# Water Quality in the Lower Susquehanna River Basin

## Pennsylvania and Maryland, 1992–95

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

Circular 1168

## A COORDINATED EFFORT

*Coordination among agencies and organizations is an integral part of the NAWQA Program. We thank the following agencies and organizations who contributed to the design of the studies and helped to review data presented in this report:*

•Academy of Natural Sciences
•Alliance for the Chesapeake Bay
•Maryland Department of the Environment
•Maryland Geological Survey
•Pennsylvania Department of Agriculture
•Pennsylvania Department of Environmental Protection
•Pennsylvania Department of Conservation and Natural Resources
•Pennsylvania Fish and Boat Commission
•Pennsylvania State University—Environmental Resources Research Institute
•Susquehanna River Basin Commission
•Tri-County Regional Planning Commission
•U.S. Army Corps of Engineers
•U.S Environmental Protection Agency
•U.S. Department of Agriculture—Agricultural Research Service
•U.S. Department of Agriculture—Natural Resources Conservation Service
•U.S. Fish and Wildlife Service—Division of Ecological Services
•University of Maryland—Water Resources Research Center

*This report summarizes work by a number of dedicated USGS scientists and technicians. It was based, in part, on USGS reports written by the following authors:* **Scott W. Ator, Mark R. Beaver, Tammy M. Bickford, Matthew H. Daly, Andrew J. Gavin, Robert A. Hainly, Joan M. Kahn, Connie A. Loper, Dennis W. Risser, and Steven F. Siwiec.** *The following are names of additional USGS personnel responsible for implementing the NAWQA Program in the Lower Susquehanna River Basin:* **Steven J. Bogush, Jodi S. Brandt, Harry L. Campbell III, Erika J. Clesceri, Christina L. Harwood, Christine M. Herbert, Scott A. Hoffman, Michael D. Lichte, Jonathan A. Peahl, David M. Pennise, Christine A. Sanderson, Steven J. Semick, and Naomi J. Weisbeker.** *This report was edited by* **Kim L. Wetzel, Robert J. Olmstead, Edward J. Swibas, Michael Eberle, Betty Palcsak, and Chester Zenone.** *The manuscript was prepared by* **Kim L. Shank.** *The tables on pages 30-34 were designed and built by* **Sarah Ryker, Jonathan Scott, and Alan Haggland.**

Front cover photograph: An aerial view looking north showing the Susquehanna River at Harrisburg, Pa. The Harrisburg metropolitan area is part of a rapidly developing corridor of historically agricultural land through the middle of the study area. Harrisburg is situated in the Great Valley Section of the Ridge and Valley Physiographic Province. (Reprinted from Alan R. Wycheck and published with permission.)

Back cover photographs: Agricultural settings in the Lower Susquehanna River Basin (left to right)—Bachman Run flowing through a part of the Lebanon Valley, Lebanon County, Pa.; Cumberland Valley in Cumberland County, Pa. (Reprinted from Harrisburg-Hershey-Carlisle Tourism and Convention Bureau and published with permission); Penns Creek Valley in Centre County, Pa. (by Albert E. Becher).

## FOR ADDITIONAL INFORMATION ON THE NATIONAL WATER-QUALITY ASSESSMENT (NAWQA) PROGRAM:

Lower Susquehanna River Basin
Study Unit, contact:
District Chief
U.S. Geological Survey
Water Resources Division
840 Market Street
Lemoyne, PA 17043-1584

Chief, NAWQA Program
U.S. Geological Survey
Water Resources Division
12201 Sunrise Valley Drive, M.S. 413
Reston, VA 20192

Information on the NAWQA Program is also available on the Internet via the World Wide Web.
You may connect to the NAWQA Home Page using the Universal Resources Locator (URL):
*http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html*

The Lower Susquehanna Study Unit's Home Page is at URL:
*http://wwwpah2o.er.usgs.gov/projects/lsus/*

# Water Quality in the Lower Susquehanna River Basin, Pennsylvania and Maryland, 1992-95

*By Bruce D. Lindsey, Kevin J. Breen, Michael D. Bilger, and Robin A. Brightbill*

U.S. GEOLOGICAL SURVEY CIRCULAR 1168

CONTENTS

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Thomas J. Casadevall, Acting Director

The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Government

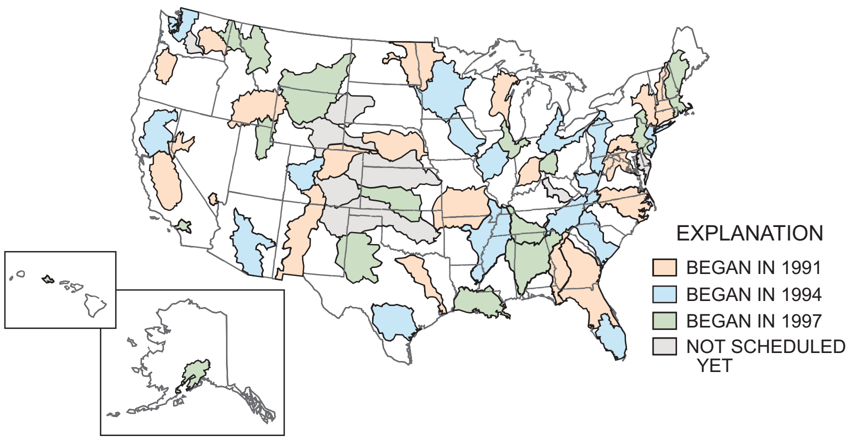
---

1998

Free on application to the
U.S. Geological Survey
Information Services
Box 25286 Federal Center
Denver, CO 80225

**Library of Congress Cataloging in Publications Data**

Water quality in the lower Susquehanna River Basin, Pennsylvania and
Maryland : 1992-95 / by Bruce D. Lindsey ... [et.al.].
p. cm. -- (U.S. Geological Survey circular ; 1168)
ISBN 0-607-89155-6
1. Water quality--Susquehanna River Watershed. I. Lindsey, Bruce
D., 1962- . II. Series.
TD225.S895W38 1998
363.739'42'09748--dc21 98-11347
CIP




Knowledge of the quality of the Nation's streams and aquifers is important because of the implications to human and aquatic health and because of the significant costs associated with decisions involving land and water management, conservation, and regulation. In 1991, the U.S. Congress appropriated funds for the U.S. Geological Survey (USGS) to begin the National Water-Quality Assessment (NAWQA) Program to help meet the continuing need for sound, scientific information on the areal extent of the water-quality problems, how these problems are changing with time, and an understanding of the effects of human actions and natural factors on water-quality conditions.

The NAWQA Program is assessing the water-quality conditions of more than 50 of the Nation's largest river basins and aquifers, known as Study Units. Collectively, these Study Units cover about one-half of the United States and include sources of drinking water used by about 70 percent of the U.S. Population. Comprehensive assessments of about one-third of the Study Units are ongoing at a given time. Each Study Unit is scheduled to be revisited every decade to evaluate changes in water-quality conditions. NAWQA assessments rely heavily on existing information collected by the USGS and many other agencies as well as the use of nationally consistent study designs and methods of sampling and analysis. Such consistency simultaneously provides information about the status and trends in water-quality conditions in a particular stream or aquifer and, more importantly, provides the basis to make comparisons among watersheds and improve our understanding of the factors that affect water-quality conditions regionally and nationally.

This report is intended to summarize major findings that emerged between 1992 and 1995 from the water-quality assessment of the Lower Susquehanna River Basin Study Unit and to relate these findings to water-quality issues of regional and national concern. The information is primarily intended for those who are involved in water-resource management. Indeed, this report addresses many of the concerns raised by regulators, water-utility managers, industry representatives, and other scientists, engineers, public officials, and members of stakeholder groups who provided advice and input to the USGS during this NAWQA Study-Unit investigation. Yet, the information contained here may also interest those who simply wish to know more about the quality of water in the rivers and aquifers in the area where they live.

Robert M. Hirsch

Robert M. Hirsch, Chief Hydrologist

**"Actual water-quality data shows us where our efforts to protect the environment are successful and what still needs to be done to prevent pollution. We depend on this valuable partnership with the U.S. Geological Survey, in cooperation with our communities, as we continue our work to protect and restore Pennsylvania's watersheds."**

***James M. Seif
Secretary,
Pennsylvania
Department of
Environmental
Protection***

**"Because the Susquehanna River provides 90 percent of the freshwater flow to the upper Chesapeake Bay, maintaining and improving water quality in the river is key to the bay restoration efforts. We hope this report will be used by government, industries, and others to improve water quality in the river, as well as the bay."**

***Paul O. Swartz
Executive Director,
Susquehanna River
Basin Commission***


**Water from 30 percent of the wells sampled and about 20 percent of the streams sampled would exceed the U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) for nitrate-nitrogen of 10 mg/L as N (milligrams per liter as nitrogen) if not properly treated before use as drinking water (p. 8).**

- Water from wells in agricultural areas underlain by limestone and crystalline bedrock commonly exceeded the USEPA MCL for nitrate in drinking water. Water from wells in urban areas underlain by limestone bedrock and in forested and agricultural areas underlain by sandstone and shale had nitrate concentrations that seldom exceeded the MCL.
- Streams in agricultural areas underlain by limestone had nitrate concentrations that, if not lessened by appropriate treatment before use as drinking water, commonly would exceed the USEPA MCL. Streams in other areas did not.
- The highest nitrate concentrations in streams were generally in the winter and spring.

**Nitrate concentrations in the Susquehanna River at Harrisburg were generally less than 2 mg/L, which is considerably below the MCL for nitrate in drinking water of 10 mg/L (discussed above) (p. 8).**

- Concentrations of nitrate at these levels, when multiplied by the large flows of the Susquehanna River, contributed large amounts of nitrate to the Chesapeake Bay when compared to other rivers entering the bay.
- Streams from agricultural areas underlain by limestone bedrock contributed large amounts of nitrate per unit area to the Lower Susquehanna River when compared to streams in areas with other land uses and bedrock types.

**The main nitrogen source in the Study Unit is animal manure used as an agricultural fertilizer (p. 9).**

- The data collected in this study provide a baseline to evaluate the effectiveness of the Pennsylvania Nutrient Management law, which requires concentrated animal operations to develop and have approved nutrient-management plans by 1998.
- Manure-application rate may be the most important factor controlling nitrate concentrations in streams in agricultural basins underlain by limestone.

**The concentration of total nitrogen in the Susquehanna River's inflow to the Chesapeake Bay has decreased in the 1985-96 time period (p. 11).**

- The concentration of nitrate (one component of total nitrogen) has remained unchanged during this period.
- The specific environmental circumstances that would explain the lack of change in nitrate concentration during a time of downward trends in total nitrogen could be related to the nitrate in streams that originates in ground water or to other nonpoint sources.

**Concentrations of pesticides in water from the wells and streams sampled rarely exceeded levels established as drinking-water standards (p. 12-14).**

- Although drinking-water standards, human-health advisory levels, and aquatic-life criteria were rarely exceeded, these criteria have not been established for many of the pesticides that were sampled for. In addition, mixtures and degradation products were not considered in developing the human-health criteria. Therefore, only a limited range of potential effects of the occurrence of pesticides in drinking water has been assessed.
- On the basis of analyses of 577 samples collected from 169 shallow wells and 155 streams, pesticides were frequently detected in ground water and streams; usually, more than one pesticide was detected at a time. More than 60 percent of well-water samples in which pesticides were present contained more than one detectable pesticide.
- The most commonly detected pesticides were the herbicides used primarily on corn: atrazine, metolachlor, simazine, prometon, alachlor, and cyanazine.
- Detections of pesticides in water were related to pesticide use, pesticide-leaching potential, and bedrock type. Pesticides were most likely to be detected in samples from agricultural and urban areas. Limestone areas were far more likely to have pesticides in well water than areas underlain by sandstone and shale.
- Seasonal variations in pesticide concentrations in water from streams are affected by the timing of pesticide application and the type of bedrock. The highest concentrations of pesticides in streams were seasonal pulses lasting up to several months.
- Concentrations of pesticides in the Susquehanna River were generally less than 1 part per billion. The pesticides detected in the Susquehanna River were similar to those detected in water from streams in agricultural areas throughout the Lower Susquehanna River Basin.

**Total coliform bacteria were detected in water from nearly 70 percent of the household wells sampled, indicating that the water should not be used for drinking without treatment (p. 15).**

- Fecal coliform and *Escherichia coli*, bacteria that indicate contamination from human or animal feces, were detected in water from 25 and 30 percent, respectively, of the wells tested.
- Few household wells from which water was sampled were grouted, and few had sealed, sanitary caps at the top of the casing. Lack of these protective features can enable the entry of bacteria into well water. It is uncertain whether bacteriological contamination of well water is caused by inadequate protection of wells from surface runoff, septic-system failure, application of animal manure to fields, or other causes.
- The presence of bacteria in water from rural wells is one of the most important water-quality issues related to human health in the Study Unit.

**None of the concentrations of the volatile organic compounds detected in samples from wells used as drinking-water supplies exceeded the MCLs or Lifetime Health Advisory Levels established by the USEPA (p. 16).**

- In the Great Valley near Harrisburg, Pa., volatile organic compounds were detected more frequently in an urban area than in an agricultural area.

**Radon, a product of the radioactive decay of uranium, is present in ground water throughout the Lower Susquehanna River Basin (p. 17).**

- Radon activities in 86 percent of the 165 ground-water samples tested for radon were greater than a previously proposed standard, now under review by the USEPA, of 300 pCi/L (picocuries per liter, a measurement of radioactivity).
- More than 30 percent of the 165 ground-water samples tested for radon contained radon at activities greater than 1,000 pCi/L. The area of the Study Unit underlain by crystalline rocks of the Piedmont Physiographic Province had the highest median ground-water radon activities, but variation in radon activities within most subunits is large.

**Correlations were found between the concentrations of trace elements in streambed sediments and the concentrations in livers of bottom-feeding fish for only 3 of 11 elements regarded as common contaminants (p. 18).**

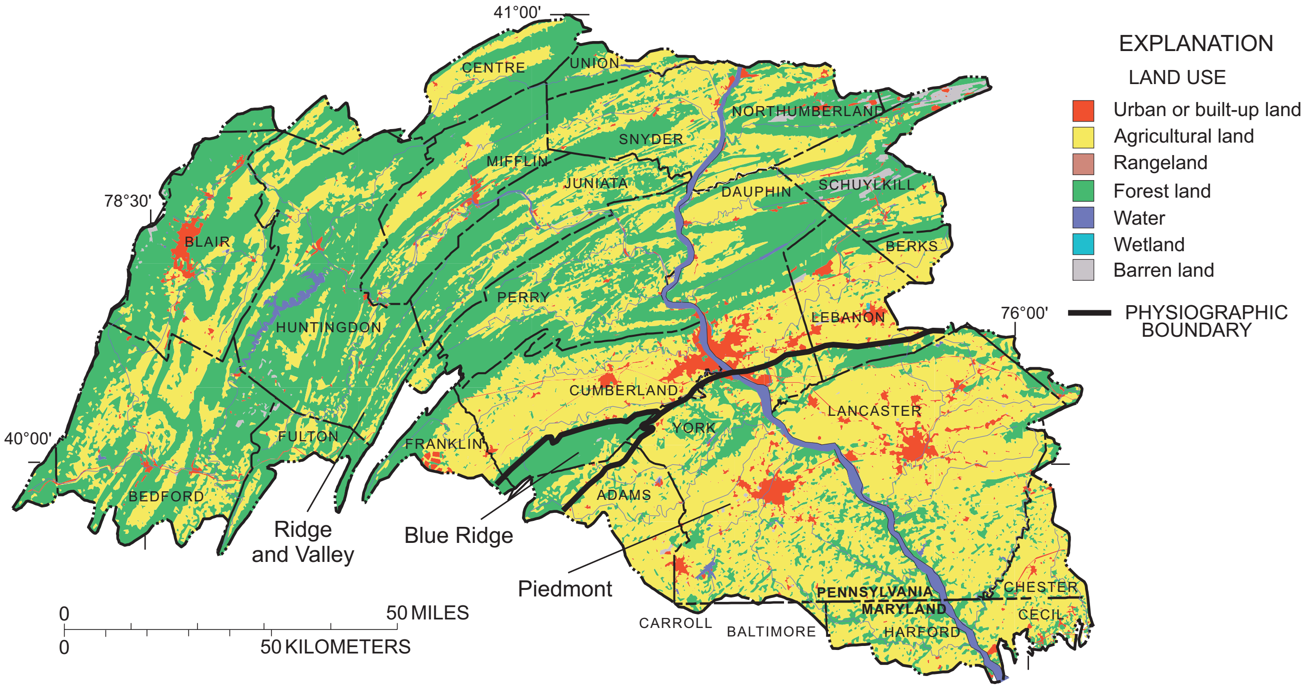
- The highest concentrations of arsenic, beryllium, cadmium, cobalt, iron, manganese, nickel, selenium, and zinc in streambed sediments were at sites affected by mine drainage.

**No organic contaminants were detected in whole fish at levels considered harmful to human health; however, some contaminants in streambed sediment were detected at levels harmful to aquatic life (p. 19-21).**

- Organic compounds were detected in whole-body fish tissue and streambed sediment at all 20 sites sampled, which represented a variety of settings. Of the 28 compounds analyzed for, 12 were detected. Although some of the detected compounds are known human health risks, an interagency work group on fish-tissue contaminants reviewed the data collected by the USGS, compared the data to U.S. Food and Drug Administration action levels, and concluded that no public health advisories were warranted for the fish species (white sucker or smallmouth bass) collected at any of the sampling sites.
- PCBs in fish tissue were associated with urban and industrial land use. DDT and chlordane and their degradation products in fish tissue showed an association with agricultural land use.
- The fish-tissue data indicate that DDT and chlordane have degraded over time and that no recent influx of these compounds has occurred. At four sites, concentrations of total DDT or total chlordane in streambed sediment exceeded USEPA Tier 1 guidelines for protection of aquatic life. Tier 1 guidelines for total PCBs were not exceeded at any of the sites.
- Concentrations of semivolatile organic compounds in streambed sediment exceeded the USEPA Tier 1 guidelines for protection of aquatic life at 4 of the 21 sites.

**Fish communities inhabiting the seven streams in long-term monitoring basins were related to the bedrock type (p. 22-23).**

- The habitat characteristics that proved most influential in defining fish communities were mean channel width, mean water temperature, mean canopy angle, and suspended sediment.
- Fish populations were healthier in the three freestone streams than in the four limestone streams. The fish population was influenced by agricultural activity in the agricultural settings, but the influence of agriculture on fish communities is related to habitat degradation rather than nutrients in the water.

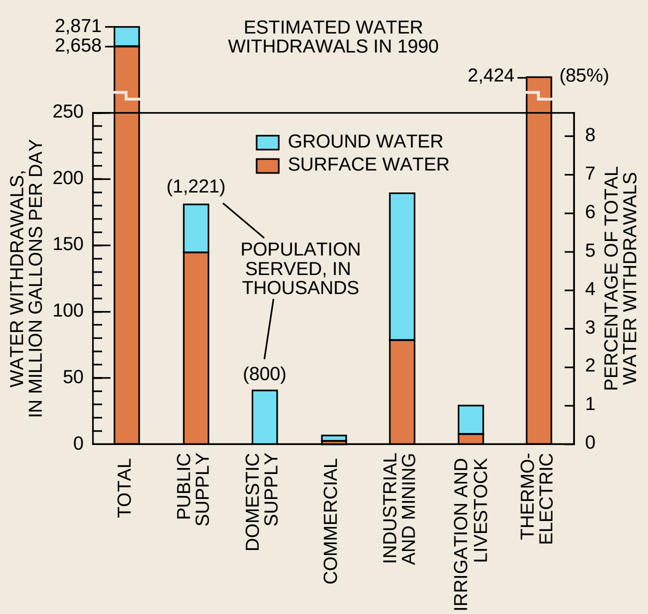



Agricultural activity on the land surface is one important factor affecting water quality in the Lower Susquehanna River Basin.

In the Lower Susquehanna River Basin Study Unit, land use is 47 percent agricultural, 47 percent forested, and 4 percent urban; 2 percent of the area is water bodies or barren land (Mitchell and others, 1977; see map above). The well-drained areas with rolling hills and valleys in the southern part of the basin contain most of the population and some of the most productive agricultural land in the Nation. These agricultural and urban areas commonly are areas underlain by carbonate (limestone) bedrock.

The study area was subdivided on the basis of land use, physiography, and bedrock type to assess the effect of these characteristics on water quality.

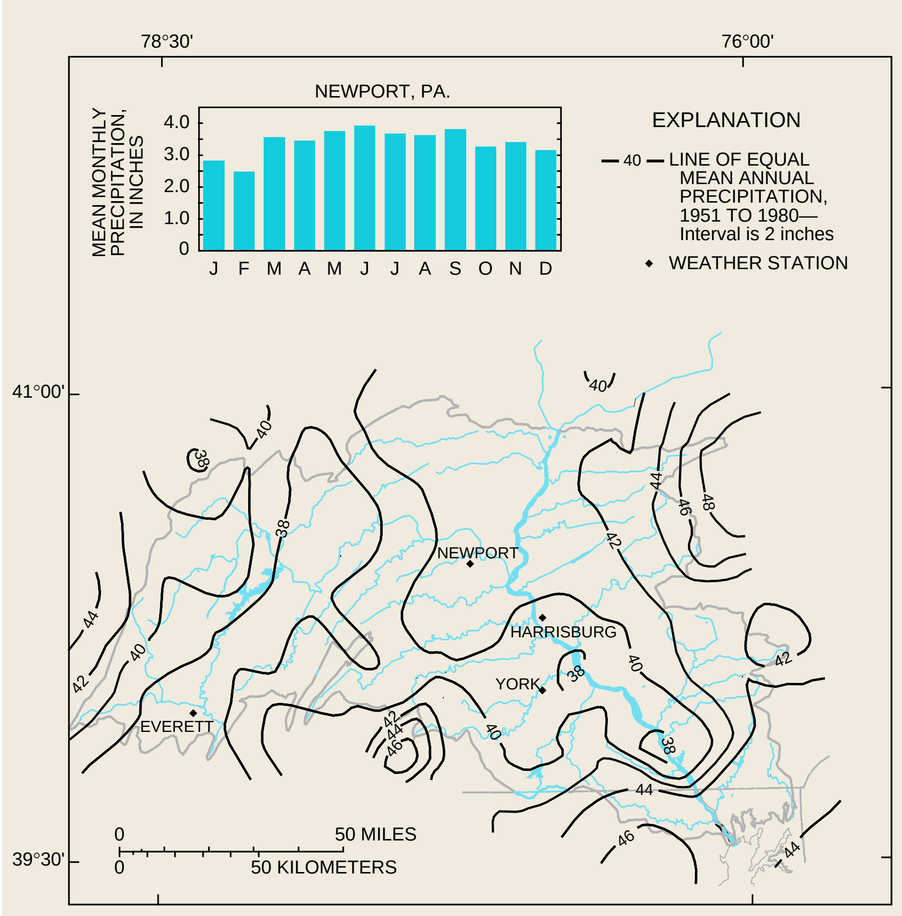
Thermoelectric, public supply, and industrial and mining are the largest water uses in the Lower Susquehanna River Basin. Rural homeowners depend chiefly on ground water for domestic supply.




