

NITRATE, VOLATILE ORGANIC COMPOUNDS, AND PESTICIDES IN GROUND WATER--A SUMMARY OF SELECTED STUDIES FROM NEW JERSEY AND LONG ISLAND, NEW YORK

Water-Resources Investigations Report 99-4027

National Water-Quality Assessment Program



NITRATE, VOLATILE ORGANIC COMPOUNDS, AND PESTICIDES IN GROUND WATER--A SUMMARY OF SELECTED STUDIES FROM NEW JERSEY AND LONG ISLAND, NEW YORK

By Rick M. Clawges, Paul E. Stackelberg, Mark A. Ayers, and Eric F. Vowinkel

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 99-4027

National Water-Quality Assessment Program

West Trenton, New Jersey

1999

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY

Charles G. Groat, *Director*

For additional information
write to:

District Chief
U.S. Geological Survey
810 Bear Tavern Road, Suite 206
West Trenton, NJ 08628

Copies of this report can be
purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

Information regarding research and data-collection programs of the U.S. Geological Survey is available on the Internet via the World Wide Web. You may connect to the Home Page for the New Jersey District Office using the Universal Resources Locator (URL) at:

<http://wwwnj.er.usgs.gov/index.html>

The URL for the New York District Office can be found at:

<http://wwwdnyalb.er.usgs.gov/index.html>

CONTENTS

Page

Abstract.....	1
Introduction.....	1
Population and land-use history.....	2
Ground water	3
Occurrence and movement	4
Importance	8
Contamination.....	8
Nitrate in ground water.....	11
Relation to aquifer conditions.....	13
Relation to depth in the aquifer.....	14
Relation to land use.....	15
Predicting vulnerability to nitrate contamination	17
Volatile organic compounds in ground water	17
Relation to aquifer conditions.....	19
Relation to depth in the aquifer.....	19
Relation to land use.....	20
Predicting vulnerability to volatile-organic-compound contamination	22
Pesticides in ground water	22
Long Island	25
New Jersey	26
Predicting vulnerability to pesticide contamination	27
Summary and conclusions	28
References cited	30

ILLUSTRATIONS

Figure 1. Map showing average population density in New Jersey and on Long Island, New York, 1990	3
2. Graph showing population of New Jersey, 1900-90	3
3. Graph showing population of Long Island, New York, 1900-90.....	3
4. Map showing land use in New Jersey and on Long Island, New York, 1990	4
5. Diagram of the hydrologic cycle.....	5
6. Diagram showing patterns of ground-water flow and relative age in a Coastal Plain aquifer system.....	6
7-9. Maps showing:	
7. Location of sections and generalized diagram of the four types of aquifers in New Jersey and on Long Island, New York	7
8. Ground-water withdrawals in New Jersey and on Long Island, New York, in 1990, by county	8
9. Percentage of the population in New Jersey and on Long Island, New York, that used ground water in 1990, by county	8
10. Graph showing number of permits issued in New Jersey for soil borings, gas vents, monitoring wells, piezometers, and recovery wells, 1983-90	10
11-15. Maps showing:	
11. Number of reported ground-water-contamination cases in New Jersey as of April 1992, by county	10
12. Number of claims received for ground-water contamination in New Jersey in 1994, by county	10

ILLUSTRATIONS--Continued

	Page
13. Amount of nitrogen fertilizer applied in New Jersey and on Long Island, New York, in 1991, by county	12
14. Amount of nitrogen input from animal manure in New Jersey and on Long Island, New York, in 1992, by county	12
15. Outcrop areas of the Potomac-Raritan-Magothy and Kirkwood-Cohansey aquifer systems in New Jersey	13
16. Graph showing the frequency of detection of nitrate in water from wells in unconfined and confined parts of the Potomac-Raritan-Magothy aquifer system, New Jersey	13
17. Map showing five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York	15
18-22. Graphs showing:	
18. Median concentration of nitrate in water from shallow and deep wells in Nassau and Suffolk Counties, Long Island, New York	15
19. Frequency of detection of nitrate in water from 645 wells in the Coastal Plain of New Jersey, by predominant land use	16
20. Median concentration of nitrate in water from 645 wells in the Coastal Plain of New Jersey, by predominant land use	16
21. Frequency of detection of nitrate in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York	17
22. Median concentration of nitrate in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York	17
23. Map showing estimated probability of detecting nitrate in a concentration greater than 3 milligrams per liter in water from wells in Nassau and Suffolk Counties, Long Island, New York	18
24. Map showing location of detections of nitrate in water from 268 wells in Nassau and Suffolk Counties, Long Island, New York	18
25. Graph showing frequency of detection of volatile organic compounds in water from wells in unconfined and confined parts of the Potomac-Raritan-Magothy aquifer system, New Jersey	19
26. Section showing relation of depth and pumpage to detection of volatile organic compounds in water from wells in the Potomac-Raritan-Magothy aquifer system, New Jersey	20
27-30. Graphs showing:	
27. Frequency of detection of volatile organic compounds in water from wells in outcrop areas of the Potomac-Raritan-Magothy and Kirkwood-Cohansey aquifer systems, New Jersey, by predominant land use	20
28. Frequency of detection of volatile organic compounds in concentrations greater than 1 microgram per liter in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York	21
29. Frequency of detection of 1,1,1-trichloroethane (TCA) in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York	21
30. Frequency of detection of trichloroethylene (TCE) in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York	21

ILLUSTRATIONS--Continued

	Page
31. Map showing estimated probability of detecting a total volatile-organic-compound concentration greater than 1 microgram per liter in water from wells in Nassau and Suffolk Counties, Long Island, New York	23
32. Map showing location of detections of volatile organic compounds in concentrations greater than 1 microgram per liter in in water from 248 wells in Nassau and Suffolk Counties, Long Island, New York	23
33-36. Graphs showing:	
33. Reported pesticide use in New Jersey, by land use and type of pesticide	24
34. Frequency of detection of five groups of pesticides in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York	25
35. Frequency of detection of five groups of pesticides in water from wells in the Potomac-Raritan-Magothy and Kirkwood-Cohansey aquifer systems, New Jersey	26
36. Percentage of New Jersey public-supply wells in each of three vulnerability groups, by major aquifer type	28
37. Map showing vulnerability of public-supply wells in New Jersey to contamination by pesticides	28

CONVERSION FACTORS AND WATER-QUALITY ABBREVIATIONS

<u>Multiply</u>	<u>By</u>	<u>To obtain</u>
<u>Length</u>		
inch (in.)	25,400	micron
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
<u>Area</u>		
square mile (mi ²)	259.0	hectare
square mile (mi ²)	2.590	square kilometer
<u>Velocity</u>		
inch per day (in/d)	2.54	centimeter per day
foot per day (ft/d)	0.3048	meter per day

Water-quality abbreviations:

mg/L	- milligrams per liter
µg/L	- micrograms per liter
VOC	- volatile organic compound

FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policy-makers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.

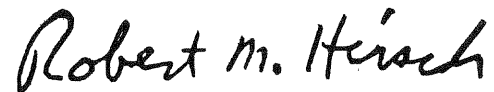
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch
Chief Hydrologist

NITRATE, VOLATILE ORGANIC COMPOUNDS, AND PESTICIDES IN GROUND WATER--A SUMMARY OF SELECTED STUDIES FROM NEW JERSEY AND LONG ISLAND, NEW YORK

By Rick M. Clawges, Paul E. Stackelberg, Mark A. Ayers, and Eric F. Vowinkel

ABSTRACT

This report describes the ground-water systems in the unconsolidated sand and gravel aquifers of the Coastal Plain of New Jersey and Long Island and in the fractured bedrock and valley-fill aquifers of northern New Jersey; summarizes current knowledge about the occurrence and distribution of nitrate, volatile organic compounds (VOCs), and pesticides in these systems; and explains why some ground-water systems are more vulnerable to contamination than others.

Although the vulnerability of ground water to contamination from the land surface is influenced by many factors, the degree of aquifer confinement, the depth of the well, and the surrounding land use are key factors. *Unconfined aquifers generally are much more vulnerable to contamination than confined aquifers.* For a well in a confined aquifer, *the farther the well is from the unconfined area, the less vulnerable it is to contamination.* Generally, *the deeper the well, the less vulnerable it is to contamination.* Finally, because human activities greatly affect the quality of water that recharges an aquifer, *the amount and type of land use in the area that contributes water to the well is a key factor in determining vulnerability.*

Nitrate contamination of ground water typically occurs in agricultural and residential areas, especially where the aquifer is very permeable and unconfined and nitrogen-fertilizer use is high. In New Jersey and on Long Island, concentrations of nitrate exceed the U.S. Environmental Protection Agency Maximum Contaminant Level (MCL) more often than those of VOCs or pesticides. Nitrate contamination generally is associated with nonpoint sources.

VOC contamination of ground water occurs primarily in urban areas, especially in mixed urban and industrial areas where chemicals are used. In general, VOC concentrations are low and do not exceed MCLs. High concentrations of VOCs generally are associated with point sources.

Pesticide contamination of ground water occurs in some agricultural and residential areas, where the aquifer is very permeable and unconfined, and where the chemicals are used. Concentrations of pesticides in New Jersey and on Long Island generally are low; in agricultural areas of Long Island, however, some have been found to exceed MCLs. Pesticide contamination generally is associated with nonpoint sources.

INTRODUCTION

The National Water-Quality Assessment (NAWQA) Program, developed by the U.S. Geological Survey (USGS), was implemented in 1991 to (1) provide a nationally consistent description of the status of surface- and ground-water quality in systems that represent a large part of the Nation's water resources, (2) determine water-quality trends, and (3) determine relations between past and present water quality and land- and waste-management practices. Information collected and interpreted as part of NAWQA will add to the scientific basis for water-management decisions and policy formulation (Leahy and others, 1990).

The NAWQA Program is organized into 59 study units distributed throughout the United States on the basis of regional aquifers and major river basins. Work in the Long Island-New Jersey (LINJ) coastal drainages study unit (6,000 mi²), one of the most heavily urbanized and populated of the study units, began in 1994. An assessment of available water-quality data and review of

previous studies provide the initial understanding upon which the design of the remainder of the study-unit investigation is based.

This report summarizes the results of selected studies on factors such as aquifer characteristics and land-use patterns that affect ground-water quality in New Jersey and on Long Island, New York. It describes the ground-water systems in the study area; summarizes current knowledge about the presence and distribution of nitrate, VOCs, and pesticides in these systems; and explains why some ground-water systems are more vulnerable to contamination than others.

Many of the findings summarized in this report are the results of the USGS Toxic Substances Hydrology Program, which was begun in 1984 to assess the quality of the Nation's ground-water resources and the nature and extent of ground-water contamination (Helsel and Ragone, 1984). Long Island and the Coastal Plain of New Jersey were two of the areas selected to study regional ground-water quality and its relation to local hydrologic and human influences (Barton and others, 1987; Eckhardt and others, 1989; Stackelberg, 1995; Eckhardt and Stackelberg, 1995; Vowinkel and Battaglin, in press). Additional information is provided from studies conducted by the USGS in cooperation with the following Federal, State, and local agencies: U.S. Environmental Protection Agency; New Jersey Department of Environmental Protection; Rutgers, The State University of New Jersey, Department of Environmental Sciences; New York State Department of Environmental Conservation; New York State Department of Environmental Services; Long Island Regional Planning Board; Nassau County Department of Health; Suffolk County Department of Health Services; and Suffolk County Water Authority.

POPULATION AND LAND-USE HISTORY

New Jersey and Long Island contain a broad mixture of land uses defined by a long history of diverse settlement patterns. The early European settlers established their homes along the easily navigable rivers and tributaries of the Coastal Plain. Industrial growth was spurred by the availability of waterpower for milling operations

and the proximity to the major ocean ports of New York City and Philadelphia (fig. 1). The building of canals and railroads in the 1820's and 1830's in New Jersey linked its expanding towns and villages and connected them to the ocean ports. Many investors became interested in the trade that took place in the 15-mi-wide corridor of New Jersey between New York City and Philadelphia. In 1900, more than 75 percent of New Jersey's population lived within this corridor (New Jersey Department of Labor, 1984). On Long Island, the population was concentrated in the western tip of the island.

By the 1920's, the increasing availability of automobiles led to residential and commercial suburbanization. As the population of New York City continued to increase, many people began moving into the cities and towns of northeastern New Jersey and western Long Island. Also, the area of southern New Jersey adjacent to Philadelphia grew substantially. After World War II, development and settlement shifted from the cities to suburban areas. Land that was once agricultural or undeveloped was converted to residential, commercial, and industrial uses. The construction of major roads and highways accelerated the suburbanization. Extensive migration from New York City into Nassau County caused a sharp population increase on Long Island. From the 1950's to the 1970's, the population of Long Island continued to grow, and eastward migration quadrupled the population of rural Suffolk County.

This pattern of increased population in suburban areas has continued from the 1970's to the present, but at a slower rate. In fact, some urban-industrialized counties in northeastern New Jersey lost population during the 1980's, as people left urban centers and relocated to suburban, rural, and coastal areas in the State. Similarly, on Long Island, Nassau County's population decreased slightly during the 1970's, largely as a result of eastward migration to rural Suffolk County. Average population density in New Jersey and on Long Island in 1990 is shown in figure 1. The populations of New Jersey and Long Island from 1900 through 1990 are shown in figures 2 and 3, respectively.

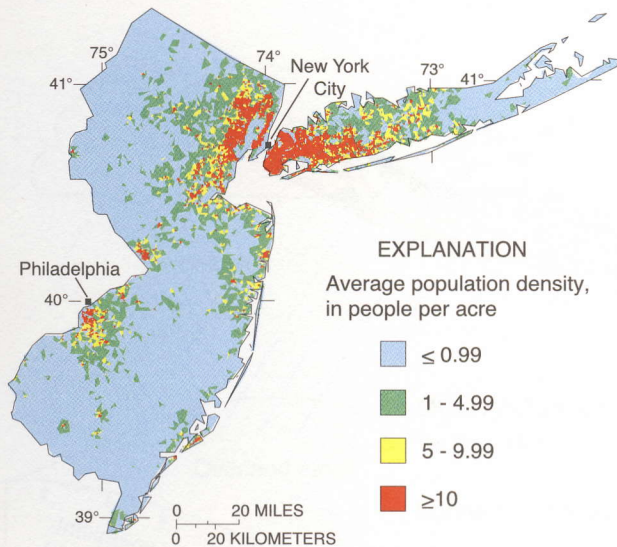


Figure 1. Average population density in New Jersey and on Long Island, New York, 1990. (Data from U.S. Bureau of the Census, 1991a and b)

The distribution of population growth in New Jersey and on Long Island has created a complex assemblage of land uses ranging from urban around the major cities of New York and Philadelphia to the relatively pristine forests of the Pine Barrens in southern New Jersey and eastern Long Island (fig. 4). The urban and suburban areas are dominated by residential, industrial, commercial, and transportation-related land uses. Agriculture is still a major land use in eastern Long Island and the western part of New Jersey. Additionally, large tracts of undeveloped land still exist in eastern Long Island and in southern and northwestern New Jersey. These include wetlands, forests, highland ridges, and parklands. Development of some of these areas is restricted by State agencies.

GROUND WATER

Water is constantly being recycled all over the Earth in a process called the hydrologic cycle (fig. 5). Major components of the hydrologic cycle include evapotranspiration, precipitation, surface runoff, and ground water. That part of precipitation that infiltrates the soil and drains to the water table is called ground-water recharge. Ground water is water saturating interconnected pores in a geologic unit or layer beneath the land surface. This section describes the occurrence and movement of ground water, its importance for water supply, and the processes that can result in its contamination.

