

The Quality of Our Nation's Waters

Water Quality in the Northern Atlantic Coastal Plain Surficial Aquifer System, Delaware, Maryland, New Jersey, New York, North Carolina, and Virginia, 1988–2009

National Water-Quality Assessment Program

Circular 1353

U.S. Department of the Interior
U.S. Geological Survey

Cover. The intersection of suburban development, farmland, forest, and wetlands near the shore of the Chesapeake Bay near Crisfield, Maryland. Photograph by Emily Nauman of the Integration and Application Network, University of Maryland Center for Environmental Science (IAN, UMCES).

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By Judith M. Denver, Scott W. Ator, Jeffrey M. Fischer, Douglas C. Harned,
Christopher Schubert, and Zoltan Szabo

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

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NAWQA

National Water-Quality Assessment Program

"USGS, through the NAWQA Program, has extensively studied the movement of nutrients through groundwater. We look forward to using this information as we work with state and local partners to implement practices on the land that have the greatest benefit to the quality of our local and Bay waters."

Nick DiPasquale
EPA Director of the Chesapeake Bay Program

Foreword

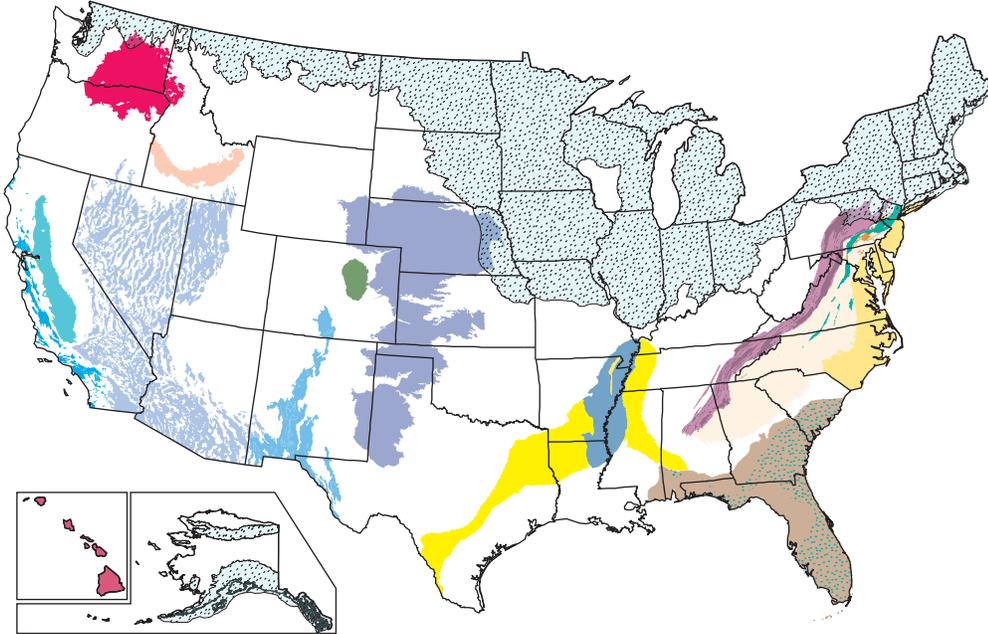
The United States has made major investments in assessing, managing, regulating, and conserving natural resources, such as water and a variety of ecosystems. Sustaining the quality of the Nation's water resources and the health of our diverse ecosystems depends on the availability of sound water-resources data and information to develop effective, science-based policies. Effective management of water resources also brings more certainty and efficiency to important economic sectors. Taken together, these actions lead to immediate and long-term economic, social, and environmental benefits that make a difference to the lives of millions of people (<http://water.usgs.gov/nawqa/applications/>).

Two decades ago, Congress established the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program to meet this need. Since then NAWQA has served as a primary source of nationally consistent information on the quality of the Nation's streams and groundwater, on ways in which water quality changes over time, and on the natural features and human activities affecting the quality of streams and groundwater. Objective and reliable data, systematic scientific studies, and models are used to characterize where, when, and why the Nation's water quality is degraded—and what can be done to improve and protect the water for human and ecosystem needs. This information is critical to our future because the Nation faces an increasingly complex and growing need for clean water to support people, economic growth, and healthy ecosystems. For example, NAWQA findings for public-supply wells, which provide water to about 105 million people, showed that 22 percent of source-water samples contained at least one contaminant at levels of potential health concern. Similarly, 23 percent of samples from domestic (or privately owned) wells, which supply untreated water to an additional 43 million people, also had contaminant levels of potential concern.

This report is one of a collection of publications that describe water-quality conditions in selected Principal Aquifers of the United States (<http://water.usgs.gov/nawqa/studies/praq/>). The collection is part of the series "The Quality of Our Nation's Waters," which describes major findings of the NAWQA Program on water-quality issues of regional and national concern and which provides science-based information for assessing and managing the quality of our groundwater resources. Other reports in this series focus on occurrence and distribution of nutrients, pesticides, and volatile organic compounds in streams and groundwater, the effects of contaminants and streamflow alteration on the condition of aquatic communities in streams, and the quality of untreated water from private domestic and public-supply wells. Each report builds toward a more comprehensive understanding of the quality of regional and national water resources (http://water.usgs.gov/nawqa/nawqa_sumr.html). All NAWQA reports are available online at <http://water.usgs.gov/nawqa/bib/>.

The information in this series primarily is intended for those interested or involved in resource management and protection, conservation, regulation, and policymaking at regional and national levels. In addition, the information should be of interest to those at a local level who wish to know more about the general quality of streams and groundwater in areas near where they live and how that quality compares with other areas across the Nation. We hope this publication will provide you with insights and information to meet your needs and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

Jerad Bales
Acting Associate Director for Water
U.S. Geological Survey



Principal Aquifers and Water-Quality Summary Reports
National summary of groundwater quality in Principal Aquifers—Circular 1360

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|  Glacial aquifer system—Circular 1352 |  Mississippi River Valley alluvial aquifer |
|  Northern Atlantic Coastal Plain surficial aquifer system—Circular 1353 |  Denver Basin aquifer system—Circular 1357 |
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Introduction to This Report

This report contains the major findings of a regional assessment of groundwater quality in Delaware, Maryland, New Jersey, New York, North Carolina, and Virginia. It is one of a series of reports by the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program that present major findings for Principal Aquifers, other aquifers, and major river basins across the Nation. In these reports, water quality is discussed in terms of local, State, regional, and national issues. Conditions in the Northern Atlantic Coastal Plain surficial aquifer system are compared to conditions found elsewhere and to selected national benchmarks, such as those for drinking-water quality.

This report is intended for individuals working with water-resource issues in local, State, or Federal agencies, universities, public interest groups, or the private sector. The information will be useful in addressing current issues, such as drinking-water quality, source-water protection, and monitoring and sampling strategies. This report will also be useful for individuals who wish to know more about the quality of groundwater in areas near where they live and how that quality of water compares with the quality of water in other areas across the region and the Nation.

Water-quality conditions in the Northern Atlantic Coastal Plain surficial aquifer system that are summarized in this report are discussed in greater detail in other reports listed in the references. Detailed technical information, data and analyses, sample collection and analytical methodology, and models, graphs, and maps that support the findings presented in this report in addition to reports in this series from other Principal Aquifers can be accessed from the NAWQA Program Web site (<http://water.usgs.gov/nawqa/>).

Companion studies of this aquifer system are discussed in the following reports:

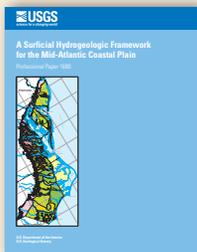


Detailed description of natural and human influences on water quality in the surficial aquifer system of the Northern Atlantic Coastal Plain:

Natural and Human Influences on Water Quality in a Shallow Regional Unconsolidated Aquifer, Northern Atlantic Coastal Plain

by Scott W. Ator

U.S. Geological Survey Scientific Investigations Report 2008–5190 available at <http://pubs.usgs.gov/sir/2008/5190/>



Detailed description of the hydrogeologic framework for the surficial aquifer system of the Northern Atlantic Coastal Plain:

A Surficial Hydrogeologic Framework for the Mid-Atlantic Coastal Plain

by Scott W. Ator, Judith M. Denver, David E. Krantz, Wayne L. Newell, and Sarah K. Martucci

U.S. Geological Survey Professional Paper 1680 available at <http://pubs.usgs.gov/pp/2005/pp1680/>



Detailed description of nitrogen transport for the surficial aquifer system in the North Carolina Coastal Plain:

Geochemistry and Characteristics of Nitrogen Transport at a Confined Animal Feeding Operation in a Coastal Plain Agricultural Watershed, and Implications for Nutrient Loading in the Neuse River Basin, North Carolina, 1999–2002

by T.B. Spruill, A.J. Tesoriero, H.E. Mew, Jr., K.M. Farrell, S.L. Harden, A.B. Colosimo, and S.R. Kraemer

U.S. Geological Survey Scientific Investigations Report 2004–5283 available at <http://pubs.usgs.gov/sir/2004/5283/>



Detailed description of water quality in the surficial aquifer system of the Delmarva Peninsula:

Factors Affecting Spatial and Temporal Variability in Nutrient and Pesticide Concentrations in the Surficial Aquifer on the Delmarva Peninsula

by Linda M. Debrewer, Scott W. Ator, and Judith M. Denver

U.S. Geological Survey Scientific Investigations Report 2005–5257 available at <http://pubs.usgs.gov/sir/2005/5257/>



Detailed description of radium occurrence in the surficial aquifer system of New Jersey:

Occurrence of Radium-224, Radium-226, and Radium-228 in Water of the Unconfined Kirkwood-Cohansey Aquifer System, Southern New Jersey

by Zoltan Szabo, Vincent T. dePaul, Thomas F. Kraemer, and Bahman Parsa

U.S. Geological Survey Scientific Investigations Report 2004–5224 available at <http://pubs.usgs.gov/sir/2004/5224/>

Chapter 1: *Overview of Major Findings and Implications*

The surficial aquifer system of the Northern Atlantic Coastal Plain is an important renewable source of drinking water, of flow to streams, and of recharge to deeper confined aquifers. Millions of people in the densely populated areas of southern New Jersey and Long Island, New York, rely on the surficial aquifer system of the Northern Atlantic Coastal Plain for public and domestic water supply. The surficial aquifer system also is the primary source of drinking water in many of the more rural areas throughout the region. This region's population and need for water will only continue to increase. The permeable sands and gravels of the surficial aquifer system do little to hinder the transport of chemicals released at the land surface down to the shallow water table of this unconfined aquifer system. Discharge from the aquifer system supplies most of the flow in local streams, and chemicals in that discharge contribute to the ecological degradation of coastal waters. Improved understanding of the natural and human factors that affect the quality of water in the surficial aquifer system supports effective and efficient water-resources management for human health and for the sustained availability of groundwater.



Groundwater from the surficial aquifer system provides most of the flow and also carries chemicals from surrounding land uses to local streams in the Northern Atlantic Coastal Plain.



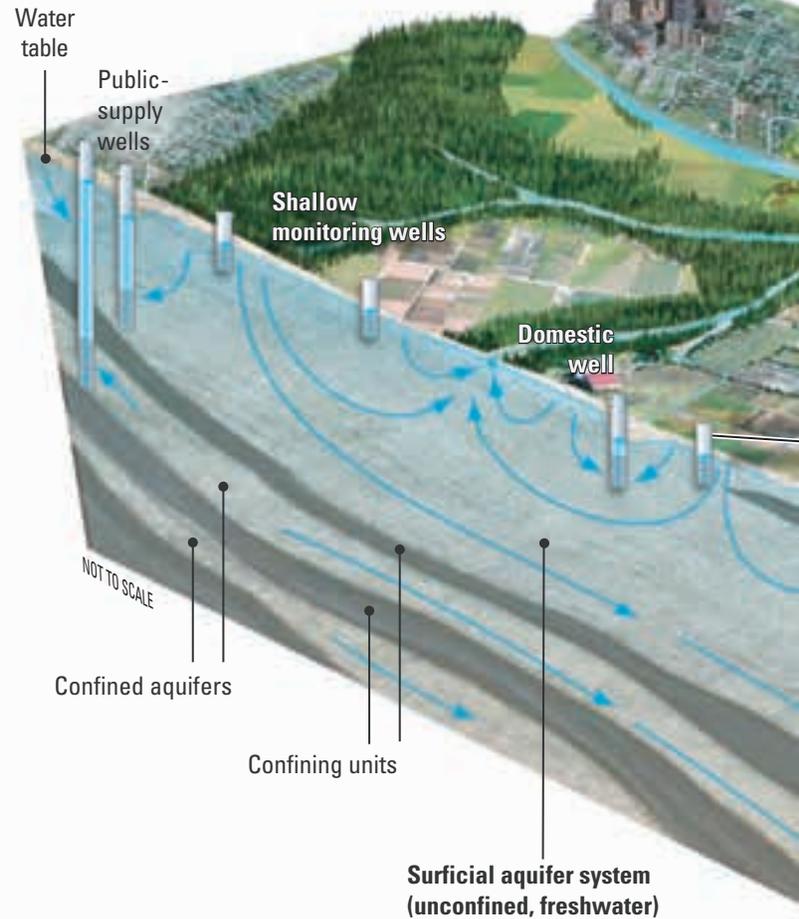
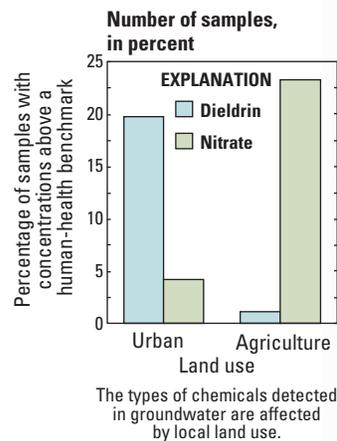
Overview of Major Findings for the Northern Atlantic Coastal



The surficial aquifer system of the Northern Atlantic Coastal Plain is made up of unconfined aquifers that underlie most of the area. This aquifer system is a critical renewable source of drinking water and is the source of most flow to streams and of recharge to underlying confined aquifers. Millions of people rely on the surficial aquifer system for public and domestic water supply, in particular in the densely populated areas of Long Island, New York, and in southern New Jersey, but also in more rural areas. Because the aquifer sediments are permeable and the water table is shallow, the surficial aquifer system is vulnerable to contamination from chemicals that are applied to the land surface and carried into groundwater with infiltrating rainfall and snowfall.

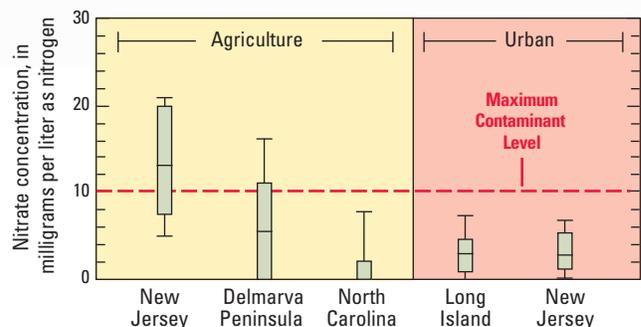
1 The quality of most groundwater produced for public and domestic water supply is suitable for drinking, although contaminants at concentrations greater than human-health benchmarks have been detected in some places

Chemical contaminants from human sources, including from fertilizers, manures, pesticides, and volatile organic compounds, occur in groundwater in many areas of the surficial aquifer system, although concentrations are generally less than human-health benchmarks. Benchmarks, however, are not available for all compounds or for mixtures of compounds. See chapter 5.



2 Nitrate is one of the most widespread contaminants in groundwater

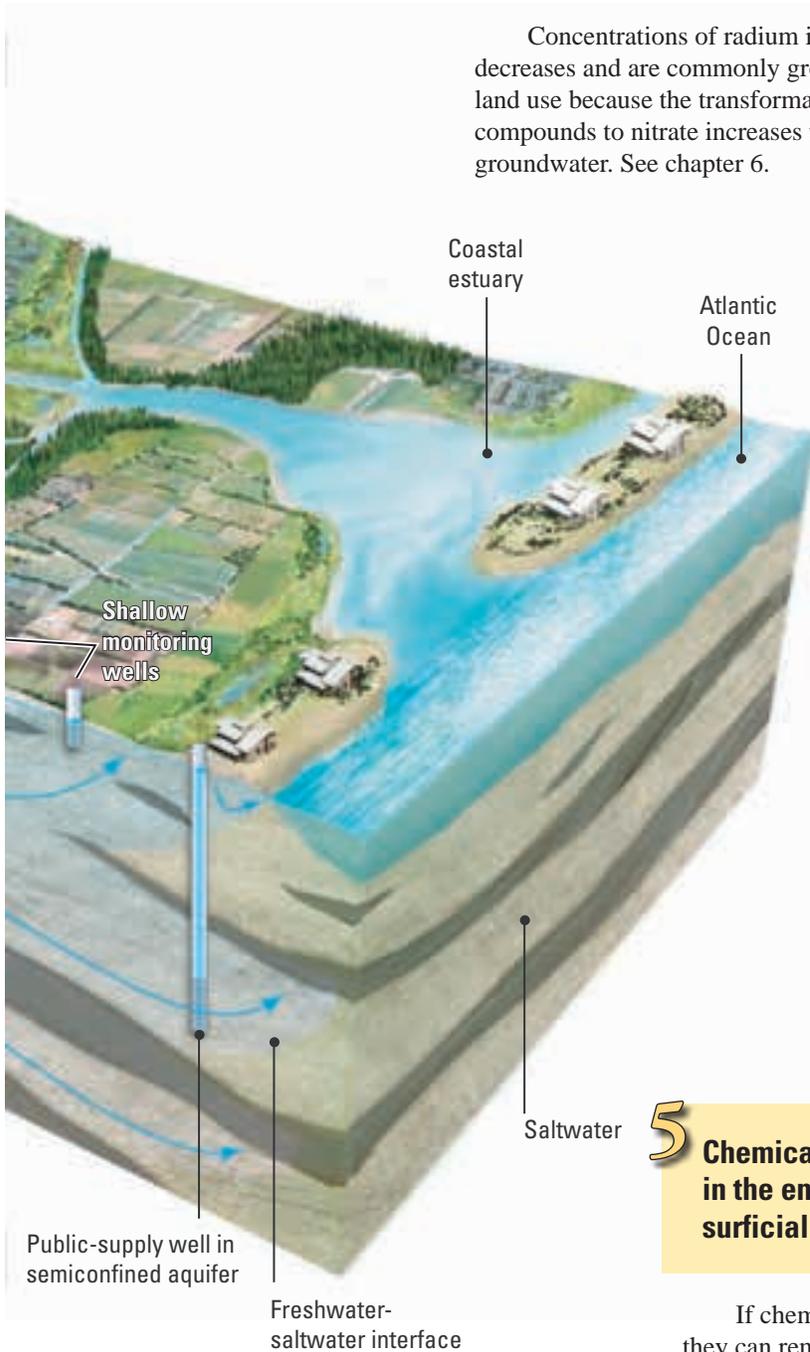
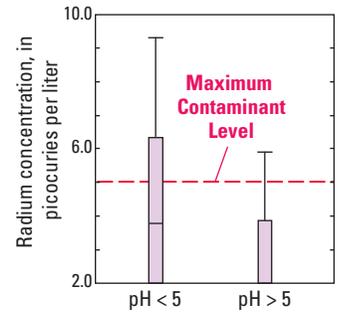
Nitrate was detected at concentrations greater than 1 milligram per liter as nitrogen (mg/L as N)—the level attributed to human-related sources—in water from more than half of the wells sampled. Nitrate moves readily in groundwater that contains dissolved oxygen (as occurs in New Jersey, Long Island, and the Delmarva Peninsula), but is lost to denitrification in areas without dissolved oxygen (as occurs in much of North Carolina). Nitrate concentrations are generally highest beneath agricultural areas, but are also elevated beneath urban areas. See chapter 6.



Plain Surficial Aquifer System

3 Radium occurs commonly in groundwater as a result of the degradation of uranium and thorium minerals naturally present in aquifer sediments

Concentrations of radium in groundwater increase as pH decreases and are commonly greater in areas with agricultural land use because the transformation of applied nitrogen compounds to nitrate increases the acidity (lowers the pH) of groundwater. See chapter 6.



4 Groundwater in the surficial aquifer system transports contaminants to surface waters

Nitrate from groundwater, in particular, contributes to the ecological degradation of many streams and coastal water bodies. Pesticides and other contaminants also are contributed from groundwater to streams and coastal waters. See chapter 7.



5 Chemicals in groundwater move slowly and can be detected in the environment for several decades after they enter the surficial aquifer system

If chemicals that enter groundwater are persistent (do not break down), they can remain in groundwater for many years after their source has been removed or reduced. For example, drinking-water suppliers in new suburban areas might encounter groundwater contaminated from activities that occurred years ago—such as with nitrate and pesticides from agricultural sources. Some contaminants whose use was banned decades ago, such as dieldrin—the pesticide most commonly detected in groundwater at a concentration of concern for human health—still are commonly detected in groundwater. See chapter 6.

Overview of Major Findings and Water-Quality Issues for the Northern Atlantic Coastal Plain New Jersey, New York, North Carolina, and Virginia

1 Chemicals from human-related sources were widely detected, but most groundwater produced for public and domestic water supply is suitable for drinking

Agricultural and urban activities are sources of many contaminants to the surficial aquifer system. The aquifer system is highly susceptible to human-related contamination in the northern part of the study area, in particular, because the soils and aquifer are composed of sandy, permeable material that allows contaminants to move readily from the land surface into the aquifer. Groundwater in these areas contains dissolved oxygen, which prevents many contaminants, such as nitrate, from degrading as they move through the aquifer. Nitrate was measured at concentrations attributed to human-related sources in water from more than one-half of the wells sampled and was measured above the U.S. Environmental Protection Agency Maximum Contaminant Level (MCL) of 10 milligrams per liter as nitrogen (mg/L as N) in 7 percent of drinking-water well samples. Pesticide and volatile organic compounds (VOCs) were detected in about one-third and one-half, respectively, of all groundwater samples although, with the exception of the pesticide dieldrin, concentrations rarely exceeded a human-health benchmark. Dieldrin, an insecticide commonly used to control termites until its use was banned in 1985, was measured at concentrations greater than its human-health benchmark of 0.002 microgram per liter ($\mu\text{g/L}$) in almost 20 percent of drinking-water wells sampled, most of which were in urban areas.

Where the surficial aquifer system is used for public water supply, the Safe Drinking Water Act (Public Law 93–523; 88 Stat. 1660) requires that contaminated groundwater that enters the distribution system be treated to reduce concentrations to below regulatory levels. Treatment, such as blending or ion exchange and, in some areas, drilling of deep wells to access groundwater that is less contaminated, increases the cost of water supplies. Millions of people in rural areas of the Northern Atlantic Coastal Plain rely on privately owned (domestic) wells that are screened in the surficial aquifer system for their drinking water. Routine testing of water from domestic wells is not required, and homeowners are responsible for maintaining and monitoring wells and for obtaining treatment to resolve any water-quality problems. As a result, there is a need for public education aimed at describing where contaminants are likely to occur and what testing and treatment options are available for domestic well owners.

2 Concentrations of nitrate, one of the most widespread contaminants in groundwater, are related to nitrogen use and are controlled by reduction/oxidation processes

Nitrate was measured at levels of concern for human health in some samples, particularly in samples from oxic (containing dissolved oxygen) groundwater

Implications

Plain Surficial Aquifer System, Delaware, Maryland,

underlying agricultural areas. For example, concentrations of nitrate in shallow groundwater on the agricultural Delmarva Peninsula exceeded the MCL in about one-third of samples and from agricultural areas of southern New Jersey exceeded the MCL in almost two-thirds of samples. Oxic groundwater underlying urban areas also was contaminated with nitrate, but to a lesser degree than groundwater underlying agricultural areas. As long as water remains oxic, nitrate in shallow groundwater has the potential to move over time into deep parts of the surficial aquifer system that are used for drinking water. In groundwater without dissolved oxygen (anoxic), nitrate can be reduced to nitrogen gas through a process called denitrification, and in parts of the surficial aquifer system where groundwater was anoxic, such as coastal North Carolina, nitrate was rarely measured at concentrations greater than the MCL.

Nitrate is colorless and odorless in water and therefore its presence in groundwater is not obvious. Owners of domestic wells that withdraw drinking water from the surficial aquifer system might be unaware of the potential for nitrate contamination in their groundwater. This is a concern, particularly in areas with intensive agriculture and with well-drained soils and sandy aquifer sediments, which are conditions under which the highest concentrations of nitrate have been measured.

3 Radium from geologic sources is a potential human-health concern in drinking water

The sediments of the surficial aquifer system contain radium, which is of concern because ingesting radium is associated with an increased risk for cancer. Radium that is associated with aquifer sediments is released into groundwater if the water is acidic (pH less than 7), which generally is the case in the surficial aquifer system (median pH 5.3). As a consequence, radium concentrations in samples of surficial aquifer groundwater were among the highest in the Nation. Some land-use practices, such as application of nitrogen-containing fertilizers, can lower the pH of the already acidic groundwater and cause radium concentrations to increase. Radium exceeded the MCL of 5 picocuries per liter (pCi/L) in about one-third of samples from drinking-water wells; the MCL was exceeded most commonly in areas where the pH was particularly low, such as in southern New Jersey. Analysis of groundwater for radium was limited mostly to the northern part of the study area, but because groundwater is acidic throughout the surficial aquifer system, radium is likely to occur in unmonitored areas as well.

Basic, inexpensive geochemical measurements of water, such as pH, can help determine where water-supply managers and homeowners might consider testing groundwater for radium. Treatment or blending of water can reduce concentrations to less than the MCL, but these remedies are costly. Understanding the factors that affect radium in groundwater can help localities prioritize areas for new groundwater development and reduce treatment costs. The potential for radium to occur in water from domestic wells where water testing is not always required emphasizes the need for public education aimed at describing where radium is likely to occur.



Photographs from top to bottom: USGS; USGS; USGS; Ron MacArthur, Cape Gazette



4 Groundwater provides the majority of streamflow in the Northern Atlantic Coastal Plain and is a substantial source of nitrogen in streams and estuaries

Ecological problems such as algal blooms and low dissolved oxygen that are caused in part by excessive nitrogen are common in estuaries along the coast of the Northern Atlantic Coastal Plain, including Chesapeake and Delaware Bays and Albemarle, Pamlico, and Long Island Sounds. Much of that nitrogen is delivered to the estuaries by the streams that flow into them, and the source of as much as 95 percent of the water in streams that originate in the Coastal Plain is groundwater that seeps up through the streambeds. Nitrogen in groundwater discharged to streams is mostly in the form of nitrate. Concentrations of nitrate in streams in the Northern Atlantic Coastal Plain range from less than the detection limit (0.05 mg/L as N) to more than 12 mg/L as N and often exceed the U.S. Environmental Protection Agency (USEPA) ecoregion nutrient criterion of 0.71 mg/L as N for these streams. The amount of nitrogen contributed by groundwater to streams depends on local hydrogeology and land use. Groundwater contributes more than 70 percent of the total nitrogen to headwater streams that flow to the Chesapeake Bay from the Eastern Shore of Maryland. In contrast, in headwater streams in the Coastal Plain of the Chesapeake Bay Western Shore in Maryland, groundwater contributes only 5 percent of the total nitrogen.

Decreasing inputs of nitrate to groundwater should aid management practices aimed at improving the quality of water in streams. However, because of the slow movement of groundwater, effects of these reductions on surface-water quality will not be immediate. It will likely take years to decades before reductions of nitrate concentrations in groundwater result in substantial water-quality improvements in streams and estuaries in this area.

5 Past land- and chemical-use practices have left a legacy of groundwater contamination

Chemicals in groundwater move slowly through the aquifer. If the chemicals are persistent, they can degrade the quality of water withdrawn by drinking-water wells or discharged into streams several decades after the chemicals entered the aquifer. An increase in nitrate concentrations in groundwater on the Delmarva Peninsula of 2 mg/L as N between 1988 and 2001 corresponds to increases in fertilizer applications that began in the 1960s. Even though fertilizer applications have stabilized, concentrations of nitrate in streams on the Delmarva Peninsula are continuing to increase as older groundwater with increased concentrations of nitrate reaches streams. Conversely, an increase in concentrations of nitrate in groundwater and streams on Long Island during the first part of the 20th century was gradually reversed after installation of sewers beginning in the 1950s.

Some contaminants whose use was banned decades ago still are commonly detected in groundwater. Dieldrin is the pesticide most frequently detected in groundwater at a concentration of concern for human health, even though its use was banned more than 30 years ago. Similarly, although applications of the pesticide aldicarb were discontinued on Long Island after 1979, aldicarb degradation products remained detectable in groundwater until well into the 1990s.

Groundwater remediation is costly and slow, so management practices that prevent the release of contaminants are likely to be the most effective way to improve or maintain the quality of groundwater. Because of the slow movement of groundwater, drinking-water suppliers in new suburban areas might encounter groundwater contaminated with chemicals—such as with nitrate and pesticides—that are associated with agricultural activities that occurred years ago. Continued groundwater monitoring coupled with models of groundwater flow and geochemistry will assist in determining when legacy contamination has diminished to acceptable concentrations.

Chapter 2: *NAWQA Approach to Assessing Groundwater Quality*

Groundwater studies conducted by NAWQA in the surficial aquifer system of the Northern Atlantic Coastal Plain were designed to answer broad questions about the occurrence, fate, and transport of contaminants in aquifers used as sources of drinking water. Water from installed monitoring wells, existing domestic wells, and public-supply wells was sampled to characterize the quality of water in the surficial aquifer system.

This chapter summarizes the study design used to investigate water quality in the Northern Atlantic Coastal Plain surficial aquifer system.

Drillers installing a monitoring well.



Assessing Water Quality in the Surficial Aquifer System of the Northern Atlantic Coastal Plain

How does one go about characterizing the groundwater over an area as large as that covered by the surficial aquifer system of the Northern Atlantic Coastal Plain, let alone the whole United States? The approach the U.S. Geological Survey (USGS) has taken is to study selected parts of these aquifers to gain a better understanding of how and why water quality varies (see sidebar, Understanding study results, this page).⁽¹⁾ These groundwater studies are the building blocks of NAWQA's water-quality assessments of Principal Aquifers (see sidebar, NAWQA assessments use a wide range of geochemical data and site information, p. 9). There were many studies in each Principal Aquifer, each with a different focus

on information needs about and the natural and human-related factors that influence groundwater quality (see appendix 1, fig. A1–1 and table A1–1). Groundwater studies that were designed to broadly assess water-quality conditions in parts of aquifers used for drinking-water supply sampled networks of randomly located monitoring wells and pumping wells (see sidebar, What types of wells were sampled, and how might that affect water quality?, p. 11). Agricultural and urban land-use studies were designed to characterize and explain the quality of recently recharged groundwater in these two land-use settings by sampling mostly shallow domestic wells and shallow monitoring (nonpumping) wells that were installed as part of the NAWQA Program. Other NAWQA studies in the Northern Atlantic Coastal Plain focused on public water supplies or groundwater quality along individual flow paths.

Understanding study results

Important aspects of the NAWQA Principal Aquifer assessments:

- Water samples were collected at the wellhead (see sidebar, Anatomy of a well, p. 14) prior to any treatment. They represent the quality of the groundwater resource but not necessarily the quality of tap water.
- The focus of the assessments is the condition of the total resource, including groundwater in a wide range of hydrologic and land-use settings across the Nation, rather than conditions at specific sites with known water-quality concerns.
- The assessments are guided by a nationally consistent study design, and all assessments use the same methods of sampling and analysis. Findings apply to water quality of a particular aquifer but also contribute to the larger picture of how and why water quality varies regionally and nationally. This consistent approach helps to determine if a water-quality issue is isolated or widespread. (See <http://water.usgs.gov/nawqa/about.html> for more information.)
- The assessments focused on aquifers used for water supply or on shallow groundwater that underlies an area with a particular type of land use. Because the NAWQA groundwater study areas do not cover the full spatial extent of the targeted Principal Aquifer, the findings may not represent the effects of the full range of geology, climate, and land use present.
- Analytical methods used by USGS chemists for assessments of water quality in Principal Aquifers are designed to measure constituents at as low a concentration as possible. As a result, constituents frequently are detected at concentrations far below human-health benchmarks for drinking water (see sidebar, Human-health benchmarks and other guidelines used in this assessment, p. 34). Low-level detections allow scientists to identify and evaluate emerging issues and to track contaminant levels over time.

NAWQA assessments use a wide range of geochemical data and site information

Constituents measured in samples from most wells	
Constituent group	Examples
Water-quality properties	pH, specific conductance, dissolved oxygen, temperature
Major ions (filtered)	Bromide, calcium, chloride, magnesium, sodium, sulfate
Trace elements (filtered)	Arsenic, boron, iron, manganese, selenium, uranium
Nutrients (filtered)	Ammonia, nitrate, phosphorus
Pesticides (filtered)	Herbicides, insecticides, fungicides
Volatile organic compounds	Solvents, gasoline hydrocarbons, refrigerants, trihalomethanes, fumigants
Organic carbon (filtered)	
Additional constituents measured in samples from some wells	
Constituent group	Examples
Radionuclides	Radon
Groundwater age tracers	Tritium, chlorofluorocarbons
Stable isotopes	Oxygen-18, hydrogen-2
Microorganisms	<i>Escherichia coli</i> and total coliforms
Additional site information	
Use of well	Land-surface elevation at well
Well depth	Land use within a 500-meter
Depth to water	(1,640-foot) radius buffer
Well-construction data	Estimates of nutrient inputs
Principal Aquifer	Estimates of pesticide use



Chemists at the USGS National Water Quality Laboratory analyze groundwater samples using an array of sophisticated techniques.



Additional information (often called “ancillary information”) about the well and the surrounding environment complements the chemical data measured. This additional information often is key to making sense of the chemical data. For example, the information might be used to determine that shallow groundwater is more (or less) vulnerable to contamination than deep groundwater, that domestic wells are more (or less) vulnerable to contamination than public-supply wells, or that urban land use is associated with different types of groundwater contamination than is agricultural land use. Chemical data without accompanying ancillary data are much less useful for understanding factors that affect groundwater quality.

This Principal Aquifer assessment brings together and interprets results from all the NAWQA groundwater studies in the Northern Atlantic Coastal Plain (see appendix 1, fig. A1–1 and table A1–1). Groundwater studies were designed to answer the following questions: How does land use affect groundwater quality? How does water quality change as it moves through an aquifer? and What is the quality of the drinking-water resource? The primary focus of these studies was the unconfined surficial aquifer system where contamination from human activities is most likely to have an effect on

water quality (see sidebar, What is a contaminant?, p. 13). Most of the samples collected were from wells screened in the unconsolidated sedimentary deposits of the Northern Atlantic Coastal Plain; samples from one network of drinking-water wells in North Carolina came from the Castle Hayne aquifer, which is composed of carbonate rocks (fig. 2–1; see sidebar, Aquifer, p. 14). The wells are distributed across much of the area overlying the aquifers, but because the wells are located only in NAWQA groundwater study areas, some parts of the surficial aquifer system are not represented.

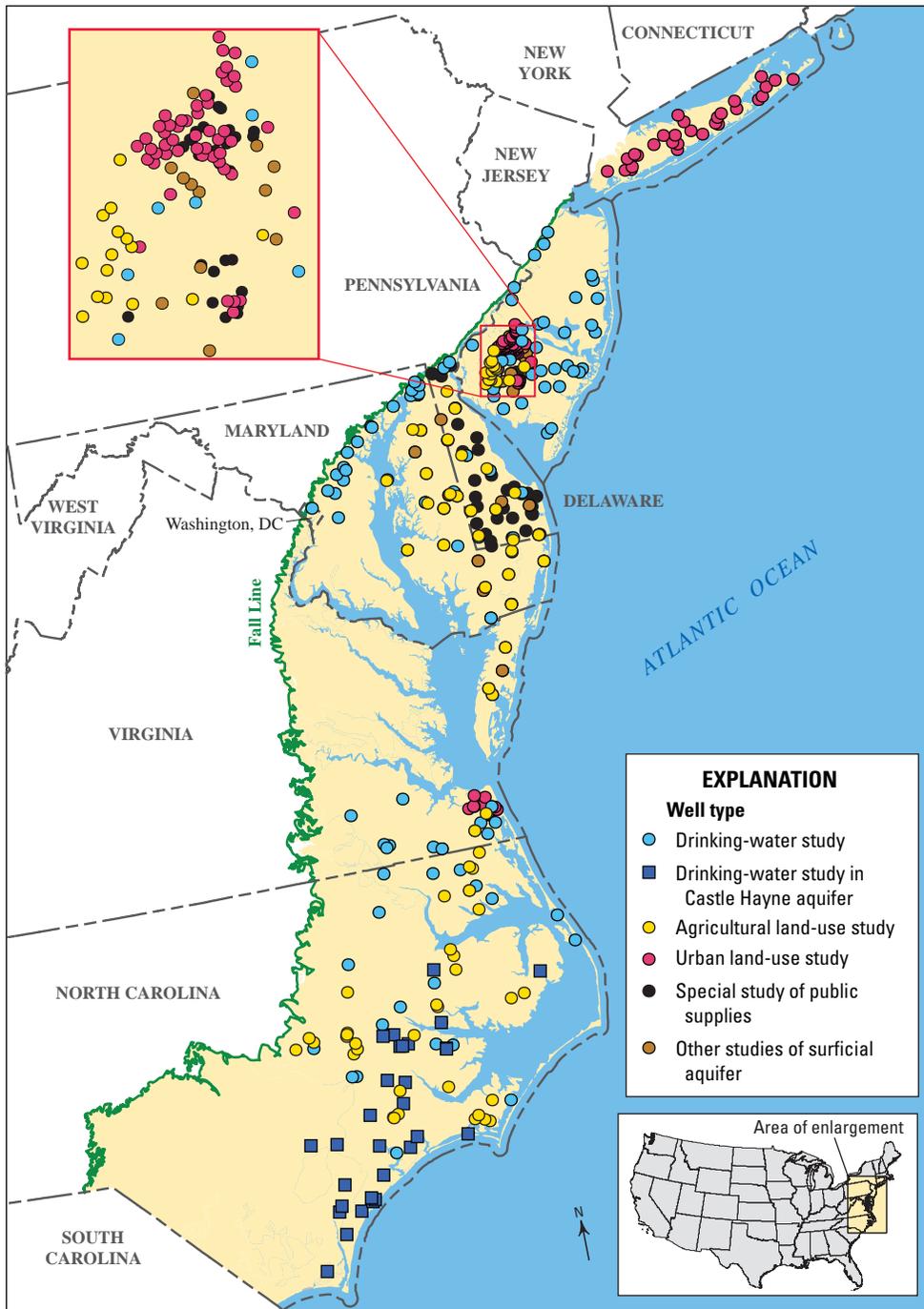


Figure 2–1. The types of wells sampled by the National Water-Quality Assessment (NAWQA) Program in the surficial aquifer system of the Northern Atlantic Coastal Plain include drinking-water wells and wells monitoring shallow groundwater underlying agricultural and urban land.

