PLAN TO EVALUATE THE EFFECTS OF HYDROGEOLOGIC CONDITIONS AND HUMAN ACTIVITIES ON WATER QUALITY IN THE COASTAL PLAIN OF NEW YORK AND NEW JERSEY

By Eric F. Vowinkel and Steven F. Siwiec

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Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre	0.4047	hectare
gallon (gal)	3.785	liter
ton	0.9072	metric ton

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ABSTRACT

The U.S. Geological Survey has developed a plan of study to characterize, quantify, and improve the understanding of the influence of human activities on ground- and surface-water quality in urban, suburban, and agricultural land-use areas in the Atlantic Coastal Plain of New York and New Jersey. The Coastal Plain of New York and New Jersey has been chosen for this study because it contains among the most densely populated urban and suburban land in the United States interspersed with agricultural and undeveloped land. The unconsolidated sediments underlying the Coastal Plain of New York and New Jersey have been designated as sole-source aquifers--more than 5 million people in this area rely on ground water as their source of drinking water.

The plan describes three major research objectives and associated research topics. The major objectives of this regional study are to (1) quantify the sources of contamination at a level of detail appropriate for a regional study, (2) develop an understanding of the movement of nonreactive and reactive chemical constituents along regional flow paths, and (3) improve methods for regional water-quality-data collection and interpretation. Water-quality constituents to be studied include nutrients, volatile organic compounds, pesticides, and trace elements.

Seven research topics, which would address the objectives listed above, include (1) evaluation of the transferability of the land-use methods and statistical results which were developed to quantify the relation between shallow ground-water quality and human activities to other areas of similar hydrogeology, climate, and land use; (2) assessment of the effects of spatial and temporal variability of water-quality, land-use, and hydrogeologic data on the relation between land use and a particular ground-water quality constituent; (3) evaluation of the effect of using various methods to estimate the area contributing water to a well when quantifying human activities on the statistical relation between land use and a water-quality constituent; (4) a test of the usefulness of additional hydrogeologic and human-activity variables for quantifying the relation between shallow ground-water quality and human activities; (5) assessment of the relation between the extent of contamination resulting from human activities and regional patterns of ground-water flow; (6) evaluation of the relation between surface-water quality and human activities and quantify the contribution of ground-water constituents to surface-water contamination; and (7) a determination of methods for improving the efficiency of sampling for regional water-quality investigations by using available hydrogeologic data.

INTRODUCTION

Contamination of ground and surface water by human activities is a major environmental problem facing the Nation today. For example, in 1985, estimated annual discharge of wastes from 22 million septic systems to the Nation's shallowest aquifers was 820 to 1,460 billion gallons. In addition, more than 42 million tons of fertilizers are applied annually to more than 360 million acres of agricultural land nationwide (U.S. Geological Survey, 1985, p. 140). As a result of these and other human activities that introduce nitrogen into the hydrologic system, more than 20 percent of nearly 124,000 wells studied nationwide contain water with concentrations of dissolved nitrate greater than 3.0 mg/L (milligrams per liter). About 6 percent of these wells contain water with nitrate concentrations greater than 10.0 mg/L (U.S. Geological Survey, 1988, p. 95), the Federal and State maximum contaminant level (U.S. Environmental Protection Agency, 1986). These estimates of ground-water contamination by nitrates can be misleading, however, because they identify neither the types and parts of aquifers that are most susceptible to contamination, nor the land uses that are associated most frequently with nitrate contamination.

Contamination of ground and surface water can be derived from point and nonpoint sources. Point sources of contamination are localized areas, generally a few acres or smaller in size. Common point sources include injection wells, landfills, pipelines, leaky storage tanks, and surface impoundments. Nonpoint sources of contamination are broad geographic areas, ranging from a few acres to tens or hundreds of square miles. Examples of nonpoint sources include agricultural and residential land to which fertilizers and pesticides are applied, mining areas, animal feedlots, and roadways on which deicing salts are applied. Multiple point sources, such as on-site septic systems in residential areas and leaky underground storage tanks in industrial areas, can be considered nonpoint sources of contamination.

In addition to the size of the geographic areas from which they originate, point and nonpoint sources differ with respect to the volume of water they affect and the resulting constituent concentrations. Point sources generally affect small volumes of water. A plume of contaminated ground water can be hundreds to thousands of feet in length and tens to hundreds of feet wide. Concentrations of contaminants that originate from a point source often are several orders of magnitude greater than those in ambient water. Contamination from nonpoint sources typically affects large volumes of water at low concentrations. Contaminant loads from point sources generally can be measured or estimated more easily than loads from nonpoint sources.

Because of the dynamic and heterogeneous nature of the hydrogeologic system and the spatial and temporal variability of contaminant sources resulting from human activities, the association of a particular constituent in the ground-water flow system with a specific source at a regional scale is difficult. Human activities such as land use and population density can be used as a surrogate measure of nonpoint and point sources of contamination.

The Coastal Plain of New York and New Jersey (fig. 1) was selected for intensive study for several reasons. Considerable research on ground-water qyality has been conducted in both States as part of the U.S. Geological Survey's Toxic Substances Hydrology Program. The area includes a complex combination of urban, suburban, and agricultural land uses and a wide range of population densities that generate a variety of contamination sources. These land-use and contaminant-source patterns are typical of large metropolitan areas in the coastal regions of the United States. The hydrogeologic framework and flow systems in both areas are well defined. The area is suitable for consideration as a single study unit because aquifer characteristics and climatic conditions are similar. Long-term water-quality data are available--more than 30 years for some inorganic constituents and more than 10 years for some organic compounds. The density of observation and production wells is high throughout much of the Coastal Plain, providing a network from which to collect water-quality data. Finally, the sediments underlying the Coastal Plain in both New York and New Jersey have been designated as sole-source aquifers by the U.S. Environmental Protection Agency; therefore, protection of the aquifer from contamination is critical.

This research will be conducted by the U.S. Geological Survey (USGS), through its Toxic Substances Hydrology Program, in cooperation with the U.S. Environmental Protection Agency (USEPA), Office of Research and Development. Research will be conducted by a multidisciplinary team of scientists from District Offices and the National Research Program of the USGS Water Resources Division and the USEPA Office of Research and Development. In addition, researchers from other Federal, State and local agencies, and universities are expected to participate in related research.

Purpose and Scope

This report presents the plans for conducting a study that will characterize, quantify, and improve the understanding of the influence of human activities on ground- and surface-water quality in the Coastal Plain of New York and New Jersey. The research objectives of the planned study are described, and research needs are identified. The research needs are designed to provide a framework within which to initiate research.

Objectives of the Study

The major objectives of this regional study are to (1) quantify the sources of contamination at a level of detail appropriate for a regional study, (2) develop an understanding of the movement of nonreactive and reactive chemical constituents along regional flow paths, and (3) improve methods for regional water-quality-data collection and interpretation. Water-quality constituents to be studied include nutrients, volatile organic compounds, pesticide residues, and trace elements.

Seven research topics, which would address the objectives listed above, include (1) evaluation of the transferability of the land-use methods, which were developed to quantify the relation between shallow ground-water quality and human activities, to other areas of similar hydrogeology, climate, and land use; (2) assessment of the effects of spatial and temporal variability of water-quality, land-use, and hydrogeologic data on these methods; (3) evaluation of the effect of using various methods to estimate the area

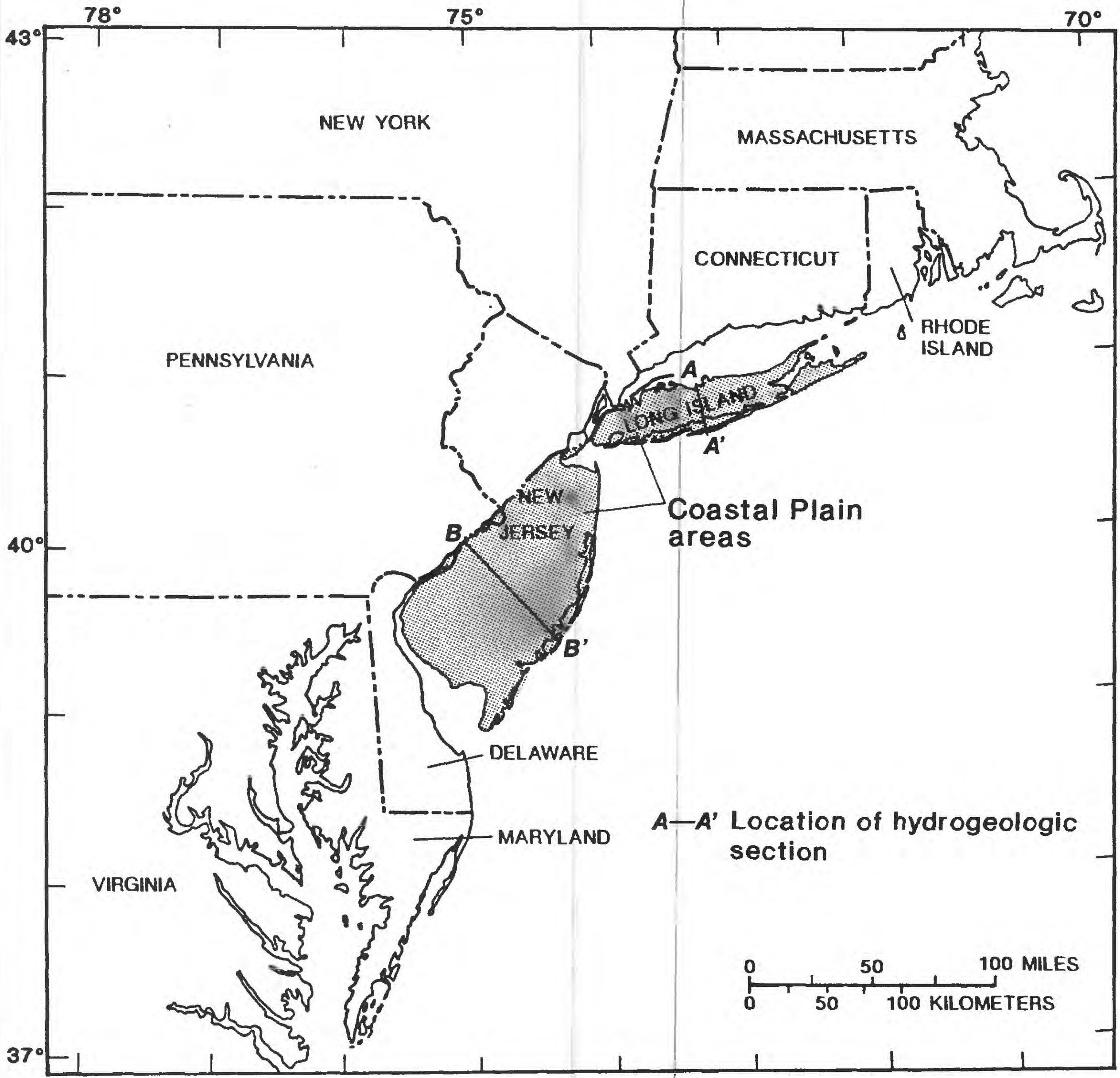


Figure 1.--The Coastal Plain of New York and New Jersey.

contributing water to a shallow well when quantifying human activities on the statistical relation between land use and a water-quality constituent; (4) a test of the usefulness of additional hydrogeologic and human-activity variables for quantifying the relation between shallow ground-water quality and human activities; (5) assessment of the relation between the extent of contamination resulting from human activities and regional patterns of ground-water flow; (6) evaluation of the relation between surface-water quality and human activities and quantify the contribution of ground-water constituents to surface-water contamination; and (7) determination of methods for improving the efficiency of sampling for regional water-quality investigations by using available hydrogeologic data.