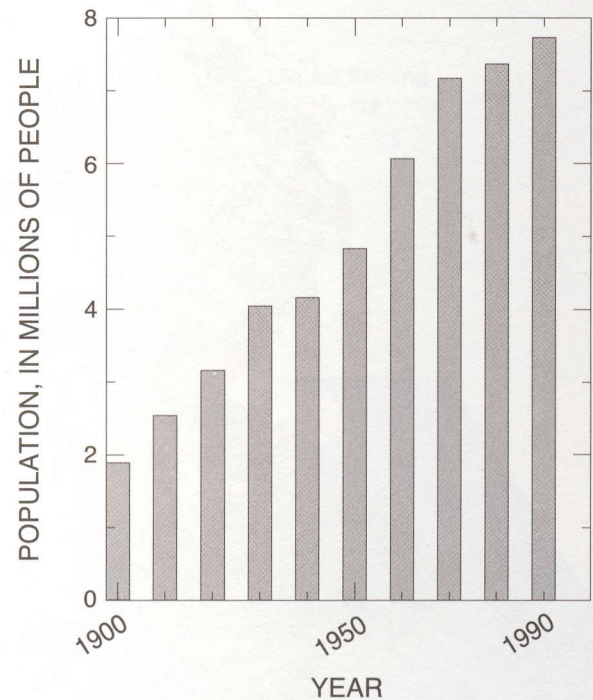


Figure 2. Population of New Jersey, 1900-90. (Data from N.J. Department of Labor, 1984, and U.S. Bureau of the Census, 1991a)

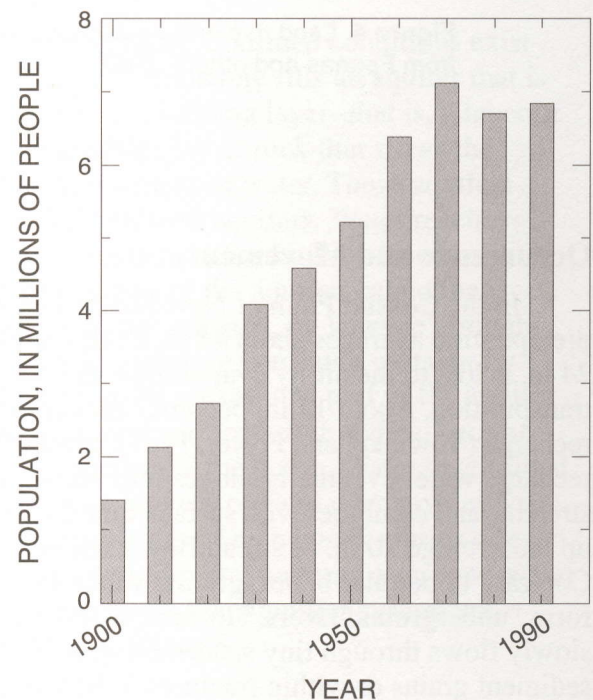


Figure 3. Population of Long Island, New York, 1900-90. (Data from U.S. Bureau of the Census, 1991b)

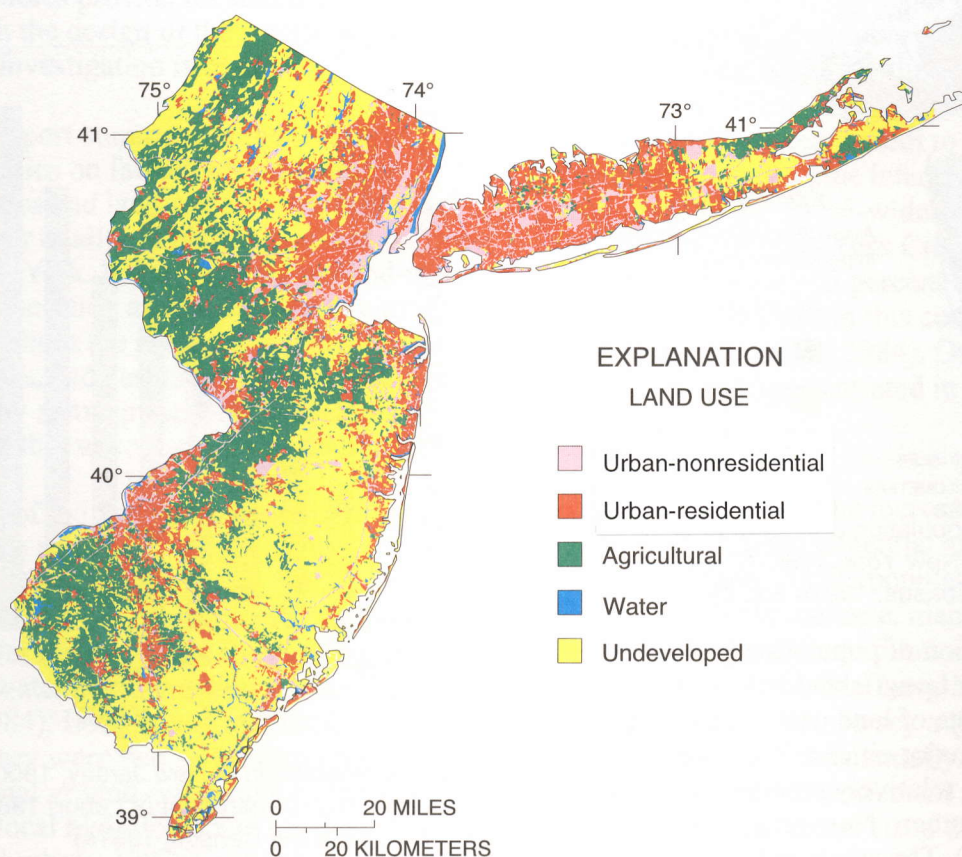


Figure 4. Land use in New Jersey and on Long Island, New York, 1990. (Modified from Fegeas and others, 1983, by using the method of Hitt, 1994)

Occurrence and Movement

In the Coastal Plain of New Jersey, annual precipitation averages about 44 in. Of this amount, 24 in. is lost to the air by evaporation and transpiration. About 17 in. becomes ground-water recharge (Vowinkel and Foster, 1981). Most of this recharge water eventually moves into lakes and streams, and combines with surface runoff to make up the average 20 in. of streamflow each year. Contrary to popular belief, ground water does not form "underground rivers." Instead, it fills and slowly flows through tiny spaces between sediment grains or within fractures in bedrock.

An aquifer is a water-bearing unit that will yield water in a usable quantity to a well or spring.

Aquifers consist of either unconsolidated deposits or consolidated rocks. Most unconsolidated deposits consist of material that can range in size from tiny fractions of an inch (clay size) to several feet (boulders), but most commonly are sand and gravel size. Water in unconsolidated aquifers is found in the voids between particles. Generally, unconsolidated aquifers composed of coarse-grained particles, such as sand and gravel, yield more water than those composed of fine-grained particles, such as silt and clay.

Consolidated rocks are composed of mineral particles of different sizes and shapes that are fused together by the effects of heat and pressure or chemical reactions. Consolidated-rock aquifers

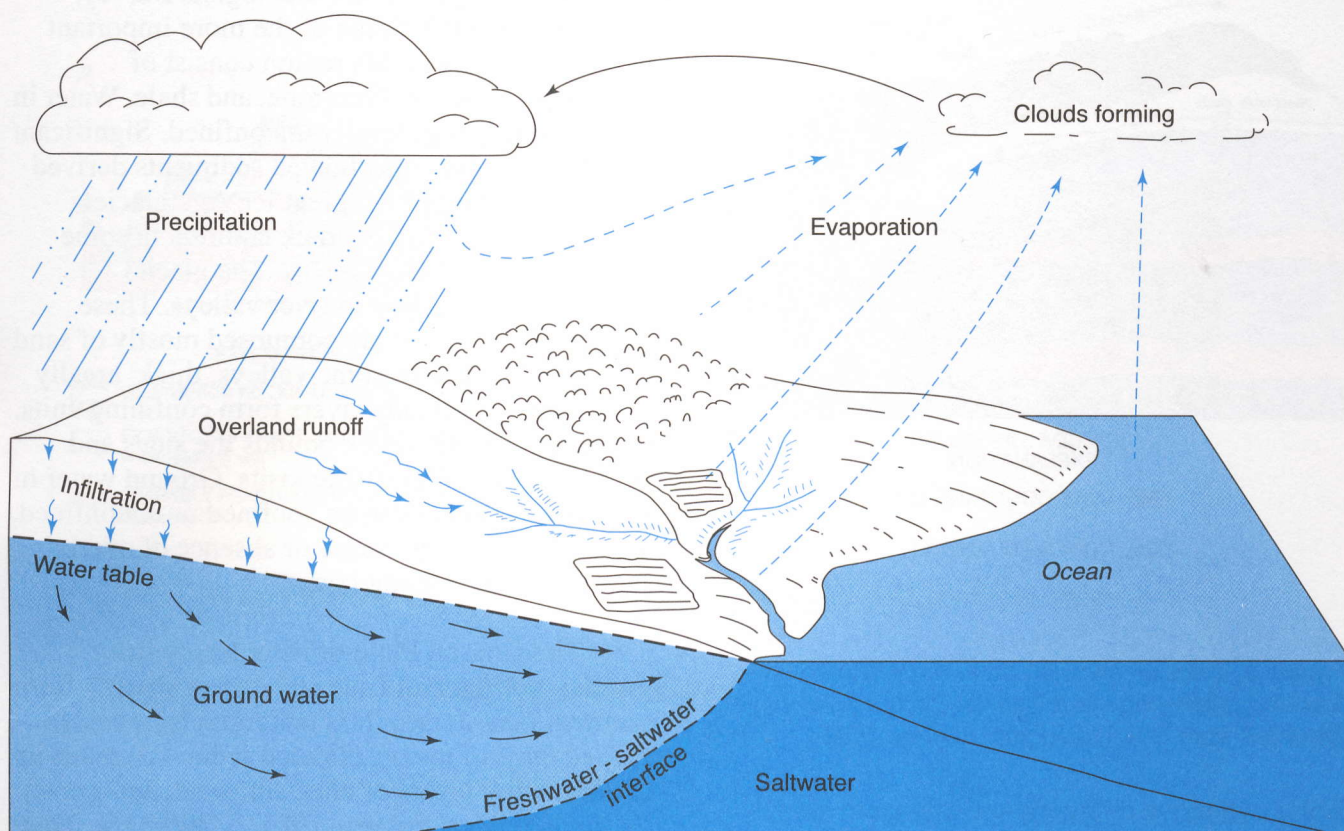


Figure 5. Diagram of the hydrologic cycle. (Modified from Heath, 1983)

are commonly referred to as bedrock aquifers. Water in bedrock aquifers is found chiefly in fractures within the rock. These fractures vary greatly in size and are more common near the land surface than at depth. The larger the fracture, the more water it can hold. Some bedrock aquifers are composed of a rock, such as sandstone, that is itself permeable. Aquifers of this type contain water both in fractures within the bedrock and in spaces between the individual sand particles that make up the bedrock.

Ground water is present in aquifers under one of two conditions--unconfined or confined (fig. 6). Unconfined conditions exist where water only partly fills an aquifer. The water surface is free to rise and fall, and fluctuates with changes in atmospheric pressure, rainfall, and other factors. Aquifers in these areas are referred to as unconfined, or water-table, aquifers. Water in unconfined aquifers is recharged by precipitation or by leakage from surface-water bodies such as

lakes and streams. Confined conditions exist where water completely fills an aquifer that is overlain by a confining layer--that is, a layer of less permeable clay or rock that slows the vertical movement of water. These aquifers are called confined aquifers. Water reaches confined aquifers either by flow from an unconfined part of the aquifer, called the recharge or outcrop area, by leakage through adjacent or bordering confining units, or by recharge into an unconfined part of the aquifer from adjoining surface water bodies, such as a lake, a stream, or the ocean. Water in confined aquifers can be very old and may have moved from distant areas of recharge centuries or even millennia ago. General patterns of ground-water flow in a Coastal Plain aquifer system are illustrated in figure 6.

The composition of an aquifer and presence or absence of overlying confining layers influence the rate of movement of water and contaminants.

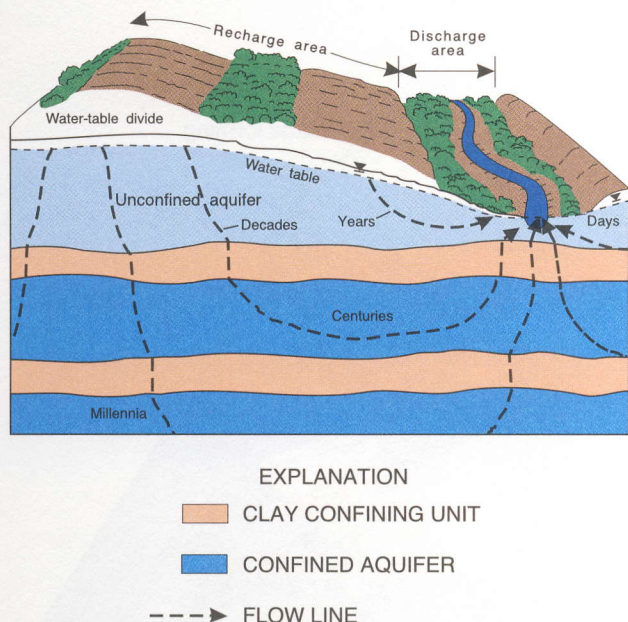


Figure 6. Diagram showing patterns of ground-water flow and relative age in a Coastal Plain aquifer system. (Modified from U.S. Geological Survey, 1985)

Water can move relatively quickly from land surface to the water table in a cavernous limestone or a highly fractured sandstone, for example, but will move more slowly in a tight, sparsely fractured shale or basalt. In fractured-rock aquifers, water moves within fractures and contaminants can be transported with this water. The rate of movement of ground water in a clay confining layer may be only a fraction of an inch per day whereas, in an aquifer composed of sand, the rate of movement may be several feet per day. The rates of movement in limestone caverns, lava tubes, and large rock fractures can approach those observed in surface streams (thousands of feet per day). The total distance that water travels underground between recharge and discharge areas can range from several feet to hundreds of miles. Total distance and depth of ground-water movement typically increase with the distance between recharge and discharge areas.

New Jersey and Long Island are underlain by several different aquifer types (fig. 7) (Cohen and others, 1968; U.S. Geological Survey, 1985, 1988; Zapecza, 1989). New Jersey is underlain by both unconsolidated aquifers and bedrock aquifers. The area north of the Fall Line in New Jersey is underlain by bedrock aquifers composed of many

different rock types (U.S. Geological Survey, 1985, p. 309-316). Some of the more important bedrock aquifers in this region consist of sandstone, siltstone, limestone, and shale. Water in these aquifers is generally unconfined. Significant thicknesses of unconsolidated sediments derived from the melting of the great Ice Age glaciers overlie the fractured-bedrock aquifers in some areas of northern New Jersey. The glacial sediments are thickest in river valleys. These "valley-fill" aquifers are composed mostly of sand and gravel layers. In some valleys, thick, areally extensive silt and clay layers form confining units. Less permeable bedrock bounds the sides and bottom of the valley-fill deposits. Ground water in valley-fill aquifers can be confined or unconfined, depending on the presence or absence of overlying silt and clay confining layers.

The Coastal Plain of New Jersey lies southeast of the Fall Line and differs sharply from northern New Jersey. It is underlain by a wedge-shaped mass of unconsolidated sediments made up of alternating layers of clay, silt, sand, and gravel (U.S. Geological Survey, 1985, p. 309-316). This wedge is less than 50 ft thick at the Fall Line and thickens to more than 6,500 ft at the southern tip of Cape May County. Five principal and several minor unconsolidated aquifers are found in the Coastal Plain. Four of the five principal aquifers are confined, except in small areas where they crop out (where the aquifer is exposed at land surface). The fifth major aquifer, the Kirkwood-Cohansey aquifer system, is unconfined. Beneath these unconsolidated sediments lies relatively impermeable bedrock.

The aquifers of the Coastal Plain of Long Island are very similar in composition to those of the New Jersey Coastal Plain. Long Island is underlain by bedrock, which in turn is overlain by a wedge-shaped mass of unconsolidated sediments, made up of alternating layers of clay, silt, sand, and gravel (U.S. Geological Survey, 1985, p. 323-328). The total thickness of overlying sediments is approximately 2,000 ft in south-central Suffolk County and decreases toward the north shore, where bedrock is exposed on the far northwestern corner of the island. Two major and two minor unconsolidated aquifers are found on Long Island. One of the major aquifers, the upper glacial aquifer, is unconfined. The underlying

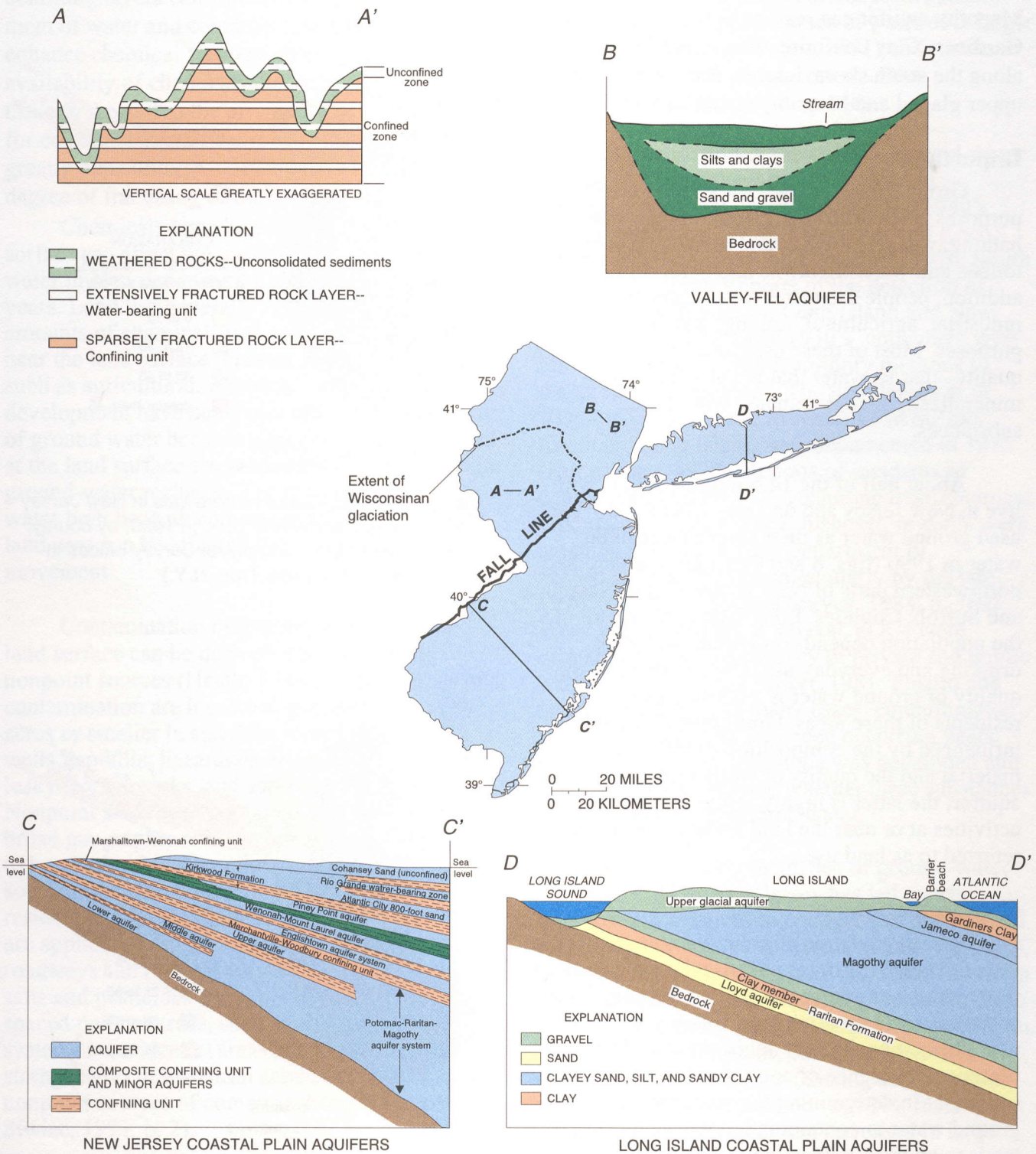


Figure 7. Location of sections and generalized diagram of the four types of aquifers in New Jersey and on Long Island, New York. (Modified from U.S. Geological Survey, 1985)

Magothy aquifer generally is unconfined; however, minor clay layers within the upper part of the Magothy aquifer can restrict flow locally. The Gardiners Clay confining unit, which is present along the south shore, inhibits flow between the upper glacial and Magothy aquifers.

