Water Quality in the Delaware River Basin

Pennsylvania, New Jersey, New York, and Delaware, 1998–2001

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

Circular 1227

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The Quality of Our Nation's Waters—Nutrients and Pesticides (Circular 1225)

Front cover: The Fairmount Water Works on the banks of the Schuylkill River in Philadelphia. Built in 1815 to supply clean water to the rapidly growing city, it was world-renowned for its innovative technology and neoclassical beauty. Today the Schuylkill River is still an important source of water supply for the city, and the waterworks serves as a water-interpretive center.

Back cover: Left, the Delaware Water Gap (Photograph by Dick Ludwig, courtesy Pocono Mountains Vacation Bureau, Inc.); right, the city of Philadelphia from Camden, New Jersey. (Photograph courtesy Delaware River Basin Commission)

Water Quality in the Delaware River Basin, Pennsylvania, New Jersey, New York, and Delaware, 1998–2001

By Jeffrey M. Fischer, Karen Riva-Murray, R. Edward Hickman,
Douglas C. Chichester, Robin A. Brightbill, Kristin M. Romanok,
and Michael D. Bilger

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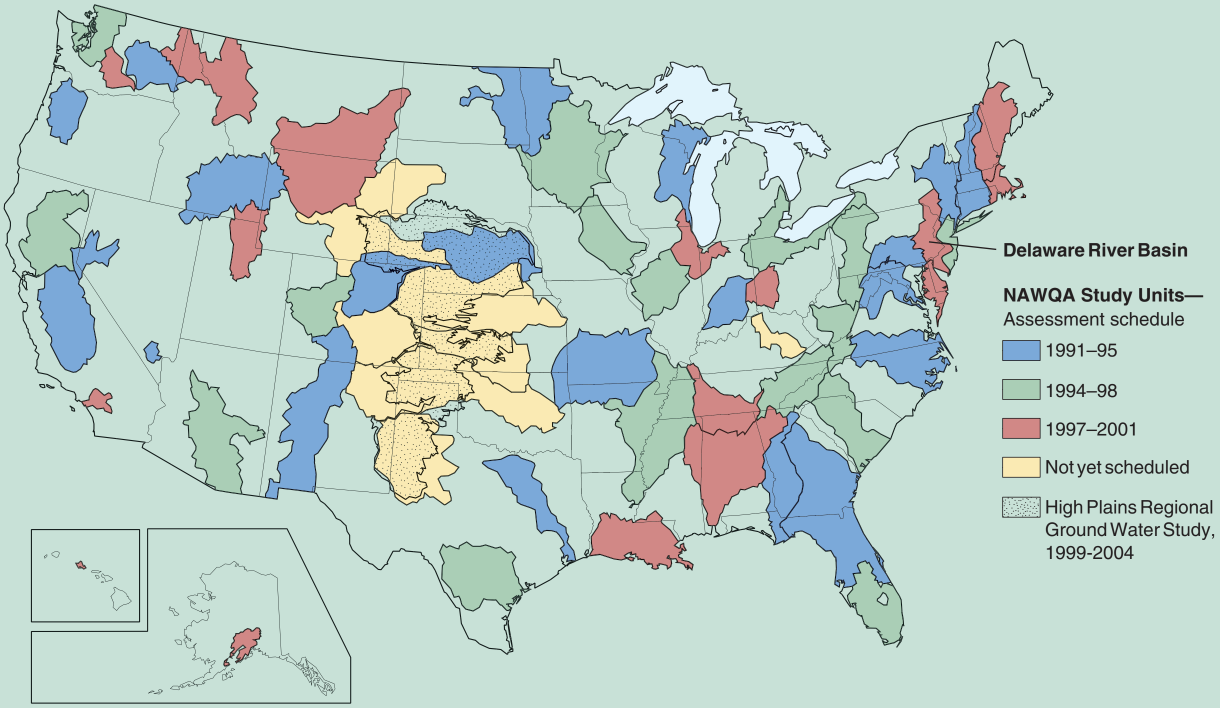
Contents

National Water-Quality Assessment Program

The quality of the Nation's water resources is integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and also suitable for industry, irrigation, and habitat for fish and wildlife. Recognizing the need for long-term, nationwide assessments of water resources, the U.S. Congress has appropriated funds since 1991 for the USGS to conduct the **National Water-Quality Assessment (NAWQA) Program**. Scientists in the NAWQA Program work with partners in government, research, and public interest groups to assess the spatial extent of water-quality conditions, how water quality changes with time, and how human activities and natural factors affect water quality. This information is useful for guiding water-management and protection strategies, research, and monitoring in different hydrologic and land-use settings across the Nation.



The Delaware River Basin is one of 51 water-quality assessments initiated since 1991. Together, the 51 major river basins and aquifer systems, referred to as "Study Units," include water resources used by more than 60 percent of the population in watersheds that cover about one-half of the land areas of the conterminous United States. Timing of the assessments varies because of the program's rotational design in which one-third of all Study Units are intensively investigated for 3 to 4 years, with trends assessed every 10 years. As indicated on the map, the Delaware River Basin is part of the third set of intensive investigations that began in 1997.

What kind of water-quality information does the NAWQA Program provide?

Water-quality assessments by a single program cannot possibly address all of the Nation's water-resource needs and issues. Therefore, it is necessary to define the context within which NAWQA information is most useful.

- Total resource assessment—NAWQA assessments are long-term and interdisciplinary, and include information on water chemistry, hydrology, land use, stream habitat, and aquatic life. Assessments are not limited to a specific geographic area or water-resource problem at a specific time. Therefore, the findings describe the general health of the total water resource, as well as emerging water issues, thereby helping managers and decision makers to set priorities.
- Source-water characterization—Assessments focus on the quality of the available, untreated resource and thereby complement (rather than duplicate) Federal, State, and local programs that monitor drinking water. Findings are compared to drinking-water standards and health advisories as a way to characterize the resource.
- Compounds studied—Assessments focus on chemical compounds that have well-established methods of investigation. It is not financially or technically feasible to assess all the contaminants in our Nation's waters. In general, the NAWQA Program investigates those pesticides, nutrients, volatile organic compounds, and metals that have been or are currently used commonly in agricultural and urban areas across the Nation. A complete list of compounds studied is on the NAWQA Web site at *http://water.usgs.gov/nawqa*.
- Detection relative to risk—Compounds are measured at very low concentrations, often 10 to 100 times lower than Federal or State standards and health advisories. Detection of compounds, therefore, does not necessarily translate to risks to human health or aquatic life. However, these analyses are useful for identifying and evaluating emerging issues, as well as for tracking contaminant levels over time.
- Multiple scales—Assessments are guided by a nationally consistent study design and uniform methods of sampling and analysis. Findings thereby pertain not only to water quality of a particular stream or aquifer, but also contribute to the larger picture of how and why water quality varies regionally and nationally. This consistent, multiscale approach helps to determine if a water-quality issue is isolated or pervasive. It also allows direct comparisons of how human activities and natural processes affect water quality in the Nation's diverse environmental settings.

Introduction to this Report

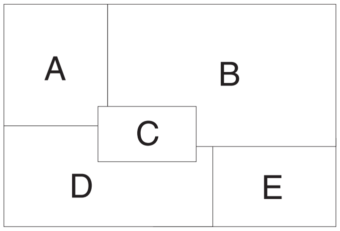
> "The work reported here is very relevant to the work done in the Division of Water, and specifically in the water-quality monitoring program."
>
> Margaret Novak,
> New York State Department of Environmental Conservation

This report contains the major findings of a 1998–2001 assessment of water quality in the Delaware River Basin. It is one of a series of reports by the National Water-Quality Assessment (NAWQA) Program that present major findings in 51 major river basins and aquifer systems across the Nation.

In these reports, water quality is discussed in terms of local, State, and regional issues. Conditions in a particular basin or aquifer system are compared to conditions found elsewhere and to selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms.

This report is intended for individuals working with water-resource issues in Federal, State, or local agencies, universities, public interest groups, or in the private sector. The information will be useful in addressing a number of current issues, such as the effects of agricultural and urban land use on water quality, human health, drinking water, source-water protection, hypoxia and excessive growth of algae and plants, pesticide registration, and monitoring and sampling strategies. This report is also for individuals who wish to know more about the quality of streams and ground water in areas near where they live, and how that quality compares to the quality of water in other areas across the Nation.

The water-quality conditions in the Delaware River Basin summarized in this report are discussed in detail in other reports that can be accessed from *http://nj.water.usgs.gov/nawqa/delr/*. Detailed technical information, data and analyses, collection and analytical methodology, models, graphs, and maps that support the findings presented in this report, in addition to reports in this series from other basins, can be accessed from the national NAWQA Web site (*http://water.usgs.gov/nawqa*).



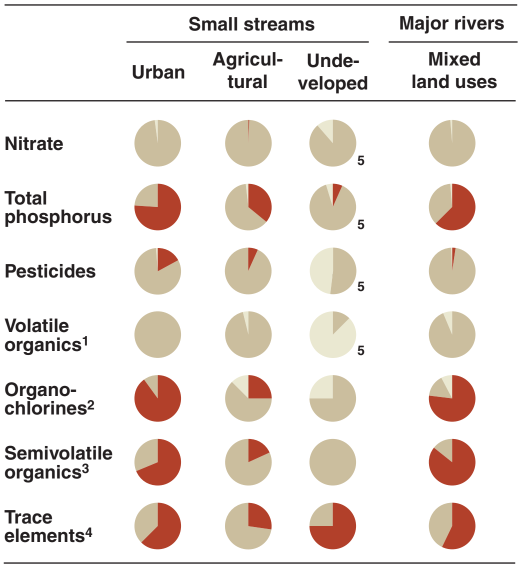
A. Stream sampling (Photo by Delaware NAWQA project personnel)
B. Farming in Valley and Ridge (Photo by U.S. Department of Agriculture, Natural Resources Conservation Service)
C. Stonefly (Photo by Lawrence E. Abele, New York State Department of Environmental Conservation)
D. Rafting on the Upper Delaware (Photo by David B. Soete)
E. Fish community sampling (Photo by Richard Spear, Pennsylvania Department of Environmental Protection)

Summary of Major Findings

Stream and River Highlights

Stream-water quality and the health of aquatic life in rivers of the Delaware River Basin (hereafter, “the basin”) are greatly affected by human activities related to agriculture and urbanization. Many nutrients, pesticides, and volatile organic compounds (VOCs) were detected in water samples from streams, but concentrations of most chemical compounds were low and rarely exceeded guidelines or standards for drinking-water quality or aquatic-life protection. Current guidelines, however, do not include many of these chemicals nor the mixtures of compounds that commonly were detected in streams. Organic and trace-metal contaminants were detected in streambed-sediment and fish-tissue samples from many streams and rivers throughout the basin. Concentrations of these compounds typically were higher in samples from urban watersheds than in those from streams in other land-use settings, and streams in urban settings commonly failed to meet guidelines for protection of fish-eating wildlife and sediment-dwelling organisms. In general, urbanization in watersheds was associated with reduced biological diversity in streams and an increase in species more tolerant of disturbance.

Selected indicators of streamwater quality

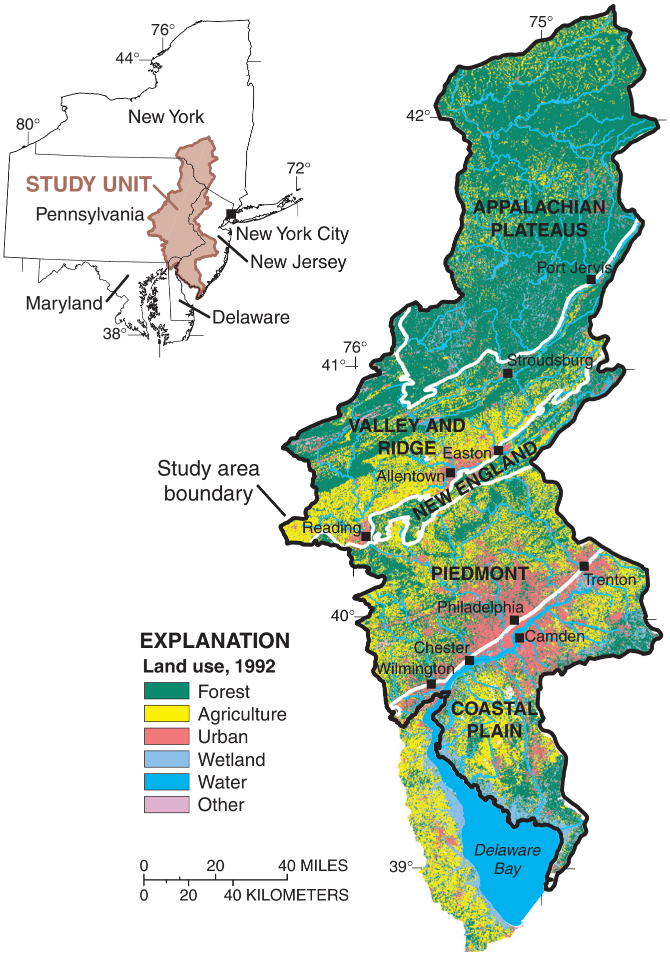


🟥 Proportion of samples with detected concentrations **greater than or equal to** health-related national guidelines for drinking water, protection of aquatic life, or the desired goal for preventing nuisance plant growth

🟫 Proportion of samples with detected concentrations **less than** health-related national guidelines for drinking water, protection of aquatic life, or below the desired goal for preventing nuisance plant growth

⬜ Proportion of samples with **no detections**

[1] Solvents, refrigerants, fumigants, and gasoline compounds in water.
[2] Chlordanes, dieldrin, DDT, and PCBs in fish tissue.
[3] Byproducts of fossil-fuel combustion; components of coal and crude oil, in sediment.
[4] Arsenic, mercury, and metals in sediment.
[5] Undeveloped sites have fewer samples over a shorter time period than the other stream types shown.



Each physiographic region of the Delaware River Basin has a different combination of land-use types and levels of development. Access to abundant water and good transportation routes have led to extensive urban and agricultural development in the southern half of the Study Unit.

- Environmentally persistent organochlorine compounds, such as DDT and polychlorinated biphenyls (PCBs), were detected in streambed sediment and fish tissue from many streams and rivers, particularly in urban areas. Concentrations at many sites exceeded guidelines established for the protection of fish-eating wildlife and sediment-dwelling organisms. (p. 6)
- Concentrations of PCBs in fish from some rivers have markedly declined from the 1970s or 1980s to the late 1990s, but this decline was not seen in two of the six rivers studied. Concentrations in game fish collected in 1998 indicated that some rivers still warrant human-health fish-consumption advisories. (p. 8)
- Concentrations of most trace metals in streambed sediment were elevated in urban watersheds and in watersheds

affected by mining and industrial activities relative to concentrations in forested or agricultural watersheds. (p. 10)

- Concentrations of mercury in fish fillets exceeded human-health criteria and wildlife-protection guidelines at 22 and 87 percent of the sampling sites, respectively. (p. 11)
- Pesticides were detected in almost all streams sampled, and their concentrations were directly related to the percentage of either urban or agricultural land in the watershed. Concentrations of selected degradation products often exceeded concentrations of the parent pesticides. Concentrations were low, however, and rarely exceeded U.S. Environmental Protection Agency (USEPA) drinking-water standards or guidelines and occasionally exceeded those for aquatic life. (p. 13)
- One or more of 42 volatile organic compounds (VOCs) were detected in 92 percent of stream samples, but concentrations were low and did not exceed USEPA drinking-water or aquatic-life standards or guidelines. Concentrations were highest at urban sites. (p. 17)
- Concentrations of nutrients in streams in agricultural and urban watersheds were elevated compared to those in forested areas. (p. 19)
- Losses of pollution-sensitive invertebrate species, decreases in habitat quality, and increases in chemical indicators such as chloride and potential pesticide toxicity were related to the extent of urbanization in a watershed. (p. 22)
- Streamflow, chemistry, and biota were affected by the extreme drought during the summer of 1999. (p. 24)

Major Influences on Streams and Rivers

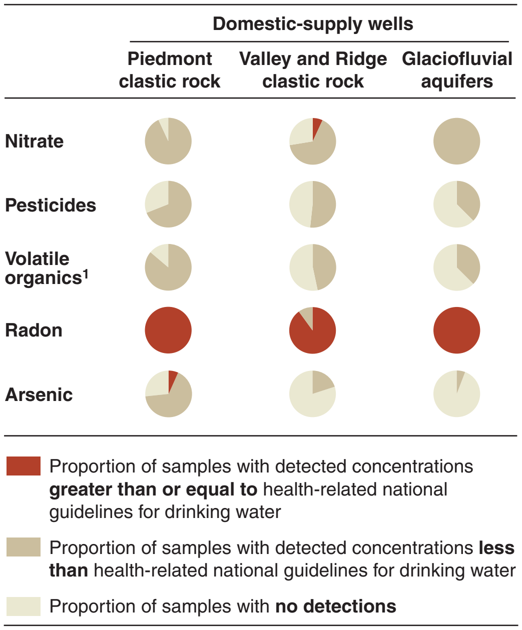
- Runoff and point-source discharges from agricultural and urban areas
- Persistence of contaminants associated with past agricultural, urban, industrial, and mining activities
- Impoundments and diversions of water

Ground-Water Highlights

Ground-water quality in the Delaware River Basin has been affected by human activities and geologic characteristics. Nutrients, pesticides, and VOCs were frequently detected, but typically less frequently and at lower concentrations than in streams. In general, the number of manmade contaminants detected and their concentrations increased with the degree of development in each region studied. Concentrations of naturally occurring radon and arsenic exceeded existing or proposed drinking-water standards. Concentrations of most other chemical compounds detected were low and did not exceed most drinking-water-quality standards or guidelines.