Methods developed as part of this research will be useful in the interpretation of the influence of human activities on water quality in other regional investigations, such as the U.S. Geological Survey's National Water Quality Assessment Program (NAWQA). The information gained from this research will be useful for regulatory agencies as they establish management priorities and may provide the basis for developing new management tools to help prevent or mitigate potential adverse effects of human activities on water quality. These tools can be used by State and local government agencies for the design and implementation of wellhead-protection programs, agricultural land-use best-management practices, and other strategies to protect the Nation's potable-water supply from contamination.

Acknowledgments

This plan of study was developed in cooperation with the U.S. Environmental Protection Agency. Hydrologists from the USEPA's Robert S. Kerr, Environmental Research Laboratory in Ada, Oklahoma, and Office of Ground Water Protection in Washington, D.C., provided insight on research needs related to nonpoint-source contamination of ground and surface water.

PREVIOUS INVESTIGATIONS

Considerable research has been conducted on point sources of contamination and the transport and fate of chemicals from these sources in the hydrogeologic system. Until recently, however, data on the effects of contamination of water from nonpoint sources have been sparse. In 1984, the USGS began preliminary regional appraisals of shallow ground-water quality in 14 areas of the United States as part of the Toxic Substances Hydrology Program (Helsel and Ragone, 1984, p. 1).

Results of 6 of the 14 studies demonstrated a relation between the quality of shallow ground water and human activities. In a paper summarizing the preliminary results of these six studies, Cain and others (1989) report that the frequency of detection of volatile organic compounds (VOC's) in shallow ground water from the upper glacial aquifer on Long Island, New York (Eckhardt and others, 1989a), and from the Potomac-Raritan-Magothy aquifer system in New Jersey (Barton and others, 1987), was significantly higher in urban and industrial areas than in less developed areas. Similar patterns were observed in ground water from stratified-drift aquifers in western Connecticut (Grady and Weaver, 1988) and in the surficial and Upper Floridan aquifers in central Florida (Rutledge, 1987); however, statistical significance could not be established in these two study areas because of insufficient data. In the High Plains aquifer of Nebraska, concentrations of nitrate and the detection frequencies of triazine herbicides were significantly higher in ground water from intensively irrigated agricultural areas than in ground water from less intensively irrigated areas (Chen and Druliner, 1987). Ground-water quality in the Fountain Creek alluvial aquifer in Colorado was found to be affected to a greater extent by ground-water withdrawals and consumptive ground-water use than by land use (Cain and Edelmann, 1986).

The results of these reconnaissance studies provided the basis for the experimental phase of research in these six areas. In each area, a conceptual model was developed to determine the predominant factors affecting ground-water quality, and hypotheses were formulated to test the validity of the conceptual models. Additional ground-water-quality, hydrogeologic, and human-activity data were collected, and experiments were designed to test each hypothesis statistically. The hydrogeologic and human-activity data provided a means of stratifying data sets prior to statistical analysis. These experimental-phase studies, initiated in 1987, are nearing completion. A summary of the findings of the New York and New Jersey studies is provided here as an indication of current knowledge and a description of the foundation from which further research can proceed.

The primary objective of the experimental-phase studies in New York and New Jersey was to determine whether statistically significant relations exist between shallow ground-water quality and land use. Although the two studies had a common objective, they were conducted independently. Each study was limited by the availability, types, and sources of ground-water-quality and land-use data in each area. Where considerable data were available, much information was discarded to ensure a sample in which statistical and other biases were minimized (Vowinkel and Battaglin, 1989a; Barringer and others, 1990). Because the design of each study was adapted to these limitations, the approaches and methods used in each study were different.

Preliminary results of the Long Island, New York (fig. 2A), study are reported by Eckhardt and others (1989b). Water-quality data from 90 shallow wells screened in the upper glacial aquifer in 5 study areas located in ground-water-recharge areas along the regional ground-water divide of Long Island were compared to assess the effects of human activities on ground-water quality. Each of the five study areas is characterized by a unique land use, which included (1) a highly suburbanized area which has been sewered for more than 22 years; (2) a highly suburbanized area that has been sewered for less than 8 years; (3) a moderately suburbanized, unsewered area; (4) an agricultural area; and (5) an undeveloped area. Statistical procedures used in this study included exploratory data analysis, nonparametric procedures, contingency-table analysis, and logistic regression.

The major findings of the New York study were that concentrations of nitrate and most inorganic constituents in shallow ground water were lowest and least variable in samples from the undeveloped area and highest and most variable in samples from the agricultural area. Inorganic trace elements in ground water were detected infrequently in all five study areas, with the

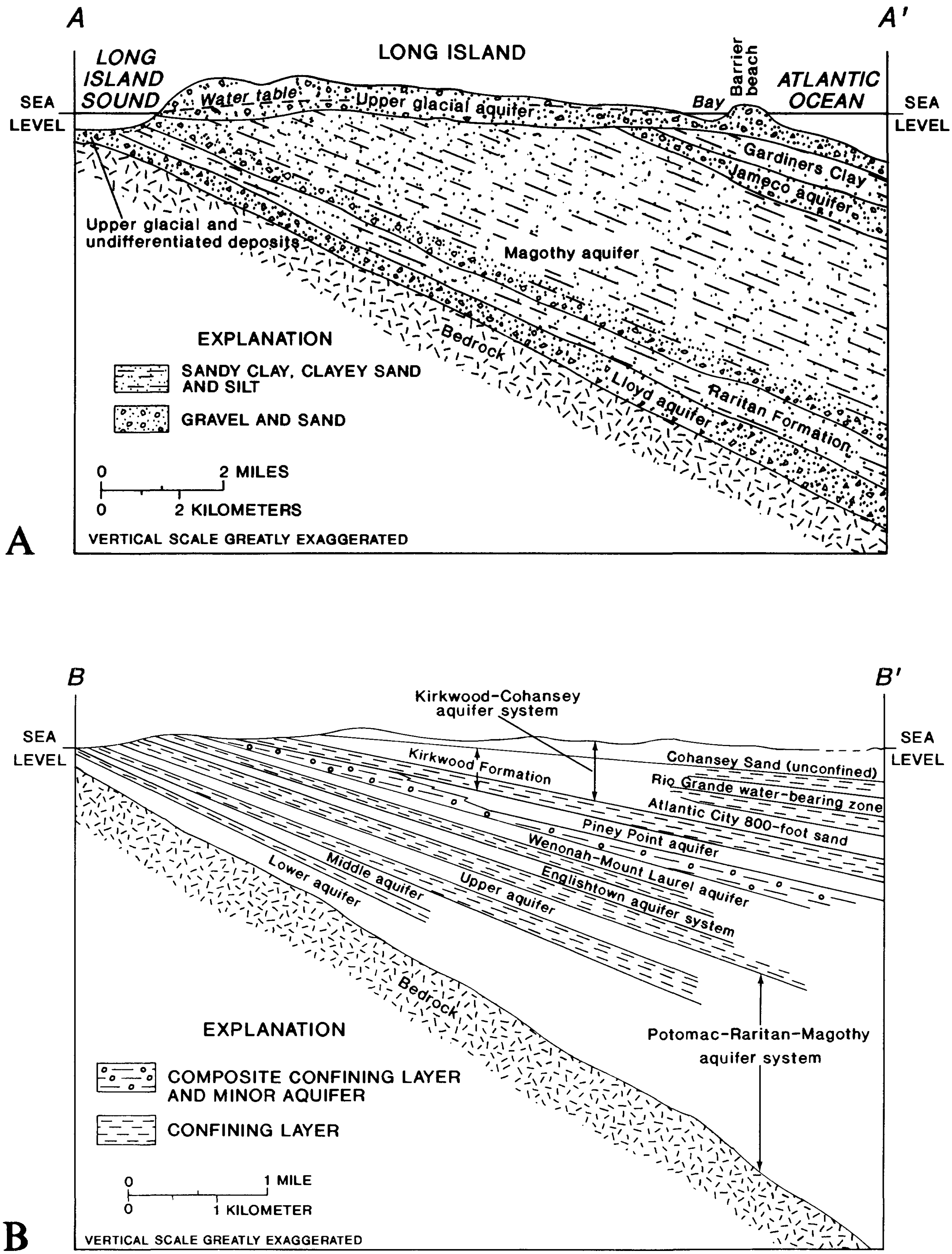


Figure 2.--Generalized hydrogeologic sections showing principal aquifers in (A) Long Island, New York (from McClymonds and Franke, 1972), and (B) the New Jersey Coastal Plain (from Eckel and Walker, 1986).

exception of boron, which was detected most frequently and at the highest concentrations in ground water in agricultural areas and in the two highly suburbanized, sewered areas. Boron is a constituent of some laundry soaps and row-crop fertilizers.

Results of contingency-table analyses indicated statistically significant differences in the frequency of detection of VOC's among the five study areas. VOC's were detected in all three suburban areas, but not in the agricultural or undeveloped area. The frequency of detection of VOC's was related to population density; the highest detection frequency was in areas of 6 to 8 people per acre, and the lowest frequency was in areas of fewer than 6 people per acre. Carbamate insecticide residues were detected almost exclusively in the agricultural area, whereas organochlorine insecticide residues were detected most frequently in the two sewered, suburban areas.

Logistic-regression analysis was used in the New York study to predict the probability of VOC detection in shallow ground water as a function of population and land use. A geographic information system (GIS) was used to compute values of population density and percentages of each land-use category within an 800-meter-radius (1/2-mi-radius) buffer area centered on each of the 90 sampled wells. These variables then were regressed in a stepwise manner on the binary-response variable, the detection or nondetection of any VOC at each well. Two separate logistic-regression equations with statistically significant (alpha < 0.01) slopes were obtained: a single-variable model with population density as the explanatory variable, and a two-variable model with percentage of residential land and percentage of commercial/industrial land as the explanatory variables.

In the New Jersey study area (fig. 2B), the relation of ground-water quality to land use was evaluated by using data from the Potomac-Raritan-Magothy aquifer system and the Kirkwood-Cohansey aquifer system. The water-quality data base was expanded to include 616 wells screened in unconfined and confined parts of the Potomac-Raritan-Magothy aquifer system and 350 wells screened in the unconfined parts of the Kirkwood-Cohansey aquifer system. Methods were developed to stratify the data sets to make them homogeneous and to minimize statistical problems such as spatial autocorrelation (Barringer and others, 1990).

Data compiled for 616 wells screened in the Potomac-Raritan-Magothy aquifer system in the New Jersey Coastal Plain were used to evaluate the presence of VOC's in ground water and their relation to selected hydrogeologic conditions, well-construction characteristics, and land use (Vowinkel and Battaglin, 1989a). The 616-well sample was stratified into two subsamples; a set of 369 wells located in the outcrop area and a set of 247 wells located downdip from the outcrop. Water from wells located in the outcrop area was assumed to have recently recharged the aquifer, whereas water from wells located downdip of the outcrop area was assumed to be too old to have been affected by human activities. VOC's were detected in water from 96 of 369 wells (26 percent) in the outcrop area. Water from only 12 of 247 wells (5 percent) downdip from the outcrop contained VOC's (Vowinkel and Battaglin, 1989a).

