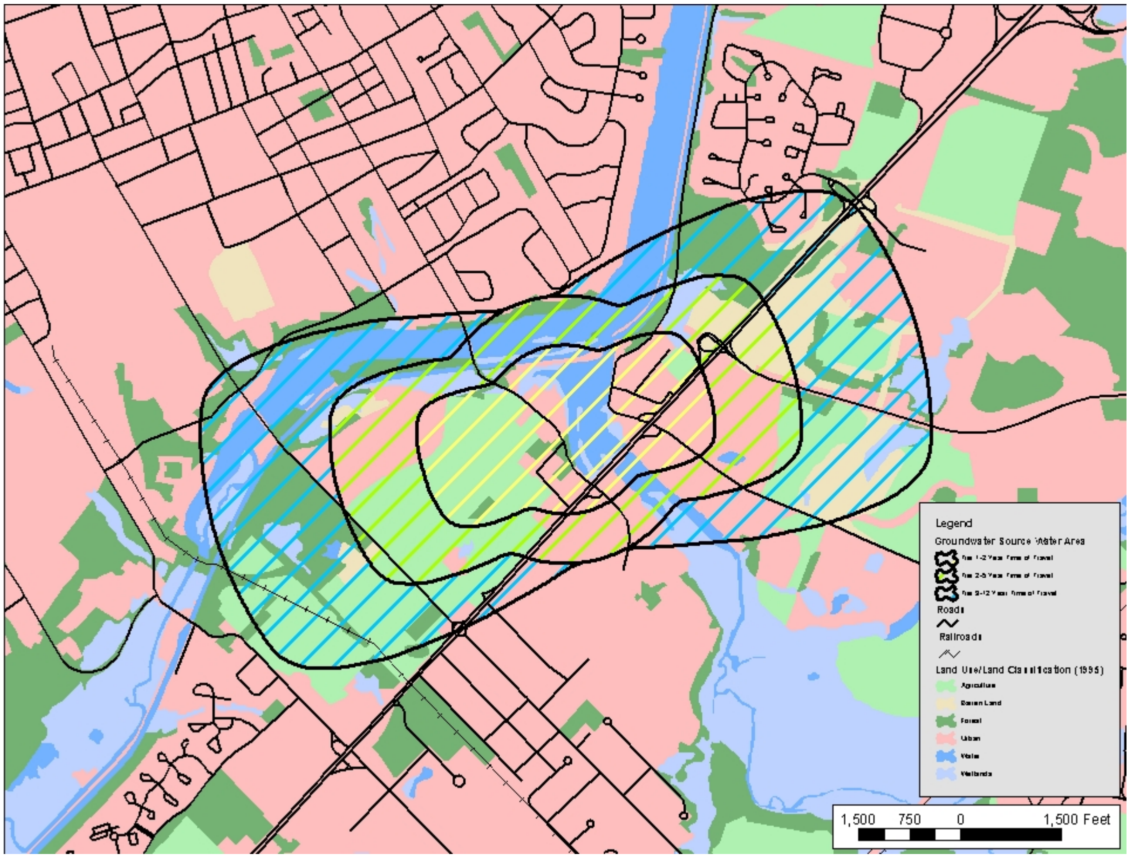

Figure 3. Example of delineated contributing area to a community water-supply well showing time of travel (TOT), land use, roads, and railroads.

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, or less precise methods were excluded. Analyses with known contamination problems also were not used. A statewide network of the 60 CWS wells in unconfined and confined aquifers was selected to develop the model. The most recent concentration measured at each well was used in each data set because the most recent sample probably was analyzed using a method with the lowest minimum reporting level (MRL) and with better precision. The number of sites with total THM data in water from raw and incubated samples from CWS wells that met or exceeded selected criteria related to the MCL are shown in table 1. Locations of wells are shown in figure 4.

In a previous study USGS investigated DBPs in New Jersey ground water. The DBPs investigated were the THMs in source water and incubated water. Total THM concentrations in raw water from 60 CWS wells in the USGS database were evaluated to give an overview of THM concentrations in source water in New Jersey (fig. 4). Source water from the same 60 CWS wells was incubated; the water was adjusted to pH 7, chlorinated, incubated for 165 hours (7 days), and analyzed for THMs to simulate the disinfection process so that THMs formed as a result of disinfection could be measured (J.A. Hopple and others, U.S. Geological Survey, written commun., 2003) (fig. 5).

The concentration of THMs formed as a result of the disinfection of water supplies is known as the THMFP and is defined as the difference in the concentration measured after treatment or incubation and the concentration (if any) measured in the source water, as in the following equation:

$$\text{THMFP} = \text{total THMs}_{\text{incubated water}} - \text{total THMs}_{\text{source water}}$$

The concentrations of the THMs measured after the 7-day incubation of the treated water samples from 60 CWS wells varied by more than two orders of magnitude, depending in part on the initial concentration in the source water, but mostly on the chemical characteristics of the ground water, which are derived, in part, from characteristics and materials inherent to the aquifer from which the water was drawn.

Scatter plots and boxplots of THMFP, total THMs, DOC, UV-254, and specific UV-254 in relation to sensitivity and intensity variables were generated to look at all relations of the data. Scatter plots of constituents in relation to other constituents were generated to look for relations between precursors and total THM in raw and incubated water. Other constituents and characteristics considered as precursors or indicators were chloride, and total organic carbon. Relations seen in these plots were used as confirmation of relations seen in plots of THMFP and variables.