Importance

Ground water is used for many domestic purposes, such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering lawns and gardens. In addition, people use water for commercial, industrial, agricultural, mining, and other purposes. Most of these uses require water of high quality--that is, water that is not salty, highly mineralized, or contaminated with toxic substances.

About half of the 14.6 million people who live in New Jersey and on Long Island, New York, used ground water as their source of drinking water in 1990 (figs. 8 and 9). In the southern and northwestern parts of New Jersey, and in Nassau and Suffolk Counties, Long Island, nearly all of the population depends on ground water for drinking and everyday use. Unquestionably, the quality of ground water is a major concern for residents of these areas. Ground-water quality is influenced by the composition of the aquifer material and the quality of water recharging the aquifer; the latter is highly influenced by human activities at or near the land surface, commonly referred to as land use.

Contamination

The degradation of ground-water quality is a major concern for those who use the water and for water managers and health officials responsible for ensuring a safe drinking-water supply for public use. The composition of aquifer material and the presence or absence of confining layers can be important in determining the vulnerability of ground water to contamination. Ground water tends to be most vulnerable to contamination in areas that have well-drained soils and are underlain by unconsolidated sand and gravel aquifers where no protective confining layer is present. These highly permeable systems allow contaminants to move easily from the land surface to the water table. In contrast, the presence of fine-

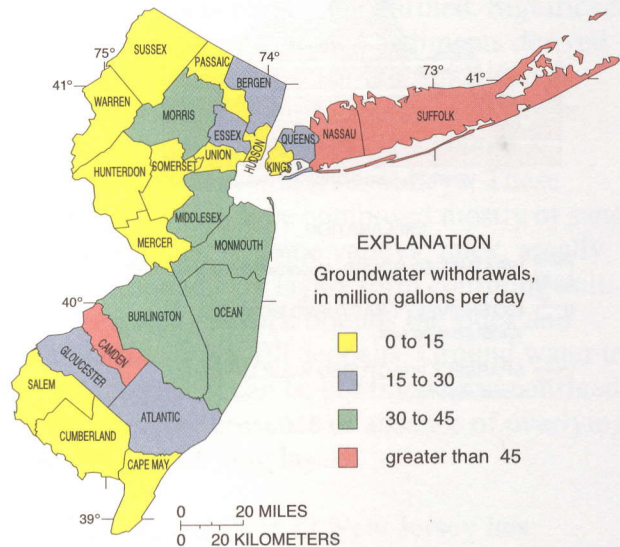


Figure 8. Ground-water withdrawals in New Jersey and on Long Island, New York, in 1990, by county. (Data on file at U.S. Geological Survey offices in West Trenton, N.J., and Troy, N.Y.)

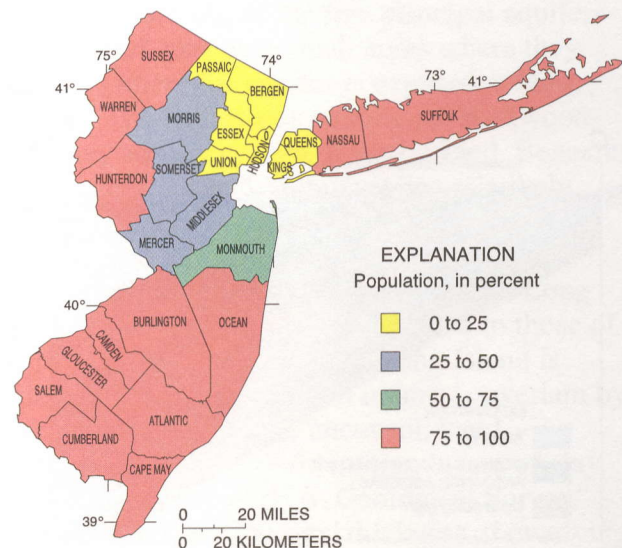


Figure 9. Percentage of the population in New Jersey and on Long Island, New York, that used ground water in 1990, by county. (Data on file at U.S. Geological Survey offices in West Trenton, N.J., and Troy, N.Y.)

grained materials such as clay and silt in soils and confining layers can restrict the downward movement of water and contaminants. Clay and silt also enhance chemical sorption, thereby decreasing the availability of chemicals that might have moved through the soil to the ground water. The potential for contamination of bedrock aquifers varies greatly depending on soil and rock type and the degree of fracturing of the rock.

Chemicals introduced at or near the land surface can affect the quality of underlying ground water in New Jersey and Long Island for many years. Land use generally reflects the types and amounts of chemicals that are introduced at or near the land surface. Present and past land uses such as agricultural, industrial, and urban development have had major effects on the quality of ground water because chemicals used or spilled at the land surface are carried to the water table in ground-water recharge. The quality of ground water both beneath and downgradient from these land uses can be affected because of ground-water movement.

Contamination of ground water from the land surface can be derived from point and nonpoint sources (Heath, 1983). Point sources of contamination are localized, generally are a few acres or smaller in size, and include injection wells, landfills, hazardous-waste sites, pipelines, leaky storage tanks, and surface impoundments. Nonpoint sources of contamination extend over broad geographic areas, ranging from a few acres to hundreds of square miles. Examples of nonpoint sources of contamination include agricultural and residential land to which fertilizers and pesticides are applied, mining areas, animal feedlots, and roadways and right-of-way areas on which deicing salts and pesticides are applied. Multiple, closely spaced 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 (Vowinkel and Siwec, 1991, p. 2).

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 but typically result in

higher contaminant concentrations than nonpoint sources. Contamination from nonpoint sources typically affects large volumes of water over larger areas (Vowinkel and Siwec, 1991) and results in lower contaminant concentrations than contamination from point sources.

Contamination of the shallow ground-water system on Long Island by fertilizers and detergents was first documented in the 1940's (Flynn and others, 1958; Perlmutter and Koch, 1964, 1971; Perlmutter and Guerrara, 1970; Smith and Myott, 1975). Reports of the detection of VOCs and pesticides on Long Island and New Jersey began in the early 1970's, coincident with the advent of improved laboratory methods to detect these compounds. The first detection of VOCs in ground water in Nassau and Suffolk Counties, Long Island, was documented in 1975 (Koppelman, 1978). Reports of incidents of contamination with VOCs resulting from chemical production, waste storage, disposal, or spills were reaching the New Jersey Department of Environmental Protection regularly by the late 1970's (U. S. Geological Survey, 1988, p. 369). Trace concentrations of several VOCs were detected in a 1978-81 survey of private and public wells in New Jersey (Tucker, 1981; Fusillo and Hochreiter, 1982). In many cases, contamination with VOCs probably had been occurring years before a laboratory technique was developed and (or) applied to determine whether these substances were present in the ground water.

The increasing incidence of ground-water contamination in New Jersey has led water-management agencies to conduct soil borings and to install gas vents, piezometers, monitoring wells, and recovery wells throughout the State. The sharp increase in the number of permits issued for these types of monitoring devices, from 2,108 in 1983 to 15,333 in 1990 (Principi, 1991), is indicative of the growing concern over existing and potential ground-water contamination (fig. 10). Installation of these types of devices has increased in large part because of the implementation of the Environmental Cleanup Responsibility Act by the New Jersey Department of Environmental Protection (NJDEP) in 1983. The Act prohibits the sale of industrial properties beneath which contaminant concentrations exceed NJDEP-designated limits. To ensure that these limits are

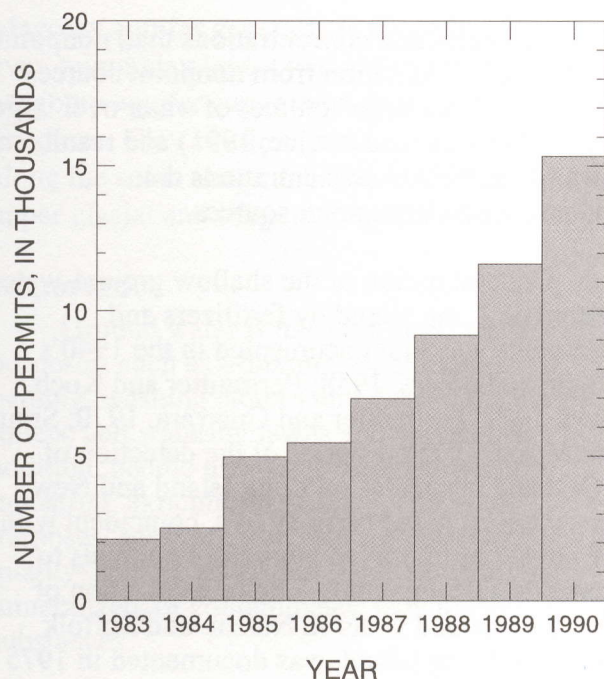


Figure 10. Number of permits issued in New Jersey for soil borings, gas vents, monitoring wells, piezometers, and recovery wells, 1983-90. (Data from Principi, 1991)

not exceeded, monitoring devices are required for the collection of ground-water, soil, and soil-vapor samples. Because of the frequency of industrial property sales in New Jersey, the installation of monitoring devices has increased substantially since the Act was adopted. In addition, the NJDEP's underground storage tank program requires the installation of monitoring devices whenever an underground storage tank is removed, contaminated soil or water is discovered near an existing tank, or new tanks are installed at gas stations (Principi, 1991, p. 6).

According to the New Jersey Department of Environmental Protection and Energy (1993, p. IV-15), nearly 5,000 cases of ground-water contamination had been reported in New Jersey as of April 1992 (fig. 11). Substances identified as contaminants included VOCs, metals, radionuclides, pesticides, dioxin, and bacteria. The number of cases was greatest in the counties adjacent to the large urban centers of New York City and Philadelphia. Some of the major sources of ground-water contamination are underground storage tanks, landfills, surface spills, and waste

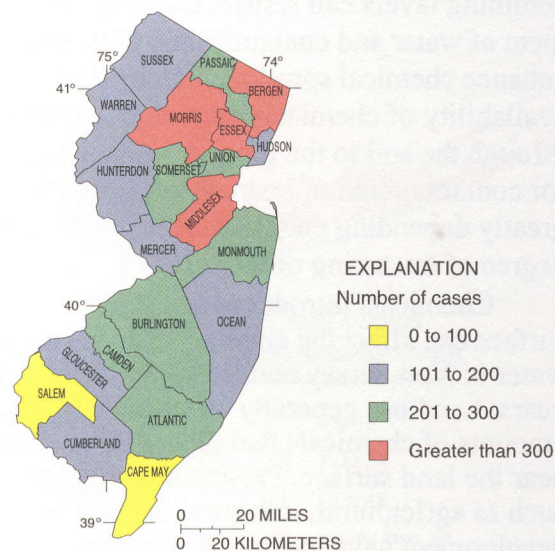


Figure 11. Number of reported ground-water-contamination cases in New Jersey as of April 1992, by county. (Data from New Jersey Department of Environmental Protection and Energy, 1993)

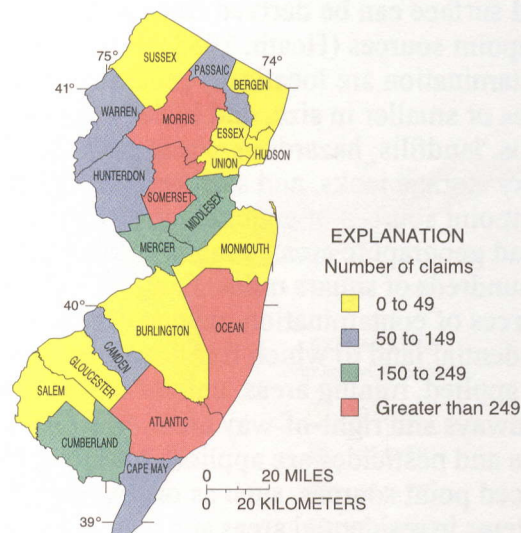


Figure 12. Number of claims received for ground-water contamination in New Jersey in 1994, by county. (Data from Ann McClung, New Jersey Department of Environmental Protection, written commun., 1995)

lagoons. In many cases, however, the source of contamination is unknown.

Ground-water contamination is a common problem on Long Island as well as in New Jersey. The New York State Department of Environmental Conservation (NYSDEC) maintains a data base of information pertaining to ground-water contamination in New York State. In 1994, this data base included more than 260 contaminated public-supply wells and more than 30 groups of contaminated private wells on Long Island. In addition, the data base contained 1,349 oil-spill recovery sites, 142 hazardous-waste remediation sites, and 70 pollution-discharge elimination sites (William O'Brien, New York State Department of Environmental Conservation, written commun., 1996).

In some instances, contaminated ground water can be treated to remove potentially harmful substances before the water is distributed to users. In 1995, 96 public water-supply facilities in New Jersey were removing VOCs from contaminated wells (Sandra Kreitzman, New Jersey Department of Environmental Protection, written commun., 1995). The New Jersey Spill Compensation Fund, set up by the New Jersey Legislature in 1985, is administered by the NJDEP to handle claims by well owners concerning ground-water contamination. The program provides money to compensate well owners for the cost of sealing wells, installing treatment systems for VOCs and (or) mercury near the wellhead, and establishing hookups or water-main extensions for well owners near public-supply systems. From 1985 through 1994, the Spill Fund handled more than 6,000 claims (fig. 12) and paid more than \$35 million to well owners and water companies to ensure a safe supply of drinking water for New Jersey residents (Ann McClung, New Jersey Department of Environmental Protection, written commun., 1995). Many residents of New Jersey depend on water pumped from shallow domestic wells. Increasingly, these wells are becoming contaminated with VOCs and mercury associated with industrial, residential, and agricultural land uses. In Ocean County, VOC contamination has led many domestic users to switch to public water supply. For example, in 1976 about 88 percent of Ocean County residents used domestic water and 12 percent used publicly supplied water. In 1996,

these percentages were reversed (Joseph Przywara, Ocean County Health Department, oral commun., 1994).

Treatment of water before use to remove contaminants is a temporary solution to a long-term problem. Regional remediation of contaminated ground water over a large area is difficult and expensive. In some cases, purge wells can be installed to pump ground water to the surface, where it is treated. The treated ground water is either reinjected into the ground, allowed to seep back into the ground through spreading lagoons, or discharged into a stream or other surface-water body. In other cases, ground-water contamination can be remediated naturally by physical, chemical, and biological processes in soil, rock, and water (Chapelle, 1995). In cases where contaminated ground water is not remediated by human treatment or natural processes, however, it will continue to move along a flow path to a discharge point such as a stream, river, lake, or well. Depending on the length of the flow path and the composition of the aquifer material, movement of contaminated ground water to a discharge point could take tens, hundreds, or even thousands of years.

The diversity of land use in the study area creates a variety of potential effects on ground-water quality that vary with duration and type of land use. The effects of nonpoint-source contamination by nitrates, VOCs, and pesticides on ground-water quality in New Jersey and Long Island are described below.

NITRATE IN GROUND WATER

Although nitrate is not a highly toxic compound, it can be reduced to nitrite by bacteria in the intestines of infants, which may result in the disease methemoglobinemia, more commonly known as "blue-baby syndrome." Infant mortality from this disease is rare when concentrations of nitrate (as nitrogen [N]) in drinking water are less than 10 mg/L, but its incidence increases with increasing concentration (Walton, 1951). The U.S. Environmental Protection Agency (USEPA) has set the maximum contaminant level (MCL) for nitrate (as N) in drinking water at 10 mg/L (U.S. Environmental Protection Agency, 1988).

Nitrate enters ground water from natural and human sources. Natural sources of nitrate are atmospheric deposition and organic matter in soil. Soil particles, plant roots, and certain bacteria within the soil use nitrate and other nitrogen compounds and slow their movement downward to ground water. Sources of nitrate related to human activities vary by land-use type. In urban areas, sources of nitrate include lawn fertilizers, septic-system wastes, leakage from sewer pipes, and industrial wastes. Sources of nitrate in agricultural areas include crop fertilizers, animal manure, and septic-system wastes. Some of the nitrate deposited from the atmosphere is related to human activities such as releases of nitrogen-rich materials from automobile exhausts and industrial smokestacks.

Estimated values of nitrogen deposition from the atmosphere to the land in the eastern United States are greater than those in the western states, primarily because emissions of nitrogen oxides are larger in urban areas (Puckett, 1995, p. 411A). Available data on nitrate concentrations in precipitation in New Jersey are limited. Median concentrations of nitrate (as N) at four precipitation collectors in an undeveloped area of the New Jersey Coastal Plain ranged from 0.3 to 0.4 mg/L (Lord and others, 1990, p. 120). Most plants require some nitrogen to grow. The amount of nitrogen entering the soil from the atmosphere generally is adequate to support natural vegetation; however, additional nitrogen from fertilizers and manure is required to maintain and increase agricultural crop yields (figs. 13 and 14), particularly in the New Jersey and Long Island Coastal Plain, where soils contain less nitrogen than do soils in northern New Jersey.