The 369 wells in the outcrop area were stratified further. Water-quality data from a stratified subsample of 98 wells screened in the outcrop area of the Potomac-Raritan-Magothy aquifer system were used to statistically compare water quality and land use (Vowinkel and Battaglin, 1989b). The criteria used to select wells in the subsample were distance between wells and well depth. A minimum distance of 1,600 meters between wells was chosen to minimize statistical problems of autocorrelation and double accounting of land uses. Three methods of quantifying land use near a well were explored: (1) the predominant method, in which the predominant land use within a specified radius of each well was assigned to that well; (2) the presence-or-absence method, in which land use was treated as a binary variable determined by its presence or absence within a specified radius of each well; and (3) the percentage method, in which the percentage of each land use within a specified radius of each well was assigned to that well. For each of these methods, land-use percentages for seven buffer-zone sizes were calculated for each well at radii of 1, 100, 250, 400, 600, 800, and 1,000 meters. The objective of using several buffer-zone sizes was to determine which radius provided the most statistically significant relation between a given water-quality constituent and land use.

Nonparametric procedures were used to test for statistically significant (alpha = 0.05) relations between water quality and land use. Statistical tests indicate that concentrations of nitrate are significantly higher in ground water beneath agricultural and urban land than in ground water beneath undeveloped land for both the Potomac-Raritan-Magothy and Kirkwood-Cohansey aquifer systems. The detection frequency of VOC's is significantly higher in water from wells in urban land than in water from wells in agricultural areas. For all comparisons, statistically significant relations were not obtained for all three methods or at all seven radii used to calculate land-use variables. These findings indicate that both the method of characterizing land use at wells and the radial area within which land-use variables are calculated influence the statistical results. In most cases, the relation between the water-quality constituent and land use was most significant at radii of 600 and 800 meters.

Water samples were collected from 81 wells in 7 counties during the summers of 1986 and 1987 to determine whether agricultural chemicals, including pesticides and nutrients, are present in ground water beneath the outcrop areas of the Potomac-Raritan-Magothy and Kirkwood-Cohansey aquifer systems in New Jersey (Louis and Vowinkel, 1989). The samples were analyzed for triazine and acetanilide herbicides, and carbamate, organochlorine, and organophosphorus insecticides. Pesticide residues were detected in water from 33 percent of the 81 wells. Residues of 21 pesticides and 3 pesticide metabolites were detected in concentrations ranging from 0.01 to 13 μg/L (micrograms per liter). The most frequently detected pesticides were carbofuran, atrazine, alachlor and the metabolites of aldicarb. The median dissolved-nitrate concentration was 5.1 mg/L, and nitrate exceeded 10 mg/L in water from 32 percent of the wells.

The results of these studies in New York and New Jersey indicate that statistically significant relations exist between shallow ground-water quality and human activities, and that the findings were similar in the New York and New Jersey study areas. In both study areas, nitrate concentrations in ground water were highest in agricultural areas and lowest in undeveloped areas. VOC's were detected most frequently in ground water beneath urban land, especially in industrial and commercial areas. Pesticides were detected most frequently in agricultural areas. In both study areas, trace elements such as lead, chromium, or cadmium were detected infrequently in ground water and the detection frequency of most trace metals did not differ significantly among land-use areas.

RESEARCH PLAN

On the basis of results of the previous investigations, seven research topics that need further investigation have been identified:

(1) Evaluation of the transferability of the land-use methods and statistical results used to quantify the relation between shallow ground-water quality and human activities to other areas of similar hydrogeology, climate, and land-use.

(2) Assessment of the effects of spatial and temporal variability of land-use and water-quality data on these land-use methods and statistical results;

(3) Evaluation of the effect of using various methods to estimate the area contributing water to a shallow well in quantifying human activities near a well on the statistical relation between a water-quality constituent and land use;

(4) Testing of the use of additional hydrogeologic and human-activity variables for quantifying the relation between shallow ground-water quality and human activities;

(5) Assessment of the relation between the extent of contamination resulting from human activities and regional patterns of ground-water flow;

(6) Evaluation of the relation between surface-water quality and human activities and quantify the contribution of ground-water constituents to surface-water contamination; and

(7) Determination of methods for improving the efficiency of sampling for regional water-quality investigations by using available hydrogeologic data.

In the following sections, each research topic is introduced with a statement of the problem. The background section that follows each problem statement focuses on the relations among each research topic, previous studies, and the other research components. A generalized approach for addressing each problem is presented to provide a foundation for initiating research activities.

Transferability of Land-Use Methods

Problem

Several methods were developed independently as part of previous studies in the New York and New Jersey study areas to test the relation between shallow ground-water quality and human activities. In some cases, the results of hypothesis testing in each study area appear to be similar. Additional investigation is needed to determine the ability of each method to reproduce results within the original study area and to determine the transferability of each method to other areas with similar land use, hydrogeology, and climate.

Background

Verification of the statistical results from a method used to quantify the relation between shallow ground-water quality and human activities provides a test of the transfer value of the method to other areas of similar land use in the same hydrogeologic and climatic setting. The verification procedure includes the "comparison of data collected in one area to those from other areas to determine whether inferences about those factors affecting ground-water quality can be extrapolated beyond the original study area" (Helsel and Ragone, 1984, p. 5).

Three methods were developed to assign a land-use class to the area surrounding a well--the predominant, the presence-or-absence, and the land-use percentage methods. Nonparametric statistical procedures were used to test hypotheses about the relation between a particular ground-water constituent and land use. Logistic regression was used to predict the probability of the presence of a contaminant based on land-use percentages or population density within the circular buffer zones surrounding a well.

In certain cases, one method might be more appropriate for quantifying land use than the others. In the New Jersey study area, the predominant-land-use method was inadequate when testing the relation between VOC's and industrial land use because industrial land use was rarely the predominant land use within an 800-meter circular buffer zone. The presence-or-absence and land-use-percentage methods were more useful than the predominant method in the New Jersey study area because industrial areas are small in comparison to other land uses.

Direct comparison of the results from the New York and New Jersey study areas is inappropriate because the procedures used to select sites to test hypotheses were different in each study area. Well depths and types of wells used in each study area also differed. In some cases, different analytical laboratories and detection limits were used. These inconsistencies need to be considered prior to comparing results between the two areas. Additional data collection in each study area may be necessary to make meaningful comparisons between study areas.

The following example illustrates the problems that need to be considered before the results from the two study areas can be compared. The land-use percentage method was used to determine whether the presence of VOC's in water from wells is independent of the percentage of industrial and commercial land within 800-meter-radius buffer zones of wells (fig. 3). In both study areas, the percentage of industrial and commercial land is significantly greater (alpha ≤ 0.05) near wells in which VOC's were detected than the percentage of industrial and commercial land near wells in which VOC's were not detected.

Although the same source of land-use data and the same buffer-zone radius were used in the two studies to characterize land use near a well, the method of selecting wells differed. The wells used for statistical analyses in the New York study were exclusively observation wells which were selected randomly by use of a grid system. The wells used in the New Jersey study were mostly withdrawal wells selected to provide a minimum separation distance between wells. The screened intervals of wells used in the New Jersey study were deeper than those of wells used in the New York study. Different analytical laboratories were used to analyze samples, and the reported minimum detection limits were different between the two studies. These differences in methods may affect the interpretation of the data sets in the two areas.

Approach

The predominant, presence-or-absence, and land-use-percentage methods will be tested consistently by using data from both study areas to determine the conditions and constituents for which each method is most appropriate. The verification procedure will include a test of the ability of each method to reproduce results within the original study area and a test of the transferability of the method to other study areas.

The ability of each method to reproduce results within the original study area will be evaluated first. Collection of additional hydrogeologic and water-quality data in areas where none currently are available will be necessary in some cases. To further test the ability of the method to reproduce results, predicted concentrations of water-quality constituents will be compared with field data in areas for which no information previously was available. In those areas where water-quality data are lacking, samples will be collected and analyzed. The analytical results will be compared with the expected values to determine the reliability of the land-use method to predict water quality.

The next step is to compare the results between the two study areas. Identical procedures will be used to develop the data sets for hypothesis testing in the New York and New Jersey study areas. The data sets will be selected to ensure that hydrogeologic conditions, well-construction characteristics, sources of land-use data, methods of characterizing land use at a well, laboratory methods, detection limits for each water-quality constituent, and well-selection criteria are consistent between the areas being compared.

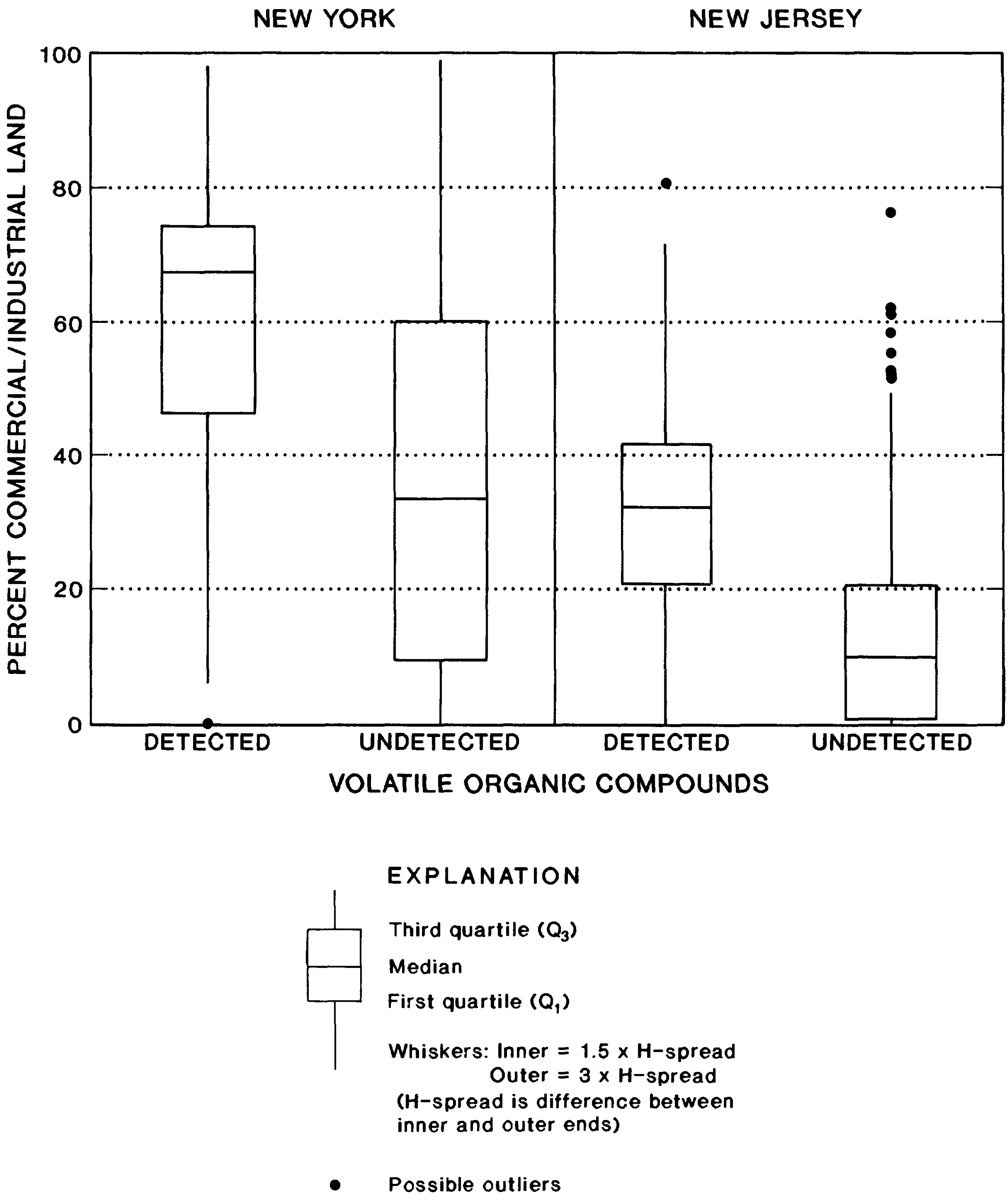


Figure 3.--Boxplots showing the percentage of industrial land within 800-meter-radius buffer zones of wells and the presence of volatile organic compounds in the New York and New Jersey study areas.