The pH of water samples was used in statistical tests and for application of models to CWS wells. The most recent analyses in the NWIS database were used to represent the pH of water from the well. If pH data were unavailable in the NWIS database, the most recent value from the NJDEP database was used. These analyses are unlike analyses in the NWIS database in that they commonly are for samples collected from facilities that receive water from more than one well, and the water may be treated. This value was used for all wells that contribute to that facility. If results of analyses were unavailable in either database, no value of pH was used and the rating scheme was adjusted accordingly.

Table 1. Number of sites at which selected constituents in samples from community water-supply wells met or exceeded selected criteria related to the MCL [μg/L = micrograms per liter, MCL = maximum contaminant level]

	Constituent	MCL, μg/L	Number of sites for which data are available	Number of sites at which constituent was detected	Number of sites at which concentration meets criterion 1[1]	Number of sites at which concentration meets criterion 2[2]	Number of sites at which concentration equals or exceeds standard
Confined	Source water total THMs	80	25	0	0	0	0
	THMFP	80	25	25	13	5	0
Unconfined	Source water total THMs	80	35	20	1	0	0
	THMFP	80	35	35	23	4	2

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

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

Data Analysis

Federal and State Safe Drinking Water Regulations require routine monitoring for many DBP precursors 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 DBP precursor model was developed to determine the variables that best describe the presence or absence of these constituents in source waters at concentrations equal to or greater than one-tenth of the MCL.

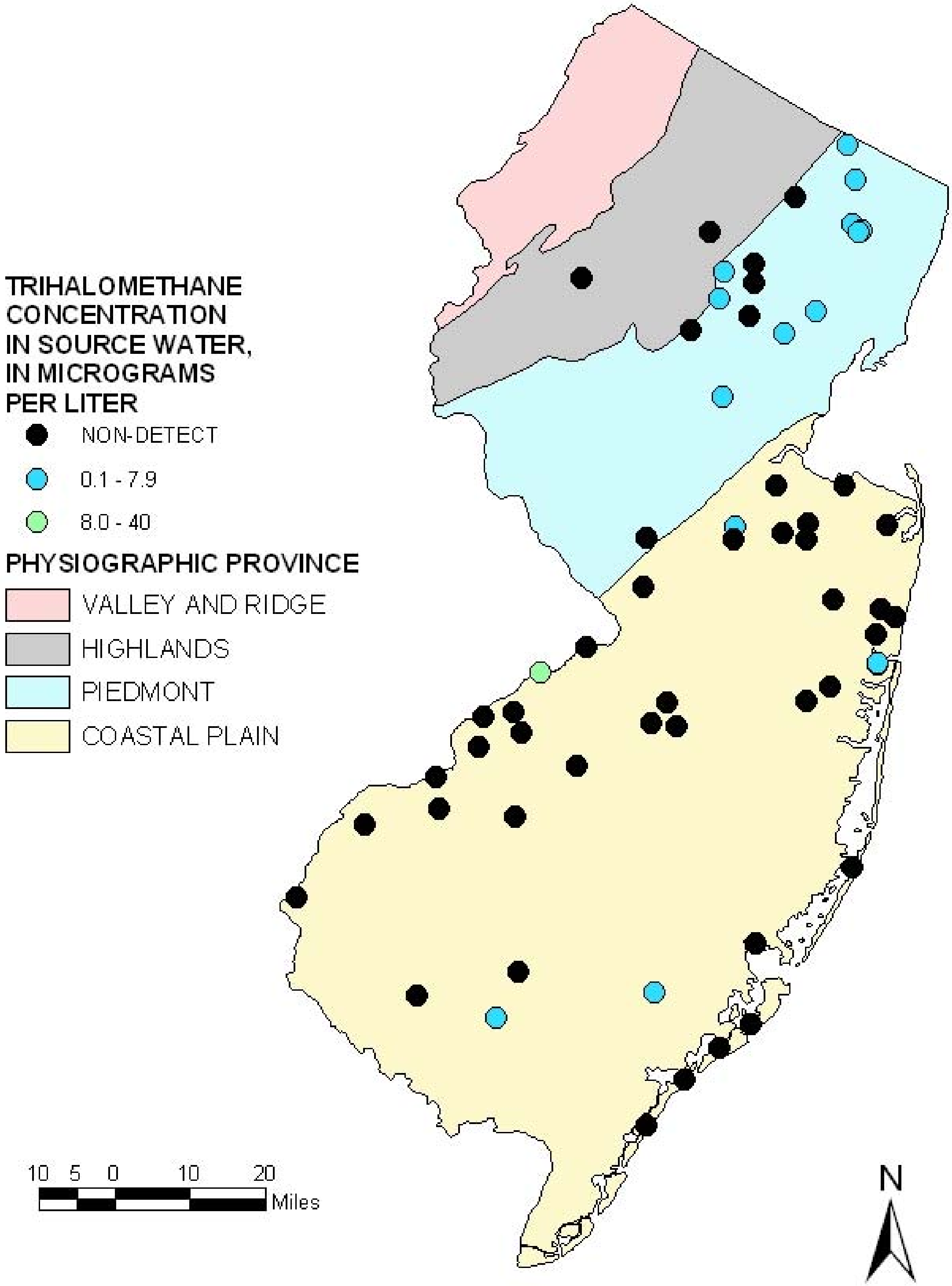

Figure 4. Concentrations of trihalomethanes in source water from 60 community water supply-wells used for development of disinfection byproduct precursors model. The Physiographic Provinces shown are regions with differing geologic and topographic characteristics.