Although the loading of nitrogen to the land surface from atmospheric deposition can be estimated (Puckett, 1995), the actual quantity of nitrate in ground water in New Jersey and Long Island that is derived from soil nitrogen and atmospheric deposition is unknown. In an analysis of nitrate concentrations in ground water from 85 wells on Long Island, Perlmutter and Koch (1972) suggest that concentrations exceeding 1 mg/L are the result of human activities.

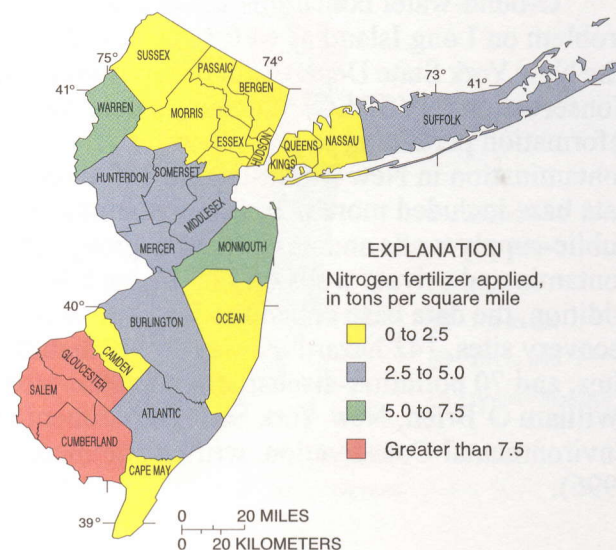


Figure 13. Amount of nitrogen fertilizer applied in New Jersey and on Long Island, New York, in 1991, by county. (Data from Anderson and Smith, 1990)

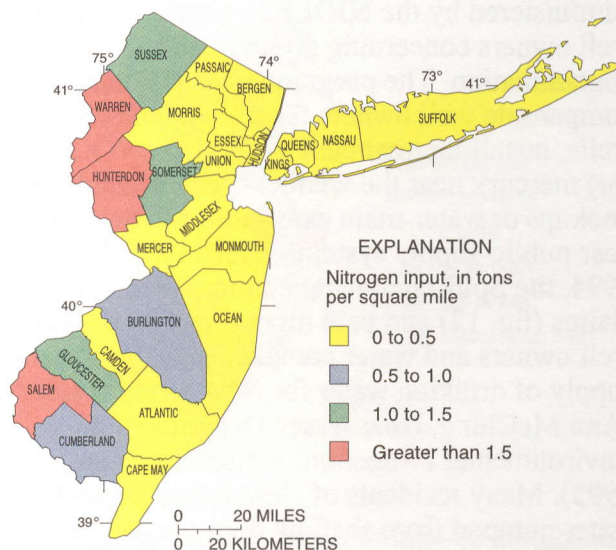


Figure 14. Amount of nitrogen input from animal manure in New Jersey and on Long Island, New York, in 1992, by county. (Data from Anderson and Smith, 1990)

Relation to Aquifer Conditions

Because confining units restrict the vertical movement of contaminants into deep parts of the aquifer system, the presence or absence of a confining unit between the land surface and an aquifer can determine whether or not contaminants are found in the ground water. In a study of 301 wells in the Potomac-Raritan-Magothy aquifer system, nitrate concentrations were found to be significantly greater in unconfined than in confined parts of the aquifer system (Vowinkel and Battaglin, in press). The Potomac-Raritan-Magothy aquifer system crops out in a narrow band extending from Raritan Bay southwest through central New Jersey and along the eastern bank of the Delaware River (fig. 15). It is unconfined in its outcrop area, but extends beneath other hydrogeologic units to the southeast, where

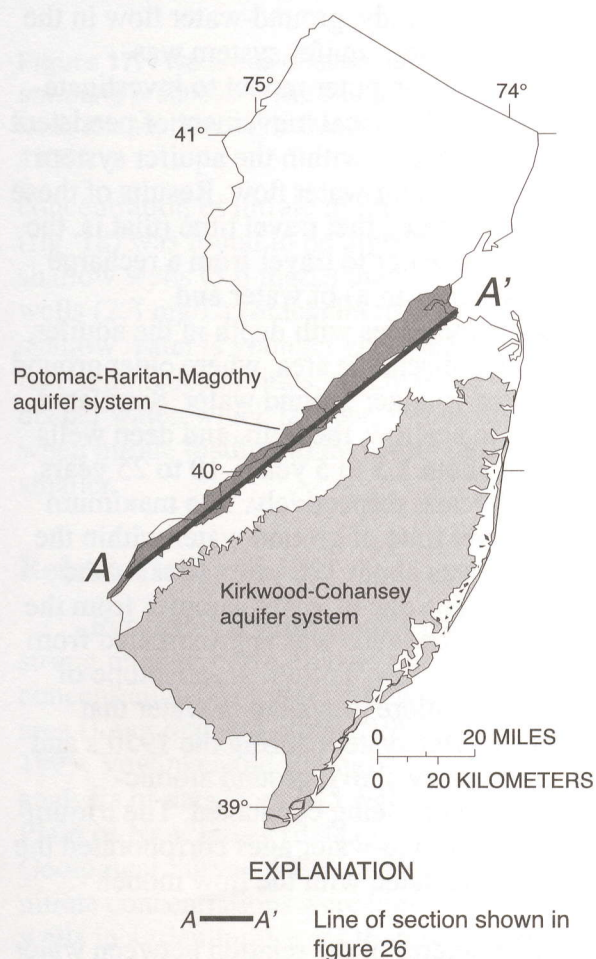


Figure 15. Outcrop areas of the Potomac-Raritan-Magothy and Kirkwood-Cohansey aquifer systems in New Jersey. (Modified from Vowinkel and Battaglin, in press)

it is confined. The outcrop area underlies a highly urbanized area of New Jersey and, therefore, is highly vulnerable to contamination by nitrate and other substances associated with human activities. The median nitrate concentration in ground water in the unconfined areas was 0.3 mg/L, whereas the median concentration in the confined areas was less than the laboratory reporting level of 0.1 mg/L. About 41 and 4 percent of samples from wells in the unconfined and confined areas, respectively, contained concentrations of nitrate equal to or greater than 1 mg/L (fig. 16). About 54 and 9 percent of samples from wells in the unconfined and confined areas, respectively, contained concentrations greater than the laboratory reporting level of 0.1 mg/L. About 6 percent of nitrate concentrations in samples from wells in unconfined areas exceeded the MCL of 10 mg/L (fig. 16); however, none of the nitrate concentrations in samples from wells in confined areas exceeded the MCL (Vowinkel and Battaglin, in press).

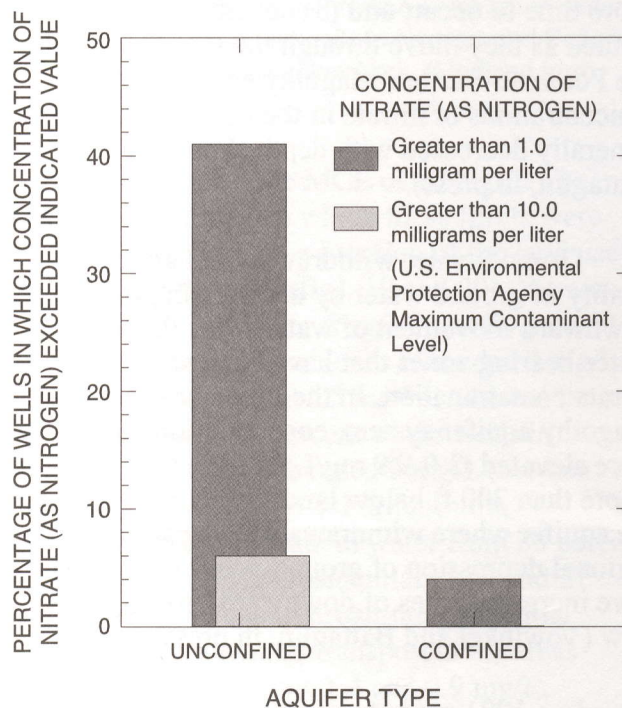


Figure 16. Frequency of detection of nitrate in water from wells in unconfined and confined parts of the Potomac-Raritan-Magothy aquifer system, New Jersey. (Data from Vowinkel and Battaglin, in press)

Concentrations of nitrate in the Potomac-Raritan-Magothy aquifer system are smaller in the confined areas than in the unconfined areas because of the effect of the overlying confining unit. The confining unit slows the movement of water to the lower aquifer so that it is older than water in the unconfined areas and, therefore, is less likely to have been affected by human activities. Also, as water flows downward through confining units, dissolved oxygen is depleted. Under these conditions, oxygen in the nitrate compound is used as an oxygen source by bacteria, resulting in the depletion of nitrate (Vowinkel and Battaglin, in press).

Relation to Depth in the Aquifer

Concentrations of nitrate and other constituents generally decrease with depth because (1) the age of ground water generally increases with depth in the flow system and, therefore, deeper water is less likely to be affected by human activities; (2) physical and chemical reactions that remove constituents from ground water have had more time to occur; and (3) constituents are diluted as they move through the flow system. In the Potomac-Raritan-Magothy aquifer system, concentrations of nitrate in the unconfined areas generally decreased with depth (Vowinkel and Battaglin, in press).

Ground-water withdrawals can affect the quality of ground water by accelerating the downward movement of water from shallow water-bearing zones that have been affected by nitrate contamination. In the Potomac-Raritan-Magothy aquifer system, concentrations of nitrate were elevated (3.0-9.9 mg/L) in deep ground water (more than 200 ft below land surface) in a part of the aquifer where withdrawals have caused a regional depression of ground-water levels and have increased rates of downward ground-water flow (Vowinkel and Battaglin, in press).

In a 1991 study to determine the vertical distribution of agricultural chemicals in the unconfined Kirkwood-Cohansey aquifer system, water samples were collected from observation wells installed at different depths (nested wells) in five areas that were farmed in or prior to 1991 (Szabo and others, 1994). The well nests were located near topographic divides, where the

vertical component of flow is greatest. Concentrations of nitrate were 10 or more times as great in water from shallow and medium-depth wells than in water from deep wells. Nitrate concentrations were greatest in water from the medium-depth wells at four of the five sites, and equalled or exceeded the USEPA MCL in water from two sites. The detection of elevated concentrations of nitrate in ground water at most depths at all five sites indicates that most of the water in the Kirkwood-Cohansey aquifer system directly underlying agricultural areas probably contains elevated concentrations of nitrate. The fact that nitrate concentrations were smallest in the deep wells, however, indicates that nitrate has not penetrated to the deep parts of the aquifer in areas where ground-water withdrawals are small or absent (Szabo and others, 1994, p. 107).

In the same study, ground-water flow in the Kirkwood-Cohansey aquifer system was simulated with a computer model to investigate the horizontal and vertical movement of persistent agricultural chemicals within the aquifer system along paths of ground-water flow. Results of these simulations indicated that travel time (that is, the time it takes for water to travel from a recharge area to a discharge area) of water and contaminants increases with depth in the aquifer, except near the discharge area, where older ground water overlies younger ground water. Simulated travel times to shallow, medium, and deep wells ranged from about 1.5 to 5 years, 10 to 25 years, and 30 to 50 years, respectively. The maximum simulated travel time of ground water within the modeled area was about 125 years (Szabo and others, 1994). The age of water samples from the nested observation wells was approximated from tritium concentrations. Tritium is an isotope of hydrogen that is more prevalent in water that entered the aquifer system during the 1950's and 1960's, when many above-ground atomic-weapons tests were being conducted. The tritium-approximated ground-water ages corroborated the travel times calculated with the flow model.

Similar studies of the relation between water quality and depth have been conducted on Long Island. In an analysis of water-quality data from a network of 207 wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties on Long Island (fig. 17), the median

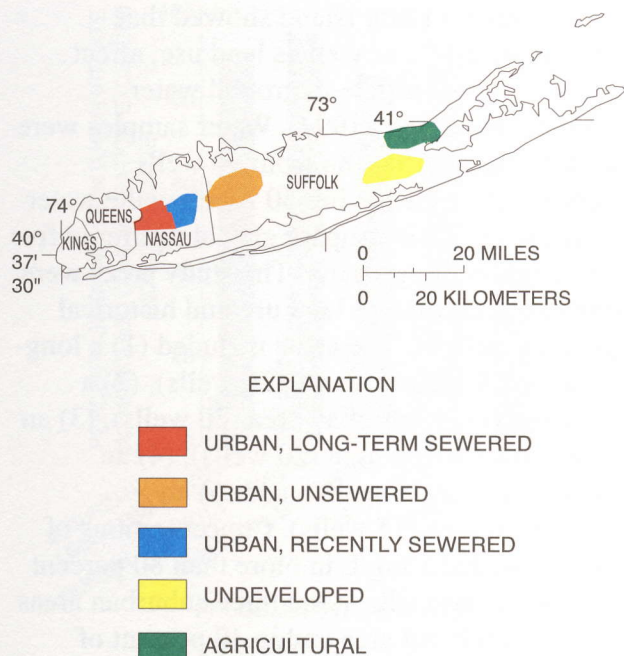


Figure 17. Five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York. (Modified from Stackelberg, 1995)

concentration of nitrate in three suburban areas (fig. 18) was found to be higher in water from shallow wells (5.6 mg/L) than in water from deep wells (2.3 mg/L) (Stackelberg, 1995, p. 31). The shallow water is younger and has been affected by recent human activities, whereas the quality of deeper water, which is older, is indicative of a time when nitrate loading to the water table was smaller.

Relation to Land Use

Results of several studies have indicated a strong relation between land use and nitrate concentrations in water from wells in the study area (Leamond and others, 1992; Stackelberg, 1995; Vowinkel and Battaglin, in press). In an analysis of data from 645 wells in the Coastal Plain of New Jersey (data on file at U.S. Geological Survey office in West Trenton, N.J.), nitrate concentrations were higher in samples from wells in agricultural areas than in samples from wells in urban or undeveloped areas. Nitrate concentrations exceeded 3 mg/L in about 30 percent of wells; that is, nearly one-third of wells sampled were affected by human inputs. Nitrate concentrations in more than 7 percent of the wells

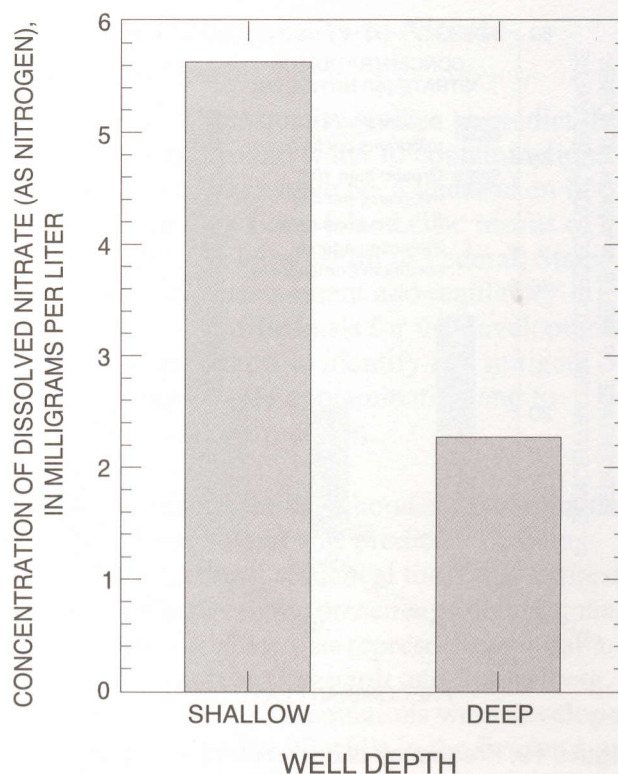


Figure 18. Median concentration of nitrate in water from shallow and deep wells in Nassau and Suffolk Counties, Long Island, New York. (Modified from Stackelberg, 1995)

sampled exceeded the MCL of 10 mg/L. The number of samples in which these limits were exceeded was largely a function of the land use surrounding the well (figs. 19 and 20). Nitrate concentrations in water from almost 70 percent of the wells in agricultural areas exceeded 3 mg/L (median concentration 5.5 mg/L), whereas those in water from only 10 percent of the wells in undeveloped areas exceeded 3 mg/L (median concentration 0.1 mg/L). Furthermore, concentrations of nitrate in water from 35 percent of the wells in urban-residential areas and 21 percent of the wells in urban-nonresidential (industrial/commercial/transportation) areas (median concentrations 1.4 and 0.9 mg/L, respectively) exceeded 3 mg/L. Nitrate concentrations in water from less than 3 percent of the wells in urban-residential, urban-nonresidential, and undeveloped areas exceeded 10 mg/L; however, those in water from more than 22 percent of the wells in agricultural areas exceeded 10 mg/L.

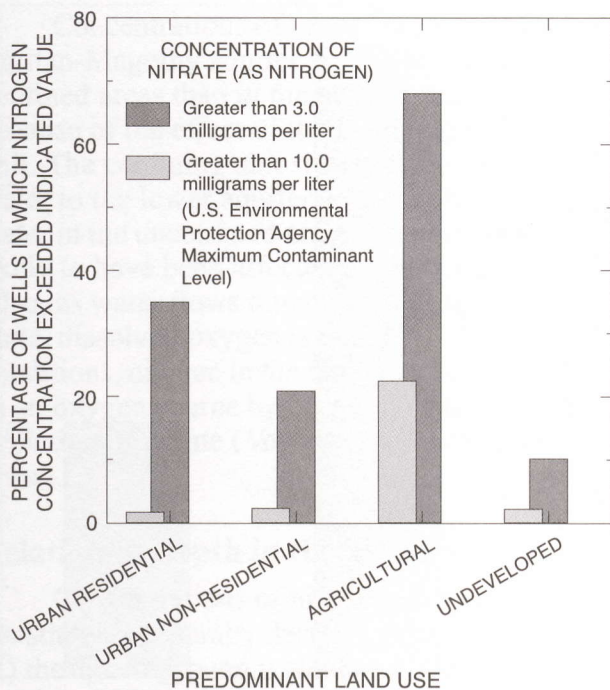


Figure 19. Frequency of detection of nitrate in water from 645 wells in the Coastal Plain of New Jersey, by predominant land use. (Data on file at U.S. Geological Survey office in West Trenton, N.J.)