What types of wells were sampled, and how might that affect water quality?

Two types of wells that supply drinking water were sampled: domestic (private) wells and public-supply wells. Domestic wells typically are shallower than public-supply wells and therefore pump water that is nearer to sources of manmade contaminants, such as fertilizers and pesticides, at the land surface than the deeper, public-supply wells. Domestic wells commonly are in rural areas so are more likely than public-supply wells to be vulnerable to contamination from agricultural chemicals. Routine testing of water from domestic wells is not required, and homeowners are responsible for testing, maintenance, and treatment of the water from their domestic wells. Public-supply wells pump water from deep in the surficial aquifer system and commonly are in suburban and urban areas so are more likely than domestic wells to be vulnerable to contamination from chemicals associated with urban activities. Public-supply wells have larger pumps and longer screened intervals than domestic wells and are pumped for longer periods of time. As a result, public-supply wells pump much larger volumes of water than domestic wells and so have much larger capture zones.⁽²⁾ Water that is provided to consumers from public-supply wells is required to be tested on a routine basis to help assure that the water meets Federal and State water-quality standards.

More than half of the groundwater samples collected from the surficial aquifer system for this study were from monitoring wells. Monitoring wells are used for measuring water levels or collecting water samples, and those sampled in the NAWQA groundwater studies were installed expressly for that purpose. Monitoring wells are not used for drinking water, irrigation, or other purposes.

A**B**

A, USGS setting up to sample a monitoring well, and B, a domestic well.

Throughout this assessment, the results are grouped as those that characterize the groundwater used as a drinking-water supply and those that characterize the quality of groundwater that has recently recharged in either an agricultural or an urban land-use setting (fig. 2–2; table 2–1). The groundwater used for drinking generally is from relatively deep wells; this water recharged the aquifer many years ago and represents the effects of past land-use practices on water quality. The groundwater used for land-use studies is generally from shallow wells. Results of the land-use studies are of interest because the information can be used to evaluate the effect of recent human activities on shallow groundwater quality and

can provide an early warning of issues that might adversely affect deep drinking-water resources in the future. Land-use studies also can provide an indication of recent changes or improvements in water quality related to changes in chemical use. About 46 percent of the wells sampled were domestic drinking-water wells, about 43 percent were monitoring wells, and less than 10 percent were public water supply and other well types. The wells sampled ranged in depth from 5 to 612 feet (ft) and most were in unconfined parts of the surficial aquifer system; some of the deepest wells, in particular eight wells with depths greater than 200 ft, were in the confined part of the system (table 2–1).

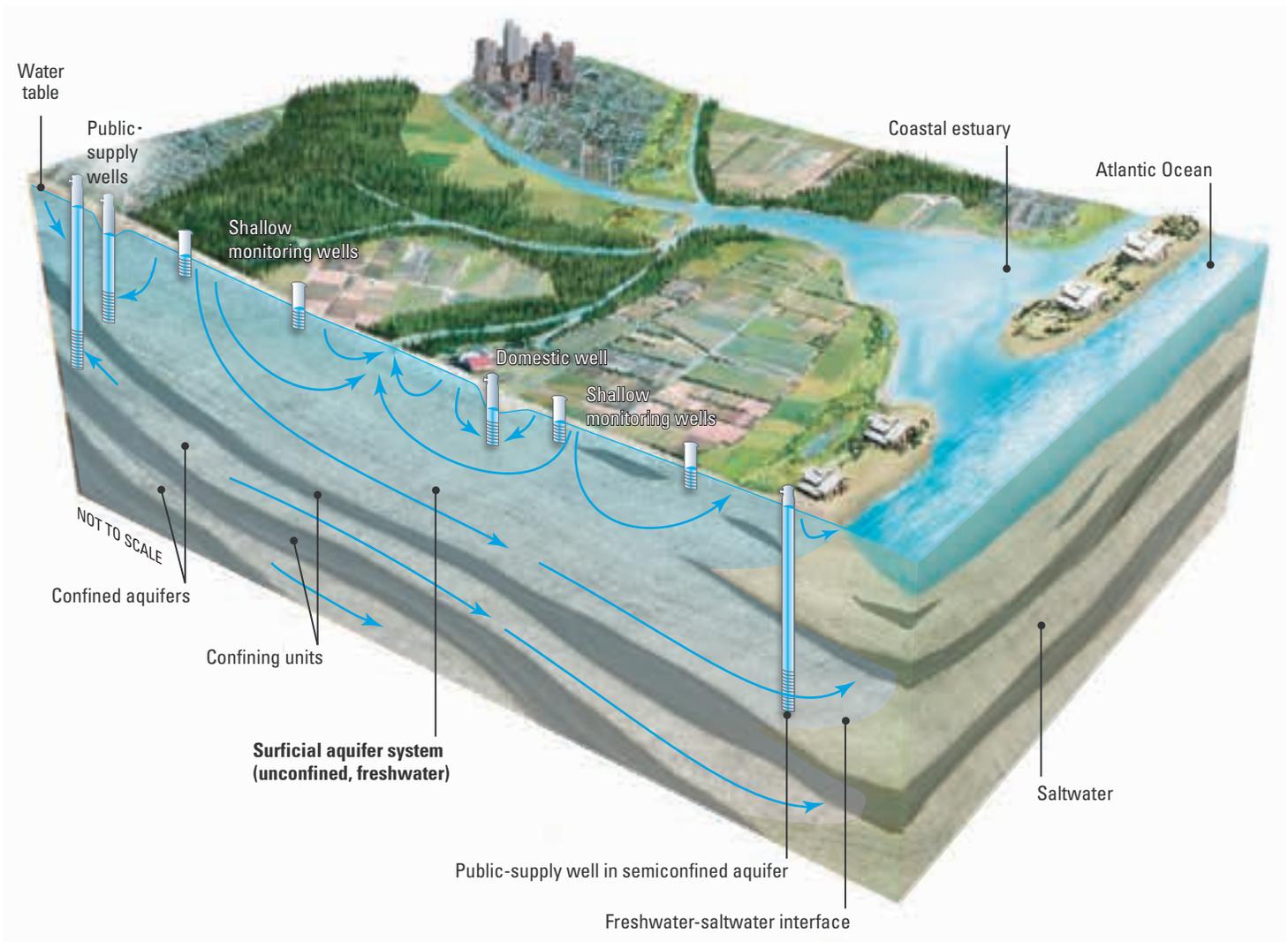


Figure 2–2. Different types of wells tap groundwater from different parts of the surficial aquifer system. Most monitoring wells were screened near the water table and tap groundwater whose quality is affected by the overlying land use. Drinking-water wells generally tap deeper water than do monitoring wells, and of those, public-supply wells generally tap deeper groundwater than do domestic-supply wells.

Table 2-1. The goals of different studies determined the types of wells sampled in the surficial aquifer system. Drinking-water studies sampled wells screened at depths that represent the part of the aquifer used for drinking water, whereas land-use studies sampled wells screened at more shallow depths (just below the water table) that represent the part of the aquifer that has received recent recharge through a particular land use.

Characteristic	Drinking-water studies	Agricultural land-use studies	Urban land-use studies
Predominant land use	Mixed	Agricultural	Residential and commercial
Number of wells	149	101	95
Types of wells	Mostly domestic, some public supply and monitoring	Mostly monitoring, some domestic	Monitoring
Median well depth (range)	80 (20–612) feet	22 (6–288) feet	40 (10–96) feet

What is a contaminant?

Contaminants have a wide range of sources, both manmade and geologic. Most organic chemicals in groundwater that are of concern for human health are manmade. In contrast, most inorganic constituents in groundwater have geologic or other natural sources, although their concentrations in groundwater may be altered by human activities, such as irrigation and groundwater pumping. Some contaminants have both manmade and natural sources. For example, nitrate in groundwater has many natural sources, but nitrate concentrations in groundwater underlying agricultural and urban areas commonly are higher than in other areas because of contributions from sources associated with human activities.

But what exactly is a contaminant? The word means different things to different people. For example, a contaminant is defined by the Safe Drinking Water Act (SDWA) as “any physical, chemical, biological, or radiological substance or matter in water” (see <http://www.epw.senate.gov/sdwa.pdf>). This broad definition of contaminant includes every substance that may be found dissolved or suspended in water—everything but the water molecule itself. This is not a very practical definition because this would imply that all water is “contaminated.” Pure water that has nothing dissolved in it does not occur naturally—not even rainfall is pure water, because it contains, at a minimum, some dissolved gases.

The U.S. Environmental Protection Agency defines a contaminant as “Any physical, chemical, biological, or radiological substance or matter that has an adverse effect on air, water, or soil” (see <http://epa.gov/region04/superfund/qfinder/glossary.html>). This definition is more practical and allows both manmade constituents and those with geologic sources in water to be defined as contaminants. However, it does not define what “adverse” means, and what may be adverse in one way might be beneficial in another. In this circular, a contaminant is defined as any physical, chemical, biological, or radiological substance or matter in groundwater that is manmade or that impairs the use of water for its intended purpose. Impairment is determined by comparing a measured concentration to benchmarks or guidelines. By this definition, all manmade compounds, such as pesticides and volatile organic compounds, are contaminants because they do not occur naturally in groundwater. If a constituent with a geologic source, such as arsenic, occurs in drinking water at a concentration above its human-health benchmark, it also is considered a contaminant.

Aquifer (aq.ui.fer)—ăk'wə-fər

An underground layer of saturated permeable materials (rock, gravel, sand, or silt) that will yield a useful quantity of water to a well.

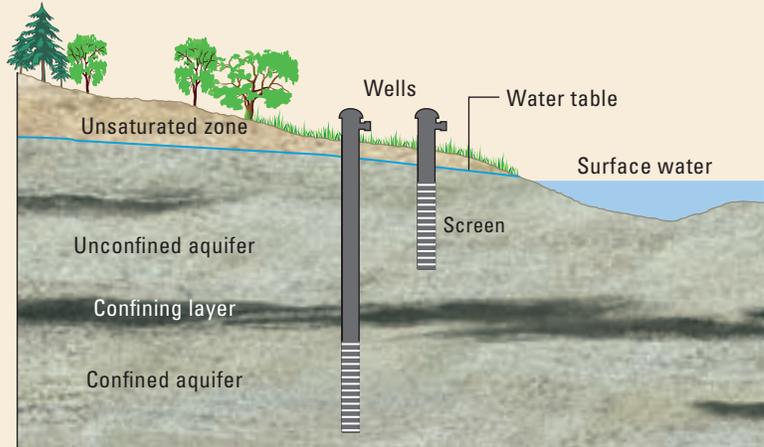
The **unsaturated zone** is the area below the land surface and above an aquifer. In addition to soil, rocks, and air, the unsaturated zone contains water from the land surface (such as rain) that is slowly moving downward to the water table of the aquifer.

An **unconfined aquifer** is bounded at its top by the water table, below which water fills all the pore spaces in the rock. Water from the land surface can move down into an unconfined aquifer.

A **confining layer** is a layer of material (often clay) through which water does not easily flow, creating a boundary between aquifers.

A **confined aquifer** is bounded at its top by a confining layer. Water enters or “recharges” confined aquifers where the confining layer is not present. Where the confining layer is not continuous or is breached (for example, by a well), flow between the unconfined and confined aquifer can occur.

The pressure within a confined aquifer can be greater than that in the overlying unconfined aquifer if the source of the water in the confined aquifer is at a higher elevation than the unconfined aquifer. In that case, water in a well in a confined aquifer will rise to a higher level than that in the overlying unconfined aquifer.



Sedimentary aquifer
Groundwater storage and flow between grains of sediment

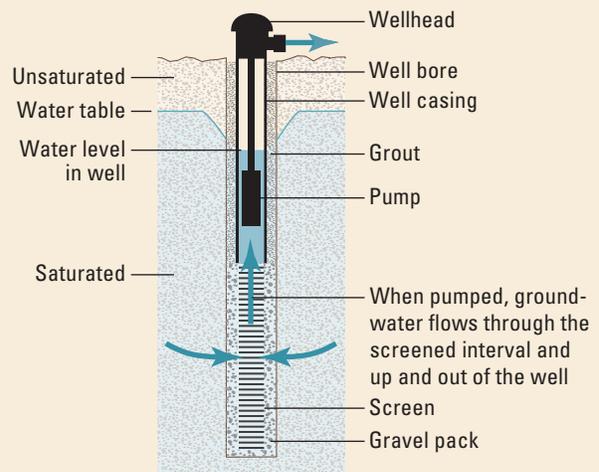
Bedrock aquifer
Groundwater storage and flow in fractures

Carbonate aquifer
Groundwater storage and flow in solution cavities or fractures



Anatomy of a well

A well is simply a hole in the ground (well bore or borehole) from which water can be removed. The well bore is lined with a well casing, such as a pipe, to prevent the well bore from collapsing. The casing, along with a sealant (called grout), also prevents water from flowing into the well from the land surface or from parts of the aquifer where the water quality may be less desirable. The casing can be open at the bottom or perforated at a specific depth with a screen, to allow water to flow into the well where it can be pumped to the surface. Coarse sand or gravel (called sand pack or gravel pack) can be placed around the well screen to help improve the flow of water into the well. Some wells are cased only near the land surface, allowing water to flow into the well from nearly the entire length of the well bore.



Drinking-Water Studies

To assess water-quality conditions of the groundwater used as a drinking-water resource, one sample was collected from each of 149 randomly selected existing pumping wells or deep monitoring wells. In addition, samples from 45 public-supply wells were collected in New Jersey and Delaware for special studies that focused on the quality of public drinking water in those areas (fig. 2–1).

Land-Use Studies

To assess the quality of recently recharged groundwater (generally less than 10 years old)⁽¹⁾ underlying agricultural and urban areas, groundwater samples were collected from existing shallow domestic wells or shallow monitoring wells in those land-use settings (fig. 2–1; table 2–1). The agricultural setting of the Northern Atlantic Coastal Plain includes areas with a variety of vegetables and row crops such as corn, soybeans, and small grains. Samples were collected in agricultural areas from southern New Jersey through North Carolina. The urban land-use setting of the Northern Atlantic Coastal Plain is similar to that of the Nation as a whole—commercial and single-family and multifamily residential development. For this study, samples were collected from three urban areas: Long Island, southern New Jersey, and Virginia Beach, Virginia. The median depth of wells sampled for agricultural studies was 22 ft, and the median depth of wells sampled for urban studies was 35 ft. The difference in depths between wells from areas with agricultural land use and those from urban areas reflects a difference in the depth to the water table from south to north. The water quality of these samples is an indication of how the chemicals—nitrogen, pesticides, solvents, gasoline—used for crop production and in day-to-day life might affect the quality of a future drinking-water resource.



Top photograph from the Chesapeake Bay Program; bottom photograph by Mark Nardi, USGS

The chemicals used in agricultural and urban or suburban areas that enter shallow groundwater might affect the quality of a future drinking-water resource in deep parts of the surficial aquifer system.



Chapter 3: *Environmental Setting and Hydrogeology*

The surficial aquifer system is unconfined, has a shallow water table, and typically is composed of sandy sediments. Abundant rainfall provides aquifer recharge, but can also carry chemicals from the land surface to the water table. Sources of potential chemical contamination from human activities are widespread—there are heavily urbanized areas in the north and areas of intensive agriculture in the south. The surficial aquifer system is a major source of public drinking-water supply in heavily populated Long Island and southern New Jersey. It also is an important source of drinking water for residents of many small towns and rural households with domestic wells. The surficial aquifer system provides as much as 95 percent of streamflow that originates in the Northern Atlantic Coastal Plain and recharges underlying confined aquifers.

Flooded marshland behind Primehook Beach, Delaware.

This chapter summarizes background information for the Northern Atlantic Coastal Plain surficial aquifer system and provides the context for understanding findings about water quality in this Principal Aquifer. The chapter covers the environmental and hydrogeologic settings, including information on population, land use, and water use.

Environmental Setting

The Northern Atlantic Coastal Plain covers about 50,000 square miles in six States and extends from the southern border of North Carolina northward through Long Island (fig. 3–1). The study area is bounded on the east by the Atlantic Ocean and on the west by the Fall Line (see sidebar, What is the Fall Line?, p. 19) and older rocks of the Piedmont Physiographic Province. The Coastal Plain sediments form

a wedge beginning at the Fall Line and the northern edge of Long Island, thickening to as much as 14,000 ft along the Atlantic coastline.^(3–5) The land surface generally slopes seaward from elevations greater than 700 ft at the Fall Line to sea level along the coast of the Atlantic Ocean and major estuaries like Chesapeake and Delaware Bays and Albemarle, Long Island, and Pamlico Sounds. Topography is generally flat to gently rolling, although the region contains some areas of moderate topographic relief.

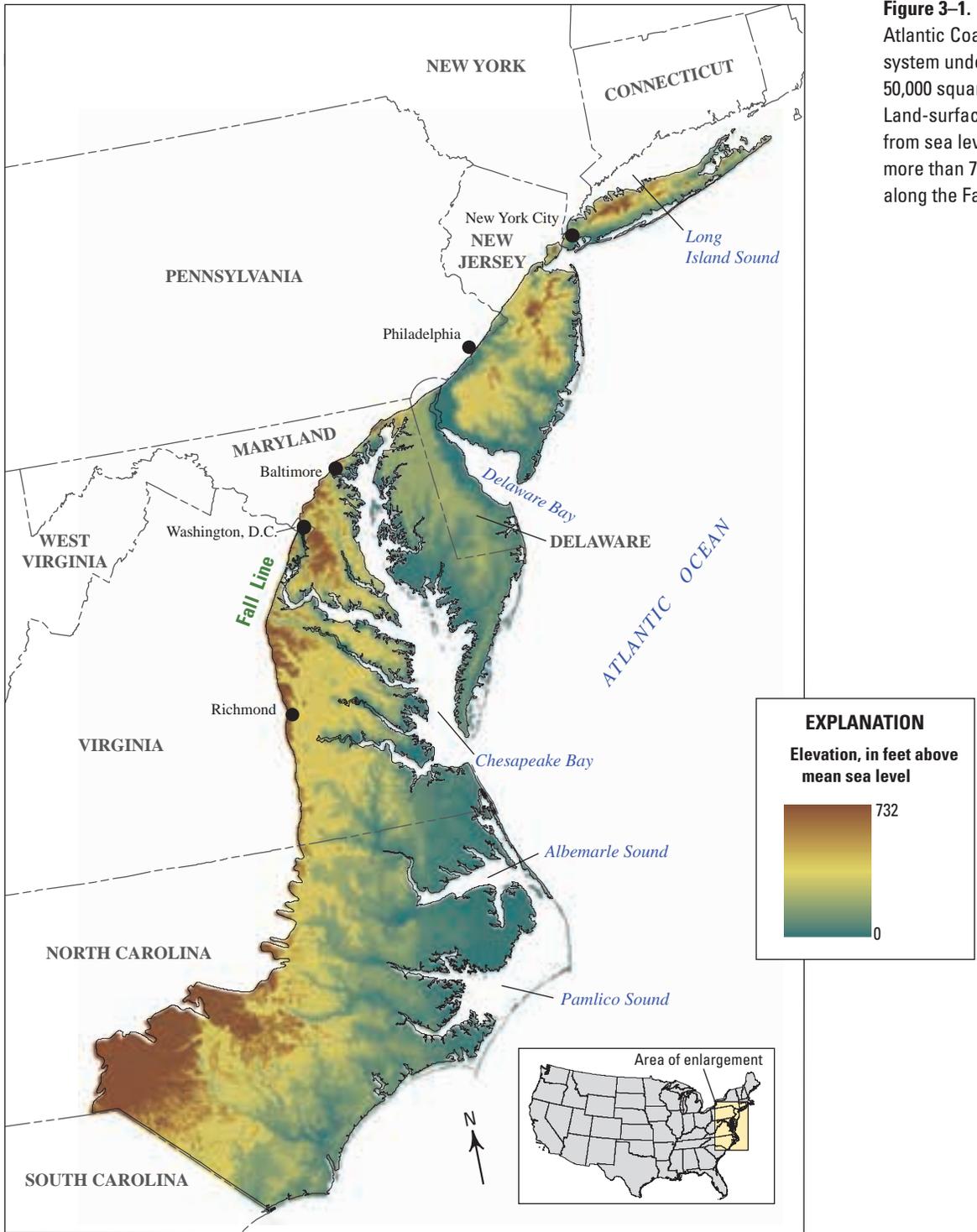
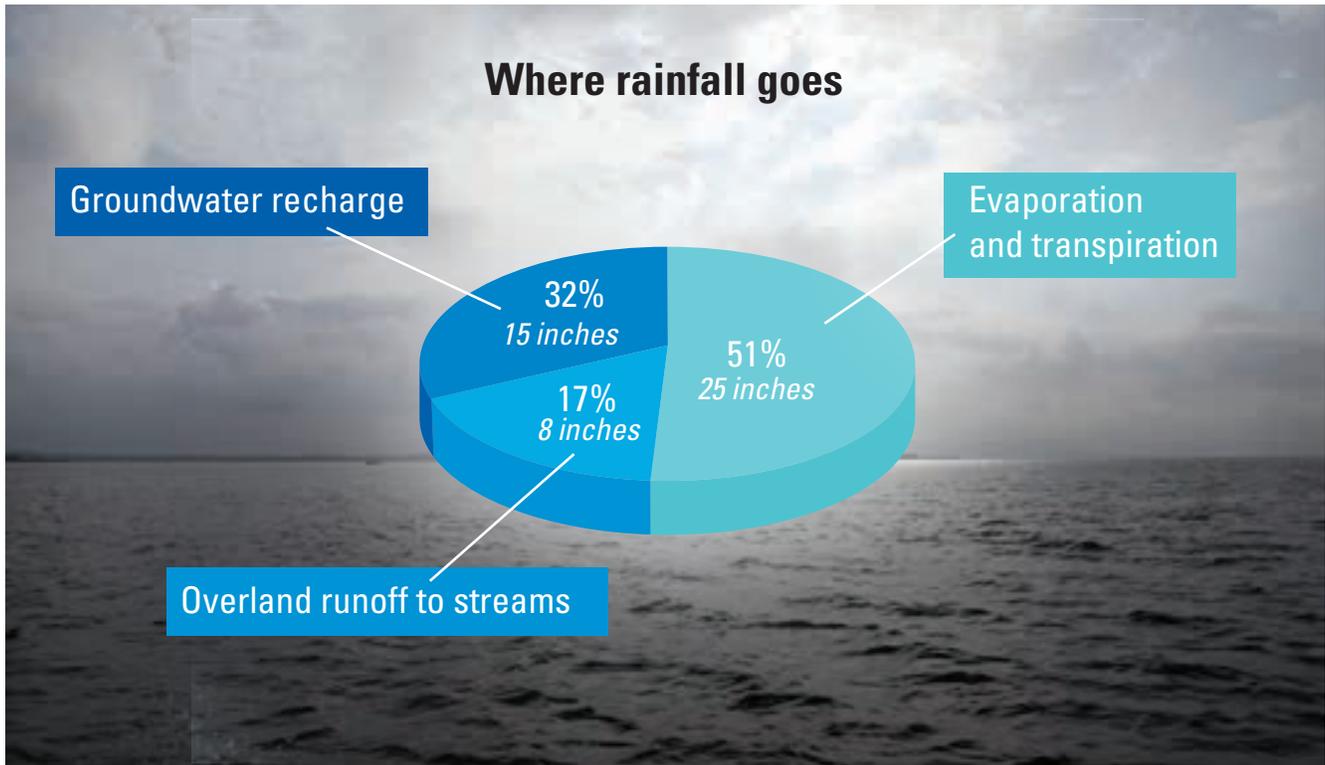


Figure 3-1. The Northern Atlantic Coastal Plain aquifer system underlies about 50,000 square miles in six States. Land-surface elevation ranges from sea level along the coast to more than 700 ft above sea level along the Fall Line.

The Northern Atlantic Coastal Plain has a humid and temperate to subtropical climate. Average annual precipitation is abundant, from about 40 inches near Washington, D.C., to more than 56 inches in eastern North Carolina.⁽⁶⁾ About one-third of this water recharges the surficial aquifer system⁽⁷⁾ (fig. 3–2). Average annual air temperatures range

from about 62 degrees Fahrenheit (°F) in the south to about 54 °F in the north. Precipitation is typically distributed fairly evenly throughout the year, although rainfall is often most intense during tropical weather systems and thunderstorms during the warm months.



Photograph from the Chesapeake Bay Program

Figure 3–2. About one-half of the precipitation that falls in the Northern Atlantic Coastal Plain evaporates or is transpired by plants, about one-third recharges the shallow groundwater system, and the remainder runs off of the land surface directly to streams.

What is the Fall Line?

The early exploration of the major rivers of the eastern United States was impeded by rapids and waterfalls along a low east-facing cliff that parallels the Atlantic coastline from New Jersey through the Carolinas. These waterfalls and rapids form what is referred to as the Fall Line and occur where the older consolidated rocks of the Piedmont Physiographic Province emerge from beneath the sediments of the Coastal Plain Physiographic Province. The potential for developing water-wheel-powered mills and other industries and the limitation of upstream river travel at the Fall Line helped to guide the location of major cities such as Baltimore, Maryland; Philadelphia, Pennsylvania; Richmond, Virginia; and Washington, D.C.



Photograph by Gary Fleming, Virginia Department of Conservation and Recreation

Hydrogeologic Setting

The surficial aquifer system is made up of unconfined parts of the many aquifers that are just below the land surface in much of the Northern Atlantic Coastal Plain (see sidebar, The surficial aquifer system includes many different local unconfined aquifers, p. 21). These aquifers extend from the water table down to the first fine-grained sediment layer (confining unit) that obstructs the downward movement of water (fig. 3–3). The water table is near the land surface in flat areas near streams and estuaries, but can be more than 30 ft deep beneath upland areas with hills and deep stream valleys,⁽⁸⁾ and is more than 200 ft deep beneath parts of Long Island.⁽³⁾ The relatively coarse and permeable sediments that compose the surficial aquifer system mostly are less than

100 ft thick, but in some areas are much thicker, particularly on Long Island and in southern New Jersey (500 to 800 ft).⁽⁹⁾ Most of these sediments were deposited by flowing streams and rivers or in tidal waters; unconsolidated glacial deposits cover these sediments and form the surface of the surficial aquifer system on Long Island. Although predominantly sandy, the texture of the sediments of the surficial aquifer system includes coarse-textured sand and gravel in some areas and fine-textured silt and clay in other areas.⁽¹⁰⁾ A part of the surficial aquifer system in the southern part of North Carolina, called the Castle Hayne aquifer, is composed of consolidated limestone.

The surficial aquifer system of the Northern Atlantic Coastal Plain is under water-table conditions (unconfined) and therefore is vulnerable to contamination from chemicals that

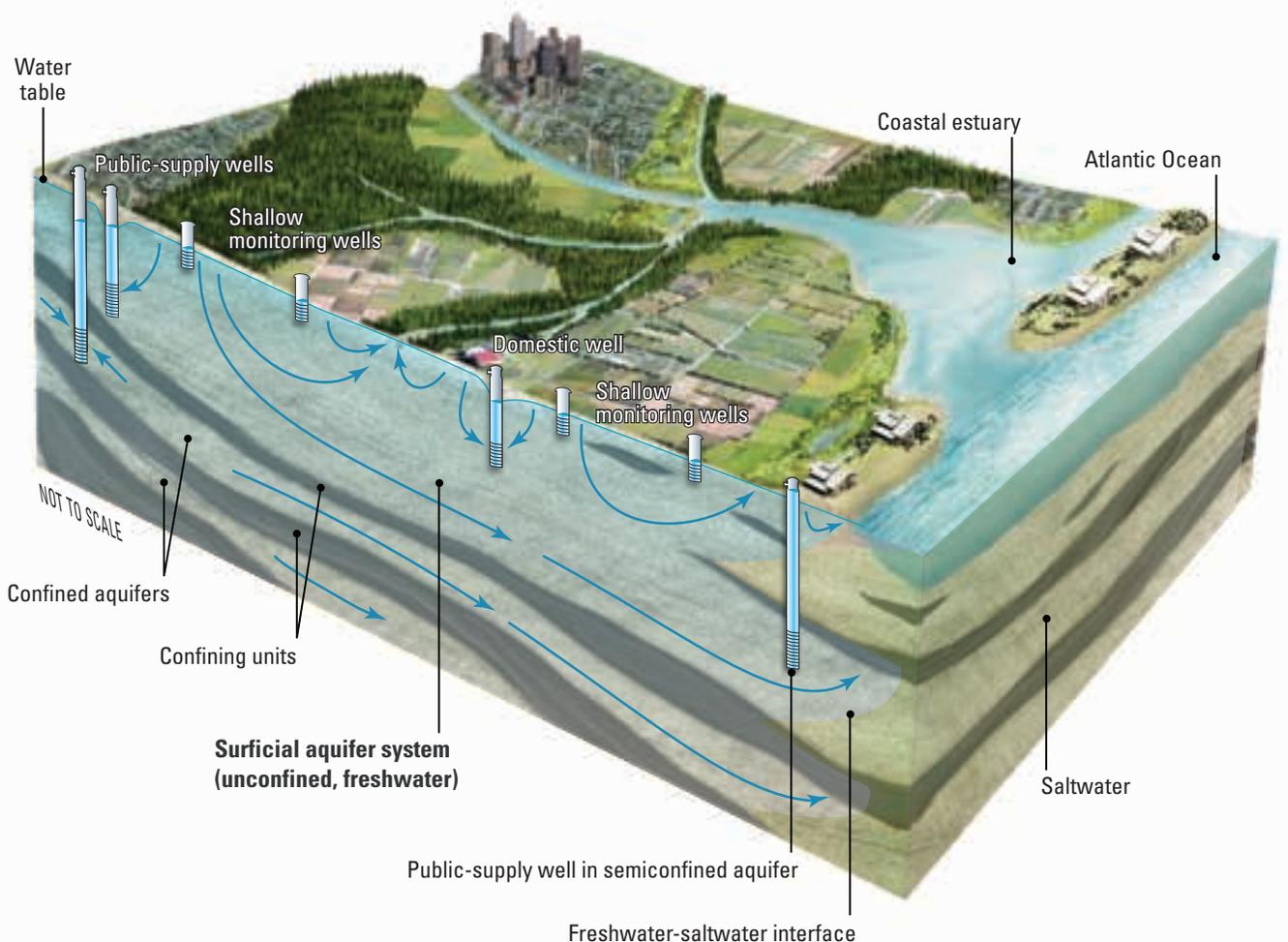


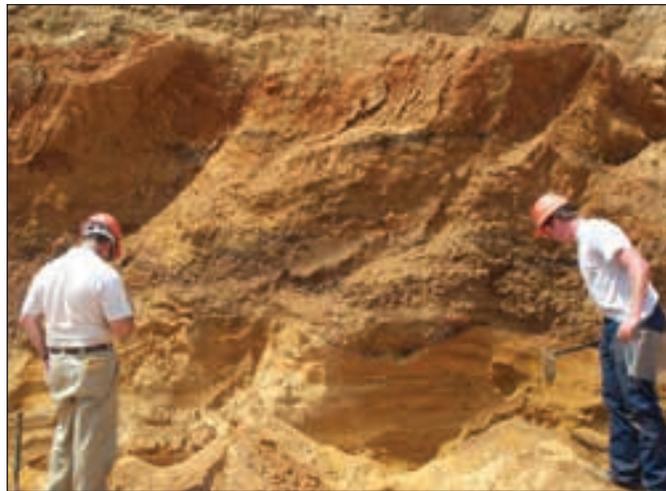
Figure 3-3. The surficial aquifer system of the Northern Atlantic Coastal Plain is under water-table conditions (unconfined) and therefore is vulnerable to contamination from chemicals that are applied to the land surface and carried into groundwater with recharging rainfall. Groundwater in the surficial aquifer system moves along flow paths from the water table in upland recharge areas to local streams and estuaries. Regional groundwater flow predominantly is from west to east, except where pumping has altered natural flow directions. The surficial aquifer system is underlain by a series of confined aquifers that are largely protected by overlying fine-textured and impermeable confining units from contamination by chemicals from human sources.

are applied to the land surface and carried into groundwater with recharging rainfall. Groundwater in the surficial aquifer system moves along flow paths from the water table in upland recharge areas to local streams and estuaries. Regional groundwater flow predominantly is from west to east, except where pumping has altered the natural direction of flow. The surficial aquifer system is underlain by a series of confined aquifers that are largely protected by overlying fine-textured and impermeable confining units from contamination by chemicals from human sources.

Groundwater in the surficial aquifer system is an important source of domestic and (where the aquifer is particularly thick) public water supplies in many areas and is the major source of freshwater flow to streams. Most groundwater in the surficial aquifer system flows along relatively short flow

paths to discharge to local streams and tidal waters (fig. 3–3); groundwater discharge provides 40 to 95 percent of flow in Coastal Plain streams.^(7, 12) About 2 percent of infiltrating groundwater recharges deeper confined aquifers and about 4 percent is withdrawn by wells.⁽⁷⁾

The surficial aquifer system is underlain by a series of alternating confined aquifers and confining units (fig. 3–3). In some areas, a part of an otherwise confined aquifer is in direct contact with the overlying unconfined surficial aquifer sediments and is considered to be part of the surficial aquifer system. The confined aquifers are composed of unconsolidated to semiconsolidated sand, gravel, or shell material. Confining units are composed of fine-textured sediments such as silt and clay that are relatively impermeable and do not easily transmit water.



Photograph from Delaware Geological Survey

Thick beds of coarse-textured sands and gravels, like those shown here, that were deposited by rivers and streams, make up some of the most productive parts of the surficial aquifer system and are widely used for drinking-water supply. Large amounts of water can be stored between the sediment grains and withdrawn by wells that tap these deposits. Because these sediments are generally buried, geologists take advantage of exposures in sand pits and other excavations to study them.

The surficial aquifer system includes many different local unconfined aquifers

On Long Island, the surficial aquifer includes the upper glacial aquifer and underlying Magothy aquifer. In New Jersey, the outcrop of the Potomac-Raritan-Magothy aquifer system near the Fall Line and the Kirkwood-Cohansey aquifer system to the east are the principal surficial aquifers. The surficial aquifer on the Delmarva Peninsula is commonly called the Columbia aquifer and includes the subcrop areas of many otherwise confined aquifers, such as aquifers of the Chesapeake Group. In Virginia and North Carolina where the sandy surficial sediments

are generally thinner than to the north, the surficial aquifer is unnamed. In Virginia, sediments of the surficial aquifer are in hydraulic connection with the Yorktown-Eastover aquifer in many parts of the eastern Coastal Plain, and in North Carolina, the surficial aquifer system also includes the Castle Hayne aquifer where it subcrops beneath the surficial sands in the southeastern part of the Coastal Plain. For more information about the aquifers of the Northern Atlantic Coastal Plain, see Trapp and Meisler.⁽⁶⁾

Land Use and Population

How land is used is important from a water-quality standpoint because some land uses—agricultural and urban, for example—are accompanied by use of manmade chemicals. Much of the Northern Atlantic Coastal Plain is forested, but intensive agriculture is common in some areas, particularly on the Delmarva Peninsula and in parts of North Carolina (fig. 3–4). This region also includes some of the

most densely populated urban areas of the Nation, supporting a growing population of more than 21 million (fig. 3–5). The greatest density of development is congregated along the Fall Line, near major cities such as Baltimore, New York, Philadelphia, and Washington, D.C. A steadily increasing population requires more and more water resources for drinking-water supplies and other uses.