- Concentrations of radon exceeded the proposed USEPA drinking-water standard of 300 picocuries per liter in nearly all wells sampled. (p. 12)

Selected indicators of ground-water quality



[1] Solvents, refrigerants, fumigants, and gasoline compounds.

- Arsenic was frequently detected in wells (about 70 percent) in the Piedmont clastic-rock aquifer. Concentrations in two of 30 wells exceeded the USEPA drinking-water standard of 10 micrograms per liter. (p. 13)
- Pesticides were detected in about one-half of the domestic wells sampled but were detected most frequently in samples from the clastic-rock aquifer of the highly urban Piedmont Physiographic Province. Concentrations were low; none exceeded USEPA drinking-water standards. Pesticide degradation products were detected in more wells and often at higher concentrations than parent compounds. (p. 13)
- One or more VOCs were detected in more than 85 percent of the domestic wells sampled in the clastic-rock aquifer in the highly urban Piedmont, but were detected less frequently elsewhere. Concentrations were low and none exceeded USEPA drinking-water standards. (p. 17)
- The median concentration of nitrate was highest in domestic wells in the Piedmont clastic-rock aquifer (2.9 milligrams per liter), but no wells in the aquifer exceeded the USEPA drinking-water standard of 10 milligrams per liter. Concentrations in two domestic wells in agricultural areas of the Valley and Ridge Province, however, exceeded the standard. (p. 19)

Major Influences on Ground Water

- Use of nutrients, pesticides, and VOCs in urban and agricultural areas
- Physical properties of soils and aquifers, and chemical properties of contaminants
- Naturally occurring radon and arsenic

Introduction to the Delaware River Basin

The Delaware River originates in the Catskill Mountains and flows south more than 200 miles to the Delaware Estuary, which extends from near Trenton, N.J., to the Delaware Bay (fig. 1). The Lehigh and Schuylkill Rivers are two of the Delaware's major tributaries. The 12,700-mi^2 (square mile) basin includes parts of four States: Pennsylvania (50 percent of the basin), New Jersey (23 percent), New York (19 percent), and Delaware (8 percent). The Delaware River Basin NAWQA Study Unit encompasses the entire watershed except for a 770-mi^2 area of the Coastal Plain in Delaware (this area is part of another Study Unit).

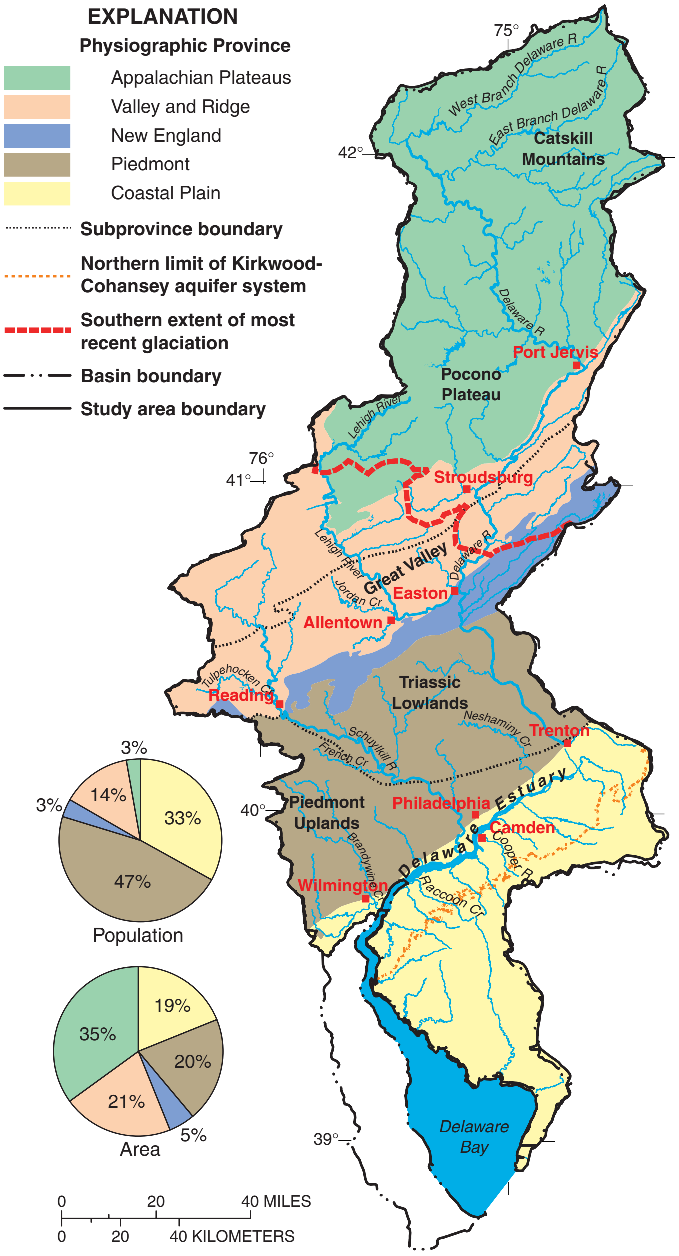


Figure 1. Physical differences across the Study Unit influence hydrologic conditions, land development, and population distribution. More than 80 percent of the Delaware River Basin population lives in the Piedmont and Coastal Plain Physiographic Provinces.

More than 7.5 million people live in the basin (2000 Census), and another 8 million people outside the basin rely on the Delaware River and its tributaries for their water supply. Land use in the basin is about 50 percent forest, 35 percent agriculture, and 5 percent urban (fig. 2). About 80 percent of the basin's population lives within about 20 miles of the Delaware Estuary. Since 1970, the suburban population has grown as much as 50 percent or more, whereas the overall population of the basin has increased less than 15 percent. Most of this suburban development has replaced previously forested or agricultural land.

Highly varied physiography and land uses influence water quality

The Delaware River Basin consists of five physiographic provinces (fig. 1), which differ considerably with respect to topography, geology, and hydrology. Physical differences have created characteristic patterns of land development in each province, and water-quality issues are related to these patterns of development. North and west of the Delaware Estuary, folded and faulted siliciclastic, carbonate, and metamorphic bedrock are found, whereas the Coastal Plain southeast of the estuary is composed of layered, unconsolidated sand and clay (fig. 3). Glaciation of the northern one-half of the basin during the Pleistocene Epoch stripped soil from the hilltops and deposited unconsolidated fill in the valleys of the Appalachian Plateaus, New England, and Valley and Ridge Physiographic Provinces.

The Appalachian Plateaus Province consists of 1,000- to 4,000-foot-high uplands composed of gently folded sandstones, shales, and conglomerates. Rivers have carved deep, narrow valleys through the rock, and hydroelectric dams are interspersed throughout the province. Three reservoirs in the Catskill Mountains provide drinking water to residents of New York City, and outflows are regulated to maintain required flows on the Delaware River for downstream users. Although the Appalachian Plateaus cover the northern one-third of the basin, only about 3 percent of the basin population lives there, and 85 percent of the land is forested (figs. 1 and 2). The aesthetic and recreational qualities of this relatively undeveloped region attract millions of outdoor-recreation enthusiasts, who temporarily, but substantially, increase local populations. In addition, the recent development of transportation corridors has spurred rapid population growth, particularly in the Pocono Plateau region. Nearly all residents of the Appalachian Plateaus rely on wells for drinking water, and septic systems are commonly used for wastewater disposal away from towns. Water-quality issues include preserving the health of the exist-

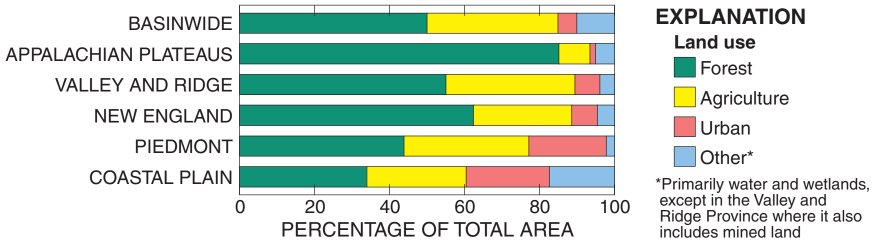


Figure 2. Land use differs among, and within, physiographic provinces and is a primary factor affecting the quality of water and aquatic life. Agriculture is an important land use in all regions south of the Appalachian Plateaus. Parts of the Piedmont and Coastal Plain Provinces are highly urbanized.

ing ecosystem and the quality of the water as development occurs. Effects of reservoir releases and diversions on downstream users and biota also are a concern.

The Valley and Ridge Province consists primarily of sandstones and shales (clastic rocks) that have been folded into extensive ridges and valleys that trend southwest to northeast. Topographic relief from ridgetop to valley bottom can exceed 1,200 feet. An extensive sequence of carbonate rocks forms the southern boundary with the New England Province, an upland ridge composed of metamorphosed shales and carbonate rocks. The Valley and Ridge and New England Provinces account for about 26 percent of the Study Unit and about 17 percent of the population (fig. 1). Most of the developed land is along the valley floors, whereas the ridges are primarily forested. More than one-third of the land in these provinces is used for agriculture. Valley floors often contain extensive agricultural development (often more than 50 percent farmland). Corn is the major crop, but dairy, poultry, and swine production are important in the southwest corner of the Valley and Ridge Province, where manure from these livestock operations is commonly applied to farm fields. These provinces are less than 7 percent urban land. Major cities straddle either the Lehigh or Schuylkill Rivers and sit upon the productive carbonate aquifer of the Great Valley. Water-quality concerns in this region include the effects of urban and agricultural activities on streams and ground-water resources, the effects of industrial and municipal discharges on larger rivers, and the need for continued mitigation of past coal mining effects near the headwaters of the Lehigh and Schuylkill Rivers.

The Piedmont Province is a highly urbanized lowland region of rolling hills and valleys with two distinct rock types. In the southwest Uplands Section, metamorphic and igneous rocks such as schist, gneiss, and granite predominate, and small areas of carbonate rock are present. In the northeast Lowlands Section, clastic rocks such as sandstones and shale are the primary rock type, and diabase intrusions form resistant hills. The Piedmont contains 47 percent of the basin's population and is the most highly developed province in the Study Unit (figs. 1 and 2). Agricultural and urban development account for more than 50 percent of the land use in the region. Currently, about one-third of the land in the Piedmont is used for agriculture, but much of this land is being converted rapidly to suburban housing. Agriculture lands are located primarily north and west of Philadelphia. Farm crops consist mainly of grasses and corn, but mushroom and horse farms are also common, particularly in the western part of the Piedmont. Urban development is centered on the Philadelphia metropolitan area, but cities have developed all along the estuary, which serves as both a transportation corridor and a source of water supply. Rivers and the estuary are used extensively for municipal and industrial water supply, wastewater discharges, and recreation. The area's long history of agricultural and industrial development, and the associated discharge of treated wastewater and runoff of nonpoint-source pollution, have degraded river and estuarine water quality. Overuse of ground water has led to the declaration of a "ground-water protection area" in the Philadelphia area.

The Coastal Plain Province is an area of low relief southeast of the Delaware Estuary. Sediments are composed of slightly dipping layers of unconsolidated clay, silt, sand, and gravel that thicken and reach a depth of 6,000 feet to the southeast. The sands and gravels store large quantities of water, which are relied upon for most of the industrial, municipal, domestic, and agricultural supply in the province. The Coastal Plain contains 33 percent of the basin's population (fig. 1). Agricultural development accounts for more than 25 percent of the land use in the Coastal Plain. Farms grow a wide variety of fruit, vegetable, and row crops. Urban and industrial development is centered on Camden, but urban growth is occurring throughout the region and currently accounts for about 22 percent of the land use. Excessive ground-water withdrawals have led to concerns about

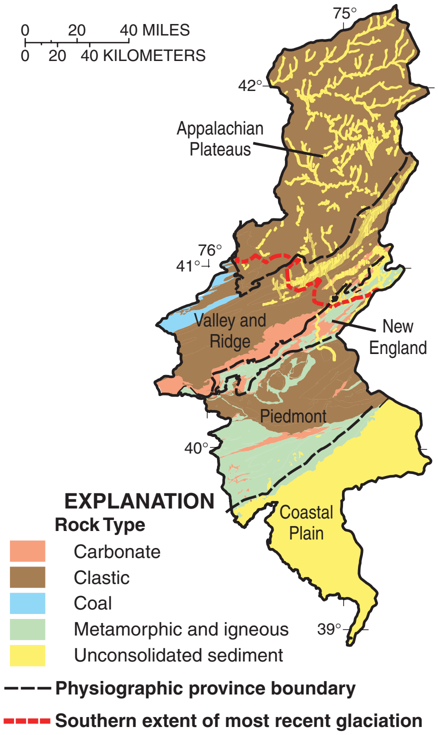


Figure 3. Physical and chemical differences between the many types of rock in the Delaware Basin are some of the factors that control water availability and vulnerability to contamination.

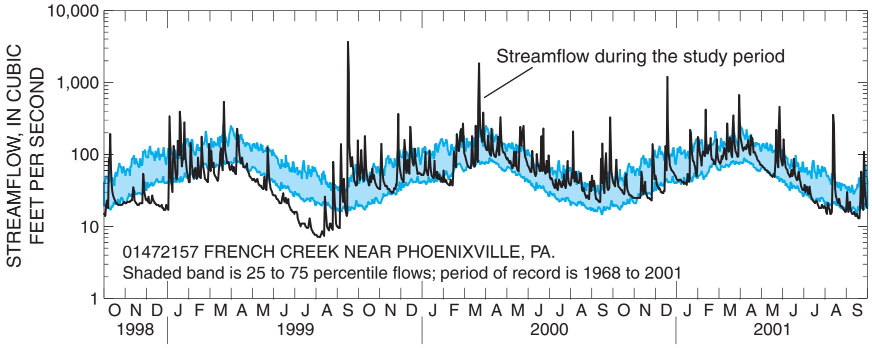


Figure 4. Streamflow in French Creek near Phoenixville, Pennsylvania, reflects the extreme drought during the summer of 1999, close to normal precipitation in 2000, and generally dry conditions in 2001.

saltwater intrusion and have resulted in mandated reductions in ground-water pumpage and increased withdrawals from the Delaware Estuary. In addition to the widespread occurrence of contaminants associated with current agricultural, industrial, and urban land uses, past agricultural practices have left some streams contaminated with long-discontinued pesticides.

Extremes in precipitation occurred during the study

The Delaware River Basin has a temperate climate, with seasonal and average yearly variations generally reflecting variations in topography. Average yearly temperature ranges from about 45°F (degrees Fahrenheit) in the north to 56°F in the south. Average annual precipitation ranges from 50 inches in the north to 42 inches in the south and is typically distributed evenly throughout the year (Jenner and Lins, 1991).

Table 1. Precipitation (in inches) during the 1999–2001 sampling period was well below the 30-year mean of 44.06 inches at Allentown, Pennsylvania, and the drought in the summer of 1999 was one of the most severe on record for the basin.

PRECIPITATION	1999	2000	2001
Yearly total	40.8	43.1	39.8
Yearly departure	–3.4	–1.1	–4.4
Summer departure	–8.5	2.8	0.2

Precipitation and streamflow were below normal during much of the 1999–2001 data-collection period (table 1 and fig. 4). Drought emergencies were declared by all four basin states during the extremely dry summer of 1999. At times, the flows of many streams were less than 20 percent of their 30-year average. Hurricane Floyd produced considerable amounts of rain across the basin in September 1999. Although this provided relief from the drought, it also caused major flooding and scouring of stream channels. Precipitation and streamflow were close to normal during 2000. The yearly rainfall deficit in 2001 was similar to that in 1999, but the summer deficit was smaller. These varying climatic conditions affected some water quality and stream biota (p. 24).

The Delaware River Basin is a vital source of drinking water

The Delaware River Basin supplies large quantities of water to two of the Nation's largest metropolitan areas—New York City and Philadelphia. Approximately 620 Mgal/d (million gallons per day) is exported from the basin to New York City, and another 100 Mgal/d is exported to northeastern New Jersey. About 4 billion gallons of water is used in the Study Unit each day, but more than one-half of this amount is for power generation. Public supply, industrial supply, and irrigation account for about 25, 15, and 1 percent, respectively, of the total water use.

Approximately 1 billion gallons of water is used each day within the Study Unit for public and domestic supply. Streams and rivers supply about 75 percent of this total. Most large cities on major rivers and the non-saline parts of the estuary (above Philadelphia) depend largely on surface water, primarily from the Delaware, Schuylkill, Lehigh, and Brandywine Rivers. Each physiographic province has a distinct pattern of drinking-water use (fig. 5). For example, most public and domestic supply in the Coastal Plain comes from its highly productive sand and gravel aquifers. Similarly, the highly productive glaciofluvial aquifer system in the Appalachian Plateaus, New England, and the Valley and Ridge Provinces is an important source of water for public and domestic supply. A large amount of water used for public supply in the Valley and Ridge Province is from a highly productive carbonate aquifer, although most public drinking water in the Valley and Ridge, as well as the Piedmont Province, is supplied by streams and rivers (fig. 5). Residents in most sparsely populated areas of all provinces in the basin depend on wells for domestic drinking-water supplies.

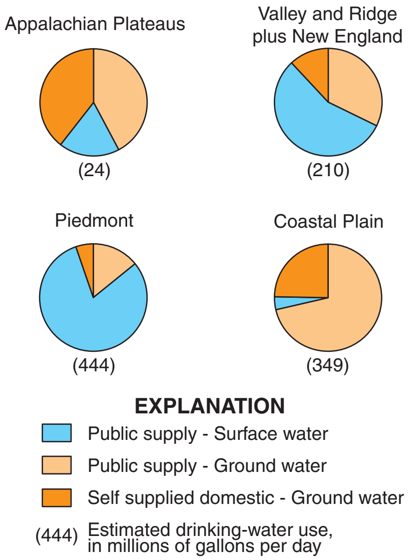


Figure 5. Drinking-water sources differ among physiographic provinces. Estimates do not include water exported from the basin.