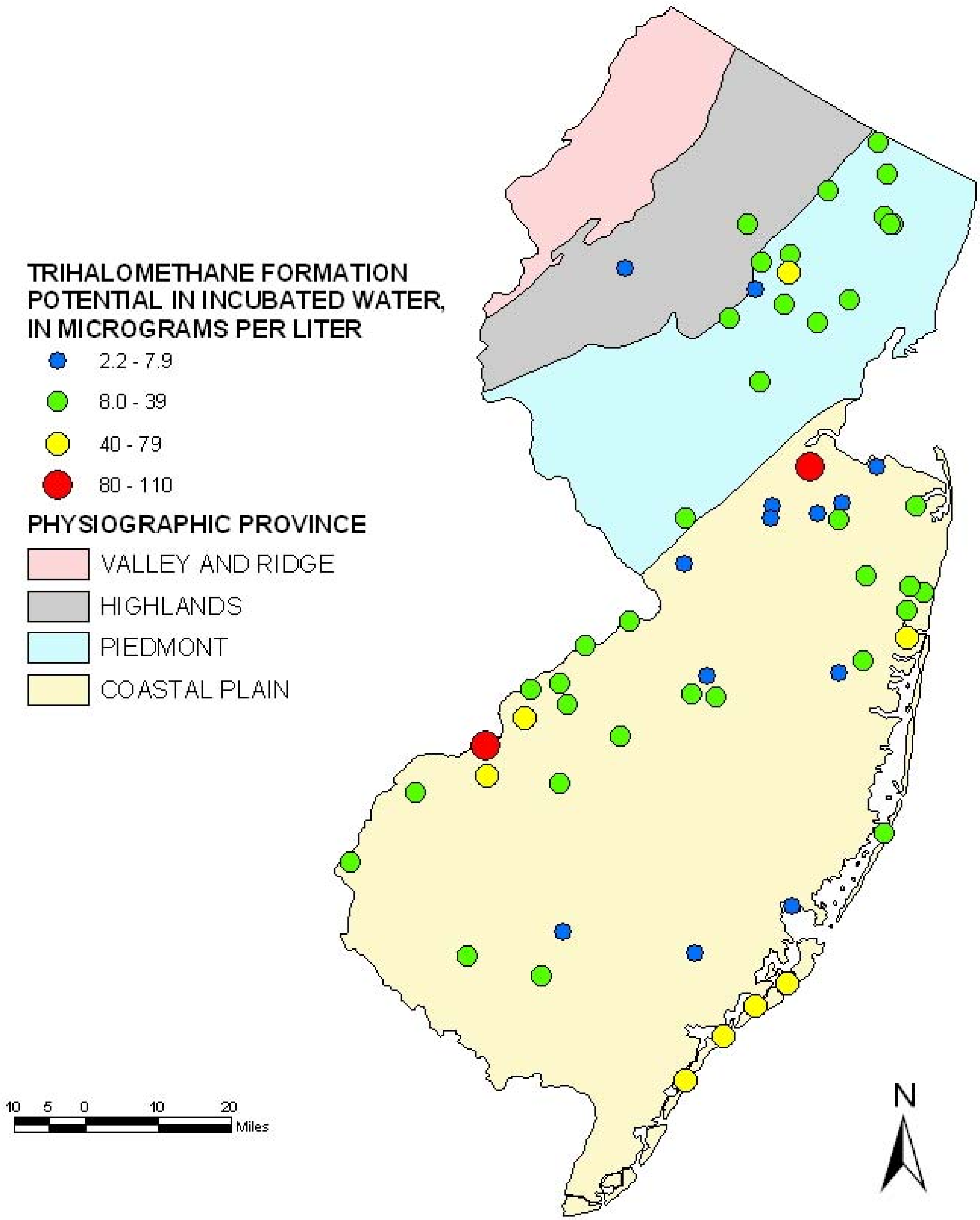

Figure 5. Concentrations of trihalomethanes formation potential in incubated water from 60 community water supply-wells used for development of disinfection byproduct precursors model. The Physiographic Provinces shown are regions with differing geologic and topographic characteristics.

Statistical tests and graphical procedures were used to evaluate the relation between THMFP and sensitivity and intensity variables to determine those variables that best describe the concentrations of DBP precursors in source waters. Univariate statistical tests were run on all variables. Univariate tests included the Kruskal-Wallis test and Spearman's rho rank correlation.

The Kruskal-Wallis test was used to determine whether distributions of variables differed between wells where the THMFP was either (1) less than one-tenth of the MCL or greater than or equal to one-tenth of the MCL or (2) less than one-half of the MCL or greater than or equal to one-half of the MCL (table 2). 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; the larger the test statistic and the smaller the p-value relative to the other values within the data set, the more significant the test result. The magnitude of the test statistic depends on the size of the data set; the larger the data set, the larger the test statistic relative to the test statistic from a smaller data set.