Photographs from top to bottom: Courtesy of the Chesapeake Bay Program; Jane Thomas, IAN, UMES; IAN, UMES; USGS

Figure 3–4. Diverse human activities across the Northern Atlantic Coastal Plain can affect groundwater quality. Intensive agriculture is common on the Delmarva Peninsula and in parts of New Jersey and North Carolina. The urban corridor along the Fall Line from the area of Washington, D.C., to the north is densely populated.

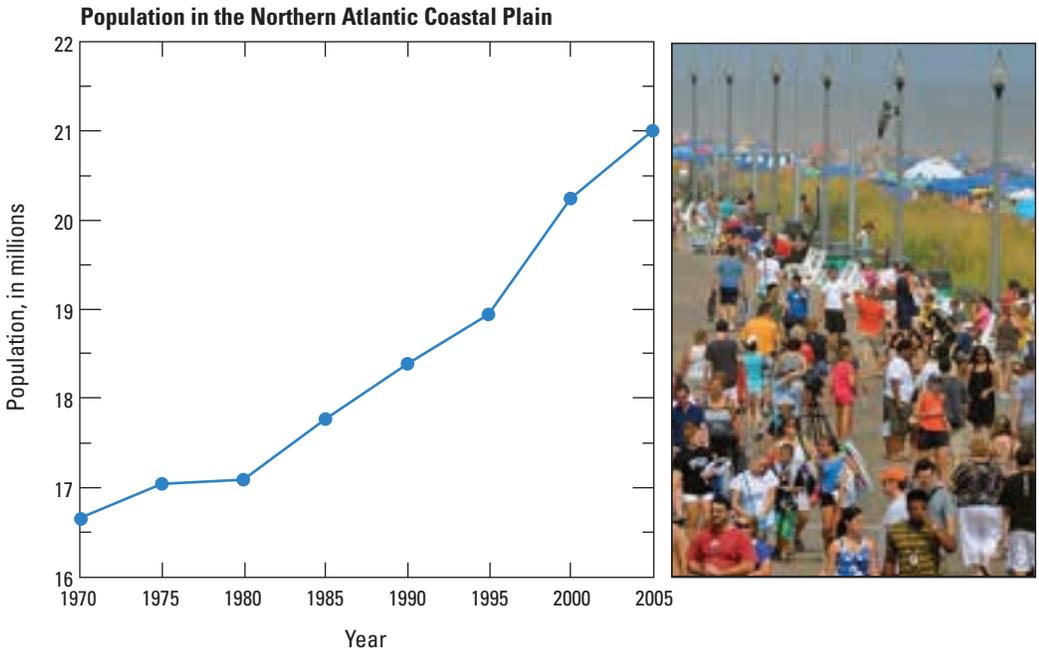


Figure 3-5. With a population of more than 21 million people (in 2005), the Northern Atlantic Coastal Plain region is one of the most populous parts of the Nation. A steadily increasing population requires more and more water resources for drinking-water supplies and other uses.

Water Use

The availability of reliable and sustainable sources of water for public water consumption, industry, agriculture, and natural ecosystems is critical to an area of diverse land uses and expanding population like the Northern Atlantic Coastal Plain. About half of the population relies on groundwater for drinking water, and the remainder relies on surface water. The main use of groundwater is for public drinking-water supply, but groundwater also is used for domestic supply, irrigation, and industrial purposes (fig. 3-6). In areas where the surficial aquifer system is thick, such as on Long Island and in southern New Jersey, it is a major source of groundwater used for drinking water. In areas where the surficial aquifer system is thin and is not sufficient for public drinking-water supply, underlying confined aquifers are more frequently used for public water supply. Public water supply is the dominant use of groundwater from the Northern Atlantic Coastal Plain region.

About 800 million gallons per day was withdrawn from unconfined and confined aquifers in the Northern Atlantic Coastal Plain to meet the demands of public water supply for about 5 million people in 2005 (Jack Monti, U.S. Geological Survey, written commun., 2012; see sidebar, The Northern Atlantic Coastal Plain aquifer at a glance, p. 24).⁽¹³⁾ On Long Island, nearly 3 million people use about 260 million gallons of water each day from the unconfined and interconnected glacial and Magothy aquifers, which are part of the surficial aquifer system, making this aquifer the largest single source

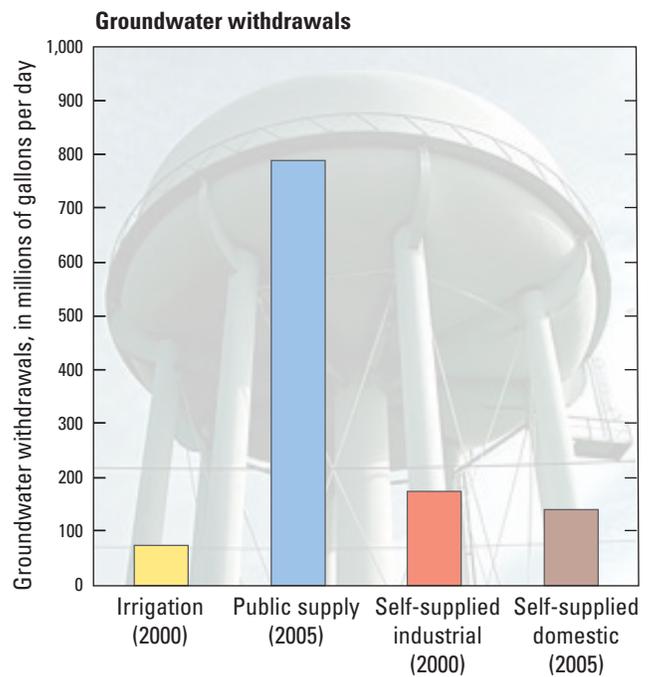


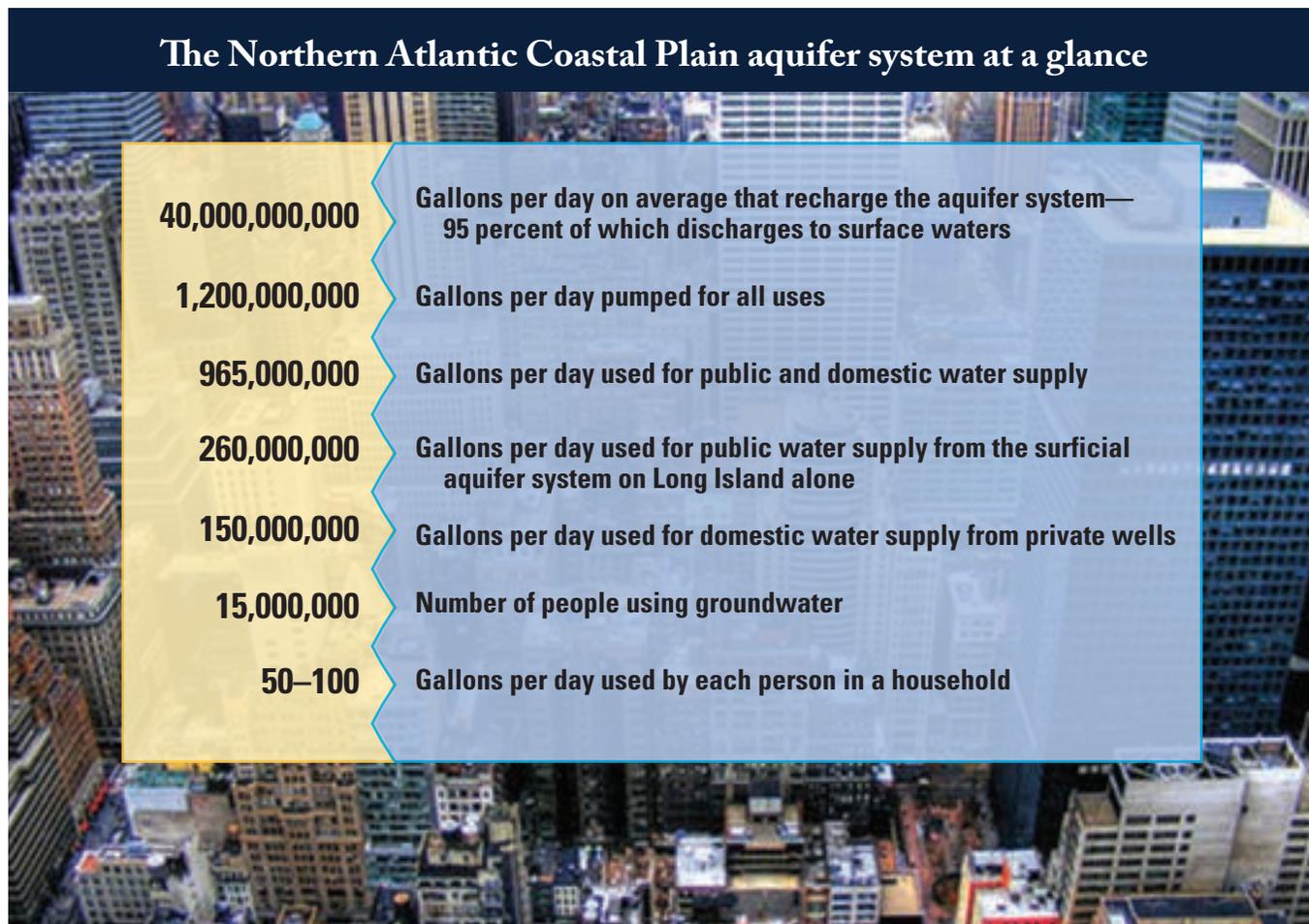
Figure 3-6. Public water supply is the dominant use of groundwater from the Northern Atlantic Coastal Plain region.

of drinking water in the region.⁽¹³⁾ Cities near the Atlantic coast typically rely primarily on confined aquifers to avoid problems with saltwater intrusion, which can occur in the surficial aquifer system where extensive groundwater pumping has drawn in saline water from nearby coastal areas. When saltwater is detected in drinking-water supplies, wells commonly are drilled deeper or moved inland. When these solutions are not available, water can be imported (as is done in Virginia Beach) or brackish water can be desalinated (as is done in Cape May, N.J.), but these solutions come with high costs, which typically are passed on to the consumer.

More than 2 million people in the Northern Atlantic Coastal Plain rely on domestic wells for drinking-water supplies. The surficial aquifer system is an important source of domestic water supply in urbanized areas of New Jersey and eastern Long Island. Groundwater is the sole source of

domestic drinking water in rural areas, and many of these wells are in the unconfined surficial aquifer system.

About half of the Northern Atlantic Coastal Plain’s drinking-water supply comes from surface water—streams, rivers, and reservoirs—located in the Piedmont Physiographic Province to the west of the Fall Line. This includes tap water in Baltimore, New York City, and Washington, D.C. Where groundwater supplies are insufficient to meet the needs of large population centers that are some distance from the Fall Line, such as in Virginia Beach, water is imported from streams and reservoirs that originate in the Piedmont to the west. Low-relief and highly permeable sediments in the Coastal Plain are not conducive to reservoir construction, but small reservoirs are important water sources in some areas. Water from streams also is used for agricultural irrigation and industrial supply.



Chapter 4: *Natural Hydrogeologic and Geochemical Processes That Affect Groundwater Quality*

The movement of water and the transport of contaminants through the surficial aquifer system are controlled by the local hydrogeologic setting and geochemical processes. Groundwater moves from recharge areas on the land surface along subsurface flow paths to discharge areas in streams, rivers, wetlands, and estuaries. The geologic materials that make up the surficial aquifer system determine the residence time of groundwater, the geochemical environment within the aquifer, and the susceptibility of groundwater to contamination from natural and human-related sources.

This chapter summarizes the natural hydrogeologic and geochemical processes that affect the movement and quality of groundwater in the surficial aquifer system of the Northern Atlantic Coastal Plain.

Farmland with poultry houses in Delaware.



Hydrogeologic Processes

Hydrogeology Affects the Movement of Groundwater and Contaminants Into and Through the Surficial Aquifer System

The route that a drop of groundwater takes through an aquifer is called a flow path. Flow paths start at the water table where precipitation infiltrates or recharges the aquifer and end where groundwater discharges into streams, rivers, wetlands, and coastal water bodies or is withdrawn by a well (fig. 4–1).

Groundwater and any dissolved chemicals it contains move readily through those parts of the surficial aquifer system where soils and sediments are coarse-grained and permeable. Because groundwater is easily pumped from permeable parts of the aquifer system, those are the parts commonly tapped for drinking water. Groundwater in permeable parts of the aquifer system is more vulnerable to contamination from chemicals applied on the land surface than is groundwater in areas with fine-grained sediments, which impede the transport of water and chemicals. Further, groundwater in the surficial aquifer system is particularly vulnerable to contamination from the land surface because the overlying unsaturated zone typically is thin (less than 30 ft). Infiltration through the soil and unsaturated zone is relatively fast in many areas, which limits the potential that contaminants will be retained in soils or sediments or degraded before they reach the water table.

The texture and composition of the sediments in the surficial aquifer system, which control whether a chemical that enters groundwater remains dissolved or whether it adheres to the sediment or is degraded, vary from one part of the system to another. Near-surface sediments in the northern

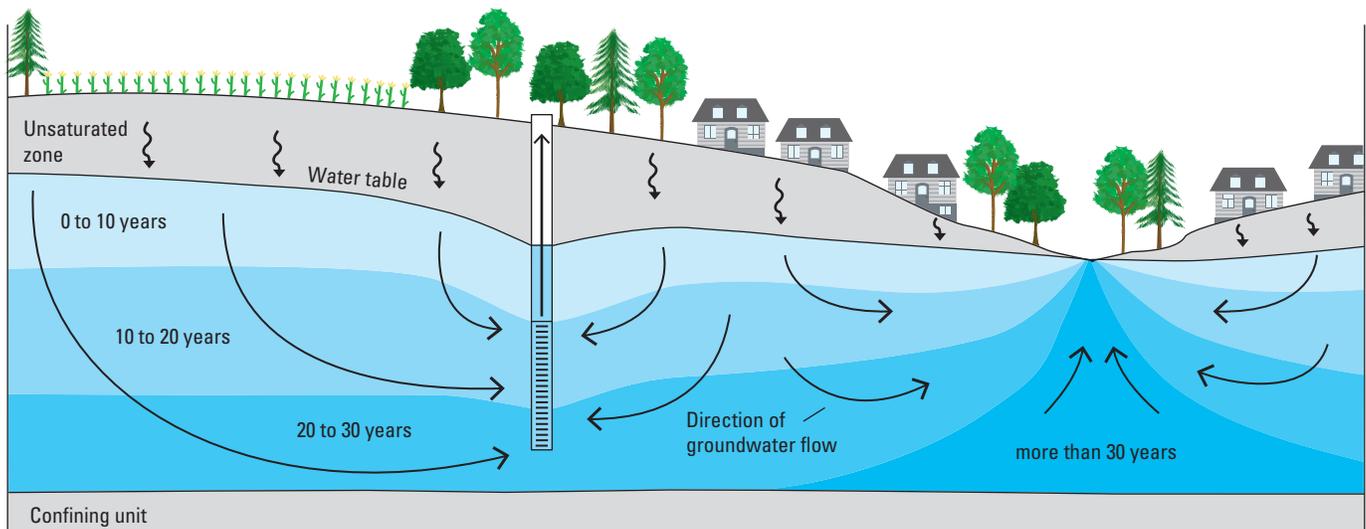


Photograph from Delaware Geological Survey



Photograph by Jessica Carpenter, USGS

Groundwater discharge is an important source of water to local streams, rivers, and coastal water bodies.



NOT TO SCALE

Figure 4–1. Groundwater in the surficial aquifer system flows from recharge areas at the water table to pumping wells or to discharge areas, such as local streams, usually within a few decades. Groundwater in shallow parts of the surficial aquifer system is young and ages over time as it moves into deeper parts of the aquifer.

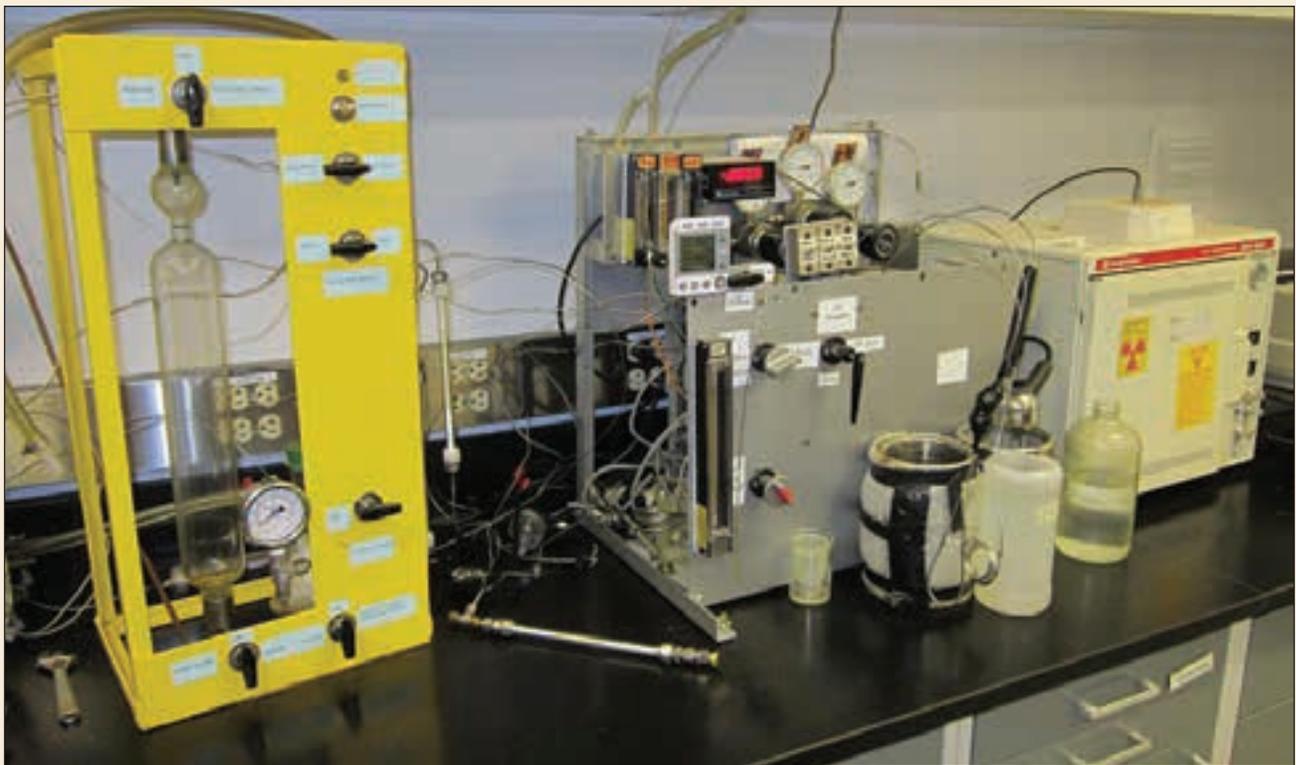
part of the study area, including Long Island, and south through the Delmarva Peninsula are mostly sands and gravels washed off of glaciers—these are some of the thickest and most permeable sediments in the Northern Atlantic Coastal Plain. Water and dissolved chemicals move readily through these sediments. In contrast, in low-lying areas near the coast, such as in Virginia and North Carolina, the surficial aquifer system generally is composed of younger sediments that were deposited in marshes, bays, and beaches that have considerable amounts of fine-grained silt, clay, and organic matter. The movement of water through the sediments in the low-lying areas near the coast is slower than through those to the north; chemicals tend to adhere to fine-grained particles, which deter their movement through the aquifer and can increase the potential for some chemicals to degrade, thus making these areas less vulnerable to contamination from the land surface.

Most Groundwater in the Surficial Aquifer System is Relatively Young

The residence time of groundwater in most parts of the surficial aquifer system ranges from a few years to several decades, with a median of 10 to 15 years in many places (see sidebar, *How is groundwater residence time determined?*, this page).^(14–16) Residence times are short—from less than 1 year to about 20 years—in areas where the surficial aquifer is thin and flow paths are short, such as in extensively ditched lowland areas near the North Carolina coast. In settings where the surficial aquifer is several hundred feet thick, such as in New Jersey and Long Island—where there are longer, more regional flow paths—the residence time of some groundwater in the surficial aquifer is more than 200 years, although most groundwater residence times are less than 50 years even in those settings.⁽¹⁴⁾

How is groundwater residence time determined?

The age of a groundwater sample, which is used to determine the residence time of water in a flow system, is the time elapsed since the water first entered the aquifer at the water table. Groundwater age is estimated by measuring concentrations of some of the manmade gases that are dissolved in the groundwater. The gases measured, which include chlorofluorocarbons (CFCs), sulfur hexafluoride, and radioactive tritium, entered the aquifer with recharge water. Concentrations of these gases in a groundwater sample are compared against atmospheric records to estimate the year that the sampled water recharged the surficial aquifer. For more information on using chemical tracers to determine groundwater age, visit the USGS Reston Chlorofluorocarbon Laboratory Web site (<http://water.usgs.gov/lab/>).



Laboratory equipment used for determination of groundwater age.

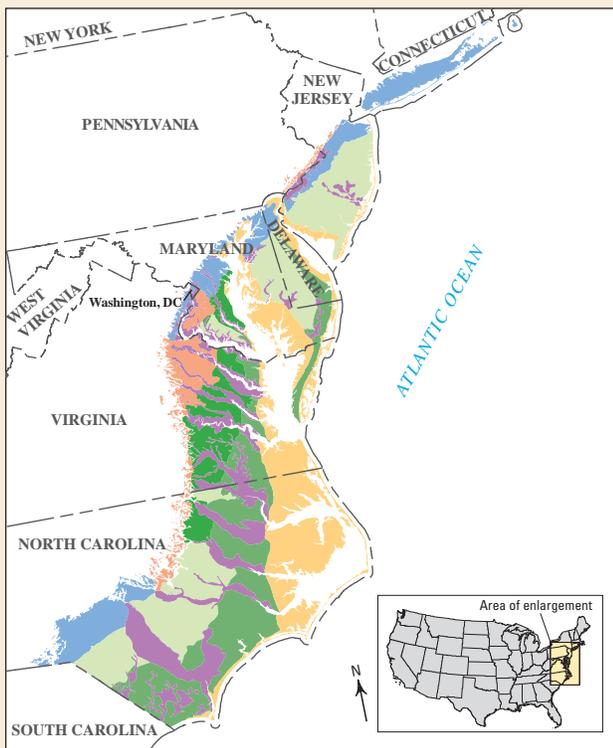
Wells screened near the water table typically intercept recently recharged groundwater (residence time less than 10 years), and the water quality of samples from these wells reflects the influence of recent land-use activities near the wells. Wells, such as most public-supply wells, that are deeper than those nearer the water table and pump at high rates have a large zone of capture and intercept a mix of older and younger water that infiltrated the groundwater system over a wide area; this water can contain contaminants from a wide variety of sources (fig. 4-1).

Geochemical Processes

Hydrogeologic Setting Controls Geochemical Processes That Affect Groundwater Quality

The capacity of chemicals that enter groundwater to remain dissolved and travel through the aquifer is affected by a variety of geochemical reactions that are related to the hydrogeologic setting through which the water passes. The surficial aquifer system has been divided into seven subregions

How hydrogeologic setting controls geochemical processes

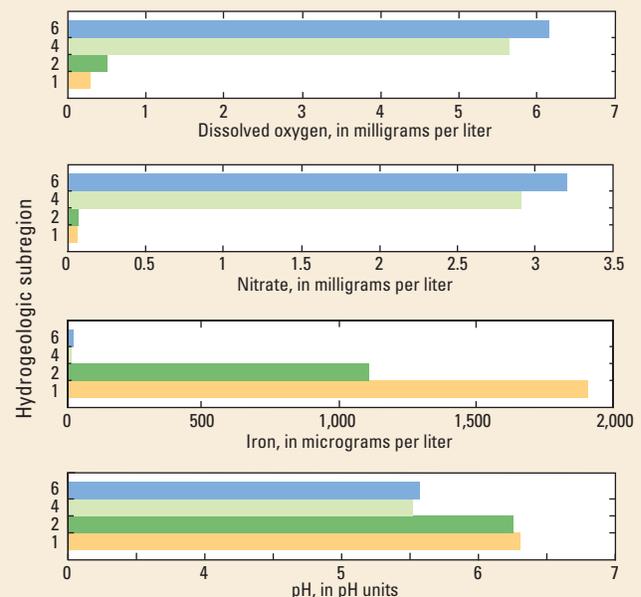


EXPLANATION

- 1 **Coastal Lowlands**—Poor natural drainage because of low elevation and relief. Groundwater typically has low dissolved-oxygen concentrations.
- 2 **MCP, Mixed Sediments**—Moderate relief. Drainage and redox vary with geology.
- 3 **MCP, Fine Sediments**—Fine sediments and moderate relief promote runoff and limit infiltration.
- 4 **MCP, Sand with Overlying Gravels**—Coarse sediments promote infiltration and oxidation in surficial aquifer.
- 5 **ICP, Upland Sand and Gravel**—Coarse sediments promote oxic conditions in shallow groundwater, but are thin and laterally discontinuous. Relief promotes runoff over infiltration.
- 6 **ICP, Dissected Outcrop Belt**—Drainage and groundwater redox varies with geology. Where unconfined, groundwater is oxic.
- 7 **Alluvial and Estuarine Valleys**—Poor natural drainage is common as a result of low relief and elevation, and fine sediments. Groundwater typically has low dissolved-oxygen concentrations, but redox condition varies with geology.

MCP, Middle Coastal Plain; ICP, Inner Coastal Plain

Seven hydrogeologic subregions were developed on the basis of the physiography and the texture and composition of surficial sediments. These subregions group general and geochemical conditions of the surficial aquifer system of the Northern Atlantic Coastal Plain to aid in interpreting and predicting the distribution of contaminants in groundwater.⁽¹⁰⁾ For example, sediments of the Middle Coastal Plain (MCP), Sand with Overlying Gravels, and Inner Coastal Plain (ICP), Dissected Outcrop Belt subregions are sandy and permeable. The surficial aquifer in these subregions is oxic and particularly vulnerable to contamination from land-based chemical applications, and nitrate contamination of groundwater is common. In contrast, in the Coastal Lowlands subregion, sediments are less permeable and contain more organic matter, which reacts with and slows the movement of many contaminants. The surficial aquifer in this subregion commonly is anoxic and less vulnerable to contamination from human sources than it is in other subregions; dissolved iron from geologic sources typically is present in groundwater. Groundwater is acidic throughout the surficial aquifer system; pH typically is lower in areas with higher concentrations of dissolved oxygen and nitrate than in areas without dissolved oxygen but with high iron concentrations.



*Note: Subregions 3, 5, and 7 did not have enough data to create bar graphs.

that summarize general characteristics and geochemical conditions of the various hydrogeologic settings (see sidebar, How hydrogeologic setting controls geochemical processes, p. 28).⁽¹⁰⁾ Groundwater residence time also can be an important control on geochemical processes because longer residence times increase the length of time groundwater interacts with aquifer sediments.

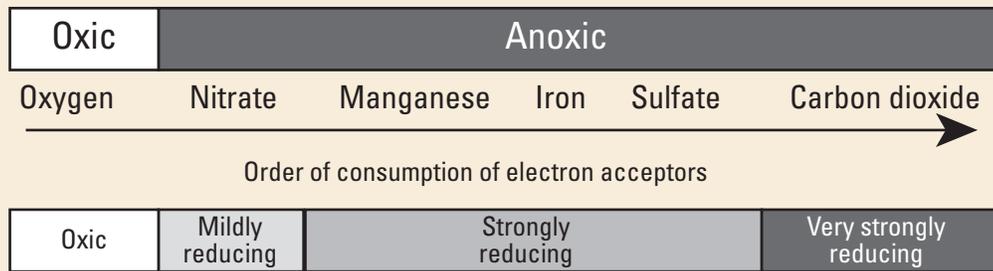
The Presence or Absence of Dissolved Oxygen in Groundwater Controls the Transformation and Transport of Many Contaminants in the Aquifer

Concentrations of dissolved oxygen in groundwater are controlled by reduction/oxidation (redox) reactions (see sidebar, How do redox reactions work?, this page). These processes are important because they control the transformation of nitrate to harmless nitrogen gas (see sidebar, How does nitrate enter groundwater? How is it lost from groundwater?, p. 31) and the degradation of many

manmade chemicals, such as solvents, gasoline compounds, and pesticides. Redox reactions also can control whether trace elements, such as arsenic, iron, and manganese, that occur naturally in sediments in most parts of the surficial aquifer system dissolve into the groundwater or remain bound up in the sediments. The distribution of organic matter in soils is a major factor controlling the dissolved-oxygen content of water entering the surficial aquifer system and is one of the factors that is characterized by the hydrogeologic subregions (see sidebar, How hydrogeologic setting controls geochemical processes, p. 28). For example, the poorly drained soils common to the Coastal Lowlands hydrogeologic subregion contain abundant organic matter, and the underlying groundwater is commonly anoxic (contains little or no dissolved oxygen). In this subregion, dissolved iron is likely to be present in groundwater. In contrast, in the more well-drained areas, such as the MCP, Sand with Overlying Gravels hydrogeologic subregion, groundwater is mostly oxic (contains dissolved oxygen), and nitrate is a common contaminant.

How do redox reactions work?

Reduction/oxidation (redox) processes require one chemical species that donates electrons and another chemical species that accepts those electrons. As a chemical species donates electrons it is “oxidized,” and as the other species accepts electrons it is “reduced.” Redox processes typically are facilitated by microbes (bacteria), which use the energy produced by the processes. In groundwater, organic carbon is the most common electron donor. If dissolved oxygen is present, it is the preferred electron acceptor, because reduction of dissolved oxygen produces more energy than reduction of other chemical species that commonly occur in groundwater. The atmosphere is the source of the dissolved oxygen, so the redox conditions in an aquifer near where recharge occurs usually are oxic (defined here as having a concentration of dissolved oxygen of at least 0.5 mg/L).



As groundwater moves through the aquifer along a flow path, the dissolved oxygen in the groundwater gradually is consumed by redox processes. Once all of the dissolved oxygen is consumed, other chemical species can accept electrons and become reduced. If nitrate is present, it will become the preferred electron acceptor until it in turn is completely consumed. This pattern continues, with manganese, iron, sulfate, and finally carbon dioxide acting as electron acceptors until they are consumed, in that order. This order of use of electron acceptors has important implications for the preservation, degradation, and even production of contaminants in groundwater. Because redox reactions occur in a sequence, it can take a long time for strongly reducing conditions to develop. For this reason, anoxic groundwater commonly is older than oxic groundwater, and, within the anoxic category, strongly reducing groundwater commonly is older than mildly reducing groundwater.

From a water-quality perspective, denitrification—the reduction of nitrate to nitrogen gas—is one of the most important redox processes that occurs in groundwater. Nitrate is a concern for human health and, where it discharges to surface water, can impair aquatic communities. Conversion of nitrate by denitrification to harmless nitrogen gas, the same gas we breathe in the atmosphere, is the primary way that nitrate is removed from water.

Sorption Processes and the pH of Groundwater Can Affect the Movement of Dissolved Metals and Other Ions in Groundwater

Sorption is a process in which ions or molecules that are dissolved in water become attached to the surfaces of solid material, such as sediment particles, either temporarily or permanently. The attachment of positively charged ions to negatively charged surfaces of clay particles and of positively charged pesticide compounds to the negatively charged surfaces of clay particles and organic matter are examples of sorption. Desorption is the release of sorbed chemicals from aquifer solids into groundwater. Whether a chemical is sorbed or desorbed at a particular point in the aquifer system depends on several factors, including the properties of the dissolved chemicals and the solid aquifer materials, the presence of other ions that compete for sorption sites, redox conditions, and groundwater pH (fig. 4–2).

Groundwater in the surficial aquifer system commonly is acidic (pH less than 7) because the aquifer sediments lack the soluble minerals, such as calcium carbonate, that can buffer (neutralize) the natural acidity of rainfall. Groundwater pH along groundwater flow paths can change over time as minerals dissolve and other chemical reactions occur. Decreases in pH can increase the movement of some constituents through the aquifer by increasing their solubility or by reducing the degree to which the constituents sorb to aquifer materials. For example, the decrease in pH caused by nitrification (see sidebar, *How does nitrate enter groundwater? How is it lost from groundwater?*, p. 31) causes manganese oxides to dissolve and radium to desorb from aquifer sediments⁽¹⁷⁾ (see chapters 5 and 6).

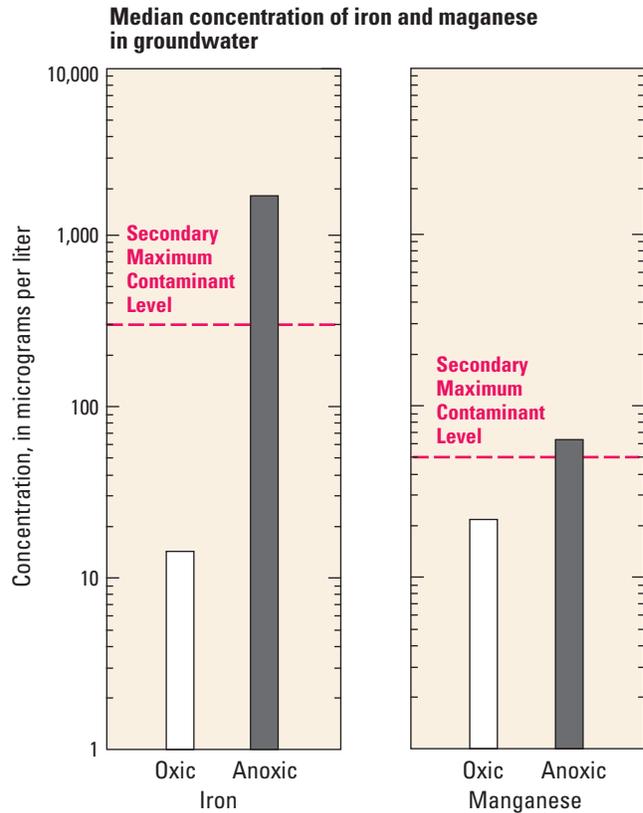
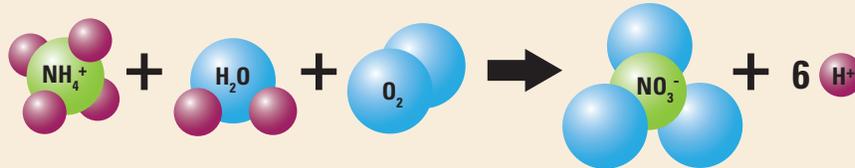


Figure 4–2. Iron and manganese sorb (attach) onto aquifer sediments where groundwater is oxic (dissolved-oxygen concentration of at least 0.5 milligram per liter) and the concentrations of iron and manganese therefore are low in oxic groundwater. When groundwater is anoxic (dissolved-oxygen concentration less than 0.5 milligram per liter), iron and manganese desorb (are released) from sediments into groundwater and therefore are present in groundwater at high concentrations, commonly greater than the U.S. Environmental Protection Agency Secondary Maximum Contaminant Level.

How does nitrate enter groundwater? How is it lost from groundwater?

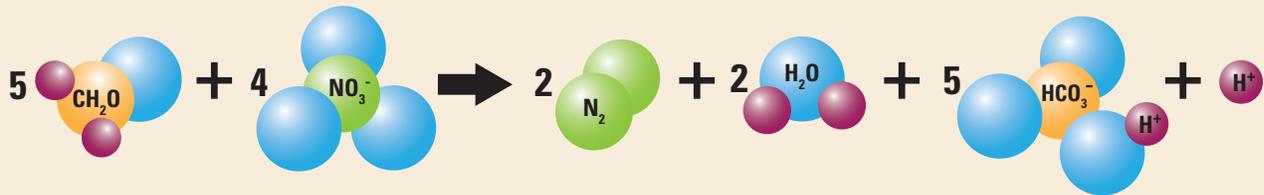
Nitrification

Nitrogen commonly is applied to fields or released from sewage disposal systems in the form of ammonium. Because oxygen usually is plentiful in soil, most of the ammonium that reaches groundwater has been transformed in the soil zone to nitrate by nitrification, a microbially driven process that requires dissolved oxygen. During nitrification, ammonium (NH_4^+) in water (H_2O) enriched with oxygen (O_2) is converted to nitrate (NO_3^-) and hydrogen ions (H^+); the release of hydrogen ions into groundwater lowers the pH (makes water more acidic).



Denitrification

Nitrate moves with groundwater through the aquifer as long as dissolved oxygen is present, sometimes along the entire length of a flow path from aquifer recharge area to discharge area. If no dissolved oxygen is present, most nitrate is reduced to harmless nitrogen gas through another microbially driven process called denitrification. During denitrification, nitrate (NO_3^-) reacts with organic matter (CH_2O) and is reduced to nitrogen gas (N_2). Bicarbonate (HCO_3^-) and carbon dioxide (CO_2) also are formed during denitrification, raising the pH (makes water more alkaline).