Major Findings

The quality of surface and ground water in the Delaware River Basin is affected by a complex combination of natural factors (for example, geology, precipitation, and streamflow) and human factors (for example, land use, chemical use, and water diversions). The Delaware River Basin NAWQA study was designed to describe water-quality conditions (including ecological health and distribution of contaminants) in selected settings within the basin and to identify the effects of natural and human factors on observed conditions. Stream-water studies were conducted throughout the basin, but ecological studies were largely focused on the Piedmont Province and the Pocono Plateau region of the Appalachian Plateaus. Ground-water studies were conducted in the clastic-rock aquifers of the Piedmont and the Valley and Ridge Provinces and the glaciofluvial aquifers in the northern one-half of the basin.

Study Methods

The Study Unit Design presented on pages 27 and 28 of this report describes the methods used to obtain results discussed in this report.

Organic Contaminants in Streambed Sediment and Fish Tissue

Many organic chemicals and trace metals that are released into the environment are more likely to be detected in streambed sediment or fish tissue than in water because of their chemical properties. These chemicals are of concern because they can interfere with the growth and reproduction of aquatic organisms. Also, many of these compounds can be bioaccumulated (increased in concentration as they move up the food chain) and can pose health risks to humans and wildlife consumers of aquatic biota.

Organochlorine pesticides and industrial compounds were widely detected in streambed sediments and fish tissue

One or more organochlorine pesticides or industrial compounds were detected in all streambed-sediment and fish-tissue samples throughout the Delaware River Basin, even though the manufacture and permitted use of these compounds were stopped or restricted more than 20 years before the current study. The most commonly detected organochlorine compounds were DDTs, PCBs, chlordanes, and dieldrin. PCBs, chlordanes, and dieldrin were detected more frequently in fish tissue than in streambed sediment (fig. 6). For instance, PCBs were detected in 84 percent of the fish samples but in only 21 percent of the streambed-sediment samples. This result indicates that these compounds persist in the physical environment at concentrations less than laboratory detection limits, and are bioaccumulated to detectable concentrations by fish and other organisms. For example, concentrations of DDT in whole fish (white sucker, *Catostomus commersoni*) were 2 to 30 times those in streambed sediments from the same sites; and the median ratio was 18:1.

DDT, the most frequently detected organochlorine compound, was found in fish tissue and (or) streambed sediments from more than 80 percent of wadeable streams in forested, agricultural, and urban watersheds (fig. 7), and from all four of the large rivers sampled. The widespread detection of DDT in a variety of land-use settings results in part from its historical use in controlling many types of insect pests in farms, homes, and forests. The degradation

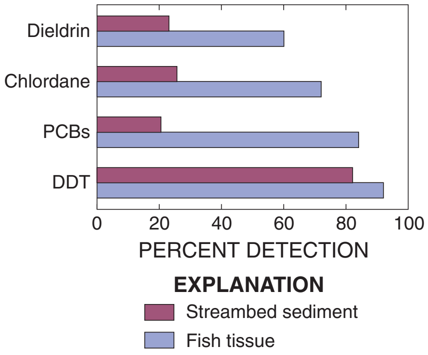


Figure 6. Although their use has been discontinued for decades, DDT, PCBs, chlordane, and dieldrin were frequently detected in fish. Lower rates of detection in streambed sediment for most compounds indicates that they are present in the environment at concentrations below laboratory detection limits and increase through the food chain to detectable levels in fish.

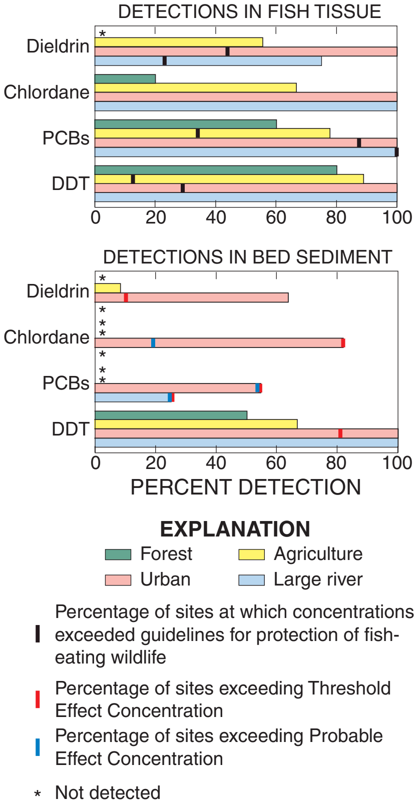


Figure 7. Streams in urban areas are more likely to have detectable concentrations of one or more organochlorine contaminants in fish tissue and streambed sediment than are streams in agricultural and forested watersheds. Concentrations in urban areas are also more likely to exceed guidelines for the protection of fish-eating wildlife and sediment-dwelling organisms. PCBs exceeded these guidelines most frequently.

A Few Notes About Fish-Tissue and Streambed-Sediment Analyses

Analyses for organochlorine compounds in fish tissue were done on composite samples of five to eight whole white suckers (*Catostomus commersoni*) from each of 25 sites; whole common carp (*Cyprinus carpio*) samples also were collected at five sites, and smallmouth bass fillets (*Micropterus dolomieu*) were collected at three sites. Concentrations of DDT and chlordane in fish tissue and streambed sediment were each calculated as the sum of the concentrations of the major components of the technical pesticide mixture plus degradation products. Total PCBs were determined by comparison to mixed aroclor standards. Normalization of organochlorine concentrations in fish tissue to lipid (fat) content and of those in streambed sediment to organic carbon content did not alter the findings presented here.

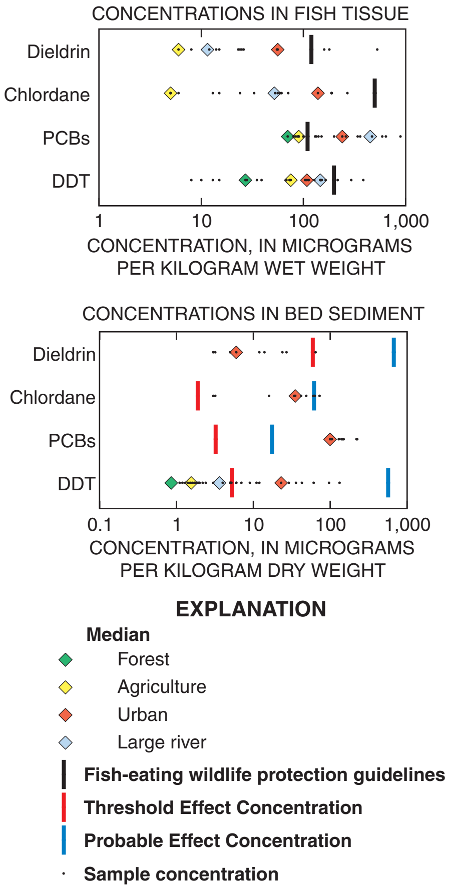


Figure 8. Concentrations of DDT, PCBs, chlordane, and dieldrin in fish tissue (whole white sucker) and streambed sediment were highest in urban areas. Guidelines for protecting fish-eating wildlife and sediment-dwelling organisms were most frequently exceeded in urban areas. Concentrations less than laboratory detection limits are not shown.

product *p,p'*-DDE was the most commonly detected form of DDT. Concentrations of DDT in fish tissue and streambed sediment (fig. 8), like its detection frequencies, were typically highest in urban watersheds and large rivers and lowest in forested watersheds. Residual contamination of recently urbanized land from former agricultural applications also may have a bearing on these findings.

Total PCBs were widely detected in fish tissue from wadeable streams in all land-use settings (fig. 7) and from all four of the large rivers sampled. Detections in streambed sediment, however, were limited to streams in urban settings and large rivers downstream from major population centers. PCB concentrations were strongly related to the intensity of urbanization in a watershed because of the historical use of PCBs in industrial and electrical applications and the disposal of PCB-laden equipment in landfills and industrial sites near urban centers.

Chlordanes and dieldrin were detected in fish-tissue samples collected from every stream in urban watersheds, from more than one-half the streams in agricultural watersheds, and from three of the four large rivers sampled. These organochlorine compounds also were detected in streambed sediment from more than 60 percent of the urban and large-river sites (fig. 7). Both of these pesticides, as well as aldrin (which degrades to dieldrin), were commonly applied around and inside houses, apartment buildings, and commercial buildings for control of termites, carpenter ants, and other insect pests. Therefore, concentrations and detection frequencies of both were highly correlated with the percentage of urban land in the watershed. Chlordane and dieldrin also were detected in agricultural settings, but concentrations were much lower than in urban areas (fig. 8). This may be because the registration of these compounds for agricultural use was canceled a decade before it was canceled for use in urban areas, or because they were not applied as heavily in agricultural areas.

Concentrations of organochlorine compounds in streambed sediment and fish tissue exceeded guidelines for protection of wildlife at many sites

Concentrations of PCBs in whole fish exceeded guidelines developed for the protection of fish-eating wildlife (Newell and others, 1987) at 52 percent of the sites. Concentrations of dieldrin and DDT also exceeded this guideline (at 16 and 12 percent of sites, respectively). Guidelines were exceeded most frequently, and often for multiple compounds, at urban and large-river sites downstream from urban or industrial areas (fig. 7). Therefore, fish in streams in urban watersheds are most likely to contain multiple organochlorine compounds at concentrations thought to affect the health of fish-eating wildlife. Concentrations of DDT and (or) PCBs in fish tissue exceeded guidelines for the protection of fish-eating wildlife at some agricultural sites, but no guidelines were exceeded in fish tissue collected from forested watersheds. Concentrations of PCBs in fish from the four large-river sites (Lehigh River near Glendon, Pa.; Schuylkill River at Philadelphia, Pa.; and the Delaware River at Trenton, N.J., and at Port Jervis, N.Y.) exceeded fish-eating wildlife guidelines, and the guideline for dieldrin was exceeded at the Schuylkill River at Philadelphia.

Streambed sediments in many urban settings may be harmful to sediment-dwelling organisms. At many urban sites, concentrations of multiple co-occurring organochlorines exceeded

Standards and Guidelines Used in This Report

Water-quality standards and guidelines generally are maximum acceptable concentrations of contaminants in water, sediment, or fish tissue above which adverse effects on humans, aquatic life, or fish-eating wildlife are thought to occur. Regulatory agencies use these guidelines for evaluating whether measured concentrations may be harmful. Given the large number of potential contaminants and exposure pathways, no single source of standards or guidelines is available. The following standards and guidelines were used in this report to evaluate contaminant concentrations measured in surface water, ground water, streambed sediments, and fish tissue:

Standard or guideline	Medium	Source
Human health	Drinking water	U.S. Environmental Protection Agency (2002a, 2003) — Maximum contaminant levels, risk-specific doses, and lifetime health advisories
Aquatic life— plants and animals	Surface water	U.S. Environmental Protection Agency (2002b, 2003) Canadian Council of Ministers of the Environment (2001) International Joint Commission, United States and Canada (1978)
Sediment-dwelling organisims	Streambed sediment	Consensus based (MacDonald and others, 2000)
Fish-eating wildlife	Fish tissue (whole fish)	N.Y. State Department of Environmental Conservation (Newell and others, 1987) U.S. Fish and Wildlife Service (Eisler, 1987)
Human health	Fish tissue (edible flesh)	Great Lakes Fish Consumption Advisory (Anderson and others, 1993) U.S. Environmental Protection Agency (2001)

Current standards and guidelines cannot completely evaluate risks to humans or aquatic life because (1) standards or guidelines have not been established for many compounds, (2) mixtures of compounds are not considered, (3) effects of seasonal exposure to high concentrations have not been evaluated, and (4) other potential effects (such as endocrine disruption) have not yet been addressed.

sediment-quality guidelines (see box, p. 9). One or more organochlorine compounds were detected at every urban site. Fewer than 20 percent of these sites had concentrations below a TEC (Threshold Effect Concentration — see box on p. 9). Concentrations of DDT or chlordanes in sediment exceeded the TEC in more than 80 percent of the streams in urban watersheds, and PCBs exceeded this threshold at more than one-half the sites (fig. 7). Furthermore, concentrations of PCBs exceeded the PEC (Probable Effect Concentration — see box on p. 9) at 55 percent of urban sites, and concentrations of chlordanes exceeded the PEC at 18 percent of urban sites. The Schuylkill River at Philadelphia was the only large-river site at which a PEC was exceeded (for PCBs). No TEC was exceeded at any other large-river site.

PCB concentrations in fish tissue from some rivers declined markedly from 1969 to 1998 but remain above fish-consumption advisory levels

An analysis of PCB concentration data from historical and recent fish collections from six reaches of four major rivers indicates that PCB concentrations in fish from four of these reaches (the upper and lower Delaware River, Brandywine Creek, and the upper Schuylkill River) declined during the past 20 to 30 years (fig. 9). The analysis considered total PCB concentrations determined by comparable methods in whole white suckers and in edible portions of American eel (*Anguilla rostrata*), as well as several other species. Limited data from the lower Lehigh River and lower Schuylkill River indicate less improvement in these reaches (Riva-Murray and others, 2003). PCB concentrations in game-fish fillets collected in 1998 from the lower Delaware, Lehigh, and Schuylkill Rivers, however, still exceeded the lowest fish-consumption advisory level for humans (Anderson and others, 1993). In addition, PCB concentrations in whole white suckers and common carp from these three river sections and the upper Delaware River (the only four river reaches with trend data at which whole-fish samples were collected during 1998) exceeded the guideline for protection of fish-eating wildlife (Newell and others, 1987).

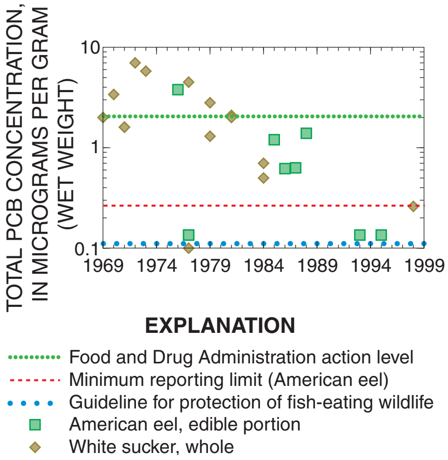


Figure 9. PCB concentrations in fish tissue from the Delaware River at Trenton have declined over the last 25 years. Declines also were seen on the upper Delaware River, Brandywine Creek, and upper Schuylkill River. Declines were not as apparent on the lower Schuylkill and lower Lehigh Rivers (Riva-Murray and others, 2003).

How are contaminated sediments evaluated?

Screening values known as effect concentrations are used to indicate when concentrations of contaminant in streambed sediments are likely to cause adverse effects in sediment-dwelling organisms. The Threshold Effect Concentration (TEC) is an estimate of the concentration of a contaminant in sediment below which adverse biological effects rarely occur. The Probable Effect Concentration (PEC) is an estimate of the concentration of a contaminant in sediment above which adverse biological effects commonly occur (MacDonald and others, 2000). Therefore, adverse biological effects are expected to be rare if streambed-sediment concentrations are less than the TEC, occasional if concentrations are between the TEC and the PEC, and frequent if concentrations exceeds the PEC.

Sediment-quality guidelines apply to whole-sediment samples, whereas samples collected as part of the NAWQA Program were sieved at 63 micrometers. Finer grained sediments commonly have higher contaminant concentrations than do whole-sediment samples. Therefore, comparison of NAWQA data to guidelines may overestimate toxicity somewhat.

Semivolatile organic compounds are widespread in streambed sediments

One or more semivolatile organic compounds (SVOCs) were detected in streambed sediments from 95 percent of the streams sampled. SVOCs for which analyses were conducted as part of this study include three broad groups: PAHs (polycyclic aromatic hydrocarbons), phthalates, and phenols. Compounds from all three groups were detected at 46 percent of the stream sites sampled. Some of these compounds are probable human carcinogens, are endocrine disruptors, and (or) are toxic to aquatic organisms. Once SVOCs enter the water, they are quickly adsorbed onto particulate matter and are deposited on stream bottoms, where they remain stable and persist (Neff, 1985).

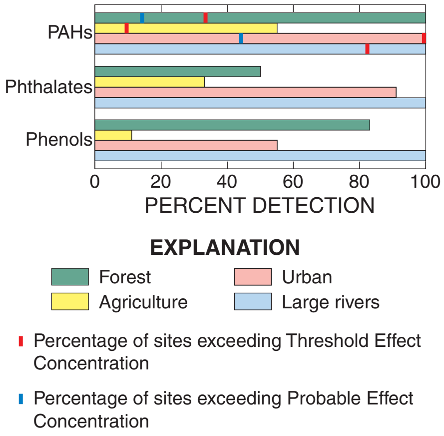
PAHs, which are formed and released into the atmosphere during the incomplete combustion of wood, coal, and fossil fuel, were detected in 90 percent of streambed-sediment samples collected. The most frequently detected PAH compound was pyrene, which was detected at 87 percent of the sampling sites. Seven other PAH compounds were detected at more than 75 percent of the sites (see Appendix). PAHs were detected in all stream samples collected in forested and urban settings and in 55 percent of the samples collected in agricultural settings (fig. 10). Total PAH concentrations were below the TEC at 33 percent of the sampling sites, were between the TEC and PEC at 49 percent of sites, and were greater than the PEC at 18 percent of the sampling sites. The effects of urban land use are indicated by increasing PAH concentrations with increasing urban land cover and population density. The TEC was exceeded most frequently at urban and large-river sites (fig. 10), and the PEC was exceeded at 46 percent of the urban and 17 percent of the forested sites. Median concentration and percentage of sites exceeding the TEC were relatively high in samples from large-river sites because these rivers drain major population and industrial centers.