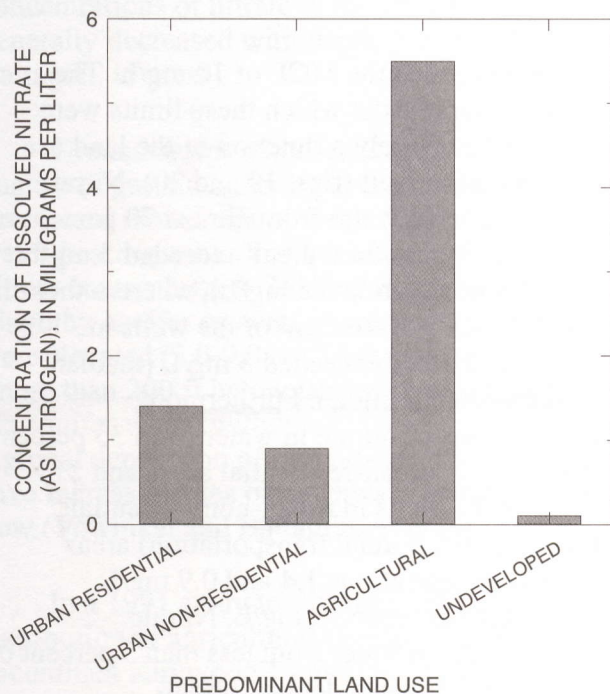


Figure 20. Median concentration of nitrate in water from 645 wells in the Coastal Plain of New Jersey, by predominant land use. (Data on file at U.S. Geological Survey office in West Trenton, N.J.)

A study on Long Island showed that sewerage practices, as well as land use, affect concentrations of nitrate in ground water (Leamond and others, 1992). Water samples were collected during 1987-88 from 90 wells completed at depths within 50 ft below the water table in the unconfined upper glacial aquifer in five study areas on Long Island. The study areas were delineated according to land use and historical sewerage practices. The areas included (1) a long-term sewerage suburban area (20 wells), (2) a recently sewerage suburban area (20 wells), (3) an unsewerage suburban area (20 wells), (4) an agricultural area (15 wells), and (5) an undeveloped area (15 wells). Concentrations of nitrate exceeded 1 mg/L in more than 80 percent of samples from wells in the three suburban areas and the agricultural area and in 40 percent of samples from wells in the undeveloped area (fig. 21). Concentrations of nitrate exceeded 10 mg/L in 40 percent of samples from wells in the agricultural area (median concentration 8.9 mg/L) and in 25 percent of samples from wells in both the recently sewerage area (median concentration 5.8 mg/L) and the unsewerage area (median concentration 6.6 mg/L) (fig. 22). Only 10 percent of samples from wells in the long-term sewerage area (median concentration 5.1 mg/L) contained nitrate concentrations greater than 10 mg/L, and no concentrations in the samples from wells in the undeveloped areas (median concentration 0.2 mg/L) exceeded the MCL (Leamond and others, 1992).

In general, concentrations of nitrate in ground water were lowest in the undeveloped areas, highest in the agricultural areas, and intermediate in the three suburban areas. The data indicate that sewerage has resulted in decreased nitrate concentrations (Leamond and others, 1992). Stackelberg (1995) found that concentrations of nitrate and other chemicals indicative of human effects have decreased in areas that have been sewerage for more than 2 decades. Median concentrations of nitrate in young, shallow ground water were highest in samples from the unsewerage suburban area and the recently sewerage area, where the effects of sewers were not yet apparent.

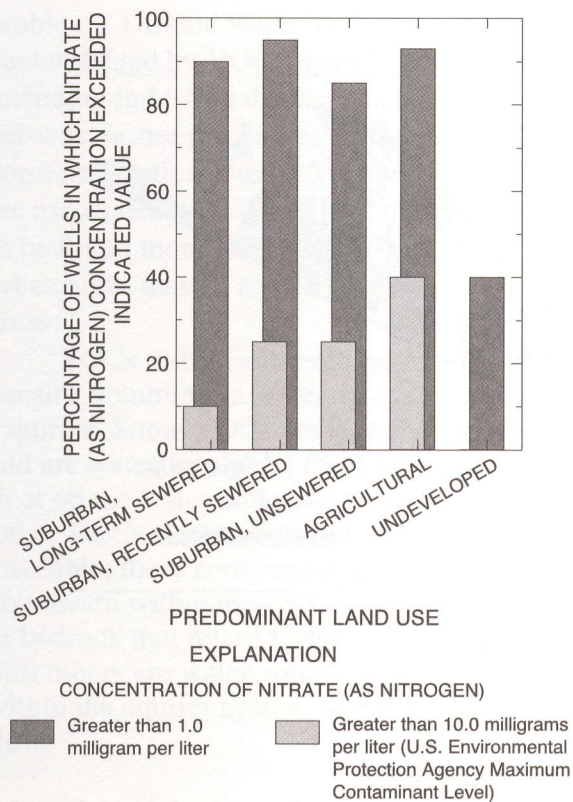


Figure 21. Frequency of detection of nitrate in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York. (Modified from Leamond and others, 1992)

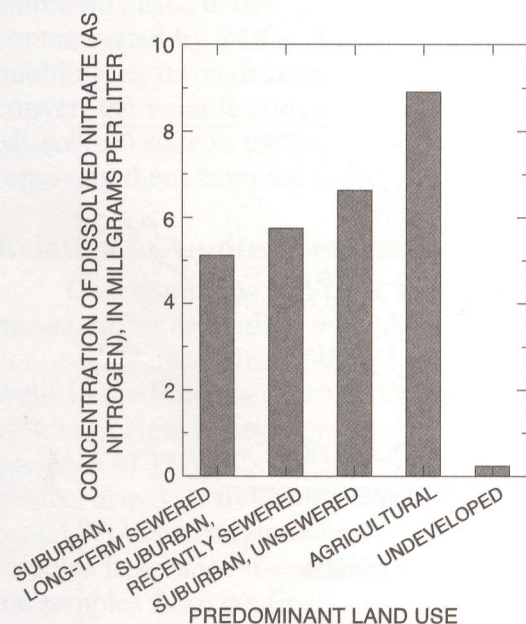


Figure 22. Median concentration of nitrate in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York. (Modified from Leamond and others, 1992)

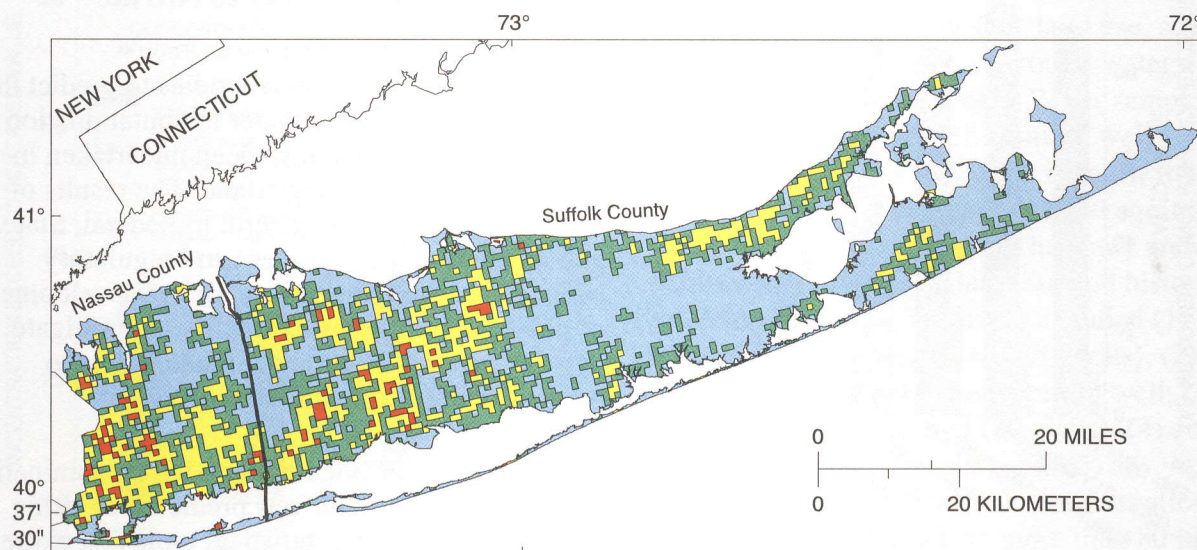
Predicting Vulnerability to Nitrate Contamination

Ground-water-quality studies to predict the vulnerability of ground water to contamination from the land surface have been undertaken in New Jersey and on Long Island. The results of these studies have been useful to Federal, State, and local water-management and regulatory agencies as a scientific basis for the development of plans and programs to identify and mitigate existing ground-water contamination and to prevent future contamination.

For example, the likelihood of contamination in parts of Long Island was predicted by using regression equations, statistical tools that express the relations between the presence of contaminants and land-use variables that represent potential contaminant sources (Eckhardt and Stackelberg, 1995). These regression equations were developed by using data from the 90 wells in the five land-use areas of Long Island described previously. One of these regression equations was applied to a gridded map of Nassau and Suffolk Counties to estimate the probability of nitrate concentrations in ground water exceeding 3 mg/L. The resulting estimates were used to construct a predictive map (fig. 23) that was compared to a map of nitrate-concentration data from 268 wells in the two-county area (fig. 24). The measured nitrate concentrations corroborate the statistically determined estimates. The data show that areas of high predicted probability of nitrate contamination are related to observed nitrate concentrations greater than 3 mg/L and that areas of low predicted probability of nitrate contamination are related to observed nitrate concentrations less than 3 mg/L (Eckhardt and Stackelberg, 1995).

VOLATILE ORGANIC COMPOUNDS IN GROUND WATER

Volatile organic compounds (VOCs) are used for many household and industrial purposes. VOCs are widely used as cleaning agents, solvent degreasers, refrigerants, and fumigants. Some VOCs are components of gasoline, oil, and heating fuels. VOCs are a concern because exposure to them has been associated with a variety of adverse health effects, including cancer, liver and kidney damage, nervous-system disorders, and respiratory



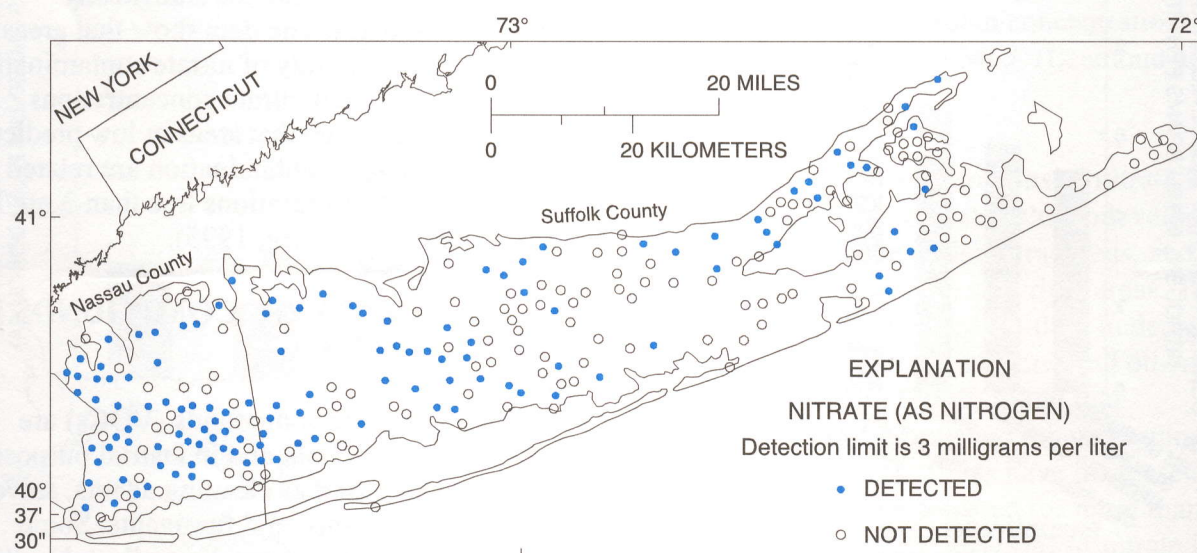
EXPLANATION

Probability of nitrate (as nitrogen) concentration
greater than 3 milligrams per liter

≤ Less than or equal to > Greater than

■ ≤0.40
 ■ >0.40-0.60
 ■ >0.60-0.80
 ■ >0.80

Figure 23. Estimated probability of detecting nitrate in a concentration greater than 3 milligrams per liter in water from wells in Nassau and Suffolk Counties, Long Island, New York. (Modified from Eckhardt and Stackelberg, 1995)



EXPLANATION

NITRATE (AS NITROGEN)

Detection limit is 3 milligrams per liter

• DETECTED

○ NOT DETECTED

Figure 24. Location of detections of nitrate in water from 268 wells in Nassau and Suffolk Counties, Long Island, New York. (Modified from Eckhardt and Stackelberg, 1995)

problems. Ground water has been and is presently contaminated by VOCs from a variety of sources, including industrial discharges, landfills, municipal-wastewater discharges, leaks and spills, and domestic septic-system effluent. Because VOCs are associated with urban land use, they are likely to be found more frequently in aquifers beneath urban areas than in aquifers beneath nonurban areas.

VOCs differ from each other with respect to density, solubility in water, and tendency to vaporize. Some VOCs are less dense than water and are water-insoluble; these compounds tend to float on the water table as a separate liquid phase. Other VOCs are heavier than water and are water-insoluble; these compounds tend to sink downward within the aquifer system to clay lenses or bedrock that retard further vertical movement. Still others are water-soluble and tend to move within the aquifer system as part of ground-water flow.

Chemical, physical, and microbial mechanisms can prevent or slow the movement of VOCs from the land surface or the soil zone into the ground-water system. Because VOCs, by definition, are volatile (easily escape from water to the atmosphere), air purging is a method commonly used to treat ground water that has been contaminated by VOCs. Air purging involves bubbling air through contaminated water to convert the volatile compounds from the liquid (dissolved) state to the vapor state, thereby removing them from the water.

Relation to Aquifer Conditions

Concentrations of VOCs, like those of nitrate, differ depending on whether the aquifer is confined or unconfined. Water samples from 241 wells in the Potomac-Raritan-Magothy aquifer system in New Jersey were analyzed for the presence of 11 VOCs at concentrations equal to or greater than 3 $\mu\text{g/L}$ (Vowinkel and Battaglin, in press). VOCs were present in 17 percent of the samples from unconfined areas and 3 percent of the samples from confined areas (fig. 25). The most commonly detected VOCs were trichloroethylene (TCE), tetrachloroethylene (PCE), 1,1,1-trichloroethane (TCA), benzene, and chloroform. Concentrations of VOCs exceeded 10 $\mu\text{g/L}$ in samples from only one well in a confined

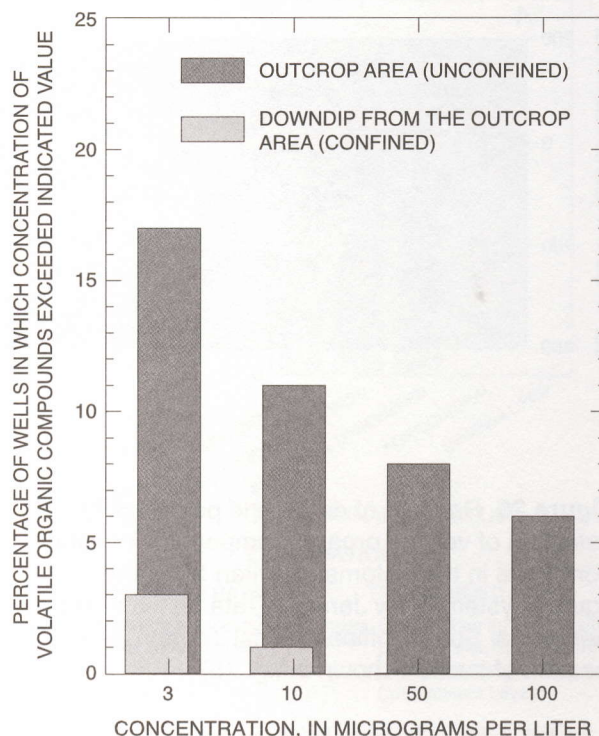


Figure 25. Frequency of detection of volatile organic compounds in water from wells in unconfined and confined parts of the Potomac-Raritan-Magothy aquifer system, New Jersey. (Data on file at U.S. Geological Survey office in West Trenton, N.J.)

area. The lower frequency of occurrence and smaller concentrations of VOCs in ground water in confined areas can be attributed to the greater age of the water and to the presence of overlying confining units, which restrict the vertical movement of contaminants from unconfined areas. Three of the four wells in confined areas that contained water with detectable concentrations of VOCs are within about 0.6 mi of an unconfined area (Vowinkel and Battaglin, in press).

Relation to Depth in the Aquifer

In the same study, VOCs were detected at depths greater than 200 ft below land surface mainly in the central and southwestern parts of the Potomac-Raritan-Magothy aquifer system outcrop area (fig. 26), in a region of heavy pumping. Because the primary direction of ground-water flow in a heavily pumped area is downward, the transport of VOCs into deep parts of the aquifer system is enhanced (Vowinkel and Battaglin, in press).