Denitrification can be an important process for nitrate loss from groundwater in wetlands and riparian zones, in poorly drained soils, and in sediments in deep parts of the aquifer where dissolved oxygen is not present.

Degradation Affects the Transport and Transformation of Manmade Chemicals in Groundwater

Bacteria in soil and groundwater use organic compounds (chemicals that contain carbon), including some manmade chemicals, such as pesticides and VOCs, as a source of energy and carbon for growth. As a result, the organic compounds are degraded or transformed into other organic or inorganic compounds called degradates. This process is referred to as biodegradation. Most of the degradation of manmade organic chemicals that are applied to or spilled on the land surface takes place in the soil zone where oxygen is abundant and bacterial activity is greatest, especially in soils that contain a lot of organic matter. Some compounds, such as gasoline hydrocarbons, can be used directly by bacteria as food sources and are rapidly degraded. Other compounds, such as chlorinated solvents, are not as easily degraded, especially where aquifer conditions are oxic. The rate at which an organic chemical biodegrades depends on its chemical structure, the environmental conditions, and the types of bacteria present. Biodegradation can result in complete degradation of organic chemicals to produce carbon dioxide, water, and other simple products or it can lead to formation of intermediate degradates that can be detected in groundwater. Degradates of common crop herbicides, including metolachlor, alachlor, and atrazine, typically are detected in groundwater in the surficial aquifer system at concentrations as high or higher than their parent compound (see chapter 6).



Photograph by Luke Myers, USGS

Leaks and waste disposal associated with chemical manufacturing plants can be a source of VOCs in groundwater.

Chapter 5: *Contaminants of Concern in Drinking Water and in Groundwater Flowing to Streams*

The quality of groundwater used for drinking water is impaired by chemicals from natural and manmade sources throughout the surficial aquifer system of the Northern Atlantic Coastal Plain. Ten chemicals were detected at a concentration that exceeded a human-health benchmark in at least one sample from wells used for drinking water. The chemicals most commonly detected in concentrations greater than a benchmark were nitrate and dieldrin, which come from human activities, and radium, which has a geologic source. Although pesticides and VOCs were widely detected in groundwater, in most cases these chemicals were present at concentrations far less than human-health benchmarks. The discharge of groundwater that contains elevated concentrations of nitrate to surface waters also is a water-quality concern because nutrient enrichment of streams and estuaries has caused widespread degradation of aquatic habitats.

This chapter provides a summary of constituents that were detected at a concentration greater than or near a human-health benchmark in water from drinking-water supply and monitoring wells tapping the surficial aquifer system of the Northern Atlantic Coastal Plain. Results from water samples from all types of wells are included in this chapter because manmade chemicals detected in shallow monitoring wells have the potential to travel over time to deep parts of the surficial aquifer system used for drinking water. Nitrate in streams also is discussed as it relates to aquatic health.



Many chemicals in groundwater, whether their source is geologic or human activities, can harm human health if they are present at elevated concentrations in drinking water. Chemicals of potential human-health concern in groundwater from the surficial aquifer system were identified by comparing the concentrations in water samples to guidelines and standards for drinking water that are considered protective of human health, referred to collectively as human-health benchmarks (see sidebar, Human-health benchmarks and other guidelines used in this assessment, this page) (table 5–1). Other chemicals that do not pose health problems but that impart an unpleasant taste or smell to water or that cause other undesirable effects also are discussed (table 5–2). Not all compounds that were measured in NAWQA studies had human-health benchmarks.



Photograph by Jessica Carpenter, USGS

Human-health benchmarks and other guidelines used in this assessment

Concentrations of constituents measured for this assessment were compared to human-health benchmarks to place study findings in the context of human health. The benchmarks are threshold concentrations in water above which the concentration of a contaminant in drinking water could adversely affect human health. Human-health benchmarks were available for about two-thirds of the 290 constituents and properties measured for the Principal Aquifer assessments. Two types of human-health benchmarks were used: U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Levels (MCLs) (<http://water.epa.gov/drink/contaminants/index.cfm>) and U.S. Geological Survey (USGS) Health-Based Screening Levels (HBSLs). MCLs are legally enforceable drinking-water standards that specify the maximum permissible level of a constituent in water that is delivered to any user of a public water system⁽⁵⁵⁾ (values used in this report were current as of February 2012). Although MCLs are used to regulate the quality of drinking water only from public-supply sources, they also are useful for evaluating the quality of water from domestic and monitoring wells. An MCL was available for 53 of the constituents measured. For some constituents for which an MCL has not been established, the USGS, in collaboration with the USEPA and others, developed non-enforceable HBSLs by using standard USEPA methods for establishing drinking-water guidelines and current toxicity information^(58, 69, 77) (values used in this report were current as of February 2012; see <http://water.usgs.gov/navqa/HBSL>). An HBSL was available for 135 constituents measured. Radon has neither an MCL nor an HBSL, but two MCLs have been proposed. Copper and lead have USEPA action levels rather than an MCL.

In addition to human-health benchmarks, non-health-based guidelines—Secondary Maximum Contaminant Levels (SMCLs)—were available for some of the constituents measured

in this assessment. The SMCLs are non-enforceable guidelines for concentrations of “nuisance” constituents in drinking water that can cause unwanted cosmetic effects, such as skin or tooth discoloration; aesthetic effects, such as unpleasant taste, odor, or color; or technical effects, such as corrosion or sedimentation of plumbing or reduced effectiveness of water treatment.⁽⁷⁸⁾

Concentrations greater than one-tenth of a human-health benchmark were used in this assessment to indicate which contaminants occurred, either individually or as mixtures, at concentrations that approach those of potential concern for human health, and to identify contaminants that might warrant additional monitoring and study. The criterion of one-tenth of a benchmark is consistent with various State and Federal practices for reporting contaminant occurrence in groundwater and for identifying contaminants of potential human-health concern (for example, see U.S. Environmental Protection Agency,⁽⁸¹⁾ New Jersey Department of Environmental Protection⁽⁹²⁾).

Screening-level assessments, such as this one, provide perspective on the potential relevance of detected contaminants to human health and can help in planning future studies.⁽⁶⁹⁾ They are not designed to evaluate specific effects of contaminants on human health and are not a substitute for comprehensive risk assessments. It is important to note that occurrence of a contaminant at a concentration greater than its benchmark does not mean that adverse effects are certain to occur, because the benchmarks are conservative (protective) and source-water samples were collected prior to any treatment or blending that could alter contaminant concentrations in finished drinking water. There are water-treatment options, such as charcoal filtration, that can be used to lower the concentration of the contaminant to below the benchmark before the water is consumed.

Dieldrin and Nitrate Were the Chemicals From Human Sources That Most Frequently Exceeded a Human-Health Benchmark

Concentrations of the insecticide dieldrin exceeded its human-health benchmark of 0.002 microgram per liter ($\mu\text{g/L}$) in almost one of every five (18 percent) samples from drinking-water wells in the surficial aquifer (table 5–1). Elevated concentrations of dieldrin can cause problems with the liver and central nervous system and can contribute to an increased risk of cancer.⁽¹⁸⁾ The surficial aquifer system has one of the highest detection rates of dieldrin in the Nation, and concentrations were particularly elevated in shallow groundwater underlying urban areas (fig. 5–1). Dieldrin was widely used for insect control from 1950 until 1974, when it was banned for all uses except termite control. The use of dieldrin was banned completely in 1987.

Seven percent of the groundwater samples from drinking-water wells in the surficial aquifer system had concentrations of nitrate greater than its MCL of 10 mg/L as N. More than one-half of samples had concentrations of nitrate greater than 1 mg/L as N (table 5–1), which is one-tenth of the MCL and is greater than the maximum concentration in the surficial aquifer system that is likely to be from natural sources (0.4 mg/L as N).⁽⁸⁾ Nitrate was one of the most common chemicals detected at concentrations greater than the national MCL in groundwater from domestic (1 percent) and public (2 percent) sources of drinking water.^(19, 20) Concentrations greater than the MCL in drinking water can put infants under the age of 6 months at risk of serious illness. Elevated concentrations of nitrate result from leaching of excess nitrogen in fertilizers and manures applied to crops and in fertilizer applied to turf in urban areas as well as from septic-tank and sewage discharges. High concentrations were most common in groundwater in agricultural areas, including in domestic wells (see sidebar, Domestic wells—The homeowner’s responsibility, this page).

Nineteen constituents were detected at a concentration greater than their human-health benchmark in groundwater from at least one well sampled in the surficial aquifer system as part of the NAWQA Program (table 5–1). In addition to nitrate and dieldrin from human sources and radium from geologic sources, seven other constituents were detected at a

Percentage of samples with concentrations above the human-health benchmark

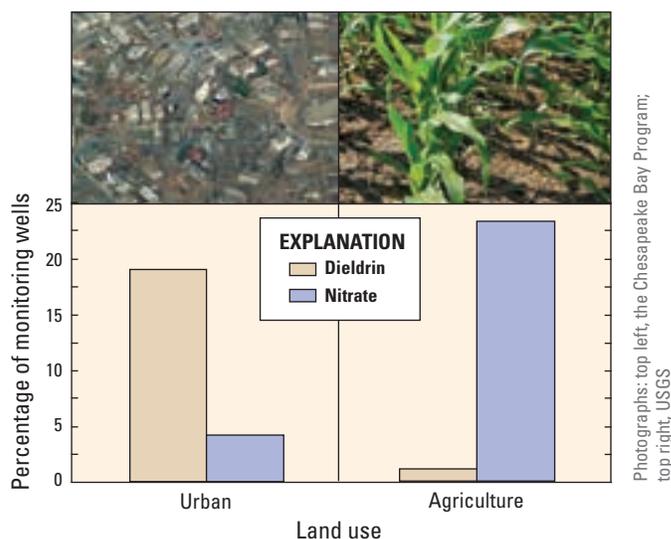


Figure 5–1. In urban areas, dieldrin was more frequently detected at a concentration greater than its human-health benchmark than was nitrate, but the reverse was true in agricultural areas. This difference is related to where chemicals are used. The pesticide dieldrin was widely used in urban areas to control termites until 1987, when its use was banned; nitrate is most widely used in agricultural areas and leaches into groundwater from fertilizer and manure applied to fields.

concentration greater than their human-health benchmark in at least one sample from a drinking-water supply well. Ten of the 19 compounds were detected at concentrations greater than a human-health benchmark in groundwater in less than 1 percent of the wells sampled.

Although numerous pesticide compounds and VOCs were detected in at least one groundwater sample from a drinking-water well, no pesticides other than dieldrin and only three VOCs were detected at a concentration greater than their respective benchmark (table 5–1). The samples containing the elevated concentrations of VOCs—the solvents perchloroethene (PCE) and trichloroethene (TCE), and the fumigant 1, 2-dibromoethane (also known as ethylene dibromide or EDB)—were from three public-supply wells.

Domestic wells—The homeowner’s responsibility

Almost 2 million people in the Northern Atlantic Coastal Plain rely on privately owned household wells for drinking water. These wells are not regulated under the Safe Drinking Water Act, which applies only to public-supply wells. In many parts of the Northern Atlantic Coastal Plain, routine testing of domestic wells is not required after the well is installed, except for some areas when the property changes owners. It is the homeowner’s responsibility to monitor the quality of the well water and take any actions to make their drinking water safe, such as replacing the well or installing and maintaining a treatment system.



Table 5–1. Nineteen constituents were detected at a concentration greater than their human-health benchmark in groundwater from at least one well concentration above their human-health benchmark in at least one sample from a drinking-water supply well. Nitrate and dieldrin, from human sources, the 19 constituents were detected above a human-health benchmark in groundwater in less than 1 percent of the wells sampled.

[AMCL, Alternative Maximum Contaminant Level; AL, Action Level; HBSL, U.S. Geological Survey Health-Based Screening Level; MCL, U.S. Environmental Protection Agency

Constituent	Human-health benchmark*		All well types			Drinking water
	Value	Type	Number of wells sampled	Frequency of concentrations greater than benchmark (percent of wells)	Frequency of concentrations within 10 percent of benchmark (percent of wells)	Number of wells sampled
						Nutrients
Fluoride	4 mg/L	MCL	422	0.2	4.3	142
Nitrate	10 mg/L as N	MCL	423	9.9	53.4	143
Alachlor	2 µg/L	MCL	390	0.3	0.8	137
Atrazine	3 µg/L	MCL	392	0.3	2.6	136
Dieldrin	0.002 µg/L	HBSL low	389	11.6	12.1	136
Diuron	2 µg/L	HBSL low	250	0.4	0.8	50
1,2-Dibromoethane	0.05 µg/L	MCL	341	0.6	0.3	140
Perchloroethene (PCE)	5 µg/L	MCL	356	1.4	3.4	143
Trichloroethene (TCE)	5 µg/L	MCL	370	0.5	1.6	143
						Trace
Arsenic	10 µg/L	MCL	275	1.1	7.3	99
Barium	2000 µg/L	MCL	275	0.4	6.9	99
Beryllium	4 µg/L	MCL	275	0.4	12	99
Boron	1,000 µg/L	HBSL	244	0.4	5.7	92
Lead	15 µg/L	AL	275	1.1	18.5	99
Nickel	100 µg/L	HBSL	275	0.4	9.1	99
Manganese	300 µg/L	HBSL	397	5.5	52.1	138
Zinc	2,000 µg/L	HBSL	275	1.1	8.0	99
						Radio
Radon-222	4,000 pCi/L	Proposed AMCL	196	0	0	90
	300 pCi/L	Proposed MCL	196	27	91.8	90
Radium-226 and radium-228	5 pCi/L†	MCL	74	28.4	90.5	59

*Human-health benchmarks are current as of August 2010. MCL values are from U.S. Environmental Protection Agency,⁽⁸⁴⁾ HBSL values are from Toccalino.⁽⁶⁹⁾

†The 5 pCi/L MCL for radium is a combined concentration of radium-226 and radium-228, the most common isotopes of radium. Water samples for radium were not collected in all parts of the Northern Atlantic Coastal Plain.

sampled in the surficial aquifer system as part of the National Water-Quality Assessment (NAWQA) Program. Ten constituents were detected at a concentration above a human-health benchmark. Ten of and radium, from geologic sources, were the constituents most frequently detected at a concentration above a human-health benchmark. Ten of

(USEPA) Maximum Contaminant Level; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; —, not analyzed]

wells—Domestic and public supply		Monitoring wells—Urban land use			Monitoring wells—Agricultural land use		
Frequency of concentrations greater than benchmark (percent of wells)	Frequency of concentrations within 10 percent of benchmark (percent of wells)	Number of wells sampled	Frequency of concentrations greater than benchmark (percent of wells)	Frequency of concentrations within 10 percent of benchmark (percent of wells)	Number of wells sampled	Frequency of concentrations greater than benchmark (percent of wells)	Frequency of concentrations within 10 percent of benchmark (percent of wells)
and major ions							
0.7	2.8	93	0	1.1	81	0	7.4
7.0	62.2	93	4.3	67.7	81	23.5	54.3
Pesticides							
0	1.5	89	0	0	80	1.3	1.3
0	2.9	91	1.1	1.1	81	0	7.4
18.4	19.1	89	19.1	20.2	80	1.3	1.3
0	2.0	73	1.4	1.4	76	0	0
VOCs							
1.4	0.7	94	0	0	32	0	0
2.8	4.9	94	1.1	5.3	42	0	0
1.4	3.5	94	0	1.1	42	0	0
elements							
0	4.0	56	1.8	5.4	56	1.8	5.4
0	4.0	56	0	7.1	56	0	7.1
0	11.1	56	0	7.1	56	0	7.1
0	1.1	56	0	7.1	56	0	7.1
1	34.3	56	0	0	56	0	0
0	6.1	56	0	8.9	56	0	8.9
0.7	30.4	93	7.5	48.4	81	11.1	71.6
0	2.0	56	0	0	56	0	0
nuclides							
0	0	1.0	0	0	30	0	0
18.9	95.6	1.0	100	100	30	60	100
32.2	91.5	0	—	—	3.0	0	100

Radium contamination of groundwater is a major concern in Vineland, New Jersey, where 33,000 people rely on the surficial aquifer system for drinking water. Construction alone of treatment facilities for radium removal cost about \$1,000,000 per well, with additional funds required annually to maintain the systems.



Radium and Radon Were the Chemicals From Geologic Sources That Most Frequently Exceeded a Human-Health Benchmark

A relatively small number of samples (59) from drinking-water wells were analyzed for radium, (herein the sum of the radium isotopes ^{226}Ra and ^{228}Ra), but more than 30 percent of those samples (table 5–1) contained radium at a concentration greater than its MCL of 5 picocuries per liter (pCi/L). All the samples analyzed for radium were collected in Delaware, Maryland, and New Jersey, so these samples may not be representative of groundwater from the entire surficial aquifer system. The radioactive minerals uranium and thorium in aquifer sediments are the source of radium in groundwater. Ingestion of radium in drinking water increases cancer risk, especially risk of bone and sinus cancers.^(21, 22)

Radon, an inert gas derived from radium, also was widely detected in groundwater. Radon dissolves readily in water, but its primary concern for human health is through inhalation of indoor air in living spaces after the radon degasses from water into air.⁽²³⁾ Inhalation of radon gas is second only to cigarette smoking as a cause of lung cancer.⁽²⁴⁾ There were no samples from wells used for drinking water where radon was detected at a concentration exceeding the proposed alternative MCL of 4,000 pCi/L, but radon was detected at concentrations greater than the proposed lower MCL of 300 pCi/L in 19 percent of samples from wells used for drinking water (table 5–1). Concentrations of radon in drinking water of the Northern Atlantic Coastal Plain generally were lower than those in most other Principal Aquifers where radon was measured (see appendix 3).

Trace Elements and Other Constituents Seldom Exceeded Human-Health Benchmarks in Groundwater

Trace elements and fluoride were less frequently detected in groundwater from this area than in groundwater from other parts of the Nation (table 5–1) because their detection is related to the occurrence of minerals that are rare in the sediments of the surficial aquifer system.⁽¹⁹⁾ Fluoride, manganese, and lead were detected in groundwater at concentrations greater than their human-health benchmarks (4 mg/L, 300 $\mu\text{g/L}$, and 15 $\mu\text{g/L}$, respectively) in only a very small percentage of samples (only one water sample for each constituent) from drinking-water wells (table 5–1). The source of manganese and fluoride is minerals in aquifer sediments.⁽²⁵⁾ The trace element lead could potentially occur in groundwater through leaching from old water pipes. Although several other trace elements were detected in drinking water at concentrations greater than one-tenth of a human-health benchmark, they were not detected at concentrations greater than a benchmark (table 5–1). Like lead, trace elements such as barium, beryllium, and nickel tend to dissolve more readily in acidic water than in water with neutral pH (fig. 5–2).

See chapter 6 for more information on radium in groundwater from the surficial aquifer system.

Tables of complete analyses of groundwater samples discussed in this report can be found at <http://dx.doi.org/10.3133/cir1360>.

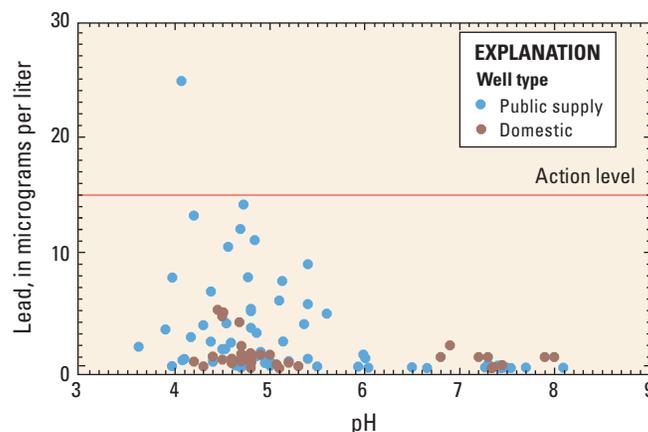


Figure 5–2. Lead was detected in more than 70 percent of samples from drinking-water wells from the surficial aquifer system, but was detected at concentrations greater than the Occupational Safety and Health Administration action level of 15 micrograms per liter in only one sample. Concentrations of lead were higher in water that had a pH less than 5.5.

Several “Nuisance” Properties and Constituents Exceeded Secondary Maximum Contaminant Levels

Secondary Maximum Contaminant Levels (SMCLs) are guidelines for nuisance constituents or properties in groundwater that can cause undesirable effects, such as unpleasant taste, odor, or color, but that do not present a direct concern for human health (see sidebar, Human-health benchmarks and other guidelines used in this assessment, p. 34). Only three of these properties or constituents—pH, iron, and manganese—were detected at a concentration exceeding a SMCL in more than one sample from a drinking-water well (table 5–2). The pH of groundwater in the surficial aquifer system was less than the USEPA recommended SMCL of 6.5 for drinking water in more than 80 percent of samples and, with a median of 5.3, is lower than that of groundwater in most other Principal Aquifers.⁽²⁶⁾ Although pH itself is not a human-health concern, water with low pH is acidic and corrodes or dissolves metals,⁽²⁷⁾ such as lead in plumbing (fig. 5–2), and can cause other constituents, such as radium and manganese, that are present in aquifer sediments to be released into groundwater.⁽²⁸⁾ The low pH of groundwater in the surficial aquifer system results from the large amount of the mineral quartz in aquifer sediments. Quartz does not dissolve readily and therefore does little to buffer (neutralize) the natural acidity of rainfall that recharges the aquifer. The acidity of groundwater also can increase as a result of denitrification, which releases hydrogen ions into groundwater and lowers the pH.

Concentrations of iron and manganese, which occur naturally in aquifer sediments, exceeded their SMCLs of 300 µg/L and 50 µg/L in 21 and 14 percent of samples of groundwater from wells used for drinking, respectively, and in more than one-third of all wells sampled (table 5–2). Iron and manganese are released from aquifer sediments into the groundwater

Staining of laundry and plumbing fixtures due to iron and manganese deposition is one of the most common water-quality problems for homeowners in the Northern Atlantic Coastal Plain

Iron and manganese in groundwater are a common water-quality problem in the Northern Atlantic Coastal Plain. When water containing dissolved iron and manganese comes into contact with the oxygen in air, the iron and manganese precipitate and are deposited as brownish stains on laundry and plumbing fixtures. Water softeners, which exchange the iron and manganese for sodium and which work best for the acidic water common to the surficial aquifer system, can be installed by homeowners to solve this problem. These systems typically cost between \$1,500 and \$3,000 per household.



Photograph courtesy of Culligan

when the groundwater is anoxic (see chapter 4). Iron can give water a bitter, astringent taste and stain laundered clothing and plumbing fixtures with a brownish color (see sidebar, Staining of laundry and plumbing fixtures due to iron and manganese deposition is one of the most common water-quality problems for homeowners in the Northern Atlantic Coastal Plain, this page). Manganese also stains laundry and plumbing fixtures and, at high levels in drinking water, is a concern for human health. Because of the unpleasant taste and staining associated with dissolved iron and manganese, domestic well water is more likely to be treated for these trace metals than for contaminants such as nitrate that have greater health risks but no taste or odor.

Table 5–2. Secondary Maximum Contaminant Levels (SMCLs) in drinking water were exceeded by some constituents in groundwater from the surficial aquifer system of the Northern Atlantic Coastal Plain—most commonly iron and manganese. These constituents are primarily from geologic or other natural sources, so their distribution is not related to a particular land use but is related to groundwater geochemistry.

[mg/L, milligrams per liter; <, less than; µg/L, micrograms per liter]

Property or major ion	Value	All well types		Drinking water wells— Domestic and public supply		Monitoring wells— Urban land use		Monitoring wells— Agricultural land use	
		Number of wells	Frequency of concentration greater than SMCL (percent)	Number of wells	Frequency of concentration greater than SMCL (percent)	Number of wells	Frequency of concentration greater than SMCL (percent)	Number of wells	Frequency of concentration greater than SMCL (percent)
Total dissolved solids	500 mg/L	366	5.0	143	0.7	93	5.4	81	7.4
pH (standard units)	< 6.5	420	81	144	85.4	89	88.8	81	86.4
	> 8.5	420	0	144	0	89	0	81	0
Chloride	250 mg/L	424	2.0	144	0	93	3.2	81	2.5
Fluoride	2 mg/L	422	0	142	1.4	93	0	81	0
Iron	300 µg/L	425	37	144	20.8	93	23.7	81	45.7
Manganese	50 µg/L	397	39	138	14.5	93	37.6	81	55.6
Sulfate	250 mg/L	424	0.2	144	0	93	0	81	1.2

Groundwater From the Surficial Aquifer System Contributes to the Degradation of Water Quality in Streams and Estuaries

See chapter 7 for more information on the transport of nitrate and other chemicals from groundwater to streams.

The health of streams and estuaries in the North Atlantic Coastal Plain, such as the Chesapeake Bay and the Albemarle and Pamlico Sounds (see fig. 3–1), has been affected by high concentrations of the nutrients nitrogen and phosphorus, which can cause large algal blooms (see sidebar, Phosphorus primarily is transported to surface water by overland runoff, this page). When the algae die, their decomposition consumes dissolved oxygen, lowering the concentration of oxygen to levels that critically affect aquatic life. Nitrate from groundwater in the surficial aquifer system is a major source of nitrogen in streams. In some parts of the Northern Atlantic Coastal Plain where nitrate concentrations in groundwater are high, the median concentration of nitrate in streams during base-flow conditions is greater than the 0.71 mg/L as N USEPA ecoregional criterion for total nitrogen (fig. 5–3).^(29, 30) Concentrations of total nitrogen, which includes nitrate and other dissolved nitrogen species, greater than this level are harmful to the health of aquatic life.

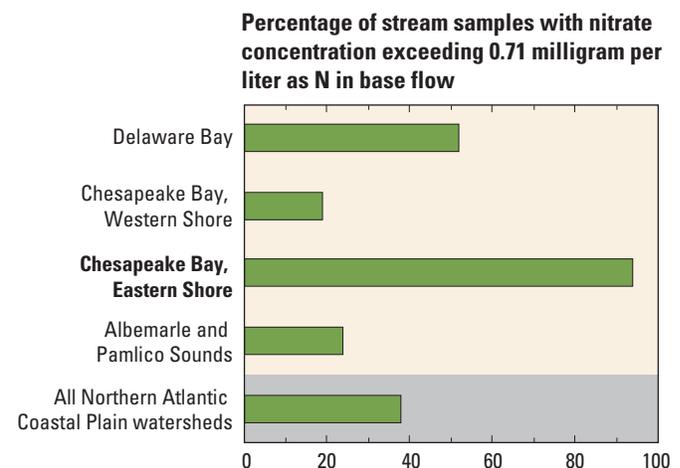


Figure 5–3. Concentrations of total nitrogen exceeding the 0.71 milligram per liter U.S. Environmental Protection Agency ecoregional criterion can be detrimental to the health of aquatic life. Nitrate commonly exceeds this concentration in Northern Atlantic Coastal Plain streams during base flow (when most stream water is from groundwater), especially on the Eastern Shore of the Chesapeake Bay. Algae growing in a stream are a sign of excessive nutrient concentrations in water that can lead to the reduction in dissolved oxygen and fish kills.

Phosphorus primarily is transported to surface water by overland runoff

Phosphorus, along with nitrate, contributes to the ecologic degradation of aquatic systems. Unlike nitrate, however, high concentrations of phosphorus are not commonly present in groundwater in most of the Northern Atlantic Coastal Plain surficial aquifer system. Phosphorus from groundwater sources therefore is not addressed in this report. Most phosphorus sorbs onto sediment particles and is transported to streams in surface runoff during storms. However, phosphorus from phosphate-bearing rocks does affect concentrations of phosphorus in groundwater in some parts of the Coastal Plain in North Carolina and can be an important source of phosphorus loading to some streams of the Albemarle-Pamlico drainage basin.⁽³¹⁾

Chapter 6: *Understanding Where and Why Key Contaminants Occur in Groundwater*

Nitrate was the most common and widespread human-related contaminant in wells sampled in the surficial aquifer system, but pesticide compounds and VOCs also were common contaminants in water samples from areas where these compounds are used. Regional differences in concentrations of nitrate, pesticides, and VOCs are related to land use and to differences in hydrogeologic settings that affect dissolved-oxygen concentrations and other geochemical conditions in groundwater. Radium was the most common contaminant from geologic sources in wells sampled. The occurrence of radium is related to the naturally acidic conditions in groundwater and to the increased acidity that results from nitrification.

This chapter describes the sources of and factors that affect concentrations of nitrate, pesticides, VOCs, and radium in the surficial aquifer system of the Northern Atlantic Coastal Plain.



Photographs (left column) from top to bottom: USGS, Chesapeake Bay Program; USDA Natural Resources Conservation Service

Photographs (right column) from top to bottom: USGS; next two from the Chesapeake Bay Program

Sources of nitrate in groundwater include manure spreading, fertilizer applications, livestock waste, and other agricultural activities. In urban areas, sources of nitrate include septic systems, leaking sewer lines, and lawn fertilizers.

Nitrate in Groundwater

Concentrations of nitrate exceeded the MCL of 10 mg/L as N in almost one-fourth of the shallow groundwater samples from areas underlying agricultural land use. Nitrate in shallow groundwater can persist for decades and travel over time to deep parts of the surficial aquifer system that supply water used for drinking.

Nitrate was measured at concentrations greater than 1 mg/L as N, the average level attributed nationally to human-related sources,⁽³²⁾ in water from more than one-half of all wells sampled in the surficial aquifer system and in water from more than 60 percent of drinking-water wells sampled (see table 5–1). Almost one-fourth of the shallow groundwater samples from areas underlying agricultural land use had nitrate concentrations greater than the MCL of 10 mg/L as N. High concentrations of nitrate present in shallow groundwater can persist for decades and travel over time to deep parts of the surficial aquifer system where water is used for drinking.

Where the surficial aquifer system is used for public water supply, nitrate contamination necessitates treatment, such as blending or anion exchange and, in some areas, drilling of wells into deeper confined aquifers that underlie the surficial aquifer; water treatment and drilling of new wells increase the cost of water supplies (see sidebar, Treatment of nitrate, p. 43). In contrast, water from domestic wells is not routinely tested and, because nitrate is colorless and odorless, many residents are not aware that groundwater from their wells might be contaminated.

Nitrogen compounds occur naturally in the environment, but substantial amounts are contributed to the land from a variety of human sources, including inorganic fertilizers, animal manure, human sewage, and combustion of fossil fuels. Nitrogen compounds in fertilizer and manure applied to the land surface are converted by bacteria to nitrate (see sidebar, How does nitrate enter groundwater? How is it lost from groundwater?, p. 31), which is highly soluble and therefore likely to leach through the soil into groundwater.⁽³³⁾ Many parts of the surficial aquifer system are vulnerable to nitrate contamination (fig. 6–1).

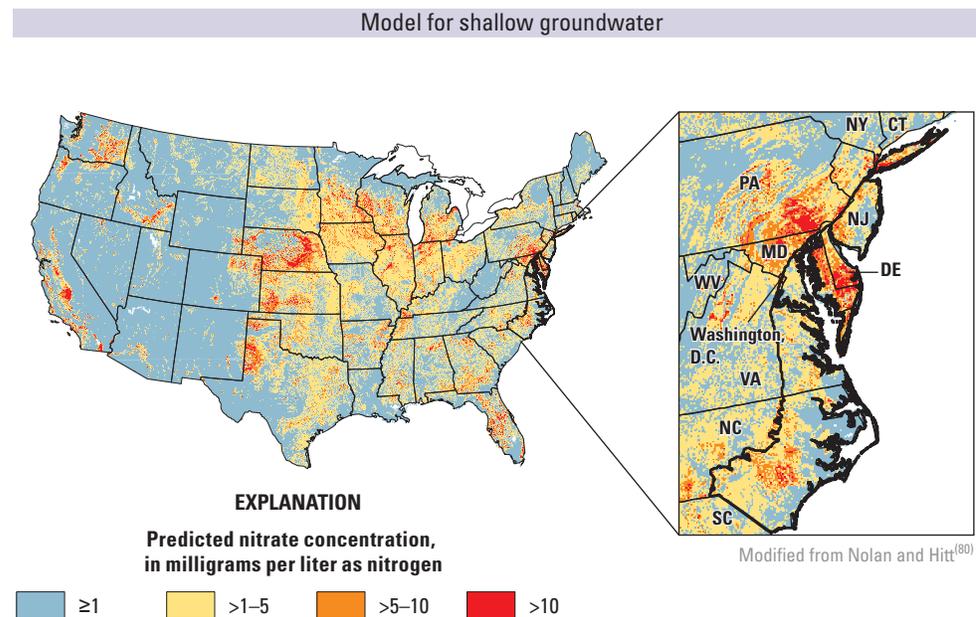


Figure 6–1. Concentrations of nitrate in parts of the surficial aquifer system, such as Delaware and eastern Maryland, are predicted to exceed the Maximum Contaminant Level of 10 milligrams per liter as nitrogen, largely because of abundant nonpoint sources of nitrogen and hydrogeologic and soil conditions that promote nitrate transport. Predicted concentrations of nitrate in groundwater were derived from a statistical model that used measured concentrations of nitrate from across the Nation to extrapolate to unsampled areas.

Treatment of nitrate

Treatment of nitrate in groundwater used for public and municipal water supplies is very expensive, often costing several hundreds of thousands to more than a million dollars for the initial construction of a treatment plant and about \$100,000 per year to operate. In some places, water utilities blend high-nitrate water from surficial aquifer system wells with low-nitrate water from deeper confined wells, which can require drilling deeper wells and building additional infrastructure at considerable expense. Water treatment using anion exchange (nitrate is exchanged for the chloride in potassium chloride) also can be used. In Delaware, the cost of water treatment is about 40 percent of the total cost paid by the consumer.



Photograph from Can Stock Photo Inc®



Photograph from the Chesapeake Bay Program

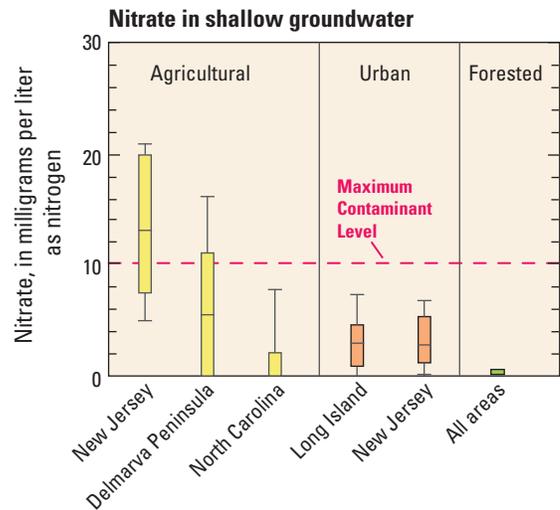
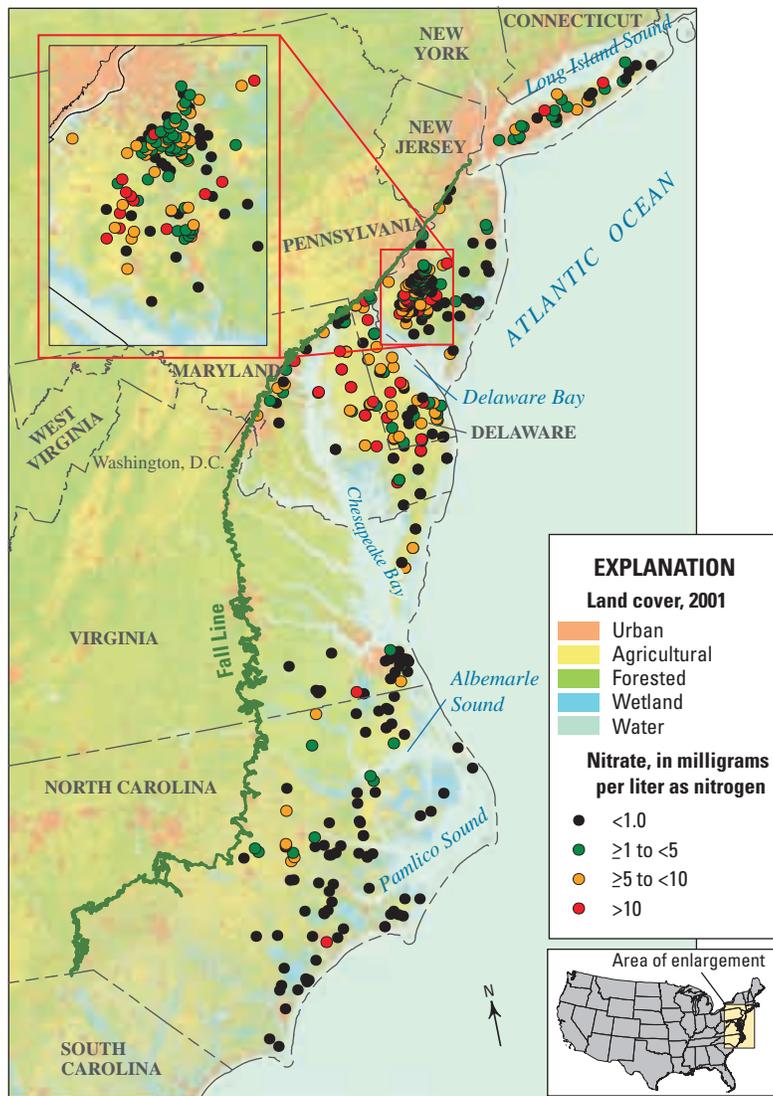
Corn is one of the most important crops produced in the Northern Atlantic Coastal Plain.