Phthalates, which are used in the manufacture of plastic products and adhesives, were detected in 72 percent of streambed-sediment samples. Detection frequency and total phthalate median concentration were highest in samples from urban sites and lowest in samples from agricultural sites (fig. 11). Concentrations are likely higher at urban and large-river sites as a result of industrial discharges, or disposal by incineration or in landfills. Phthalate detections in forested settings were not expected. There are no sediment-quality guidelines for phthalates, so the potential effects of phthalates on sediment-dwelling organisms cannot be assessed.

Phenols are used as disinfectants and in chemical production, and they occur in combustion products. P-cresol, the only phenol detected of the five compounds analyzed for, was detected in 54 percent of the samples. Although p-cresol use is greatest in urban areas, median concentrations and frequencies of detection were higher at large-river and forested sites than at agricultural or urban sites (fig. 11). There are no sediment-quality guidelines for phenols,

More information on PCB trends in the Delaware River Basin are in the following report:

Trends in concentrations of polychlorinated biphenyls in fish tissue from selected sites in the Delaware River Basin in New Jersey, New York, and Pennsylvania, 1969–98, by Karen Riva-Murray and others: U.S. Geological Survey Water-Resources Investigations Report 01–4066 at *http://ny.usgs.gov/pubs/wri/wri014066/*



(Sediment guidelines have not been established for phenols or phthalates)

Figure 10. Semivolatile organic compounds were widely detected in streambed sediments from all land-use settings except agricultural areas. The reasons for high rates of detections in some forested settings are not clear.

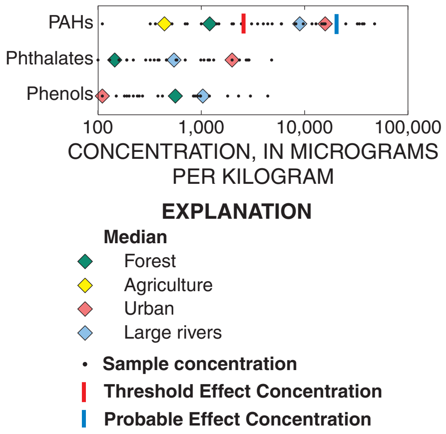


Figure 11. Higher median concentrations of phthalates and polycyclic aromatic hydrocarbons at urban and large-river streambed-sediment sampling sites reflect the high rate of use and disposal of these compounds in these settings.

so the potential effects of phenols on sediment-dwelling organisms cannot be assessed.

PAHs, phthlates, and phenols were detected more frequently at forested sites than at agricultural sites, and median concentrations tended to be higher than concentrations in agricultural areas (figs. 10 and 11). The reasons for these findings are not clear. Possible explanations may include local sources where wood or trash is burned, large leaf areas in forests scavenging chemicals from the air, and preferential deposition from regional atmospheric sources to forests that are topographically higher than agricultural lands.

Trace-Metal Contaminants in Streambed Sediment and Fish Tissue

Sediment-dwelling organisms may be at risk from multiple trace-metal contaminants in sediment

Trace metals that are contaminants of concern, including arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc, were detected in streambed sediment at all 39 sites sampled in the basin. Although these trace metals occur naturally in the environment, their presence in high concentrations in many streams throughout the Study Unit indicates that sediment-dwelling organisms may be at risk from streambed sediments contaminated by multiple trace metals (fig. 12). The median number of TECs exceeded for metals was six, and at least three TECs were exceeded at all sites. Concentrations of chromium, lead, nickel, and zinc most frequently exceeded a PEC (each at about 20 percent of all sites sampled).

Concentrations of each trace-metal contaminant (except arsenic) generally were highest in streams draining watersheds that are associated either with historical or current industrial activities. Because many of these metals are associated with industrial processes and disposal practices, and because of the high population density and long history of industrial activity in the basin, this finding is not unexpected. Yet some streams in forested areas also contained elevated concentrations of some trace metals. Many of the forested sites at which levels of cadmium and zinc were elevated are in the headwaters of the Lehigh and Schuylkill Rivers, where coal was mined extensively from the 1870s to the 1950s. Moreover, concentrations of cadmium

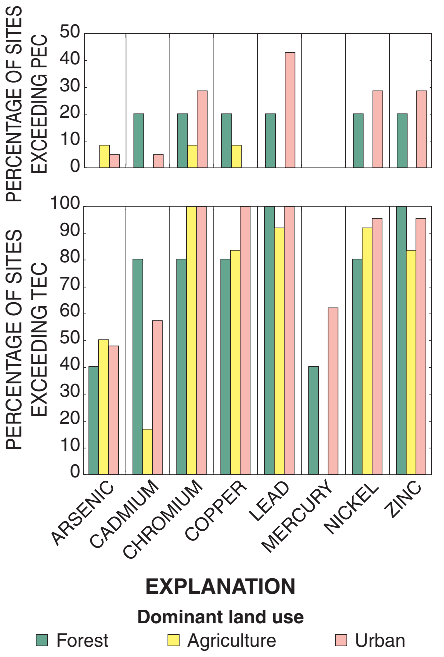


Figure 12. Many metals exceeded the Threshold Effect Concentration (TEC), the concentration at which adverse biological effects are expected to begin, in streambed sediments in all land-use settings. Streambed sediments of urban streams are likely to contain multiple metal contaminants at concentrations that may be harmful to sediment-dwelling organisms.

Health Effects of Methylmercury

Methylmercury, the biologically active and toxic form of mercury, is a potent neurotoxin to humans and wildlife. It can cause neurological damage, mental retardation, blindness, deafness, kidney malfunction, and even death. The developing fetus is especially vulnerable to harmful effects of methylmercury. Consumption of contaminated fish and shellfish is a primary route of transmission of methylmercury to humans. Methylmercury is also harmful to wildlife that regularly consume contaminated fish and other organisms, particularly because it becomes increasingly concentrated as it is transferred up the food chain. This "bioaccumulation" can cause very high levels of mercury in top predator fish, which then pose health risks to humans and wildlife consumers. In 2001, the U.S. Environmental Protection Agency lowered the maximum advisable concentration of mercury in fish and shellfish to 0.3 micrograms per gram of edible tissue to protect consumers in the general population. Many States have much more stringent advisories for children, pregnant women, and women who are considering becoming pregnant. The sources of mercury and the environmental processes favoring its methylation are subjects of current research by the USGS and other agencies. Additional information about methylmercury is on the World Wide Web at URLs *http://minerals.usgs.gov/mercury* and *http://www.epa.gov/waterscience/criteria/methylmercury/factsheet.html*

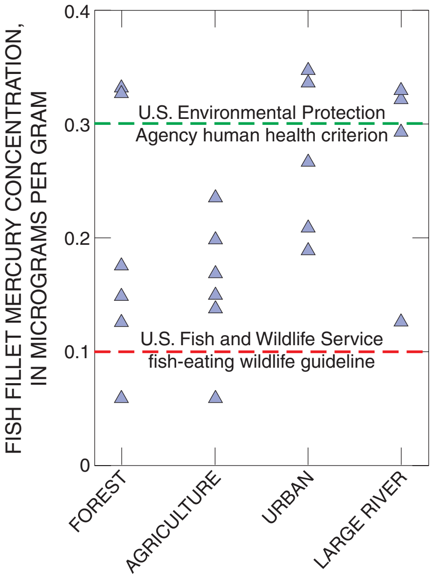


Figure 13. Mercury concentrations in smallmouth bass fillets sometimes exceeded the human health criterion and often exceeded the fish-eating wildlife-protection guideline.

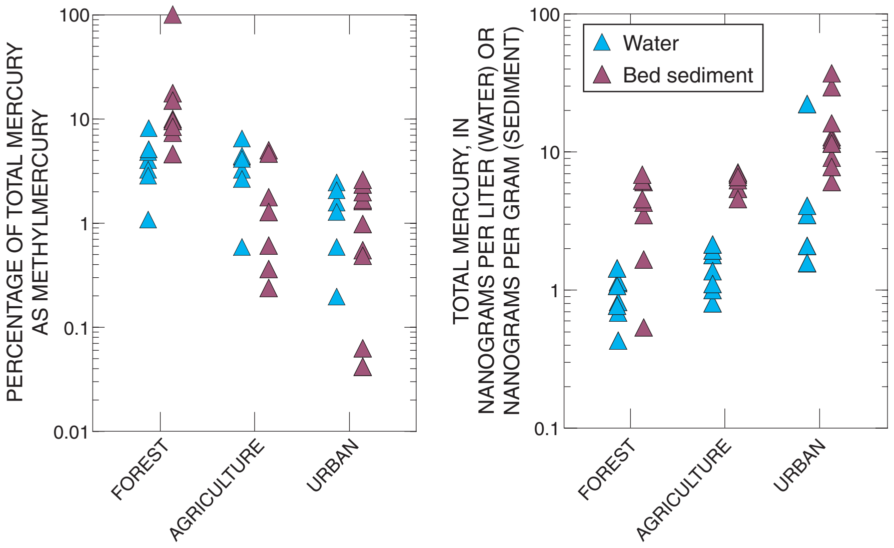


Figure 14. Formation of methylmercury (methylation efficiency), the bioavailable and toxic form of mercury, was much higher in forested settings than in other land-use settings. This helps explain why some fish-fillet samples from forested areas contained mercury concentrations as high as those found in urban areas, even though total mercury concentrations in water and sediment were higher in urban areas.

and zinc were highest at the two stream sites on the Lehigh River near a metals smelter (PECs were exceeded at both sites). The next highest concentrations of these elements were at the downstream site on the Delaware River at Trenton, N.J. Past contamination of the Schuylkill River by lead and other metals is also well documented (Stamer and others, 1985). Concentrations of trace metals were typically lowest in streams draining agricultural areas.

Concentrations of arsenic were elevated at sites in the western part of the Coastal Plain in the basin. Arsenic concentrations in streambed sediment from three of four western Coastal Plain streams were higher than at any other sites sampled throughout the basin, and concentrations exceeded the PEC at these three sites. Comparison of these findings with other sediment data from U.S. Geological Survey's National Water Information System database and the National Uranium Resource Evaluation Program indicates that elevated concentrations of arsenic in the Coastal Plain were confined to the area where many geologic formations crop out west of the Kirkwood-Cohansey aquifer system (fig. 1). Whether these elevated arsenic concentrations are related to natural sources in clays or are a result of past use of arsenate pesticides (Murphy and Aucott, 1998) or other human disturbances is not clear.

Mercury levels in fish are of concern to health of humans and wildlife

Elevated concentrations of mercury were found in fish fillets throughout the Delaware River Basin (fig. 13). Concentrations of total mercury exceeded the human health criterion of 0.3 µg/g (micrograms per gram) set by the USEPA (2001) at 22 percent of the 31 sites sampled, and exceeded the 0.1 µg/g guideline set by the U.S. Fish and Wildlife Service for protecting fish-eating wildlife (Eisler, 1987) at 87 percent of the sites sampled. These levels were exceeded at sites in both urban and forested settings, and the wildlife guideline was exceeded at some agricultural sites.

Concentrations of total mercury in water and streambed sediment were lowest in forested settings (fig. 14) and highest in urban settings; however, the methylation efficiency (concentration of methylmercury divided by total mercury) was higher in forested settings than the urban settings (fig. 14). Methylmercury is the most bioavailable form of mercury (U.S. Environmental Protection Agency, 1997), and higher methylation rates in the forests, where the natural environment may be more conducive to the methylation process, contribute to the elevated concentrations in fish fillets at these sites (Brightbill and others, 2003). The primary source of mercury at forested sites is atmospheric deposition from incinerators, coal-fired power-

More information on mercury in the Delaware River Basin is in the following report:

Total mercury and methylmercury in game fish fillets, water, and bed sediment from selected streams in the Delaware River Basin, New Jersey, New York, and Pennsylvania, 1998–2001, by R.A. Brightbill and others: U.S. Geological Survey Water-Resources Investigations Report 03–4183 at *http://pa.water.usgs.gov/reports/wrir03-4183/*

Some mercury findings in the Delaware River Basin were similar to those from national study

Mercury concentrations in fish fillets in the Delaware River Basin ranked eighth highest among concentrations measured in 20 NAWQA Study Units that were sampled as part of a National pilot program (Brumbaugh and others, 2001). A geometric mean concentration of 0.26 µg/g total mercury in fillets was calculated for the basin using data from this study combined with data from more recently collected samples. The geometric means across the Nation ranged from 0.03 to 3.34 µg/g. National findings on the relation of mercury concentrations to land-use patterns were similar to those in the Delaware River Basin. Total mercury concentrations in both water and sediment were higher at urban sites than at forested or agricultural sites. Similarly, median methylation efficiencies were lower at urban sites than at forested sites (Krabbenhoft and others, 1999). Findings from the national study, which included a wide range of environmental settings, also indicated that methylation is related to the percentage of wetlands in a watershed and is enhanced by environmental variables such as the presence of sulfate, organic matter, and dissolved oxygen. However, similar relations were not observed in the Delaware River Basin study. The factors affecting methylation rates in different environmental settings is an area of current research (*http://minerals.usgs.gov/mercury/*).

plants and other fossil-fuel combustion sources. The presence of high total mercury concentrations in sediment in some urban settings indicates additional local inputs, but lower methylation efficiencies or other processes in urban regions limit uptake in fish. The high methylation rate in forests and low rate in urban areas could explain why concentrations of mercury in fish from both forested and urban settings were similar.

Naturally Occurring Contaminants in Ground Water

Of the 23 trace elements (see Appendix) analyzed for in domestic wells in the clastic-rock aquifers of the Piedmont and Valley and Ridge Provinces and the glaciofluvial aquifers, only the concentrations of arsenic and radon exceeded established drinking-water standards or guidelines. Some trace elements are vital to human and aquatic organisms; yet some can be toxic at high concentrations. Although trace elements can occur naturally, they can be mobilized as a result of human activities that change subsurface geochemical conditions. Trace elements from contaminated materials emplaced at the surface also can leak into aquifers.

Radon concentrations in most wells exceeded proposed drinking-water standard

In the Delaware River Basin, concentrations of radon (a naturally occurring gas, see box on p.13) were greater than 300 pCi/L (picocuries per liter), the proposed drinking-water standard for public water-supply systems, in more than 96 percent of the domestic wells sampled. The standard was exceeded in all the wells sampled in the Piedmont clastic-rock and glaciofluvial aquifers and in 90 percent of the wells in the Valley and Ridge clastic-rock aquifer. Concentrations ranged from 60 to 6,020 pCi/L (fig. 15); the median concentration was highest in the Piedmont clastic-rock aquifer (1,820 pCi/L), followed by the Valley and Ridge clastic-rock aquifer (1,400 pCi/L) and the glaciofluvial aquifers (1,011 pCi/L). Because radon is produced naturally by the radioactive decay of uranium in rocks, concentrations in the Delaware Basin were similar to those in nearby NAWQA Study Units that sampled wells in the Appalachian Mountains but exceeded concentrations in most other areas of the country.

Other forms of radioactive materials in water have also been identified as health risks. Some of these elements, such as radium-224, radium-226, and radium-228, as well as alpha and beta radiation, were analyzed for and detected in wells in the clastic-rock aquifers of the Piedmont and Valley and Ridge. Many of these compounds are short-lived (decaying in a matter of days) but nevertheless are a concern because particles emitted in the decay process can cause genetic damage and cancers. Alpha radiation was detected in 72 percent of the wells sampled in the Piedmont and 8 percent of the wells in

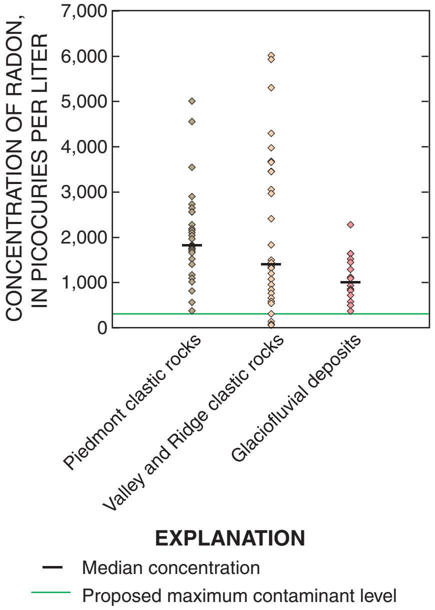


Figure 15. Radon concentrations exceeded the proposed 300-pCi/L drinking-water standard for public water suppliers in almost all domestic wells sampled.

More Information on Radon

Radon is a colorless and odorless gas that is produced naturally by the radioactive decay of uranium in rocks and soils. Airborne radon has been identified as a leading cause of lung cancer. The USEPA has identified ground water as a source of radon in homes and recommends testing of well water, especially in areas where radon concentrations are known to be elevated, such as the bedrock areas of the Delaware River Basin. Additional information about radon can be found on the World Wide Web at URLs *http://energy.cr.usgs.gov/radon/radonhome.html* and *http://www.epa.gov/iaq/radon/*.

the Valley and Ridge clastic rocks, and exceeded the 15-pCi/L drinking-water standard in 10 and 3 percent of the domestic wells in each aquifer, respectively. Beta radiation was detected in 41 percent of the wells sampled in the Piedmont and 30 percent of the wells in the Valley and Ridge clastic rocks, but did not exceed the 15-pCi/L standard. One or more of the different radium isotopes were detected in all of the wells sampled. The 5-pCi/L drinking-water standard for radium-226 plus radium-228 was exceeded in 3 percent of the wells in the Piedmont and none of the wells in the Valley and Ridge clastic-rock aquifer. Results in the Piedmont were similar to those reported by Szabo and Zapecza (1991) for public-supply wells.