Effects of Spatial and Temporal Variability of Data on Statistical Results

Problem

Preliminary results indicate that statistical relations between shallow ground-water quality and human activities depend on the scale of the land-use data. The methods need to be tested in study areas of various sizes to determine whether these methods produce consistent results at regional and local scales. In addition, little is known about the effects of seasonal and long-term variability of water quality and human activities on the relation between a ground-water constituent and land use.

Background

Water-quality conditions, as do human activities, vary in space and time. In water-quality investigations, problems of spatial variations can result from the distribution of, and variations in hydrogeologic conditions, human activities, and water quality with respect to study-area size and map resolution. Temporal variations can result from either seasonal trends in water quality or changes in land use and water quality over time.

Water-quality investigations can be conducted at regional, local, or site-specific scales. Regional water-quality studies can cover areas ranging in size from hundreds to thousands of square miles; they provide a general evaluation of the water-quality conditions at the multi-county, state, or multi-state level. Local studies can focus on water-quality problems at the county or township level. Site-specific studies generally focus on known contamination sites in order to determine the mass balance of contaminants within the hydrogeologic system. Most of the previous research in the New York and New Jersey study areas has been conducted at the regional scale in areas comprising more than 1,000 mi^2 (square miles). More research is needed to determine whether the land-use methods can be used to predict water quality at the local scale in areas of 10 to 100 mi^2.

The spatial resolution of the land-use data can affect the magnitude of the statistical relation or whether a hypothesis is accepted or rejected. At certain scales, the minimum-sized mapping unit may exclude or misclassify some land-use classes (Fitzpatrick-Lins, 1980). For example, two different sources of digital land-use data were used to test the relation between VOC's in shallow ground water and industrial and residential land use in Long Island, New York. Differences in land-use classification within the Huntington, New York, quadrangle were analyzed using a GIS (Siwiec and Stackelberg, 1989). Figure 4A is a map of residential land in the Huntington quadrangle in 1973 at a scale of 1:250,000 (Fegeas and others, 1983). Figure 4B is a map of industrial and commercial land at a scale of 1:24,000 from a 1981 base (Long Island Regional Planning Board, 1982). Figure 4C shows land classified as industrial or commercial at a scale of 1:24,000 but as residential at a scale of 1:250,000--approximately 4 percent of the total area of the quadrangle.

EXPLANATION

A

RESIDENTIAL LAND
U.S. Geological Survey
National Cartographic
Information Center (NCIC)
Scale: 1:250,000

B

INDUSTRIAL/COMMERCIAL LAND
Long Island Regional
Planning Board (LIRPB)
Scale: 1:24,000

C

INDUSTRIAL/COMMERCIAL LAND
from LIRPB, but classified
as residential in NCIC
Scale: 1:24,000

Figure 4.--Discrepancies in land-use classification between two map scales.

Logistic-regression models were fit to data from both land-use sources; each model was significant for industrial/commercial and residential land uses at an alpha level of greater than or equal to 0.01. The strength of the relation between VOC's and industrial/commercial and residential land varied with the scale of the land-use data, however. When the 1:250,000-scale land-use data were used, the relation of VOC's to residential land use was higher than that of VOC's to industrial/commercial land use. In contrast, when the 1:24,000-scale land-use data were used, the relation of VOC's to industrial/commercial land use was higher. The differences resulted from the differences in spatial resolution--the identification of industrial/commercial land use was about 4 percent higher at the 1:24,000 scale than at the 1:250,000 scale. Small industrial/commercial land-use parcels (less than 10 acres in size) are not resolvable at the 1:250,000 scale and obscure the relation of VOC's to industrial/commercial land use. This example indicates the need for more research to assess the effect of spatial resolution of data on the results of methods used to relate ground-water quality to human activities.

The effect of temporal variability within the study area needs to be evaluated. Problems associated with temporal scale can be related to the distribution and variability of hydrogeologic conditions, human activities, and water quality with respect to time. Temporal variations in hydrogeologic conditions usually are related to changes in water levels and the rate of ground-water movement that can result from changes in recharge rates from precipitation or ground-water withdrawals. Temporal changes in human activities can be seasonal or long term. Seasonal changes in human activities include the application of fertilizers and pesticides to crops and lawns. Long-term changes in human activities include the replacement of undeveloped or agricultural land by urban land or a change in population density. Temporal variations in ground-water quality also can be seasonal or long-term, and can be on the order of years, decades, or centuries. Seasonal variability in constituent concentrations can affect whether a hypothesis is accepted or rejected.

Approach

Previously available and recently collected hydrogeologic, human-activity, and water-quality data will be used to evaluate the effect of spatial and temporal scale on the methods used to quantify the relation between shallow ground-water quality and human activities. Hypotheses will be formulated and tested to determine whether the size of the study area, the scale at which the land-use maps were created, and seasonal and long-term variability of water quality and human activities within the study area affect the results of each land-use method.

Data sets from the New York and New Jersey studies will be split into smaller data sets for variable-sized areas to determine whether the size of the study area affects the results of hypothesis testing. Results of statistical tests from the study areas will be compared. Collection of additional water-quality, hydrogeologic, and human activity data may be needed to determine whether the relations between shallow ground-water quality and land use or population density at the local scale are comparable to those relations observed at the regional scale.

Hypotheses will be tested to determine whether the methods used to quantify land use are independent of map scale and resolution. The relation between shallow ground-water quality and land use will be evaluated by using maps generated at various scales in the New York study area. If comparable sets of land-use maps can be obtained for the New Jersey Coastal Plain, the effects of map scale on the statistical relations observed for the New York and New Jersey study areas will be compared.

Also, hypotheses will be formulated and tested to determine the effect of seasonal variations in constituent concentrations on the methods used to test the relation between shallow ground-water quality and land use. Previously available and recently collected water-quality data will be used to determine the statistical significance of seasonal variation in a particular water-quality constituent. Those water-quality constituents showing significant seasonal variations will be identified. Methods of minimizing the effect of seasonal variations on the results of the statistical analyses will be developed.

Historical and recent water-quality and human-activity data from selected areas of the New York and New Jersey Coastal Plain will be used to evaluate the effect of land-use change on regional water quality in unconfined aquifers. Current land-use maps will be obtained to evaluate the effect of land-use change in these selected areas. Areas for intensive study will be selected on the basis of the availability of historical water-quality and land-use data. Changes in nitrate and pesticide concentrations in ground water beneath residential land that was recently converted from agricultural land will be evaluated.

Areas Contributing Water to Shallow Wells

Problem

Methods previously developed to test the relation between shallow ground-water quality and human activities made use of circular buffer zones about a well in which to quantify land use and population density. In most cases, a circular buffer zone does not represent the area that contributes water to a well screened in a sand and gravel aquifer. Statistical results probably would be more accurate if only those human activities within the area contributing water to the well were quantified. Also, water-quality samples were collected from both observation wells and pumping wells. The contributing area of a pumping well can be different from that of an observation well, and can be more difficult to define. Methods of characterizing human activities within the contributing area of each type of well need to be explored.

Background

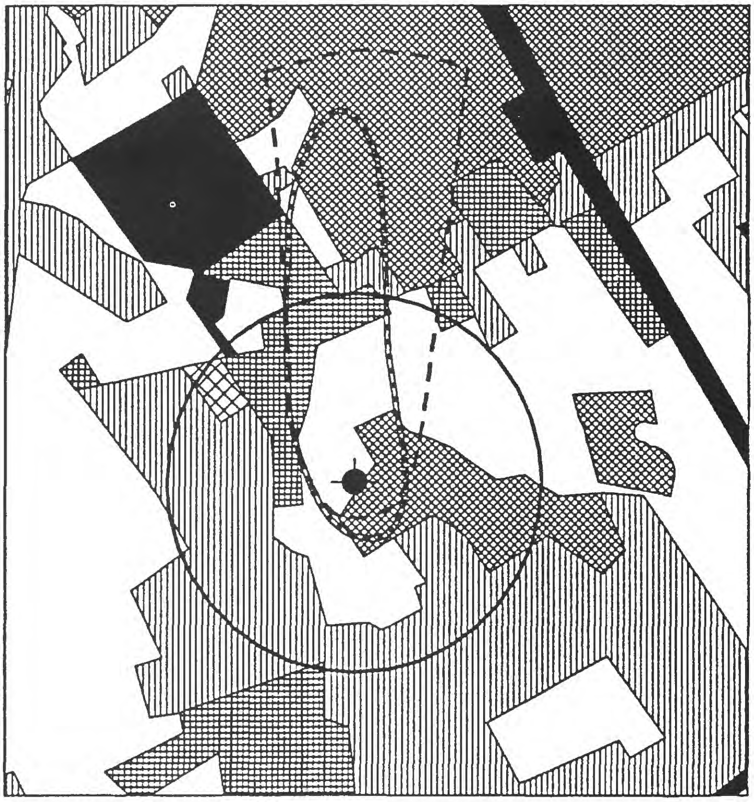
The Amendments to the Safe Drinking Water Act (SDWA) that were passed by Congress in June 1986, established the first nationwide program to protect ground-water resources used for public water supplies from a wide range of potential threats. The SWDA authorized states to establish State Wellhead Protection Programs with a goal to protect wellhead areas from contaminants that may have an adverse effect on the health of persons. One of the major elements of the State Wellhead Protection Programs is the determination of zones within which contaminant source assessment and management will be addressed. These zones, denoted as wellhead-protection areas, are defined as the surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield (U.S. Environmental Protection Agency, 1987, p. ES-1). To avoid any association with regulatory functions, in this report the term "wellhead-protection area" will be called the area contributing water to a withdrawal well, or "contributing area."

Methods for estimating the shape and size of the area contributing water to a pumping well include arbitrary fixed radii, calculated fixed radii, simplified variable shapes, analytical methods, hydrogeologic mapping, and numerical methods/transport models (U.S. Environmental Protection Agency, 1987). These methods are listed in order of increasing complexity and time required to estimate the contributing area. An objective of this part of the research is to determine whether the more complex methods provide a more statistically significant relation between a particular water-quality constituent and a human activity than the simpler fixed-radii or calculated-fixed-radii approaches.

Figure 5 illustrates the effect of using various methods to estimate the area contributing water to a well on the relation between a particular water-quality constituent and land use. The percentage of each land use within the contributing area of a hypothetical well on Long Island was determined by using three different methods--fixed radius, analytical solution, and numerical model (table 1). The total contributing area and the percentage of each land use within it are different for each method. For instance, the contributing area determined by using the fixed-radius method (radius = 800 meter) is equivalent to 0.198 mi^2, but is 0.124 mi^2 for the analytical solution and 0.068 mi^2 for the numerical model. Despite the differences in total area, the relative percentage of open space within the contributing area is similar for each method; however, the percentage of residential and agricultural land is different for each method. The differences in land-use percentages can affect the statistical relation being tested. A statistical evaluation of this type can provide insight about the relative costs and benefits of using the more complex methods to determine the area contributing water to a well.