Major water issues in the Study Unit include the effects of agricultural land use on water quality and ground-water contamination in areas underlain by limestone bedrock. These issues were used to prioritize the selection of major environmental settings for study (Risser and Siwiec, 1996).

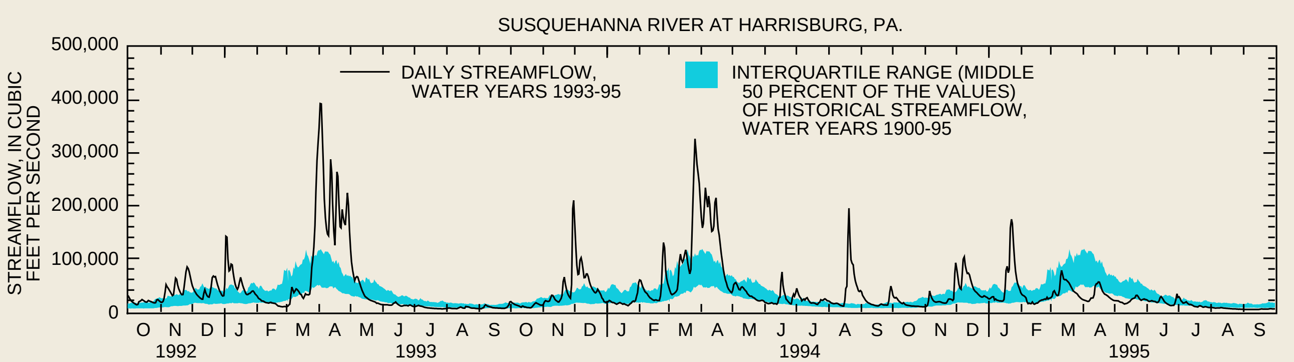
Water used for public supply is largely from surface water, and only about 25 percent of the water used for public supply comes from ground-water sources (see graph at left). In 1990, more than 1.2 million people used public-supplied water. In addition, 800,000 rural homeowners depended on water from wells for domestic (household) supply. Thermoelectric cooling, industrial and mining, and public-supply withdrawals are the major uses of water. Withdrawals for thermoelectric cooling are much greater than withdrawals for other uses. The water-quality degradation in return flows from water used for cooling primarily involves increases in water temperature.

Mean annual precipitation in the Lower Susquehanna River Basin Study Unit ranges from 38 to 48 inches (see figure at right). The precipitation is generally less in the center of the basin because of storm patterns; however, the entire Study Unit receives enough rainfall so that irrigation is not common except in periods of drought. The precipitation is distributed fairly evenly throughout the year. About 45 percent of the precipitation is contributed by storms in May through September during the growing season, and much of this precipitation is used by plants. Most of the remaining 55 percent occurs when vegetation is dormant; therefore, this precipitation is more available to infiltrate into bedrock and enter ground-water systems.




The Lower Susquehanna River Basin has a temperate climate, with adequate precipitation for the crops grown in the area. (Modified from Risser and Siwiec, 1996.)

The hydrologic conditions during the study were variable, including wet and dry years. This information is important in the interpretation of the water-quality data collected. For example, the nitrate loads were calculated for 1994, a wet year, and may provide a higher estimate for loads than would have been calculated during a year with more normal flow. The spring of 1993 and 1994 and the summer of 1994 were periods of greater than normal precipitation and streamflow (see figure below). Heavy winter snowstorms in these years caused high flows in the spring. The snowmelt from the winter of 1993 caused a record high average streamflow of 250,100 cubic feet per second from the Susquehanna River to the Chesapeake Bay during April of that year. Higher than normal flows were observed throughout 1994, when streamflow in the Susquehanna River at Harrisburg was 42 percent greater than normal. The summer of 1993 and most of 1995 were dry periods. Drought declarations were in effect for most of the counties in the Study Unit in September 1995.




Higher than normal flows were observed throughout 1994, when streamflow in the Susquehanna River at Harrisburg was 42 percent greater than normal. Drought declarations were in effect for most of the counties in the Study Unit in September 1995.

Water quality in the Lower Susquehanna River Basin is affected by diverse geologic conditions and land-use factors. The intense agricultural activity, in conjunction with the importance of the Lower Susquehanna River Basin as a major source of freshwater to the Chesapeake Bay, makes runoff of nitrogen one of the most important water-quality issues. Contamination of stream water and ground water by pesticides and other organic chemicals, which are used in agricultural and urban areas, is another important issue. Much of the rural population, which relies on ground water for household water supply, is in areas underlain by limestone bedrock. The shallow limestone aquifers in valleys of primarily agricultural land use are vulnerable to contamination by activities on the land surface. The effect of urban and mining land uses on water quality are also important issues.

Drinking-water standards (U.S. Environmental Protection Agency, 1996a) apply only to waters used for public supply that have been filtered and treated (finished water). The NAWQA Program is designed to assess natural waters, not finished waters. The standards were only used in this report to place the observed concentrations in samples from wells used as household drinking-water supplies and samples from streams into a common frame of reference. Aquatic-life criteria (U.S. Environmental Protection Agency, 1996b) and other measures were used to assess the ecological health of the streams. Selected ecological data for invertebrates and algae have not been analyzed and are not included in the major findings. Major findings for nutrients, pesticides, selected contaminants in ground water, contaminants in fish tissue and streambed sediment, fish-community structure and health, and stream habitat are presented to illustrate the quality of the water resources.

The study was designed to address natural and human factors affecting water quality. The design was an integrated assessment of water quality including stream-water chemistry, stream-water ecology, and ground-water chemistry. Some assessments involved large geographic areas of the Study Unit (basinwide studies), whereas other assessments focused on specific environmental settings (subunit studies). From the 14 major environmental settings based on land use, bedrock type, and physiography, 7 subunits (see table below and map on page 7) were selected to provide the basis for assessing the effects of land use and bedrock type on water quality.

Long-term monitoring sites (see table below and map on page 7) were established in one stream in each of the seven subunits to evaluate the temporal variation in stream-water chemistry and ecology. To assess stream-water chemistry, samples were collected monthly to weekly at each of the seven long-term monitoring sites for a total of 316 samples over the study period. Most of the samples were collected when flow was low and dominated by ground water (base flow). Relatively few stormflow samples were collected at the long-term monitoring sites; therefore, issues such as the transport of phosphorus and ammonia, which are predominantly transported during storms, cannot be assessed. The first 3 years of data collection are not sufficient to detect trends in the water-quality conditions, but these data serve as a baseline for future studies. Detailed ecological studies of fish, invertebrates, and algae also took place at each of these seven long-term monitoring sites. The structure and health of the fish community were assessed, and characteristics of the stream habitat were analyzed.

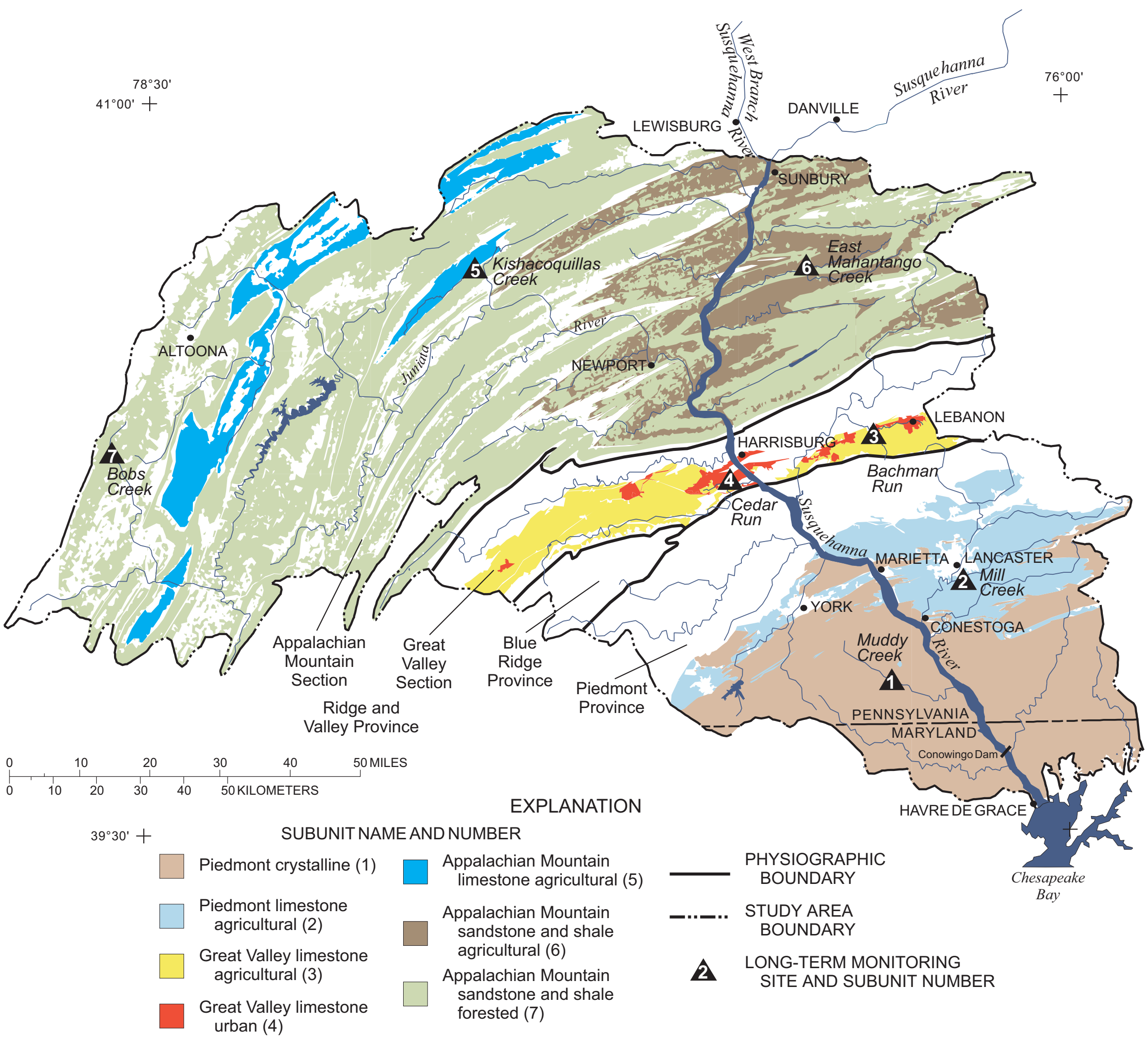
Basinwide studies were done to determine ecological conditions and the occurrence of contaminants. Streambed-sediment samples were collected at 21 sites, and fish-tissue samples were collected at 20 sites. These sites (see map on page 28) included all of the long-term monitoring sites except for Bobs Creek and Cedar Run. Studies of biological communities and stream habitat were done at an additional 45 sites (see map on page 28).

| Environmental subunit name and number | Physiographic province (section) | Bedrock type | Dominant land use | Long-term monitoring basin (stream type) | Ground-water study type |
|---|---|---|---|---|---|
| **Piedmont crystalline (1)** | Piedmont | Igneous and metamorphic (crystalline) | Agriculture | Muddy Creek (freestone) | Subunit survey |
| **Piedmont limestone agricultural (2)** | Piedmont | Limestone and dolomite | Agriculture | Mill Creek (limestone) | Land-use study |
| **Great Valley limestone agricultural (3)** | Ridge & Valley (Great Valley) | Limestone and dolomite | Agriculture | Bachman Run (limestone) | Land-use study |
| **Great Valley limestone urban (4)** | Ridge & Valley (Great Valley) | Limestone and dolomite | Urban | Cedar Run (limestone) | Land-use study |
| **Appalachian Mountain limestone agricultural (5)** | Ridge & Valley (Appalachian Mountain) | Limestone and dolomite | Agriculture | Kishacoquillas Creek (limestone) | Land-use study |
| **Appalachian Mountain sandstone and shale agricultural (6)** | Ridge & Valley (Appalachian Mountain) | Sandstone and shale | Agriculture | East Mahantango Creek (freestone) | Subunit survey |
| **Appalachian Mountain sandstone and shale forested (7)** | Ridge & Valley (Appalachian Mountain) | Sandstone and shale | Forest | Bobs Creek (freestone) | Sampled as part of subunit 6 survey |

Synoptic studies were done to evaluate the conditions of a selected area during a specific time period. Subunit studies also enhanced the understanding of processes such as those that influence the relation between ground-water quality and stream-water quality. The subunit-synoptic sampling sites were located within the colored areas on the map below; individual sites for ground-water and stream-water synoptic studies are shown on the site maps on page 28. Wells or streams within the subunits were sampled to determine the variations in water quality among areas of different bedrock type, land use, and physiography. Synoptic studies of stream-water chemistry took place at 187 sites and were focused geographically on individual subunits or on basinwide issues.

Synoptic studies of the chemical and bacterial quality of ground water were done in the subunits by collecting well-water samples at 169 sites. Ground-water sampling was done as a land-use study (collecting samples from an area of a single land-use type) or as a subunit survey (collecting samples from all land uses within a selected aquifer). The sandstone and shale subunit survey was limited geographically to the eastern area of the basin and included parts of the forested and agricultural subunits. Only six subunit-synoptic studies of ground water were done. For data-analysis purposes, however, the samples from the forested and agricultural areas of the sandstone and shale subunit survey were considered separately to allow comparisons to the seven surface-water subunits. Not all issues were studied in each subunit; for example, bacteriological studies were not done in the urban subunit. Moreover, not all analyses were done at each of the 169 sites, so the number of samples available for data analysis varies.

An outline of the sampling plans is given in the table on page 29. Details of the sampling for studies of water quality are given in Siwiec and others (1997). Data from this study are published in Durlin and Schaffstall (1994, 1996, 1997).




The study design was based on a combination of land use, physiography, and bedrock type. This map and table (page 6) illustrate and describe the subunits that formed the basis of the study. The subunits are the colored areas; streams used as long-term monitoring basins are labeled.

Wells and streams in the Lower Susquehanna River Basin Study Unit were sampled, and the waters were analyzed for nitrate and other forms of nitrogen. Nitrate was the dominant form of nitrogen in the water. Nitrate was detected in 98 percent of the samples, and 92 percent had concentrations of nitrate that were above 0.3 mg/L (milligram per liter as N, or part per million). In addition to human health effects of drinking water with nitrate concentrations greater than 10 mg/L, nitrate can stimulate excessive growth of algae in lakes and streams at concentrations as low as 0.3 mg/L. The nitrate studies focused on describing the concentrations in seven major subunits (Lindsey, Loper, and Hainly, 1997). Nitrate analyses from 161 wells and 156 stream sites were completed for this study. Data from other studies of nitrogen in the Susquehanna River (Hainly and Loper, 1997) were used to supplement USGS data to describe trends in concentrations.

## Spatial Distribution of Nitrate Concentrations

*Water from 30 percent of the wells sampled and about 20 percent of the streams sampled would exceed the U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) for nitrate-nitrogen of 10 mg/L if not properly treated before use as drinking water.* Most of the samples representing sources of drinking water were the samples collected from wells used for household supply. Ground waters in agricultural areas were most likely to have nitrate concentrations that exceeded drinking-water standards, though not all agricultural areas were the same. Land use and bedrock type accounted for most of the variation in nitrate concentrations in ground water (see graph on page 9). *Ground-water nitrate concentrations were highest in agricultural areas underlain by limestone, where 45 percent of the samples exceeded the MCL. Waters from 36 percent of the wells in agricultural areas underlain by crystalline bedrock also had nitrate concentrations greater than 10 mg/L. Water from wells in urban areas underlain by limestone and in forested and agricultural areas underlain by sandstone and shale had nitrate concentrations that seldom exceeded the MCL.*

**Nitrate in drinking water at levels in excess of 10 mg/L can result in methemoglobinemia (blue-baby syndrome) in bottle-fed infants up to 6 months old. The Centers for Disease Control and Prevention (1996) studied several cases in Indiana where pregnant women who were drinking water with nitrate concentrations in the range of 20 to 30 mg/L had multiple miscarriages. The link between nitrate and miscarriages was suggestive but not conclusive in that study.**

*Streams in agricultural areas underlain by limestone had nitrate concentrations that, if not lessened by appropriate treatment before use as drinking water, commonly would exceed the USEPA MCL. Streams in other areas did not.* Some streams in limestone areas have nitrate concentrations of 10 mg/L or more year round. In limestone areas, streams were commonly fed by springs that discharged ground water containing high concentrations of nitrate. Water from tributaries in limestone areas, such as Mill Creek (see graph on bottom of page 10), had nitrate concentrations near 10 mg/L with some seasonal fluctuation. In limestone and other areas, *the highest nitrate concentrations were generally in the winter and spring*. Seasonally high concentrations of nitrate are an issue for some water suppliers. Suppliers of drinking water regularly monitor nitrate concentration.

*Nitrate concentrations in the Susquehanna River at Harrisburg were generally less than 2 mg/L, which is considerably below the MCL for nitrate in drinking water of 10 mg/L. Concentrations of nitrate at these levels, when multiplied by the large flows of the Susquehanna River, contributed*

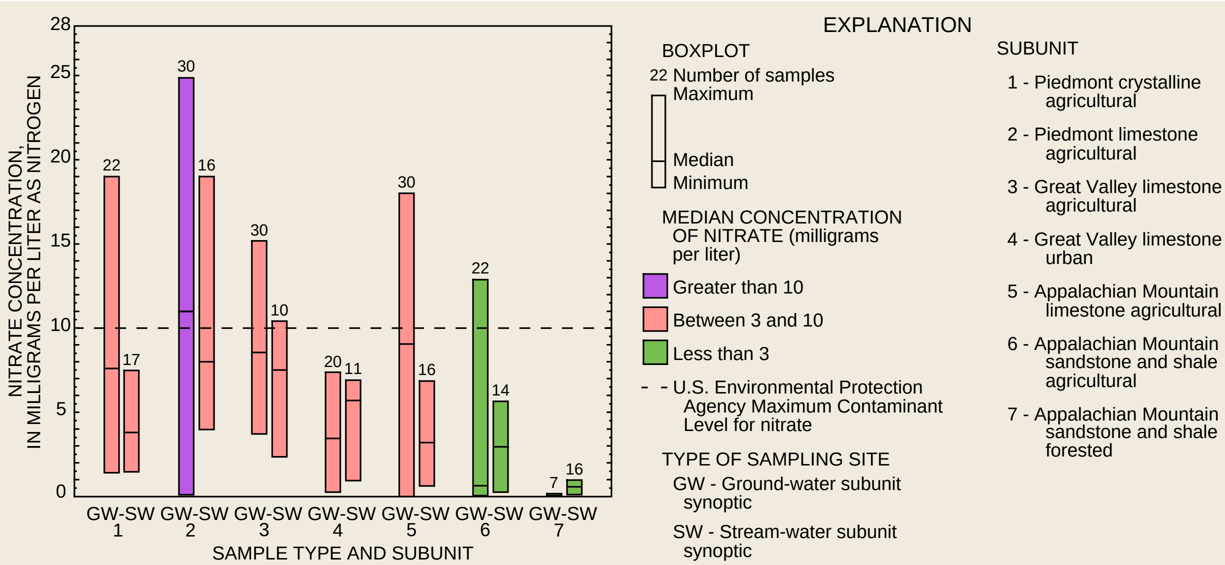
Ground-water and stream-water quality are related to manure management and application rates. Best-management practices, like the manure-storage structure (concrete structure with chain-link fence) on this farm in Lancaster County, Pa. (left), help keep manure from being applied to the fields in the winter when nitrate is more likely to enter streams and ground water (above, photograph by Dennis W. Risser, U.S. Geological Survey).

Nitrate concentrations in ground water are highest in agricultural areas underlain by limestone bedrock, where almost half of the samples collected exceed 10 mg/L of nitrate. Shallow bedrock depth and highly fractured bedrock in valleys underlain by limestone can allow nitrate from manure and fertilizer to infiltrate rapidly into the ground water.

*large amounts of nitrate to the Chesapeake Bay when compared to other rivers entering the bay.* Although safe for human consumption after filtration and water treatment, the water flowing from the Susquehanna River into the Chesapeake Bay still contained enough nitrate to stimulate algae growth and affect the bay ecosystem. Estimates of loads and yields of nitrate for 1994 from samples collected when the flow was dominated by ground water (base flow) showed that *streams from agricultural areas underlain by limestone bedrock contributed large amounts of nitrate per unit area to the Lower Susquehanna River when compared to streams in areas with other land uses and bedrock types.* However, streams in agricultural areas underlain by sandstone and shale and crystalline bedrock also provide large amounts of nitrate to the Susquehanna River.

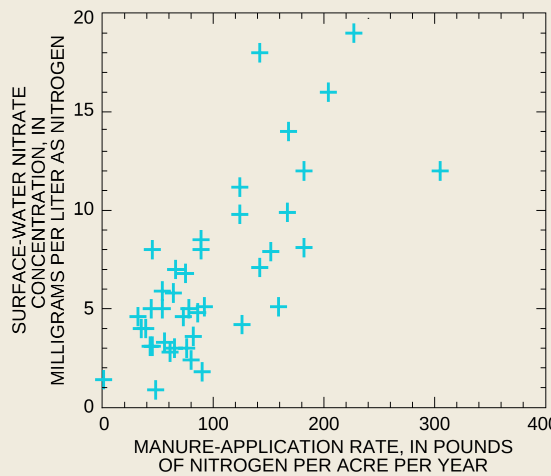
*The main nitrogen source in the Study Unit is animal manure used as an agricultural fertilizer.* High manure-application rates showed a strong association with elevated nitrate concentrations in areas of specific land uses and bedrock types. Nitrogen in manure and fertilizers added to agricultural land is essential to plant growth; however, concentrated animal operations can produce more manure than the crops grown on that farm can use. The number of concentrated animal operations is increasing in some parts of the basin. Improper or excess application can cause nitrate and other forms of nitrogen to enter the ground water or streams. Recently, through the efforts of the Chesapeake Bay Restoration Program, many agricultural operations have voluntarily taken advantage of new technologies to manage manure more efficiently. *The data collected in this study provide a baseline to evaluate the effectiveness of the Pennsylvania Nutrient Management law, which requires concentrated animal operations to develop and have approved nutrient-management plans by 1998.*

The nitrate data from the seven subunits were compared to determine factors that affect nitrate movement and concentration. Nitrate concentrations were higher in stream water in areas underlain by limestone than in areas underlain by other




For agricultural areas underlain by crystalline or limestone bedrock, nitrate concentrations generally were higher in ground water than stream water. In urban areas and areas underlain by sandstone and shale, nitrate concentrations generally were higher in stream water than in ground water.

A comparison of samples from 41 streams in agricultural areas underlain by limestone (subunits 2, 3, and 5) shows a strong relation between manure-application rate and nitrate concentration.




bedrock types; however, these areas generally had the highest manure-application rates. When an agricultural area underlain by limestone and an agricultural area underlain by sandstone and shale with similar manure-application rates were compared, nitrate concentrations in streams were not significantly different. *Manure-application rate may be the most important factor controlling nitrate concentrations in streams in agricultural basins underlain by limestone.* A comparison of 41 basins in agricultural areas underlain by limestone shows that the manure-application rate is strongly correlated with nitrate concentration (see graph above).