Arsenic concentrations in Piedmont wells can exceed drinking-water standards

Arsenic was detected in more than 70 percent of the domestic wells sampled in the Piedmont clastic-rock aquifer but in only 20 and 6 percent of the wells in the in the Valley and Ridge clastic-rock and glaciofluvial aquifers, respectively (fig. 16). The median concentration for arsenic was 2.8 µg/L in samples from the Piedmont clastic-rock aquifer and less than 1.0 µg/L in the Valley and Ridge clastic-rock aquifer and glaciofluvial aquifers. Arsenic concentrations in samples from two domestic wells in the Piedmont exceeded the 10-µg/L drinking-water standard. Arsenic in the clastic rocks of the Piedmont is from natural sources, and its occurrence is related to ancient depositional environments and current geochemical conditions (Serfes and others, 2004). Arsenic in high concentrations is a human health concern because it can contribute to cancers of the skin, bladder, and other organs (National Research Council, 1999).

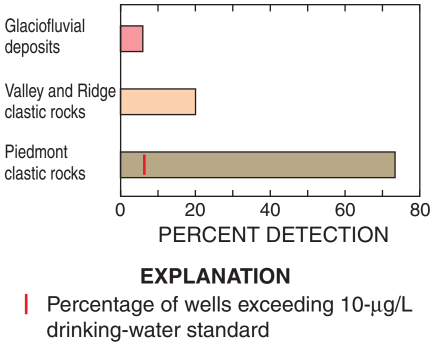


Figure 16. Arsenic was detected much more frequently and at higher concentrations in samples from wells in the Piedmont clastic-rock aquifer than in those from wells in other parts of the Delaware River Basin. Data were censored to a common reporting limit of 1.0 micrograms per liter.

Pesticides in Streams and Ground Water

Pesticides include a wide variety of chemicals that are used to control undesirable plants (herbicides), insects (insecticides), molds (fungicides), and other agricultural, urban, or forest pests. Concerns about the potential effects of pesticides on human health, as well as on aquatic and terrestrial ecosystems, have led to a wide range of monitoring and management programs by State and Federal agencies. However, the types and amounts of pesticides used changes over time and many compounds are transformed once they are applied. Data collected in a consistent manner over time are needed to assess the implications of these changes.

Pesticides were detected in most streams and in many wells sampled

One or more pesticides were detected in 93 percent of samples from 94 stream and river sites and in 43 percent of 76 domestic wells sampled. Of the 43 pesticides for which analyses were conducted, 28 were detected in stream samples and 15 were detected in wells. The number of pesticides detected in stream samples ranged from 0 to 13, and the number of pesticides detected in well samples ranged from 0 to 7.

The most commonly detected pesticides in surface water and in ground water were the herbicides atrazine, metolachlor, and simazine (fig. 17). Atrazine and metolachlor, two of the most heavily applied pesticides in agricultural areas of the basin (Gianessi and Marcelli, 2000), were detected in more streams (over 70 percent) and wells (almost 30 percent) than any other pesticide. Simazine also was frequently detected in streams (about 70 percent) and wells (about 7 percent) in various land-use settings throughout the basin. Also commonly detected in streams (but less frequently in ground water) was the herbicide prometon, which is used on road and utility rights-of-way, and the insecticides diazinon and carbaryl, which are commonly used to control residential and household pests. The most widely detected pesticides in the basin are also among the most widely detected pesticides nationwide (Larson and others, 1999).

Although similar pesticides were detected in surface water and ground water, they typically were detected less frequently in ground water. This difference can be attributed to the slow rate of water movement through the subsurface—recently applied pesticides are less likely to be detected in wells because they are still in transit. Slow water movement in the subsurface and intimate contact with the sediment also increases the likelihood that a transported pesticide will stick to soil (adsorb), break down (degrade), or become a gas (volatilize).

Chemical properties of pesticides determine how they transform and interact and may explain why some widely used pesticides were detected less frequently than others. For instance, pendimethalin was frequently detected in streams in the spring, rarely detected in streams in the late summer, and never detected in ground water (fig. 17). The tendency for this chemical to attach to organic matter in soil, rather than dissolve in water, in large part limits its movement and detection in ground water. Also, some pesticides, such as alachlor, break down rapidly and are more likely to be found as degradation products than as the parent compound.

Pesticide degradation products were detected more frequently and often at higher concentrations than parent compounds

Many pesticides are unstable and can degrade into other compounds. Samples were analyzed for deethylatrazine (for all sites) and several degradation products of metolachlor, alachlor, and acetochlor (for all ground-water sites and two surface-water sites – Tulpehocken Creek, Pa., and the Schuylkill River at Philadelphia). Seven of 10 degradation products analyzed for in both ground-water and surface-water samples were detected. Degradation products of atrazine, metolachlor, and alachlor were some of the most frequently detected pesticide compounds in surface water and ground water, and concentrations were often higher than parent compounds (fig. 18). These results indicate that many more pesticide compounds are present in surface water and ground water than are detected in routine analyses that are designed to measure only parent compounds.

Deethylatrazine was the most frequently detected degradation product. It was the most frequently detected pesticide compound in ground water and the second most frequently detected pesticide compound in surface water. Typically it was detected in about the same percentage of samples and at about the same concentrations as atrazine, its parent compound. However, concentrations of both atrazine and deethylatrazine typically were lower in ground water than in surface water. Deethylatrazine was detected in 79 percent of surface-water samples collected in the spring, with a median concentration of 0.053 µg/L (micrograms per liter). In ground water it was detected in 39 percent of the wells sampled, with a median concentration below the detection limit (0.002 µg/L). In the Piedmont clastic rock aquifer, deethylatrazine had a median concentration of 0.004 µg/L and was detected in 60 percent of the wells (a rate twice that of atrazine).

Degradation products of metolachlor, alachlor, and acetochlor were detected at much higher concentrations than parent compounds, particularly in ground water. Degradation products were detected in 43 of 76 wells, whereas parent compounds were detected in only 33 wells, even though the parent compounds had lower detection limits (fig. 18). In particular, metolachlor ethane sulfonic acid (ESA) was detected in 37 percent of the wells, at concentrations between 0.05 and 10.4 µg/L, whereas metolachlor (the parent compound) was detected in 3 percent of the wells, at concentrations above 0.05 µg/L. Results for the two stream sites where acetanilide herbicide degradation products were sampled were similar to results for ground-water samples.

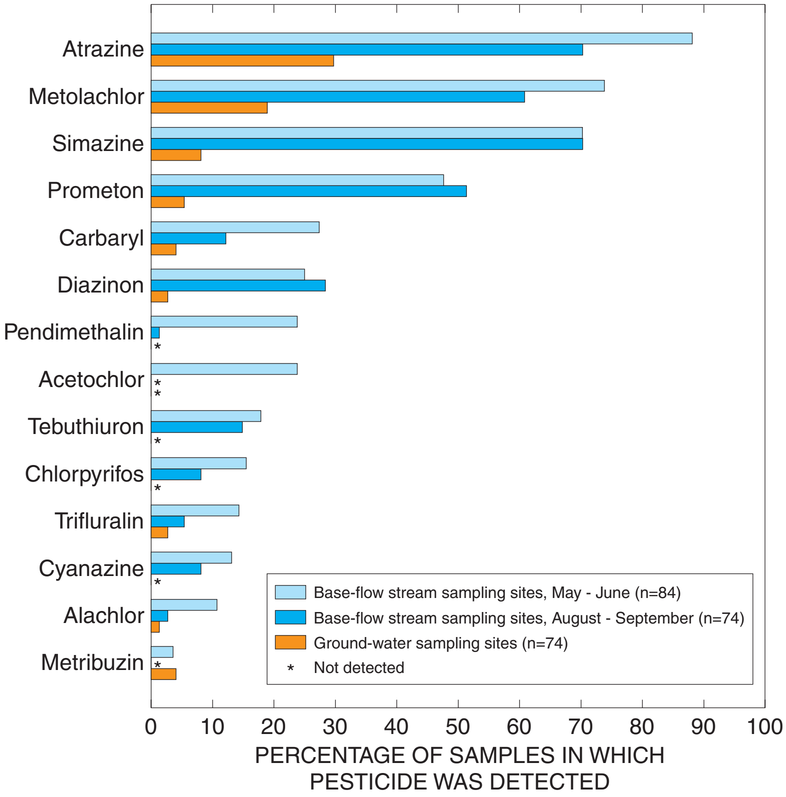


Figure 17. Thirteen different pesticides were detected in more than 10 percent of streams sampled, and nine different pesticides were detected in more than 5 percent of wells sampled. Typically, the same pesticides were detected in streams and ground water in the basin, although almost all pesticides were detected less frequently in ground water.

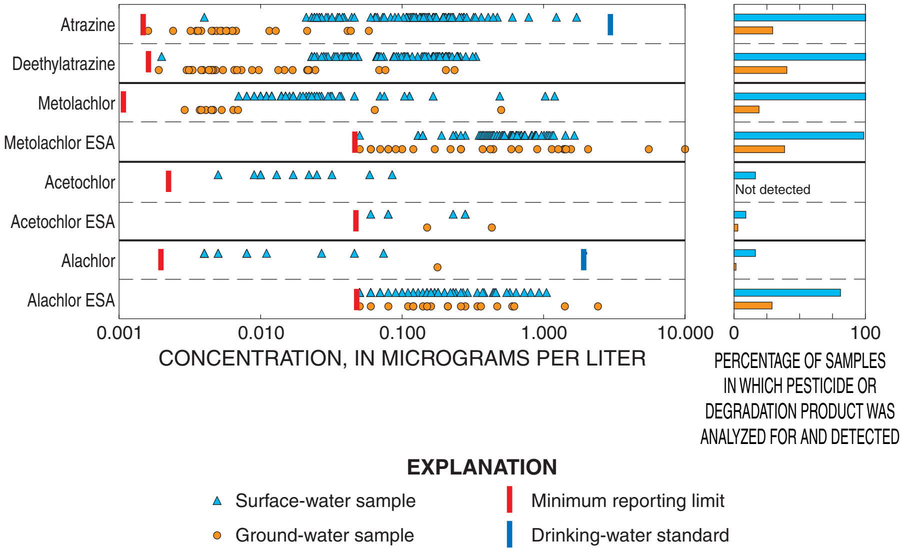


Figure 18. Degradation products of the pesticides metolachlor, alachlor, and acetochlor (ethane sulfonic acids or ESA) were typically detected at higher concentrations than parent compounds, particularly in ground water. Deethylatrazine (a degradation product of atrazine) was generally detected at concentrations similar to those of its parent compound. Most of these degradation products are not routinely measured in water-quality studies, and their health effects are unknown.

Pesticide concentrations rarely exceeded standards or guidelines for drinking water and sometimes exceeded those for the protection of aquatic life

Concentrations of pesticides in surface water and ground water rarely exceeded drinking-water standards or guidelines (see box on p. 8). No drinking-water standards or guidelines were exceeded in any of the 76 homeowner wells sampled. Of the 531 stream samples collected at 94 sites, only 7 samples from 6 sites contained pesticides at concentrations that exceeded one or more drinking-water standard or guideline. These exceedances (for atrazine, simazine, or dieldrin) were found in stream samples collected from the Piedmont Province in the summer of 2000.

Pesticide concentrations in 6 percent of the stream samples (29 samples collected at 11 sites) exceeded aquatic-life guidelines (see box on p. 8) for one or more of five pesticides. Diazinon was the pesticide that most often exceeded its aquatic-life guideline (in 19 samples collected at 7 sites). Of the 19 exceedances, 15 were from multiple samples collected at three sites: Little Neshaminy Creek, Pa.; Cooper River, N.J.; and Raccoon Creek, N.J. (see fig. 39A). Other compounds whose concentrations exceeded their aquatic-life guidelines were carbaryl (seven samples), lindane (two samples), atrazine (two samples), and chlorpyrifos (one sample).

Because drinking-water or aquatic-life standards or guidelines have not been established for all pesticides and degradation products, some of the risks of pesticides to humans and aquatic life may be overlooked. For the 35 pesticide compounds detected in the basin, drinking-water standards or guidelines have been established for 21 and aquatic-life guidelines for 17 (including 7 of the 10 most frequently detected pesticides). In particular, pesticide degradation products may be of concern because they are frequently detected at concentrations equal to or greater than parent compounds and can have similar or even greater toxicities than the parent compounds. Pesticide degradation products are not detected in routine water analyses that look only for parent compounds; therefore, harmful effects may be underestimated. Another concern is that none of the standards or guidelines take into account the possible synergistic effects of the mixtures of pesticides that are common in water samples. For instance, cumulative concentrations of all pesticides and degradation products in more than 20 percent of the domestic wells sampled in the Piedmont clastic rocks exceeded 1µg/L (fig. 19), and five or more compounds were detected in more than 18 percent of the wells. The combined effects of prolonged exposure to multiple co-occurring compounds on human health are unknown.

Pesticide concentrations are related to application rates on agricultural and urban lands

Concentrations of pesticides in streams were related to land use and pesticide-application rates in agricultural and urban settings (fig. 20). Concentrations of herbicides in stream samples (such as atrazine, metolachlor, and pendimethalin) increased with increasing amounts of agricultural land in a watershed. For example, concentrations of atrazine increased from about 0.001 µg/L in a watershed with minimal

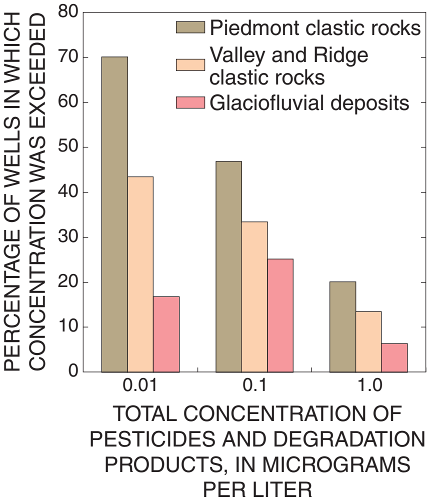


Figure 19. Total concentrations of pesticides and degradation products in ground-water samples were consistently higher in the Piedmont than in other parts of the basin. Samples from 20 percent of the wells in the Piedmont clastic-rock aquifer, which has more agricultural and urban development than the other aquifers, had concentrations of 1.0 microgram per liter or more.

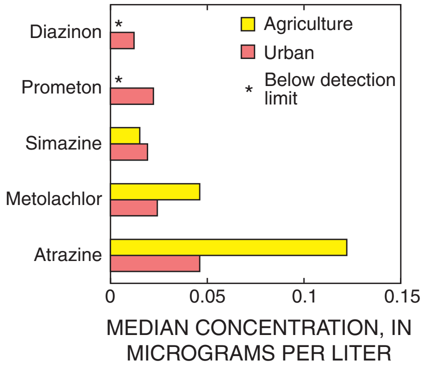


Figure 20. Concentrations of frequently detected pesticides reflected the land-use setting in which they were used. Streams in agricultural areas had higher concentrations of atrazine and metolachlor than streams in urban areas because these pesticides are primarily applied to crops. Conversely, streams in urban areas had higher concentrations of prometon and diazinon than streams in agricultural areas because prometon is primarily used along roads and diazinon is used to control insects around housing. Simazine is applied in both urban and agricultural areas.

to no agricultural land to about 1.00 µg/L in a basin with 70 percent agricultural land (fig. 21). Concentrations of atrazine generally were highest in the counties with the highest rates of application to agricultural lands (fig. 22). Some pesticides were used and detected only in a specific region. Terbacil, which is used extensively on peaches and blueberries, was frequently detected in streams of the Coastal Plain, where peaches and blueberries are major crops. Results of previous studies (Reiser and O'Brien, 1998; Stackelberg and others, 1997) also indicate that terbacil is present in streams and aquifers of the Coastal Plain. Terbacil was not detected in surface water or ground water elsewhere in the basin where other crops predominate and terbacil is not widely used.

Surface-water concentrations of four other frequently detected pesticides—prometon, diazinon, carbaryl, and chlorpyrifos—increased with the percentage of the watershed occupied by urban land. Concentrations of these pesticides were highest in and near Philadelphia and other urban areas (fig. 23). A comparison of use and detection rates could not be made, however, because few good estimates of rates of application of these pesticides in urban areas are available.

In general, more pesticides were detected in base-flow samples at urban sites than at agricultural sites. The median number of pesticides detected in streams at urban sites was 9, whereas the median at agricultural sites was 6, and the median at forested sites was 1. A wider variety of pesticides, such as prometon, diazinon, carbaryl, and chlorpyrifos, are used around homes, lawns, and rights-of-way in urban areas than on farmland. Some pesticides, such as simazine, are used in both agricultural and urban areas. In addition, low concentrations of atrazine, metolachlor, and other pesticides that are associated primarily with agricultural land use were commonly detected at urban sites. These pesticides may be derived from small areas of active farming or may represent residual pesticides in soils or ground water from previous land uses. Also, low concentrations of these pesticides may be carried into the area by rain (McConnell and others, 2002).