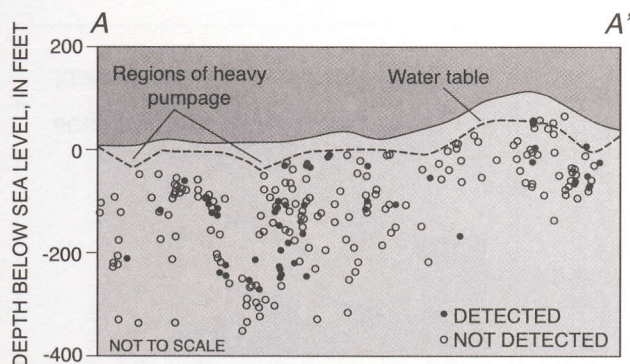
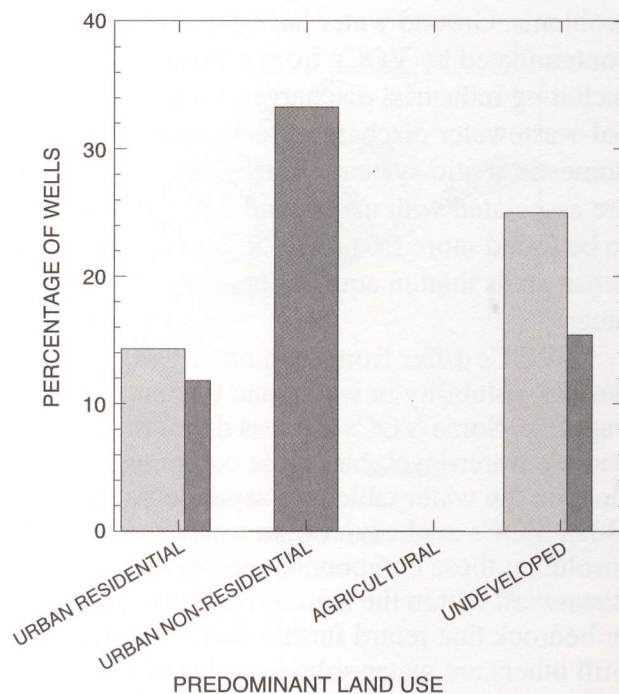


Figure 26. Relation of depth and pumpage to detection of volatile organic compounds in water from wells in the Potomac-Raritan-Magothy aquifer system, New Jersey. (Data on file at U.S. Geological Survey office in West Trenton, N.J.; location of section shown in fig. 15)

Relation to Land Use

An analysis of water-quality data from the Potomac-Raritan-Magothy and Kirkwood-Cohansey aquifer systems (fig. 15) conducted as part of the same study, showed that of the 11 VOCs for which samples were analyzed, none was detected in shallow ground water in agricultural areas in either aquifer system (fig. 27). These VOCs generally are not used in agricultural areas. VOCs were detected most frequently in water from wells in the unconfined part of the Potomac-Raritan-Magothy aquifer system with overlying urban-nonresidential (commercial/industrial) land use. Possible sources of VOCs in this area include leaking oil-refinery storage tanks and waste lagoons or landfills containing industrial solvents. The frequency of detection of VOCs in samples from undeveloped areas was greater than expected, most likely because although the area immediately surrounding the well was undeveloped, urban land generally was present near the well. Urban land, in fact, is found within 0.25 mi of 24 of the 27 wells in the study area that contained VOCs. Benzene and TCE were the most frequently detected VOCs (Vowinkel and Battaglin, in press).

Water samples collected during 1987-88 from the 90 wells in the five study areas on Long Island also were analyzed for VOCs (Leamond



EXPLANATION

CONCENTRATION OF VOLATILE ORGANIC COMPOUNDS GREATER THAN 3 MICROGRAMS PER LITER IN WATER FROM WELLS IN THE OUTCROP AREA OF THE

- POTOMAC-RARITAN-MAGOTHY AQUIFER SYSTEM
- KIRKWOOD-COHANSEY AQUIFER SYSTEM

Figure 27. Frequency of detection of volatile organic compounds in water from wells in outcrop areas of the Potomac-Raritan-Magothy and Kirkwood-Cohansey aquifer systems, New Jersey, by predominant land use. (Data on file at U.S. Geological Survey office in West Trenton, N.J.)

and others, 1992). VOCs were detected at concentrations at or above the reporting limit of 1 $\mu\text{g/L}$ in samples from 37 percent of the wells and most commonly in samples from wells in the recently sewered suburban area (74 percent), followed by the long-term sewered suburban area (50 percent) and the unsewered suburban area (40 percent) (fig. 28). VOCs were detected in only 1 of 15 samples from wells in the undeveloped area and in none of the samples from wells in the agricultural area (Leamond and others, 1992).

The most commonly detected VOCs in samples from the three suburban areas were TCA

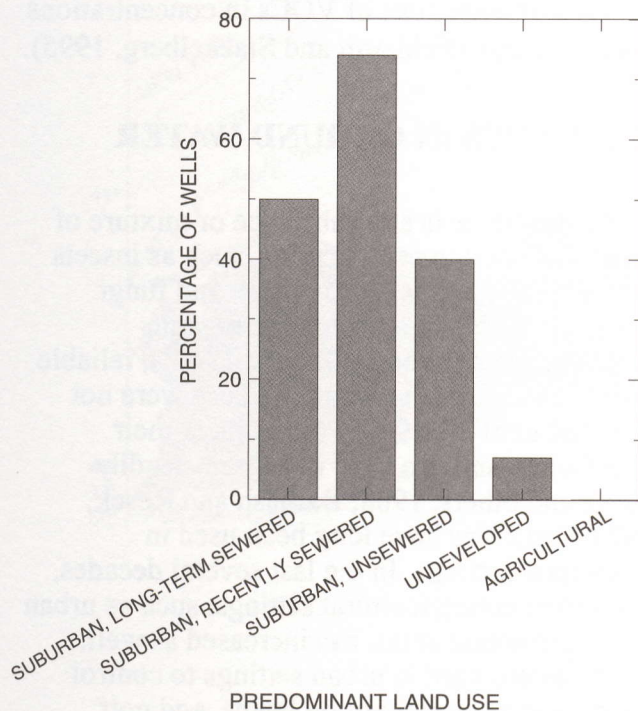


Figure 28. Frequency of detection of volatile organic compounds in concentrations greater than 1 microgram per liter in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York. (Data from Leamond and others, 1992)

and TCE, which are common industrial and commercial organic solvents. TCA was detected in 39 percent of samples and was detected most frequently in samples from the recently sewered suburban area (68 percent) (fig. 29), where the highest concentration was 12,000 $\mu\text{g/L}$. Frequent detection of TCA in samples from unsewered suburban areas was expected because use of this compound as a septic-system degreaser was widespread before its ban in 1981. Concentrations of TCA exceeded the USEPA MCL of 50 $\mu\text{g/L}$ in one well each in the recently sewered and unsewered areas. TCE was detected in 22 percent of samples and also was detected most frequently in samples from the recently sewered suburban area (26 percent) (fig. 30), where the highest concentration was 390 $\mu\text{g/L}$. Like TCA, concentrations of TCE exceeded the USEPA MCL of 50 $\mu\text{g/L}$ in one well each in the recently sewered and unsewered areas (Leamond and others, 1992).

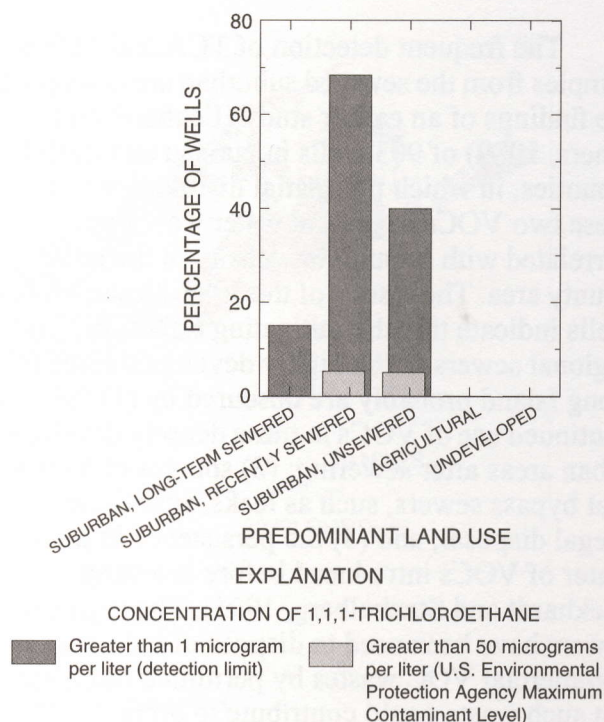


Figure 29. Frequency of detection of 1,1,1-trichloroethane (TCA) in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York. (Data from Leamond and others, 1992)

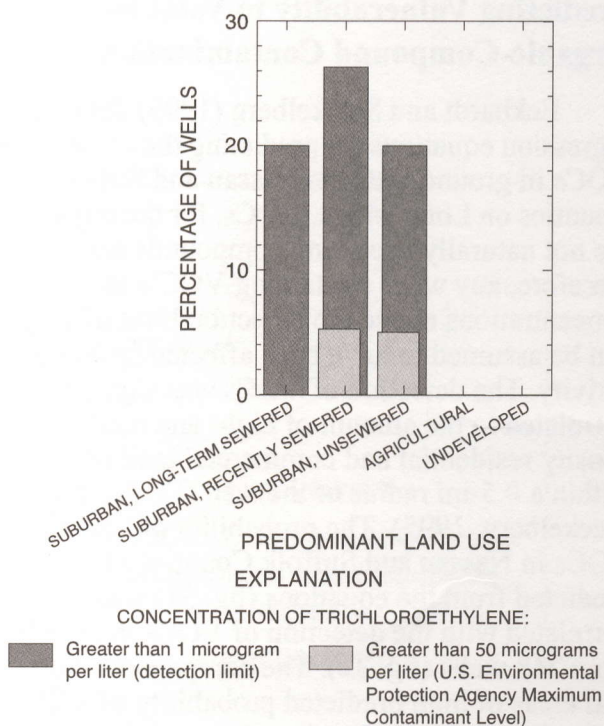


Figure 30. Frequency of detection of trichloroethylene (TCE) in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York. (Data from Leamond and others, 1992)

The frequent detection of TCA and TCE in samples from the sewered suburban areas supports the findings of an earlier study (Eckhardt and others, 1989) of 903 wells in Nassau and Suffolk Counties, in which the spatial distributions of these two VOCs in ground water were directly correlated with population density in the two-county area. The results of the 1987-88 study of 90 wells indicate that the mitigating effects of regional sewers in the highly developed areas of Long Island probably are obscured by (1) the continued use of VOCs in these densely developed urban areas after sewerage; (2) sources of VOCs that bypass sewers, such as leaks, spills, and illegal disposal; and (3) the persistence in ground water of VOCs introduced before sewerage (Eckhardt and Stackelberg, 1995). The regional sewers have been used to dispose of industrial and commercial VOC wastes by permitted discharge, but such waste could contribute to ground-water contamination wherever the sewer lines leak. For these reasons, the frequency of detection of VOCs in samples from the long-term sewered suburban area was similar to those in samples from the other suburban areas (Eckhardt and Stackelberg, 1995).

Predicting Vulnerability to Volatile-Organic-Compound Contamination

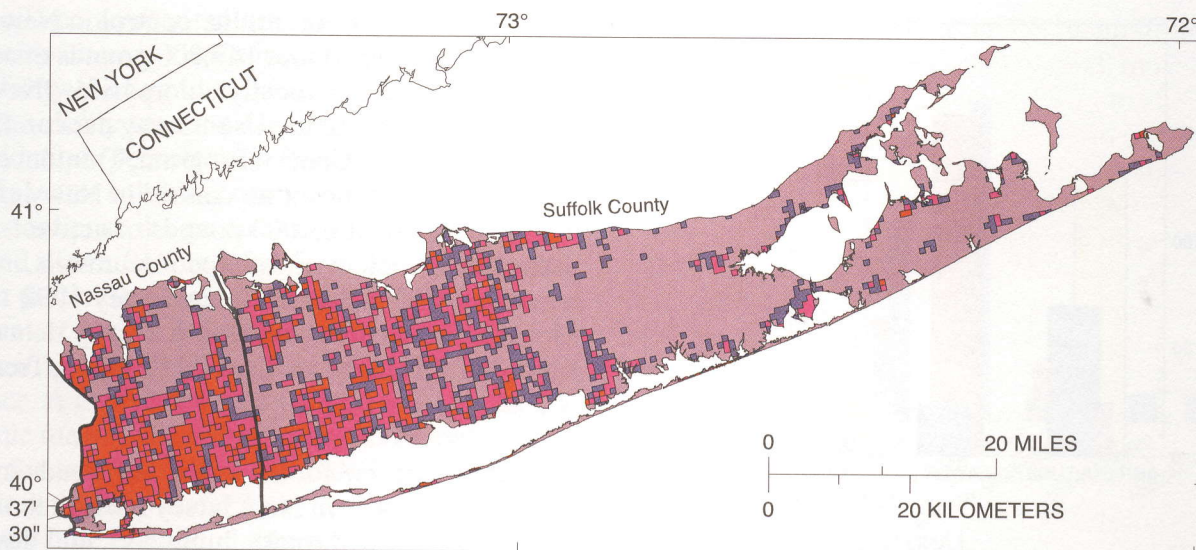
Eckhardt and Stackelberg (1995) developed regression equations for predicting the presence of VOCs in ground water in Nassau and Suffolk Counties on Long Island. VOCs, for the most part, are not naturally occurring compounds and, therefore, any wells containing VOC's at concentrations above the detection limit of 1 $\mu\text{g/L}$ can be assumed to have been affected by human activity. The detection of VOCs was significantly correlated to the amount of high- and medium-density residential and commercial land uses within a 0.5-mi radius of the well (Eckhardt and Stackelberg, 1995). The probability of finding VOCs in Nassau and Suffolk Counties as predicted from the equations (fig. 31) was correlated with the detection of VOCs in samples from 248 wells (fig. 32). The comparison shows that areas of high predicted probability of VOC contamination are related to observed detections of VOC concentrations greater than 1 $\mu\text{g/L}$ and that areas of low predicted probability of VOC contamination are related to an observed absence

of VOCs or detections of VOCs in concentrations less than 1 $\mu\text{g/L}$ (Eckhardt and Stackelberg, 1995).

PESTICIDES IN GROUND WATER

A pesticide is any substance or mixture of substances used to control pests, such as insects (insecticides), weeds (herbicides), and fungi (fungicides). Although synthetic organic pesticides were introduced in the 1940's, reliable records on their manufacture and use were not compiled until the 1960's. Since then, their manufacture and use have increased steadily (Smith and others, 1988; Barbash and Resek, 1996). Pesticides have long been used in agricultural settings. In the last several decades, their use in nonagricultural settings, such as urban and undeveloped areas, has increased as well. Pesticides are used in urban settings to control insects, weeds, and fungi on lawns, and golf courses, and in cemeteries, parks, and private and public gardens; to control pests in and around homes and commercial buildings; and to control vegetation on railroad, transmission-line, and roadway rights-of-way. Insecticides also are used to control mosquito and other pest populations in urban and undeveloped areas for the protection of public health and for nuisance reduction (Barbash and Resek, 1996). More than 10,000 products containing more than 400 major active ingredients are currently registered for use as pesticides in New Jersey (Hamilton and Meyer, 1994).

In New Jersey, agriculture accounts for the largest use of pesticides by volume (fig. 33). In 1991, nearly 1 million acres of agricultural land in New Jersey was treated at least once with a pesticide (Hamilton and Meyer, 1994). More than 1.6 million pounds of active ingredients was applied to New Jersey crops in 1994 (New Jersey 1994 Agricultural Pesticide Use Survey data on file at NJDEP, Pesticide Control Program, Trenton, N.J.). Fungicides (sulfur, captan, and chlorothalonil) accounted for the largest amount used, followed by herbicides (metolachlor, atrazine, and alachlor) and insecticides (petroleum oils and sodium aluminofluoride). The large diversity of crops grown in New Jersey results in a correspondingly large diversity in the types of pesticides used in the State.