Nitrate concentrations were higher in ground water than in streams in agricultural areas underlain by limestone bedrock and in agricultural areas underlain by crystalline bedrock. Conditions in these areas allow much of the agriculturally applied nitrogen to enter the ground water. Under certain conditions, forested areas near streams (riparian buffers) can remove nitrate from the ground water before it flows into the stream.

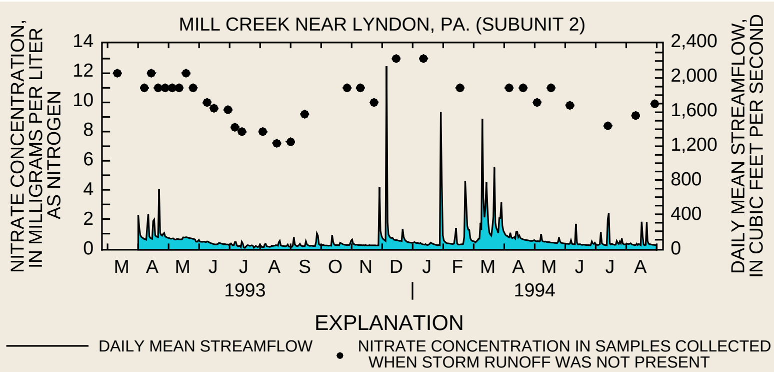
Nitrate concentrations were higher in streams than in ground water in urban areas underlain by limestone. Streams in urban areas were affected by point-source discharges. Nitrate concentrations were also higher in stream water than ground water in both agricultural and forested areas underlain by sandstone and shale. The conditions in the sandstone and shale aquifers are not favorable for the movement of nitrate into the ground water. Conditions in these aquifers also were such that nitrate could change chemically to other forms of nitrogen (denitrification) and potentially leave the water system and enter the atmosphere. The sandstone and shale subunits had the lowest median nitrate concentrations in streams and ground water compared to the other subunits.

The relation of topography and land use is important in understanding nitrate occurrence. In the Ridge and Valley Physiographic Province, where agricultural areas are in the valleys and forested areas are on the ridges, the ground water under the valleys may be mixed with water from the ridges, which dilutes agricultural contaminants. In areas of the Piedmont underlain by crystalline bedrock, agricultural land use is commonly on the hilltops, and the steep hillsides are forested. There, the ground water under the agricultural land contains contaminants from the agricultural land use, but contaminants may be absorbed by vegetation or diluted as the water passes under the forested areas on the way to the stream.

## Temporal Variation in Nitrate Concentration in Streams

Temporal variation in nitrate concentrations in streams during periods when storm runoff is absent (base flow) and flow is dominated by ground-water flow was determined from the analyses of samples collected throughout the year at seven long-term monitoring sites (see map on page 7). Nitrate concentrations were commonly higher in the winter months than in the summer months. An example plot for Mill Creek is shown below.

Statistical analysis showed that high flows in the streams were related to high nitrate concentrations. This variation may have been caused by the seasonal change in the amount of water that flows through the ground and carries nitrate to the streams (more water transports more nitrate). Other possible explanations for this variation include the seasonal cycle in plant uptake of nitrogen and seasonal fluctuations in uptake of nitrate by algae in streams. Because no information was available about the time for ground water to travel from land surface to streams, interpretation of this temporal variation was not conclusive. Nitrate concentrations in stream base flow are unlikely to change quickly in response to land-management practices because it may take years for ground water now in aquifers underlying the basin to flow into streams.



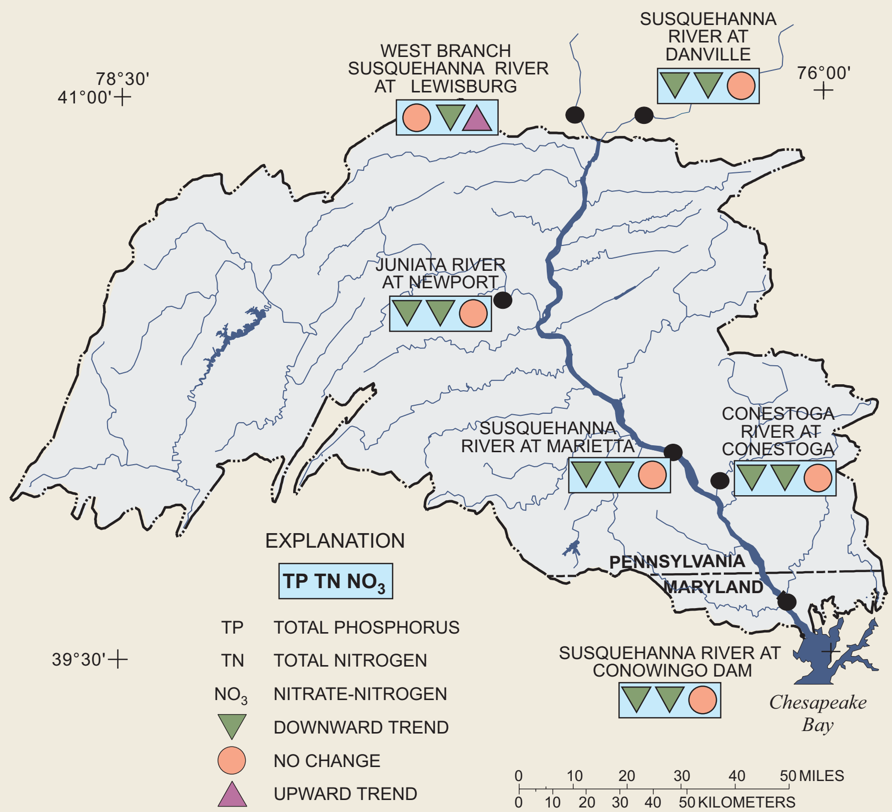

Nitrate concentrations in stream base flow decline through the summer and increase through the fall, reaching the highest concentrations in the winter months.

Because the stream samples primarily were collected when the flow was low and dominated by ground water (base flow), the occurrence and trends of phosphorus and other forms of nitrogen such as ammonia are difficult to determine from the NAWQA data. These nutrients generally are associated with storm runoff and would not be well characterized by an analysis of base-flow data. Therefore, data from an ongoing study of the Susquehanna River (Langland and others, 1998) was used to show trends for these nutrients. The study showed that *the concentration of total nitrogen in the Susquehanna River at Conowingo Dam, the river's inflow to the Chesapeake Bay, decreased in the 1985-96 time period. The concentration of nitrate (one component of total nitrogen) remained unchanged during this period.*

The downward trends in total nitrogen (see map and table at right) are probably the result of large decreases in concentrations of ammonia and organic nitrogen—other components of total nitrogen. The decreases in concentrations of ammonia and organic nitrogen, and subsequent decreases in total nitrogen, are attributed to improvements in sewage-treatment plants and implementation of agricultural best-management practices. *The specific environmental circumstances that would explain the lack of change in nitrate concentration during a time of downward trends in total nitrogen could be related to the nitrate in streams that originates in ground water or to other nonpoint sources.* Further study would be needed to determine the causes of these opposing trends.

Studies of phosphorus show that trends in concentration have decreased throughout the basin. These trends are attributed to a ban on phosphate detergents as well as improvements in sewage-treatment plants and implementation of agricultural practices that decrease surface runoff.

A study of nutrient concentrations in the Susquehanna River Basin from 1985 to 1996 indicated downward trends in concentrations of total nitrogen and phosphorus (Langland and others, 1998). These trends are attributed to improvements in sewage-treatment plants, a ban on phosphate detergents, and implementation of agricultural best-management practices. Nitrate, a component of total nitrogen, showed an upward trend at Lewisburg and no change at any other sites. Constant or increasing nitrate concentrations may be related to flow from ground water and nonpoint sources. (Map modified from U.S. Environmental Protection Agency, 1997.)




| Site location | Percentage change in nutrient concentrations 1985-96 minimum/**trend**/maximum | | |
|---|---|---|---|
| | Total phosphorus | Total nitrogen | Nitrate-nitrogen[1] |
| Susquehanna River at Danville | –41/**–27**/–10 | –37/**–31**/–23 | No change |
| West Branch Susquehanna River at Lewisburg | No change | –24/**–15**/–4 | 8/**18**/29 |
| Juniata River at Newport | –59/**–51**/–41 | –31/**–26**/–21 | No change |
| Susquehanna River at Marietta[2] | –47/**–35**/–20 | –37/**–30**/–22 | No change |
| Conestoga River at Conestoga | –32/**–20**/–6 | –23/**–19**/–14 | No change |
| Susquehanna River at Conowingo Dam | –62/**–53**/–42 | –25/**–18**/–10 | No change |

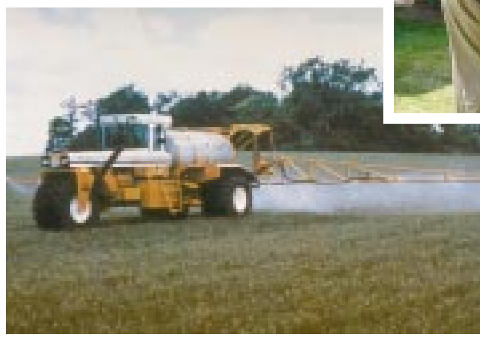
[1]The trend shown is for total nitrate plus nitrite nitrogen, which is a close approximation to the trend in nitrate-nitrogen.
[2]The trend for Marietta is based on data from 1987 to 1996.

The table above shows the trends in concentrations calculated by Langland and others (1998), illustrating the magnitude of the trends shown on the map as a percentage. The bold number on the table is the trend from the statistical model used to detect changes in concentration over time (Cohn and others, 1992). The maximum and minimum results illustrate the range of possible trends. Negative numbers indicate downward trends. The term "no change" is used in cases where it is uncertain whether the trend is upward or downward.

Wells and streams in the Lower Susquehanna River Basin Study Unit were sampled and the waters analyzed for many of the most commonly used pesticides in the United States. The pesticides analyzed for are soluble in water. The samples were collected to provide information on the spatial distribution of pesticides in ground water and streams, as well as the seasonal patterns of pesticides in streams (Breen and others, 1995; Hainly and Kahn, 1996; Hainly and Bickford, 1997).

*Concentrations of pesticides in water from the wells and streams sampled rarely exceeded levels established as drinking-water standards.* Only 10 of the measured concentrations in untreated waters from streams exceeded a level established as a drinking-water standard. Seasonal factors, such as storm runoff of pesticides during the major application period in the spring, contribute to high concentrations of pesticides in streams. Very few storm samples were collected for this study; however, 8 of the 10 exceedances were measured in storm-affected samples. More work would be needed to understand fully the high-concentration pulses of pesticides in stormflow. None of the samples collected from household-supply wells had concentrations that exceeded drinking-water standards.

The timing and rate of agricultural pesticide applications (below) were important factors in describing the seasonal and spatial concentration patterns detected in ground water and streams.



Indicators of residential, commercial, and industrial pesticide use (above) helped to explain concentration patterns of pesticides not used extensively for agricultural purposes.

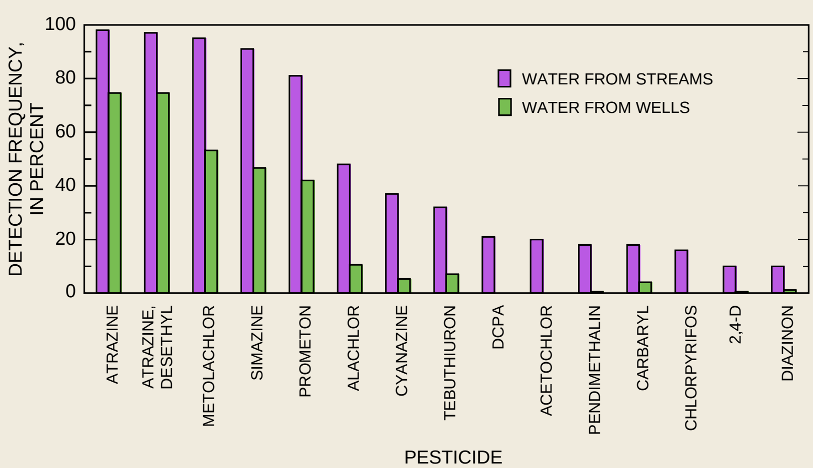
Guidelines for protection of aquatic life were exceeded in samples from nine streams. Concentrations of malathion, chlorpyrifos, and methylazinphos exceeded guidelines for protection of aquatic life (U.S. Environmental Protection Agency, 1991). Although no guidelines have been established in the United States for atrazine, cyanazine, and metolachlor, these pesticides exceeded the Canadian guidelines for protection of aquatic life (Canadian Council of Resource and Environment Ministers, 1996).

*Although drinking-water standards, human-health advisory levels, and aquatic-life criteria were rarely exceeded, these criteria have not been established for many of the pesticides that were sampled for. In addition, mixtures and degradation products were not considered in developing the human-health criteria. Only a limited range of the potential effects of pesticides in drinking water has been assessed.* Therefore, it is important to evaluate pesticide occurrence and trends even though current standards were rarely exceeded.

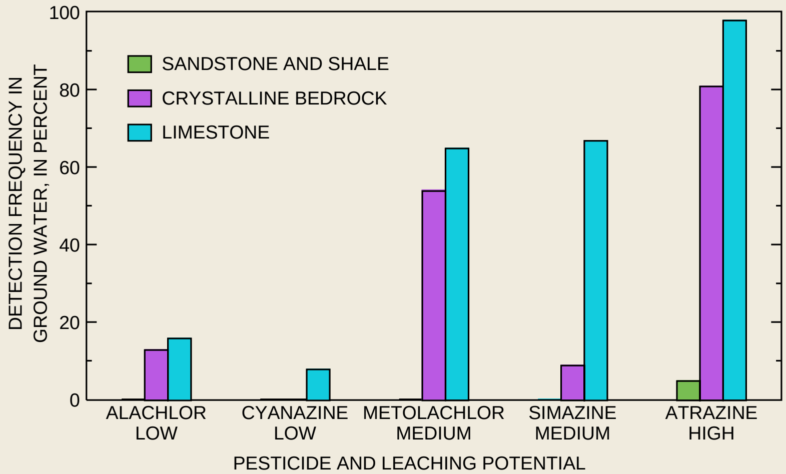
### Spatial Distribution of Pesticide Concentrations

*Pesticides were detected frequently in ground water and streams; usually, more than one pesticide was detected at a time.* Spatial and seasonal patterns of pesticide concentrations were documented using 577 samples that were tested for 47 herbicides or insecticides. A subset of the stream-water samples and all ground-water samples were tested for an additional 38 pesticides. In total, nearly 40,000 analyses of concentrations for individual pesticides were made on waters from 155 stream sites and 169 shallow wells from 1993 to 1995. For this study, shallow wells were defined as those less than 200 ft deep.

In more than 90 percent of the samples collected, at least one pesticide was detected, and two or more pesticides per sample were frequently detected. *More than 60 percent of well-water samples in which pesticides were*




The six most frequently detected pesticides were the same for water from wells and water from streams.




In water from wells in areas of limestone bedrock, where water easily infiltrates into the aquifer, pesticides with high leaching potential, such as atrazine, were almost always detected. Less widely used pesticides with low leaching potential, such as cyanazine, were rarely detected in these same areas. In areas of sandstone and shale, where the infiltration is poor, even pesticides with high leaching potential and high use, such as atrazine, were rarely detected in water from wells.

*present contained more than one detectable pesticide.* In general, measured concentrations of individual pesticides were very low; only 22 samples of stream water and 2 samples of ground water had concentrations that exceeded 2 µg/L (micrograms per liter, or parts per billion).

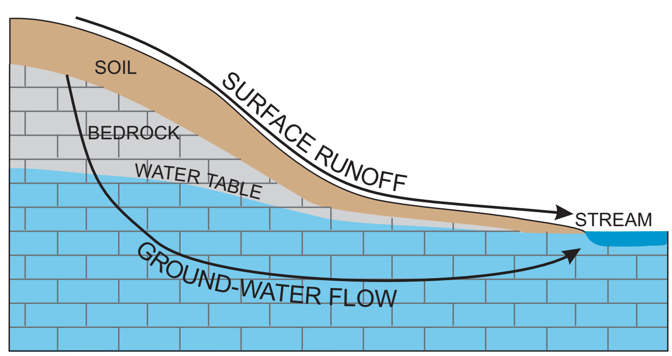
*The most commonly detected pesticides were the herbicides used primarily on corn: atrazine, metolachlor, simazine, prometon, alachlor, and cyanazine (see graph on page 12).* Metolachlor and atrazine are the two most used agricultural pesticides in the Study Unit. Atrazine was detected in 98 percent of the stream samples and in 74 percent of the ground-water samples. Desethylatrazine (a breakdown product of atrazine) was usually detected with atrazine. Metolachlor was detected in 95 percent of the stream samples and in 53 percent of the ground-water samples. Nearly half of all the pesticides analyzed for were not detected in any sample. Of the 45 pesticides that were detected at least once, only 5 were detected in more than half of the samples collected.

Average annual pesticide use for agricultural purposes and nonagricultural (residential, commercial, and industrial) pesticide-use indicators were related to patterns of pesticide concentrations in waters from wells and streams. The timing and rate of agricultural pesticide applications for the high-use pesticides described a major part of the seasonal concentration patterns observed in water from streams and the spatial patterns observed in water from streams and wells. Indicators of nonagricultural use helped to explain concentration patterns of pesticides not used extensively in agriculture.

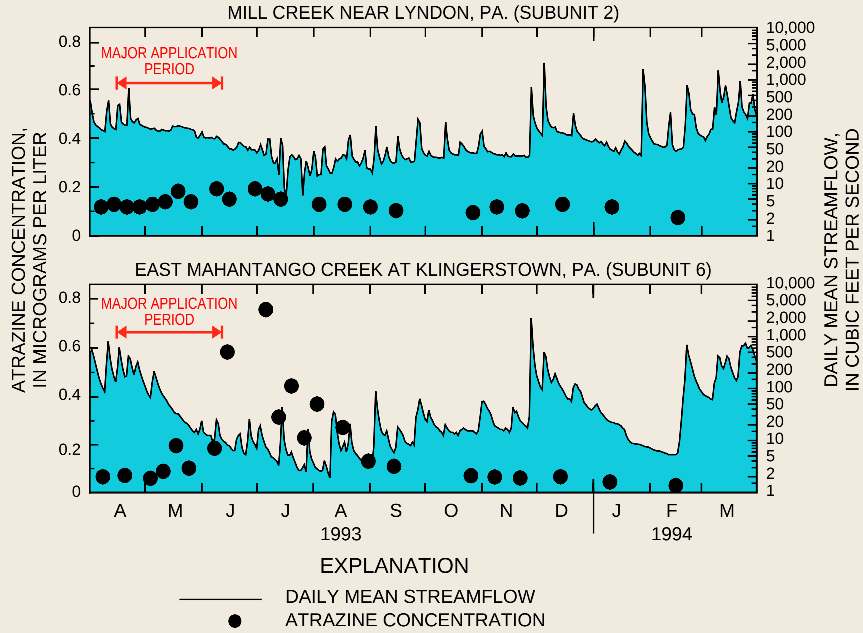
*Detections of pesticides were related to pesticide use, pesticide-leaching potential, and bedrock type. Pesticides were most likely to be detected in samples from agricultural and urban areas. Limestone areas were far more likely to have pesticides in well water than areas underlain by sandstone and shale.* Bedrock type influences the movement and discharge of ground water and affects spatial patterns of pesticide concentrations, as shown in the graph to the left and in the figure below. Some commonly used pesticides with low leaching potential (low potential to infiltrate into the ground with the water), such as alachlor and cyanazine, were detected in streams more often than in wells because they are more likely to be transported in surface runoff.

To help understand how differences in bedrock type control concentrations of highly soluble pesticides in stream base flow, Study Unit personnel compared atrazine concentrations in streams during the dry times of the year, when the flow is low and dominated by ground water (base flow), to concentrations in ground water from shallow wells. Results differed considerably between limestone systems and non-limestone systems. In subunits with limestone bedrock, atrazine concentrations in waters from streams and shallow wells were similar, indicating

The amount of water that runs off the land surface or infiltrates into the ground depends on factors such as slope and how easily water can flow through the soil and bedrock material. In areas of limestone bedrock, where water can readily infiltrate into the ground, pesticides were commonly detected in ground water. The same pesticides detected in ground water were usually detected in streams during times when the flow in the streams is sustained by flow from ground water. In areas of sandstone and shale, where water does not easily flow through the soil and bedrock material, the easiest pathway for the water is to run off over the land. Pesticides were rarely detected in ground water in these areas.



a system of ground-water flow through large fractures and springs to the streams. In the sandstone and shale subunit, atrazine concentrations in well waters were lower than concentrations in the streams, indicating that water reaching the stream may be flowing from the aquifer to the stream through a system of fractures in a shallower layer of the aquifer than the layer penetrated by the wells. The graphs to the right illustrate the differences between pesticide concentrations in streams in limestone settings and sandstone and shale settings.




In limestone streams, such as Mill Creek, atrazine concentrations were nearly constant year round. In streams in sandstone and shale areas, such as East Mahantango Creek, atrazine concentrations increased significantly after the major pesticide application period.

## Temporal Variation in Pesticide Concentrations in Streams

*Seasonal variations in pesticide concentrations in water from streams are affected by the timing of pesticide application and the type of bedrock. The highest concentrations of pesticides were seasonal pulses lasting up to several months (see graph at right).* Peak concentrations were smaller in a limestone stream compared with a stream in a sandstone and shale area. Elevated concentrations in streams were related to the seasonality of agricultural-use applications. The seasonal variations in climate also were an important factor in explaining seasonal patterns.

Mill Creek, a limestone stream, shows a slight rise in atrazine concentration after the major application period because some atrazine is in runoff. Some atrazine infiltrates into the ground water and provides constant levels of atrazine to the stream for the rest of the year. This is a limestone stream pattern. Levels of atrazine remain between 0.1 and 0.2 µg/L because ground water provides most of the water to the stream.

The pattern at East Mahantango Creek, a stream in an area of sandstone and shale, shows a pulse or increase in atrazine concentration after application, followed by lower concentrations throughout the rest of the year. Topography and soils in this basin favor runoff of atrazine over leaching to the ground water. The levels of atrazine after the application period when the streamflow is supplied from ground water are lower in East Mahantango Creek than in Mill Creek.

## Pesticide Concentrations in the Susquehanna River

*Concentrations of pesticides in the Susquehanna River were generally less than 1 µg/L.* Analyses of 11 water samples from the Susquehanna River at Harrisburg from June 1994 to August 1995 indicated that mixtures of pesticides and their degradation products were frequently present in the river but at concentrations generally less than 1 µg/L (see table below). *The pesticides detected at this site were similar to those detected in water from streams in agricultural areas throughout the Lower Susquehanna River Basin.*

Pesticides were not detected in samples collected during synoptic studies at the main-stem Susquehanna River at Danville and were detected in low concentrations in the West Branch Susquehanna River at Lewisburg (upstream from the Lower Susquehanna River Basin). This pattern indicates that the pesticides present in the Susquehanna River at Harrisburg are most likely introduced by the tributaries in the Lower Susquehanna River Basin.