Results of ground-water studies, which were not specifically designed to

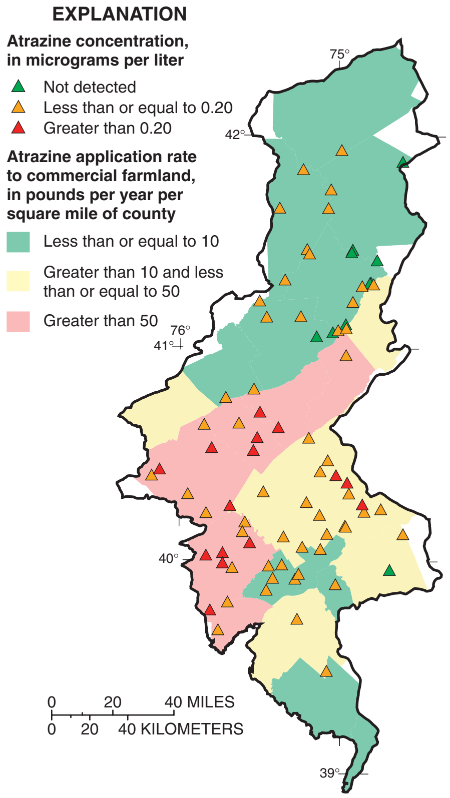


Figure 22. Atrazine was widely detected throughout the basin, but the highest concentrations were found in counties in which the highest quantities of atrazine were applied to agricultural land.

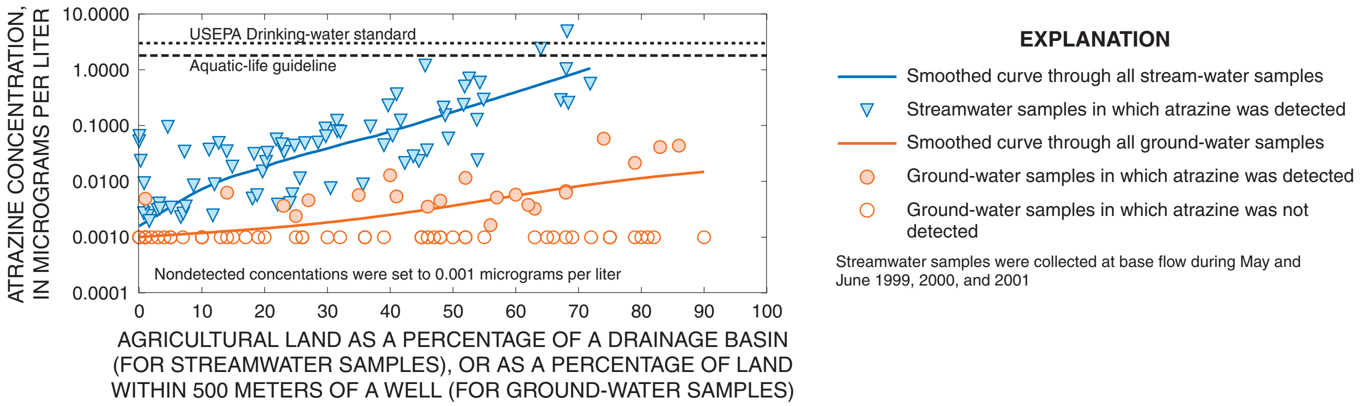


Figure 21. Concentrations of atrazine, a herbicide used on row crops, increased in streams and ground water with increasing agricultural land use.

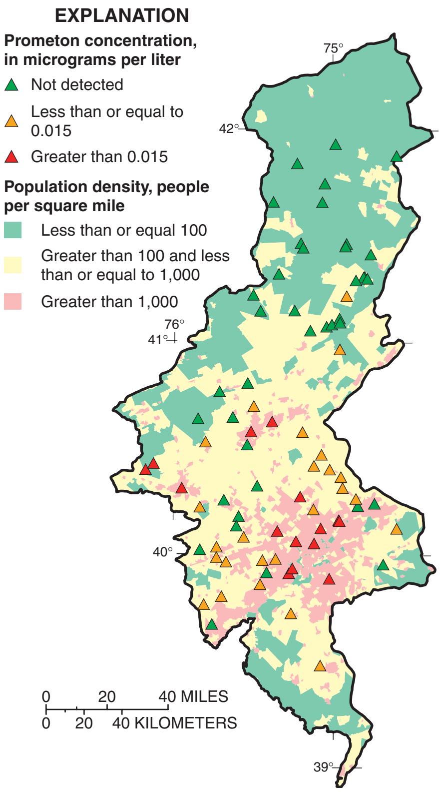


Figure 23. Prometon, a herbicide used extensively on roads and other rights-of-way, was typically found in streams draining highly populated watersheds.

account for the effects of land use, were similar to surface-water findings. In general, more pesticides were detected in wells in the more developed southern part of the basin than in wells in the less developed northern part. A total of 12 pesticide compounds were detected in well samples from the Piedmont clastic-rock aquifer, 10 in samples from the Valley and Ridge clastic-rock aquifer, and 3 in samples from the glaciofluvial aquifers. Concentrations of atrazine and metolachlor generally were lowest in the northern part of the basin, where agriculture development is least intense. Detections of prometon, diazinon, carbaryl, and chlorpyrifos in ground water were few because these insecticides are likely to sorb to soil or degrade. However, these compounds are used and detected most frequently in urbanized regions like the Piedmont; they were detected less frequently in the Valley and Ridge and not at all in the relatively undeveloped Appalachian Plateaus.

Pesticide concentrations in streams were highest during the growing season

Concentrations of pesticides in streams were highest during the growing season, when most pesticides are applied. Concentrations of pesticides used in agricultural areas (atrazine, metolachlor, and acetochlor) peaked from May to July (fig. 24) when they are typically applied. In contrast, concentrations of pesticides used primarily in urban areas (prometon, diazinon, carbaryl, and chlorpyrifos) are elevated over the entire growing season because they are applied repeatedly to control weeds and insect pests. The seasonal pattern in agricultural pesticide concentrations has been noted in streams nationwide (Larson and others, 1999) and has been attributed to pesticides being washed off by rainstorms during the period they are applied.

VOCs in Streams and Ground Water

One or more volatile organic compounds (VOCs) were detected in 92 percent of stream samples and 59 percent of well samples. Water samples were analyzed for 85 VOCs. Forty-two different VOCs were detected in stream samples (170 samples collected at 10 sites), and 26 VOCs were detected in well samples (one sample from each of 76 wells). Compounds typically detected in ground water also were found in surface water, although for most VOCs the detection frequency in surface water was generally greater (fig. 25). The most frequently detected classes of VOC compounds were chlorinated solvents and disinfection byproducts (compounds produced when water is treated with a disinfectant). Many components of gasoline, such as benzene, toluene, ethylbenzene, and xylenes, were detected frequently in surface water but were not detected in ground water, most likely because they are readily biodegraded in the subsurface. Gasoline-related compounds that were found most frequently in ground water were oxygenates such as methyl *tert*-butyl ether (MTBE) that are not readily biodegraded.

Although VOCs were detected frequently, concentrations generally were low. Only five VOCs (acetone, MTBE, toluene, chloroform, and trichloroethene) had median concentrations greater than 0.01 µg/L, and only acetone and MTBE were detected at concentrations greater than 1.0 µg/L.

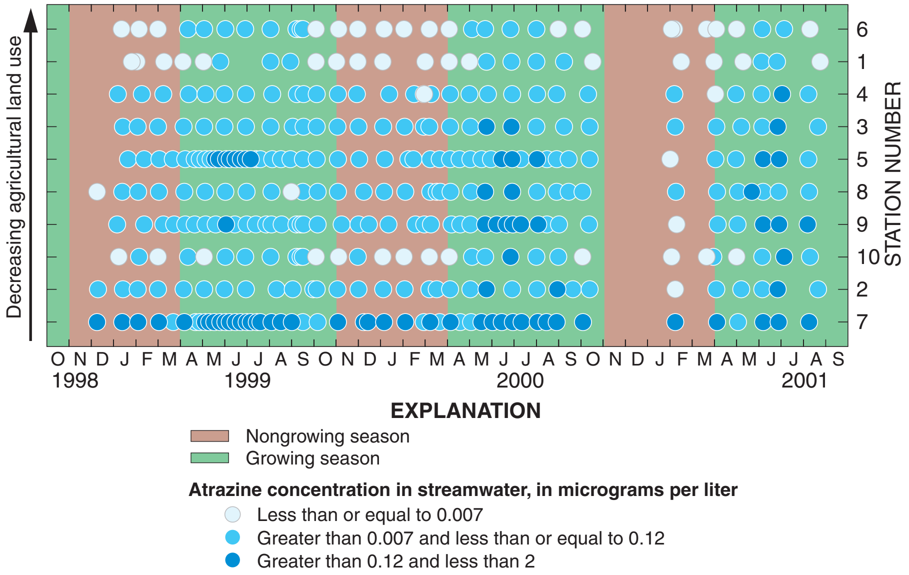


Figure 24. Concentrations of atrazine in streams were highest during the growing season (May, June, and July). This pattern has been noted for many pesticides in streams nationwide (Larson and others, 1999) and has been attributed to rain washing off pesticides applied in the spring. Station locations are shown in figure 39.

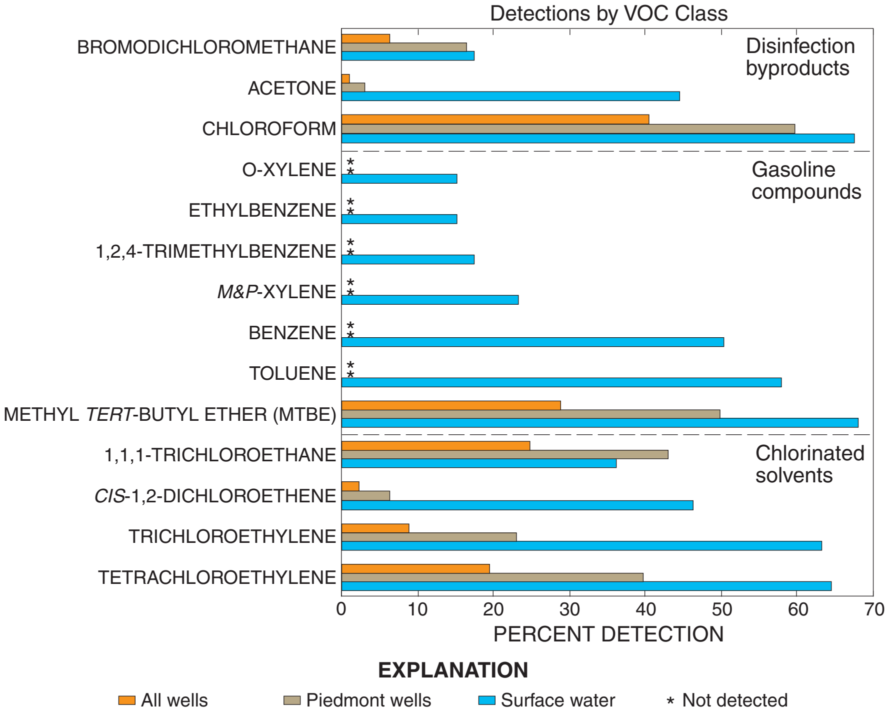


Figure 25. Volatile organic compounds (VOCs) were frequently detected in surface-water and ground-water samples, but concentrations did not exceed drinking-water standards or guidelines. Many of the gasoline compounds, such as benzene, were detected in surface water but were not detected in wells because they are readily degraded in the subsurface.

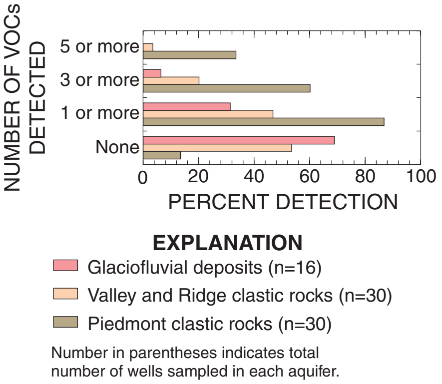


Figure 26. VOCs were detected in a higher percentage of wells in the Piedmont clastic-rock aquifer than in wells in other regions. This is likely due to higher use of VOCs in the heavily urban Piedmont region.

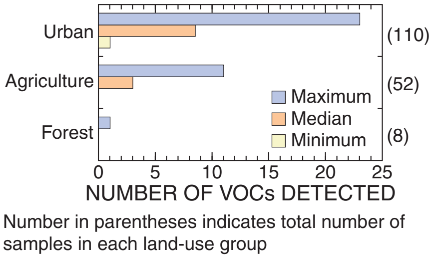


Figure 27. VOCs were frequently detected in streams in both urban and agricultural settings, but the number of VOCs detected was greater in urban areas.

In ground water, only chloroform and MTBE were detected at concentrations above 0.01 µg/L in more than 10 percent of the wells. Concentrations of VOCs in surface water and ground water did not exceed drinking-water standards or guidelines, and concentrations in surface water did not exceed aquatic-life guidelines (see box on p. 8). The health effects of VOCs are not completely understood, however, because drinking-water standards or guidelines have been established for only 23 of 42 VOCs detected in surface water and 21 of 26 VOCs detected in ground water, and aquatic-life guidelines have been established for only 10 of the 42 VOCs detected in streams.

VOCs were detected in streams and ground water in urban and agricultural areas

VOCs were detected in water samples collected in urban and agricultural areas, but the number of compounds detected and the frequency of detections were greatest in urban areas. This pattern of higher VOC detection in both surface and ground water in urban areas reflects a greater intensity of use and production of solvents, gasoline products, and sewage in urban areas. For example, the frequency of VOC detections was greater in wells in the urban Piedmont clastic-rock aquifer (87 percent) than in wells completed in either the agricultural Valley and Ridge clastic-rock aquifer (47 percent) or the less developed glaciofluvial areas farther north (31 percent) (figs. 25 and 26). Similarly, the number of VOCs detected was greater in the Piedmont clastic-rock aquifer than the other aquifers. Three or more VOCs were detected in 60 percent of the Piedmont wells, and five or more were detected in 33 percent of the wells. In contrast, three or more compounds were detected in only 20 percent of the wells in the Valley and Ridge, and only one well had five or more.

Analyses of surface-water samples also indicated that the number of VOCs detected and the frequency of detection were highest in the group of urban sites, intermediate in the group of agricultural sites, and lowest at the forested site (fig. 27). MTBE was the only compound detected at the forested site (Delaware River at Port Jervis, N.Y.) and was detected in only one of eight samples. In general, the same classes of compounds (solvents, gasoline, and disinfection byproducts) were detected at both agricultural and urban sites, but the frequency of detection and the number of compounds detected were lower at agricultural sites than at urban sites.

Concentrations and detection frequencies of VOCs vary seasonally

More than two-thirds of detections of most chlorinated solvents and gasoline-related compounds in surface water were in samples collected in winter and spring. This pattern is similar to that reported by Reiser and O'Brien (1998) and can be attributed to the fact that VOCs are less likely to be detected in warm water because they become more volatile and are driven into the atmosphere. In contrast, at two large-river sites (Schuylkill River at Philadelphia and the Delaware River at Trenton), the detection frequency and concentration of MTBE was greater in the summer than in other seasons, whereas concentrations of other gasoline-related compounds showed no increase in the summer (most likely because they are more volatile and degrade more readily than MTBE). The use of motorized watercraft is most likely responsible for the summer peaks in MTBE concentration and detection frequency at these two sites (the only locations studied where motorized watercraft are used routinely). A similar seasonal pattern has been noted in lakes used for motor boating, both locally (Baehr and Reilly, 2001) and in other parts of the Nation (Boughton and Lico, 1998). In contrast to solvents and gasoline, no seasonal trends in concentrations were noted for most disinfection byproducts, such as chloroform and acetone, probably as a result of limited variability in point-source inputs and streamflow.

Nutrients in Streams and Ground Water

Nutrients (forms of nitrogen and phosphorus) are essential for plant growth, but elevated concentrations are undesirable for two reasons. First, consumption of drinking water containing high concentrations of some forms of nitrogen can reduce oxygen concentrations in the blood of infants to dangerously low levels (blue-baby syndrome). Second, elevated concentrations in surface water can degrade water quality by promoting excessive growth of algae and other aquatic plants. This growth can be aesthetically unpleasing; can interfere with recreational activities such as swimming, boating, and fishing; and can clog water intakes. When algae die and decay, resulting oxygen depletion can affect other aquatic communities and can produce foul odors and tastes.

Nutrients in the Delaware River Basin originate from point and nonpoint sources. Point sources are primarily municipal and industrial dischargers. Nonpoint sources are primarily related to application of commercial fertilizers and manure in agricultural settings, and commercial fertilizer in urban settings. Atmospheric deposition can also be a significant source of nitrogen. In areas without public sewers, septic-system leachate can contribute nitrogen to aquifers. Nutrients on the land surface are often carried into streams with storm runoff, or they can infiltrate into the ground where they can travel for months or years before being discharged to streams.

Agricultural and urban lands are the primary sources of nutrients in streams and aquifers

Concentrations of total nitrogen in streams increased with the percentage of agricultural or urban land in a watershed. Total nitrogen increased with increasing amounts of agricultural land in watersheds in which urban land makes up a small part (10 percent or less) of the basin (fig. 28). A similar increase was seen with increasing urbanization in streams where agricultural land makes up a small part (about 10 percent or less) of the basin. In watersheds with a mix of agricultural and urban land, nutrient-concentration increases were related to both land uses. In addition to land-use associations, high concentrations of total nitrogen were sometimes associated with large point-source discharges.