Table 2. Results of univariate statistical tests for explanatory variables used in disinfection byproduct precursor model

Intensity or Sensitivity	**Variables**	**Kruskal-Wallis rank test**		**Conceptual variable**
		Kruskal-Wallis score	**p-value**	
Wells in Unconfined Aquifers				
Sensitivity	Average percent soil organic matter	3.46	0.0628 [1]	Yes [2]
	Hydrologic unit group		Not significant [1]	Yes [2]
Intensity	Number of potential contaminant sites [3]	5.39	0.0203	No
	Area of wetlands, 1995, in square miles	2.17	0.1046 [1]	Yes [4]
Wells in Confined Aquifers				
Sensitivity	Hydrologic unit group	11.31	0.0102	No
	pH of water-quality sample	7.09	0.0077	No

[1] Not significant at the alpha <0.05 level.
[2] This conceptual variable shows a graphical relation, improves the model, and is supported by scientific investigations.
[3] Number of New Jersey Pollutant Discharge Elimination System sites, Discharge Prevention & Countermeasures Plans & Discharge Clean-up & Removal Plans sites, Transfer Facilities, Resource Recovery Facilities, Class B Recycling Facilities, and Class C Compost Facilities.
[4] This conceptual variable shows a graphical relation and improves the model.

Spearman's rho, the nonparametric equivalent of a correlation coefficient, was used to evaluate linear trends between ranked variables because environmental variables rarely are normally distributed (Helsel and Hirsch, 2002). Scatter plots and boxplots of all variables in relation to the THMFP in incubated water were generated to confirm the results of statistical tests and 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. Only variables that were used in the model will be discussed.

Multivariate statistical tests were conducted on selected statistically significant and conceptual variables to narrow the list of variables to be used in the susceptibility assessment model and to determine those variables that collectively are best predictors of potential contamination of water from water-supply wells. Multivariate tests included logistic regression and principal components analysis. Variables used in the susceptibility assessment model were selected on the basis of results of summary statistics, univariate and multivariate statistical tests, and graphical procedures.

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 DBP model that assigned points to each variable used in the model for ground-water 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 graphically. 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 disinfection byproduct precursors in water from community water-supply wells

Ground Water Disinfection Byproduct Precursor Model

Disinfection Byproduct Precursor Rating:

Wells in unconfined aquifers: 0-13 MEDIUM, 14-16 HIGH

Wells in confined aquifers: 0-3 LOW, 4-7 MEDIUM, 8-10 HIGH

	Sensitivity Points- Wells in Unconfined Aquifers					**Conceptual variable**
Variable	1	2	3	4	5	
Average percent soil organic matter			> 0 - 0.99		> 0.99	Yes [1]
Hydrologic unit group [2]			All units			Yes [1]

	Intensity Points – Wells in Unconfined Aquifers					**Conceptual variable**
Variable	1	2	3	4	5	
Number of potential contaminant Sites [3]	0		> 0			No
Area of wetlands, 1995, in square miles			0 – 0.17		> 0.17	Yes [4]

	Sensitivity Points - Wells in Confined Aquifers					**Conceptual variable**
Variable	1	2	3	4	5	
Hydrologic unit group [2]	4	2 or 3			1	No
pH of water-quality sample	< 6.1		< 6.7		≥ 6.7	No

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

[2] Hydrologic Unit Group is described in table 4.

[3] Number of New Jersey Pollutant Discharge Elimination System sites, Discharge Prevention & Countermeasures Plans & Discharge Clean-up & Removal Plans sites, Transfer Facilities, Resource Recovery Facilities, Class B Recycling Facilities, and Class C Compost Facilities.

[4] This conceptual variable shows a graphical relation and improves the model.

Relation of Trihalomethane Formation Potential in Ground Water to Susceptibility Variables

Relations between concentrations of THMFP in water from CWS wells and various hydrogeologic sensitivity and potential contaminant-use intensity variables were investigated to select the variables that best predict the susceptibility of CWS wells in New Jersey to contamination by DBP precursors. Variables were selected using the THMFP concentrations in incubated water from the 60 wells in unconfined and confined aquifers.

Natural sources of organic carbon in ground water include (1) decomposing plants and other organic matter that infiltrate in recharge from soils or are carried in recharge by surface waters to ground water, and (2) altered (in some cases, fossilized) remnants of organic matter, such as lignite and kerogen, in the geologic materials that compose aquifers (Thurman, 1985). Decomposition of organic material in soil can cause more aromatic compounds to be present, and it is these compounds that represent the DOC that contributes to the formation of DBPs (Amy and others, 1990; Reckhow and others, 1990; Owen and others, 1993). Water containing high concentrations of organic compounds has a greater potential for DBP formation when chlorinated than does water with low concentrations of organic compounds. Average percent soil organic matter, a conceptual variable, was used in the model for wells in unconfined aquifers to represent the probability that water from wells with contributing areas that have greater percentages of soil organic matter may form greater concentrations of THMs than water from wells with contributing areas with smaller percentages of soil organic matter (fig. 6A).

Anthropogenic sources of organic carbon that may contribute to the formation of DBPs include septic-system effluent, animal feedlots, and composting facilities. Other sources of organic molecules that may contribute to the formation of DBPs could come from the potential contaminant sites included in the model, the number of New Jersey Pollutant Discharge Elimination System sites, Discharge Prevention & Countermeasures Plans & Discharge Clean-up & Removal Plans sites, Transfer Facilities, Resource Recovery Facilities, Class B Recycling Facilities, and Class C Compost Facilities. The number of potential contaminant sources generally is greater when THMFP concentrations are greater (fig. 6B).