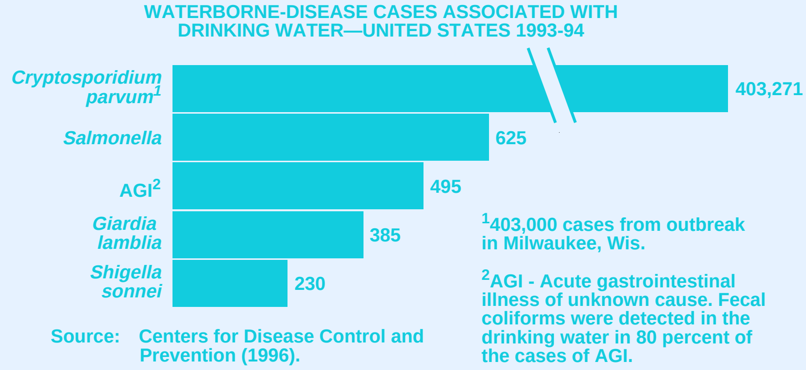
Pesticide concentrations in the Susquehanna River at Harrisburg, 1994-95, were generally less than (<) 1 microgram per liter.

| Compound | Minimum concentration | Maximum concentration | Median concentration |
|---|---|---|---|
| | micrograms per liter (parts per billion) | | |
| Alachlor | <0.002 | 0.730 | <0.002 |
| Atrazine | .014 | 1.20 | .037 |
| Atrazine, desethyl | .015 | .118 | .027 |
| Cyanazine | <.004 | .280 | <.004 |
| Metolachlor | .007 | 2.30 | .018 |
| Prometon | <.018 | .035 | <.018 |
| Simazine | <.005 | .124 | .009 |

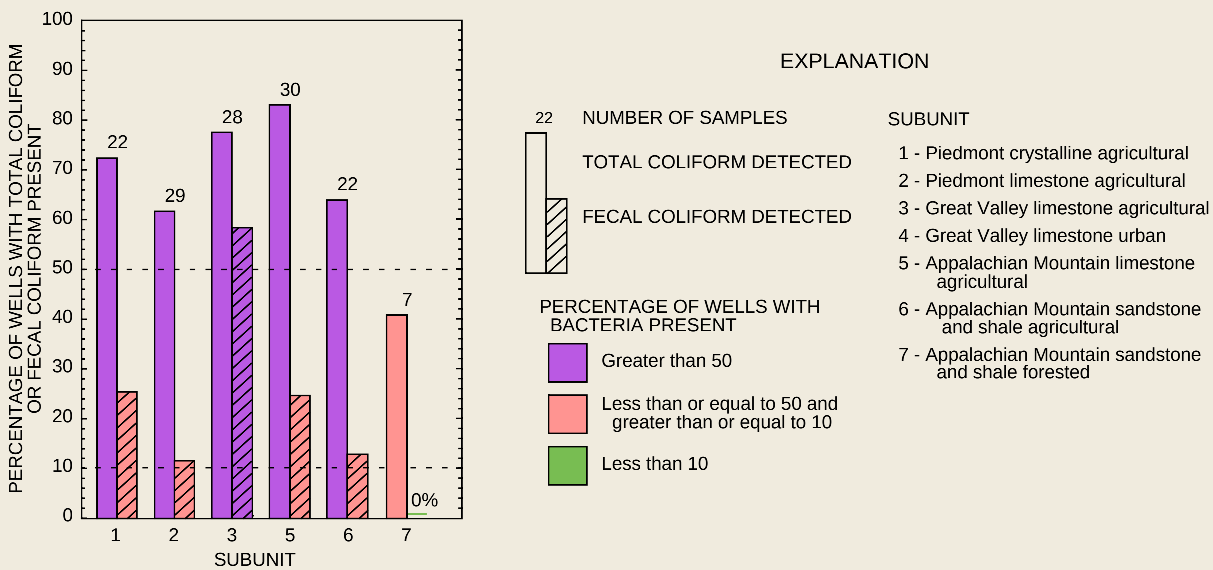
Samples from 146 household-supply wells were analyzed for organisms indicative of fecal contamination, including total and fecal coliform bacteria (Bickford and others, 1996). *Total coliform bacteria were detected in water from nearly 70 percent of the household wells sampled, indicating that the water should not be used for drinking without treatment. Fecal coliforms were present in water from about 25 percent of those same wells. In an 88-well subset, approximately 30 percent had waters containing Escherichia coli bacteria (*E. coli*).* Fecal streptococcus bacteria were present in water from about 65 percent of the wells sampled. Bacteriological contamination was more likely to occur in water from wells in agricultural areas than in water from wells in forested areas. Water from wells in areas underlain by limestone had higher concentrations of bacteria than areas with other types of bedrock.

*Few household wells from which water was sampled were grouted, and few had sealed, sanitary caps at the top of the casing. Lack of these protective features can enable the entry of bacteria into well water and may have contributed to the number of detections of bacteria.* It is uncertain whether the bacteria detected were the result of widespread aquifer contamination or local factors. In most counties in Pennsylvania, testing and treatment of private wells is not required. *It is uncertain whether bacteriological contamination of well water is caused by inadequate protection of wells from surface runoff, septic-system failure, application of animal manure to fields, or other causes.*

Although samples were not tested for protozoan pathogens, such as *Giardia lamblia* and *Cryptosporidium*, the presence of fecal bacteria indicates the potential for these protozoans and other pathogens of fecal origin to be present in the drinking water. Gastrointestinal diseases related to wells used for household-water supply have symptoms such as diarrhea and stomach cramps and commonly go unreported. *With waters from nearly 70 percent of the wells sampled showing one or more bacteriological indicators, the presence of bacteria in water from rural wells is one of the most important water-quality issues related to human health in the Study Unit.*




**Fecal contamination of water supplies is a leading cause of waterborne-disease outbreaks. Most outbreaks shown here are from public supplies; outbreaks of diseases involving water from private household wells are usually neither identified nor reported. The cases from public supplies illustrate the potential effects of drinking contaminated water. All of the cases listed above except acute gastrointestinal illness of unknown cause (AGI) are transmitted by fecal contamination.**




The presence of bacteria in water from rural household wells is an important drinking-water issue. Total coliform and fecal coliform bacteria were detected in water from many of the wells.

Water samples for analysis of volatile organic compounds (VOCs) were collected from 118 of the 169 wells used in this assessment; at least 1 compound was present in water from 26 of the 118 wells (Daly and Lindsey, 1996; Lindsey, Breen, and Daly, 1997). Analyses for 60 VOCs at detection levels ranging from 0.2 to 1.0 µg/L revealed the presence of 23 compounds. These compounds are present in commonly used industrial solvents and degreasers or are components of gasoline.

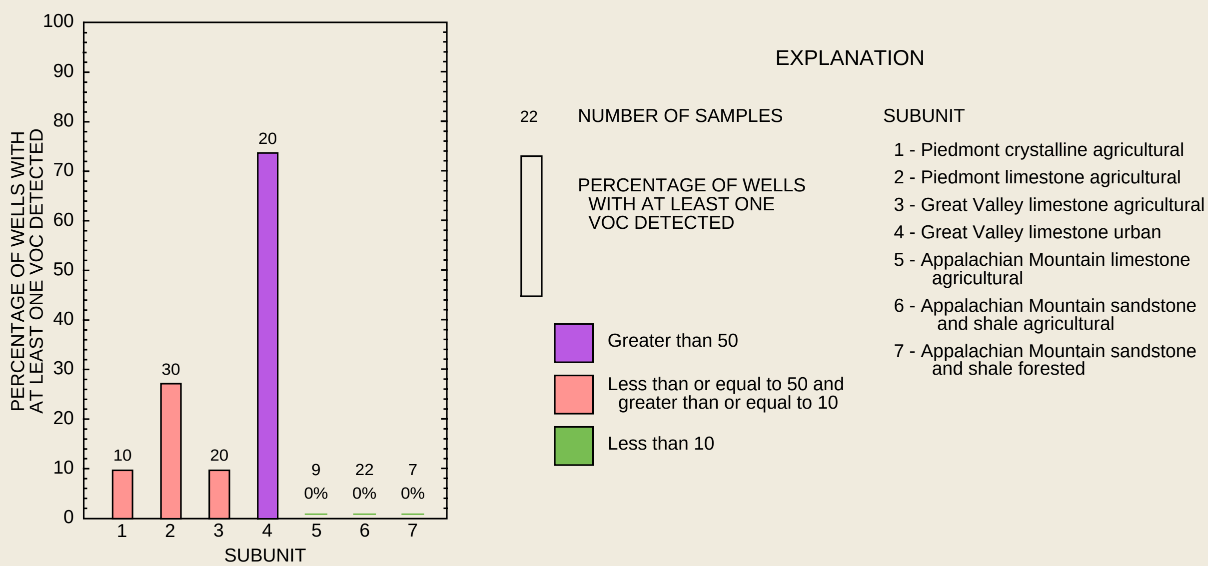
*None of the concentrations of the VOCs detected in samples from wells used as drinking-water supplies exceeded the MCLs or Lifetime Health Advisory Levels established by the USEPA.* Methyl *tert*-butyl ether, a gasoline additive, was the most commonly detected compound. Concentrations of methyl *tert*-butyl ether, detected in 11 of the 118 wells, ranged from 0.2 to 51 µg/L. The 51 µg/L of methyl *tert*-butyl ether, detected in a monitoring well, exceeded the lower limit of the compound's Lifetime Health Advisory Level. Chloroform was the second most commonly detected compound. Chloroform is a byproduct of using chlorine as a disinfectant. Chloroform also is present in septic-system effluent, and it has industrial uses. The highest chloroform concentration detected in a water sample was 61 µg/L.

The presence of VOCs in limestone aquifers in the Great Valley near Harrisburg, Pa., is affected by land use as illustrated by the graph below. *VOCs were detected more frequently in the urban area (subunit 4) than in the agricultural area (subunit 3).* Within the urban area, analyses of samples from wells, springs, and a spring-fed stream indicate that contaminated ground water flows from springs into the streams.

The frequency of detections of VOCs in urban areas is likely to be a result of the numerous urban sources of VOCs, including spills, leaks from underground tanks, improper disposal, atmospheric deposition, runoff from pavement, and leaking sewerlines.

In the rural areas in the Appalachian Mountain subunits, no VOCs were detected in well water (see graph below). The low population densities in rural areas and fewer sources of VOCs are likely explanations for the lack of detections of VOCs. In rural areas, leaking storage tanks, septic systems, improper disposal, and atmospheric deposition are potential sources of VOCs.

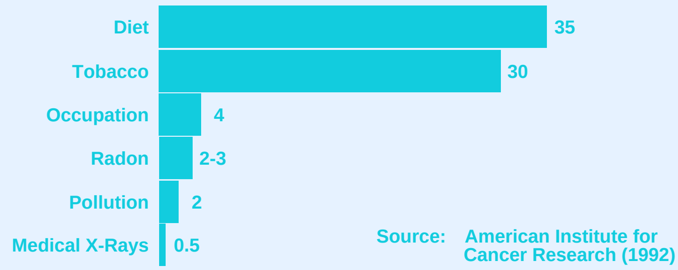
Underground storage tanks that contain gasoline and other fuels can be a source of VOCs in ground water. The drill rig shown above is used to install monitoring wells so the property owner can determine whether leakage or contamination has occurred.




Numerous sources of VOCs in urban areas are a likely explanation for the high frequency of detections in the urban subunit. In the urban area, ground water contaminated with VOCs flows from springs that feed coldwater streams known for their trout populations.

*Radon, a product of the radioactive decay of uranium, is present in ground water throughout the Lower Susquehanna River Basin* (Lindsey and Ator, 1996). Airborne radon has been cited by the Surgeon General of the United States as the second leading cause of lung cancer, and the USEPA has identified ground-water supplies as possible contributing sources of indoor radon. *Radon activities in 86 percent of the 165 ground-water samples tested for radon were greater than a previously proposed standard, now under review by the USEPA, of 300 pCi/L (picocuries per liter, a measurement of radioactivity). More than 30 percent of the 165 ground-water samples tested for radon contained radon at activities greater than 1,000 pCi/L.*

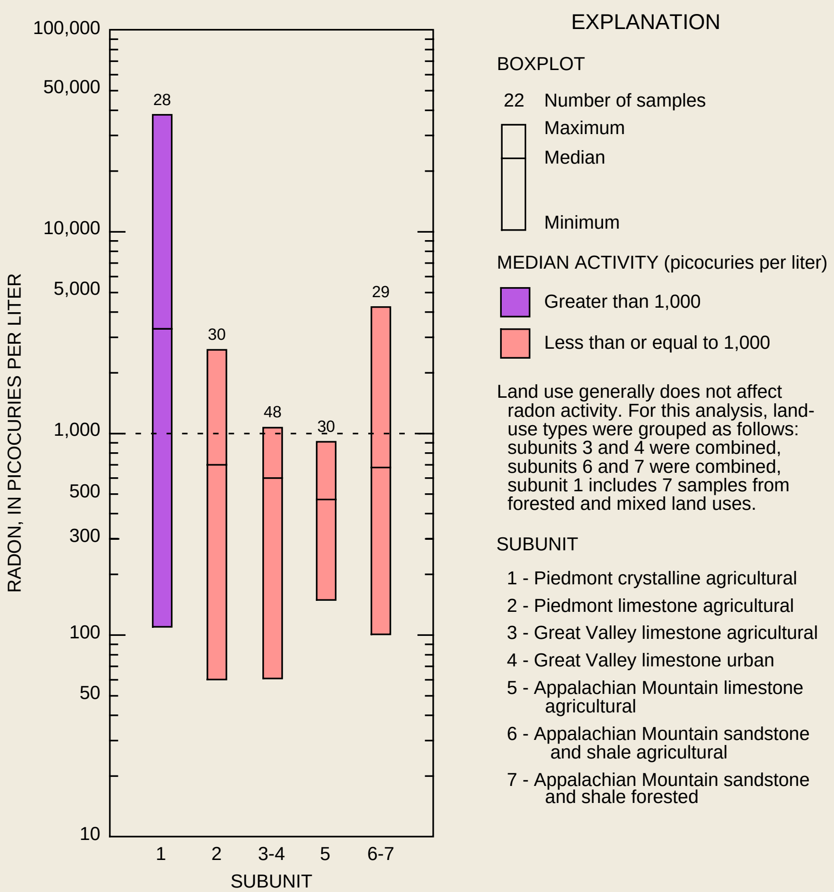
PERCENTAGES OF CANCER DEATHS ATTRIBUTED TO VARIOUS FACTORS




Many of the known cancer-causing agents cause only a relatively small percentage of cancer deaths. The risk of radon can be put in perspective by comparing the risk of radon exposure to other factors that have been identified as causes of cancer. This figure accounts for all exposures to radon, not only radon in water (not all factors are shown).

*The subunit of the Study Unit underlain by crystalline rocks of the Piedmont Physiographic Province had the highest median radon activities in ground water (greater than 1,000 pCi/L), but variation in radon activities within most subunits is large.* Lower median radon activities (less than 1,000 pCi/L) were measured in ground water in subunits underlain by limestone. The median activity in ground water in the subunit underlain by sandstone and shale also was less than 1,000 pCi/L; however, the maximum activity was higher than the maximum activity in any of the subunits underlain by limestone. Land use generally does not affect radon activity.

Although the ground water in some areas has higher activities of radon relative to other areas, the only way to be sure of the radon activity in water from a well is to have it tested. In homes where high indoor radon levels are measured and where water is supplied by a well, the USEPA recommends testing well water as a potential contributing source of radon. For every 10,000 pCi/L of radon in water, about 1 pCi/L of radon is released to the air, in addition to any airborne radon that may enter a home through the basement (only 1 of the 165 ground-water samples contained greater than 10,000 pCi/L of radon). If a large percentage of the radon in the house is from the water, the USEPA recommends that installation of a water-treatment system to remove radon be considered. Homes and water supplies both can be treated to reduce radon levels.




The activities of radon in ground water were varied but followed general patterns according to bedrock type.

Streambed sediments and liver tissues of fish were analyzed for selected trace elements. Trace-element analyses were not done for ground water or surface water. Trace elements are present naturally in water and sediments at concentrations that depend on the type of rock where sediments originate (Hainly and others, 1994). Concentrations can be elevated above natural levels as a result of discharges from wastewater-treatment plants, industrial activity, or mining. Sediment samples from 21 sites were analyzed. Livers from bottom-feeding fish (white sucker) from 20 sites also were analyzed. Livers from bottom-feeding fish species (white sucker) and predator fish species (smallmouth bass) were collected at 3 of the 20 sites. Streambed sediments were analyzed for 27 trace elements; 24 were detected. Liver tissues of fish were analyzed for 22 trace elements; 18 were detected.

Human-health issues were not the focus of the trace-element studies. Because trace-element concentrations were determined only for fish livers and not for edible portions, no statements about suitability of fish for human consumption can be made. The U.S. Food and Drug Administration (FDA) action level for mercury is 1 part per million in the edible portion (fillets) of fish. Mercury concentrations in fish livers at four sites were close enough to the FDA action level to suggest a need for further study of mercury. Liver tissue from smallmouth bass in the Susquehanna River at Danville and the West Branch Susquehanna River at Lewisburg and white sucker in Codorus Creek and the Frankstown Branch Juniata River had mercury concentrations that ranged from 0.5 to 0.7 part per million.

*Correlations were found between the concentrations in streambed sediments and the concentrations in livers of bottom-feeding fish for only 3 of 11 elements regarded as common contaminants. Arsenic, chromium, copper, lead, mercury, nickel, selenium, and zinc were not significantly correlated.* Concentrations of cadmium, silver, and vanadium in livers from white sucker and the concentrations of these trace elements in streambed sediments were correlated. Although these associations do not imply direct cause and effect relations, they may indicate that these elements travel pathways through the aquatic system in a manner different from the other elements.

Livers were removed from fish and analyzed for trace elements.

Trace-element concentrations in liver tissue from a predator species (smallmouth bass) and a bottom-feeding species (white sucker) were determined for samples from three sites. The liver tissue of smallmouth bass had higher concentrations of aluminum, cobalt, iron, mercury, selenium, strontium, and vanadium. The liver tissue of white sucker had higher concentrations of copper, manganese, and silver. These differences indicate that the two fish species may have different bioaccumulation mechanisms for these elements.

The bioavailability of trace elements in the sediments is not clearly understood but is known to depend on such local factors as concentration of dissolved solids and dissolved organics, pH, hardness, and sediment load, which also influence the prevailing chemical forms of trace elements in aquatic systems (Neilson, 1994). Therefore, the trace elements present in the streambed sediment may not have been bioavailable for uptake by fish. Moreover, the sediment samples may not have been collected in that part of the stream channel where the fish were most actively in contact with the streambed. These factors may help explain the lack of correlation between the concentrations detected in streambed sediments and the concentrations of the same element detected in the liver tissue of fish.

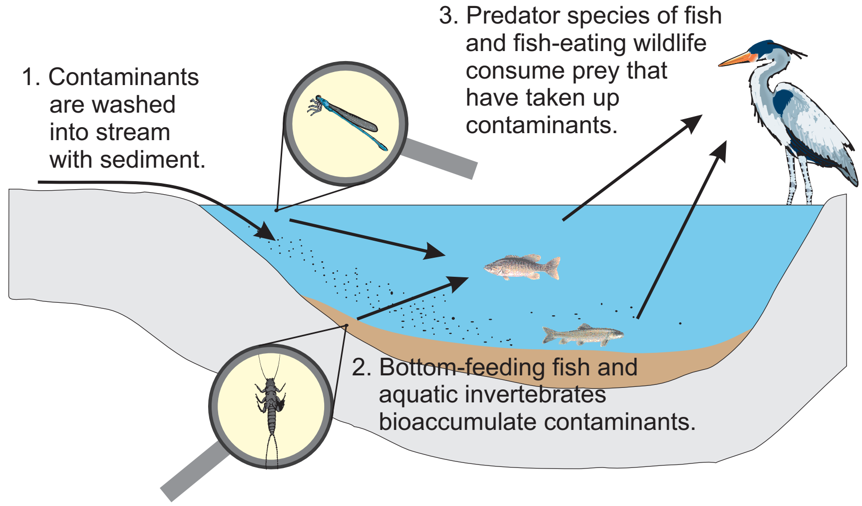
*The highest concentrations of arsenic, beryllium, cadmium, cobalt, iron, manganese, nickel, selenium, and zinc in streambed sediment were at sites affected by mine drainage.* Streambed sediment from the Susquehanna River at Danville had high to moderately high concentrations of all of these elements. Tributaries such as the West Branch of the Susquehanna River and Mahanoy Creek are affected by mine drainage and have the highest concentrations of beryllium, cadmium, cobalt, manganese, nickel, and zinc. The highest concentrations of lead were at sites on Codorus Creek and Quittapahilla Creek downstream from urban and industrial areas. Lead is also present in high concentrations in streambed sediment from Mahanoy Creek. Sediment from some sites in basins in the Piedmont Physiographic Province that have no industrial or mining activity also contained elevated concentrations of nickel, indicating that the bedrock in that area may be a natural source of nickel.

To better understand transport of trace elements to the Susquehanna River from a tributary affected by mine drainage, Study Unit personnel collected samples from Mahanoy Creek—including streambed sediment, water, coatings on rock surfaces, and liver tissue from white suckers— and analyzed all these substances for trace elements (Breen and Gavin, 1995). Most trace elements being transported downstream were in the form of suspended particles or colloids. The coatings on rock surfaces contained high concentrations of trace elements, and the coatings could be dislodged from the rock surfaces during storms. Calculations showed that the transport of trace elements dislodged from rock surfaces during a storm would be small relative to the daily transport from suspended particles and colloids.

## Organochlorine Pesticides and PCBs in Fish Tissue

Some pesticides and organic compounds were in widespread use for nearly 40 years until banned or restricted in the 1970's and 1980's (Smith and others, 1988), when it was learned that many of these compounds are toxic and also accumulate in the food chain. These compounds include organochlorine pesticides (such as DDT and chlordane) and polychlorinated biphenyls (PCBs, formerly used as electrical insulators). Because of the low chemical reactivity, resistance to oxidation, and resistance to other degenerative processes, residues of these compounds have been shown to be persistent in the environment (Great Lakes Basin Commission, 1975). These compounds generally are not soluble in water but can accumulate in the tissues of organisms that live in the water. As a result, tissue samples of fish are collected and analyzed for the presence of these compounds.

Twenty sites were sampled from 1992 to 1995 to determine the occurrence and distribution of selected organochlorine compounds. Whole-body tissue samples of white sucker were collected at 19 of the 20 sites and smallmouth bass were collected at 5 sites. *Organic compounds were detected in whole-body fish tissue and the streambed sediment at all 20 sites sampled, which represented a variety of settings.* Of the 28 compounds analyzed for, 12 were detected.




Contaminants on the land surface can be washed into streams, commonly attached to sediment. The contaminants can enter the food chain and bioaccumulate in predator species.