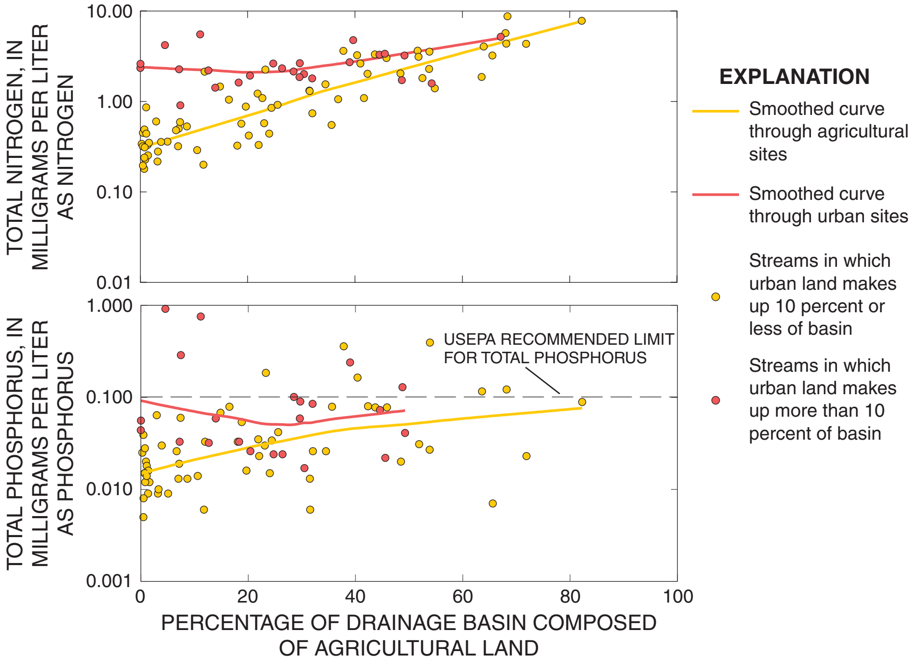


Figure 28. In agricultural watersheds with little urban land (10 percent or less), concentrations of nitrogen and phosphorus increase with agricultural development. In urban watersheds with little agricultural land (10 percent or less), concentrations of nutrients increase with urbanization. In watersheds with a mix of land uses, the two sources of nutrients are difficult to separate. Concentrations shown were measured at base flow, May and June 1999–2001.

In streams, the predominant forms of nitrogen were nitrate and organic nitrogen plus ammonia. Nitrate was detected in more than 95 percent of the streams sampled and often amounted to more than 75 percent of the total nitrogen in surface-water samples. Concentrations of total nitrate ranged from nondetectable to 10.5 mg/L as N, with a median of 0.87 mg/L. The drinking-water standard for nitrate (10 mg/L as

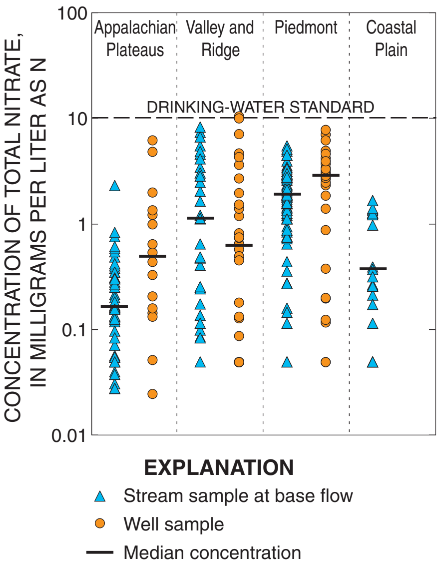


Figure 29. Concentrations of nitrate in streams and aquifers in the intensely developed Piedmont Province are among the highest in the basin. High nitrate concentrations in wells in this region indicate that ground water is one likely source of nitrates to streams during periods of low flow. Stream samples were collected May–June 1999–2001 at base flow.

N) was exceeded in one stream sample (10.5 mg/L in Tulpehocken Creek). Organic nitrogen plus ammonia also was frequently detected in streams (99 percent of samples) and usually amounted to about 20 percent of the total nitrogen in stream samples.

In ground water, more than 95 percent of the total nitrogen was nitrate (a form of nitrogen that is soluble, not easily degraded, and unlikely to sorb to sediments). Concentrations of nitrate in wells ranged from nondetectable to 10.7 mg/L as N, with a median of 1.1 mg/L. The drinking-water standard for nitrate (10 mg/L as N) was exceeded in two domestic supply wells, both in the Valley and Ridge Province (10.1 and 10.7 mg/L). Nitrate was not detected in about 13 percent of the wells sampled (detection limit, 0.05 mg/L), which were mostly in parts of aquifers with minimal to no oxygen.

Differences in nitrate concentrations were related to differing levels of agricultural and urban development in each aquifer studied. The median concentration was highest in the Piedmont aquifer, which has the highest percentage of urban and agricultural land (over 50 percent), followed by the Valley and Ridge, and glaciofluvial aquifers (fig. 29). In the Valley and Ridge clastic-rock aquifer, nitrate concentrations generally were higher in the Great Valley, where agricultural development is much more extensive than elsewhere. Higher concentrations of nitrate in wells than in streams in the Piedmont and Appalachian Plateaus (fig. 29), as well as parts of the Valley and Ridge Provinces, indicates that ground water can be a major contributor of nitrate to streams during base flow.

Total phosphorus concentrations in stream samples ranged from nondetectable to 1.4 mg/L as P, with a median of 0.068 mg/L. Concentrations commonly exceeded 0.1 mg/L, a goal established by USEPA for minimizing nuisance plant growth. For example, total phosphorus concentrations at 5 of the 10 streams sampled throughout the year under all flow conditions exceeded this goal more than 50 percent of the time (fig. 30). Only 15 percent of the 81 streams sampled only once or twice under base-flow conditions exceeded this goal. The lower percentage in the base-flow samples likely reflects the fact that phosphorus is often transported in stormwater. Concentrations of total phosphorus at 8 of 10 streams sampled routinely were higher during storms because phosphorus is often attached to sediment, and sediment concentrations increase during storms.

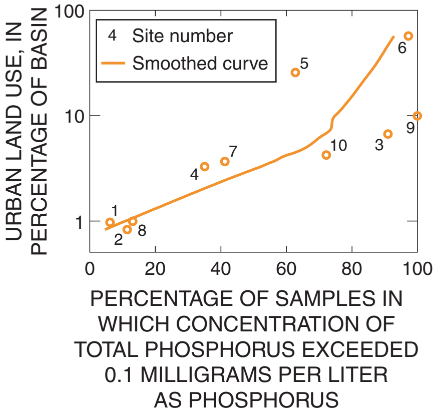


Figure 30. The percentage of stream samples in which the USEPA recommended limit for total phosphorus (0.1 milligrams per liter) was exceeded increased as the percentage of the watershed composed of urban land increased. Sites locations are shown in figure 39.

Concentrations of total phosphorus in streams increased with the percentage of agricultural or urban land in a watershed (fig. 28). Concentrations of phosphorus in streams in urban and agricultural settings also were more likely to exceed the USEPA goal for minimizing nuisance plant growth. Under base-flow conditions, phosphorus concentrations were highest (greater than 0.5 mg/L as P) in streams in which point-source discharges constitute a large percentage of total flow. These streams include Pennypack Creek, Wissahickon Creek, and the Lehigh and Schuylkill Rivers.

Concentrations of dissolved phosphorus in well samples ranged from nondetectable to 0.317 mg/L as P, with a median of 0.014 mg/L. Most phosphorus detected in well samples was orthophosphate, which is extremely soluble. Most other forms of phosphorus are not very soluble and are filtered out by sediments near the surface or are taken up by plants. For this reason, concentrations of phosphorus were lower in most well samples than in stream samples. As with nitrate, differences in orthophosphate concentrations in each aquifer studied were related to differing levels of agricultural and urban development. Median orthophosphate concentrations were highest in the more urban Piedmont clastic rock aquifer (0.031 mg/L as P), followed by the agricultural Valley and Ridge clastic rock aquifer (0.014 mg/L as P), and the least developed glaciofluvial aquifers (below 0.005 mg/L as P).

Nutrients increase algal biomass and alter diatom communities

Algal biomass and the types of algal species present in streams generally are indicative of nutrient enrichment (elevated concentrations of nutrients) because algae require nutrients for growth and reproduction. The number and types of algae in the water or attached to rocks provide important information about a stream's nutrient

Nutrient concentrations span the range of national findings

Concentrations of nitrogen and phosphorus at sites sampled monthly in the Delaware River Basin were similar to or slightly higher than those in 479 streams sampled throughout the Nation (fig. 33). Flow-weighted mean concentrations of total nitrogen at sites on Tulpehocken Creek, Jordan Creek, and the Schuylkill River (sites 7, 2, and 9 in fig. 33) exceeded those at 75 percent of the sites nationwide, and the mean concentration at the agricultural site on Tulpehocken Creek exceeded those at 95 percent of the sites. The highest mean concentration of total phosphorus in the basin was measured at the urban site at Cooper River (site 6). This value exceeded concentrations measured at 80 percent of the sites nationwide. In contrast, phosphorus and nitrogen concentrations at the forested site on the Delaware River at Port Jervis, N.Y. (site 1), were among the lowest measured nationally.

Concentrations of phosphorus and nitrogen in domestic wells from the Valley and Ridge clastic-rock and glaciofluvial aquifers of the basin were similar to those in other domestic wells sampled throughout the Nation (fig. 34). Median concentrations of nitrate and orthophosphate phosphorus in domestic wells in the Piedmont clastic-rock aquifer, however, were among the highest measured. The median nitrate concentration for the Piedmont well survey was greater than that found in 91 percent of the well surveys nationwide. The median concentration of orthophosphate phosphorus in the Piedmont clastic-rock aquifer also was high, exceeding concentrations measured in 81 percent of the wells nationwide. These elevated concentrations reflect the long history of intensive agricultural and urban development in the Piedmont.

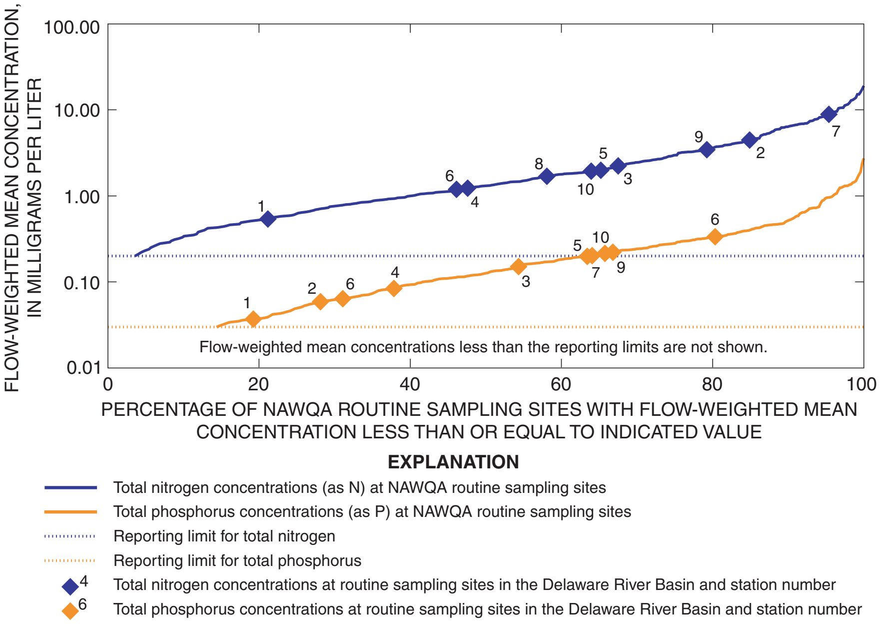


Figure 33. Flow-weighted mean concentrations of total nitrogen and total phosphorus in stream samples from sites sampled routinely in the Delaware River Basin span the range of concentrations measured in 479 streams throughout the Nation. Site locations are shown in figure 39.

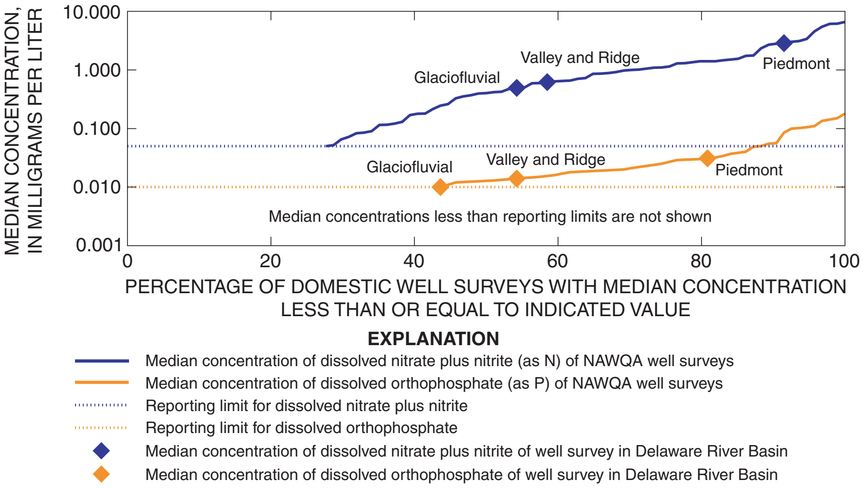


Figure 34. Median concentrations of nutrients in well samples from the Piedmont clastic-rock aquifers of the Delaware River Basin were greater than the median concentrations in most of the 94 domestic well surveys made nationwide.

status and whether nutrients may be contributing to ecological degradation. Furthermore, algae are a main source of food for certain insects, snails, other invertebrates, and fish and can affect the structure and function of invertebrate and fish communities.

Algae samples collected from rocks (periphyton) indicate that Delaware River Basin streams are affected by nutrient enrichment from human activities, although none of the stream samples indicated eutrophic conditions (having excessive plant growth from elevated nutrient concentrations). Median and maximum concentrations of chlorophyll-*a*, one indicator of algal quantity, were 18.6 mg/m^2 (milligrams per square meter) and 79.8 mg/m^2, respectively. Comparison with published values (Dodds and others, 1998) indicates that the typical wadeable stream sampled is mesotrophic (has a level of nutrients that allows for moderate plant growth).

Agricultural sources of nutrients appear to influence algal density (the number of algal cells per unit area of rock) because algal density increased with the percentage of agricultural land in a basin (fig. 31). This relationship is not straightforward because trees can reduce algal densities in streams by reducing the available sun and heat that algae need to grow.

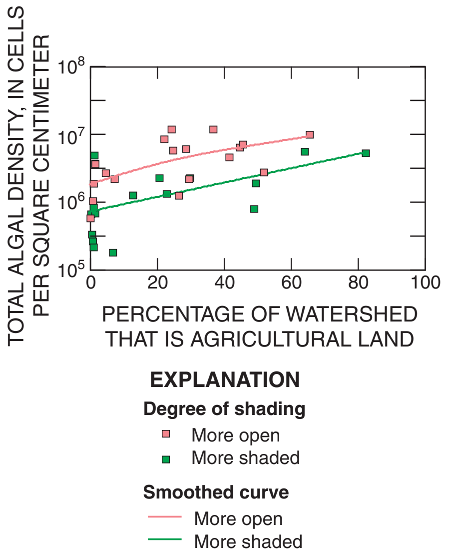


Figure 31. Algal density, an indicator of nutrient enrichment, increased with agricultural land use. Shading from trees can reduce algal densities.

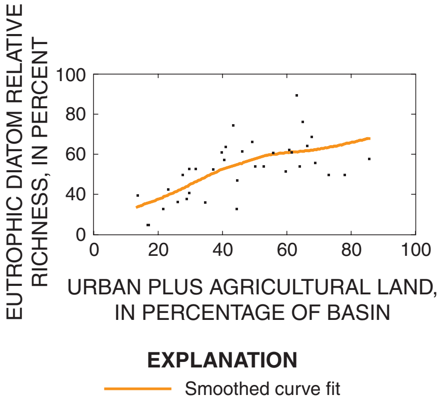


Figure 32. Relative species richness of diatoms that are tolerant of nutrient enrichment (eutrophic) increased with increasing agricultural and urban land cover. This change in algal community structure can affect other biota and the stream ecosystem in general.

Most highly urbanized basins had higher algal densities than less urbanized basins, but a clear pattern of increasing algal density with urban land use is not evident. This is most likely because of substantial scatter in the data at low levels of urbanization, possibly caused by nutrients from multiple sources and previous land uses. It is also possible that high flows and scouring of stream channels after rainstorms may serve to control algal growth in some of the urban streams sampled. Another factor influencing algal density is the presence of shade trees along streambanks.

The presence and numbers of particular species of diatoms seemed to be a more sensitive indicator of nutrient enrichment than either chlorophyll-*a* or algal density. Increases in the percentage of diatom algae species considered tolerant of nutrient enrichment (Van Dam and others, 1994) were related to increases in the percentage of land used for agricultural and (or) urban activities (fig. 32). Both the algal-density and diatom-species findings indicate that algal communities are responding to increased nutrients from agricultural and urban land uses, and that some of the streams may be susceptible to further degradation if nutrient inputs increase and (or) stream shading is reduced.

Effects of Urbanization and Streamflow on Water Quality and Aquatic Communities in Streams

Stream chemistry and the health of aquatic communities can be affected by many interrelated natural and manmade factors. For example, aquatic communities often respond to habitat changes caused by flow variations but can also be affected by changes in water or sediment chemistry. Stream chemistry, in turn, can be affected by natural or human-induced variations in flow. The relative importance of these many factors on chemistry and biology can vary in different settings and can change over time.

Urbanization degrades water quality and ecological health

Urbanization affects the physical, chemical, and biological characteristics of streams in the Delaware River Basin. (For a broader geographic perspective on urbanization effects see page 25.) Stream-dwelling biota are affected by urbanization, as indicated by decreases in the numbers and relative abundances of pollution-sensitive invertebrate species as road density (an indicator of urbanization — see box on p. 23) increased (fig. 35A). This included a general decline in “EPT richness”—or numbers of mayfly (Ephemeroptera), stonefly (Plecoptera), and caddisfly (Trichoptera) taxa—with increasing road density. Similarly, diatoms that are attached to rocks in streams can be sensitive indicators of environmental disturbance. In this study, diatom species that are less tolerant of salt than other species (Van Dam and others, 1994) decreased with increasing road density, most likely because of increased salinity from road runoff and other urban sources. The loss of sensitive invertebrates and other biological changes that occur in streams in urbanized areas may be the result of multiple interrelated disturbances associated with urbanization. These include chemical inputs from point and nonpoint sources, alteration of natural flow regimes, and loss of suitable habitat.