Concentrations of nitrate in groundwater in the surficial aquifer system exceeded the MCL most frequently in areas of intensive agriculture with well-drained soils and sandy aquifer sediments in Delaware, Maryland, and New Jersey.

Nitrate Occurrence in Groundwater Reflects the Distribution of Nitrogen Sources and the Hydrogeologic and Geochemical Processes That Affect Nitrate Movement

The highest concentrations of nitrate in groundwater were in areas of intensive agriculture in the northern part of the surficial aquifer system (fig. 6–2). On the agricultural Delmarva Peninsula, nitrate concentrations exceeded the nitrate MCL of 10 mg/L as N in about one-third of groundwater samples, and in agricultural areas of southern New Jersey nitrate concentrations exceeded the MCL in almost two-thirds of samples. In these areas, well-drained sandy soils and aquifer sediments are well-suited for agriculture. Soils and shallow aquifer sediments are permeable and weathered and contain minimal amounts of organic matter; in addition, the groundwater remains oxic for many decades as it moves along flow paths to discharge at wells and streams (fig. 6–3A). These characteristics are favorable for the formation and transport of nitrate from fertilizer and manure applications to groundwater and prevent its breakdown to harmless nitrogen gas. Concentrations of nitrate generally are much lower in the surficial aquifer system in North Carolina. In this area, agricultural sources are similar to those in the north, but poorly drained soils and organic-rich aquifer sediments promote suboxic or anoxic conditions in groundwater;^(16, 31) as a result, nitrate is lost through denitrification as groundwater moving down a flow path becomes anoxic (fig. 6–3B).

Nitrate in groundwater—all sampled wells



See sidebar, Boxplots, p. 45

Figure 6–2. Nitrate occurred in all types of wells in the surficial aquifer system throughout the Northern Atlantic Coastal Plain. Concentrations most commonly approached or exceeded the MCL of 10 mg/L as nitrogen in areas of intensive agriculture and urban development in the northern part of the Northern Atlantic Coastal Plain. In these areas, groundwater is oxic, which prevents the breakdown of nitrate to nitrogen gas. Nitrate concentrations commonly were lower to the south, where, similarly to the north, nitrogen is applied to agricultural land, but groundwater is predominantly anoxic, which facilitates nitrate breakdown. Concentrations were lowest in forested areas where there are few nitrogen sources.

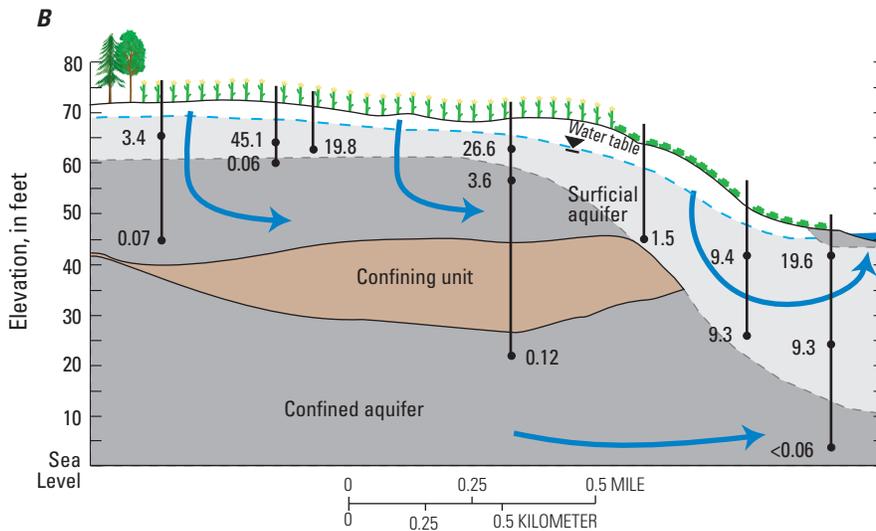
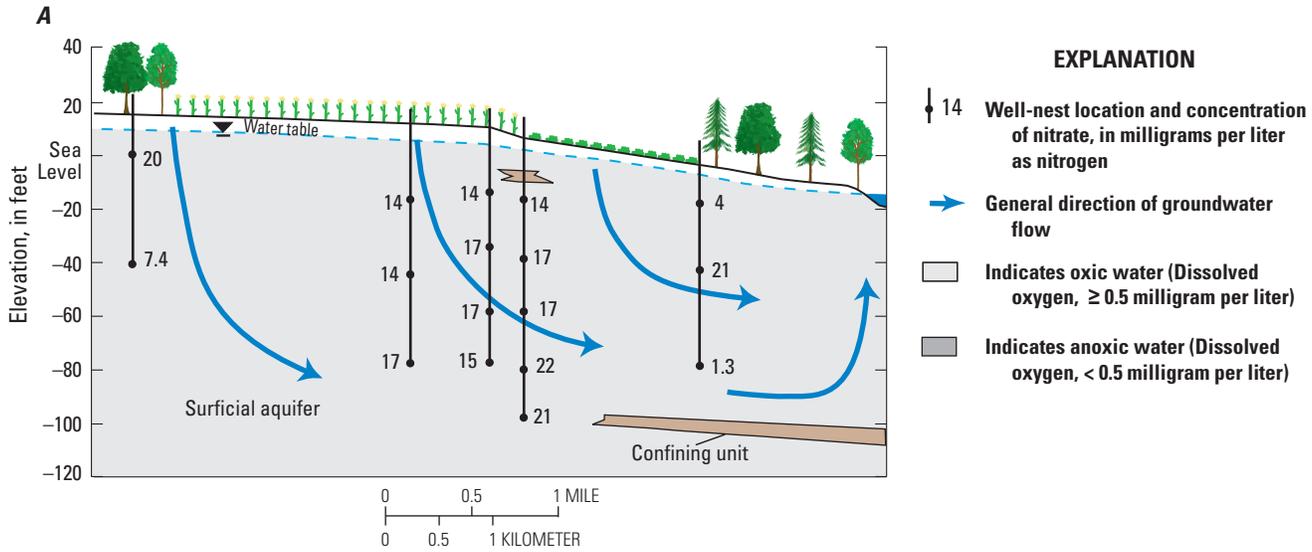


Figure 6-3. A, Elevated concentrations of nitrate from agricultural sources occur throughout the surficial aquifer where conditions are oxic, as seen in part of Delaware, where the entire aquifer is oxic and concentrations of nitrate more than 20 milligrams per liter as nitrogen are present as deep as 100 feet below the land surface. B, In contrast, at an agricultural site in North Carolina, concentrations of nitrate are high in the shallow part of the surficial aquifer where the groundwater is oxic, but 10 or more times lower in the deeper part of the aquifer where the groundwater is anoxic, because denitrification occurs only under anoxic conditions.^(16, 61)

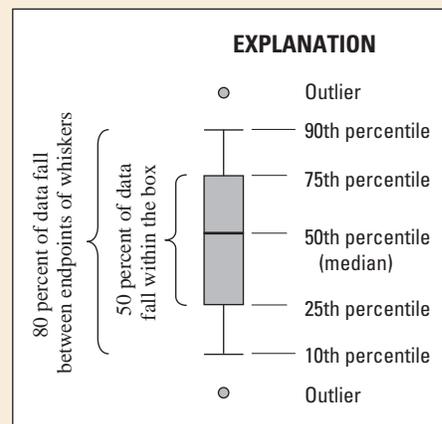
Boxplots

Boxplots are used to illustrate how results are distributed within a group. The “box” ranges from the 25th to the 75th percentile and represents 50 percent of the data. The horizontal line in the middle of the box is the median value—one-half of the values in the group are greater than the median and one-half are less.

Percentiles describe the percentage of values in a group that are less than the given value: 25 percent of the values in a group are less than the 25th percentile; 75 percent of the values in a group are less than the 75th percentile. The median is also the 50th percentile.

If, for example, the 75th percentile for the measured concentration of a contaminant in a group of wells is equal to the human-health benchmark for that contaminant, then 75 percent, or three-fourths, of the wells have a concentration of that contaminant less than the benchmark, and 25 percent, or one-fourth, have a concentration greater than the benchmark.

The “whiskers” (vertical lines) in these figures extend to the 10th and 90th percentiles; box and whiskers together represent 80 percent of the data. Values greater than the 90th or less than the 10th percentile are shown as individual points (outliers).



Changes in concentrations of nitrate in wells can lag many years or even decades behind changes in nitrogen application at the land surface.

Concentrations of nitrate also are commonly elevated in groundwater in areas of dense urban and suburban development on Long Island and in New Jersey as a result of septic-system discharge and other sources of wastewater return flow. Nitrate concentrations in urban and suburban areas, however, generally are lower than in predominantly agricultural areas (fig. 6–2).⁽³⁴⁾

Many public-supply wells in small towns and most domestic wells in rural areas pump water from the surficial aquifer system. Where the groundwater is oxic, water from these wells commonly contains nitrate from agriculture and other human sources, which can limit its potability (fig. 6–4). Public water supplies are tested to ensure that the MCL is not exceeded. Because domestic wells commonly are located in agricultural areas where concentrations of nitrate in groundwater are more likely to be elevated, contamination by nitrate is a concern (fig. 6–4).

Changes in Nitrogen Applications to the Land Surface Might Not Be Reflected in Groundwater Quality for Many Years

Changes in land use or land-use practices over time can result in changes in concentrations of nitrate in groundwater. Because groundwater flows slowly from where it recharges at the land surface to where it discharges at a well or stream, changes in concentrations of nitrate in groundwater withdrawn from wells generally lag many years or even decades behind changes in nitrogen application at the land surface.⁽¹⁴⁾ For example, fertilizer use has increased greatly in the last half century (fig. 6–5). The average applications of nitrogen from fertilizer on corn in the United States increased from 72 kilograms per hectare (kg/ha) in 1965 to more than 150 kg/ha in the 1980s.⁽³³⁾ Increasing concentrations of nitrate in the surficial aquifer system on the Delmarva Peninsula between 1988 and 2001 (fig. 6–6) are related to the increase of the amount of nitrogen used in various applications that occurred decades earlier;⁽³⁶⁾ similar trends are apparent in agricultural areas in other parts of the surficial aquifer system.^(14, 16) In contrast, removal of nitrogen sources can cause concentrations of nitrate in groundwater to decrease over time, such as occurred in western Long Island following sewerage of residential areas that had previously been on septic systems (see sidebar, After years of increasing nitrate concentrations, improved infrastructure caused nitrate to decrease in groundwater in parts of Long Island, p. 48).

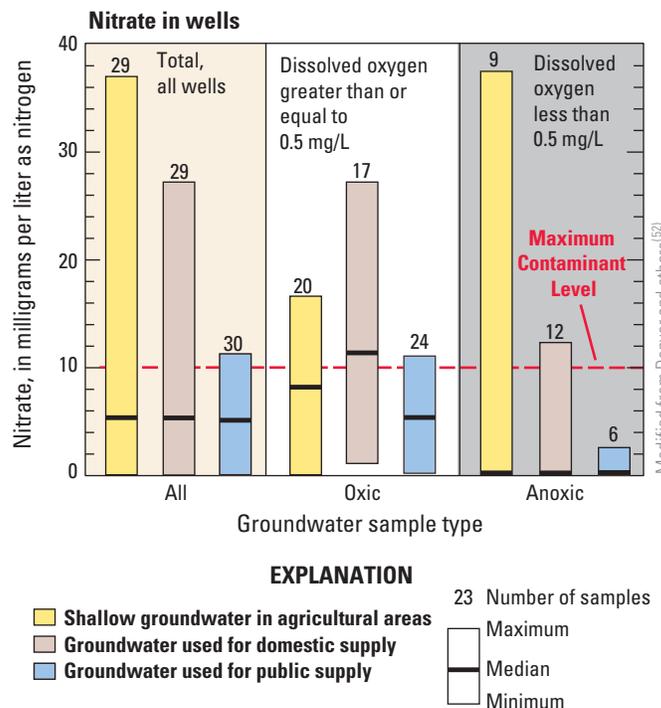


Figure 6–4. On the Delmarva Peninsula, the median concentration of nitrate in water from all types of wells was about 5 milligrams per liter as nitrogen (mg/L as N). Where groundwater was oxic, the median concentration of nitrate in samples from domestic wells was greater than the Maximum Contaminant Level of 10 mg/L as N for drinking water. Median nitrate concentrations in groundwater that was anoxic were below the detection level of 0.05 mg/L as N.

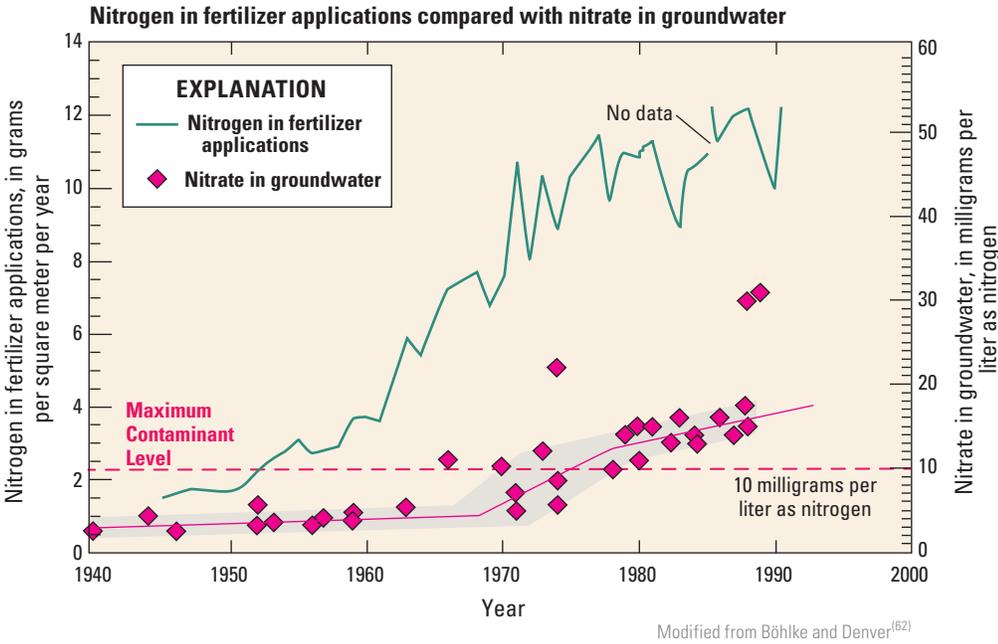
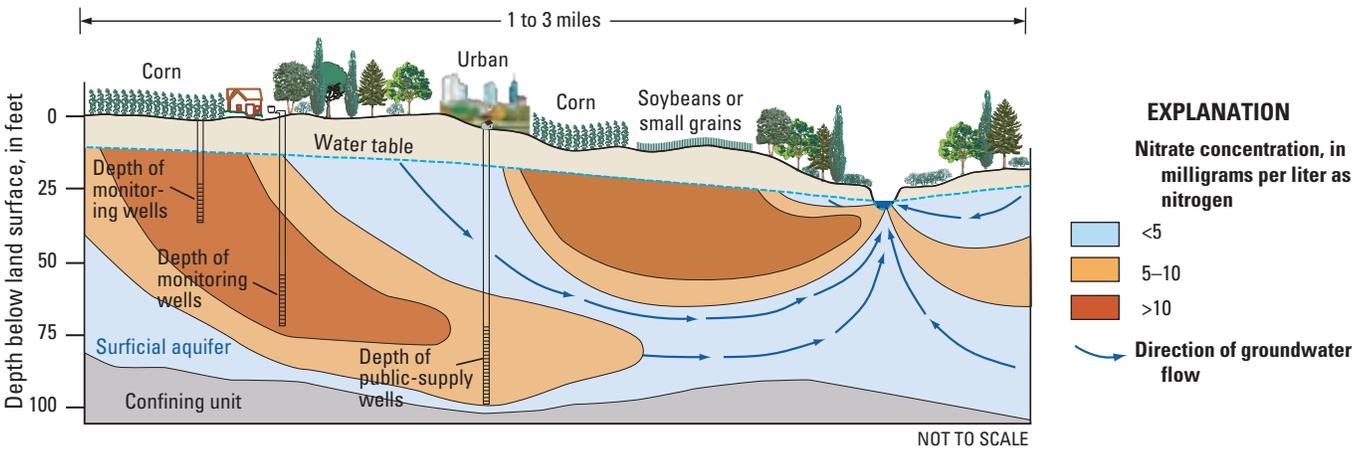


Figure 6-5. Increases in nitrate concentration in groundwater samples from shallow monitoring wells lagged behind those in nitrogen fertilizer applications by almost two decades in an agricultural area in Kent County, Maryland. About 30 percent of the nitrogen applied for agricultural crop production has leached into shallow groundwater in this area. Dates shown for groundwater represent the estimated year that groundwater recharged the aquifer (see sidebar, How is groundwater residence time determined?, p. 27).



Median nitrate concentration in oxic groundwater

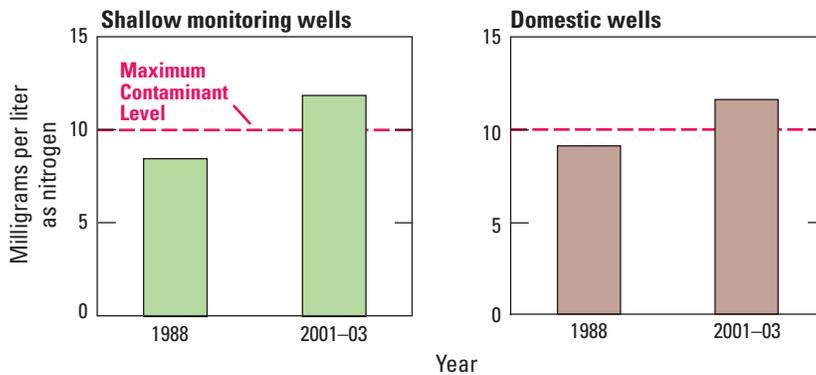
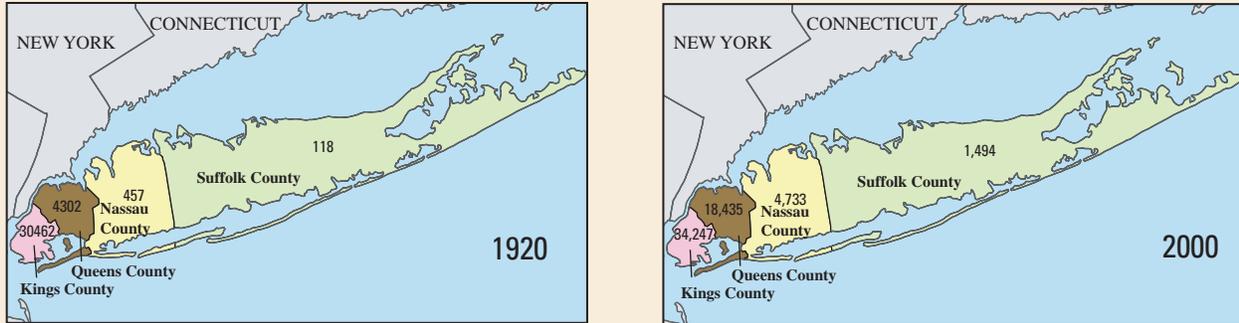


Figure 6-6. Nitrate moves along flow paths in the surficial aquifer system of the Delmarva Peninsula from recharge areas to where groundwater discharges to wells and surface water. Nitrate concentrations in samples collected from shallow monitoring and domestic wells in the 1980s and again in the 2000s demonstrate that concentrations of nitrate have increased. These higher nitrate concentrations will continue to move through the aquifer toward deeper wells and discharge areas, provided that the groundwater remains oxic.

After years of increasing nitrate concentrations, improved infrastructure caused nitrate to decrease in groundwater in parts of Long Island

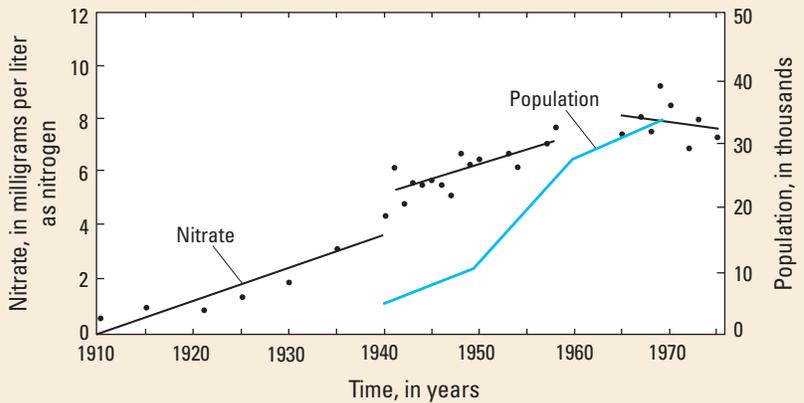
Population density, 1920 and 2000



*Note: Number indicates population density per square mile in each county.

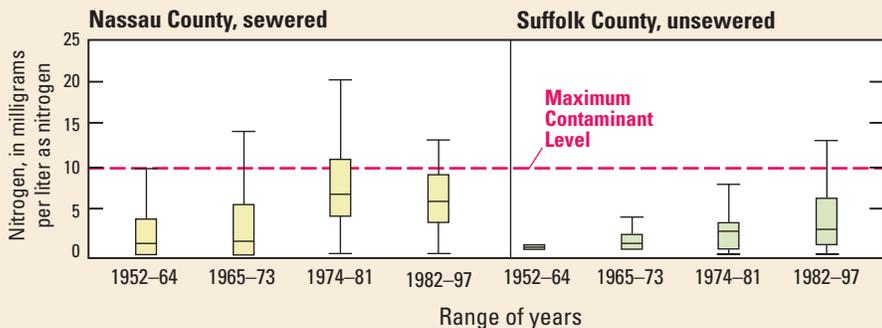
Concentrations of nitrate in shallow groundwater on Long Island increased substantially with the expansion of population in urban centers and to the east beginning in the early 1900s. In Nassau County, concentrations of nitrate in groundwater increased from less than detectable levels in 1910 to about 10 mg/L as N in 1975 because of increased wastewater disposal through cesspools and septic tanks in dense residential developments.^(63, 64) Groundwater is the sole source of freshwater on Long Island. Increases in pumping drew nitrate-enriched water down to depths as great as 500 ft or more in this area, causing concern over the quality of this important source of drinking water.

Nitrate in groundwater in Nassau County



In response to deteriorating groundwater quality, installation of sewer systems in parts of Nassau County began in the 1950s. The quality of groundwater has since improved,^(51, 70) although these improvements lag the installation of sewerage because of the slow movement of groundwater from the water table to wells. In unsewered areas of Suffolk County, which have had slower population growth than Nassau County and have some agricultural land use as well, concentrations of nitrate in groundwater have continued to increase slowly.

Nitrogen concentration in sewered and unsewered areas



See sidebar, Boxplots, p. 45

Manmade Organic Compounds in Groundwater

Abundant use of pesticides and VOCs and the sandy sediments and oxic conditions of the surficial aquifer system have led to widespread occurrence of these chemicals in groundwater. As a result, pesticides and VOCs occur widely in the surficial aquifer system, but concentrations, with the exception of those for dieldrin, rarely exceeded established drinking-water standards or other human-health benchmarks.

Pesticides

Pesticides occur more frequently in groundwater in agricultural areas in the northern part of the surficial aquifer system than in many of the other intensively farmed areas of the Nation, including much of the Corn Belt in the Midwest and the Central Valley in California (fig. 6–7). This pattern is related to a combination of factors that affect pesticide occurrence in groundwater. These factors include where and how much of a pesticide is used, the chemical properties of the pesticide, and characteristics of the soil and the aquifer that affect whether a pesticide breaks down and whether it adheres to solids or remains dissolved in groundwater.



Pesticide compounds include herbicides, insecticides, and fungicides used for weed and pest control. The most intensively used pesticide compounds are agricultural herbicides, although insecticides and other pesticide compounds are heavily used in some urban areas as well.

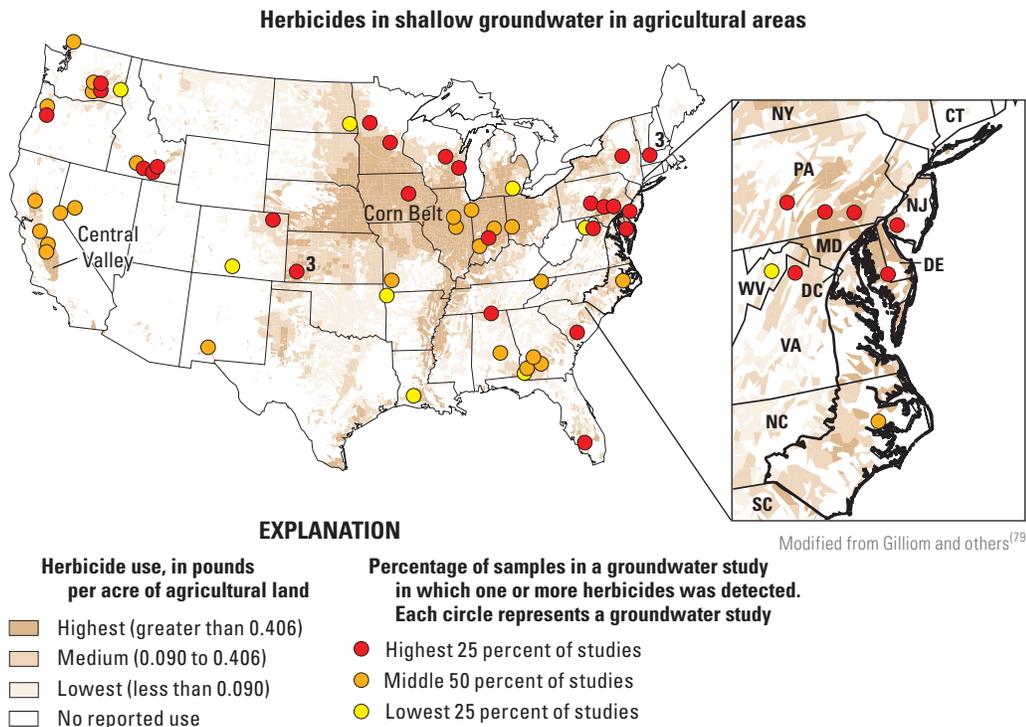
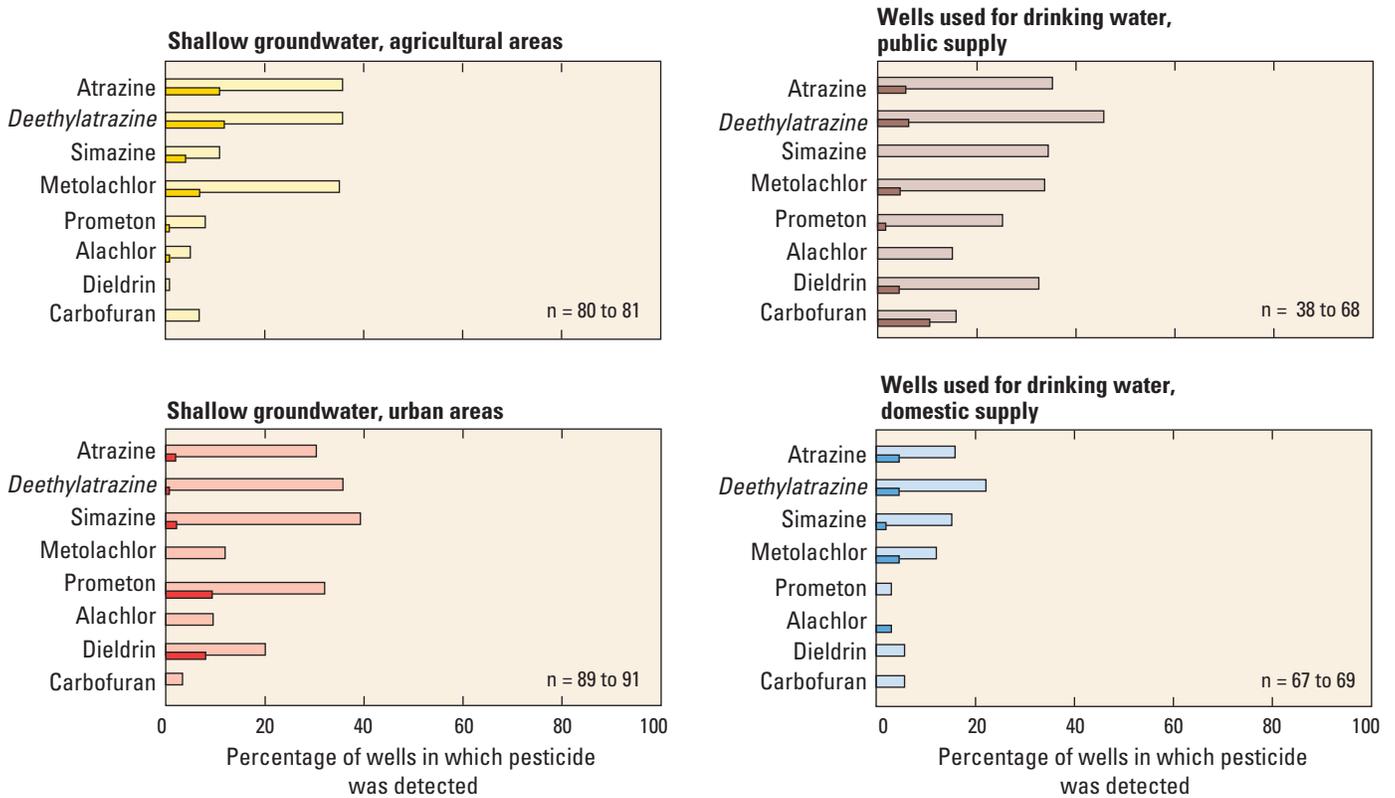


Figure 6–7. In the northern part of the Northern Atlantic Coastal Plain, herbicides are heavily applied and can infiltrate readily through sandy soils and aquifer sediments down to the water table. Herbicides were detected more frequently in this area than in some of the most intensively farmed areas of the United States, including the Corn Belt in the Midwest and the Central Valley in California.⁽⁷⁹⁾

Individual pesticides were detected most commonly in groundwater in those land-use settings where they primarily are used (fig. 6–8). For example, metolachlor is a broad-spectrum herbicide for control of weeds in farm fields and, not surprisingly, was detected more commonly in samples from wells monitoring shallow groundwater in agricultural areas than from wells in urban areas. Some pesticides, like atrazine, are used in both cropland and urban settings and were detected in wells in both agricultural and urban areas. Simazine and prometon, which are used for roadside weed control, were detected most commonly in samples from wells monitoring shallow groundwater in urban areas.



EXPLANATION

Concentration, in micrograms per liter		Network type
Any	≥0.1	
		Wells monitoring shallow groundwater
		Agricultural areas
		Urban areas
		Wells used for drinking water
		Public supply
		Domestic
n = 89 to 91		Number of samples
		Italics indicate pesticide degradate

Figure 6–8. The pesticide compounds most frequently detected in groundwater of the surficial aquifer system were herbicides, with the exception of the insecticides dieldrin and carbofuran. Pesticide occurrence generally reflects broad-use patterns, especially in agricultural areas, although pesticides also can reflect local use, especially in urban areas.

Chemical characteristics and environmental factors also affect pesticide occurrence. Commonly detected compounds, such as atrazine, metolachlor, and their degradates, are more water soluble and break down less readily in groundwater than some other compounds that also are used frequently but that have chemical properties that limit their movement to and in groundwater, such as glyphosate.^(37, 38) Although twice as much of the herbicide glyphosate is applied in the Northern Atlantic Coastal Plain than atrazine (table 6–1), glyphosate was not among the pesticides most frequently detected (fig. 6–8). Organic-rich soils impede the movement of pesticides to the water table, and as a result, pesticide concentrations generally are lower in groundwater in poorly drained organic-rich areas than in areas with well-drained soils (fig. 6–9).

Table 6–1. Of the top 10 pesticides (in terms of pounds applied) used on agricultural crops in the Northern Atlantic Coastal Plain in 2007, 9 were herbicides and only 1 was an insecticide. Of these 10 pesticides, only the herbicides atrazine, S-metolachlor, metolachlor, and alachlor were detected frequently in groundwater.

Compound	Type	Number of counties with reported use	Total applied (millions of pounds)
Glyphosate	Herbicide	125	4.52
Atrazine	Herbicide	123	2.27
S-metolachlor	Herbicide	125	1.47
Acetochlor	Herbicide	57	0.38
Linuron	Herbicide	113	0.22
Alachlor	Herbicide	98	0.18
Fluometuron	Herbicide	40	0.10
Terbufos	Insecticide	100	0.10
Trifluralin	Herbicide	118	0.08
Metolachlor	Herbicide	57	0.07

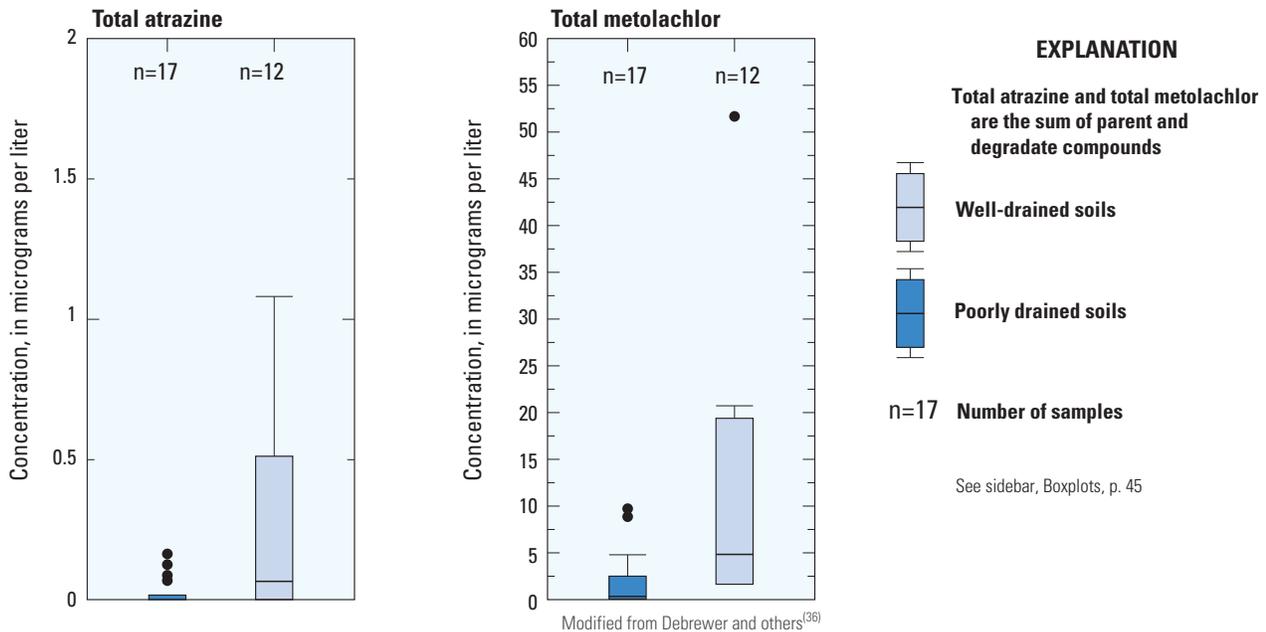


Figure 6–9. In agricultural areas of the Delmarva Peninsula, pesticide compounds were detected more frequently in samples of groundwater in areas with well-drained, permeable soils that contained little organic matter than in samples of groundwater from areas with poorly drained, organic-rich soils.

Degradates of Some Pesticide Compounds Were Detected in Groundwater at Higher Concentrations Than Were the Parent Compounds

There are no human-health benchmarks for pesticide degradates in drinking water, and little is known about their potential to affect human health.

If a pesticide degradate is soluble in water and does not break down in the environment, it can infiltrate down through the unsaturated zone into groundwater along with any remaining parent compound. Degradates of some herbicides, such as alachlor and metolachlor, were measured in surficial aquifer system groundwater at concentrations that were 10 to 100 times greater than those of their parent compounds (fig. 6–10).^(36, 39) Deethylatrazine and other atrazine degradates also occur commonly, but concentrations of deethylatrazine generally were similar to those of its parent compound atrazine (fig. 6–10).