*Although some of the detected compounds are known human-health risks, an interagency work group on fish-tissue contaminants (composed of representatives of the Pennsylvania Department of Environmental Protection, Pennsylvania Fish and Boat Commission, and Pennsylvania Department of Health) reviewed the data collected by the USGS, compared the data to FDA action levels, and concluded that no public-health advisories were warranted for the fish species (white sucker or smallmouth bass) collected at any of the sampling sites.* Concentrations in the whole body of fish and the edible portions (fillets) are not directly comparable. Nevertheless, the FDA action level for human consumption for total chlordane [300 µg/kg (micrograms per kilogram)], total DDT (5,000 µg/kg) (U.S. Food and Drug Administration, 1992), or total PCBs (2,000 µg/kg) (U.S. Food and Drug Administration, 1995) in the edible portion was not exceeded in the whole-body tissues at any of the sample locations. The collection of whole fish and fillet data in future studies would aid in identifying problem sites and evaluating the need for fish-consumption advisories.

Organochlorine pesticides (many of which are now banned) are persistent in the environment. Trace amounts are present in streambed sediment and fish. Fish are collected for study by a team of biologists using equipment like this barge-mounted electroshocker. (Photograph by Steven F. Siwiec, U.S. Geological Survey.)

*PCBs in fish tissue were associated with urban and industrial land use. The organochlorine pesticides and their degradation products in fish tissue showed an association with agricultural land use.* Organochlorine concentrations detected in fish tissue were evaluated in terms of the major land uses present in the basin (agricultural, forested, urban) as shown in the graph below. The two sites representing basins with a mixture of agricultural, urban, and industrial land uses had the highest concentrations of total PCBs, total DDT, and total chlordane. DDT and chlordane were associated with the highest percentages of agricultural land use. Tissue samples from sites whose drainage included the greatest percentage of urban land use, although never a dominant land use, had higher total PCB concentrations than those at sites downstream from less urban use. Samples from sites categorized as forest dominant (greater than 50 percent of the basin area forested) had the lowest number of detectable organochlorine compounds and the lowest concentrations overall.

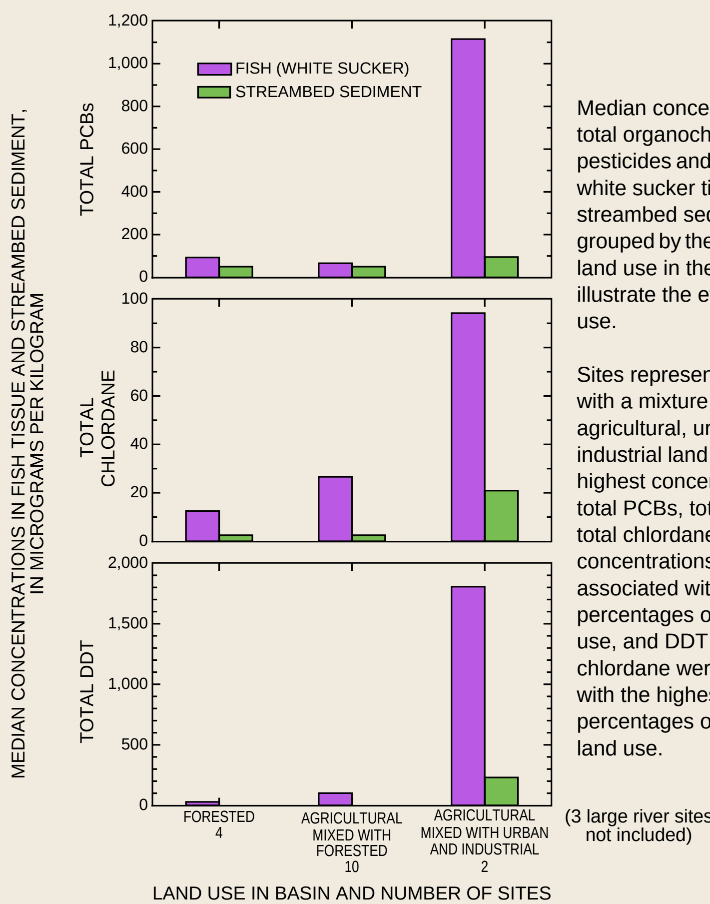
*The fish-tissue data indicate that DDT and chlordane have degraded over time and that no recent influx of these compounds has occurred.* Organochlorine pesticides such as DDT and chlordane degrade in the environment over time into a series of breakdown products called metabolites. The most persistent metabolite of DDT—*p,p'*- DDE—made up about 50 percent of the total DDT detected in fish tissue. Because the metabolite *p,p'*- DDE is the most persistent, it can be expected to be the major metabolite present late in the degradation process. The high percentage of *p,p'*- DDE indicates no recent influx of total DDT within the basin. Concentrations of two components of total chlordane, *cis*-chlordane and *trans*-nonachlor, were the highest among the chlordane components detected in fish tissue. These are the most abundant and persistent components of chlordane. The high concentrations of more persistent components indicate that degradation has taken place.

## Synthetic Organic Compounds in Streambed Sediment

*At four sites, concentrations of total DDT or total chlordane in streambed sediment exceeded USEPA Tier 1 guidelines for protection of aquatic life (U.S. Environmental Protection Agency, 1996b). Tier 1 guidelines for total PCBs were not exceeded at any of the sites. Of the 32 compounds analyzed for, 15 were detected.* The highest concentrations were for metabolites of DDT and components of total chlordane, more specifically, the concentrations of the *p,p'*- forms of DDD, DDE, and DDT, *trans*-nonachlor, and *cis*-nonachlor. Further analysis of the data shows a strong correlation between the concentrations of these compounds and PCBs in the streambed sediments and whole-fish tissues, indicating the possibility of a direct contaminant pathway. For example, the highest concentrations of total DDT and chlordane in streambed sediments were in Quittapahilla Creek. The fish-tissue samples at that site also had the highest concentrations of DDT and chlordane. Codorus Creek had the highest concentrations of total PCBs in both streambed sediment and fish tissue.

The concentration patterns for streambed sediment and fish tissue with respect to land use were similar (see graph below). Sites representing basins with agricultural and mixed urban and industrial land use had the highest concentrations of total PCBs, total DDT, and total chlordane. Sites representing basins with the highest percentage of agricultural land use showed the highest concentrations of total DDT and total chlordane. Sites representing basins with the greatest percentage of urban and industrial land use (though never dominant) had the highest concentrations of total PCBs. Streambed sediments from the forest-dominated sites had the lowest concentrations of all organochlorine compounds and PCBs.

At most sites where DDT was detected, the DDE/DDT ratio was greater than 1, indicating long-term degradation of the DDT. At only 3 of




Median concentrations of total organochlorine pesticides and total PCBs in white sucker tissue and streambed sediment are grouped by the predominant land use in the basin to illustrate the effects of land use.

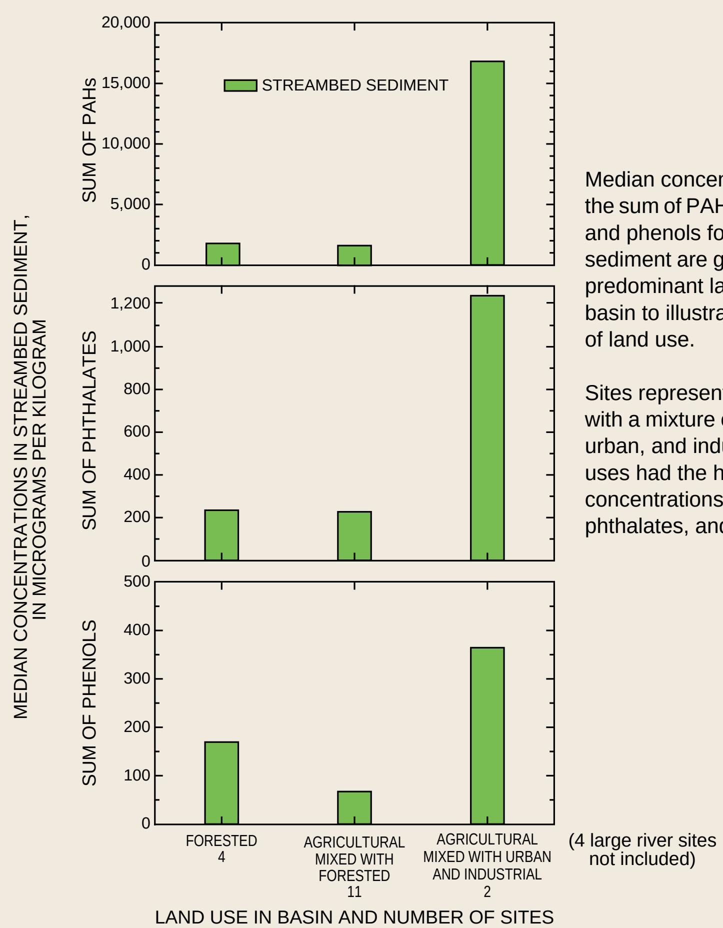
Sites representing basins with a mixture of agricultural, urban, and industrial land uses had the highest concentrations of total PCBs, total DDT, and total chlordane. PCB concentrations were associated with the highest percentages of urban land use, and DDT and chlordane were associated with the highest percentages of agricultural land use.

the 21 sites did concentrations of DDT in the sediment and DDE/DDT ratios indicate a recent influx of DDT. At six of the sites, data were available to compare concentrations of organic compounds in sediment detected in 1974 (Hollowell, 1975) to the concentrations detected in the 1992-95 NAWQA survey. At most of these sites, total DDT and total chlordane concentrations declined between 1974 and 1995. The concentrations of the most persistent metabolite—*p, p'*-DDE— increased at most of these sites, illustrating the continued degradation of DDT. Concentrations of total DDT and total PCBs increased significantly at the Codorus Creek site, indicating a recent influx of these contaminants. This is also one of the sites where the DDE/DDT ratio indicated a recent influx of DDT. The evidence of a recent influx of DDT at the Codorus Creek site or the other two sites was not apparent from the analysis of DDT in fish tissue.

*Concentrations of semivolatile organic compounds (SVOCs) in streambed sediment exceeded USEPA Tier 1 guidelines for protection of aquatic life at 4 of the 21 sites.* All the SVOCs that exceeded the guidelines were polycyclic aromatic hydrocarbons (PAHs), a group of organic compounds that result from incomplete combustion of fossil fuels, wood, and municipal solid waste or are present naturally in coal. A nationwide study using NAWQA data (Lopes and others, in press) showed concentrations of PAHs were strongly correlated with population density, urban land use, and toxic releases to the air.

The sites where concentrations of PAHs exceeded Tier 1 guidelines include Quittapahilla Creek and Codorus Creek. These basins have agricultural land mixed with urban and industrial land use (see graph below) and also have the highest concentrations of PCBs, DDT, and chlordane in streambed sediment and fish tissue. Concentrations of PAHs also exceeded guidelines at Swatara Creek, which drains an area of significant coal-mining activity, and at the Susquehanna River at Conowingo Reservoir.

The sum of PAHs was well above the NAWQA medians even at sites with little urban, industrial, or mining land use. The proximity of the Study Unit to major metropolitan areas of the northeastern United States is a probable explanation for this fact because PAHs are also distributed regionally by atmospheric deposition. The sum of phthalates also was higher than the national NAWQA median at all of the sites. Phthalates are commonly from industrial sources. The sum of phenols ranged from well below the national median to well above the national median. Phenols are used in industrial, agricultural, and sanitation activities and also can occur naturally.




Median concentrations for the sum of PAHs, phthalates, and phenols for streambed sediment are grouped by the predominant land use in the basin to illustrate the effects of land use.

Sites representing basins with a mixture of agricultural, urban, and industrial land uses had the highest concentrations of PAHs, phthalates, and phenols.

The fish community and the stream habitat were evaluated at selected reaches in each of the seven long-term monitoring basins (see map on page 7) to determine the distribution of fish populations and the relations of fish populations to stream habitat (Bilger and Brightbill, in press). Studies of fish-community composition were done annually from June 1993 to June 1995. As with other parts of the NAWQA study, each basin represented an environmental subunit. Environmental characteristics for the selected reaches consisting of instream and riparian habitat, hydrology, and water quality were determined.

A total of 33,143 fish were collected from the 28 samples from multiple reaches in the 7 basins during the 3-year intensive sampling period from 1993 to 1995. Thirty-nine species were collected from eight families. The Cyprinidae (minnows) were represented by the greatest number of species (17), followed by the Centrarchidae (sunfishes) with 7 species, and by the Percidae (perches and darters) with 4 species. The most abundant and frequently collected species were the blacknose dace, white sucker, and mottled and slimy sculpins. Together, these species made up 49 percent of the total fish collected. Statistical analysis determined that the composition of fish communities for each stream did not differ between years and multiple reaches.

*Fish communities inhabiting the seven streams were related to the bedrock type.* Limestone and dolomite bedrock are associated with limestone streams (see table on page 6). Sandstone, shale, and crystalline rocks are associated with freestone streams (see table on page 6). Limestone streams were located in valley areas and receive much of their flow from large springs (Shaffer, 1991). Limestone springs discharge cool water to the stream throughout the year. The limestone (calcium carbonate) dissolved in the spring water provides for a stable pH. These factors make the conditions favorable for sensitive fish such as trout species. Limestone streams are known for naturally low numbers of fish species and high abundances of aquatic plants and invertebrate life. The valuable limestone farmland is commonly cultivated to the edge of the streambank, leaving little or no riparian vegetation (canopy cover). This, in turn, affects water temperature. Agricultural areas with little or no riparian buffers can also have increased sedimentation.

Freestone streams tend to be fed from runoff and by small feeder-type streams and gain water a little at a time. The flow and temperature in these streams is more variable. Freestone streams do not have as much dissolved calcium as the limestone streams and are vulnerable to changes in pH. These streams also tend to flow off ridges and through areas with hilly topography, making the riparian zones less likely to be cultivated. Although freestone streams do not have the large springs discharging to the stream, the absence of alterations to the riparian habitat is favorable for fish communities.

*The habitat characteristics that proved most influential in defining fish communities in the seven long-term monitoring basins were mean channel width, mean water temperature, mean canopy angle, and suspended sediment.* These four variables combined accounted for about 79 percent of the variation in the stream habitat-species relation.

Fish are sensitive to water temperature. Warm-water streams support different fish communities than cool-water streams. Streams with moderate

Freestone streams, such as Stony Creek (right), tend to be supplied by runoff from small streams that flow off ridges. Riparian vegetation provides favorable habitat conditions by shading the stream and reducing sedimentation.

Limestone streams, like Bachman Run (left), are supplied by springs that have nearly constant ambient temperatures throughout the year. Agriculture is a dominant land use that can degrade habitat conditions by reducing riparian vegetation and increasing sedimentation. Habitat degradation can offset the natural benefits of having a supply of cool water from springs.

water temperatures have species found in both the cooler and warmer streams. Canopy angle and channel width, which affect water temperature, influence the fish species that are able to inhabit a stream. Canopy angle determines the amount of sunlight that reaches the stream surface. A wide stream can have a well-established riparian zone, but the canopy cannot shade the entire stream; thus, the water temperature is typically higher than for a smaller stream with the same type of riparian zone.

Fish were sensitive to suspended sediment; therefore, erosional bank conditions also influenced fish communities. Steep, high banks with little vegetative cover have a greater chance of erosion during storms than lower banks with more vegetation. Banks consisting of finer sediment are more erodible than banks that consist of cobbles and boulders. The more tolerant fish species were present at sites that were warmer and where the banks were more eroded than at sites that were cooler and had more stable banks. These factors also influence the amount of oxygen in the stream water. Fish with high oxygen demands typically thrive in cooler waters with little to no erosion and with fairly high oxygen concentrations. Fish with lower oxygen demands can live in warmer waters where lower oxygen concentrations are common.

The health or general condition of the fish community was determined by examining the populations of pollution-tolerant and -intolerant species, the numbers of nonnative species, the percentage of omnivores, and the percentage of individuals with external anomalies. *The assessment of the fish community, based on these factors, showed that fish populations were healthier in the three freestone streams than in the four limestone streams.* This may be the result of a number of interrelated factors, such as riparian vegetation and canopy angle, which affect temperature and sedimentation. The intense agricultural activity in limestone areas can have an influence on the fish community. *The influence of agriculture on fish communities is related to habitat degradation rather than nutrients in the water.* The limestone agricultural settings appear to adversely affect the fish community in many ways. Although limestone streams have many characteristics that would support a healthy fish population, changes in the land use around the stream can adversely affect the native fish populations (Shaffer, 1991). The limestone agricultural streams chosen for this study were chosen to assess the effects of intense agricultural activity and do not represent the fish populations of all limestone streams.

The Susquehanna River at the Rockville Bridge at Marysville, Pa., looking west. (Reprinted from Alan R. Wycheck and published with permission.)

**Other Ecological Indicators**

In summary, the overall ecological condition of the Lower Susquehanna River Basin appears to represent good water quality for aquatic life and low contaminant levels. In addition to analyses of the fish community, preliminary analysis of benthic-invertebrate communities collected and analyzed at the seven long-term monitoring sites are mostly indicative of the natural conditions that would be expected. For example, headwater limestone streams have fewer species than larger freestone streams. No sites had benthic-invertebrate communities that indicated adverse effects from water quality. Examination of long-term retrospective data generated by local regulatory agencies confirms that ecological conditions in the basin are improving. Sensitive water-quality indicators such as mayflies are now considered a local nuisance species at nighttime sporting events along the Susquehanna River at Harrisburg, Pa.

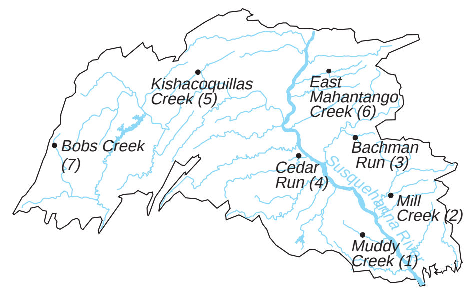
## Comparison of Stream Quality in the Lower Susquehanna River Basin with Nationwide Findings

Seven major water-quality characteristics were evaluated for stream sites in each NAWQA Study Unit. Summary scores for each characteristic were computed for all sites that had adequate data. Scores for each site in the Lower Susquehanna River Basin were compared with scores for all sites sampled in the 20 NAWQA Study Units during 1992–95. Results are summarized by percentiles; higher percentile values generally indicate poorer quality compared with other NAWQA sites. Water-quality conditions at each site also are compared to established criteria for protection of aquatic life. Applicable criteria are limited to nutrients and pesticides in water and semivolatile organic compounds, organochlorine pesticides, and PCBs in sediment. (Methods used to compute rankings and evaluate aquatic-life criteria are described by Gilliom and others, in press.)

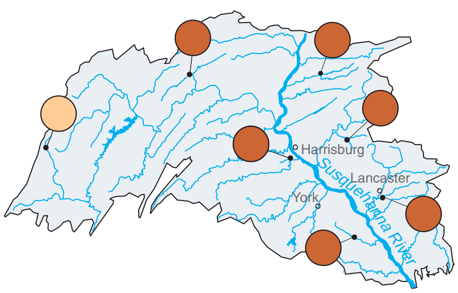
EXPLANATION

RANKING OF STREAM QUALITY RELATIVE TO ALL NAWQA STREAM SITES—Darker colored circles generally indicate poorer quality. Bold outline of circle indicates that one or more aquatic life criteria were exceeded.

- Greater than the 75th percentile (among the highest 25 percent of NAWQA stream sites)
- Between the median and the 75th percentile
- Between the 25th percentile and the median
- Less than the 25th percentile (among the lowest 25 percent of NAWQA stream sites)

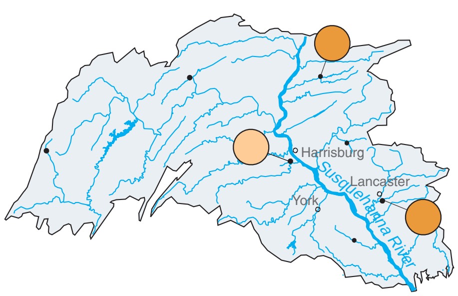



Surface-water long-term monitoring sites and subunit numbers



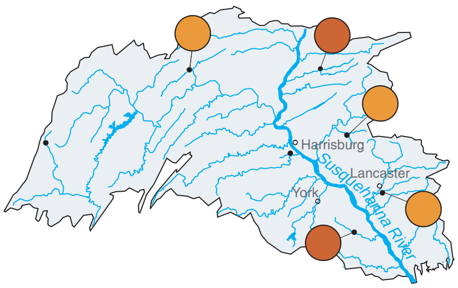

### NUTRIENTS in water

Comparisons of scores based on nitrate, phosphorus, and ammonia concentrations in streams showed that the agricultural and urban sites were among the highest of all NAWQA Study-Unit sites (above the 75th percentile). Animal manure and fertilizer are the primary sources of the nitrogen. The forested site was above the 25th percentile nationally, which may be related to atmospheric deposition of nitrogen or the small part (less than 15 percent) of the basin in nonforested land use.




### PESTICIDES in water

The scores based on total herbicide concentrations and total insecticide concentrations were higher than the national median at the two agricultural sites. The score for total herbicides and total insecticides was slightly lower than the national median at the urban site.

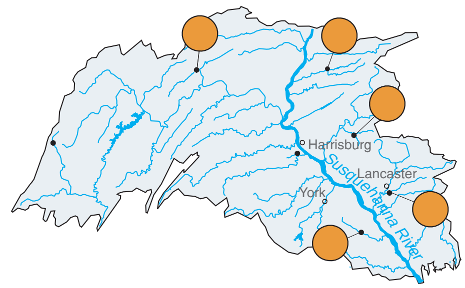



### ORGANOCHLORINE PESTICIDES and PCBs in streambed sediment and biological tissue

Comparison of scores based on total PCBs and organochlorines in fish tissue and streambed sediment showed two of the agricultural sites to be among the highest of all NAWQA Study-Unit sites; the other three agricultural sites were between the median and 75th percentile. The Pennsylvania interagency work group composed of key agencies compared the data to FDA action levels and concluded that there was no evidence of concentrations in fish tissue that would warrant human-health advisories for fish consumption. Although persistent, the major compounds detected showed signs of degradation. None of the five long-term monitoring sites shown here exceeded the USEPA Tier 1 sediment guidelines for total DDT, total chlordane, or total PCBs. Two of the long-term monitoring sites did not have sufficient sediment or target fish species for sample collection.

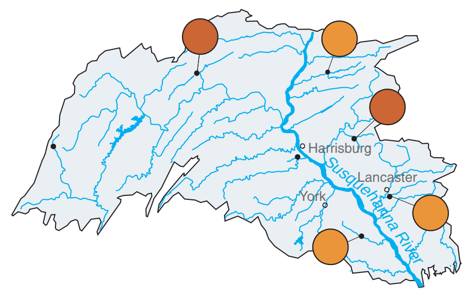
### TRACE ELEMENTS in streambed sediment

Scores based on trace-element concentrations in streambed sediments at the five long-term monitoring sites where sediment was collected were above the national median for all NAWQA Study Unit sites. The concentrations of trace elements in sediment were not well correlated with concentrations in fish liver tissue for 8 of the 11 trace elements, indicating that the elements in the sediment may not have been bioavailable.