The area of wetlands within the source water assessment area was selected as a conceptual variable. Organic compounds in wetlands are composed of a complex mixture of organic molecules that are the result of the natural process of decomposition and leaching of wetlands vegetation and surface detritus (Thurman, 1985). Wetland environments and the water that discharges from wetlands contain abundant amounts of DOC. New Jersey wetlands typically are ground-water discharge zones; however, under some conditions (as described by Winter and others, 1999), wetlands can contribute recharge to ground water. Recharge in wetland areas may occur as a result of the reversal of hydraulic gradients that may occur during flood events or in response to nearby ground-water pumping. During periods of recharge, wetlands may contribute organic carbon to ground water, as described by Speiran (2000). The concentrations of THMFP in water from CWS wells appeared to increase as the area of wetlands in 1995 increased for the CWS wells used to develop the DBP precursor model (figs. 6C and 6D). Although ground water recharge from wetlands is not common, using the area of wetlands as a conceptual variable improved the model. This result could be related to circumstances in which wetlands recharge ground water. Another possible explanation is that the area of wetlands may represent a surrogate for other unidentified variables that affect the concentration of DBP precursors in ground water.

Sources of DBP precursors can be related to both natural and human-induced constituents—these processes include biological degradation of organic matter, mineral dissolution and precipitation, ion exchange, oxidation-reduction reactions, adsorption and desorption of solutes, and generation/coagulation of colloids. NJGS hydrologic unit designations for wells were grouped by geology to create the hydrologic unit groups used in this model. Hydrologic unit group was found to be an important predictor for formation of THMs in water from wells finished in confined aquifers because the aquifer material is a source of DBP precursors (table 4 and fig. 7A). No statistical difference was found among hydrologic unit groups relative to concentrations of THMFP in water from wells finished in unconfined aquifers.

Table 4. Description of Hydrologic Unit Group and the contribution to the sensitivity of the water to DBPs

Confined or unconfined	Hydrologic unit group	Hydrologic unit name	Sensitivity
Confined	1	Atlantic City 800-foot sand aquifer	High
		Kirkwood-Cohansey aquifer system	
Confined	2	Englishtown aquifer system	Medium
		Mount Laurel-Wenonah aquifer	
Confined	3	Upper Potomac-Raritan-Magothy aquifer	
Confined	4	Middle Potomac-Raritan-Magothy aquifer	Low
Unconfined	All groups	All groups	Medium

Concentrations of THMFP in source water from confined aquifers exceeded one-tenth and sometimes one-half of the MCL when the source water pH was greater than 7.2 pH units; concentrations generally increased with increasing pH (fig. 7B). This relation is not well understood because water samples were adjusted to a pH of 7 prior to incubation. The pH of source water may represent a surrogate for other unidentified variables that affect the concentration of DBP precursors in ground water.

Of the 2,237 community wells for which susceptibility ratings were developed, 641 are finished in confined aquifers. The susceptibility ratings for DBPs in water from wells in confined aquifers are influenced by the sensitivity variables of the model because the sources of organic carbon are naturally occurring. The susceptibility ratings for DBPs in water from wells in unconfined aquifers are influenced by both the sensitivity and intensity variables of the model because the sources of organic carbon in unconfined aquifers can be both naturally occurring and anthropogenic. The quality of the water provided by wells finished in unconfined aquifers can be affected by contaminants introduced by human activities at or near the land surface. Confined aquifers, which can contain water that entered as recharge hundreds to thousands of years ago, are less vulnerable to this type of contamination. Water in both aquifer types can be affected by naturally occurring precursors released by the aquifer materials, however.

Although THMs were detected in source water from 20 of the 60 wells sampled, most concentrations were small—total THM concentration exceeded one-tenth the MCL in water from a well in unconfined Coastal Plain aquifers, 38.4 µg/L (fig. 4). THMs were not detected in source water from the wells used for development that were finished in confined aquifers. Consequently, in most cases, the THMFP reflects all or nearly all of the THMs measured following incubation of the chlorinated water samples. The concentrations of the total THMs measured after the 7-day incubation of the treated water samples varied by more than two orders of magnitude, depending in part on the initial concentration in the source water, but mostly on the chemical characteristics of the ground water, which are derived, in part, from characteristics and materials inherent to the aquifer from which the water was drawn (fig. 5). In general, higher concentrations of THMs tended to form in incubated water from wells in Coastal Plain aquifers than in water from the other aquifers from which samples were collected. Incubated water samples from 11 wells, 5 from unconfined Coastal Plain aquifers, 5 from confined Coastal Plain aquifers, and 1 from a Piedmont Physiographic Province aquifer contained total THMs at concentrations that exceeded one-half of the MCL. Incubated water from two of the wells in unconfined Coastal Plain aquifers contained total THMs at concentrations that exceeded the MCL.

The variables selected to estimate sensitivity in water from CWS wells in unconfined aquifers to contamination by DBP precursors are the hydrologic unit group and average percent soil organic matter. Both variables are conceptual. The variables selected to estimate intensity in water from CWS wells in unconfined aquifers to contamination by DBP precursors are area of wetland lands in 1995, a conceptual variable, and the number of potential contaminant sites. Potential contaminant sites in this model include the following: the number of New Jersey Pollutant Discharge Elimination System sites, Discharge Prevention & Countermeasures Plans & Discharge Clean-up & Removal Plans sites, Transfer Facilities, Resource Recovery Facilities, Class B Recycling Facilities, and Class C Compost Facilities. The variables selected to estimate sensitivity of water from wells in confined aquifers are the hydrologic unit group and the pH of water-quality samples. No intensity variables were selected for wells in confined aquifers because the water in confined aquifers typically is not susceptible to contamination from the land surface.