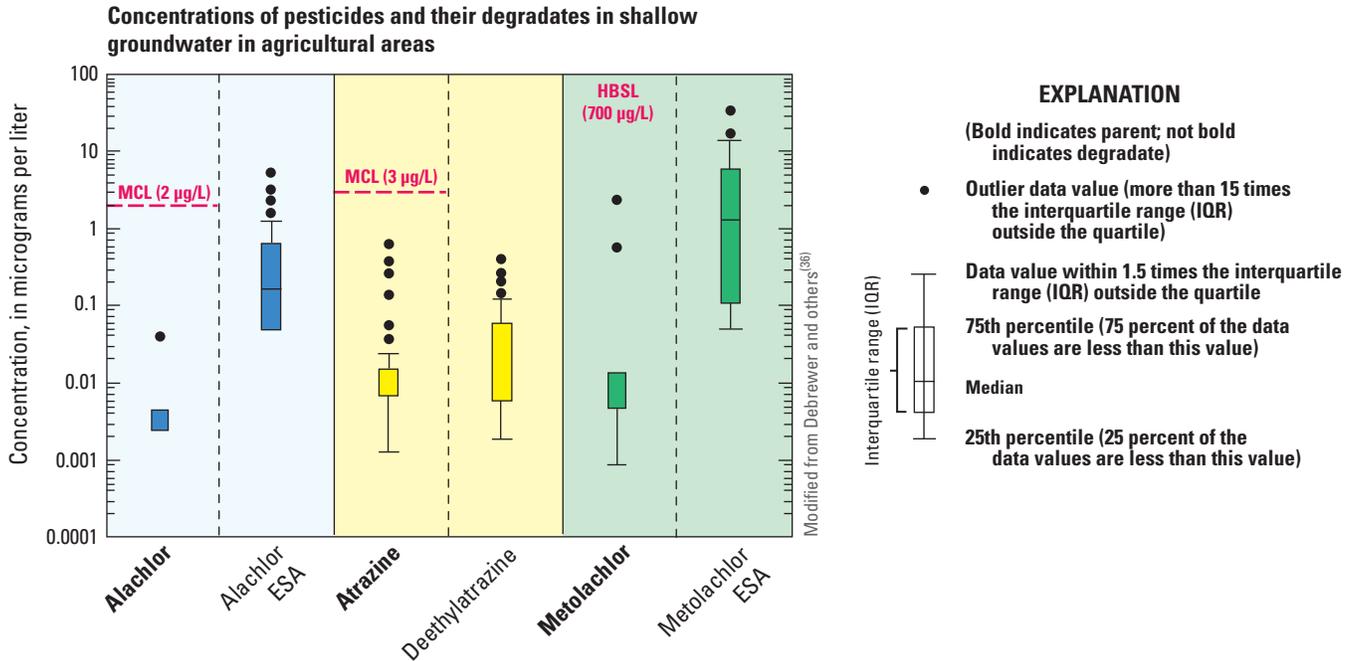


Figure 6–10. Concentrations of alachlor and metolachlor degradates were much higher than those of their parent compounds in samples of shallow groundwater from monitoring wells in agricultural areas of the Delmarva Peninsula. Concentrations of the atrazine degradate, deethylatrazine, however, were similar to those of atrazine. (ESA, ethyl sulfonic acid)

Pesticides Commonly Occur in Groundwater as Mixtures of Compounds

More than half of samples from the surficial aquifer system in which at least one pesticide was detected also contained additional pesticides (fig. 6–11). In groundwater samples collected in the Maryland Coastal Plain during 2001 through 2004, 30 of 32 samples in which a pesticide was detected also contained at least one other pesticide compound, and one sample contained 11 different pesticide compounds.⁽³⁸⁾ Mixtures of pesticides might occur in groundwater because pesticides often are applied as mixtures of several active ingredients and several different pesticides are applied for different purposes in the same area. Also, groundwater withdrawn by wells often contains water from many different flow paths, which originate in different areas and therefore can carry different chemicals.

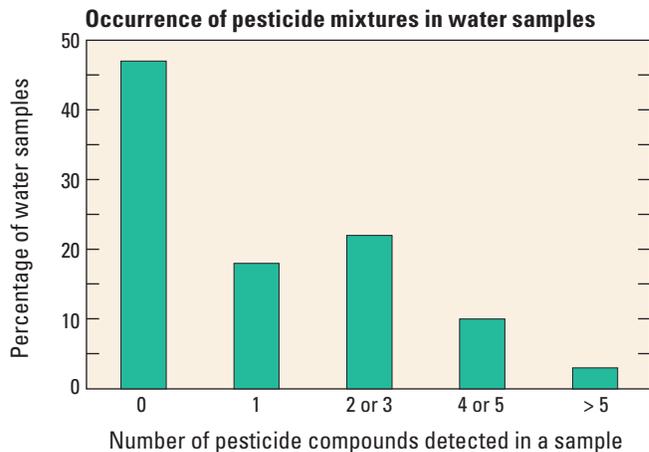


Figure 6–11. Pesticides commonly occurred as a mixture of multiple compounds in wells sampled throughout the surficial aquifer system. More than half of samples in which at least one pesticide was detected also contained one or more additional pesticides.

Some Pesticide Compounds Are No Longer Used and Yet Are Still Detected in Groundwater

Patterns of pesticide use change over time (fig. 6–12) as a result of changes in regulations, monitoring results, effectiveness, cost, and other factors. In many places, herbicides and their degradates continue to be detected in the surficial aquifer system as much as several decades after their use ceased (see sidebar, The legacy of aldicarb contamination in groundwater on eastern Long Island, p. 54).^(16, 36) For example, use of dieldrin was discontinued in 1987, but it was detected in samples of surficial aquifer system groundwater collected in the late 1990s and early 2000s.^(37, 38) Degradates of dichlorodiphenyltrichloroethane (DDT), the use of which was discontinued in the 1970s, continued to be detected as much as 25 years later.⁽³⁹⁾

Human-health benchmarks have been developed for individual pesticide compounds, but the human-health effects of mixtures of pesticides are largely unknown.

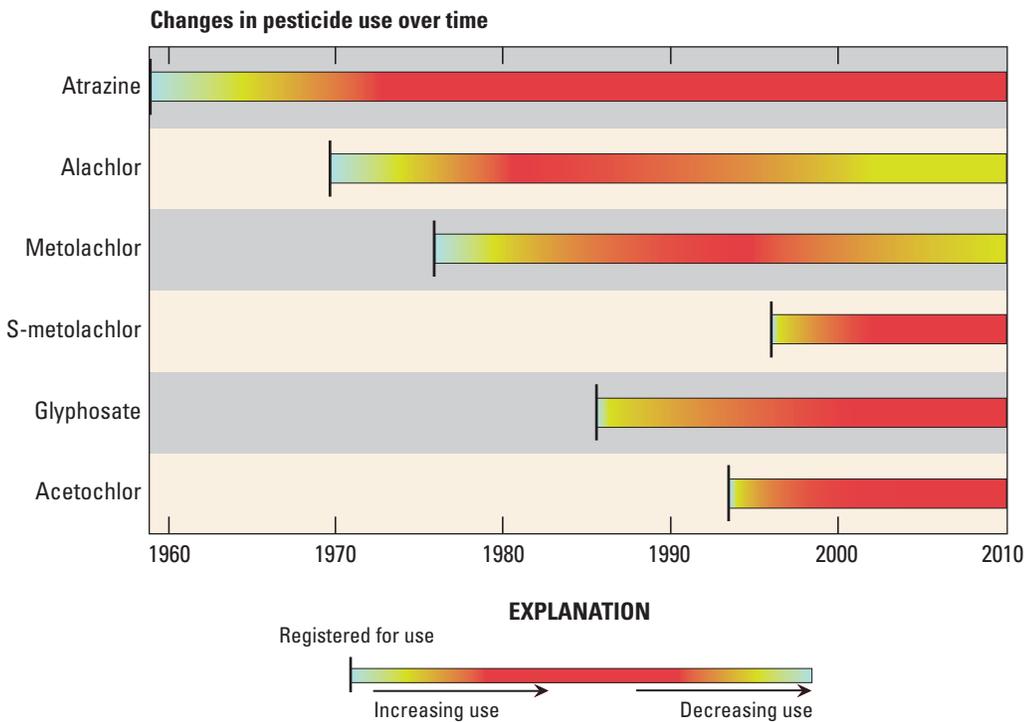
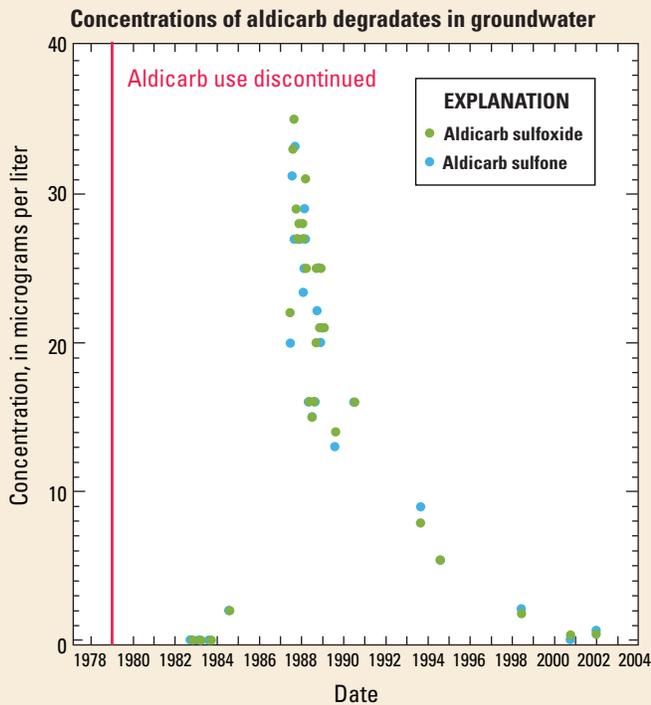


Figure 6–12. Use of different pesticide compounds changes as some pesticides are phased out and new pesticides are registered and begin to be used. Some of these changes are related to new farming practices; use of glyphosate for weed control, for example, has increased dramatically with the development of genetically modified corn and soybeans that are glyphosate resistant. The use of alachlor and metolachlor has decreased as new herbicides, including acetochlor, glyphosate, and s-metolachlor, have entered the market.

The legacy of aldicarb contamination in groundwater on eastern Long Island

The insecticide aldicarb was used extensively on potato crops on eastern Long Island starting in 1975, but its use was discontinued in 1979 because it was detected in groundwater at levels that exceeded the New York State recommended level for drinking water.^(65, 67) Aldicarb degradates continued to be detected in groundwater for at least two decades after that because of the length of time it takes for groundwater to move from the point of recharge to the point of discharge. Although concentrations of these degradates began to decrease in shallow groundwater near potato fields by the early 1980s, aldicarb degradates were not detected in water from a deeper monitoring well (84 ft) until several years after aldicarb use had been banned. This case study illustrates how changes in groundwater quality often lag years or even decades behind changes in chemical use at the land surface.



Potato field

Photograph from Can Stock Photo Inc.®

VOCs in Groundwater

Most VOCs are used in urban areas because of common urban practices such as water treatment using chlorine, the use of solvents for dry cleaning and manufacturing, and the storage and use of gasoline hydrocarbons. As a result, most VOC detections, including detections of multiple VOCs in individual water samples, were in urbanized areas of the surficial aquifer system where leaks and spills are most likely to occur rather than in rural areas (figs. 6–13 and 6–14). VOCs were more frequently detected in samples of groundwater from the surficial aquifer system in the highly urbanized northern part of the surficial aquifer system than in samples across the Nation as a whole.⁽⁴⁰⁾

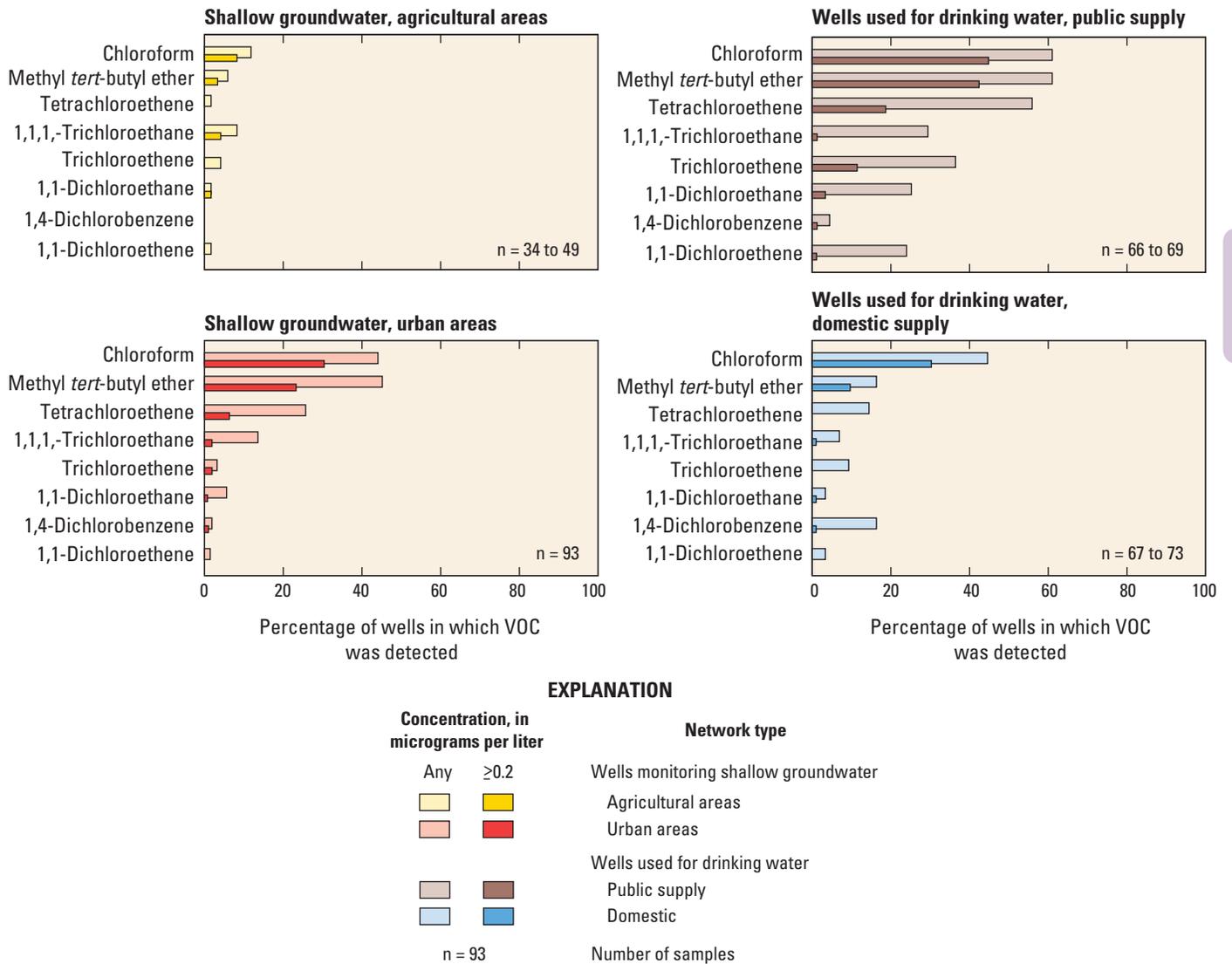


Figure 6–13. Volatile organic compounds (VOCs) were detected most frequently in samples of groundwater from public-supply wells. Most public-supply wells sampled in this study are located in urban areas, which is where VOCs are most commonly used. Chloroform, the VOC most commonly detected in both public- and domestic-supply wells, forms when water is treated with chlorine for disinfection. VOCs detected in groundwater of the surficial aquifer system include compounds that are used commonly and that are relatively stable in oxic groundwater.

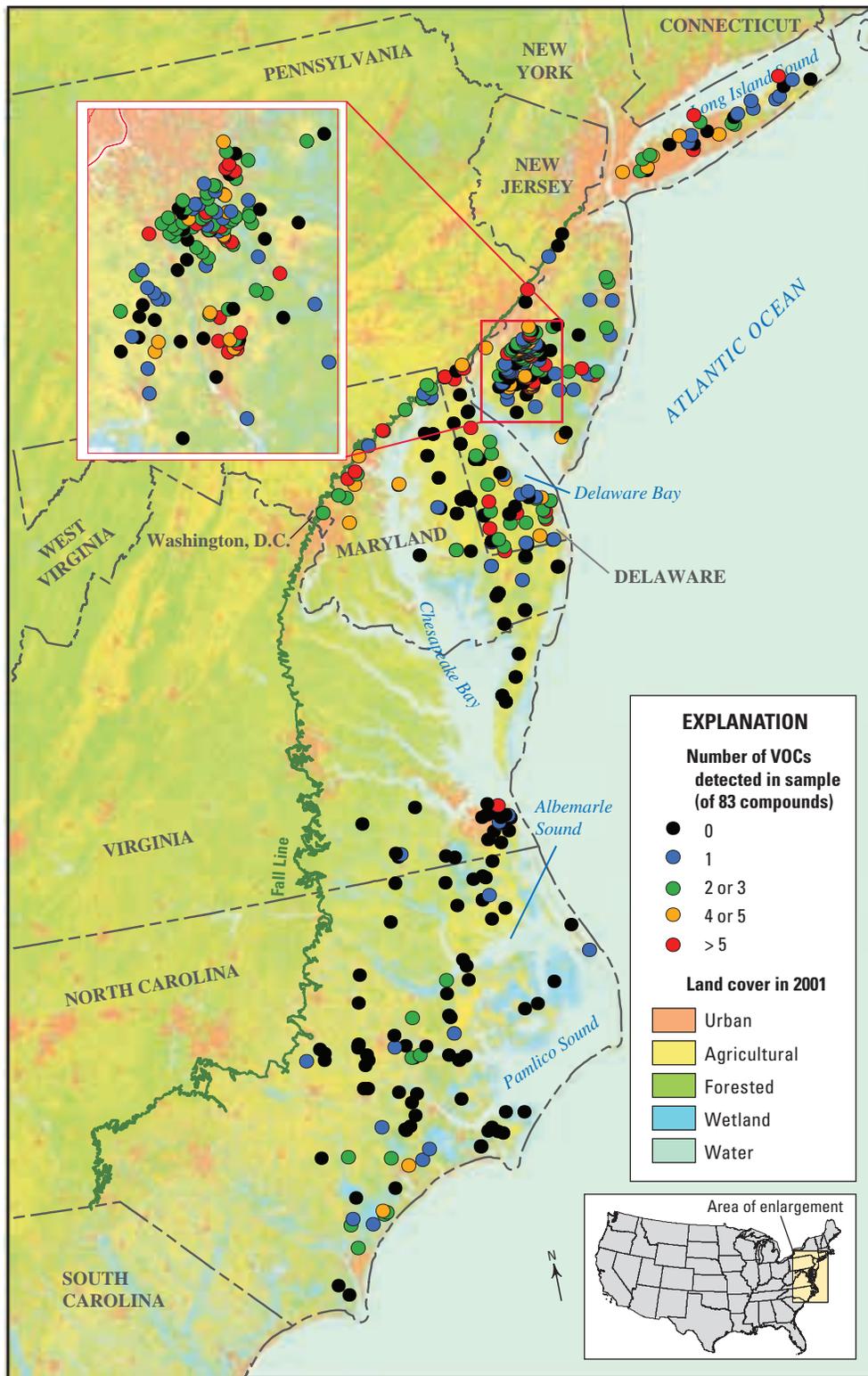


Figure 6–14. In the highly urbanized northern part of the Northern Atlantic Coastal Plain, at least one volatile organic compound (VOC) was detected in about 80 percent of samples, and three or more VOCs were detected in more than 35 percent of samples. In the less urbanized southern part of the Northern Atlantic Coastal Plain, VOCs were detected in less than 50 percent of samples, and three or more VOCs were detected in less than 25 percent of samples.

VOCs were more frequently detected in the highly urbanized northern part of the surficial aquifer system than in Principal Aquifers across the Nation as a whole.



Photographs from top to bottom: Connie J. Ross, USGS; USGS Circular 1292; Luke Meyers, USGS

VOCs are a class of organic compounds common in commercial and household products such as fuels, solvents, paints, refrigerants, and cleaners. VOCs also are used in many manufacturing applications and some are used as pesticides.

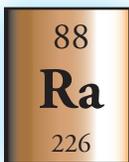
The VOCs that were most commonly detected in samples from the surficial aquifer system were the disinfection byproduct chloroform, the gasoline oxygenate methyl *tert*-butyl ether (MTBE), and the chlorinated solvents perchloroethene (PCE), 1,1,1-trichloroethane (TCA), and trichloroethene (TCE) (fig. 6–13). These VOCs also were among those most frequently detected nationally.⁽⁴⁰⁾ Chloroform typically is produced when water is disinfected using chlorine, a common practice at water treatment plants and in domestic wells, although it also can form naturally. The widespread detection of chloroform in samples from monitoring wells in urban areas and in drinking-water wells relative to its detection in samples from monitoring wells in agricultural areas might indicate leakage of chlorinated water from sewer lines and septic systems or treatment of domestic wells to remove bacteria. The presence of MTBE in groundwater at elevated concentrations, typically in urban areas, can result from gasoline leakage or spills. Its detection in groundwater at low concentrations in less urbanized areas might result from equilibration with MTBE in the atmosphere.⁽⁴⁰⁾ The chlorinated solvents detected in groundwater most likely come from point-source leaks or spills, such as dry cleaners, automotive shops, or manufacturing operations. VOCs were detected infrequently in agricultural areas of the Northern Atlantic Coastal Plain.

VOCs were detected more frequently in public-supply wells than in domestic wells (fig. 6–13), likely because most public-supply wells are in urban areas, whereas many of the domestic wells sampled are in rural areas where VOC use is low. Additionally, public-supply wells, which have larger capacity than domestic wells, have larger capture zones than domestic wells, so they are more likely to intercept water from multiple local sources of contamination (see sidebar, What types of wells were sampled, and how might that affect water quality?, p. 11). Unlike public-supply wells, routine monitoring of domestic wells is not required, and VOC contamination can go undetected.

Characteristics of soil and aquifer sediments and the presence or absence of dissolved oxygen can affect VOC occurrence in groundwater. Water can move more rapidly through sandy sediments, allowing little time for the VOCs contained in the water to break down. Groundwater moves more slowly through finer textured sediments, which allows more time for chemical reactions to occur.⁽⁴⁰⁾ Many commonly used VOCs, such as chloroform and some solvents, are unlikely to break down under oxic conditions and are common in sandy sediments of the urbanized northern part of the surficial aquifer system. Chlorinated solvents and MTBE, the VOCs most frequently detected, degrade slowly in oxic conditions and can persist for many decades in oxic groundwater. Other VOCs, such as gasoline hydrocarbons, degrade much more rapidly in oxic conditions; consequently, these VOCs were detected much less frequently, even though they are produced and used in great quantities. Although VOCs are used less in rural areas than in urban areas, anoxic conditions present in some parts of the surficial aquifer system such as coastal North Carolina (fig. 6–14) that are favorable for the degradation of some VOCs might contribute to the lower frequency of detection in that area.

The most frequently detected VOCs—a drinking water disinfection byproduct, a gasoline additive, and three chlorinated solvents—are unlikely to degrade in the groundwater.

Radium



Samples collected from the northern part of the surficial aquifer system were analyzed for the carcinogenic radionuclide radium. Of the samples from drinking-water wells that were analyzed for radium, the concentration of radium exceeded the MCL of 5 pCi/L in one-third of those samples (fig. 6–15). In a NAWQA Program study of radium that included the Northern Atlantic Coastal Plain surficial aquifer system, the Mid-Century and Ozark Plateau Cambro-Ordovician aquifer system was the only other Principal Aquifer where the concentration of radium exceeded the MCL in more than one-fourth of samples.⁽²⁸⁾ Exposure to radium can increase the risk of cancer, particularly when the exposure is from ingesting radium dissolved in drinking water.^(21, 22, 41)

Unstable radioactive elements are found in all rocks, soil, and water at a wide range of concentrations. The most common radioactive elements—uranium and thorium, which are present in sediments of the surficial aquifer system (fig. 6–16)—decay slowly and produce other radioactive elements, such as radium and radon, which in turn decay to yet other elements (see sidebar, Sequence of radionuclide decay, p. 60).⁽⁴²⁾ Radioactive decay of radium produces radon gas, which is also a known carcinogen.

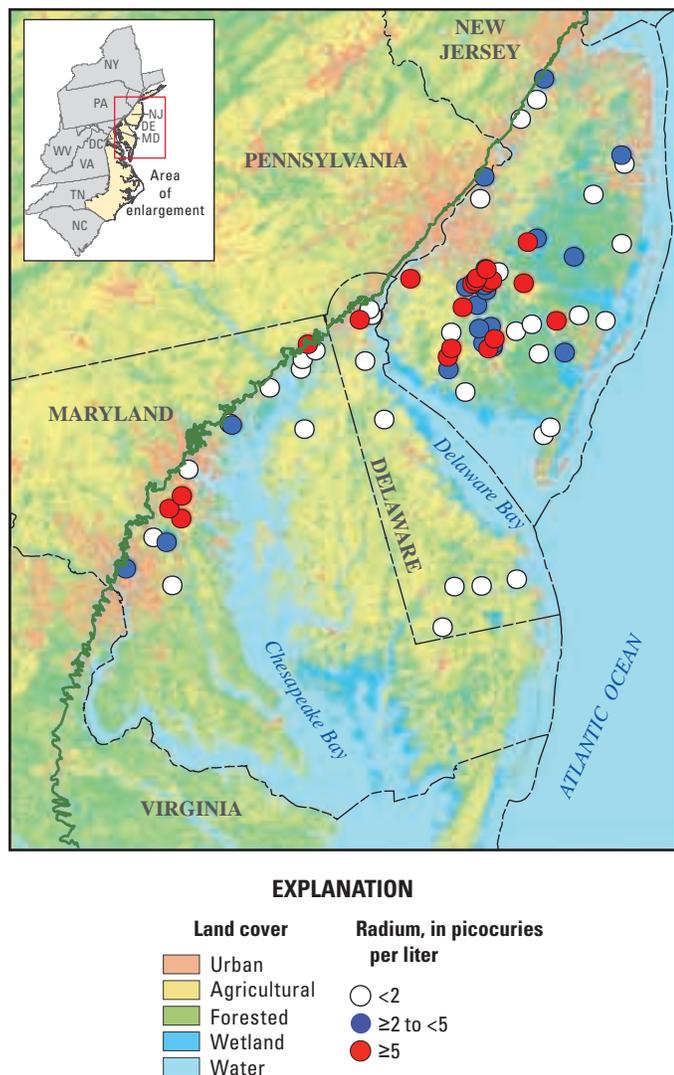


Figure 6–15. Concentrations of radium exceeded the U.S. Environmental Protection Agency Maximum Contaminant Level of 5 picocuries per liter in areas with well-weathered quartz-rich sediments and naturally acidic (low pH) groundwater and in areas of agricultural and urban land use. In agricultural and urban areas, the groundwater can become more acidic as the result of biogeochemical reactions involving applied nitrogen compounds.⁽⁴²⁾



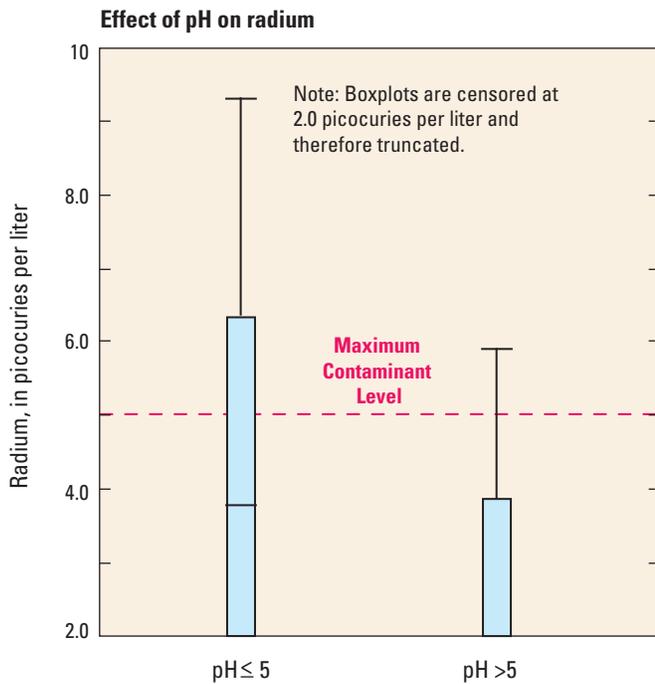
Figure 6–16. Sediments of the Northern Atlantic Coastal Plain contain small amounts of the radioactive elements uranium and thorium. The natural radioactive decay of these elements produces the radium and radon present in groundwater. Here, a U.S. Geological Survey scientist uses a Geiger counter to measure radioactivity in sediments.

The Acidity of Surficial Aquifer System Groundwater Causes Radium in Aquifer Sediments to Be Released to Groundwater

Radium is more soluble in acidic (pH less than 7) groundwater than in alkaline (pH greater than 7) groundwater and therefore typically occurs at higher concentrations where groundwater pH is low (fig. 6–17). Groundwater in many areas of the surficial aquifer system is naturally acidic where aquifer sediments are weathered and composed mostly of relatively insoluble quartz sand. Such insoluble aquifer sediments are particularly abundant in parts of the Middle and Inner Coastal Plain hydrogeologic subregions of the surficial aquifer system, which occur mostly in New Jersey, in the Delmarva Peninsula, and in North Carolina near the Fall Line (see sidebar, How hydrogeologic setting controls geochemical processes, p. 28). Some of the highest concentrations of radium measured in the surficial aquifer system were in parts of the Maryland Coastal Plain where pH was less than 3.9⁽⁴³⁾ and in parts of the New Jersey Coastal Plain where pH was less than about 4.9.^(44, 45) Water with low pH that leads to release of radium from aquifer sediments also occurs in areas of the surficial aquifer system that have not been sampled for radium,⁽²⁸⁾ indicating that radium could be a broader-scale human-health concern in drinking water than is currently documented.

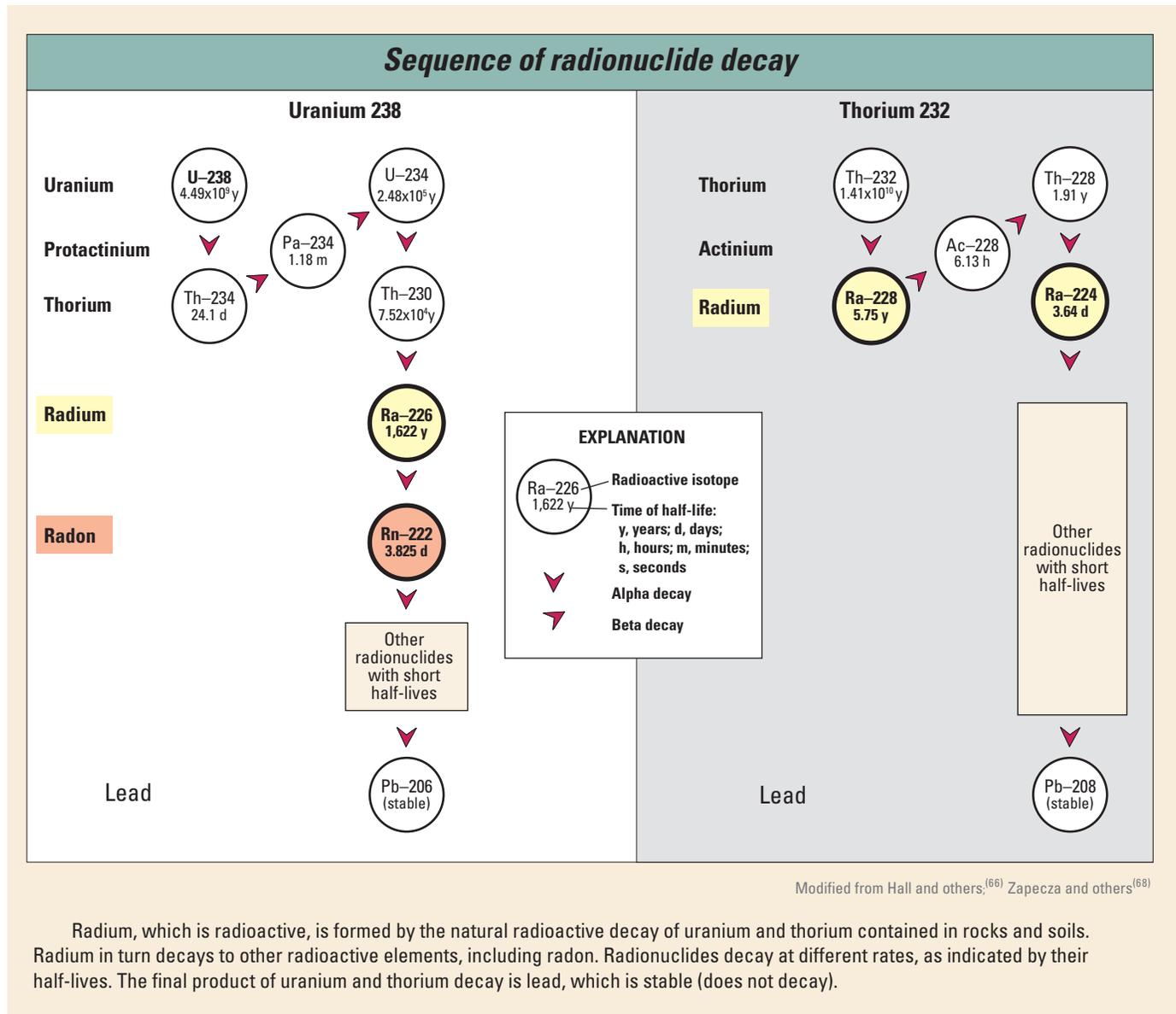
Concentrations of radium commonly are greater in groundwater in agricultural areas than in urban areas in the surficial aquifer system.⁽⁴²⁾ This difference might be related to fertilizer applications. Geochemical reactions that convert the nitrogen compounds in agricultural fertilizer to nitrate lower the pH (increase the acidity) of groundwater, causing radium in aquifer sediments to be released to groundwater.^(43, 45) Lime commonly is applied where nitrogen fertilizers are applied, and ion-exchange reactions resulting from the constituents in the lime also can enhance release of radium from aquifer sediments into the groundwater.⁽⁴²⁾ Radium concentrations in shallow groundwater are higher than those in deep groundwater; concentrations decrease with depth because acidic groundwater is slowly neutralized (the pH increases) as it moves downward along flow paths and reacts with aquifer sediments.

Radium could be a broader-scale human-health concern in drinking water from the surficial aquifer system than is currently documented because acidic groundwater, which tends to have higher concentrations of radium than alkaline groundwater, occurs in parts of the surficial aquifer system that have not been tested for radium.



See sidebar, Boxplots, p. 45

Figure 6–17. Concentrations of radium in groundwater samples typically were higher in water with a pH less than 5 than in less acidic groundwater, but most samples contained at least some radium.



Measurement of Elevated Concentrations of Radium in Groundwater Has Led to New Guidelines or Mandates for Testing of Domestic Well Water in Some Areas

Under the Clean Water Act (Public Law 92–500, 86 Stat. 816), water that is supplied to consumers from public-supply wells is required to be tested on a regular basis for concentrations of nitrate, radium, and other contaminants. Routine testing of water from domestic wells, however, is not required. The measurement of radium at concentrations exceeding drinking-water standards has motivated new guidelines or mandates for monitoring of groundwater from domestic wells in some areas of the surficial aquifer system where radium is known to occur, including parts of Maryland⁽⁴⁶⁾ and New Jersey.⁽⁴⁷⁾ Once homeowners are aware of the problem, they can lower concentrations of radium to an acceptable level with a well-maintained water softener (cation-exchange) system^(45, 48) or other treatment.

Chapter 7: *Groundwater as a Source of Contaminants to Streams and Estuaries*

Nitrate, pesticides, and other contaminants discharge with groundwater to surface waters. In particular, the discharge of nitrate in groundwater to Northern Atlantic Coastal Plain streams is a concern because nutrient enrichment of streams and estuaries has caused widespread degradation of aquatic habitat. Improving the ecological condition of coastal waters will require that nitrogen contributions from groundwater decrease. It will take years to decades, however, before reductions in nitrogen inputs at the land surface are reflected in lower nitrate concentrations in groundwater that discharges to streams and coastal water bodies.

This chapter describes the transport of contaminants from groundwater in the surficial aquifer system to surface waters of the Northern Atlantic Coastal Plain.

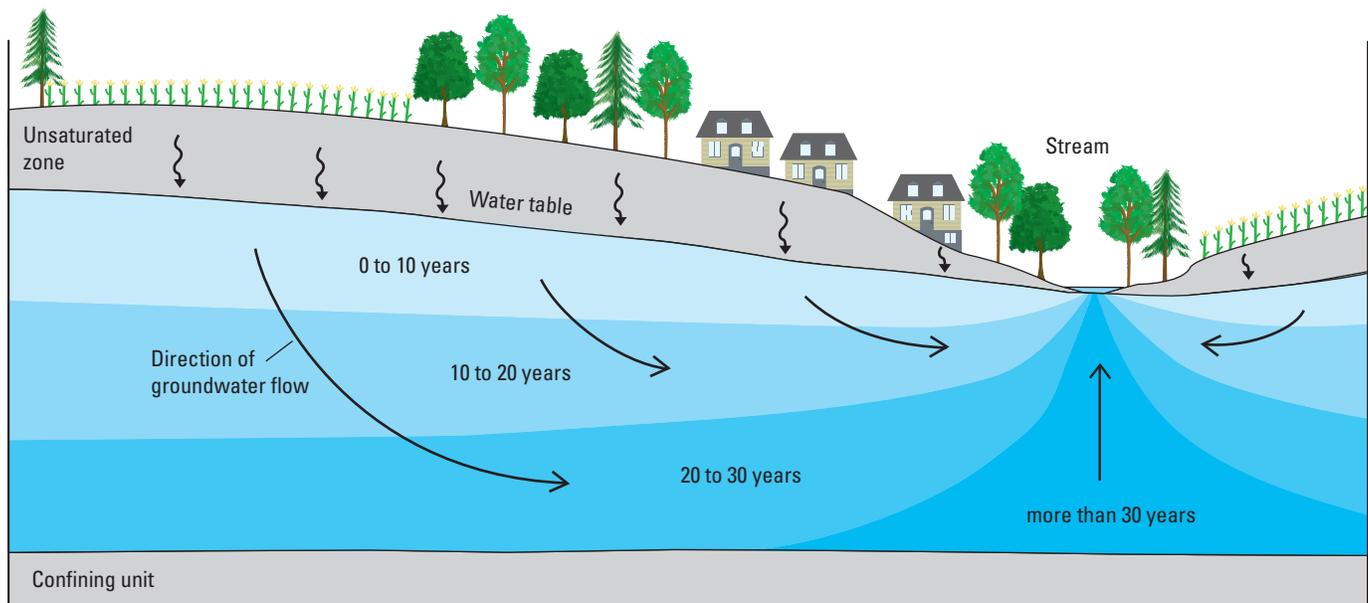


Groundwater Provides Most of the Water and Nitrate in Streams That Flow to Estuaries

Groundwater and the nitrate it contains discharges to streams and directly into estuaries.