Approach

A subset of wells from the New York and New Jersey data bases will be selected randomly to test the hypothesis that the relation between a water-quality constituent and a particular human activity is independent of the size or shape of the contributing area used to quantify the human activity. A hierarchical approach, beginning with the least complex methods, will be used in the analysis. The effect of the shape and size of the contributing area on the land-use methods will be tested by using a few constituents or groups of constituents. The relation between VOC's and industrial/commercial land use, and the relation between nitrate and agricultural and residential land use, also will be tested.



EXPLANATION

LAND-USE CATEGORY

Residential

Commercial

Institutional

Open space

Agriculture

Transportation

ESTIMATED BUFFER-ZONE SIZE BY:

Fixed-radius method

Analytical-solution method

Numerical-model method

Figure 5.--Diagram of a hypothetical well and land uses within areas contributing water to wells estimated by three methods.

Table 1.--Total areas and land-use percentages within areas contributing water to wells determined by three methods

[mi^2, square mile]

Land-use class	Fixed-radius method 0.198 mi^2	Analytical solution 0.124 mi^2	Numerical model 0.068 mi^2
	Percent of total area[1]		
Residential	34.8	3.8	4.9
Commercial	11.3	12.7	21.5
Institutional	1.7	0	0
Open space	36.8	30.8	36.7
Agricultural	15.4	52.7	36.9
Transportation	0	0	0

[1]Determined from figure 6 by using geographic information system.

First, the relation between the contaminant and land use within an area contributing water to a well, estimated by using the arbitrary fixed-radius approach, will be tested for statistical significance. Nonparametric statistical tests will be used to determine the relation between the constituent and the land uses in the contributing area for each of the three methods used to quantify land use. Land-use percentages within various fixed radii will be calculated to determine which radius yields the most significant relation. Next, the calculated-fixed-radius approach will be used to determine land uses within the contributing area of each well. Then, the simplified-variable-shapes, analytical-solution, and hydrogeologic-mapping approaches will be used to estimate contributing areas and land uses in these areas. The results obtained by using the different methods will be compared to determine which method provides the most significant relation between a water-quality constituent and a specific land use.

Estimation of the contributing area for each well by using analytical methods, hydrogeologic mapping, and numerical methods may be impractical because these methods are data-intensive and time- and cost-prohibitive. This is especially true for the numerical methods. Instead, factors that affect the contributing area may be estimated for wells located in areas that meet specific hydrogeologic criteria. Initially, this approach will require categorization the types of hydrogeologic conditions at most pumping wells in the Coastal Plain of New York and New Jersey. A three-dimensional ground-water-flow model will be designed for each hydrologic setting. This numerical model will be used to simulate aquifer response to various pumping rates, aquifer characteristics, system geometry, and well characteristics. Finally, a particle-tracking algorithm (Pollock, 1988) will be used as part of the model simulation to estimate ground-water-flow paths and time of travel along particle flow lines. Areas contributing water to wells at the land surface will be estimated for desired travel times.

Additional Hydrogeologic and Human-Activity Factors

Problem

The methods developed previously to test relations between shallow ground-water quality and human activities were limited to a few variables that describe hydrogeologic conditions or human activities. Previous studies were not designed to determine whether variability in hydrogeologic conditions, such as soil type and thickness of the unsaturated zone, influences the probability of contamination of the aquifer. Only land-use and population-density variables were used to quantify human activities near a well. Other variables that describe human activities need to be tested for their usefulness in predicting ground-water contamination by nutrients, metals, VOC's, and pesticides.

Background

The shallow ground-water-quality/human-activity models developed for the Coastal Plain in both New York and New Jersey usually tested univariate relations between a particular contaminant and a few hydrogeologic or human-activity factors. The wells selected for statistical testing of hypotheses were stratified by hydrogeologic characteristics before samples were collected. In the New Jersey study area, variability in hydrogeologic conditions within the data sets usually was insufficient to determine which hydrogeologic factors affect the distribution of a contaminant most strongly (Vowinkel and Battaglin, 1989a). Hydrogeologic and human-activity factors generally were not tested in the same model. The statistical analyses were not designed to determine which factors best explained the distribution of a contaminant.

Experiments and statistical analyses will be designed to determine those hydrogeologic factors that most accurately predict the distribution of a particular contaminant in shallow ground water. Hydrogeologic variables can be classified as part of either the unsaturated zone or the saturated zone. Aller and others (1985) developed a standardized system called DRASTIC to evaluate the ground-water contamination potential of an aquifer. A similar rating method called SEEPAGE is being developed by the U.S. Department of Agriculture to determine which hydrogeologic factors influence the behavior and movement of contaminants within the unsaturated zone (J. Moore, U.S. Soil Conservation Service, written commun., 1989). These contamination-potential rating systems provide insight into those hydrogeologic factors that ideally need to be considered in regional shallow ground-water-quality appraisals (table 2). Variations in well-construction characteristics also need to be tested to determine whether these factors cause biases in the statistical design (table 2).

Previous studies made use of generalized land-use classes or population density to quantify human activities near wells. More specific indicators of nonpoint and point sources of contamination need to be tested for their usefulness as predictors of regional shallow ground-water quality (table 3). For instance, the results of tests conducted by using data from the Coastal Plain of New York and New Jersey indicate a statistically significant relation between the presence of VOC's and industrial land use. Not all industries are potential sources of discharge of VOC's to shallow ground water. Those types of industrial land uses that are most likely to introduce VOC's into ground water need to be identified. The U.S. Environmental Protection Agency, Office of Ground-Water Protection, recommends identification of industrial land use by use of the Standard Industrial Use Code (SIUC) (Ron Hoffer, U.S. Environmental Protection Agency, written commun., 1989).

Approach

A matrix of hydrogeologic and well-construction variables (table 2) and human-activity variables (table 3) will be stored as point, line, or polygon coverages in the GIS data base to assist in hypothesis testing. Multivariate models will be developed and factor analysis will be performed to determine which factors best predict the presence or concentration of a particular constituent in a shallow aquifer. The factors listed in tables 2 and 3 will be evaluated if the information is available. Hypotheses will be developed, tested, and verified to evaluate the relation of metals, nutrients, VOC's, and pesticides to multiple hydrogeologic and human-activity variables.

Table 2.--Hydrogeologic and well-construction factors to consider in regional shallow ground-water-quality appraisals

[NWIS/GWSI, National Water Information System/Ground-Water Site Inventory; SCS, Soil Conservation Service; SWUDS, State Water Use Data System; USGS, U.S. Geological Survey]

Factor	Source of information
Hydrogeologic conditions	
Unsaturated zone	
Topography	USGS topographic maps
Soils	SCS maps
Recharge rate	USGS reports
Thickness (depth to water)	USGS reports
Drainage-basin divides	USGS topographic maps
Saturated zone	
Aquifer and confining-unit material	USGS reports
Hydraulic conductivity	USGS reports
Ground-water-flow path direction/length	Map reports and flow models
Saturated-aquifer thickness	USGS reports
Rivers and lakes	USGS topographic maps
Distance from saltwater bodies	USGS topographic maps
Proximity to other withdrawal wells	NWIS/GWSI data base
Well-construction characteristics	
Well depth	NWIS/GWSI data base
Screened interval	NWIS/GWSI data base
Specific capacity	NWIS/GWSI data base
Casing and screen material	NWIS/GWSI data base
Casing and screen diameter	NWIS/GWSI data base
Pumpage rate and historical withdrawals	NWIS/GWSI and SWUDS data bases

Table 3.--Human-activity factors to consider in regional ground-water-quality appraisals

[USGS, U.S. Geological Survey; ERDAS, Earth Resources Data Analysis System; NCIC, National Cartographic Information Center; NPDES, National Pollution Discharge Elimination System; RCRA, Resource Conservation and Recovery Act.]

Factor	Source of information
Indicators of nonpoint sources of contamination	
Land use	
Land-use/land-cover data	NCIC digital data base
ERDAS land-use data	ERDAS data base
Other land-use maps	State and county maps
Population density	U.S. Bureau of the Census
Housing density	U.S. Bureau of the Census
Road density	U.S. Bureau of the Census
Septic tank density	State and county files
Sewered areas	State and county maps
Pesticide use	State and county files
Power consumption	Power company and state files
Air releases	Community Right to Know data
Indicators of point sources of contamination	
Sewage-treatment plants	NPDES data base
Municipal and industrial discharges	
Industrial releases	Community Right to Know files
Hazardous waste sites	RCRA files
Landfills	Federal, state, and county files
Gas stations	Federal, state, and county files
Underground storage tanks	Federal, state, and county files
Other indicators of contamination	
Economic trends	U.S. Bureau of the Census
Social indicators	U.S. Bureau of the Census

An example of an approach that can be used to evaluate detailed land use is described here. Section 313 of the Emergency Planning and Community Right-to-Know Act of the Superfund Amendments and Reauthorization Act requires owners of certain businesses to report the amounts of chemicals stored at their facilities and released to the environment, either routinely or as the result of accidents (New Jersey Department of Environmental Protection, 1987). The law requires that owners of these facilities submit annual reports to the U.S. Environmental Protection Agency and designated State agencies concerning the types and amounts of chemicals discharged to the air, to the water, and onto the land.

In New Jersey, these data are stored in a computer system as part of the New Jersey Department of Environmental Protection (NJDEP) Worker and Community Right to Know Program. Site-description and address data from this computer system were matched with addresses from a GIS file obtained from the U.S. Bureau of the Census files which allowed for these sites to be stored as a point coverage in the GIS (Patricia Cummins, New Jersey Department of Environmental Protection, written commun., 1989). The facilities can be identified by SIUC and by the type of chemical stored or released by the facility (fig. 6). This data base can be used to statistically test the relation between a particular ground-water constituent and a specific type of industrial land use.

Contamination Within the Regional Ground-Water-Flow System

Problem

Previous investigations concerning the transport of contaminants resulting from human activities into deep portions of the regional ground-water-flow systems in the New York and New Jersey Coastal Plain are limited. The three-dimensional extent of contamination within the hydrogeologic system needs to be determined and the parts of the aquifer systems that are susceptible to contamination caused by human activities at the land surface need to be identified.

Background

In order to evaluate the influence of human activities on water quality in deep parts of an aquifer system, hydrogeologic conditions, sources of water, and potential sources of contamination must be determined. Also, it is important to determine whether the water in deep parts of the aquifer system infiltrated before human activities could have affected its quality. Ground-water-flow models and stable isotopes can be used to estimate the source and age of the water in deep parts of the aquifer system. Tritium and carbon isotopes frequently are used to determine the age of the water. In general, if the residence time of the water in the aquifer is greater than 75 to 100 years, then the ground water should be unaffected by contaminants from human activities.