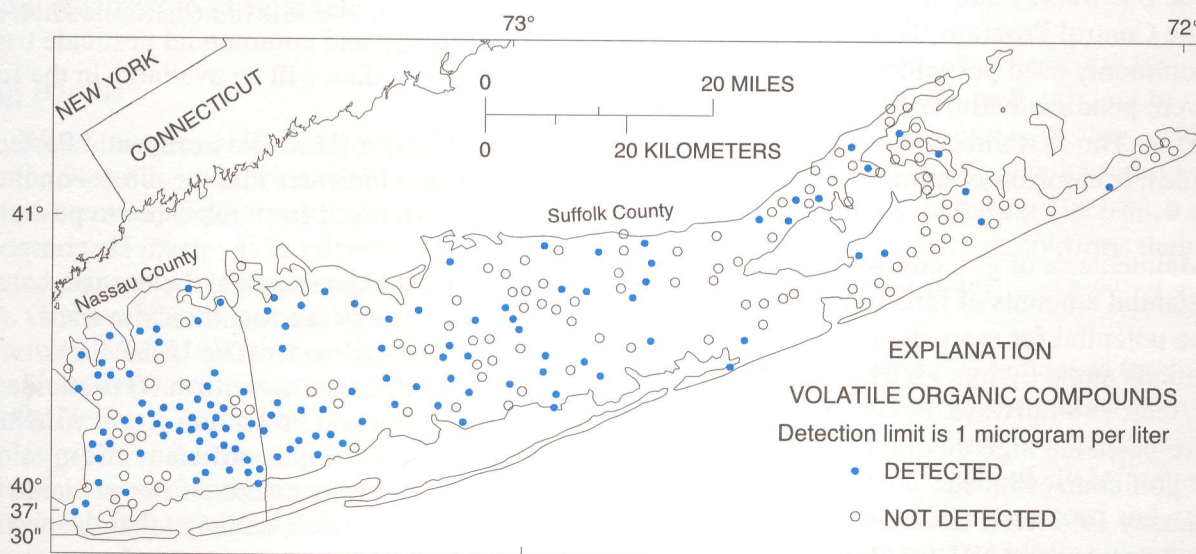
EXPLANATION

Probability of total volatile-organic-compound
concentration greater than 1 microgram per liter

≤ Less than or equal to > Greater than

≤0.40
 >0.40-0.60
 >0.60-0.80
 >0.80

Figure 31. Estimated probability of detecting a total volatile-organic-compound concentration greater than 1 microgram per liter in water from wells in Nassau and Suffolk Counties, Long Island, New York. (Modified from Eckhardt and Stackelberg, 1995)



EXPLANATION

VOLATILE ORGANIC COMPOUNDS

Detection limit is 1 microgram per liter

• DETECTED

○ NOT DETECTED

Figure 32. Location of detections of volatile organic compounds in concentrations greater than 1 microgram per liter in water from 248 wells in Nassau and Suffolk Counties, Long Island, New York. (Modified from Eckhardt and Stackelberg, 1995)

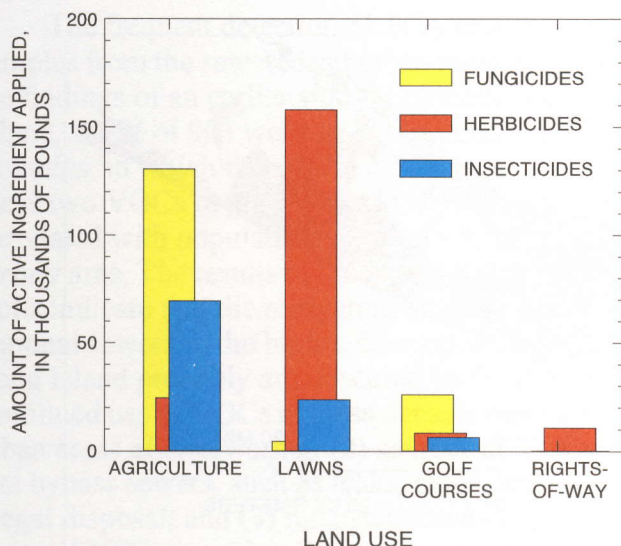


Figure 33. Reported pesticide use in New Jersey, by land use and type of pesticide. (Data from Hamilton and Meyer, 1994, and data on file at New Jersey Department of Environmental Protection, Pesticide Control Program, Trenton, N.J.)

Residential lawn care accounts for the second largest use of pesticides in New Jersey. In 1995, more than 370,000 pounds of active pesticide ingredient, mostly herbicides with smaller amounts of insecticides and fungicides, was applied (New Jersey 1995 Lawn Care Pesticide Use Survey data on file at NJDEP, Pesticide Control Program, Trenton, N.J.). The most commonly used pesticides for lawn care in 1995 were pendimethalin, 2,4-D, mecoprop, and trichlorfon. The first three compounds are herbicides; trichlorfon is an insecticide.

Maintenance of golf courses requires the use of substantial amounts of fertilizers and pesticides with the potential for more than 30 different applications annually to a variety of areas, such as greens, tees, and fairways. About 202,000 pounds of active pesticide ingredient reportedly was used on 207 golf courses in New Jersey during 1993 (New Jersey 1993 Golf Course Pesticide Use Survey data on file at NJDEP, Pesticide Control Program, Trenton, N.J.). Fungicides were used the most (72 percent of total use), followed by insecticides (16 percent) and herbicides (12 percent).

Pesticide use for termite control in New Jersey in 1992 was about 147,000 pounds of active pesticide ingredient, mostly chlorpyrifos (New Jersey 1992 Termiticide Use Survey data on file at NJDEP, Pesticide Control Program, Trenton, N.J.). Pesticide use for mosquito control in New Jersey in 1993 was about 63,000 pounds of active pesticide ingredient, mostly petroleum oils, temephos, and malathion (New Jersey 1992 Mosquito Control Pesticide Use Survey data on file at NJDEP, Pesticide Control Program, Trenton, N.J.).

Pesticide use for the control of weeds in right-of-way areas in New Jersey such as those adjacent to railroad tracks, highways, and power lines in 1992 was about 54,000 pounds of active pesticide ingredient (New Jersey 1992 Right-of-Way Pesticide Use Survey data on file at NJDEP, Pesticide Control Program, Trenton, N.J.). Diuron and glyphosate accounted for 80 percent of the use.

Farmers, commercial applicators, and pesticide manufacturers report the use and sales of pesticides on Long Island to the New York State Department of Environmental Conservation. Because most of this information is not readily available, little is known about the amount of pesticide use on Long Island. Legislation enacted in 1996 in New York required the establishment of a statewide computer registry of pesticide use and sales by farmers and commercial pesticide users; therefore, these data will be available in the future.

The USEPA (U.S. Environmental Protection Agency, 1988) indicates that the effects on human health that can result from exposure to pesticides depend on the toxicity of the pesticide compound, the duration of exposure, and the dosage. Pesticides typically are found only in trace amounts in ground water. The USEPA has established MCLs for more than 60 pesticides (U.S. Environmental Protection Agency, 1988). MCLs are set only when sufficient information concerning the health effects of the pesticide is available and when it is believed that the pesticide may find its way into water supplies.

The potential of individual pesticides to contaminate ground water depends on their chemical characteristics and the characteristics of

the soil and aquifer material they penetrate. Pesticide characteristics include water solubility, the ability to cling to soil matter (soil adsorption), and the ability to resist decomposition or degradation (persistence). Pesticides that are highly water soluble, poorly sorbed, and highly persistent pose the greatest risk of contaminating ground water. Soil and aquifer characteristics that affect pesticide movement include soil texture, amount of organic matter, number and size of pores in the soil, and depth to water from the land surface. A coarse-textured (sandy) soil low in organic matter will allow pesticides to move easily from the land surface to the underlying aquifer. Shallow depth to water from the land surface increases the likelihood that pesticides will reach ground water.

Pesticides can be grouped according to their chemical composition. In the discussions that follow, insecticides are categorized into one of three groups (carbamate, organochlorine, or organophosphorous), and herbicides are categorized into one of two groups (acetanilide/triazine or chlorophenoxy acid). Use of organochlorine insecticides has been severely restricted since the 1970's; however, residues of these compounds are persistent and are sometimes detected at low concentrations in ground water. Many pesticides in the other groups are currently used in New Jersey and on Long Island and have been detected in ground water.

Long Island

Water samples collected during 1987-88 from the 90 wells in the five study areas on Long Island were analyzed for pesticides (fig. 34) (Leamond and others, 1992). Insecticides were detected primarily in suburban and agricultural areas. Organochlorine insecticides were the most frequently detected class of pesticides in all five study areas. Detectable concentrations were found in water from 80, 71, and 50 percent of the sampled wells in the recently sewered area, the agricultural area, and the long-term sewered area, respectively. Organochlorine insecticides detected in the three suburban areas were dieldrin, heptachlor epoxide, and chlordane. In the agricultural area, heptachlor epoxide was detected most frequently, followed by dieldrin, endosulfan, and DDD. Endosulfan was the only

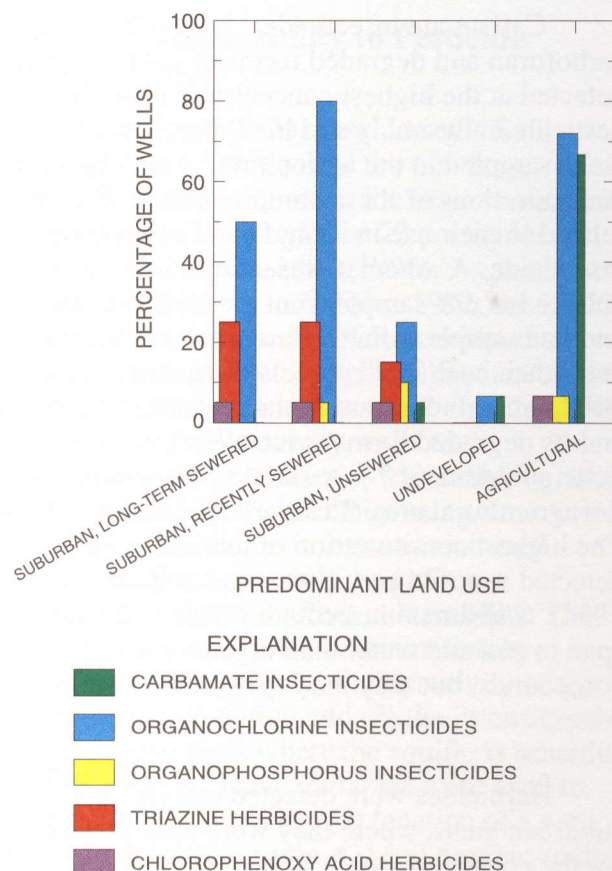


Figure 34. Frequency of detection of five groups of pesticides in water from wells in five areas of differing land use and sewerage practices in Nassau and Suffolk Counties, Long Island, New York. (Data from Leamond and others, 1992)

organochlorine insecticide detected in the undeveloped area (in one well adjacent to agricultural land) (Leamond and others, 1992). The detection of organochlorine insecticides in water samples collected during 1987-88, a decade after their use was restricted, confirms their persistence in ground water.

Organophosphorus insecticides (mainly diazinon) were detected in the recently sewered suburban area, the unsewered suburban area, and the agricultural area, but relatively infrequently and at low concentrations (Leamond and others, 1992). Compared to organochlorine insecticides, organophosphorous insecticides have a relatively short half-life in soil and water. Organophosphorus insecticides tend to sorb to soils or degrade before they can be transported into the aquifer system.

Carbamate insecticides, primarily carbofuran and degraded forms of aldicarb, were detected at the highest concentrations of any pesticide in the study and in 67 percent of the wells sampled in the agricultural area. The high concentrations of these compounds are directly related to their use in Long Island agriculture as insecticides. Carbamate insecticides also were detected in one sample from the undeveloped area and one sample from the unsewered suburban area, each near small parcels of agricultural land. Total aldicarb concentrations (the sum of aldicarb and its degraded forms) exceeded the New York State guideline of 7 $\mu\text{g/L}$ in 60 percent of wells in the agricultural area (Eckhardt and others, 1989). The highest concentration of total aldicarb detected was 104 $\mu\text{g/L}$ (Leamond and others, 1992). Carbamate insecticides have a shorter life span in soil and water than organochlorine compounds, but they tend to be more soluble in water.

Herbicides were detected mainly in the suburban areas, where they were used extensively for the control of weeds in lawns. Triazine herbicides were detected in 15 to 25 percent of the sampled wells in the three suburban areas, but no triazine herbicides were detected in the agricultural or undeveloped areas. Triazine compounds detected include atrazine, simazine, and prometon (Leamond and others, 1992). Chlorophenoxy-acid herbicides were detected infrequently and at low concentrations in the three suburban areas and the agricultural area.

New Jersey

In a 1985 study of shallow ground water in the Potomac-Raritan-Magothy aquifer system, samples collected from 66 wells were analyzed for organochlorine and organophosphorus insecticides and triazine herbicides (Barton and others, 1987). Pesticides were detected most frequently in agricultural areas and least frequently in urban and undeveloped areas. Furthermore, the frequency of detection of pesticides in ground water within 0.25 mi of agricultural land (23 percent) was significantly larger than that in ground water more than 0.25 mi from agricultural land (5 percent).

Water samples collected from 81 wells in agricultural areas of the Potomac-Raritan-

Magothy and Kirkwood-Cohansey aquifer systems during 1986-87 (Vowinkel and Battaglin, in press) were analyzed for three insecticide groups (organochlorine, organophosphorus, and carbamate) and two herbicide groups (chlorophenoxy acid and triazine/acetanilide) (fig. 35). Pesticide residues were detected in water from 27 of the 81 wells (33 percent); 13 insecticides and 6 herbicides were detected, generally at low levels. Alachlor was the most commonly detected herbicide, but only one sample contained a concentration of alachlor greater than the applicable USEPA MCL of 2 $\mu\text{g/L}$ (Vowinkel and Battaglin, in press).

The frequency of detection of each of the five pesticide groups was similar in the Potomac-

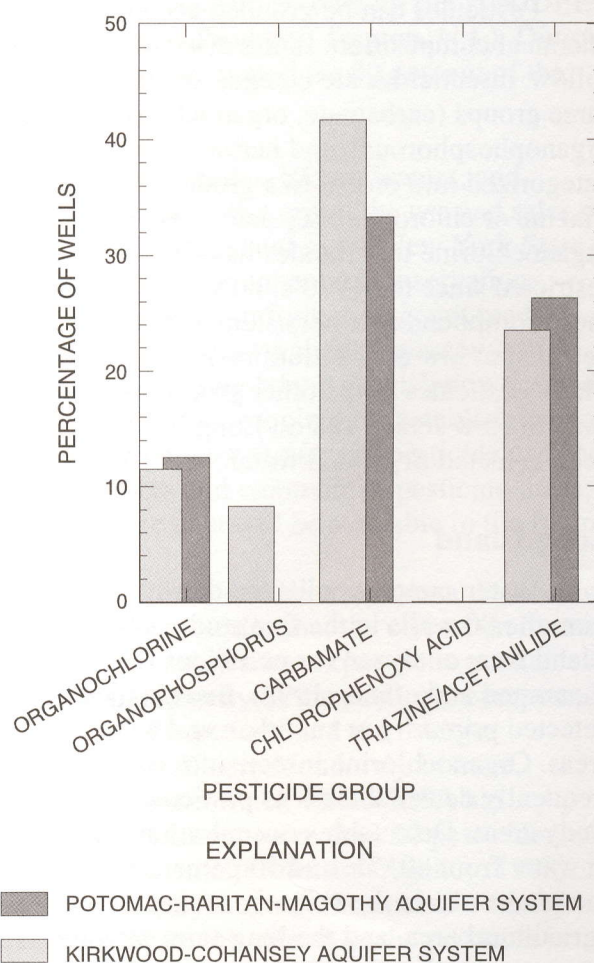


Figure 35. Frequency of detection of five groups of pesticides in water from wells in the Potomac-Raritan-Magothy and Kirkwood-Cohansey aquifer systems, New Jersey. (Data from Vowinkel and Battaglin, in press)

Raritan-Magothy and Kirkwood-Cohansey aquifer systems. Herbicides of the triazine and acetanilide groups were detected in more than 20 percent of the samples from both aquifer systems; atrazine and alachlor were detected most frequently. No chlorophenoxy-acid herbicides were detected. Carbamate insecticides were detected in more than 30 percent of the samples from both aquifer systems; carbofuran and the degraded forms of aldicarb were detected most frequently. Organochlorine compounds were detected in about 10 percent of the samples from both aquifer systems; dieldrin was detected most frequently and lindane was detected at the largest concentration. Diazinon, the only organophosphorus insecticide detected, was present at the laboratory reporting level of $0.01 \mu\text{g/L}$ in only one water sample. The similar frequencies of detection of the pesticide groups in shallow ground water in the two aquifer systems probably reflect similar pesticide-use patterns and similar vulnerability to contamination of the two systems (Vowinkel and Battaglin, in press).

In a 1991 study to investigate the movement of agricultural chemicals in the Kirkwood-Cohansey aquifer system, nested wells (wells installed at different depths in the same location) in five active or historically active agricultural sites were sampled for pesticides and other constituents (Szabo and others, 1994). Pesticides were detected in shallow wells at four of the sites, but were not detected in the deep wells. The maximum depth at which any pesticide (bromacil in this case) was detected was 60 ft below land surface (40 ft below the water table). Bromacil, a carbamate insecticide, is a particularly persistent and mobile compound. The detection of pesticides in shallow ground water at four of the five sites indicates that most of the shallow ground water in the Kirkwood-Cohansey aquifer system directly underlying agricultural areas (where pesticides were likely applied) probably contains low concentrations of one or more pesticides. The fact that pesticides were not detected in water from the deep wells at these five sites indicates that pesticides have degraded and (or) have not yet penetrated to deeper parts of the aquifer system (Szabo and others, 1994).

Predicting Vulnerability to Pesticide Contamination

Beginning in 1995, New Jersey's Safe Drinking Water Act required the 626 large community water systems in the State to monitor their 2,600 wells quarterly for 23 pesticides (Vowinkel and others, 1994, 1996). As part of a 3-year study that began in October 1992, the USGS, in cooperation with the NJDEP, developed a geographic information system (GIS) data base to provide data with which to assess the vulnerability of water from public-supply wells to contamination by pesticides. A vulnerability rating was determined for each well by using a numerical rating method based on information on well construction, land use, soils, and other characteristics that can affect vulnerability. The vulnerability of a well to contamination by pesticides is defined by (1) the sensitivity of the aquifer to contamination and (2) the intensity of pesticide use in areas where the aquifer is sensitive to contamination. Three variables were used to predict aquifer sensitivity: (1) location of a well relative to the outcrop area, (2) soil organic-matter content, and (3) depth from the land surface to the top of the open interval of the well (top of the well screen for wells in unconsolidated sediments and top of the open hole for bedrock aquifers). Three variables were used to predict pesticide-use intensity near wells that are sensitive to contamination: (1) predominant land use near the well, (2) distance from the nearest agricultural area, and (3) distance from the nearest golf course (Vowinkel and others, 1994, 1996). The vulnerability rating will be used by the State to determine the required level of monitoring for each well and to issue waivers if a well is determined to have low vulnerability to contamination.