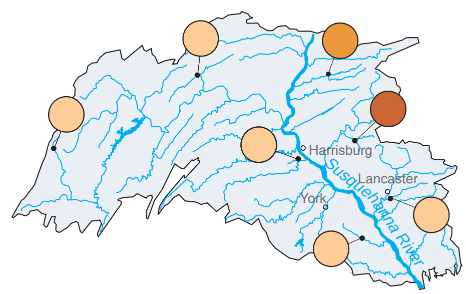

### SEMIVOLATILE ORGANIC COMPOUNDS (SVOCs) in streambed sediment

Comparison of SVOCs showed that the concentrations of phthalates, PAHs, and phenols at two of the sampling sites were among the highest of all NAWQA Study-Unit sites. Concentrations at the three other sites were above the national median. None of the long-term monitoring sites sampled exceeded the USEPA Tier 1 guidelines for SVOCs in streambed sediment.



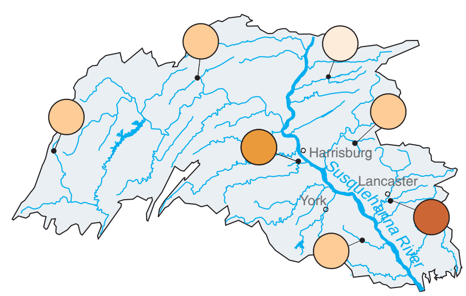

### STREAM-HABITAT DEGRADATION

Stream-habitat scores at six of the seven sites were ranked between the 25th and 75th percentile nationally. Bachman Run had the poorest stream-habitat score because of high bank erosion and minimal vegetative bank stability; it was ranked as one of the most degraded of all NAWQA Study-Unit sites.




### FISH-COMMUNITY DEGRADATION

Fish communities at five of the seven sites were ranked between the 25th and 75th percentile nationally. East Mahantango Creek exhibited a diverse and healthy fish community and was ranked as having one of the least degraded fish communities of all NAWQA Study-Unit sites. The fish community at Mill Creek scored poorly because of the high percentage of pollution-tolerant and omnivorous species and the high incidence of anomalies; it ranked among the poorest of all NAWQA Study-Unit sites.




### CONCLUSIONS

In the Lower Susquehanna River Basin Study Unit, compared to the other NAWQA study units:

- Nutrient concentrations in streams are high and, in agricultural areas, often would exceed drinking-water standards if the water was not filtered and treated before use as a public-water supply.
- Pesticide concentrations are near the national median but would rarely exceed drinking-water standards.
- Concentrations of PCBs and organochlorine pesticides in fish tissue at some sites are among the highest; however, an interagency work group concluded that no human-health advisories for fish consumption were warranted.

## Comparison of Ground-Water Quality in the Lower Susquehanna River Basin with Nationwide Findings

Five major water-quality characteristics were evaluated for ground-water studies in each NAWQA Study Unit. Ground-water resources were divided into two categories: (1) drinking-water aquifers, and (2) shallow ground water underlying agricultural or urban areas. Summary scores were computed for each characteristic for all aquifers and shallow ground-water areas that had adequate data. Scores for each aquifer and shallow ground-water area in the Lower Susquehanna River Basin were compared with scores for all aquifers and shallow ground-water areas sampled in the 20 NAWQA Study Units during 1992–95. Results are summarized by percentiles; higher percentile values generally indicate poorer quality compared with other NAWQA ground-water studies. Water-quality conditions for each drinking-water aquifer also are compared to established drinking-water standards and criteria for protection of human health. (Methods used to compute rankings and evaluate standards and criteria are described by Gilliom and others, in press.)

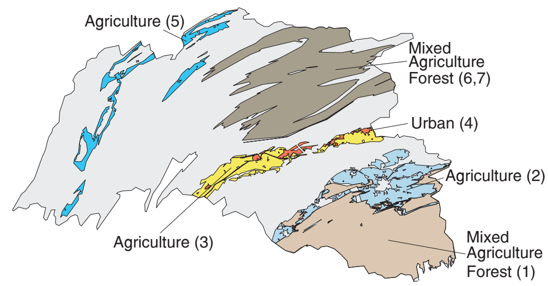
EXPLANATION

| SUBUNIT NUMBER | SUBUNIT NAME |
|---|---|
| 1 | Piedmont crystalline (mixed land use) |
| 2 | Piedmont limestone agricultural |
| 3 | Great Valley limestone agricultural |
| 4 | Great Valley limestone urban |
| 5 | Appalachian Mountain limestone agricultural |
| 6,7 | Appalachian Mountain sandstone and shale (mixed land use) |

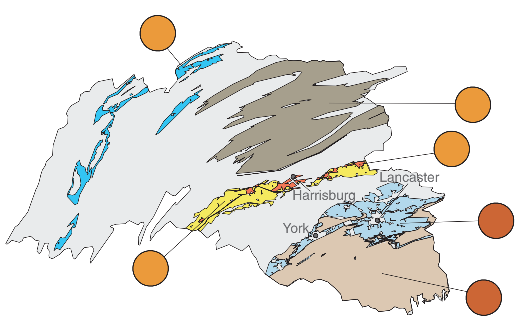
All of these subunits represent both shallow ground-water areas and drinking-water aquifers. For national comparison purposes, these subunits were compared to the summary scores from other drinking-water aquifers.

RANKING OF GROUND-WATER QUALITY RELATIVE TO ALL NAWQA GROUND-WATER STUDIES—Darker colored circles generally indicate poorer quality. Bold outline of circle indicates one or more standards or criteria were exceeded

- Greater than the 75th percentile (among the highest 25 percent of NAWQA ground-water studies)
- Between the median and the 75th percentile
- Between the 25th percentile and the median
- Less than the 25th percentile (among the lowest 25 percent of NAWQA ground-water studies)
- Insufficient data for analysis

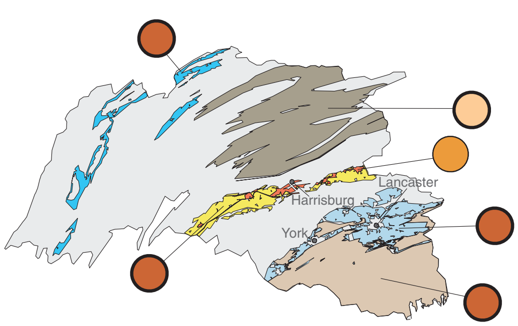



Ground-water subunits for Land-use Studies and Subunit Surveys




### RADON

Radon activities in limestone and crystalline subunits in the Piedmont Physiographic Province were among the highest of all NAWQA Study Units. Activities in the remaining subunits were slightly above the 50th percentile when compared to other subunits representing drinking-water aquifers in all NAWQA Study Units.

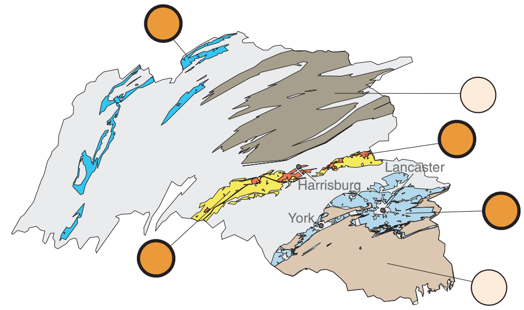



### NITRATE

Nitrate concentrations in agricultural areas underlain by limestone bedrock were among the highest of all NAWQA Study Units, and numerous drinking-water samples exceeded the drinking-water standard for nitrate. Ground water in the subunits underlain by crystalline bedrock also had high nitrate concentrations. Ground water in the urban subunit and the subunit underlain by sandstone and shale had nitrate concentrations closer to the median when compared to all subunits representing drinking-water aquifers in all NAWQA Study Units.

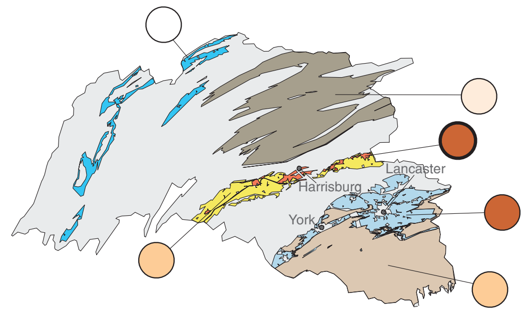
## DISSOLVED SOLIDS

Scores based on concentrations of dissolved solids were above the 50th percentile for all of the subunits underlain by limestone. The subunits underlain by crystalline bedrock and the subunit underlain by sandstone and shale had scores for dissolved solids that were among the lowest of all the subunits representing drinking-water aquifers in all NAWQA Study Units.



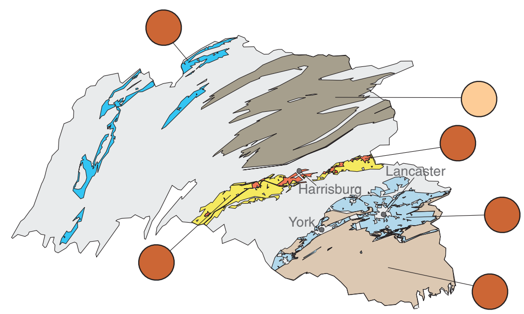

## VOLATILE ORGANIC COMPOUNDS (VOCs)

Scores based on the frequency of detections of VOCs in the Great Valley limestone urban subunit and the Piedmont limestone agricultural subunit were among the highest of subunits representing drinking-water aquifers in all NAWQA Study Units; however, the frequency of detection was much higher in the urban subunit. No VOCs were detected in the subunits in the Appalachian Mountains, which is the more rural part of the Study Unit. The Piedmont crystalline subunit and Great Valley carbonate agricultural subunit also had scores that indicated a low frequency of detections of VOCs when compared to national data.




## PESTICIDES

Pesticides were detected frequently in all the subunits except for the Appalachian Mountain sandstone and shale subunit. The limestone agricultural, limestone urban, and crystalline agricultural subunits were ranked as having some of the highest pesticide-detection frequencies of subunits representing drinking-water aquifers in all NAWQA Study Units; however, none of the detections of pesticides in water from any of the wells sampled exceeded drinking-water standards.




## CONCLUSIONS

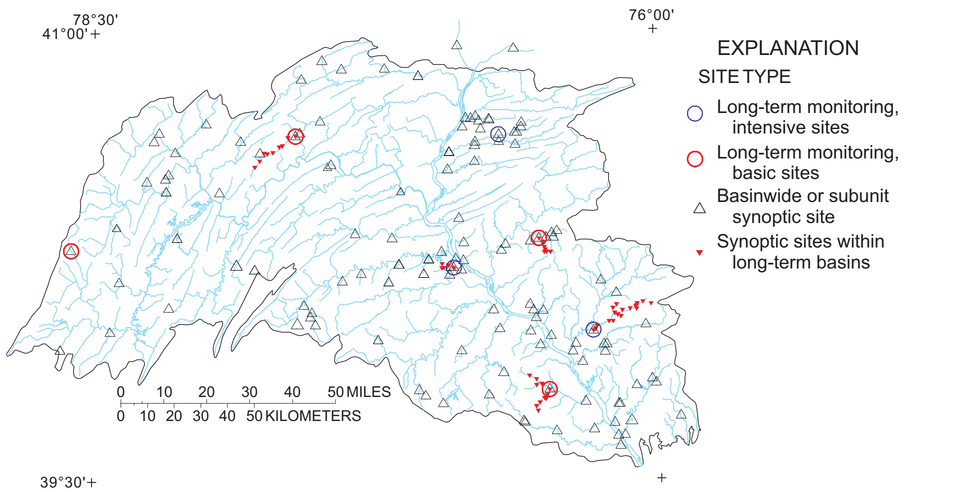
In the Lower Susquehanna River Basin Study Unit, compared to the other NAWQA study units:

- Nitrate concentrations in waters from household wells in agricultural subunits underlain by limestone are some of the highest and represent a human-health concern.
- The number of pesticide detections was high for subunits underlain by limestone and crystalline bedrock. Pesticide concentrations did not exceed USEPA MCLs for drinking water.

An overview of data collection is presented here. For details on the design and implementation of the study, see Siwiec and others (1997).

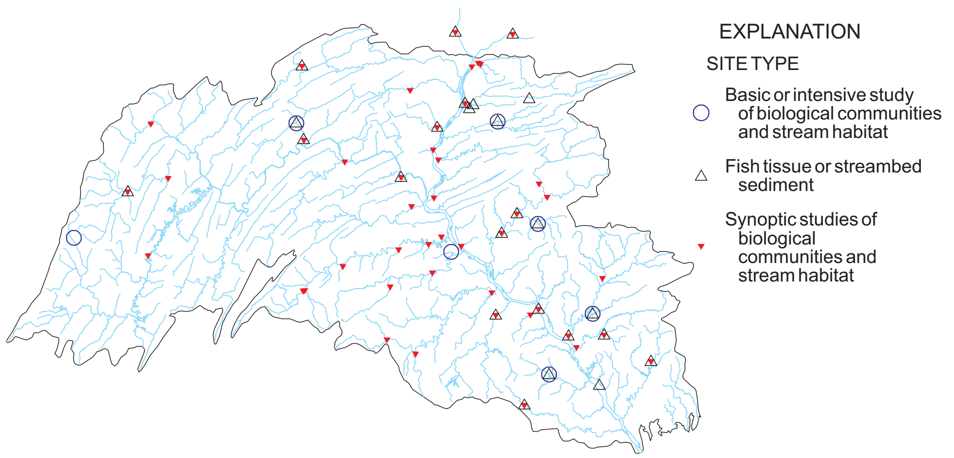
## Stream-Water Chemistry

Long-term monitoring sites were sampled periodically to determine the occurrence and seasonal variability of contaminants. To determine short-term occurrence and distribution of concentrations over a broad-scale area, synoptic studies were of three designs: (1) basinwide, to define concentrations and loads of selected constituents during periods of seasonal herbicide application; (2) within the subunits, to determine the spatial variability in constituent concentrations and to evaluate the representativeness of the long-term monitoring site; or (3) within long-term monitoring-site basins, to describe spatial variability in water quality due to point and nonpoint influxes of constituents.



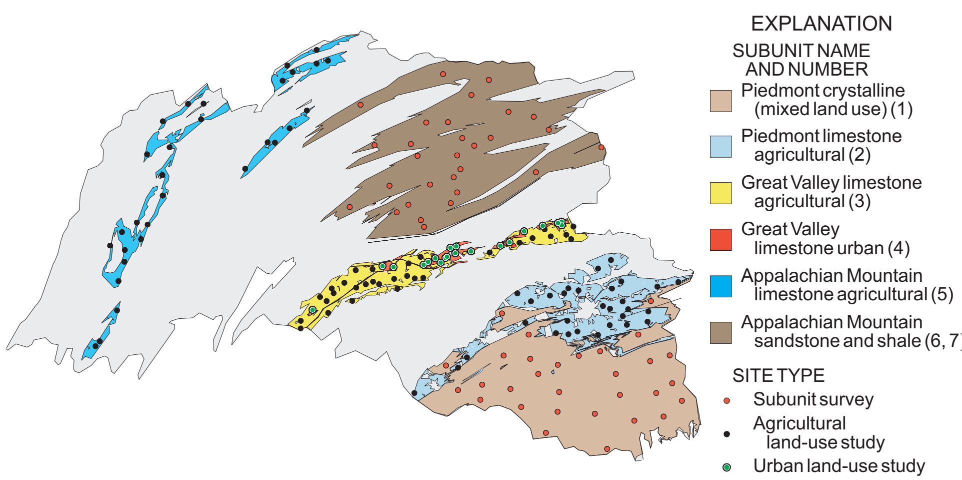

## Biological Communities, Stream Habitat, and Contaminants in Fish Tissue and Streambed Sediment

Ecological assessments included analysis of stream habitat, fish communities, invertebrates, and algae. Contaminants in streambed sediment and fish tissue were analyzed at sites on the main stem, major tributaries, and selected smaller tributaries to determine the occurrence and distribution of contaminants. Data on invertebrate communities and algae have not been analyzed and are not included in this report.




## Ground-Water Chemistry

The wells shown represent three agricultural land-use studies, one urban land-use study, and two subunit surveys. Most of the wells sampled were less than 200 feet deep. Samples from these wells generally contain water that has infiltrated through the ground in recent years and therefore could be used to indicate whether land-use practices have affected ground-water quality. All of the aquifers sampled are used for drinking-water supply.



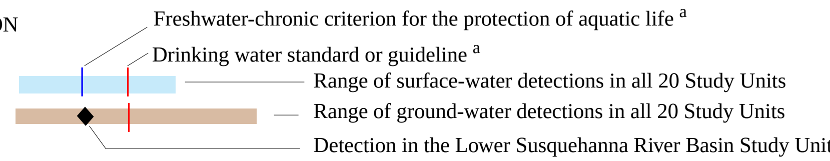
SUMMARY OF DATA COLLECTION IN THE LOWER SUSQUEHANNA RIVER BASIN STUDY UNIT, 1992-95

| **Study component (number of sites)**<br>What data were collected and why | **Types of sites sampled** | **Sampling frequency and period** |
|---|---|---|
| **Stream-Water Chemistry** | | |
| **Long-term monitoring, basic sites (4)** | | |
| Occurrence and seasonal variability of concentrations. Data included streamflow, nutrients, major ions, organic carbon, suspended sediment, water temperature, specific conductance, pH, and dissolved oxygen. In addition, 47 dissolved pesticides during synoptics and, at the site in subunit 4, 47 dissolved pesticides during base flow and selected stormflow events. | Streams draining basins ranging from 7.72 to 71.9 square miles representing four subunits (1, 3, 5, and 7). | Monthly plus storms: Apr. 1993 – Aug. 1994;<br>One site semimonthly to monthly plus storms: Nov. 1994 – Aug. 1995 |
| **Long-term monitoring, intensive sites (3)** | | |
| Occurrence and seasonal variability of concentrations—Data included all of the above constituents plus 84 dissolved pesticides in all routine base-flow samples plus selected storm samples until Sept. 1994. Data collected through Aug. 1995 at the site in subunit 4 included 47 dissolved pesticides in base-flow and selected stormflow events. Six samples for volatile organic compounds analysis were collected at the site in subunit 4. | Streams draining basins ranging from 12.6 to 54.3 square miles representing three subunits (2, 4, and 6). | Weekly: Apr. – Sept. 1993;<br>Semimonthly to monthly: Oct. 1993 – Sept. 1994;<br>One site semimonthly to monthly plus storms: Nov. 1994 – Aug. 1995 |
| **Synoptic studies (187)** | | |
| Short-term occurrence and distribution of concentrations were studied over a broad-scale area—synoptic studies were of three designs: (1) basinwide; (2) within the subunits; or (3) within long-term monitoring site basins. Data included streamflow, nutrients, pesticides, major ions, suspended sediment, water temperature, specific conductance, pH, dissolved oxygen, and volatile organic compounds (five sites in subunit 4) during low-flow conditions. | Main-stem and tributary sites for the synoptics done in the late spring and early summer during periods of seasonal herbicide application. For other synoptics, sites on streams draining basins representing the seven subunits. | Summers of 1993, 1994, and 1995. Most sites were sampled once. Selected sites were sampled two or more times as part of separate synoptic studies. |
| **Biological Communities, Stream Habitat, and Contaminants in Fish Tissue and Streambed Sediment** | | |
| **Basic and intensive assessments (7)** | | |
| Structure and function of major aquatic communities—algae, fish, and invertebrates—in three habitats (richest, depositional, and multiple) at each site; quantitatively describe habitat. | Long-term monitoring sites from stream-water chemistry component of the study design. The three intensive long-term monitoring sites were used for multiple-reach sampling. | One reach per site each year, 1993, 1994, and 1995.<br>Two additional reaches at two sites in 1994.<br>Three additional reaches at one site in 1994. |
| **Synoptic studies (45)** | | |
| Structure and function of selected aquatic communities—algae and invertebrates—in two habitats (richest and multiple) at each site; quantitatively describe habitat. Sites were chosen to match ecological surveys by other agencies in the 1970’s and 1980’s. | Sites on main stem, major tributaries, and selected smaller tributaries. Sites represented selected subunits and mixed land uses. | Once during 1993-95. |
| **Contaminants in fish tissue (20)** | | |
| Occurrence and spatial distribution of concentrations of contaminants—total PCBs, 27 organochlorine pesticides, and 22 trace elements—in fish tissue (white sucker and smallmouth bass). Whole fish were analyzed for organic contaminants; fish livers were analyzed for trace elements. | Sites on main stem, major tributaries, and selected smaller tributaries with white sucker present were primary choices. | Once at 16 sites in 1992, 5 in 1993, 5 in 1994, and 4 in 1995. The 1993-94 sites also were sampled in 1992. |
| **Synoptic studies—streambed sediment (21)** | | |
| Occurrence and spatial distribution of concentrations of contaminants—total PCBs, 31 organochlorine pesticides, 63 semivolatile organic compounds, forms of carbon, and 27 trace elements. Most sites were selected to match sites sampled for contaminants in fish tissue. | Depositional zones on main stem, major tributaries, and selected smaller tributaries representing the seven subunits plus an area of anthracite coal mining. | Once at 17 sites in 1992; once at 4 sites in 1995 |
| **Ground-Water Chemistry** | | |
| **Subunit surveys (59)** | | |
| Occurrence and distribution of concentrations in water from wells representing the subunit—nutrients, major ions, 60 volatile organic compounds, 84 pesticides, methylene blue active substances, tritium, stable isotopes of oxygen and hydrogen, bacteria (total coliform, fecal coliform, fecal streptococcus 1993-95 and *Escherichia coli* 1994-95), dissolved organic carbon, uranium, and radon. | Wells used for household supply in subunit 1 and subunits 6 and 7 combined. | One sample per well: subunits 6 and 7, 1993; subunit 1, 1994. |
| **Land-use effects—agriculture (90)** | | |
| Same as above. | Wells used for household supply in subunits 2, 3, and 5. | One sample per well: subunit 2, 1993; subunit 3, 1994; subunit 5, 1995. |
| **Land-use effects—urban (20)** | | |
| Same as above. | Wells in subunit 4. Well types include monitoring (6), household (13), and public (1). | One sample per well in 1995. |

The following tables summarize data collected for NAWQA studies during 1992-1995 by showing results for the Lower Susquehanna River Basin Study Unit compared to the NAWQA national range for each compound detected. The data were collected at a wide variety of places and times. In order to represent the wide concentration ranges observed among Study Units, logarithmic scales are used to emphasize the general magnitude of concentrations (such as 10, 100, or 1,000), rather than the precise numbers. The complete data set used to construct these tables is available upon request. The groups of compounds analyzed for were selected on the basis of national usage of pesticides and other criteria. This summary includes compounds that may not be registered for use in Pennsylvania or Maryland. Some of the compounds analyzed for have previously been registered in Pennsylvania or Maryland, but either have not been renewed or have had the registration revoked.