Hydrogeologic conditions in deep parts of the aquifer system need to be characterized to determine which parts of the aquifer system are most susceptible to contamination. The geometry, boundary conditions, and hydraulic characteristics of the aquifers and confining units in the Coastal Plain of New York and New Jersey are well documented. Historical water-

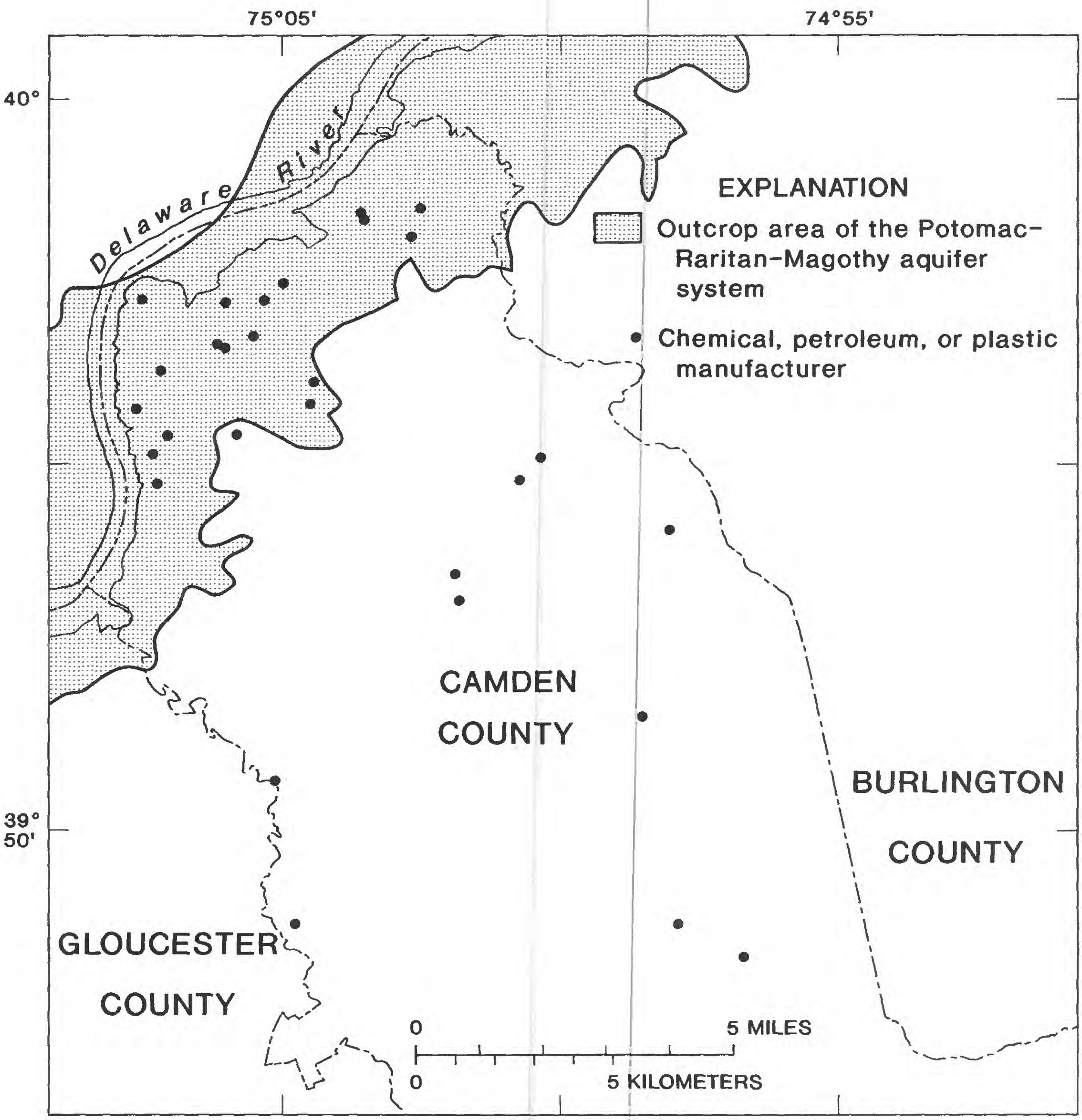


Figure 6.--Locations of chemical, petroleum, and plastic-manufacturing facilities in Camden County, New Jersey, from the New Jersey Department of Environmental Protection Agency's Worker and Community Right-to-Know data base.

level data also are available for the confined parts of the Coastal Plain aquifers in both New York and New Jersey. Information on ground-water withdrawals for public-supply, industrial, and agricultural use and their influence on regional ground-water levels is available.

Ground-water-flow models can provide information on the areas contributing water to deep parts of the aquifer system. Recharge areas for the confined Magothy and Lloyd aquifers of Long Island, New York, have been estimated by using a three-dimensional model and particle-tracking to simulate ground-water flow (H.T. Buxton, U.S. Geological Survey, written commun., 1989). Sources of water to confined parts of the Potomac-Raritan-Magothy aquifer system and the Atlantic City 800-foot sand in the New Jersey Coastal Plain were determined by using a multilayer finite-difference model (Martin, 1990). The time of travel along flow paths from the recharge area in the outcrop area to deep parts of the aquifer system can be estimated from these models. In conjunction with stable isotope data, these models can be used to estimate the age of the water in deep parts of the aquifer system.

Approach

Previously collected and additional water-quality data will be used to determine which parts of the aquifer systems in the New York and New Jersey Coastal Plain are most susceptible to contamination from human activities. Those hydrogeologic factors that are most important in describing the three-dimensional distribution of contaminants within deep parts of the aquifer systems will be determined (table 4). The movement of contaminants along flow paths from the outcrop area to confined parts of the aquifer system will be evaluated. Ground-water-flow models will be used as interactive tools to guide sampling strategies and to develop an understanding of the fate of contaminants within the regional flow system. Ground-water-flow and particle-tracking models will be used to determine sources of recharge to deep parts of the aquifer system, to estimate the age of water, and to identify parts of the aquifer that are most susceptible to contamination.

For example, a cross-sectional analysis of ground-water-flow patterns on Long Island was conducted for a 15-mile-wide, north-south, corridor by using a fine-mesh finite-element model (H.T. Buxton, U.S. Geological Survey, written commun., 1990). Figure 7 is a section through the modeled area that shows the estimated 75-year equal-age line of the ground water. Concentrations of nitrate in water from wells screened above and below this line are identified. Water from all wells screened in the parts of the aquifer that contain water less than 75 years old contained concentrations of nitrate-nitrogen greater than 2.0 mg/L; the mean nitrate concentration in water from these wells was 8.8 mg/L. Water from wells screened at intervals deeper than the 75-year line contained nitrate in concentrations less than 0.5 mg/L (mean 0.14 mg/L). Additional cross-sectional models will be developed for other areas in the Long Island, New York, and New Jersey Coastal Plain to identify those parts of the aquifer system that are most susceptible to contamination.

Table 4.--Hydrogeologic factors to consider in regional appraisals of water quality in deep aquifers

[USGS, U.S. Geological Survey; RASA, Regional Aquifer Systems Analysis; SWUDS, State Water Use Data System.]

Factor	Source of information
Age of water	Ground-water-flow and particle-tracking models and isotope dating of water
Sources of recharge to the aquifer	RASA and other USGS flow models
Aquifer hydraulic conductivity and thickness	USGS reports and ground-water-flow models
Distance along flow path from recharge area	USGS ground-water-flow models
Confining unit hydraulic conductivity and thickness	USGS reports and ground-water-flow models
Ground-water withdrawals	SWUDS
Water levels	USGS synoptic water-level measurements

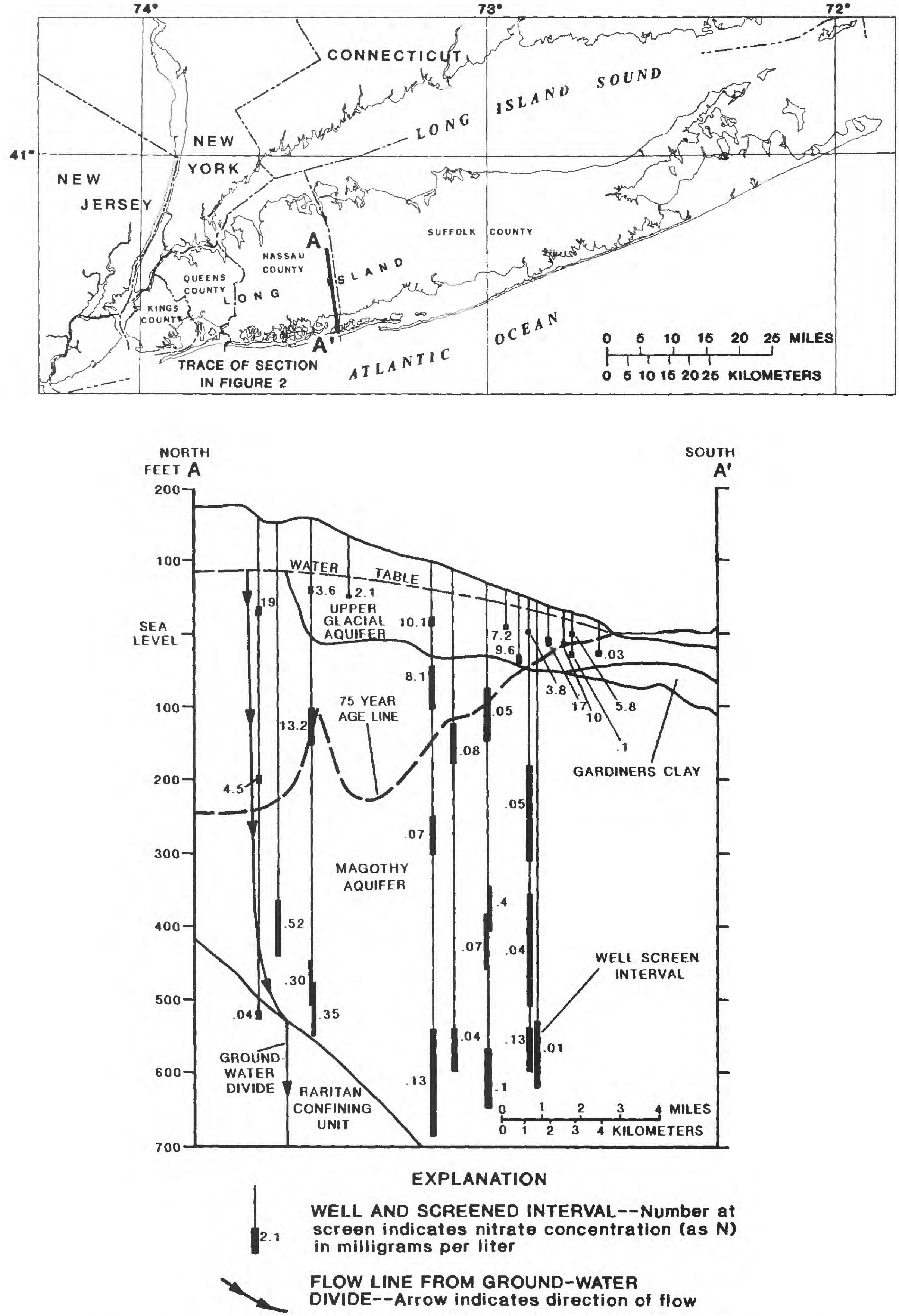


Figure 7.--Hydrogeologic section through Long Island, New York, showing concentrations of nitrate nitrogen in selected wells (H.T. Buxton, U.S. Geological Survey, written commun., 1990).

In the New Jersey Coastal Plain, VOC's were detected at concentrations of 3 µg/L or greater in 12 of 247 wells screened in the confined parts of the Potomac-Raritan-Magothy aquifer system downdip from the outcrop (Vowinkel and Battaglin, 1989a). Seven of these 12 wells are located within a mile of the outcrop where the confining units are thin or absent. The five contaminated wells located further downdip from the outcrop are within the regional cones of depression of the aquifer system where ground water moves both horizontally and vertically into confined parts of the aquifer system. Cross-sectional and particle-tracking models of ground-water flow in the Potomac-Raritan-Magothy and Kirkwood-Cohansey aquifer systems will be developed to determine sources of water to deep parts of the aquifer system.

The presence and movement of nitrate, metals, VOC's, pesticides residues, and other organic constituents into deep parts of the aquifer system need to be evaluated. In addition, the effect of ground-water withdrawals on the movement of these contaminants into deep parts of the aquifer system needs to be assessed. Contamination of the Magothy and Lloyd aquifers in the Long Island Coastal Plain and the confined parts of the Potomac-Raritan-Magothy aquifer system and the Atlantic City 800-foot sand in the New Jersey Coastal Plain also needs to be assessed.