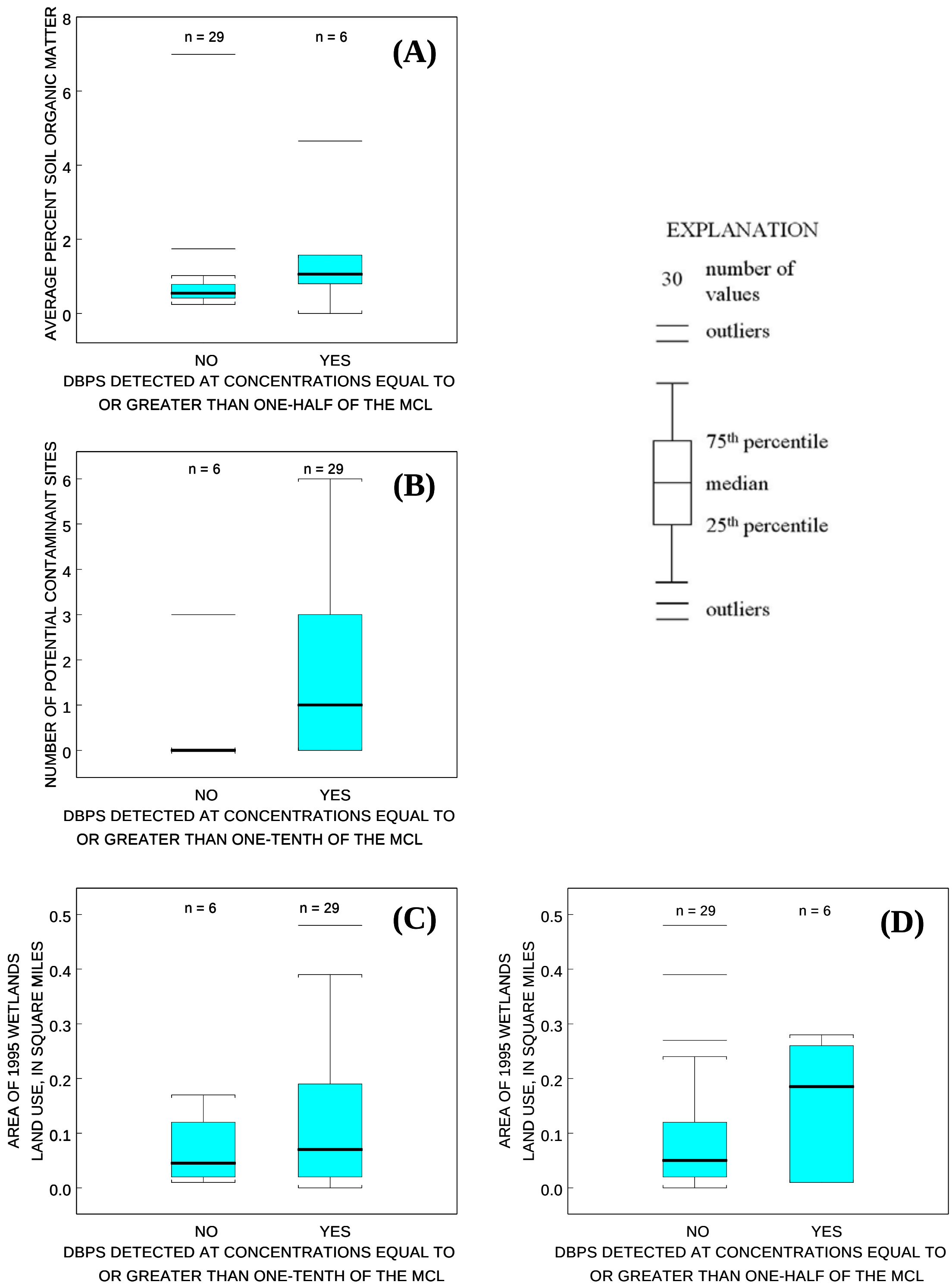

Figure 6. Distribution of THMFP concentration in incubated water from wells in unconfined aquifers to (A) average percent soil organic matter relative to one-half the MCL; (B) number of potential contaminant sites relative to one-tenth the MCL; and (C) area of wetland land use, 1995, relative to one-tenth the MCL; and (D) area of wetland land use, 1995, relative to one-half the MCL. [MCL = maximum contaminant level]