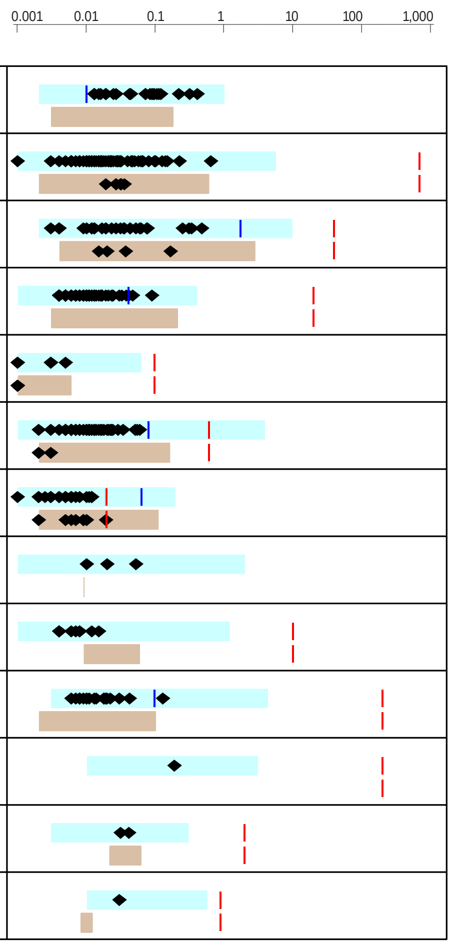
Concentrations of herbicides, insecticides, volatile organic compounds, and nutrients detected in ground water and streams of the Lower Susquehanna River Basin Study Unit. [mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; %, percent; <, less than; - -, not measured; trade names may vary]

EXPLANATION

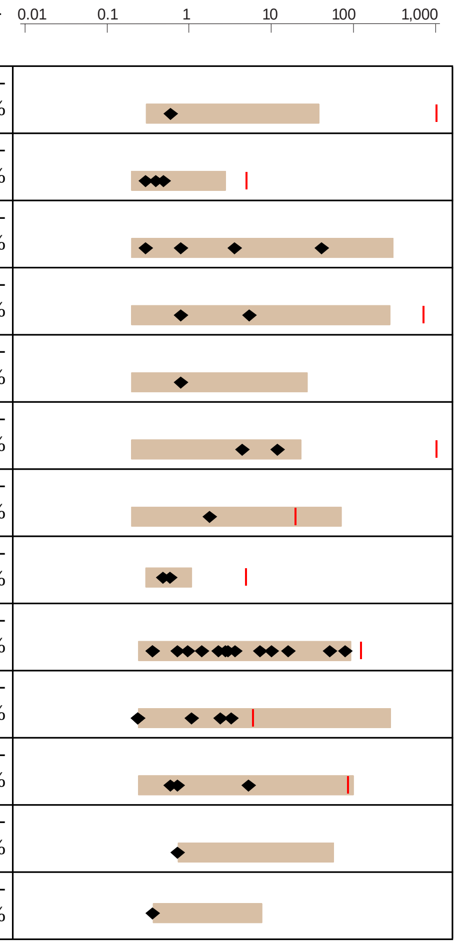



| **Herbicide** (Trade or common name) | Rate of detection [b] | Concentration, in µg/L (0.001, 0.01, 0.1, 1, 10, 100, 1,000) |
|---|---|---|
| Acetochlor (Harness, Surpass) | 13%<br>0% | |
| Acifluorfen (Blazer, Tackle 2S) | 1%<br>1% | |
| Alachlor (Lasso) | 34%<br>5% | |
| 2,6-Diethylaniline (Alachlor metabolite) | <1%<br><1% | |
| Atrazine (AAtrex) | 96%<br>66% | |
| Atrazine, Desethyl[c] (Atrazine metabolite) | 95%<br>72% | |
| Benfluralin (Balan, Benefin) | 2%<br><1% | |
| Bentazon (Basagran, bentazone) | 0%<br>2% | |
| Bromacil (Hyvar X) | 0%<br>1% | |
| Butylate (Sutan) | <1%<br><1% | |
| Cyanazine (Bladex) | 33%<br>4% | |
| 2,4-D (Esteron, Weedone) | 10%<br>1% | |
| DCPA (Dacthal) | 5%<br>0% | |
| Dicamba (Banvel) | 1%<br>1% | |
| Diuron (Karmex) | 7%<br>3% | |
| EPTC (Eptam) | 2%<br><1% | |

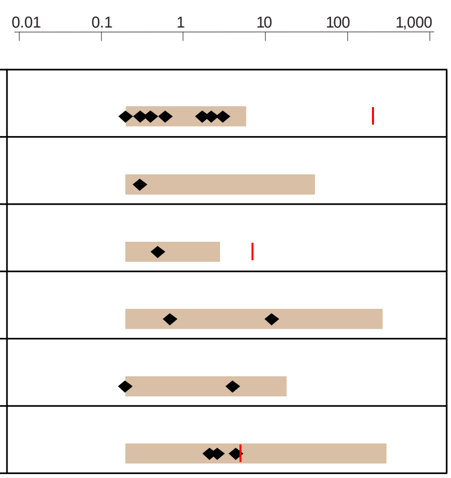
| **Herbicide** (Trade or common name) | Rate of detection [b] | Concentration, in µg/L (0.001, 0.01, 0.1, 1, 10, 100, 1,000) |
|---|---|---|
| Linuron (Lorox, Linex) | 4%<br>1% | |
| MCPA (Selectyl 40,) | 1%<br>0% | |
| Metolachlor (Dual, Pennant) | 89%<br>28% | |
| Metribuzin (Lexone, Sencor) | 4%<br><1% | |
| Napropamide (Devrinol) | 1%<br>1% | |
| Oryzalin (Surflan) | 0%<br>1% | |
| Pebulate (Tillam) | <1%<br>1% | |
| Pendimethalin (Prowl) | 13%<br><1% | |
| Prometon (Pramitol) | 75%<br>32% | |
| Pronamide (Kerb, propyzamid) | 0%<br>1% | |
| Propachlor (Ramrod, propachlore) | 1%<br>0% | |
| Simazine (Aquazine, Princep) | 87%<br>36% | |
| Tebuthiuron (Spike, Tebusan) | 26%<br>6% | |
| Terbacil[c] (Sinbar) | 2%<br>1% | |
| Trifluralin (Treflan) | 4%<br><1% | |

| **Insecticide** (Trade or common name) | Rate of detection [b] | Concentration, in µg/L |
|---|---|---|
| Azinphos-methyl[c] (Guthion) | 6%<br>0% |  |
| Carbaryl[c] (Sevin, Sevimol) | 14%<br>4% | |
| Carbofuran[c] (Furadan) | 6%<br>2% | |
| Chlorpyrifos (Dursban, Lorsban) | 8%<br>0% | |
| *p,p'*-DDE (*p,p'*-DDT metabolite) | <1%<br><1% | |
| Diazinon (Spectracide) | 6%<br><1% | |
| Dieldrin (Panoram D-31, Octalox) | 1%<br>1% | |
| Ethoprop (Mocap) | 1%<br>0% | |
| Fonofos (Dyfonate) | <1%<br>0% | |
| Malathion (malathon, Cythion) | 3%<br>0% | |
| Methomyl (Lannate, Nudrin) | 1%<br>0% | |
| Methyl parathion (Penncap-M) | <1%<br>0% | |
| Terbufos (Counter) | <1%<br>0% | |

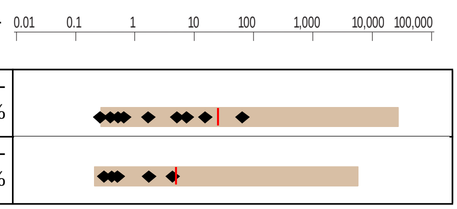


| **Volatile organic compound** (Trade or common name) | Rate of detection [b] | Concentration, in µg/L |
|---|---|---|
| Dichlorodifluoromethane (CFC 12) | --<br>1% |  |
| Dichloromethane (Methylene chloride) | --<br>2% | |
| Dimethylbenzenes (Xylenes (total)) | --<br>3% | |
| Ethylbenzene (Phenylethane) | --<br>2% | |
| Isopropylbenzene (Cumene) | --<br>1% | |
| Methylbenzene (Toluene) | --<br>2% | |
| Naphthalene | --<br>1% | |
| Tetrachloromethane | --<br>2% | |
| total Trihalomethanes | --<br>11% | |
| Trichloroethene (TCE) | --<br>5% | |
| *cis*-1,2-Dichloroethene | --<br>2% | |
| *n*-Propylbenzene (Isocumene) | --<br>1% | |
| *p*-Isopropyltoluene (*p*-Cymene) | --<br>1% | |

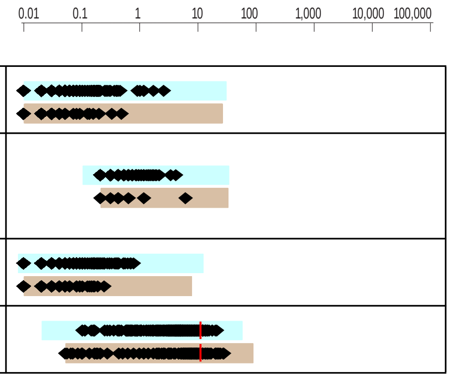


| **Volatile organic compound** (Trade or common name) | Rate of detection [b] | Concentration, in µg/L |
|---|---|---|
| 1,1,1-Trichloroethane | --<br>7% |  |
| 1,1-Dichloroethane | --<br>1% | |
| 1,1-Dichloroethene (Vinylidene chloride) | --<br>1% | |
| 1,2,4-Trimethylbenzene (Pseudocumene) | --<br>2% | |
| 1,3,5-Trimethylbenzene (Mesitylene) | --<br>2% | |
| Benzene | --<br>2% | |

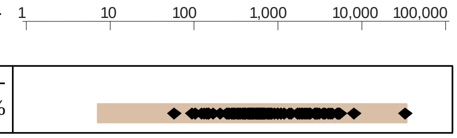


| **Volatile organic compound** (Trade or common name) | Rate of detection [b] | Concentration, in µg/L |
|---|---|---|
| Methyl *tert*-butyl ether[d] (MTBE) | --<br>11% |  |
| Tetrachloroethene (Perchloroethene) | --<br>7% | |

| **Nutrient** (Trade or common name) | Rate of detection [b] | Concentration, in mg/L |
|---|---|---|
| Dissolved ammonia | 90%<br>76% | |
| Dissolved ammonia plus organic nitrogen as nitrogen | 55%<br>5% | |
| Dissolved phosphorus as phosphorus | 70%<br>38% | |
| Dissolved nitrite plus nitrate | 100%<br>92% | |




| **Other** | Rate of detection [b] | Concentration, in pCi/L |
|---|---|---|
| Radon 222 | --<br>100% | |




Herbicides, insecticides, volatile organic compounds, and nutrients not detected in ground and surface waters of the Lower Susquehanna River Basin Study Unit.

### Herbicides

2,4,5-T (Fruitone A)
2,4,5-TP (Silvex, Fenoprop)
2,4-DB (Butyrac)
Bromoxynil ( Bromotril)
Chloramben (Amiben)
Clopyralid (Stinger)
Dacthal mono-acid (Dacthal metabolite)
Dichlorprop (2,4-DP)
Dinoseb (Dinitro)
Ethalfluralin (Sonalan)
Fenuron (Fenulon)
Fluometuron (Flo-Met)
MCPB (Thistrol)
Molinate (Ordram)
Neburon (Neburyl)
Norflurazon (Evital)
Picloram (Grazon, Tordon)
Propham (Tuberite)
Thiobencarb (Bolero)
Triallate (Far-Go, Avadex)
Triclopyr (Garlon)

### Insecticides

3-Hydroxycarbofuran (Carbofuran metabolite)
Aldicarb sulfone (Standak)
Aldicarb sulfoxide (Aldicarb metabolite)
Aldicarb (Temik, Ambush)
Disulfoton (Disyston)
Methiocarb (Slug-Geta)
Oxamyl (Vydate L)
Parathion (Roethyl-P)
Phorate (Thimet, Granutox)
Propargite (Comite, Omite)
Propoxur (Baygon)
*alpha*-HCH (*alpha*-lindane)
*cis*-Permethrin (Ambush)
*gamma*-HCH (Lindane)

### Volatile organic compounds

1,1,1,2-Tetrachloroethane
1,1,2,2-Tetrachloroethane
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113, CFC 113)
1,1,2-Trichloroethane
1,1-Dichloropropene
1,2,3-Trichlorobenzene
1,2,3-Trichloropropane
1,2,4-Trichlorobenzene
1,2-Dibromo-3-chloropropane (DBCP)
1,2-Dibromoethane (EDB, Ethylene dibromide)
1,2-Dichlorobenzene
1,2-Dichloroethane
1,2-Dichloropropane
1,3-Dichlorobenzene
1,3-Dichloropropane
1,4-Dichlorobenzene
1-Chloro-2-methylbenzene (*o*-Chlorotoluene)
1-Chloro-4-methylbenzene (*p*-Chlorotoluene)
2,2-Dichloropropane
Bromobenzene
Bromochloromethane
Bromomethane
Chlorobenzene
Chloroethane
Chloroethene (Vinyl Chloride)
Dibromomethane
Ethenylbenzene (Styrene)
Hexachlorobutadiene
*cis*-1,3-Dichloropropene
*tert*-Butylbenzene
*trans*-1,2-Dichloroethene
*trans*-1,3-Dichloropropene

### Nutrients

No non-detects

[a] Selected water-quality standards and guidelines (Gilliom and others, in press).

[b] Rates of detection are based on the number of analyses and detections in the Study Unit, not on national data. Rates of detection for herbicides and insecticides were computed by only counting detections equal to or greater than 0.01 µg/L in order to facilitate equal comparisons among compounds, which had widely varying detection limits. For herbicides and insecticides, a detection rate of “<1%” means that all detections are less than 0.01 µg/L, or the detection rate rounds to less than one percent. For other compound groups, all detections were counted and minimum detection limits for most compounds were similar to the lower end of the national ranges shown. Method detection limits for all compounds in these tables are summarized in Gilliom and others (in press).

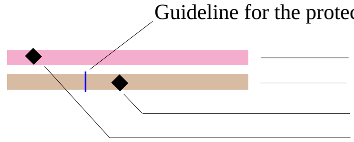
[c] Detections of these compounds are reliable, but concentrations are determined with greater uncertainty than for the other compounds and are reported as estimated values (Zaugg and others, 1995).

[d] The guideline for methyl *tert*-butyl ether is between 20 and 40 µg/L; if the tentative cancer classification C is accepted, the lifetime health advisory will be 20 µg/L (Gilliom and others, in press).

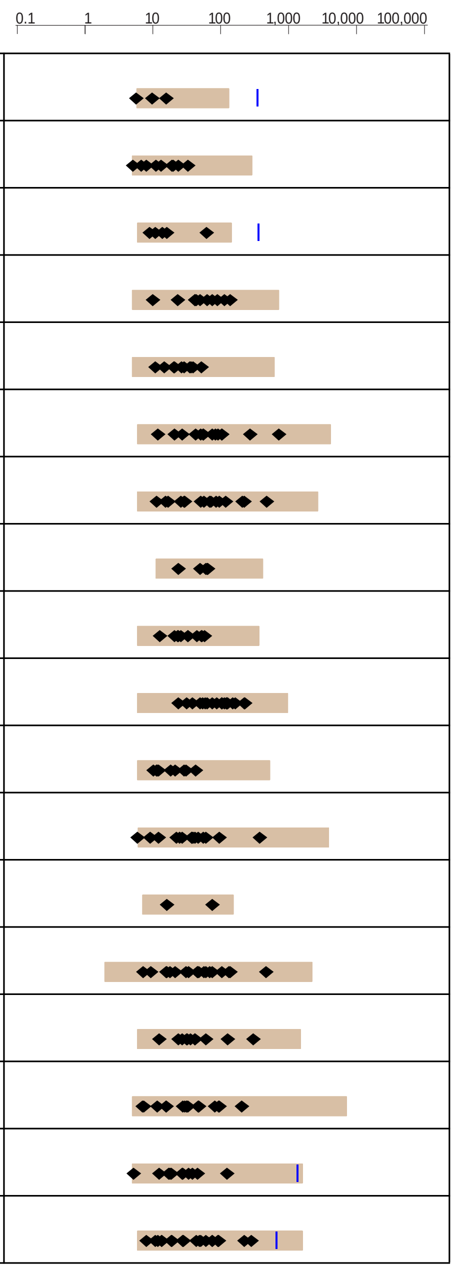
[e] Selected sediment-quality guidelines (Gilliom and others, in press).

Concentrations of semivolatile organic compounds, organochlorine compounds, and trace elements detected in fish tissue and streambed sediment of the Lower Susquehanna River Basin Study Unit. [µg/g, micrograms per gram; µg/kg, micrograms per kilogram; %, percent; <, less than; - -, not measured; trade names may vary]

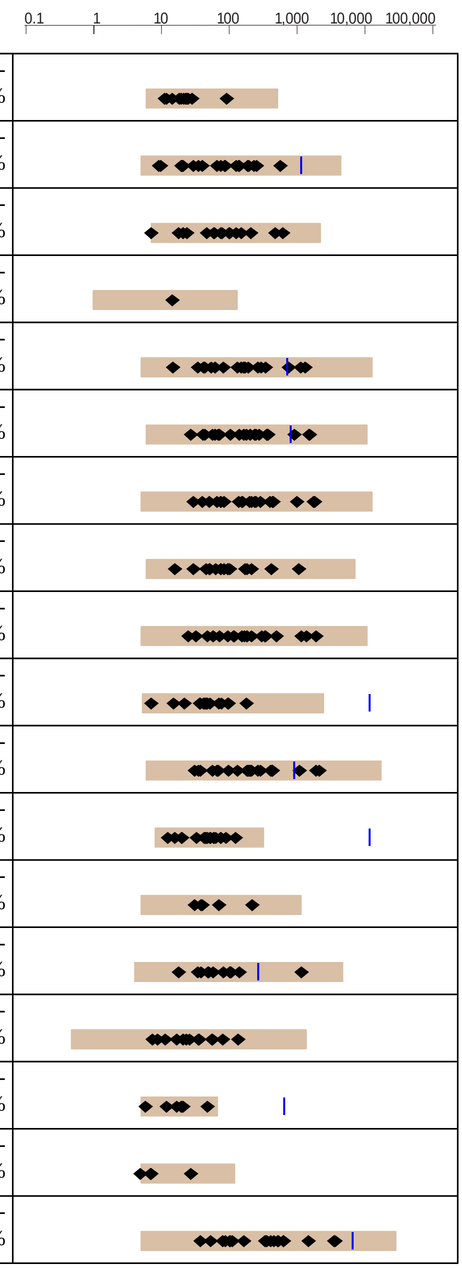
EXPLANATION



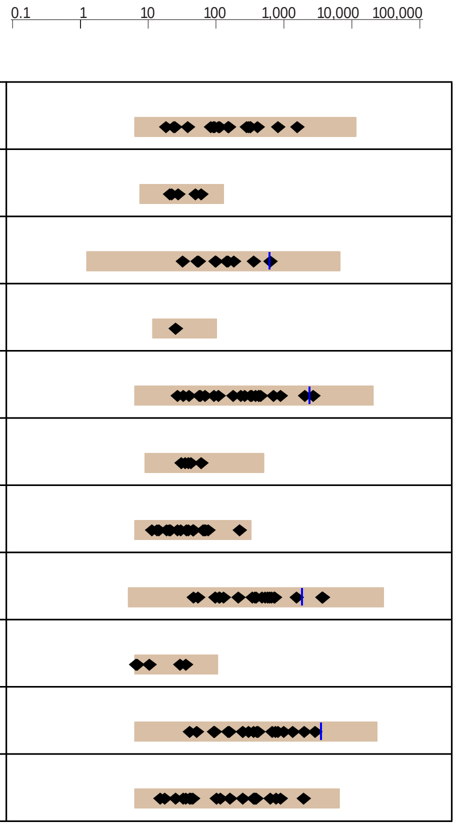

| Semivolatile organic compound | Rate of detection [b] | Concentration, in µg/kg |
|---|---|---|
| 1,2-Dichlorobenzene | --<br>14% | |
| 1,2-Dimethyl-naphthalene | --<br>43% | |
| 1,4-Dichlorobenzene | --<br>24% | |
| 1,6-Dimethyl-naphthalene | --<br>52% | |
| 1-Methyl-9H-fluorene | --<br>48% | |
| 1-Methylphen-anthrene | --<br>67% | |
| 1-Methylpyrene | --<br>76% | |
| 2,2-Biquinoline | --<br>24% | |
| 2,3,6-Trimethyl-naphthalene | --<br>52% | |
| 2,6-Dimethyl-naphthalene | --<br>100% | |
| 2-Ethylnaphthalene | --<br>53% | |
| 2-Methylanthracene | --<br>71% | |
| 3,5-Dimethylphenol | --<br>10% | |
| 4,5-Methylenephen-anthrene | --<br>90% | |
| 9H-Carbazole | --<br>52% | |
| 9H-Fluorene | --<br>76% | |
| Acenaphthene | --<br>52% | |
| Acenaphthylene | --<br>100% | |



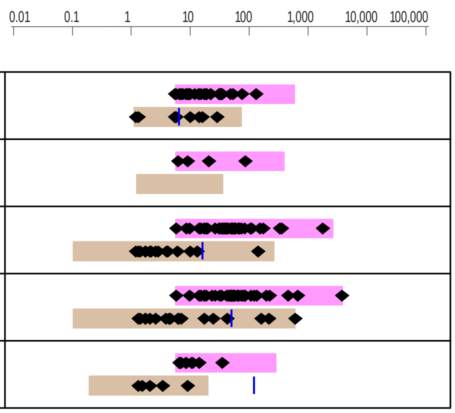

| Semivolatile organic compound | Rate of detection [b] | Concentration, in µg/kg |
|---|---|---|
| Acridine | --<br>52% | |
| Anthracene | --<br>100% | |
| Anthraquinone | --<br>76% | |
| Azobenzene | --<br>5% | |
| Benz[ *a* ]anthracene | --<br>90% | |
| Benzo[ *a* ]pyrene | --<br>100% | |
| Benzo[ *b* ]fluor-anthene | --<br>100% | |
| Benzo[*g,h,i*] perylene | --<br>81% | |
| Benzo[ *k* ]fluoran-thene | --<br>100% | |
| Butylbenzylphthalate | --<br>81% | |
| Chrysene | --<br>100% | |
| Di- *n* -butylphthalate | --<br>90% | |
| Di- *n* -octylphthalate | --<br>24% | |
| Dibenz[ *a,h* ] anthracene | --<br>57% | |
| Dibenzothiophene | --<br>62% | |
| Diethylphthalate | --<br>33% | |
| Dimethylphthalate | --<br>19% | |
| Fluoranthene | --<br>100% | |



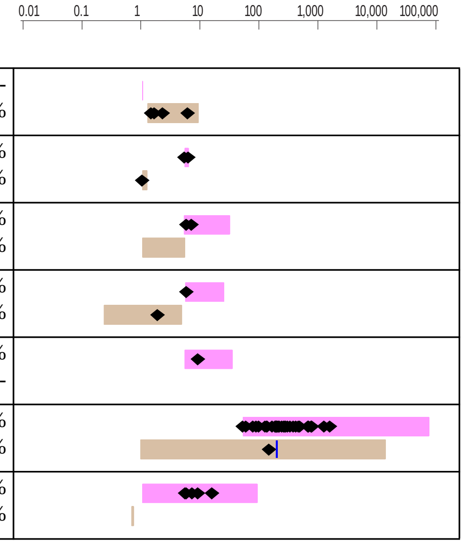
| Semivolatile organic compound | Rate of detection [b] |
|---|---|
| Indeno[1,2,3- *cd* ] pyrene | --<br>90% |
| Isoquinoline | --<br>24% |
| Naphthalene | --<br>48% |
| *N*-Nitrosodi-phenylamine | --<br>10% |
| Phenanthrene | --<br>100% |
| Phenanthridine | --<br>24% |
| Phenol | --<br>86% |
| Pyrene | --<br>100% |
| Quinoline | --<br>24% |
| bis(2-Ethyl-hexyl)phthalate | --<br>100% |
| *p*-Cresol | --<br>95% |



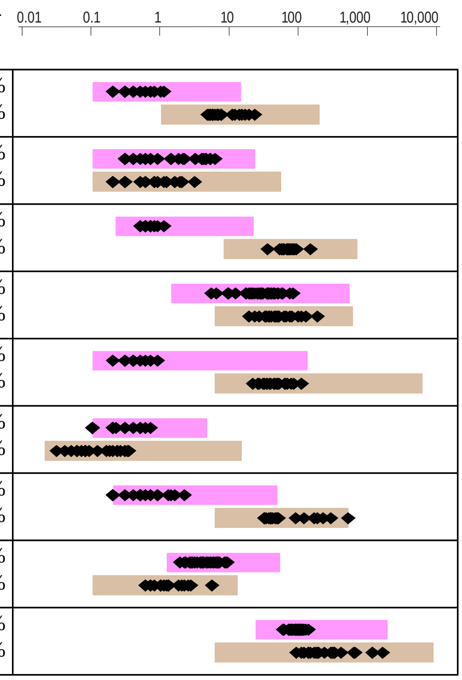

| Organochlorine compound (Trade or common name) | Rate of detection [b] |
|---|---|
| total-Chlordane | 82%<br>43% |
| DCPA (dacthal, chlorthal-dimethyl) | 10%<br>0% |
| *p,p'*-DDE | 100%<br>81% |
| total-DDT | 100%<br>86% |
| Dieldrin (Panoram D-31, Octalox) | 29%<br>24% |




| Organochlorine compound (Trade or common name) | Rate of detection [b] |
|---|---|
| Endosulfan I (*alpha*-endosulfann) | --<br>19% |
| *beta*-HCH (*beta*-BHC, *beta*) | 5%<br>5% |
| *gamma*-HCH (lindane) | 5%<br>0% |
| Heptachlor epoxide | 2%<br>5% |
| Hexachlorobenzene | 2%<br>-- |
| PCB, total | 83%<br>5% |
| Pentachloroanisole | 12%<br>0% |




| Trace element | Rate of detection [b] |
|---|---|
| Arsenic | 51%<br>100% |
| Cadmium | 90%<br>100% |
| Chromium | 67%<br>100% |
| Copper | 100%<br>100% |
| Lead | 31%<br>100% |
| Mercury | 74%<br>100% |
| Nickel | 56%<br>100% |
| Selenium | 100%<br>100% |
| Zinc | 100%<br>100% |




Semivolatile organic compounds, organochlorine compounds, and trace elements not detected in fish tissue and streambed sediment of the Lower Susquehanna River Basin Study Unit.