Ground-Water-/Surface-Water-Quality Interactions

Problem

The relation between surface-water quality and shallow ground-water quality is poorly understood. The contribution of contamination from ground water to surface water generally is unknown. Because most of the streams in the Coastal Plain of New York and New Jersey are gaining, the contribution of chemical constituents in ground water to surface-water contamination probably is large. The statistical relation between surface-water quality and land use, therefore, should be similar to the relation between shallow ground-water quality and land use.

Background

Objective and consistent methods for regional assessment of the influence of human activities on surface-water quality are needed (R.A. Smith, U.S. Geological Survey, written commun., 1989). Most water-quality data are collected at locations that do not represent regional conditions. This is a major difficulty in assessing the influence of human activities on surface-water quality. Most surface-water samples are collected at sites near known sources of contamination rather than at randomly selected sites. Analyses of water, suspended sediment, and bed sediment for inorganic and organic compounds usually are unavailable. In areas for which water-quality data are available, the number of sites commonly is inadequate. As a result, extrapolation of water-quality conditions beyond the sampled locations, and quantification of the influence of point and nonpoint sources of contamination on surface-water quality at a regional scale are currently impossible.

Prior to evaluating the relation between surface-water quality and land use, it is necessary to determine (1) hydrogeologic characteristics of the drainage basin and surface-water body, (2) the area contributing water to the surface-water body, and (3) human activities within the contributing area that may affect surface-water quality. Hydrogeologic characteristics of the drainage basin and surface-water body play a major role in determining the concentration, rate of movement, and final deposition of point and nonpoint contaminants in surface-water systems. Hydrogeologic factors affecting surface-water quality include climate, soils, lithology, and channel hydraulics. When statistically evaluating the relation between surface-water quality and human activities, hydrogeologic characteristics must be evaluated to minimize statistical biases and to ensure that, for the sites being compared, data are derived from the same population.

The hydrogeologic characteristics of the drainage basin and surface-water body help determine the contributing area to a particular water body. The size and shape of the contributing area depends on the sources of water to the surface-water body and the contact time of the water with the soil and sediments. In general, four primary processes are involved in contributing water to a surface-water body: (1) direct precipitation, (2) overland flow or direct runoff, (3) storm seepage, and (4) ground-water runoff. In the Coastal Plain, the amount of water from overland flow and storm seepage to a surface-water body is small. Most surface water is derived from ground-water runoff; in the New York and New Jersey Coastal Plain 75 to 90 percent of the flow in streams is from ground-water runoff (Franke and McClymonds, 1972; Vowinkel and Foster, 1981). Therefore, ground water probably is a predominant source of surface-water contamination in many areas of the Coastal Plain.

The contact time of water with soils and sediments is an important factor controlling the chemical composition of surface water (Wolock and others, 1989). This contact time, which depends on the flow path that the water takes in traversing the drainage basin, can be on the order of days, years, decades, centuries, or longer. In the Coastal Plain, most surface water is derived from ground water adjacent to and upgradient from the surface-water body. Contaminants generated by human activities at the land surface and situated within a contributing area that represents a contact time of less than 100 years could affect surface-water quality.

Point and nonpoint sources of contamination affect every major waterway in New Jersey and New York; however, the magnitude of contamination from each source generally is unknown. Human activities that occur within the contributing area of a surface-water body need to be assessed. One type of point-source contamination is direct discharge of treated or untreated effluent from industrial or municipal sewage-treatment facilities. These sources can be identified and contaminant loadings can be determined from chemical analyses of the effluent and the rate and periodicity of discharge to surface water. Nonpoint sources of contamination that can degrade surface-water quality include precipitation and ground-water runoff. Also, the use of stormwater-collection systems, which collect runoff during precipitation or storms, can cause nonpoint sources of contamination such as road salts, oil and grease, and agricultural chemicals, to become point-sources discharges to surface water. Contamination from nonpoint sources is difficult to quantify, because constituent loads are affected by such factors as precipitation intensity and duration and the amount and types of chemicals present within the drainage area during the storm.

Approach

The approach to this part of the study will follow the strategy described in Helsel and Ragone (1984) and subsequent ground-water-quality studies undertaken in the New York and New Jersey Coastal Plain. The first step is a reconnaissance of relevant surface-water-quality, hydrogeologic, and human-activity data and the development of a conceptual model. The remaining steps are experimental design, collection of additional data, data analysis, and verification of the results. Methods described in an unpublished proposal for a project to study the spatial distribution of surface-water quality in New Jersey also will be considered (R.A. Smith, U.S. Geological Survey, written commun., 1989).

The conceptual model is based on the assumption that surface-water quality is related to hydrogeologic conditions and human factors such as land use and population density. The experimental design will consist of collection of water-quality, hydrogeologic, and human-activity data from a random sample of rivers, streams, lakes, and ponds and their contributing areas in the Coastal Plain. Water-quality and sediment samples will be collected at surface-water sites that are chosen to represent residential, industrial, and agricultural land uses. The sampling design for the residential land-use group will represent at least two levels of population density. Surface-water sites in undeveloped drainage basins will serve as a baseline for comparison with the other land-use groups. Water, suspended-sediment, and bed-sediment samples will be collected at each site. Water and sediment samples will be analyzed for selected trace elements, nutrients, pesticides, base-neutral/acid-extractable organic compounds, and bacteria.

Hydrogeologic characteristics of each drainage basin and surface-water body will be determined from published reports, topographic maps, aerial photographs, field data, and digital data bases (table 5). Drainage-basin characteristics that will be evaluated include climate, topography, vegetation, soils, impervious surface area, drainage density, and water use. Surface-water-body characteristics that will be investigated include the contributing drainage area, hydraulic geometry, and flow characteristics. These hydrogeologic characteristics will be used to select sites to ensure that the sampled sites being compared are from the same population. The hydrogeologic characteristics will be used to estimate the size and shape of the contributing area to a surface-water body that may be affected by human activities.

Indicators of point and nonpoint sources of contamination within each surface-water body contributing area will be evaluated. Information from the National Pollution Discharge Elimination System (NPDES) computer files will be used to determine the location, flow rate, and chemical composition of discharges to a surface-water body (fig. 8). Contamination of surface water by other point sources such as landfills and hazardous-waste sites also will be examined.

Table 5.--Hydrogeologic factors to consider in regional surface-water-quality appraisals

[NWIS, National Water Information System; SCS, Soil Conservation Service; SWUDS, State Water Use Data System; USGS, U.S. Geological Survey.]

Factor	Source of information
Drainage-basin characteristics	
Climate	National Weather Service
Precipitation quantity and quality	
Temperature	
Wind direction	
Topography	USGS topographic maps
Soils	SCS maps
Porosity, organic matter	
Contact time	
Impervious surface area	Federal, state, and local maps
Drainage-basin divides	USGS topographic maps
Stream order	
Drainage density	
Water use	SWUDS
Lake and pond characteristics	
Contributing drainage area	USGS topographic maps
Geometry	
Surface area	USGS topographic maps
Bathymetry	Field measurements
Volume	Calculated
Stratification and turnover	Reports and field measurements
Stream characteristics	
Contributing drainage area	USGS topographic maps
Hydraulic geometry	Reports and field measurements
Channel slope	Calculated
Depth	
Volume	
Flow characteristics	NWIS
Base flow	
Average flow	
Peak discharge	
Storm runoff volume	
Duration of runoff	
Turbulence	

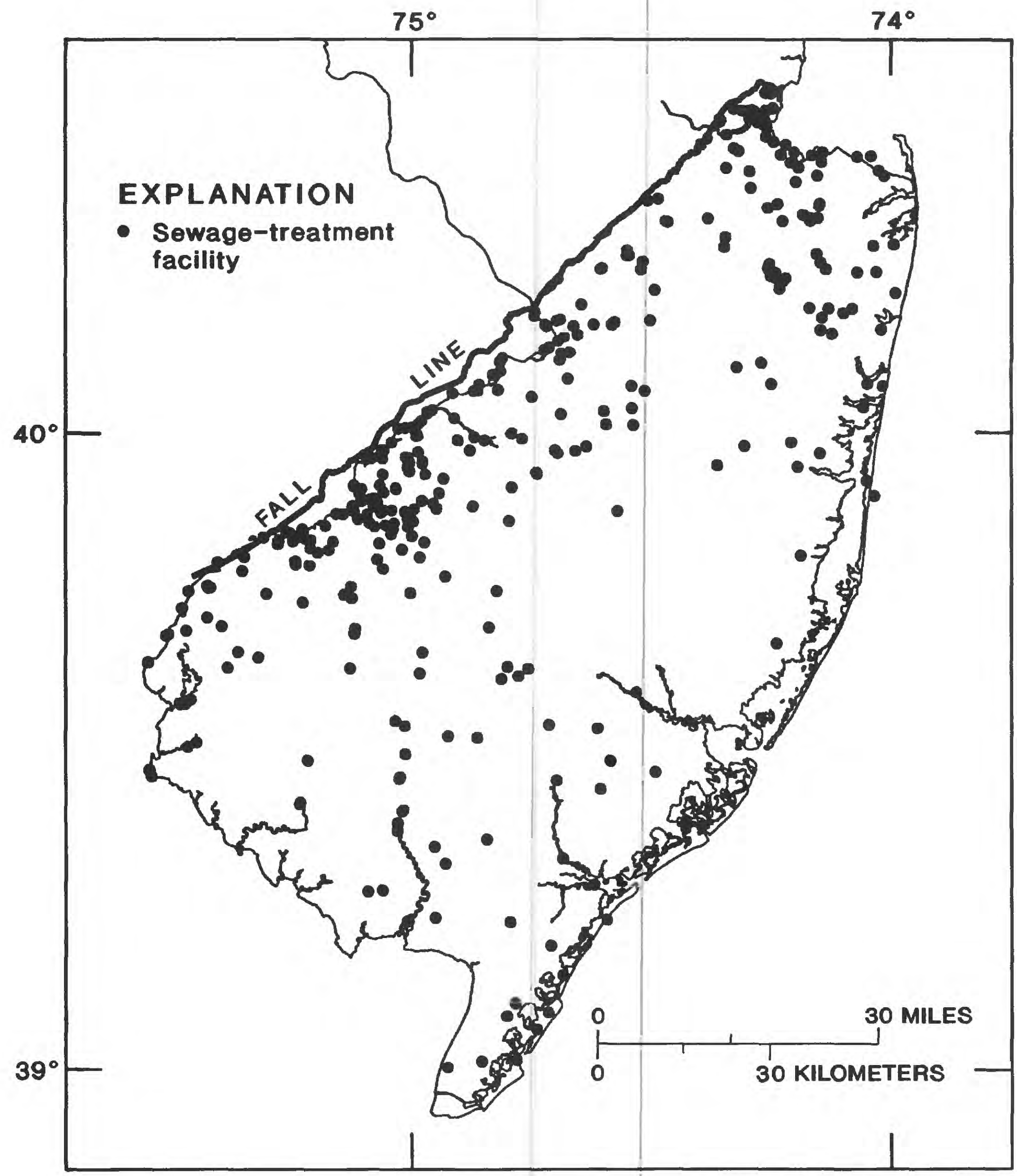


Figure 8.--Locations of National Pollution Discharge Elimination System point-source discharge sites in the New Jersey Coastal Plain.