Without groundwater, streams in the Northern Atlantic Coastal Plain would be dry most of the time. Groundwater provides 50 to 95 percent of freshwater flow in streams that originate in the surficial aquifer system and that flow to estuaries, such as Chesapeake and Delaware Bays, and to Long Island, Albemarle, and Pamlico Sounds.⁽¹²⁾ Virtually all (about 99 percent) of the groundwater that discharges to these streams, which is referred to as base flow, is from the surficial aquifer system.⁽⁷⁾ Groundwater also discharges directly to estuaries and other coastal waters (see sidebar, Groundwater discharge to coastal waters, p. 63).^(49, 50) It takes from a few years to a few decades for groundwater to move from the water table through most parts of the surficial aquifer system and discharge to local surface waters (fig. 7–1). Groundwater that moves along deeper flow paths in thicker parts of the surficial aquifer system or through confined aquifers can take hundreds of years to discharge to streams and estuaries.⁽⁷⁾

Nitrogen, in the form of nitrate, is transported by groundwater to surface water. The primary source of nitrogen in most streams in the Northern Atlantic Coastal Plain is nitrate from the surficial aquifer system (fig. 7–2). During late winter and spring 2000, groundwater contributed more than 44,000 pounds of nitrogen in the form of nitrate (or 1.9 pounds per square mile on average) daily to headwater streams in the Northern Atlantic Coastal Plain that flow into ecologically sensitive coastal waters (see sidebar, Nitrate from groundwater discharging to surface water contributes to the ecological degradation of Northern Atlantic Coastal Plain coastal waters, p. 65⁽²⁹⁾).



NOT TO SCALE

Figure 7–1. Most flow in local streams is contributed by groundwater that discharges from the surficial aquifer system. A stream contains a mixture of groundwater of different ages that is contributed from many different groundwater flow paths. Because groundwater recharge originates at different points within the stream watershed, stream chemistry reflects many local natural and human influences that are distributed throughout the watershed.

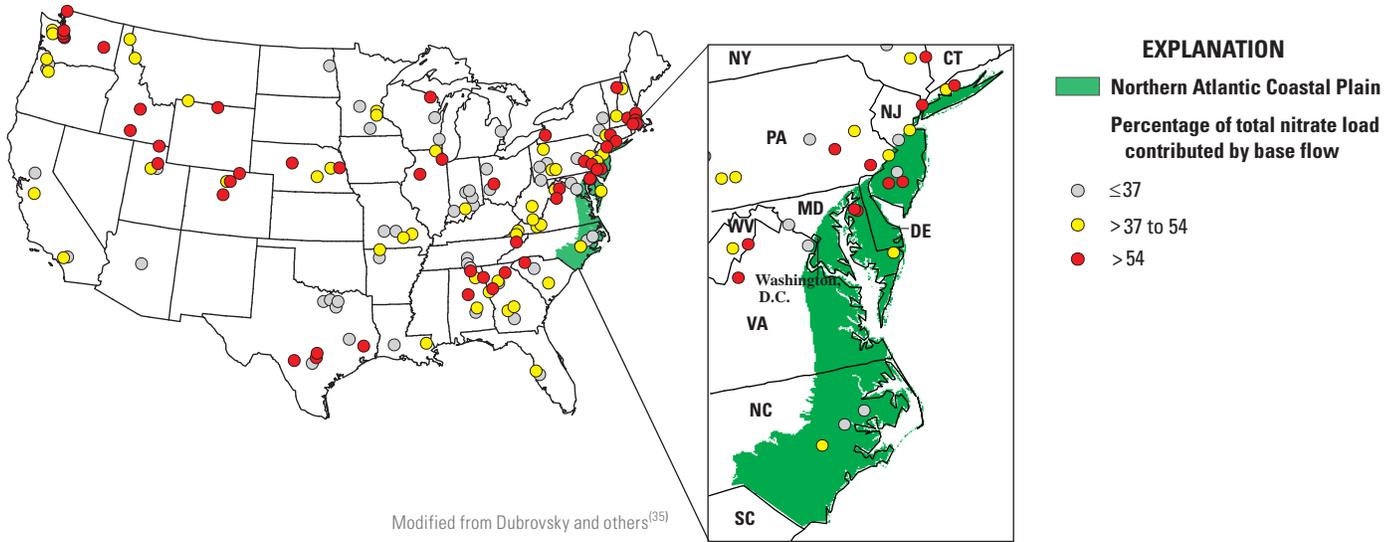


Figure 7-2. Groundwater discharge contributes a substantial portion of the total amount of nitrate carried by streams in the Northern Atlantic Coastal Plain, particularly in the north where nonpoint nitrogen sources are abundant and concentrations of nitrate in groundwater are high. In the northern part of the surficial aquifer system, groundwater contributions of nitrate to streams are among the highest in the Nation.⁽⁶⁹⁾

Groundwater discharge to coastal waters



Nitrate-rich groundwater discharge can contribute substantial loads of nitrogen to tidal creeks, estuaries, and the ocean.^(51, 75, 86) However, sediments in many coastal discharge areas, such as salt marshes and the bottom sediments of tidal creeks and lagoons, have a high organic carbon content,⁽⁴⁹⁾ and nitrate in discharging groundwater is removed by denitrification (see sidebar, How does nitrate enter groundwater? How is it lost from groundwater?, p. 31).

Aerial image of Queenstown, Maryland, along Queenstown Creek. Photograph by Jane Thomas, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/).

Concentrations of nitrate in streams commonly decrease during high-flow periods.

Concentrations of nitrate in streams usually are highest during base-flow conditions when most of the water is from groundwater, especially in winter, when consumption of nitrogen by aquatic organisms is minimal.^(11, 53, 54) Although the median concentration of nitrate in streams of the Northern Atlantic Coastal Plain during base flow is less than 1 mg/L as N, concentrations greater than 10 mg/L as N have been measured in some streams.^(11, 51) During high flow, concentrations of nitrate typically are lower because contributions from precipitation and overland runoff, which have low concentrations of nitrate, dilute the contributions from nitrate-rich groundwater (fig. 7–3).^(11, 52, 56)

If nitrate-rich groundwater flows through an anoxic zone (dissolved oxygen less than 0.5 mg/L), such as can occur in the riparian zone or in the fine-grained organic-rich sediments of the hyporheic zone, the nitrate can be removed by denitrification (fig. 7–4). The greatest potential for denitrification in riparian-zone sediments is where the surficial aquifer is very thin and where organic-rich sediments with reducing conditions extend to the base of the aquifer, such as in eastern North Carolina.^(57, 60) In contrast, at a study site in Maryland with a thick sandy aquifer and sandy streambed sediments with little organic matter, nitrate discharged relatively unaltered to the stream.⁽⁶²⁾ Settings similar to those at the Maryland study site are most common in the northern part of the surficial aquifer system where the aquifer is thick enough that groundwater flows beneath the influence of the riparian zone (fig. 7–4).

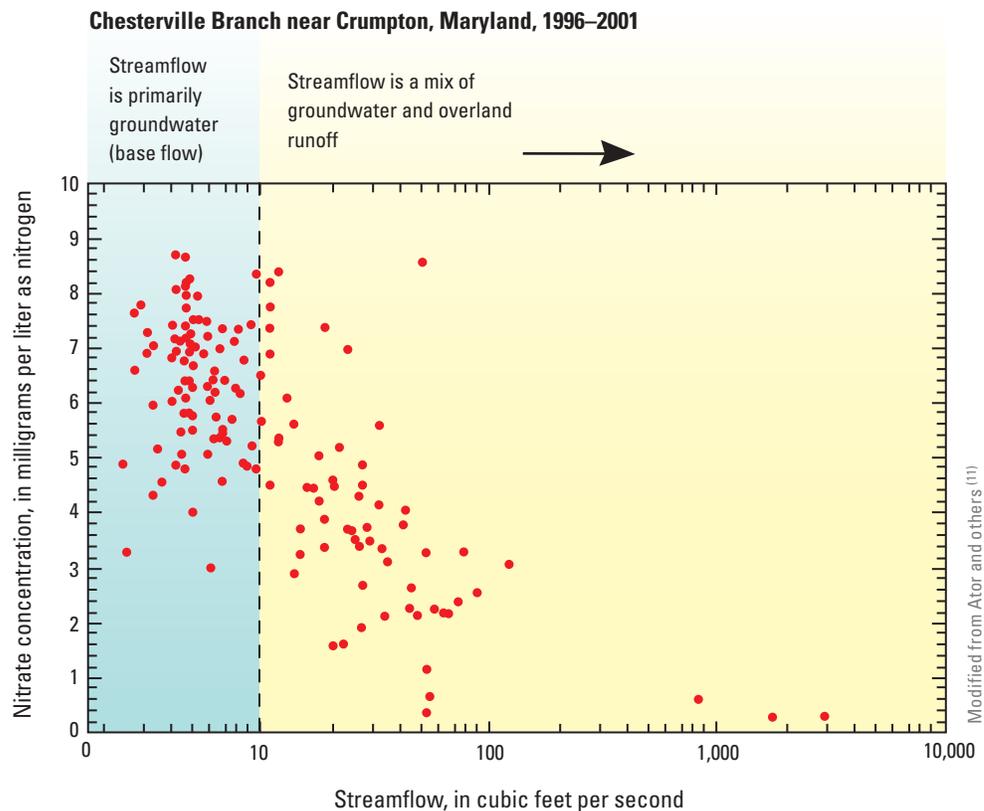


Figure 7-3. In Chesterville Branch near Crumpton, Maryland, nitrate concentrations approached 10 milligrams per liter as nitrogen during base-flow periods, but decreased substantially during higher flow conditions as groundwater discharge was diluted by low-nitrate water from precipitation and runoff.

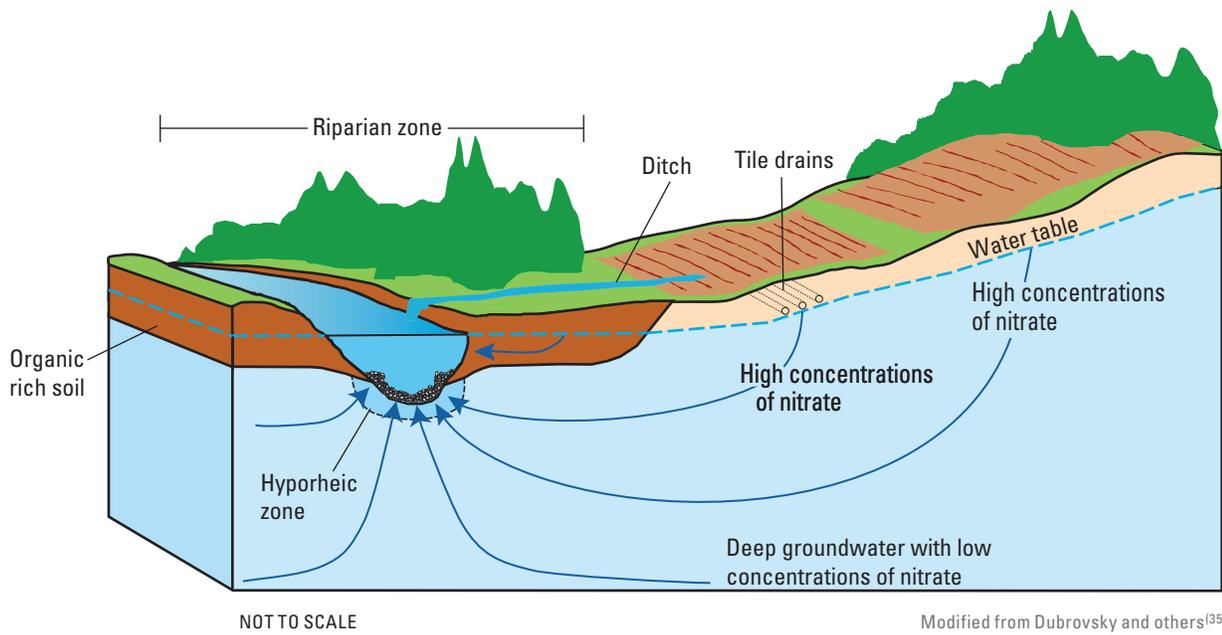
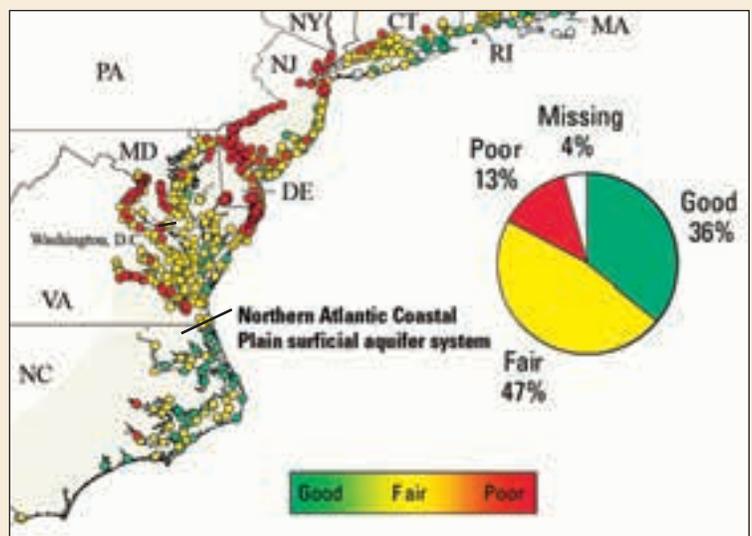


Figure 7-4. Many factors and processes can affect nitrate-rich groundwater as it moves from the point of recharge to discharge in streams. Where the aquifer is thick, nitrate-rich water can flow beneath the organic-rich, reducing soils of the riparian zone and discharge relatively unaltered to streams through sandy streambed sediments. This nitrate-rich groundwater can be diluted by nitrate-poor groundwater that recharged through the riparian zone, or by deep, old groundwater that is nitrate-poor because it recharged before the widespread use of fertilizers or other sources of nitrogen. Nitrate can be removed from groundwater in various ways before it discharges to streams. Nitrate can be taken up by plants in the riparian zone or in the stream channel. If sufficient organic matter is present in the aquifer, in the riparian zone, or in the streambed sediments of the hyporheic zone, nitrate can be transformed by denitrification to nitrogen gas. However, groundwater recharge that contains nitrate can be intercepted by tile drains or ditches and diverted to surface water before the groundwater encounters reducing conditions.

Nitrate from groundwater discharging to surface water contributes to the ecological degradation of Northern Atlantic Coastal Plain coastal waters

High concentrations of nitrogen (often in the form of nitrate from groundwater) and phosphorus from fertilizers, manures, and sewage contribute to the fair to poor water quality in tidal estuaries and other coastal waters along much of the Northern Atlantic Coastal Plain.⁽⁹³⁾ Ecological problems associated with excessive nutrients include algal blooms, decreased dissolved oxygen, abundance of submerged aquatic vegetation, and degradation of aquatic life habitats, leading to declining fisheries. The water-quality index is based on a combination of indicators of ecological health that are measured throughout the region. These indicators include levels of nitrogen, phosphorus, chlorophyll *a* (in algae), water clarity, and dissolved oxygen.

Water-quality index



Groundwater Discharge Contributes Pesticides to Streams in the Northern Atlantic Coastal Plain

Soluble pesticides and their degradates in groundwater are transported along flow paths and discharge to streams (fig. 7–5).^(11, 71) Although most pesticides are transported to streams in overland flow that happens when there are storms during the pesticide application season, groundwater provides a continuous source of pesticide compounds to streams throughout the year. During late winter and spring 2000, more than 57 pounds of alachlor, atrazine, metolachlor, and certain degradates (combined) were contributed daily from groundwater to headwater streams of the Northern Atlantic Coastal Plain.⁽²⁹⁾ Concentrations of individual pesticide compounds in base flow generally were less than 0.1 µg/L, but concentrations of some pesticide degradates in some streams were more than 3 µg/L. As in groundwater, pesticide compounds in stream base flow often occur in mixtures of several compounds; at least five different pesticides or degradate compounds were detected in each of the 23 headwater streams sampled on the Delmarva Peninsula during base flow in late winter and spring 2000, and one stream contained 17 different compounds.⁽⁵²⁾ Pesticide concentrations in Northern Atlantic Coastal Plain streams during base flow generally are far below levels likely to harm fish and aquatic invertebrates.⁽⁵⁹⁾

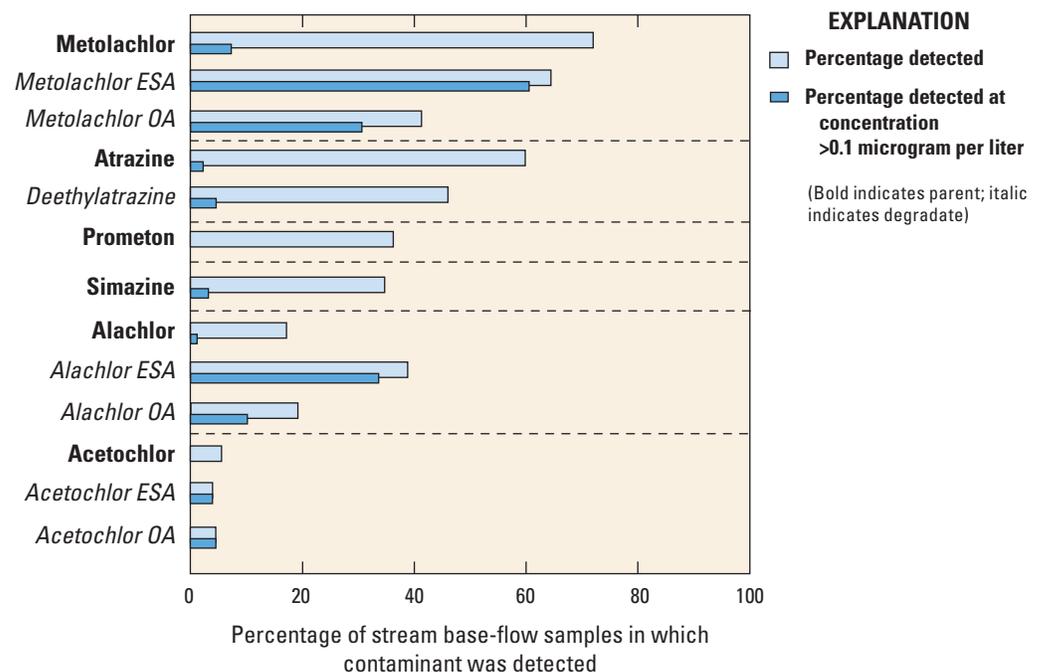


Figure 7–5. Pesticide (parent and degradate) compounds are detected frequently in streams of the Northern Atlantic Coastal Plain during base-flow conditions, when groundwater discharge is the primary source of water. The compounds detected most frequently in streams are among those detected most frequently in groundwater (see figure 6–8).

Chemical Properties and Local Natural and Human Influences Control the Transport of Chemical Contaminants From Groundwater to Streams

Only compounds that dissolve in water and that do not break down in groundwater, such as atrazine, metolachlor, and nitrate, will survive the typically years- to decades-long trip along groundwater flow paths to streams. Concentrations of nitrate and pesticides in stream base flow generally are greatest near areas where they are used and where local soil, hydrogeologic, and geochemical conditions promote their movement and stability in groundwater (see chapters 5 and 6).^(53, 73, 74) Nitrate, for example, is stable along groundwater flow paths where groundwater is oxic, but is transformed to nitrogen gas where groundwater passes through anoxic areas before discharging to streams.^(16, 61)

Groundwater on the Delmarva Peninsula is particularly effective at transporting contaminants to streams because contaminant sources at the land surface are abundant and because well-drained and well-oxygenated soils and a shallow water table promote the movement of nitrate and other chemicals into and through the shallow surficial aquifer (see sidebar, The effects of groundwater nitrate on restoration of the Chesapeake Bay, p. 68). The Eastern Shore of the Chesapeake Bay, which is on the Delmarva Peninsula, generates more than half of the fluxes of base-flow alachlor, atrazine, metolachlor, and nitrate to streams in the entire Northern Atlantic Coastal Plain (excluding Long Island, for which data were not available), even though it makes up only 9 percent of that area (fig. 7–6).⁽²⁹⁾

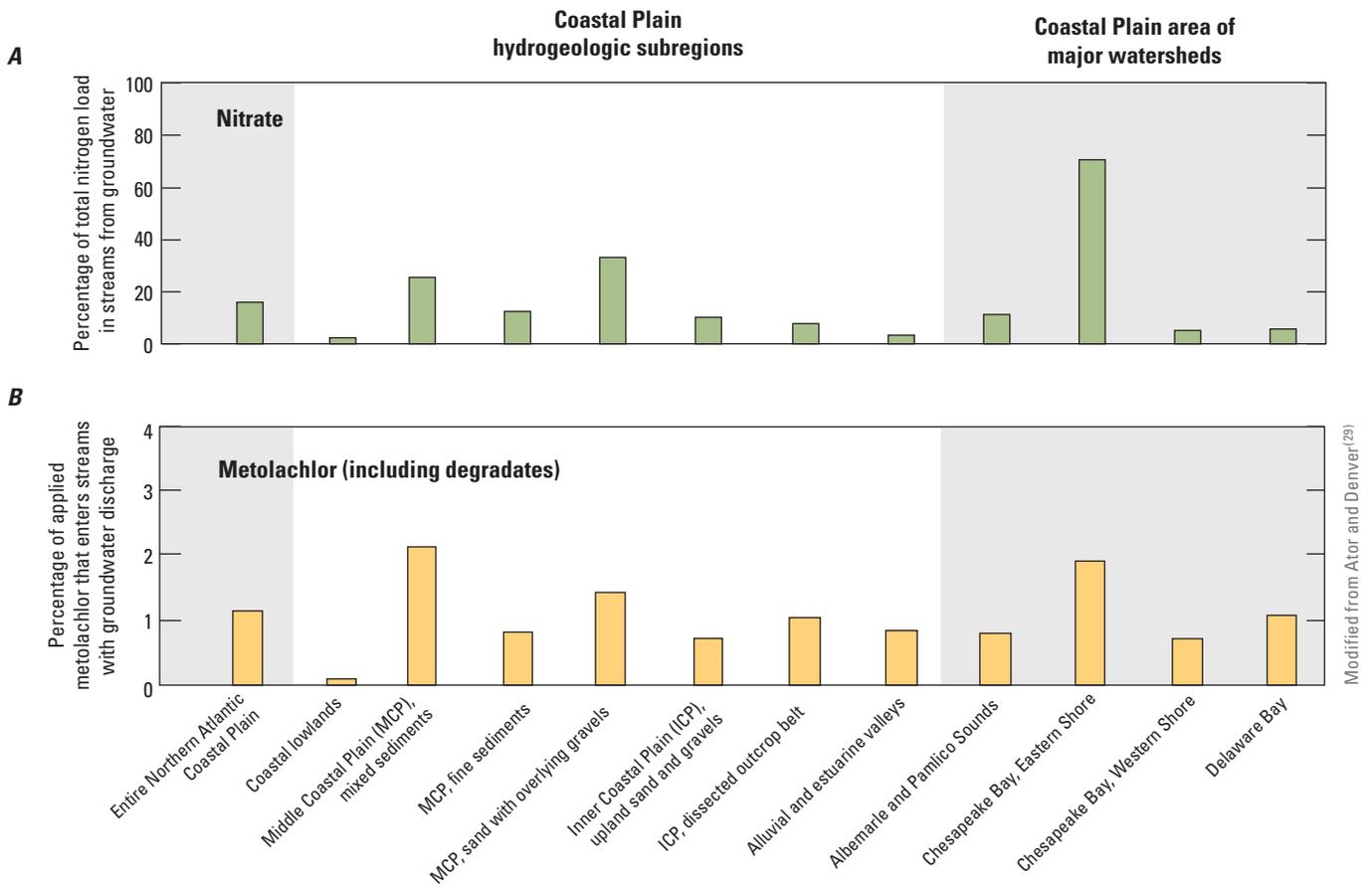


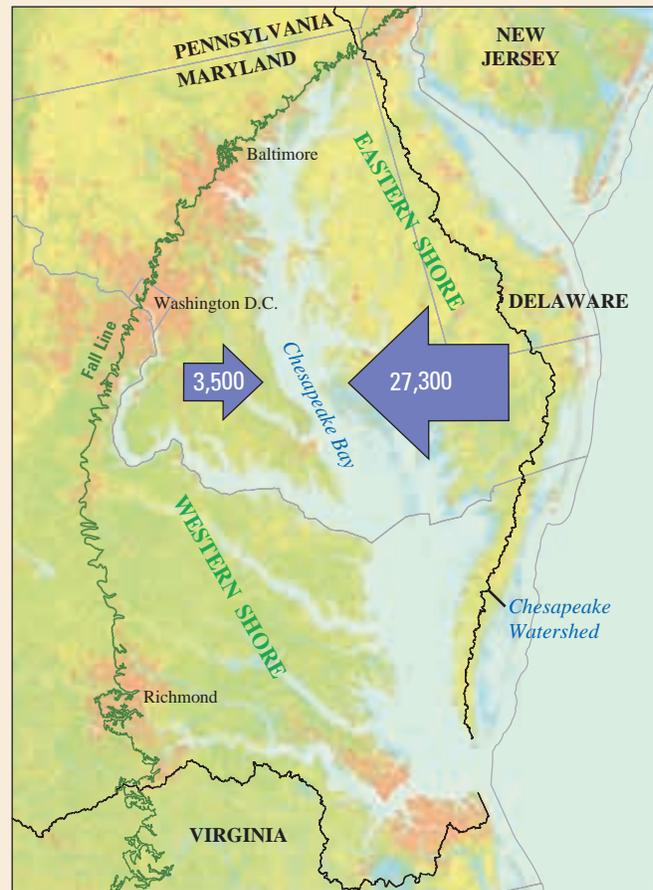
Figure 7–6. Patterns across hydrologic subregions (see sidebar, How hydrogeologic setting controls geochemical processes, p. 28) and major watersheds in *A*, the percentage of nitrate in total nitrogen loads in streams that comes from groundwater are similar to *B*, the percentage of applied metolachlor that enters streams with groundwater discharge. This similarity in patterns likely occurs because the factors that control the transport of nitrate through groundwater to surface water also control the transport of metolachlor. Nitrate from groundwater provides much of the daily load of nitrogen in streams in some parts of the Northern Atlantic Coastal Plain. About 1 to 3 percent of applied metolachlor reaches streams in the Northern Atlantic Coastal Plain through groundwater discharge, mostly in the form of degradate compounds.

The effects of groundwater nitrate on restoration of the Chesapeake Bay

The Chesapeake Bay, which is the largest and one of the most biologically diverse estuaries in North America, was listed as “impaired” under the Clean Water Act in 2000 partly because of excessive concentrations of nitrogen.⁽⁷²⁾ Most of the nitrogen in the Chesapeake Bay comes from tributary streams⁽⁷⁶⁾ that receive about half of their nitrogen from groundwater.⁽⁸⁵⁾ A total maximum daily load (TMDL) has been established to help manage nitrogen reductions in the bay,⁽⁸⁷⁾ and Federal agencies have been directed to develop a new strategy to protect and restore Chesapeake Bay.⁽⁹⁰⁾

Management activities designed to limit nitrogen loading to the Chesapeake Bay will have to address the groundwater contribution of nitrate. They will also have to consider the substantial lag times between improvement to shallow groundwater quality and the discharge of that groundwater to streams and the estuary. The problem is particularly acute on the Eastern Shore, where groundwater contributions of nitrate make up 70 percent of the total nitrogen load to the bay from that area.

The Eastern Shore Coastal Plain is less than half the size of the Western Shore Coastal Plain, but it is intensively agricultural and its sandy sediments are favorable for transport of nitrate into and by groundwater to surface water. The Western Shore, in contrast, which has more fine-grained aquifer sediments, has more urban and forested land and less agriculture. As a result, Eastern Shore tributaries deliver nearly eight times more nitrate (27,300 pounds per day) to the Chesapeake Bay than Western Shore tributaries that originate in the Coastal Plain (3,500 pounds per day).



Contributions of Contaminants From Groundwater to Streams Reflect the History of Local Land Use, Land Management, and Chemical Applications

It will take years to decades for reduction in inputs of nitrate and other contaminants to groundwater to be reflected in water-quality improvements in streams and estuaries.

Management practices aimed at improving the quality of Northern Atlantic Coastal Plain surface water will require lowering inputs of nitrate to groundwater. However, the effect of reductions of nitrate to groundwater will not immediately improve surface-water quality. Because of the time it takes for groundwater to move from the point of recharge to the point of discharge, it will take years to decades before reductions in nitrogen inputs to the water table result in substantial water-quality improvements in streams and coastal estuaries. The time required will be even longer in areas where the unconfined aquifer is thick and flow paths are long (fig. 7–7).⁽¹⁴⁾

Water quality of stream base flow reflects both recent and past chemical inputs at the land surface and other influences. An increase in concentrations of nitrate in the Choptank River on the Delmarva Peninsula in recent decades (1980s to 2000s), for example, is related to intensive fertilizer applications in previous decades, which are just now being reflected in concentrations of nitrate in discharging groundwater.^(82, 88) On Long Island, the beneficial effects of sewer installation in the 1950s were still being seen into the 1990s, as concentrations of nitrogen in surface water receiving groundwater discharge continued to decrease (fig. 7–8).

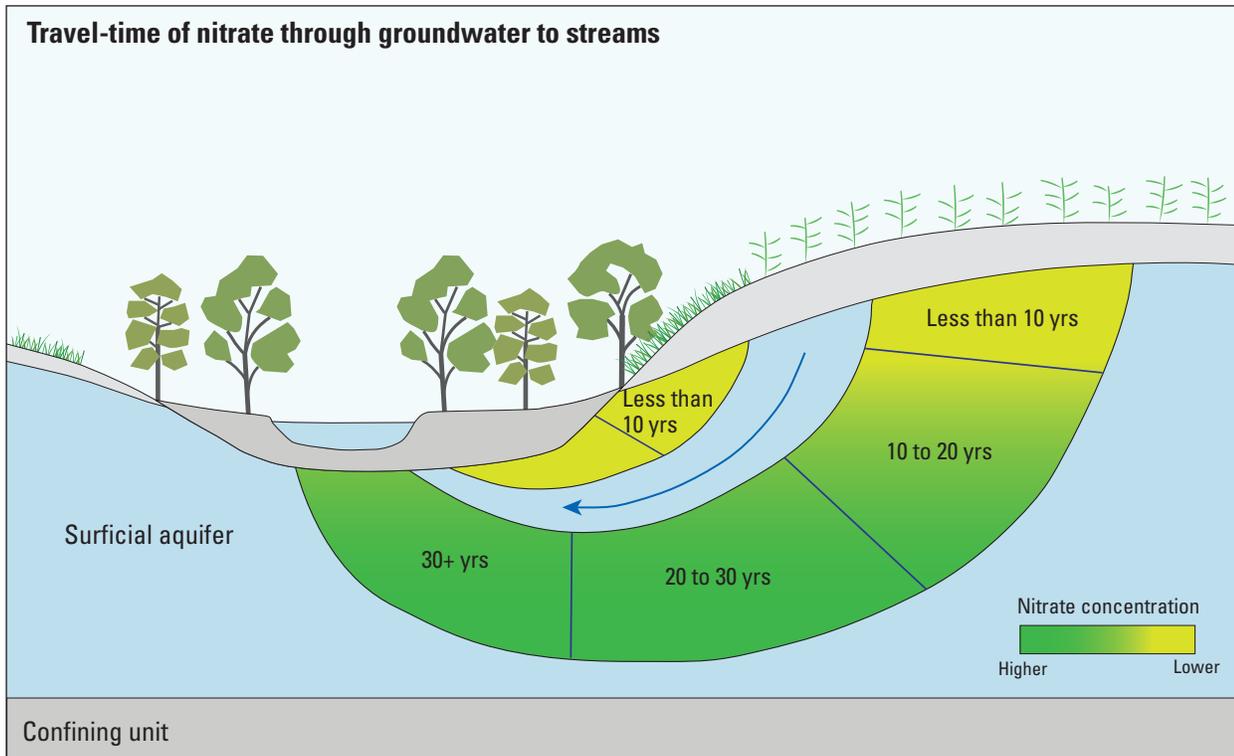


Figure 7-7. For streams that receive much of their nitrate from groundwater discharge, many years or even decades are typically required before results of management actions or land-use changes that reduce nitrogen inputs at the land surface are fully reflected in surface-water quality.

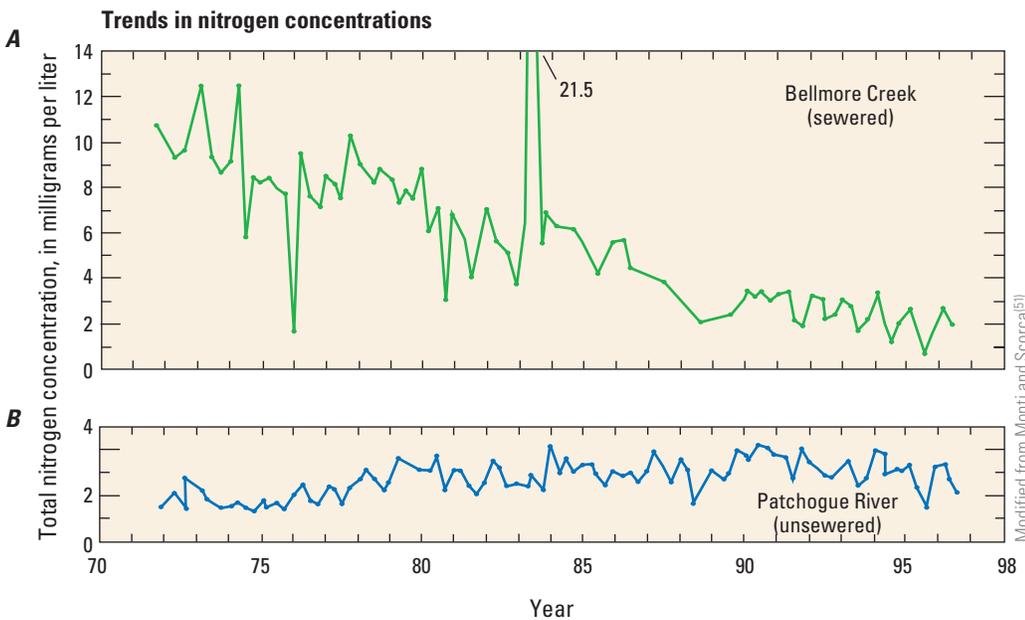


Figure 7-8. Trends in nitrogen concentrations in two streams on Long Island, New York, reflect changes in groundwater contamination that resulted from contrasting changes in waste-water disposal practices. *A*, Nitrogen concentrations in streams have decreased substantially in an area with intensive development where sewers were installed beginning in the 1950s. *B*, Nitrogen concentrations are slowly increasing in an unsewered area where onsite sewage disposal with septic systems is continuing.



***For more information about NAWQA Principal
Aquifer studies***

Groundwater quality for many of the Nation's Principal Aquifers is characterized in U.S. Geological Survey Circular 1360. This report and links to other Principal Aquifer circulars are available at <http://water.usgs.gov/nawqa/pasumm/>. More than 2,000 NAWQA Program reports are available at <http://water.usgs.gov/nawqa/bib/>.

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Glossary

A

adsorb/adsorption Process in which ions or molecules dissolved in groundwater become attached to the surfaces of solid materials, such as sediment or rock particles in aquifers, either temporarily or permanently. *See* sorption.

anoxic Water with no dissolved oxygen or a very low concentration (less than 0.5 milligram per liter) of dissolved oxygen.

anthropogenic Associated with, occurring because of, or influenced by human activity.

apparent groundwater age The time elapsed since the recharge water became isolated from the atmosphere. The term "age" is normally qualified with the word "apparent" to signify that the accuracy of the determined age depends on many variables.

aquifer A geologic formation, group of formations, or part of a formation that contains a sufficient amount of saturated permeable material (for example, soil, sand, gravel and (or) rock) to yield substantial quantities of water to wells and springs.