## Semivolatile organic compounds

1,2,4-Trichlorobenzene
1,3-Dichlorobenzene
2,4-Dinitrotoluene
2,6-Dinitrotoluene
2-Chloronaphthalene
2-Chlorophenol
4-Bromophenyl-phenylether
4-Chloro-3-methylphenol
4-Chlorophenyl-phenylether
Benzo [*c*] cinnoline
C8-Alkylphenol
Isophorone
*N*-Nitrosodi-*n*-propylamine
Nitrobenzene
Pentachloronitrobenzene
bis (2-Chloroethoxy)methane

## Organochlorine compounds

Aldrin (HHDN, Octalene)
Chloroneb (Tersan SP)
Endrin
Heptachlor
Isodrin
Mirex (Dechlorane)
Toxaphene (Camphechlor)
*alpha*-HCH (*alpha*-BHC, *alpha*-lindane)
*cis*-Permethrin (Ambush, Pounce)
*delta*-HCH (*delta*-BHC)
*o,p'*-Methoxychlor
*p,p'*-Methoxychlor
*trans*-Permethrin (Ambush, Pounce)

## Trace elements

No non-detects

American Institute for Cancer Research, 1992, Everything doesn't cause cancer: Washington, D.C., 4 p.

Bickford, T.M., Lindsey, B.D., and Beaver, M.R., 1996, Bacteriological quality of ground water used for household supply, Lower Susquehanna River Basin, Pennsylvania and Maryland: U.S. Geological Survey Water-Resources Investigations Report 96-4212, 31 p.

Bilger, M.D., and Brightbill, R.A., in press, Fish communities and their relation to selected physical and chemical characteristics of streams at seven long-term monitoring sites in the Lower Susquehanna River Basin, Pennsylvania and Maryland, 1993-95: U.S. Geological Survey Water-Resources Investigations Report 98-4004.

Breen, K.J., and Gavin, A.J., 1995, Reconnaissance of trace-metal loadings in Mahanoy Creek—A tributary to the Lower Susquehanna River, Pennsylvania, affected by acidic mine drainage [abs.]: EOS, Transactions of the American Geophysical Union, Supplement with abstracts for the 1995 Spring Meeting, Baltimore, Md., v. 76, no. 17, p. S133.

Breen, K.J., Gavin, A.J., and Schnabel, R.R., 1995, Occurrence and yields of triazine herbicides in the Susquehanna River and tributaries during base-flow conditions in the Lower Susquehanna River Basin, Pennsylvania and Maryland, June 1993, *in* Hill, Paula, and Nelson, Steve, eds., Toward a Sustainable Watershed—The Chesapeake Experiment, Proceedings of the 1994 Chesapeake Research Conference, Norfolk, Va., June 1-3, 1994: Edgewater, Md., Chesapeake Research Consortium Publication 149, p. 312-328.

Breen, K.J., Hainly, R.A., and Hoffman, S.A., 1991, National Water-Quality Assessment Program—The Lower Susquehanna River Basin: U.S. Geological Survey Open-File Report 91-168, 2 p.

Canadian Council of Resource and Environment Ministers, 1996, Canadian water quality guidelines: Ottawa, Ontario, prepared by the Task Force on Water Quality Guidelines, Canadian Council of Resource and Environment Ministers, originally published 1987, plus 21 appendixes published through May 1996 (variously paged).

Centers for Disease Control and Prevention, 1996, Surveillance for waterborne-disease outbreaks—United States, 1993-1994: Atlanta, Ga., Morbidity and Mortality Weekly Reports, v. 45, no. SS-1.

Cohn, T.A., Caulder, D.L., Gilroy, E.J., Zynjuk, L.D., and Summers, R.M., 1992, The validity of a simple statistical model for estimating fluvial constituent loads—An empirical study involving nutrient loads entering Chesapeake Bay: Water Resources Research, v. 289, no. 9, p. 2,353-2,363.

Daly, M.H., and Lindsey, B.D., 1996, Occurrence and concentrations of volatile organic compounds in shallow ground water in the Lower Susquehanna River Basin, Pennsylvania and Maryland: U.S. Geological Survey Water-Resources Investigations Report 96-4141, 8 p.

Durlin, R.R., and Schaffstall, W.P., 1994, Water resources data, Pennsylvania, water year 1993, v. 2, Susquehanna and Potomac River Basins: U.S. Geological Survey Water-Data Report PA-93-2, 361 p.

____1996, Water resources data, Pennsylvania, water year 1994, v. 2, Susquehanna and Potomac River Basins: U.S. Geological Survey Water-Data Report PA-94-2, 418 p.

____1997, Water resources data, Pennsylvania, water year 1995, v. 2, Susquehanna and Potomac River Basins: U.S. Geological Survey Water-Data Report PA-95-2, 518 p.

Gilliom, R.J., Mueller, D.K., and Nowell, L.H., in press, Methods for comparing water-quality conditions among National Water-Quality Assessment Study Units, 1992-1995: U.S. Geological Survey Open-File Report 97-589.

Great Lakes Basin Commission, 1975, Great Lakes basin framework study, Appendix 8: Ann Arbor, Mich., Great Lakes Basin Commission, p. 47-49.

Hainly, R.A., and Bickford, T.M., 1997, Factors affecting pesticide concentrations in streams and shallow wells of the Lower Susquehanna River Basin, Pennsylvania and Maryland, 1993-95 [abs.]: EOS, Transactions of the American Geophysical Union, Supplement with abstracts for the 1997 Spring Meeting, Baltimore, Md., v. 78, no. 17, p. S135.

Hainly, R.A., Bilger, M.D., and Siwiec, S.F., 1994, Trace elements in bed sediment of streams in the Ridge and Valley Physiographic Province of Pennsylvania, Lower Susquehanna River Basin study unit of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program—A comparison of sampling methods and results for selected element concentrations from the NAWQA and National Uranium Resource Evaluation (NURE) Programs [abs.]: Abstract Booklet, Mid-Atlantic Highlands Area Environmental Monitoring and Assessment Conference, Hershey, Pa., February 23-25, 1994, p. 46-47.

Hainly, R.A., and Kahn, J.M., 1996, Factors affecting herbicide yields in the Chesapeake Bay Watershed, June 1994: Water Resources Bulletin, v. 32, no. 5, p. 965-984.

Hainly, R.A., and Loper, C.A., 1997, Water-quality assessment of the Lower Susquehanna River Basin, Pennsylvania and Maryland—Sources, characteristics, analysis, and limitations of nutrient and suspended-sediment data, 1975-90: U.S. Geological Survey Water-Resources Investigations Report 97-4209, 138 p.

Hainly, R.A., and Siwiec, S.F., 1994, Nitrogen sources and measured nitrogen loads in streams in the Lower Susquehanna River Basin, Pennsylvania and Maryland [abs.]: EOS, Transactions of the American Geophysical Union, Supplement with abstracts for the 1994 Fall Meeting, San Francisco, Calif., v. 75, no. 44, p. 247.

Hollowell, J.R., 1975, Results of initial sampling of heavy metals and pesticides found in stream bottom sediments in the Susquehanna River Basin: Harrisburg, Pa., Susquehanna River Basin Commission, 12 p.

Langland, M.J., Edwards, R.E., and Darrell, L.C., 1998, Trends and yields of nutrients and sediment and methods of analysis for the Nontidal Synthesis and River Input Programs, Chesapeake Bay Basin: U.S. Geological Survey Open-File Report 98-17, 59 p.

Lindsey, B.D., and Ator, S.W., 1996, Radon in ground water of the Lower Susquehanna and Potomac River Basins: U.S. Geological Survey Water-Resources Investigations Report 96-4156, 6 p.

Lindsey, B.D., Breen, K.J., and Daly, M.H., 1997, MTBE in water from fractured-bedrock aquifers, south-central Pennsylvania [abs.]: American Chemical Society, Division of Environmental Chemistry, Preprints of Extended Abstracts for the 213th National Meeting, April 13-17, 1997, San Francisco, Calif., v. 37, no. 1, p. 399-400.

Lindsey, B.D., Loper, C.A., and Hainly, R.A., 1997, Nitrate in ground water and stream base flow in the Susquehanna River Basin, Pennsylvania and Maryland: U.S. Geological Survey Water-Resources Investigations Report 97-4146, 66 p.

Lopes, T.J., Furlong, E.T., and Pritt, J.W., in press, Occurrence and distribution of semivolatile organic compounds in stream bed sediments, United States, 1992-95: Environmental Toxicology and Risk Assessment, v. 7.

Mitchell, W.B., Guptill, S.C., Anderson, K.E., Fegeas, R.G., and Hallam, C.A., 1977, GIRAS—A geographic information and retrieval and analysis system for handling land use and land cover data: U.S. Geological Survey Professional Paper 1059, 16 p.

Neilson, A.H., 1994, Organic chemicals in the aquatic environment—Distribution, persistence, and toxicity: Boca Raton, Fla., CRC Press, 438 p.

Risser, D.W., and Siwiec, S.F., 1996, Water-quality assessment of the Lower Susquehanna River Basin, Pennsylvania and Maryland—Environmental setting: U.S. Geological Survey Water-Resources Investigations Report 94-4245, 135 p.

Shaffer, L.L., 1991, The limestone streams of Pennsylvania: Harrisburg, Pa., Pennsylvania Fish and Boat Commission, 4 p.

Siwiec, S.F., Hainly, R.A., Lindsey, B.D., Bilger, M.D., and Brightbill, R.A., 1997, Water-quality assessment of the Lower Susquehanna River Basin, Pennsylvania and Maryland—Design and implementation of water-quality studies, 1992-95: U.S. Geological Survey Open-File Report 97-583, 121 p.

Smith, J.A., Witkowski, P.J., and Fusillo, T.V., 1988, Manmade organic compounds in the surface waters of the United States—A review of current understanding: U.S. Geological Survey Circular 1007, 92 p.

U.S. Environmental Protection Agency, 1991, Water-quality criteria summary: Washington, D.C., U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology, Health and Ecological Effects Division (wall poster).

_____1996a, Drinking water regulations and health advisories: Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA 822-B-96-002, 11 p.

_____1996b, The National Sediment Quality Survey—A report to Congress on the extent and severity of sediment contamination in surface waters of the United States: Washington, D.C., U.S. Environmental Protection Agency, Office of Science and Technology, draft report EPA 823-D-96-002, (variously paged).

_____1997, Chesapeake Bay nutrient reduction reevaluation summary report: Washington, D.C., EPA 903-R-97-030, 37 p.

U. S. Food and Drug Administration, 1992, Action levels for poisonous or deleterious substances in human food and animal feed: Washington, D.C., 16 p.

_____1995, Tolerances for unavoidable poisonous or deleterious substances: Federal Register, April 1, 1995, 21 CFR 109.30.

Zaugg, S.D., Sandstrom, M.W., Smith, S.G., and Fehlberg, K.M., 1995, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—determination of pesticides in water by C-18 solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 95-181, 49 p.

**The terms in this glossary were compiled from numerous sources. Some definitions have been modified and may not be the only valid ones for these terms.**

**Algae**–Chlorophyll-bearing nonvascular, primarily aquatic species that have no true roots, stems, or leaves; most algae are microscopic, but some species can be as large as vascular plants.

**Anomalies**–As related to fish, externally visible skin or subcutaneous disorders, including deformities, eroded fins, lesions, and tumors.

**Aquatic life criteria**–Water-quality guidelines for protection of aquatic life. Often refers to U.S. Environmental Protection Agency water-quality criteria for protection of aquatic organisms. *See also* **Water-quality criteria.**

**Aquifer**–A water-bearing layer of soil, sand, gravel, or rock that will yield usable quantities of water to a well.

**Atmospheric deposition**–The transfer of substances from the air to the surface of the Earth, either in wet form (rain, fog, snow, dew, frost, hail) or in dry form (gases, aerosols, particles).

**Background concentration**–A concentration of a substance in a particular environment that is indicative of minimal influence by human (anthropogenic) sources.

**Base flow**–Sustained, low flow in a stream; ground-water discharge is the source of base flow in most places.

**Bedrock**–General term for consolidated (solid) rock that underlies soils or other unconsolidated material.

**Best management practice (BMP)**–An agricultural practice that has been determined to be an effective, practical means of preventing or reducing nonpoint source pollution.

**Bioaccumulation**–The biological sequestering of a substance at a higher concentration than that at which it occurs in the surrounding environment or medium. Also, the process whereby a substance enters organisms through the gills, epithelial tissues, dietary, or other sources.

**Bioavailability**–The capacity of a chemical constituent to be taken up by living organisms either through physical contact or ingestion.

**Breakdown product**–A compound derived by chemical, biological, or physical action upon a pesticide. The breakdown is a natural process that may result in a more or less toxic and a more or less persistent compound.

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

**Community**–In ecology, the species that interact in a common area.

**Concentration**–The amount or mass of a substance present in a given volume or mass of sample. Usually expressed as microgram per liter (water sample) or micrograms per kilogram (sediment or tissue sample).

**Concentrated animal operation**–Operation where the animal density exceeds two animal units per acre on an annual basis as defined for the Pennsylvania nutrient management legislation. An animal unit is 1,000 pounds of live weight.

**Contamination**–Degradation of water quality compared to original or natural conditions due to human activity.

**Crystalline rocks**–Rocks (igneous or metamorphic) consisting wholly of crystals or fragments of crystals.

**Criterion**–A standard rule or test on which a judgment or decision can be based.

**Degradation products**–Compounds resulting from transformation of an organic substance through chemical, photochemical, and(or) biochemical reactions.

**Denitrification**–A process by which oxidized forms of nitrogen such as nitrate ($NO_3^-$) are reduced to form nitrites, nitrogen oxides, ammonia, or free nitrogen; commonly brought about by the action of denitrifying bacteria and usually resulting in the escape of nitrogen to the air.

**Detection limit**–The concentration below which a particular analytical method cannot determine, with a high degree of certainty, a concentration.

**Drainage basin**–The portion of the surface of the earth that contributes water to a stream through overland runoff, including tributaries and impoundments.

**Drinking-water standard or guideline**–A threshold concentration in a public drinking-water supply, designed to protect human health. As defined here, standards are U.S. Environmental Protection Agency regulations that specify the maximum contamination levels for public water systems required to protect the public welfare; guidelines have no regulatory status and are issued in an advisory capacity.

**Ecosystem**–The interacting populations of plants, animals, and microorganisms occupying an area, plus their physical environment.

**Environmental setting**–Land area characterized by a unique combination of natural and human-related factors, such as row-crop cultivation or glacial-till soils.

**Eutrophication**–The process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

**FDA action level**–A regulatory level recommended by the U.S. Environmental Protection Agency for enforcement by the FDA when pesticide residues occur in food commodities for reasons other than the direct application of the pesticide. Action levels are set for inadvertent pesticide residues resulting from previous legal use or accidental contamination. Applies to edible portions of fish and shellfish in interstate commerce.

**Fish community**–*See* **Community.**

**Herbicide**–A chemical or other agent that applied for the purpose of killing of undesirable plants. *See also* **Pesticide.**

**Human health advisory level**–Guidance provided by U.S. Environmental Protection Agency, State agencies, or scientific organizations, in the absence of regulatory limits, to describe acceptable contaminant levels in drinking water or edible fish.

**Insecticide**–A substance or mixture of substances intended to prevent, destroy, or repel insects.

**Leaching–**The removal of materials in solution from soil or rock to ground water; refers to movement of pesticides or nutrients from land surface to ground water.

**Load–**A general term that refers to a material or constituent in solution, in suspension, or in transport; usually expressed in terms of mass or volume.

**Maximum Contaminant Level (MCL)–**The maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCL's 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. The median is also known as the 50th percentile.

**Micrograms per liter (µg/L)**–A unit expressing the concentration of constituents in solution as weight (micrograms) of solute per unit volume (liter) of water; equivalent to one part per billion in most streamwater and ground water. One thousand micrograms per liter equals 1 milligram per liter.

**Milligrams per liter (mg/L)–**A unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water; equivalent to one part per million in most streamwater and ground water. One thousand micrograms per liter equals 1 mg/L.

**Nitrate**–An ion consisting of nitrogen and oxygen ($NO_3^-$). Nitrate is a plant nutrient and is very mobile in soils.

**Nonpoint source–**A pollution source that cannot be defined as originating from discrete points such as pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from plants and trees are types of nonpoint source pollution. *See also* **Point source.**

**Nutrient–**Element or compound essential for animal and plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium.

**Occurrence and distribution assessment–**Characterization of the broad-scale spatial and temporal distributions of water-quality conditions in relation to major contaminant sources and background conditions for surface water and ground water.

**Organochlorine compound–**Synthetic organic compound containing chlorine. As generally used, the term refers to compounds containing mostly or exclusively carbon, hydrogen, and chlorine. Examples include organochlorine insecticides, polychlorinated biphenyls, and some solvents containing chlorine.

**Organochlorine insecticide–**A class of organic insecticides containing a high percentage of chlorine. Includes dichlorodiphenylethanes (such as DDT), chlorinated cyclodienes (such as chlordane), and chlorinated benzenes (such as lindane). Most organochlorine insecticides were banned because of their carcinogenicity, tendency to bioaccumulate, and toxicity to wildlife.

**Organochlorine pesticide–***See* **Organochlorine insecticide.**

**Pesticide–**A chemical applied to crops, rights of way, lawns, or residences to control weeds, insects, fungi, nematodes, rodents, and other "pests." *See also* **Herbicide, Insecticide**.

**Point source–**A source at a discrete location such as a discharge pipe, drainage ditch, well, or concentrated livestock operation. *See also* **Nonpoint source**.

**Riparian–**The area adjacent to a stream or river with a high density, diversity, and productivity of plant and animal species relative to nearby uplands.

**Species diversity**–An ecological concept that incorporates both the number of species in a particular sampling area and the evenness with which individuals are distributed among the various species.

**Species (taxa) richness**–The number of species (taxa) present in a defined area or sampling unit.

**Synoptic sites–**Sites sampled during a short-term investigation of specific water-quality conditions during selected seasonal or hydrologic conditions to provide improved spatial resolution for critical water-quality conditions.

**Tier 1 sediment guideline–**Threshold concentration above which there is a high probability of adverse effects on aquatic life from sediment contamination, determined by using modified procedures from the U.S. Environmental Protection Agency (1996b).

**Trace element–**An element found in only minor amounts (concentrations less than 1.0 milligram per liter) in water or sediment; includes arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc.

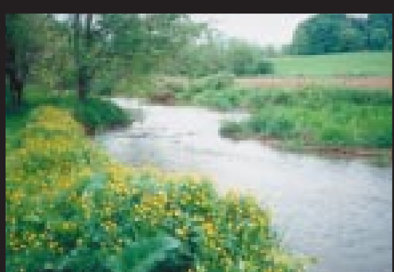
**Volatile organic compounds (VOCs)–**Organic chemicals that have a high vapor pressure relative to their water solubility. VOCs include components of gasoline, fuel oils, and lubricants, as well as organic solvents, fumigants, some inert ingredients in pesticides, and some byproducts of chlorine disinfection.

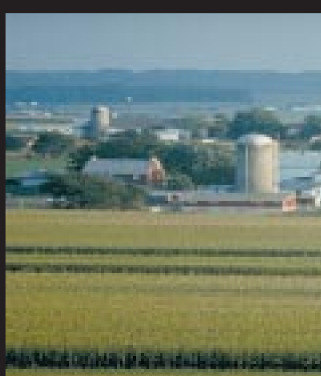
**Water-quality criteria–**Specific levels of water quality which, if reached, are expected to render a body of water unsuitable for its designated use. Commonly refers to water-quality criteria established by the U.S. Environmental Protection Agency. Water-quality criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

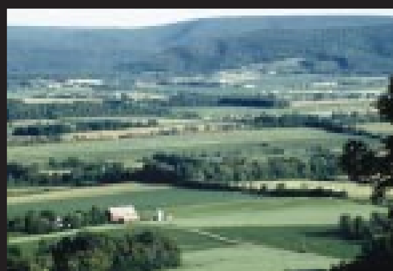
**Yield**–The mass of a material or constituent transported by a river in a specified period of time divided by the drainage area of the river basin.

# NAWQA

National Water-Quality Assessment (NAWQA) Program
Lower Susquehanna River Basin





Lindsey and others • Water Quality in the Lower Susquehanna River Basin
USGS Circular 1168 • 1998


ISBN 0-607-89155-6
9 780607 891553