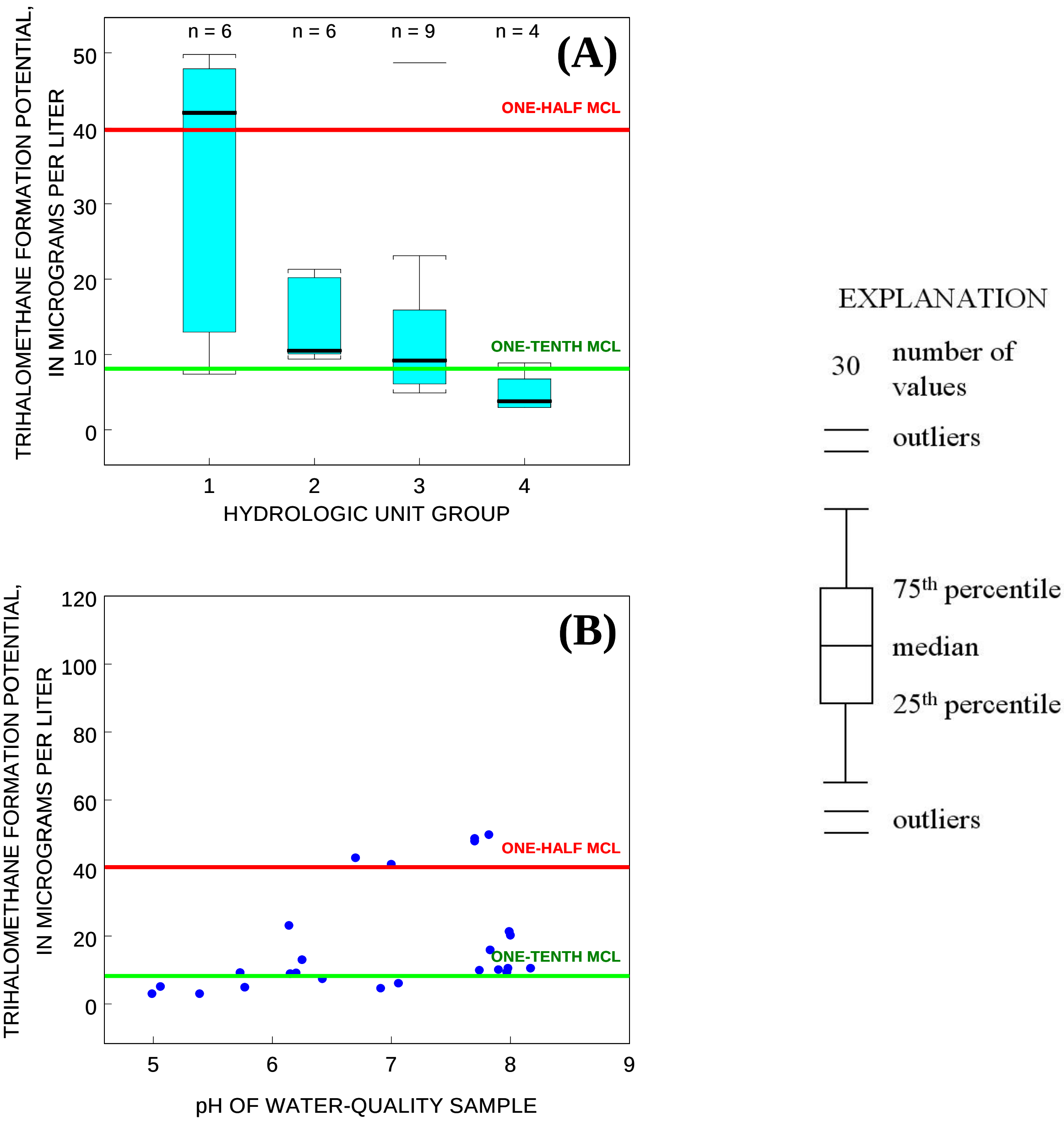

Figure 7. Distribution of THMFP concentration in incubated water from wells in confined aquifers to (A) hydrologic unit group, and relation of THMFP concentration to (B) pH of water-quality sample. [Hydrologic unit group: 1 - Atlantic City 800-foot sand aquifer and Kirkwood-Cohansey aquifer system, 2 - Englishtown aquifer system and Mount Laurel-Wenonah aquifer, 3 - Upper Potomac-Raritan-Magothy aquifer, and 4 - Middle Potomac-Raritan-Magothy aquifer]

Susceptibility of Ground-Water Sources

The results of the susceptibility assessment model indicate that as intensity and sensitivity increase, the concentrations of DBPs increase (fig. 8). Of the CWS wells used for model development, the susceptibility to contamination by DBP precursors was low for 8 percent, medium for 69 percent, and high for 23 percent of the wells. The rating scheme created during model development was applied to the sensitivity and intensity variables of the 2,237 CWS wells for which the susceptibility was to be determined. The susceptibility to contamination by DBP precursors was low for 37 (2 %), medium for 1717 (76 %), and high for 486 (22 %) of the CWS wells (figs. 1 and 2; table 5).

Table 5. Number of community water-supply wells in New Jersey with low, medium, and high susceptibility to contamination by disinfection byproduct precursors, by aquifer type

Confined or unconfined	Susceptibility rating	Number of CWS wells
Confined	LOW	37
	MEDIUM	433
	HIGH	171
Unconfined	MEDIUM	1,281
	HIGH	315