Well-construction characteristics and location were determined for 2,100 of the 2,600 public-supply wells in New Jersey; available information was insufficient for the remaining 500 wells. The 2,600 wells are located in three different aquifer types: (1) Coastal Plain unconsolidated sand and gravel deposits, (2) unconsolidated glacial-deposit sediments, and (3) fractured bedrock. By using the numerical rating method, each of the 2,100 wells was assigned to one of three vulnerability groups on the basis of its

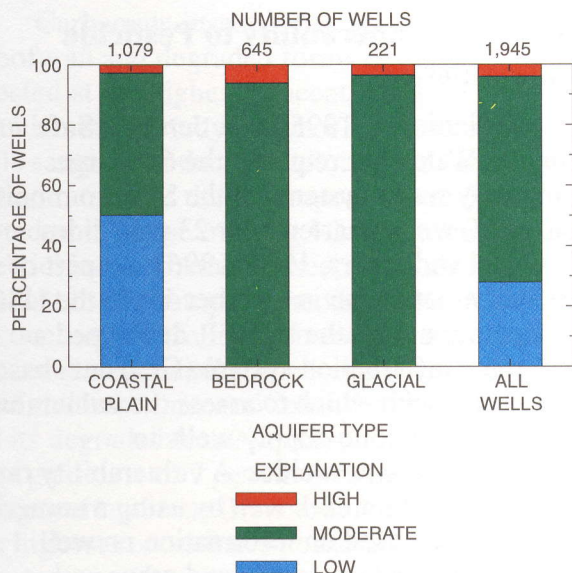


Figure 36. Percentage of New Jersey public-supply wells in each of three vulnerability groups, by major aquifer type. (Modified from Vowinkel and others, 1996)

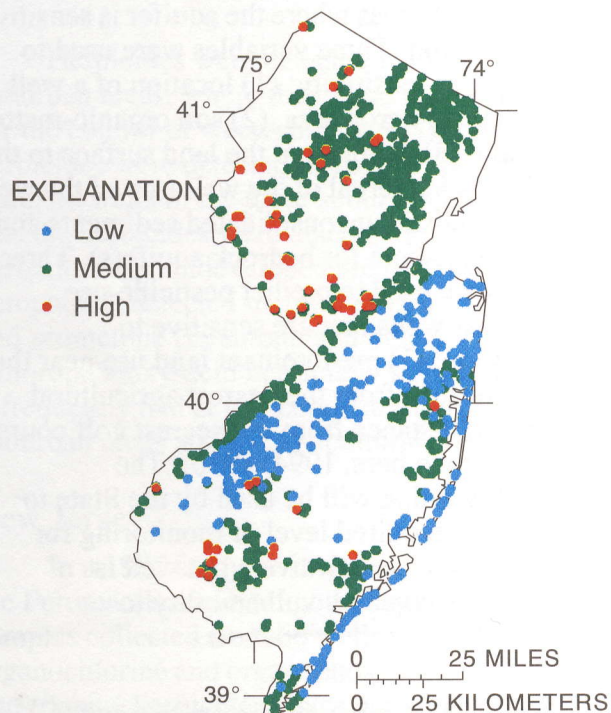


Figure 37. Vulnerability of public-supply wells in New Jersey to contamination by pesticides. (Modified from Vowinkel and others, 1996)

sensitivity and intensity ratings (figs. 36 and 37). About 26 percent of the public-supply wells are ranked in the low-vulnerability group. All wells in this group are in the confined parts of Coastal Plain aquifers. About 4 percent of all public-

supply wells are ranked in the high-vulnerability group. These wells are in the unconfined parts of aquifers and are in or adjacent to agricultural land. The remaining 70 percent of all wells were determined to be moderately vulnerable to contamination from human activities; most are completed in unconfined aquifers and are in or adjacent to residential or agricultural land (Vowinkel and others, 1994, 1996).

Vulnerability ratings were validated by analyzing water samples from a subset of 90 public-supply wells throughout New Jersey for pesticides and nitrate. Wells were chosen from each combination of vulnerability group and aquifer type. Pesticides were detected in water from 6 of the 90 wells sampled. Three of these wells were rated in the high-vulnerability group; the other three were rated as having moderate vulnerability (Vowinkel and others, 1994, 1996).

Ground-water studies like those conducted to predict nitrate and VOC contamination of ground water on Long Island by using regression analysis and pesticide contamination of ground water in New Jersey by using the vulnerability rating method can lead to substantial cost savings. The NJDEP estimated that monitoring waivers granted for wells determined to have low vulnerability to contamination by pesticides will save taxpayers almost \$5 million annually for a one-time cost of \$1 million (Vowinkel and others, 1994, 1996). In addition, Federal, State, and county agencies, consulting firms, universities, and the public make requests daily for the water-use, water-quality, and hydrogeologic data resulting from these and similar studies.

SUMMARY AND CONCLUSIONS

This report summarizes the results of selected studies on factors such as aquifer characteristics and land-use patterns that affect ground-water quality in New Jersey and on Long Island, New York. It describes the ground-water systems in the study area; summarizes available information about the occurrence and distribution of nitrate, VOCs, and pesticides in these systems; and explains why some ground-water systems are more vulnerable to contamination than others.

The geology and hydrology of fractured bedrock and valley-fill aquifers of northern New Jersey are considerably more complex and locally variable than those of the more areally extensive unconsolidated sand and gravel aquifers of the Coastal Plain on Long Island and in New Jersey; hence, the quality of water in these aquifers is more difficult to generalize or extrapolate from available data. Therefore, additional data collection and research are needed to investigate water quality and factors controlling ground-water contamination in these areas.

Although the vulnerability of ground water to contamination from the land surface is influenced by many factors, the degree of aquifer confinement, the depth of the well, and the surrounding land use are key factors. For example, whether the well is in the unconfined or confined part of the aquifer is important--***unconfined aquifers generally are much more vulnerable to contamination than confined aquifers***. For a well in a confined aquifer, however, the distance of the well from the unconfined (outcrop) area is a factor--***generally, the farther the well is from the unconfined area, the less vulnerable it is to contamination***. The depth of the well also can be influential, especially in an unconfined aquifer--***generally, the deeper the well, the less vulnerable it is to contamination***. Finally, because human activities greatly affect the quality of recharge water to an aquifer, ***the amount and type of land use in the area that contributes water to the well is a key factor in determining vulnerability***.

Nitrate contamination of ground water typically occurs in agricultural and residential areas, especially where the aquifer is very permeable and unconfined, and nitrogen-fertilizer use is high. In New Jersey and on Long Island, concentrations of nitrate exceed the U.S. Environmental Protection Agency Maximum Contaminant Level more often than those of VOCs or pesticides. Nitrate contamination generally is associated with nonpoint sources.

VOC contamination of ground water occurs primarily in urban areas, especially in urban-industrial areas where chemicals are used. In general, VOC concentrations are low and do not exceed MCLs. High VOC concentrations generally are associated with point sources.

Pesticide contamination of ground water occurs in some agricultural and residential areas, where the aquifer is very permeable and unconfined, and where chemicals are used. Concentrations of pesticides in New Jersey and on Long Island generally are low; however, some have been found to exceed MCLs in agricultural areas of Long Island. Pesticide contamination generally is associated with nonpoint sources.

Most of the regional studies of water quality in New Jersey and on Long Island conducted thus far have focused on the occurrence and spatial distribution of contaminants within the ground-water system. Although valuable information has been learned from these studies, such as the probability of finding a contaminant based on location, depth, and land use, other questions have arisen. Some of these questions include--

--What specific human activities result in ground-water contamination and how can these activities be minimized?

--Will the contamination eventually affect deeper ground-water supplies? On Long Island in particular, when and where will the deeper aquifer systems be affected by water from the extensively contaminated surficial aquifers?

--Are contaminants in ground water reaching and affecting streams, wetlands, and other surface-water bodies?

--What other components of the hydrologic cycle, such as the atmosphere and unsaturated soil zone, must be investigated in order to learn more about the sources and movement of contaminants?

--What is the ultimate fate of these contaminants and how do various hydrologic, chemical, microbiological, and other processes affect the extent of contaminant movement?

--How will the quality of water in the contaminated parts of aquifer systems change in 25 to 50 years and how might conditions change under various management strategies?

Finding the answers to these and other questions will be the responsibility of water-management agencies and research organizations in the years to come.

REFERENCES CITED

- Anderson, R.B., and Smith, R.A., 1990, County-level estimates of nitrogen and phosphorus fertilizer use in the United States, 1945 to 1985: U.S. Geological Survey Open-File Report 90-130, 12 p.
- Barbash, J.E., and Resek, E.A., 1996, Pesticides in ground water--Distribution, trends, and governing factors: Chelsea, Mich., Ann Arbor Press, Inc., 588 p.
- Barton, Cynthia, Vowinkel, E.F., and Nawyn, J.P., 1987, Preliminary assessment of water quality and its relation to hydrogeology and land use--Potomac-Raritan-Magothy aquifer system, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 87-4023, 79 p.
- Chapelle, F.H., 1995, Bioremediation: Nature's way to a cleaner environment: U.S. Geological Survey Fact Sheet FS-054-95, 2 p.
- Cohen, Philip, Franke, O. L., and Foxworthy, B. L., 1968, An atlas of Long Island's water resources: New York State Water Resources Commission Bulletin 62, 117 p.
- Eckhardt, D.A.V., and Stackelberg, P.E., 1995, Relation of ground-water quality to land use on Long Island, New York: Ground Water, v. 33, no. 6, p. 1019-1033.
- Eckhardt, D.A.V., Flipse, W. J., Jr., and Oaksford, E. T., 1989, Relation between land use and ground-water quality in the upper glacial aquifer in Nassau and Suffolk Counties, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 86-4142, 35 p.
- Fegeas, R.G., Claire, R.W., Guptill, S.C., Anderson, K.E., and Hallam, C.A., 1983, Land use and land cover digital data: U.S. Geological Survey Circular 895-E, 21 p.
- Flynn, J.M., Andreoli, Aldo, and Guerrera, A.A., 1958, Study of synthetic detergents in ground water: American Water Works Association Journal, v. 50, no. 12, p. 1551-1562.
- Fusillo, T.V., and Hochreiter, J.J., Jr., 1982, Relationship of organic contamination in ground water to land use--A case study in the New Jersey Coastal Plain (abstract): American Geophysical Union Transactions, v. 63, p. 317.
- Hamilton, G.C., and Meyer, R., 1994, A nine-year comparison of pesticide use in New Jersey, in Weigmann, D.L., ed., New directions in pesticide research, management, and policy: Blacksburg, Virginia, Virginia Water Resources Research Center, November 1-3, 1993, p. 355-365.
- Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 85 p.
- Helsel, D.R., and Ragone, S.E., 1984, Evaluation of regional ground-water quality in relation to land use: U.S. Geological Survey Water-Resources Investigations Report 84-4217, 33 p.
- Hitt, K.J., 1994, Refining 1970's land-use data with 1990 population data to indicate new residential development: U.S. Geological Survey Water-Resources Investigations Report 94-4250, 15 p.
- Koppelman, L.E., 1978, Long Island comprehensive waste treatment management plan: Hauppauge, N.Y., Nassau-Suffolk Regional Planning Board, v. 4, 61 p.
- Leahy, P.P., Rosenshein, J.S., and Knopman, D.S., 1990, Implementation plan for the National Water-Quality Assessment program: U.S. Geological Survey Open-File Report 90-174, 10 p.

- Leamond, C.E., Haefner, R.J., Cauller, S.J., and Stackelberg, P.E., 1992, Ground-water quality in five areas of differing land use in Nassau and Suffolk Counties, Long Island, New York: U.S. Geological Survey Open-File Report 91-180, 67 p.
- Lord, D.G., Barringer, J.L., Johnsson, P.A., Schuster, P.F., Walker, R.L., Fairchild, J.E., Sroka, B.N., and Jacobsen, Eric, 1990, Hydrogeochemical data from an acid deposition study at McDonalds Branch basin in the New Jersey Pinelands, 1983-86: U.S. Geological Survey Open-File Report 88-500, 132 p.
- New Jersey Department of Environmental Protection and Energy, 1993, New Jersey 1992 state water quality inventory report: Trenton, N.J., New Jersey Department of Environmental Protection, section IV, 44 p.
- New Jersey Department of Labor, 1984, New Jersey population trends--1790 to 1980: Trenton, N.J., 52 p.
- Perlmutter, N.M., and Guerrara, A.A., 1970, Detergents and associated contaminants in ground water at three public-supply well fields in southwestern Suffolk County, Long Island, New York: U.S. Geological Survey Water-Supply Paper 2001-B, 22 p.
- Perlmutter, N.M., and Koch, Ellis, 1964, Contamination of ground water by detergents in a suburban environment--South Farmingdale area, Long Island, New York, *in* Geological Survey Research 1964: U.S. Geological Survey Professional Paper 501-C, p. C170-C175.
- _____, 1971, Preliminary findings on the detergent and phosphate contents of water of southern Nassau County, New York, *in* Geological Survey Research 1971: U.S. Geological Survey Professional Paper 750-D, p. D171-D177.
- _____, 1972, Preliminary hydrogeologic appraisal of nitrate in ground water and streams, southern Nassau County, Long Island, New York: U.S. Geological Survey Professional Paper 800-B, p. 225-235.
- Principi, V.L., 1991, The State of New Jersey 1991 well permit data report: Trenton, N.J., New Jersey Department of Environmental Protection, 44 p.
- Puckett, L.J., 1995, Identifying the major sources of nutrient water pollution: Environmental Science & Technology, v. 29, no. 9, p. 408A-414A.
- Smith, J.A., Witkowski, P.J., and Fusillo, T.V., 1988, Man-made organic compounds in the surface waters of the United States--A review of current understanding: U.S. Geological Survey Circular 1007, 92 p.
- Smith, S.O., and Myott, D.H., 1975, Effect of cesspool discharge on ground water quality on Long Island, New York: Journal American Water Works Association, v. 67, no. 8, p. 456-458.
- Stackelberg, P.E., 1995, Relation between land use and quality of shallow, intermediate, and deep ground water in Nassau and Suffolk Counties, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 94-4080, 82 p.
- Szabo, Zoltan, Rice, D.E., Ivahnenko, Tamara, and Vowinkel, E.F., 1994, Delineation of the distribution of pesticides and nitrate in an unconfined aquifer in the New Jersey Coastal Plain by flow-path analysis, *in* Weigmann, D.L., ed., New directions in pesticide research, management, and policy: Blacksburg, Virginia, Virginia Water Resources Research Center, November 1-3, 1993, p. 100-119.

- Tucker, R.K., 1981, Groundwater quality in New Jersey: An investigation of toxic contaminants: Trenton, N.J., New Jersey Department of Environmental Protection, Office of Cancer and Toxic Substances Research, 60 p.
- U.S. Bureau of the Census, 1989, 1987 Census of Agriculture: v.1 (geographic area series), part 30 (New Jersey State and county data), 237 p.
- U.S. Bureau of the Census, 1991a, Census of population and housing, 1990: Public Law 94-171 data for New Jersey: Washington, D.C., U.S. Bureau of the Census, machine-readable data files (CD-ROM).
- U.S. Bureau of the Census, 1991b, Census of population and housing, 1990: Public Law 94-171 data for New York: Washington, D.C., U.S. Bureau of the Census, machine-readable data files (CD-ROM).
- U.S. Environmental Protection Agency, 1988, National revised primary drinking-water regulations--Maximum contaminant levels (subpart G of part 141, National interim primary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1988, p. 586-587.
- U.S. Geological Survey, 1985, National water summary 1984--Hydrologic events, selected water-quality trends, and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, 467 p.
- U.S. Geological Survey, 1988, National Water Summary 1986--Hydrologic events and ground-water quality: U.S. Geological Survey Water-Supply Paper 2325, 560 p.
- Vowinkel, E.F., and Battaglin, W.A., in press, Analysis of nonpoint-source ground-water contamination in relation to land use: Chapter D, Relation of ground-water quality to hydrogeology and land use in the Coastal Plain of New Jersey: U.S. Geological Survey Water-Supply Paper 2381-D, 110 p.
- Vowinkel, E.F., Clawges, R.M., Buxton, D.E., and Stedfast, D.A., 1996, Vulnerability of public drinking water supplies in New Jersey to pesticides: U.S. Geological Survey Fact Sheet FS-165-96, 3 p.
- Vowinkel, E.F., Clawges, R.M., and Uchirin, C.G., 1994, Evaluation of the vulnerability of water from public supply wells in New Jersey to contamination by pesticides, *in* Weigmann, D.L., ed., New directions in pesticide research, management, and policy: Blacksburg, Virginia, Virginia Water Resources Research Center, November 1-3, 1993, p. 495-510.
- Vowinkel, E.F., and Foster, W.K., 1981, Hydrogeologic conditions in the Coastal Plain of New Jersey: U.S. Geological Survey Open-File Report 81-405, 39 p.
- Vowinkel, E.F., and Siwiec, S.F., 1991, Plan to evaluate the effects of hydrogeologic conditions and human activities on water quality in the Coastal Plain of New York and New Jersey: U.S. Geological Survey Water-Resources Investigations Report 91-4091, 42 p.
- Walton, G., 1951, Survey of literature relating to infant methemoglobinemia due to nitrate-contaminated water: American Journal of Public Health, v. 41, p. 986-996.
- Zapeczka, O.S., 1989, Hydrogeologic framework of the New Jersey Coastal Plain, Regional Aquifer-System Analysis--Northern Atlantic Coastal Plain: U.S. Geological Survey Professional Paper 1404-B, 49 p.