Land-use and population-density data will be investigated as variables to quantify nonpoint sources of contamination. Several methods of characterizing human activities that can affect surface-water quality will be evaluated. The first method used to quantify land use will be to determine the percentage of each land use within a fixed distance from a stream or pond (fig. 9). The relation between a given constituent and a particular land use within the contributing drainage area will be compared by use of the predominant, presence-or-absence, and land-use-percentage methods previously developed for the ground-water investigations. The relation between the constituent and population density within the contributing drainage area also will be tested for statistical significance. Experiments will be conducted to determine whether the size and shape of the buffer zone used to estimate the area contributing water to the surface-water body affect the relation between surface-water quality and land use.

Nonparametric statistical tests will be used to determine whether relations between surface-water quality and human activities, such as land use and population density, are significant. Examples of selected hypotheses that may be tested are described briefly.

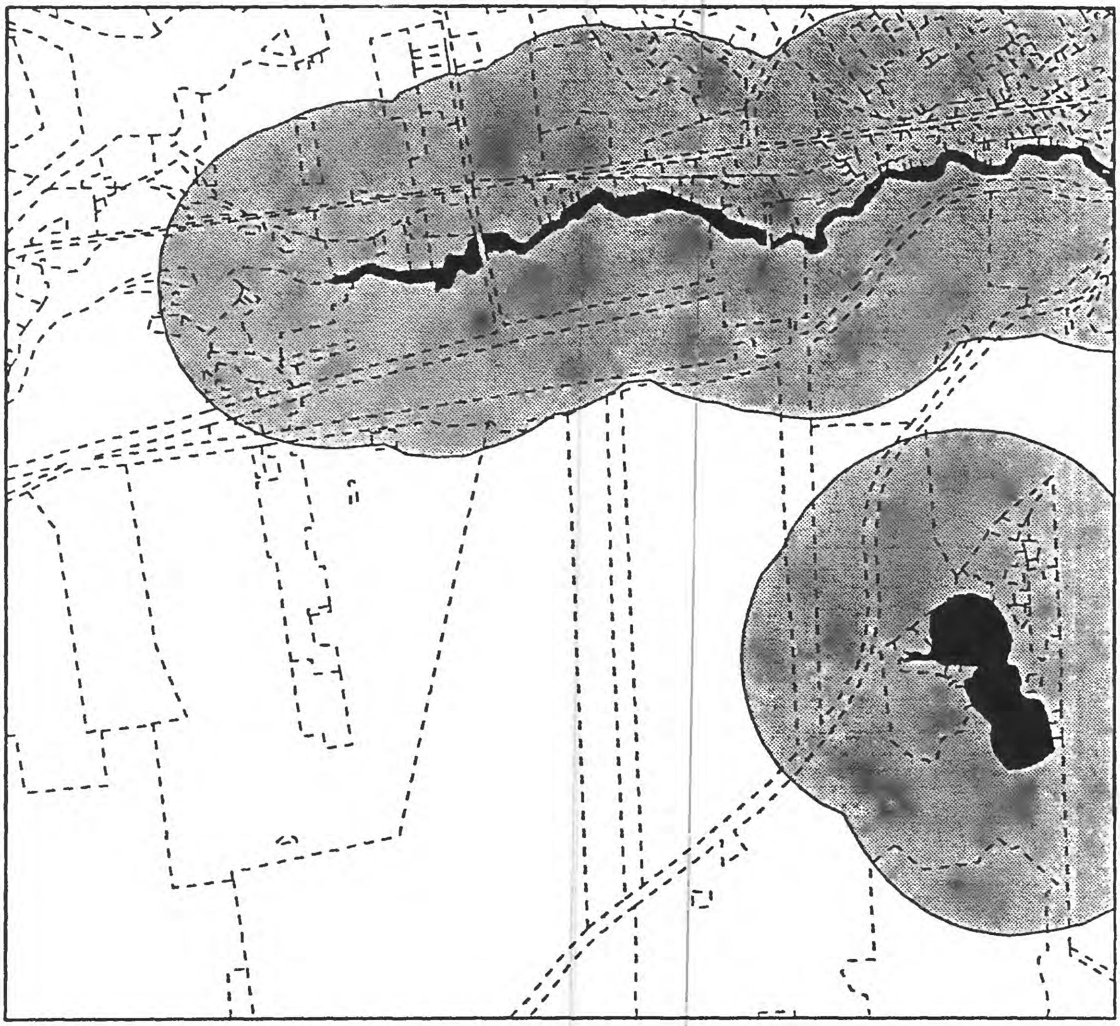
1. The relation of concentrations of nutrients in surface water with land use and with population density will be evaluated. Concentrations of dissolved nitrate in surface water are expected to be significantly higher in agricultural and urban areas than in undeveloped areas. Nitrate concentrations in surface water probably will be found to increase with population density.

2. The relation of selected metals in both surface water and sediments with human activities will be tested. Significantly higher concentrations of lead, chromium, arsenic, and cadmium are expected in surface water near industrial and agricultural land than in surface water near undeveloped land.

3. The relation of selected pesticides in both surface water and sediments with land use will be evaluated. Concentrations, or the frequency of detection, of most pesticides is expected to be greater in samples collected in agricultural areas than in samples from residential or undeveloped areas.

4. The relation of base-neutral/acid-extractable compounds in surface water and sediments with land use will be tested. Concentrations of these organic compounds are expected to be greater in samples collected in industrial areas than in samples from other land areas.

The results from methods developed to test the relation between surface-water quality and human activities will be verified in other areas of similar hydrogeologic settings. Methods described earlier in the section on verification of previous results of shallow ground-water-quality/human-activity models will be used to verify the surface-water quality/human-activity models. Water-quality, hydrogeologic, and land-use data from surface-water sites in the New York Coastal Plain will be compared with similar data from sites the New Jersey Coastal Plain. The verification



EXPLANATION

Surface-water body

1/2-mile-radius buffer zone around surface-water body

-------- Boundary of land-use polygon

Figure 9.--Land use within a fixed-distance buffer zone of a stream and pond on Long Island, New York.

procedure also will include a comparison of results of the shallow ground-water-quality/land-use models with the results of the surface-water-quality/land-use models. Because most of the water in surface-water bodies in the Coastal Plain is derived from ground water, results of the ground-water and surface-water models are expected to be similar.

Water-Quality Sampling Strategies

Problem

The design of a field sampling network for regional water-quality studies should be based on sound physical and statistical principles. While some attention has been paid to the need for statistically sound designs in a regional assessment, the use of available information about hydrogeology to improve the efficiency of sampling has not been addressed.

Background

Most regional assessments of ground-water quality are designed to estimate the distribution of a specific constituent within an area and also to relate ground-water quality to some explanatory variables. Usually, these regional studies involve some type of grid-based random sampling, stratified random sampling, or systematic sampling designed to be unbiased toward any particular constituent, problem area, or geographic feature within the aquifer being sampled. Random sampling is simply the selection of either existing wells or potential well sites on a purely random basis throughout a study area. Random sampling can be improved further by stratifying the population (study area) by some factor such as land use, age of water, or range of hydraulic gradient. Systematic sampling is considered to be a type of probability sampling and usually is carried out in a regularly spaced grid pattern.

It remains to be shown, however, whether knowledge-based sampling that formally incorporates hydrogeologic information about a study area, can lead to further improvements in design. Knowledge-based sampling is the selection of sampling locations on the basis of available information that relates one location to other locations through assumptions of continuity in the medium, hydrologic processes, and causative factors. For example, knowledge of recharge rates, hydraulic gradients, and flow paths might justify the spread of samples among waters of different ages. In other words, a conceptual hydrologic model provides a physical basis for stratified sampling. Knowledge-based sampling, as defined here, is a subset of probability sampling that is based on available information about the physical system to the greatest possible extent.

If the objectives of a regional assessment can be quantified in terms of either the estimation of summary water-quality statistics or the testing of hypotheses about correlative relations between water quality and other factors, then sampling can be explicitly designed to maximize the appropriate type of information and at the same time minimize cost. This proposition needs to be tested on a data-rich study area for which extensive knowledge of the hydrogeology is available. The Coastal Plain areas of Long Island and New Jersey are ideal sites to compare methods of knowledge-based sampling with other sampling-design methods.

Approach

First, a description of water quality for a few selected constituents will be assembled by using all available data for a given time period. Then, three types of probability-based sampling methods will be compared: stratified-random sampling, systematic sampling on a regularly spaced grid, and knowledge-based sampling. Small subsets of the data will be selected according to each of the sampling methods and inferences will be drawn about water-quality conditions on the basis of this limited information. These descriptions will be compared to the description derived from the set of all available data.

This research is expected to result in the development of a simulation tool for evaluating regional sampling strategies on the basis of hydrogeologic knowledge (D.S. Knopman, U.S. Geological Survey, written commun., 1990). This tool will take the form of a general methodology that will be sufficiently flexible to be adapted for use in other study areas. The methodology will be a modular flow model linked to a GIS, and a set of computer programs to select sampling designs, evaluate summary statistics and spatial distribution of constituents, compare effectiveness of designs, and produce graphical output.

The purpose of using a three-dimensional flow model is to integrate hydrogeologic information into the design of a regional sampling strategy. The flow model can be used to create coverages of travel time along flow lines, recharge and discharge areas, and hydraulic gradients. The McDonald-Harbaugh finite-difference model (McDonald and Harbaugh, 1988) is best suited for this purpose because of its simplicity, flexibility, and availability.

A GIS will be used to organize and integrate the hydrologic information with the information from field sampling to determine constituent concentrations. Available GIS based algorithms for choosing sampling sites on the basis of fixed and randomly placed grids will be used whenever possible (J.C. Scott, U.S. Geological Survey, written commun., 1990). Sites will be chosen either from an available population of wells or from a potential population generated by the user. The algorithms also offer several options for stratifying the population by any user-defined factor; several of these options will be explored.

SUMMARY

The U.S. Geological Survey has developed a plan of study to characterize, quantify, and improve the understanding of the effect of human activities on ground- and surface-water quality in urban, suburban, and agricultural land-use areas in the Atlantic Coastal Plain of New York and New Jersey. The Coastal Plain of New York and New Jersey has been chosen for this study because it contains among the most densely populated urban and suburban land in the United States interspersed with agricultural and undeveloped land. The unconsolidated sediments underlying the Coastal Plain of New York and New Jersey have been designated as sole-source aquifers--more than 5 million people in this area rely on ground water as their source of drinking water.

The plan describes three major research objectives and associated research topics. The major objectives of this planned regional study are to (1) quantify the sources of contamination at a level of detail appropriate for a regional study, (2) develop an understanding of the movement of nonreactive and reactive chemical constituents along regional flow paths, and (3) improve methods for regional water-quality-data collection and interpretation. Water-quality constituents to be studied include nutrients, volatile organic compounds, pesticides, and trace elements.

Seven research topics, which would address the objectives listed above, include (1) evaluation of the transferability of the land-use methods and statistical results which were developed to quantify the relation between shallow ground-water quality and human activities to other areas of similar hydrogeology, climate, and land use; (2) assessment of the effects of spatial and temporal variability of water-quality, land-use, and hydrogeologic data on the relation between land use and a particular ground-water quality constituent; (3) evaluation of the effect of using various methods to estimate the area contributing water to a well when quantifying human activities on the statistical relation between land use and a water-quality constituent; (4) a test of the usefulness of additional hydrogeologic and human-activity variables for quantifying the relation between shallow ground-water quality and human activities; (5) assessment of the relation between the extent of contamination resulting from human activities and regional patterns of ground-water flow; (6) evaluation of the relation between surface-water quality and human activities and quantify the contribution of ground-water constituents to surface-water contamination; and (7) determination of methods for improving the efficiency of sampling for regional water-quality investigations by using available hydrogeologic data.

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