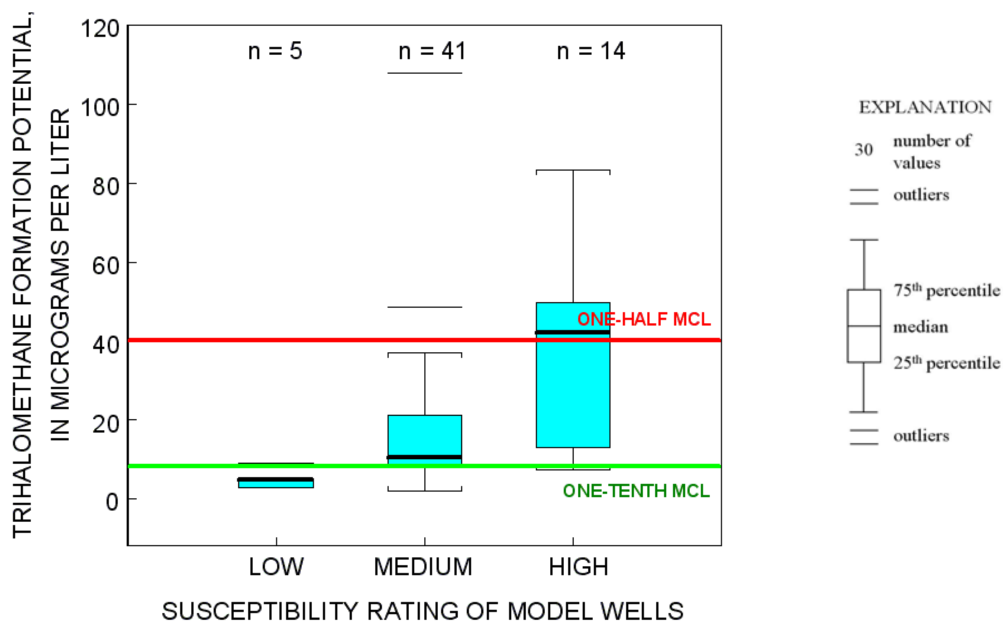

Figure 8. Results of disinfection byproduct precursor susceptibility assessment model for 60 community water-supply wells in New Jersey showing distribution of THMFP concentration by susceptibility rating. [MCL = maximum contaminant level]

Model Verification

NJDEP Bureau of Safe Drinking Water (BSDW) total THM data for 2001-02 were used to verify the DBP precursor susceptibility model. Total THM concentrations were calculated as a running average of quarterly samples collected from 108 single-source distribution systems. Low susceptibility wells were not compared; only three single-source systems with BSDW data were rated as having low susceptibility. As predicted, median concentrations of medium susceptibility wells were less than median concentrations of high susceptibility wells, indicating the viability of the model (fig. 9). Differences between data used to develop the model and data used to verify the model may explain differences in predicted susceptibility and actual system concentrations. The model well data are from single samples incubated in a laboratory for 7 days, and the verification data are a running average of quarterly samples, disinfected at the system; time and condition in the distribution system before analysis are unknown. Water temperature, pH, amount of free chlorine, and residence time and conditions in distribution system have an affect on the rate of formation of DBPs. Each affects the formation of DBPs differently, but total THMs generally increase with higher pH and over time (Chen and Weisel, 1998).

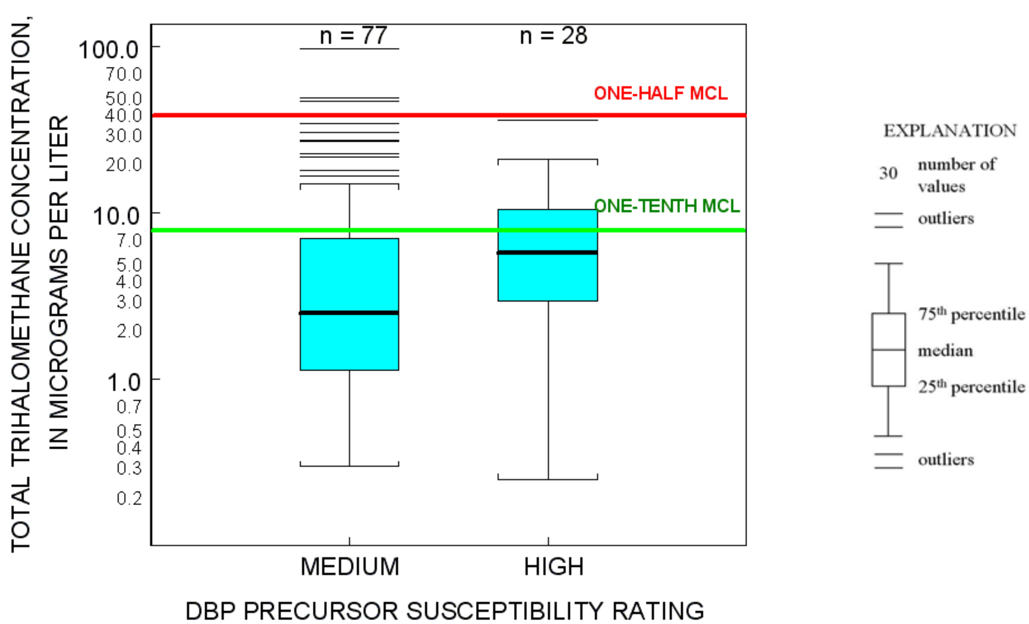

Figure 9. Distribution of Bureau of Safe Drinking Water concentration data for total trihalomethanes in water from CWS wells, by DBP precursor susceptibility rating.

Discussion

Several limitations to the susceptibility assessment model should be noted. The model should be used only as screening tools to identify potential contamination problems. The concentrations used for a well in the analysis were those measured in the most recently analyzed sample 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 may bias statistical results, and land-use changes may cause spurious relations. The method used to determine source water assessment areas and tiers representing times of travel of water to the well is inexact and produces only estimates of the actual contributing area and the length of time the water is in transit before it reaches the well.

Results of statistics performed on THMFP, relative to the threshold of concentrations of concern of the NJDEP, might differ if performed on other DPBs. 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.

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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