B

base flow Groundwater seepage into a stream or river. The continual contribution of groundwater to streams and rivers is an important source of streamflow between rain events.

carbonate rock Rocks, such as limestone or dolostone, that are composed primarily of minerals, such as calcite and dolomite, containing the carbonate ion (CO_3^{2-}).

C

confined aquifer (artesian aquifer) An aquifer in which the groundwater is bounded between layers of relatively impermeable material, such as clay or dense rock. When tapped by a well, water in a confined aquifer is forced up, sometimes above the land surface, by pressure within the aquifer.

confining unit A hydrogeologic unit of impermeable or distinctly less permeable material within an aquifer or bounding one or more aquifers.

constituent A chemical or biological substance in water, sediment, or biota that can be measured by an analytical (laboratory) method.

contaminant For the purposes of this report, any manmade compound at any concentration, or any constituent with a geologic source measured at a concentration exceeding the designated human-health benchmark.

D

degradate A compound formed by the transformation of a parent compound, typically an organic contaminant or another degradate, by chemical, photochemical, or biological reactions.

degradation The breakdown of a compound to a chemically simpler compound by abiotic or biotic processes.

denitrification The bacterial reduction of dissolved nitrate to nitrogen gas. Denitrification is the primary process by which nitrate can be eliminated naturally in groundwater.

desorption The release of a sorbed material from the solid to which it was sorbed. Opposite process of adsorption.

discharge The rate of flow of surface water or groundwater past a given point at a given moment, expressed as volume per unit of time. Also, the outflow from an aquifer, spring, or well or up through a streambed.

domestic well A privately owned well that typically serves one home and supplies water for human consumption and other homeowner uses.

drinking-water standard or guideline A threshold concentration in a public drinking-water supply designed to protect human health or to identify acceptable concentrations of constituents that cause unpleasant tastes, odors, or colors in the water.

E

eutrophication The enrichment of water by nutrients, most commonly phosphorus and nitrogen. During eutrophication, respiration processes that use organic matter cause a marked decline in dissolved-oxygen concentrations of water.

evapotranspiration Loss of water from soil by evaporation and plant transpiration combined.

F

flow path The route or pathway of water flowing through the hydrologic system. Typically refers to subsurface (groundwater) flow.

fumigant A pesticide in the volatile organic compound (VOC) chemical class that is applied to soils to reduce populations of plant parasitic nematodes (harmful rootworms), weeds, fungal pathogens, and other soil-borne microorganisms.

G

groundwater Water that exists beneath the land surface, but most commonly refers to water in fully saturated soils and geologic formations.

groundwater age See apparent groundwater age.

groundwater discharge The flow of water from the saturated zone, for example, from a spring or a well or as seepage to surface water.

groundwater flow path See flow path.

groundwater recharge The infiltration of water to the saturated zone. Also refers to water that reaches the water table by infiltration of precipitation or irrigation water through the unsaturated zone or by seepage of water from surface-water bodies such as streams and lakes.

groundwater residence time The average amount of time it takes for groundwater to move from the point where it enters the aquifer to a specific point of discharge such as a well or stream.

H

half-life The time required for the concentration of a compound in a given environmental medium to be reduced to one-half of its original value by one or more processes, such as degradation or transport into another environmental medium.

headwater stream The upper part of a stream, especially a large stream or river, including the upper drainage basin.

Health-Based Screening Level (HBSL) An estimate of concentration (for a noncarcinogen) or concentration range (for a carcinogen) in water that (1) may be of potential human-health concern, (2) can be used as a threshold value against which measured concentrations of contaminants in ambient groundwater samples can be compared, and (3) is consistent with U.S. Environmental Protection Agency Office of Water methodologies.

herbicide A chemical pesticide designed to control or destroy plants, weeds, or grasses.

human-health benchmark A threshold concentration above which the concentration of a contaminant in drinking water could have adverse effects on human health. Treatment or other measures can be used before the water is consumed to lower the concentration of the contaminant below the benchmark.

hydrogeologic setting A unit with common hydrogeologic characteristics and therefore common susceptibility to contamination; a composite description of all the major geologic and hydrologic factors that affect and control the movement of groundwater into, through, and out of an area.

hydrogeology The geologic and hydrologic features that control the movement of water, solutes, and small particles through the subsurface.

hyporheic zone The region beneath and next to a streambed where surface water and shallow groundwater mix.

I

infiltration Movement of water, typically downward, into soil or porous rock.

isotope Each of two or more forms of the same element with the same atomic number (the same number of protons) but a different number of neutrons and therefore different atomic weights.

L

land-use study A study by the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program to assess the effects of a specific land-use type (generally agricultural or urban) on groundwater quality, in most cases by sampling groundwater from monitoring wells that tap water from or near the water table.

M

major aquifer A regionally extensive subsurface geologic formation or group of formations that is used, or has the potential to be used, as a substantial groundwater resource.

major aquifer study A study by the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program that involves sampling of water at 20 to 30 domestic and (or) public-supply wells that withdraw water from major aquifers. The major aquifer studies represent a mix of land uses and target water that is used for drinking-water supply.

Maximum Contaminant Level (MCL) Maximum permissible level of a contaminant in water that

is delivered to any user of a public water system. MCLs are enforceable standards established by the U.S. Environmental Protection Agency.

median The middle or central value in a distribution of data ranked in order of magnitude such that one-half of the data are higher than the median and one-half are lower. The median is also called the 50th percentile.

milligrams per liter (mg/L) A unit expressing the concentration of a chemical constituent as weight (milligrams) of constituent per unit volume (liter) of water; equivalent to one part per million in most streamwater and groundwater. One thousand micrograms per liter ($\mu\text{g/L}$) is equivalent to 1 mg/L.

monitoring well A well used to measure water quality or groundwater levels continuously or periodically. Not typically used as a source of drinking water. Sometimes referred to as an "observation well."

N

nitrate An ion consisting of one nitrogen atom and three oxygen atoms (NO_3^-). Nitrate is a plant nutrient and is very mobile in soils.

nitrification The formation of nitrates by the oxidation of ammonium salts to nitrites followed by oxidation of nitrites to nitrates.

nonpoint source A contaminant source that is not a discrete point, such as a pipe, ditch, or tunnel. Areas of fertilizer and pesticide applications, atmospheric deposition, and stormwater runoff are examples of sources of nonpoint contamination.

nutrient An element or compound essential for animal and plant growth. Common nutrients include nitrogen, phosphorus, and potassium, such as are found in fertilizer.

O

organic matter Matter resulting from the decay of a plant or an animal and containing organic carbon compounds. Organic matter is rich in nutrients and is an essential component of soils.

organic compound A chemical compound containing the element carbon. A few types of carbon-containing compounds, including oxides of carbon (such as carbon dioxide, or CO_2), are not considered to be organic. Organic compounds include petroleum products, solvents, and many pesticides.

oxic Water with a concentration of dissolved oxygen greater than or equal to 0.5 milligram per liter.

oxidation The loss of electrons by a chemical species as a result of transfer to another chemical species, typically dissolved oxygen. The species donating electrons is "oxidized."

P

permeable Capable of transmitting liquids or gases through pores or openings.

pesticide Any substance, organic or inorganic, used to kill plant or animal pests.

pH A measure of the acidity (pH less than 7) or alkalinity (pH greater than 7) of a solution; a pH of 7 is neutral. Formally defined as the logarithm of the reciprocal of the hydrogen ion concentration (activity) of a solution.

point source A stationary location or fixed facility from which contaminants are discharged, for example, a pipe, ditch, ship, ore pit, or factory smokestack.

precipitation Any or all forms of water particles that fall from the atmosphere, such as rain, snow, hail, and sleet. Also, the process in which a solid is formed from a fluid supersaturated with dissolved ions.

Principal Aquifer A regionally extensive aquifer or aquifer system that has the potential to be used as a source of potable water. A Principal Aquifer can be composed of one or more major aquifers.

public-supply well A privately or publicly owned well that provides water for public use to (1) a community water system, (2) a transient noncommunity water system such as a campground, or (3) a nontransient, noncommunity system, such as a school.

R

radioactive decay The spontaneous emission of particles (alpha or beta) and gamma rays from an atom with an unstable nucleus (radionuclide).

recharge The addition of water to the saturated zone naturally by precipitation or runoff or artificially by spreading or injection. Also, the water that is added.

reduction The gain of electrons by a chemical species, typically dissolved oxygen, as a result of transfer from another chemical species. The species accepting electrons is "reduced." Once all of the dissolved oxygen has been reduced, other chemical species can accept electrons, following the most energetically favorable order.

reduction/oxidation (redox) Chemical reactions that involve the transfer of electrons from one chemical species to another, resulting in a

change in the valence state of the species. Redox processes in groundwater often are microbially facilitated.

residence time The average amount of time that a solute, particle, organism, or other entity spends within a given environmental medium, such as a lake, groundwater, and the atmosphere.

riparian zone Pertaining to or located on the bank of a body of water, especially a stream.

runoff Excess rainwater or snowmelt that is transported to streams by flow over the land surface.

S

Secondary Maximum Contaminant Level (SMCL) Guidelines set by the U.S. Environmental Protection Agency for concentrations of "nuisance" constituents in drinking water that may cause unwanted effects, such as unpleasant taste, color, or odor; discoloration of skin or teeth; or corrosion or staining of plumbing fixtures. Public drinking-water systems are recommended but not required to comply with these guidelines.

siliciclastic rocks Rocks formed by the compaction and cementation of quartz-rich mineral grains. Sandstone and shale are examples of siliciclastic rocks.

sorption The general process by which solutes, ions, and colloids become attached to solid matter.

study unit A major hydrologic system of the United States, geographically defined by surface- or groundwater features, in which U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program sampling studies are focused.

subsurface The region of earth materials beneath the land surface that encompasses the soil and unsaturated and saturated zones.

T

tile drain A drain installed to collect subsurface water and route it to a drainage ditch, stream, or wetland. Originally constructed using short segments of clay or cylindrical concrete

"tiles" and installed manually, modern tile drains typically are corrugated, perforated plastic pipes installed 3 to 6 feet below the soil surface by mechanical trenchers.

trace element An element found in only minor amounts (concentrations less than 1 milligram per liter) in water or sediment; includes arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc.

U

unconfined aquifer An aquifer that has a water table; an aquifer containing unconfined groundwater.

unsaturated zone A subsurface zone containing both water and air. The unsaturated zone is limited above by the land surface and below by the water table.

V

volatile organic compound (VOC) An organic chemical that has a high vapor pressure relative to its water solubility. VOCs include components of gasoline, fuel oils, lubricants, organic solvents, fumigants, some inert ingredients in pesticides, and some byproducts of chlorine disinfection.

vulnerability The tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. The vulnerability of a groundwater resource to contamination depends both on the intrinsic susceptibility of the resource and on the locations and types of human and geologic sources of contaminants, locations of wells, and the characteristics of the contaminant(s).

W

watershed The land area that drains into a particular stream, river, lake, estuary, or coastal zone.

water table The upper surface of the saturated zone below which all voids (spaces) are filled with water.

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Appendix 1. Study Components of the Northern Atlantic Coastal Plain Surficial Aquifer System

How does land use affect groundwater quality? How does water quality change as it moves through an aquifer? What is the quality of the drinking-water resource? National Water-Quality Assessment (NAWQA) Program groundwater assessments include different types of studies, specifically designed to answer questions such as these. The following is a brief listing of the various NAWQA studies. The general location of these studies and a description of each are shown in figure A1-1 and table A1-1.

- Land-use studies sampled water from water-table monitoring wells installed in urban and agricultural areas to assess the effects of these land uses on the quality of the underlying groundwater. Although not usually used for drinking, this water supplies recharge to deep parts of the aquifer system.
- Flow-path studies investigate how water quality changes as it moves along a groundwater flow path. Samples were collected from wells installed along a groundwater flow path.⁽¹⁾
- Major aquifer studies provide a broad overview of the quality of the deep parts of the aquifer system used for drinking-

water supply. Most of the wells sampled were domestic wells that were distributed across a large area in a mixture of land uses.

- Source-water quality assessment studies sampled water from public-supply wells to understand occurrence of unregulated manmade chemicals in the groundwater resources that serve large numbers of people.⁽⁹¹⁾

Results of these studies were reinforced by locating some of the studies within the boundaries of larger studies. For example, the recharge areas for flow-path studies were located within the boundaries of the land-use studies to provide information on the quality of the recharge. In turn, the boundaries of the land-use studies were located within the boundaries of the major aquifer studies to provide information on how the quality of the recharge affects that of the groundwater from the deep parts of the aquifer. Each study sampled water from a network of a few to as many as 30 wells. Data from these studies were available for the Principal Aquifer assessments.

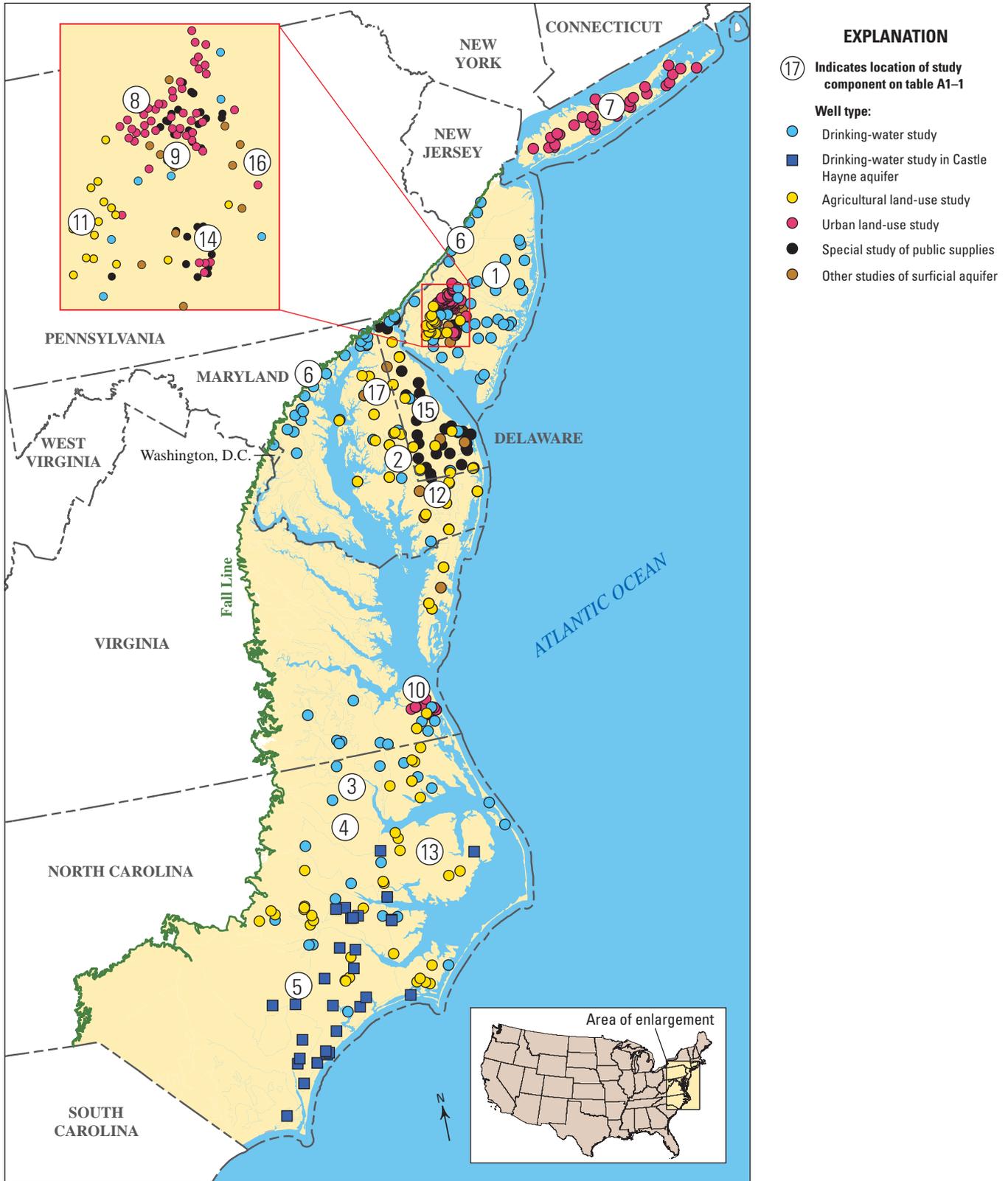


Figure A1-1. General location of components of the study of the Northern Atlantic Coastal Plain surficial aquifer.

Table A1–1. Study components of the Northern Atlantic Coastal Plain surficial aquifer system assessment.

[F, field parameters including water temperature, specific conductance, pH, alkalinity, and dissolved oxygen; M, major ions; N, nutrients; T, trace elements; P, pesticide compounds; V, volatile organic compounds; R, radon; RA, radium; PWS, public-supply wells; MON, monitoring wells; DOM, domestic wells; ft, feet]

Map number	Study location	Water-quality parameters	Year(s) sampled	Number of wells	Well types	Range of well depths (ft)
Drinking-water studies						
1	New Jersey	F,M,N,P,V,T	1998, 2002	33	DOM	38–175
2	Delmarva Peninsula	F,M,N,P,V,T,R	2001	29	DOM, MON	15–100
3	Virginia, North Carolina	F,M,N,P,V,T	1994, 2002	27	MON, DOM	5–75
4	North Carolina, confined wells	F,M,N,P,V,T	1994	6	PWS	329–612
5	North Carolina, Castle Hayne aquifer	F,M,N,P,V,T	2002–03	30	MON, DOM, PWS	22–240
6	New Jersey, Delaware, Maryland	F,M,N,P,V,T	2003–04	24	DOM, MON	41–155
Urban land-use studies						
7	Long Island, NY	F,M,N,P,V	2006	30	MON	12–96
8	New Jersey, Glassboro area	F,M,N,P,V	2005	28	MON	14–71
9	New Jersey, Glassboro area	F,M,N,P,V	1996, 1997	23	MON	5–51
10	Virginia Beach, VA	F,M,N,P,V	1995	14	MON	35–95
Agricultural land-use studies						
11	New Jersey, Glassboro area	F,M,N,P	1996	15	MON	19–61
12	Delmarva Peninsula	F,M,N,P	2001	29	MON, DOM	9–38
13	North Carolina	F,M,N,P	1994, 2002	49	MON, DOM	7–45
Special drinking-water studies						
14	New Jersey, Glassboro area	F,M,N,P,V,T	2007	15	PWS	173–775
15	Delaware, public-supply study	F,M,N,P,V,RA,R	2000	30	PWS	37–139
Other surficial aquifer studies						
16	New Jersey, forested area	F,M,N,P	1996	13	MON	9–32
17	Delmarva, NAWQA pilot study	F,M,N,P,T,R	1988	38	MON, DOM	29–38

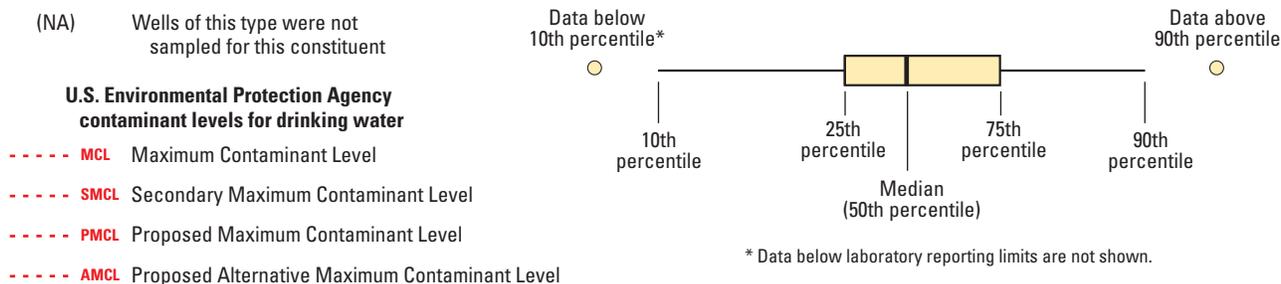
Appendix 2. Water-Quality Properties and Constituents Measured, a Summary of Data, and Complete Data Archive for 1988–2009

Water-quality properties and constituents measured and a summary of data for 1988–2009, including laboratory reporting levels and human-health benchmarks for drinking water, are presented only online. A data summary is available for download at <http://pubs.usgs.gov/circ/1353/> and includes appendix 2 and the table listed below. The complete data archive is included with the report that summarizes groundwater quality for many of the Nation's Principal Aquifers⁽²⁶⁾ and is available at <http://pubs.usgs.gov/circ/1360/>.

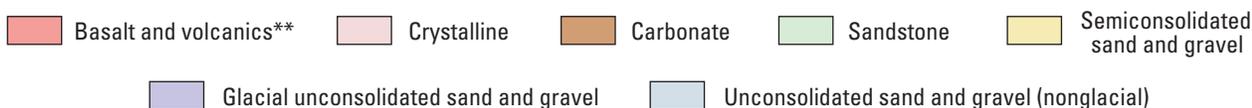
Table A2–1 Comprehensive list of water-quality properties and constituents analyzed in samples collected during 1988–2009 in the Northern Atlantic Coastal Plain surficial aquifer system, Delaware, Maryland, New Jersey, New York, North Carolina, and Virginia, including laboratory reporting levels and human-health benchmarks for drinking water.

Appendix 3. Water Quality of the Northern Atlantic Coastal Plain Surficial Aquifer System in a National Context

Principal Aquifer (number of samples)



Lithology

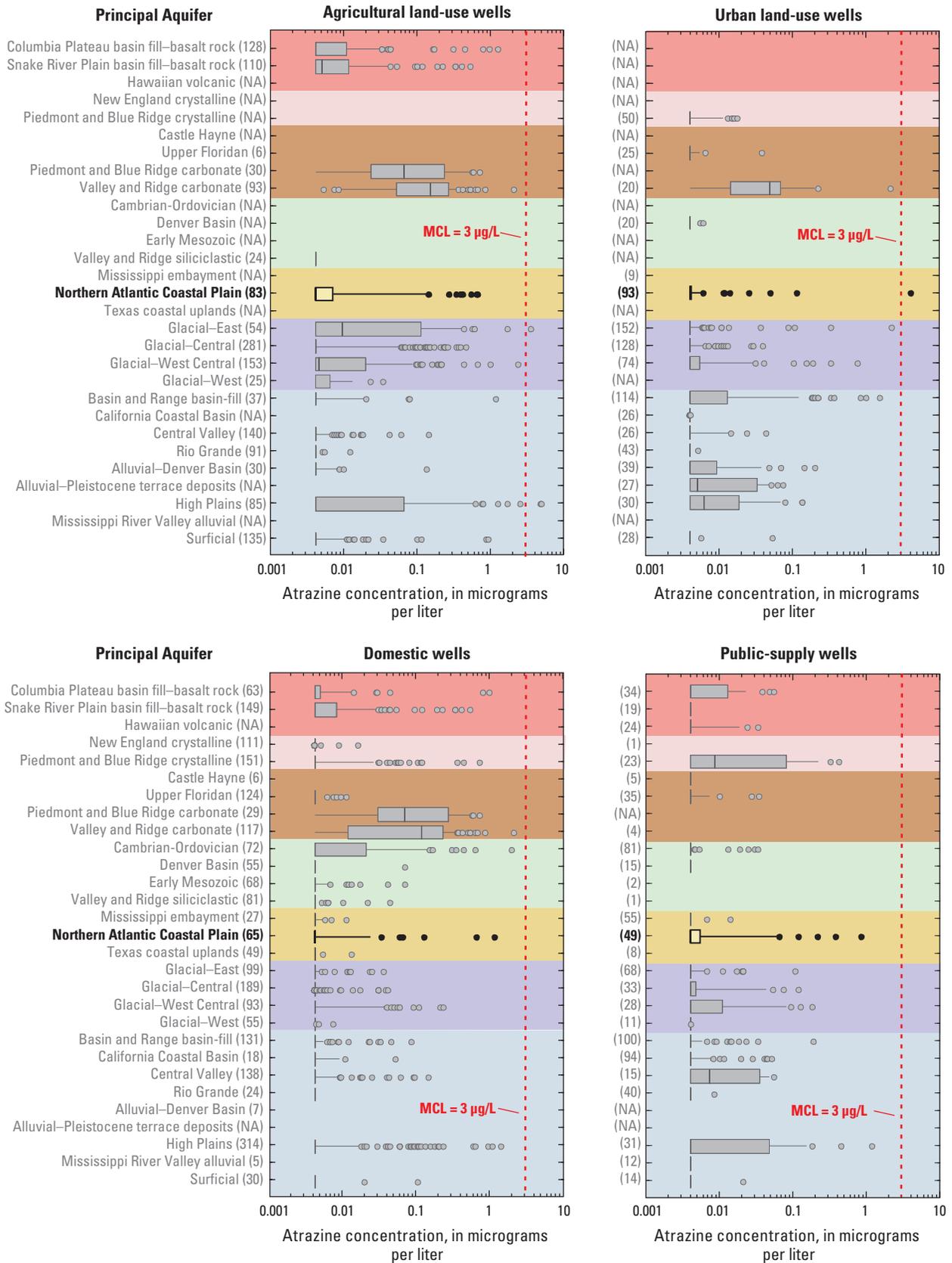


This appendix shows graphical comparisons of chemical concentrations (1991 to 2010) for selected inorganic and organic constituents of potential health or aquatic-life concern in selected Principal Aquifers of the United States. For each constituent, the concentration data are grouped according to five well types: agricultural land-use study wells (includes shallow agricultural monitoring wells), urban land-use study wells (includes shallow urban monitoring wells), major aquifer study wells, domestic wells, and public-supply wells. For each well type, the aquifers also are grouped according to aquifer lithology: basalt and volcanics,** crystalline, carbonate, sandstone, semiconsolidated sand and gravel, glacial unconsolidated sand and gravel, and unconsolidated sand and gravel (nonglacial).

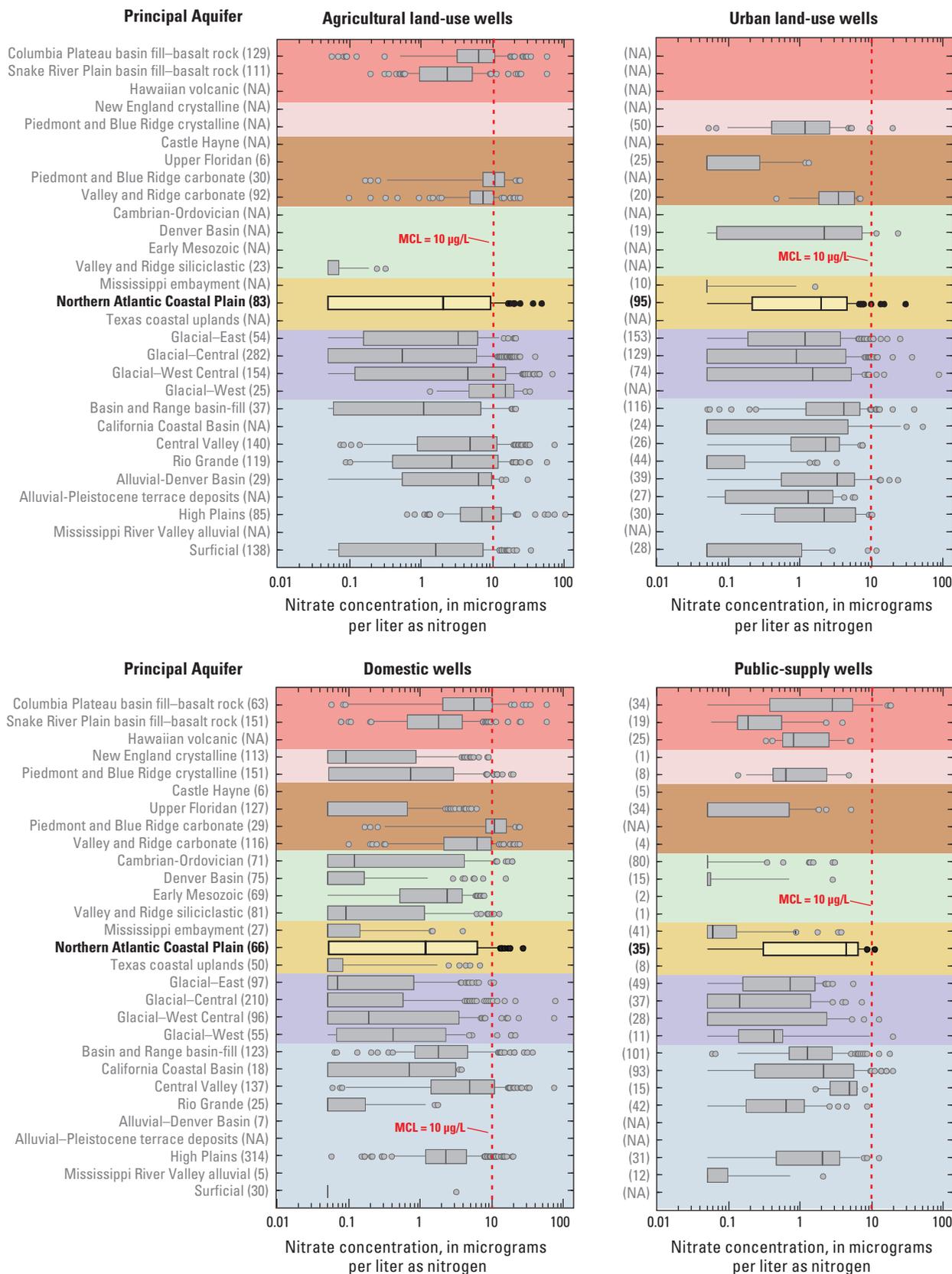
The number of samples for a constituent varies among Principal Aquifers, and data for a particular compound were not plotted if there were fewer than 10 samples for a Principal Aquifer. Not all Principal Aquifers for which data are available are shown. Note that analytical detection limits vary among the constituents. Boxplots are truncated at common assessment levels and data reported as non-detects or analytical values below common assessment levels are not shown. The data used in this appendix and boxplots for additional constituents are available at <http://pubs.usgs.gov/circ/1360/>.

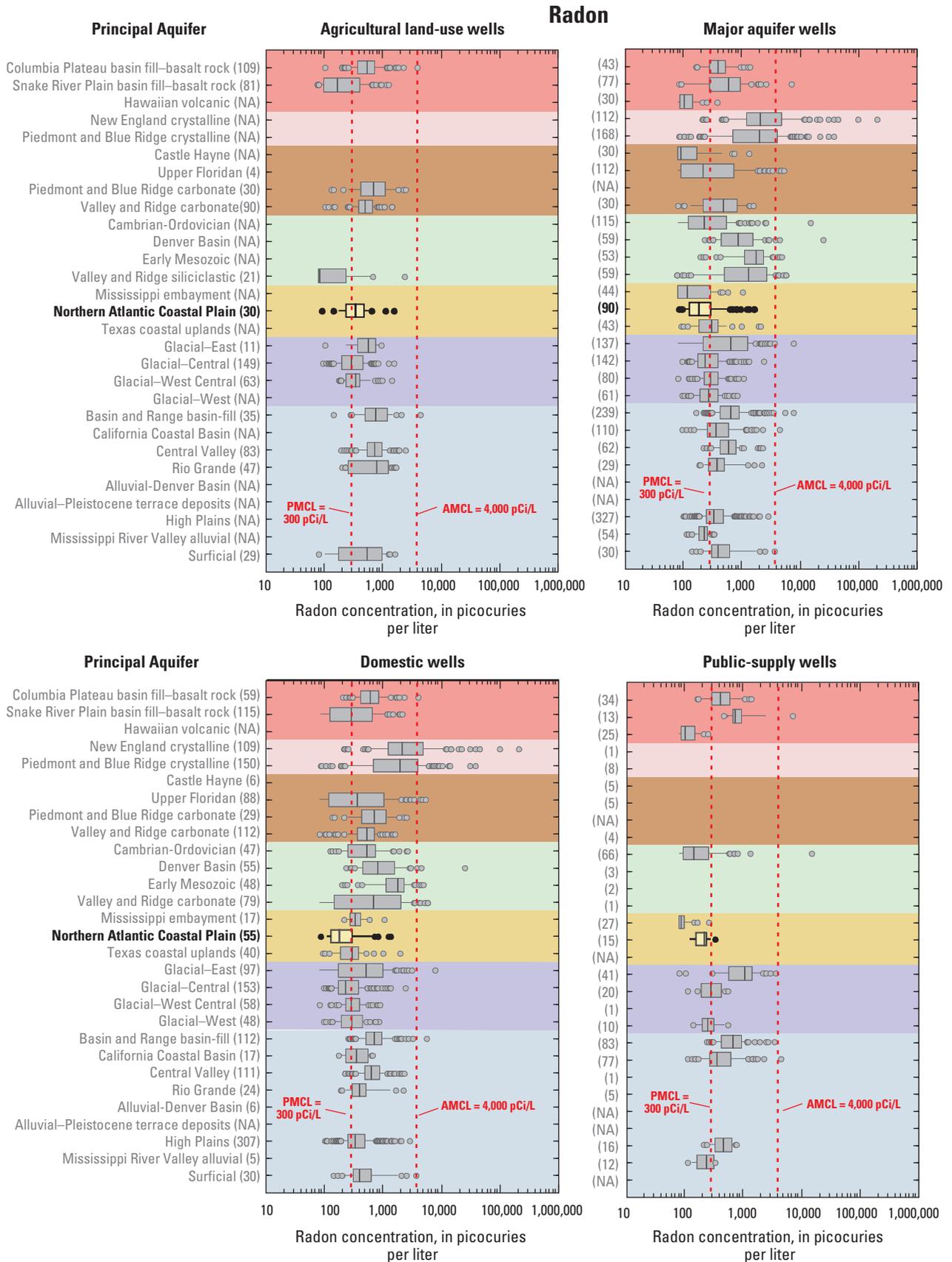
** Note: Two of the Principal Aquifers in this group include limited samples from basin-fill aquifers within the extent of the basaltic aquifer.

Atrazine



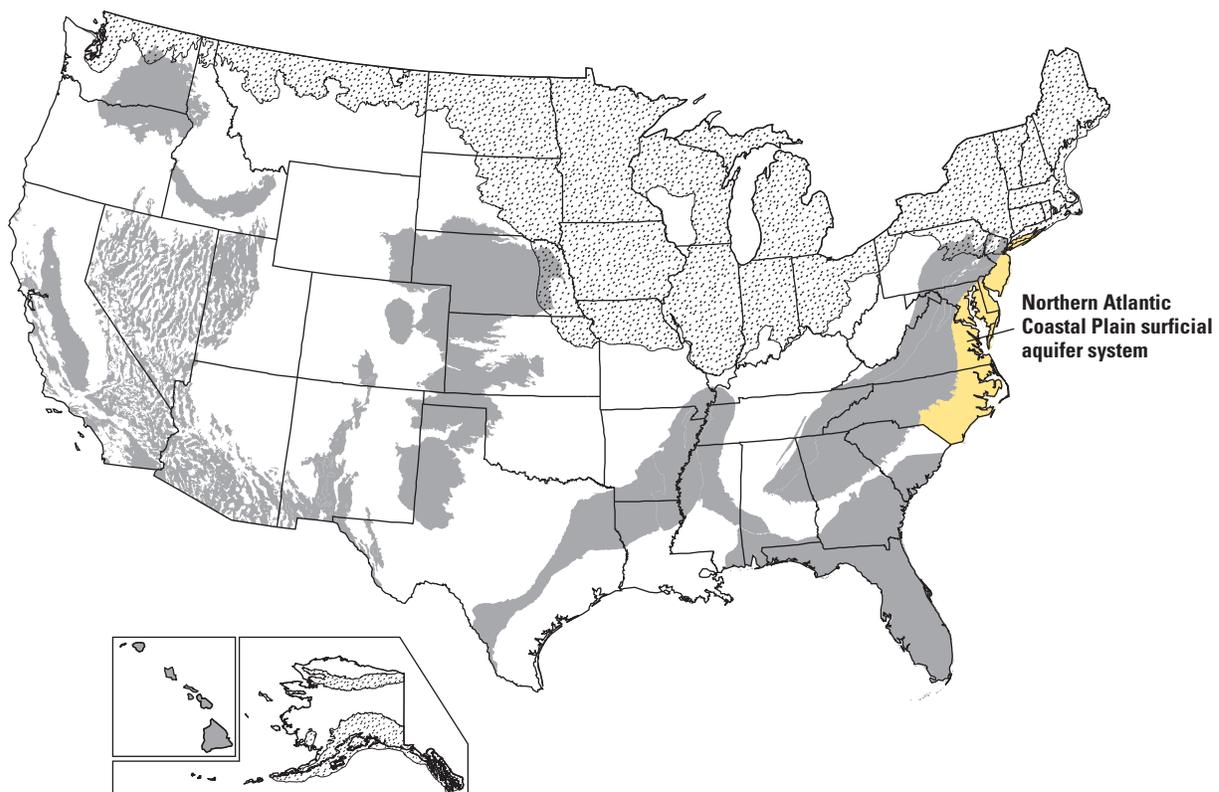
Nitrate plus nitrite (nitrate)





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