Urban Factors That Were Studied

Water chemistry, physical conditions, and ecological communities were surveyed during 2000 at 28 Piedmont sites in the Philadelphia metropolitan area and during 2001 at 16 sites in the Pocono plateau region (fig. 39A). Effects of urbanization were examined by comparing physical, chemical, and biological conditions among sites having relatively low to relatively high levels of urbanization. Road density (miles of roads divided by square miles of watershed area) is used as an indicator of urbanization in this section of the report because it provides a more accurate representation of urbanization in the Poconos than does percentage of urban land from satellite data (which often do not discern developed land where there is substantial tree cover).

An increase in chloride concentration with increasing road density (fig. 36B) indicates that invertebrate, diatom, and other aquatic communities may be responding to chemical changes associated with urban road runoff, water-softening and septic system leachate, and municipal and industrial wastewater. Chloride is an indicator of multiple chemical inputs and other disturbances associated with these sources. Concentrations of sodium, sulfate, and other major ions also increased with urbanization.

Pesticides that are applied to farms, lawns, golf courses, roadsides, and other settings are found in surface-water samples in the Delaware Basin (see p. 15). A Pesticide Toxicity Index (PTI; see box on p. 24) was applied to pesticide concentration data collected during late spring and late summer in order to assess the potential toxicity of the detected pesticide mixtures to invertebrates and fish. Findings indicate increasing potential pesticide toxicity of streamwater from both sampling periods with increasing urbanization (fig. 35C shows late summer PTI for invertebrates). A seasonal difference was also seen, in that PTI from late summer samples was more closely related to urbanization than was PTI from late spring samples. This reflects the application of pesticides (primarily insecticides) throughout the summer in urban settings, whereas pesticides (primarily herbicides) are applied to agricultural areas primarily in the spring (see p. 15).

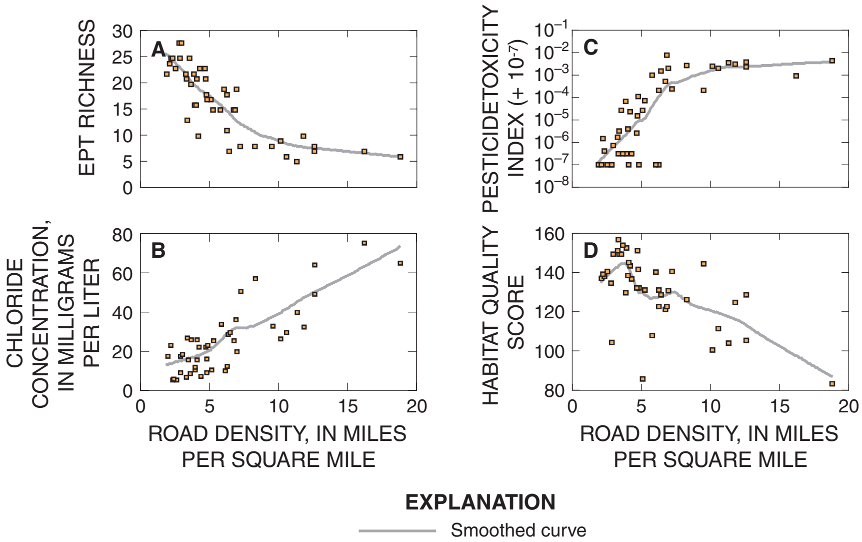


Figure 35. Biological, chemical, and physical changes in streams are associated with increasing urbanization (indicated here by road density). EPT richness (A) is number of mayfly, stonefly, and caddisfly invertebrate taxa; chloride concentrations (B) are from base-flow samples collected in May or June; Pesticide Toxicity Index (C) is calculated from concentrations in base-flow samples collected in late summer and is based on toxicity to invertebrates; habitat quality (D) is based on visual assessments of in-stream and streambank condition; and road density is miles of road per square mile of drainage area.

Nutrient concentrations were generally higher in samples from streams in the more urban Piedmont than in samples from streams in the more forested Poconos region. An urban-related pattern of nutrient concentrations in the Piedmont, however, is not clear because of agricultural activity in some slightly to moderately urbanized watersheds (fig. 28). However, algal biomass and the types of algal species present in streams were related to agricultural and urban sources of nutrients (see p. 20).

In general, habitat quality decreased with increasing road density (fig. 35D), as indicated by the USEPA's qualitative assessment method (Barbour and others, 1999). Variations in particular physical characteristics such as substrate size and water temperature, however, may also be influenced by natural factors, such as stream size, slope, and geology. For example, road density in the Piedmont region was related to an increase in mean daily minimum water temperature and a decrease in the percentage of streambed substrate composed of cobble — two factors that affect aquatic biota (Allan, 1995), but these patterns were revealed only when sites were limited to those in clastic rock settings. Responses of particular habitat variables to urbanization can be obscured by other complicating factors such as effects of agricultural activity in watersheds with low amounts of urbanization, the length of time an area has been urbanized, and the extent of riparian-zone (streambank and floodplain) disturbance. Some of these factors may account for the unusually low or high habitat quality scores in relation to levels of urbanization for some sites shown in figure 35D.

Elevated concentrations of some organic and trace-metal contaminants in water, streambed sediment, and fish tissue are also related to the extent of urbanization (see p. 6 and 10). In some

What is the PTI?

The Pesticide Toxicity Index (PTI; Munn and Gilliom, 2001) is the sum of the concentrations of all herbicides and insecticides detected after each is weighted by its presumed toxicity to particular forms of aquatic life. Although the PTI provides no information regarding a sample's actual toxicity to invertebrates or fish, it does allow for the ranking of sites as to their relative potential toxicity. Only one of the stream samples used in the PTI calculation for the Delaware River Basin exceeded an aquatic-life guideline for pesticides.

cases, contaminants such as VOCs in surface water and SVOCs in streambed sediments increased with increasing watershed urbanization, indicating that currently urbanizing areas may be at risk for increasing concentrations of these contaminants. In other cases, "legacy" contaminants, such as organochlorine pesticides and PCBs, are associated primarily with older urban sites (see p. 7).

These studies suggest that continued urban growth in the basin may be expected to result in further changes in chemical, physical, and biological conditions of streams. Some of the changes observed in this study were similar to those observed in other NAWQA urbanization studies (see p. 25) and suggest areas for additional study and monitoring. In particular, macroinvertebrates, which are already routinely collected by many monitoring agencies, appear to be sensitive indicators of stream response to urbanization. Chemical responses such as potential pesticide toxicity and chloride (the latter which is relatively inexpensive to measure) also show fairly clear trends with urbanization. Habitat degradation appears to occur with urbanization, but finer scale landscape information may be required in order to more fully describe the specific physical changes that occur in these streams.

Highly variable annual streamflow affects water chemistry and aquatic biota

Flows in streams throughout the Delaware River Basin were well below normal in 1999 and slightly below normal in 2001 (fig. 4) as a result of lower than normal precipitation during those years. In 2000, differences in precipitation patterns produced above-normal flows in northern streams and near-normal flows in southern streams. Within each year, seasonal patterns in flow generally corresponded with seasonal variation in evapotranspiration; highest streamflows usually occurred in the spring and lowest flows usually occurred in the late summer (fig. 4). Underlying geology also influenced the seasonal variation in flow and the degree to which flows were affected by drought. Streams flowing through areas of carbonate rocks and unconsolidated sediments typically had higher flows per unit area than streams flowing through areas of less permeable clastic rocks (fig. 36). The Catskills did not fit this general pattern because of greater precipitation and higher permeabilities in that region. Point-source discharges at some sites can also help maintain flows in dry years, but can adversely affect water quality.

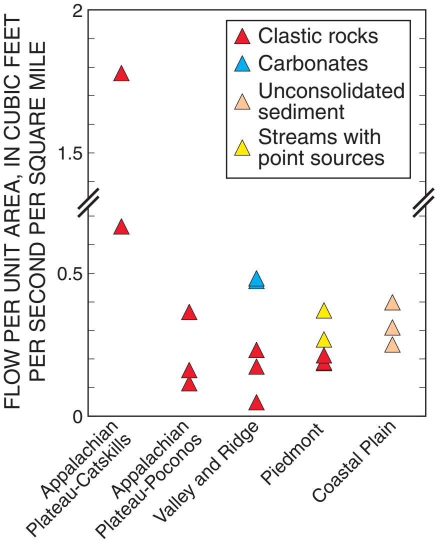


Figure 36. During summer 1999, streamflow per unit area was generally higher in more permeable carbonate rocks and unconsolidated sediments than in less permeable clastic rocks. Greater precipitation in the Catskills also produced higher flows per unit area.

The year-to-year differences in streamflow affected water quality in the basin, particularly for nutrients and pesticides. For instance, the concentration and number of pesticides detected at monthly sample sites in the wettest year, 2000, were greater than those in other years (fig. 37). It is not clear whether this difference was due to greater wash-off of pesticides in 2000, or whether smaller amounts of pesticides were applied during dry periods (when crops and lawns were less likely to grow). Total phosphorus concentrations at some routine sampling sites were higher during 1999, the drought year, than during 2000 or 2001. This is likely due to point-source discharges from wastewater-treatment plants, which made up a greater percentage of the streamflow at some of these sites. Streamwater concentrations of chloride, ammonia, and organic nitrogen behaved similarly to pesticides and usually decreased during dry years. Concentrations increased during dry years, however, on some streams with large point-source discharges.

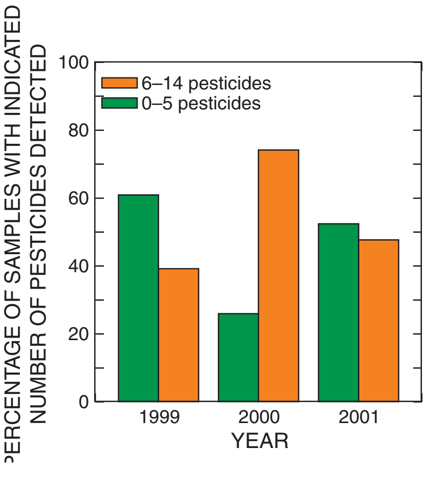
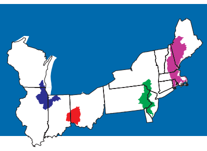


Figure 37. The number of pesticides detected was greatest in 2000, a year with more precipitation than 1999 or 2001.

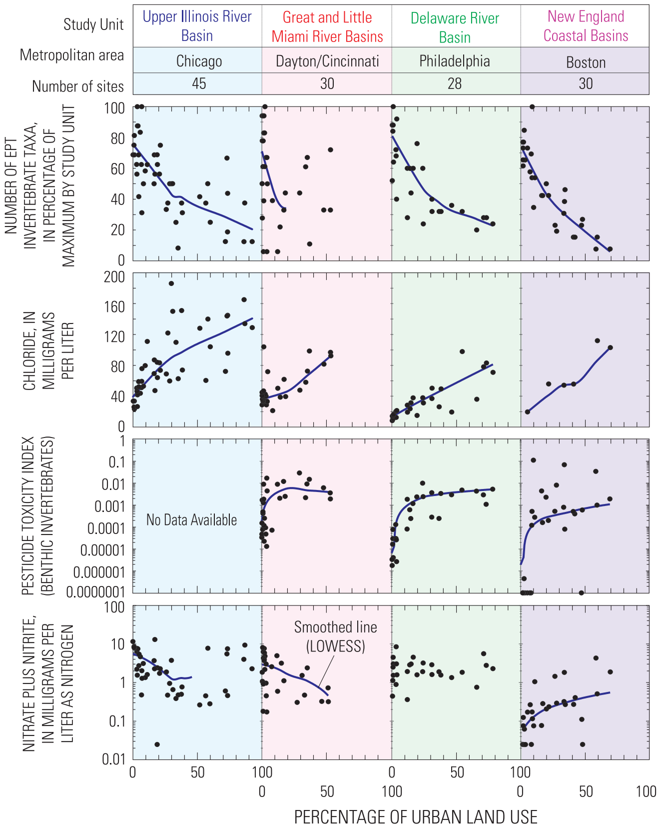


Stream quality degrades as urbanization increases in four major metropolitan areas

Urbanization can degrade water quality and affect sensitive aquatic life, according to a comparison of NAWQA findings among studies in the major metropolitan areas of Boston (New England Coastal Basins), Philadelphia (Delaware River Basin), Dayton and Cincinnati (Great and Little Miami River Basins), and Chicago (upper Illinois River Basin). These studies, which compared conditions among streams in watersheds ranging from minimally to highly urbanized, showed declines in indicators of biological-community health—and increases in chemical indicators of human activity—with increases in percentage of urban land. For example, the number of benthic invertebrate species sensitive to pollution, such as the “EPT taxa” (mayflies [Ephemeroptera], stoneflies [Plecoptera], and caddisflies [Trichoptera]) generally decreased with increasing urban-land percentage in all four metropolitan areas. The declines in EPT taxa were steepest from 0 to about 20 percent urban land, and with the exception of Dayton/Cincinnati, the decline continues with increased urbanization. The anomalous pattern in the Dayton/Cincinnati area may be associated, in part, with effects of high percentages of agricultural land in some of its less urbanized watersheds, as well as the absence of study sites with much more than 50 percent urban land.

Over space and time, invertebrate communities integrate the effects of many factors, including chemical changes, physical habitat alterations, and changes in types of food available to invertebrate consumers. Among the chemical changes noted with increasing urban land in the metropolitan areas studied were increased chloride concentrations and increased potential pesticide toxicity to benthic invertebrates. Chloride sources include municipal and industrial discharges, septic systems, and road-salt runoff. Other organic and inorganic chemicals may be associated with chloride from these sources. The potential toxicity of the mixture of pesticides detected in streamwater increased with increasing urban land percentage, according to the Pesticide Toxicity Index (a measure for ranking sites based on summed concentrations of detected pesticides and the toxicity of each pesticide to benthic invertebrates [Munn and Gilliom, 2001]). The increase was especially pronounced at relatively low percentages of urban land. Contributing factors may include the amount, relative toxicity, and timing of pesticides—particularly insecticides—that are applied in urban settings.

Patterns of nitrate concentration with increasing urban land were not consistent among the four metropolitan areas. In fact, the only clear increase in nitrate concentrations with urbanization was in the Boston area. This is, in part, because nutrients in Boston-area streams are associated primarily with urban sources and are not affected by additional sources, such as fertilizers applied on agricultural land. Moreover, watersheds with minimal urban land in the Boston area are mainly forested, and nitrate concentrations in those streams were low (less than 0.1 mg/L). In contrast, nitrate concentrations in streams decreased with increasing urbanization in the Dayton/Cincinnati area and in minimally to moderately urban settings of the Chicago area, whereas in the Philadelphia area they neither increased nor decreased; fertilizers applied to crops contribute to the higher nitrate concentrations in some less urbanized watersheds in these settings. Sewage may be a factor contributing to the high nutrient concentrations in some highly urban Chicago streams.



Selected examples of biological and chemical indicators, in relation to urbanization. Smoothed lines are shown in plots for which Spearman rank correlations were statistically significant at a probability value of less than 0.05.

In summary, biological and chemical characteristics in streams respond to increases in urban land in their respective watersheds. The responses may differ in pattern and in rate, however, so approaches for monitoring the effects of urbanization on streams may need to be tailored to specific metropolitan areas. Findings of these NAWQA studies may help in developing and prioritizing optimal management strategies for a particular setting.

Algae, fish, and invertebrates were affected by the drought

Algae, fish, and invertebrates were affected by the extreme drought during the summer of 1999. The extent to which a stream's biota were affected varied with the stream's degree of departure from normal flows (fig. 38A) and the extent to which its water and habitat quality normally support species that are sensitive to pollution and other disturbances. Effects of the drought were generally more apparent in streams in forested or low-agricultural watersheds than in streams in urbanized basins. Biological communities in highly urbanized streams may be less responsive to droughts than other streams because their biota consist largely of tolerant species even in normal-flow years. Therefore, streams in watersheds that are in the early stages of urbanization could be especially vulnerable to landscape changes that affect minimum flows required to maintain healthy aquatic communities. These results also suggest that water quality and land-use relationships may not be as strong in a drought year.

Algal growth rates can increase during dry periods as a result of decreased streamflow and increased water temperatures and nutrient concentrations. In the Delaware River Basin, this was indicated by higher algal biovolume (a measure of the quantity of algae collected from a specified area of rocky surfaces) during the drought than during the more normal-flow years at the five streams in less-developed watersheds (fig. 38B). Environmental stress associated with drought also was manifested in the relative abundance of intolerant diatom algae growing on rocks or woody substrate, even where the drought did not produce high algal biovolume. At seven of eight streams studied, diatom species considered tolerant of environmental stress (Bahls, 1993) made up higher percentages of total diatom densities in drought-year samples than in samples collected during one or both of the higher flow years (data not shown).

Noninsect invertebrates (such as worms and snails), a group that is generally more tolerant of environmental disturbance than are many insect species, exhibited higher relative richness (percentage of the total number of invertebrate species) during the drought year than during the normal-flow years at four of the sites in less-developed watersheds (fig. 38C). However, the two streams in highly urbanized settings (Cooper River and Little Neshaminy Creek) showed little variation over time in noninsect relative richness. Biota in these streams may be less responsive to droughts because they consist primarily of tolerant species even in normal-flow years. Riffle habitats in Little Neshaminy Creek were devastated by the extreme high flows from Hurricane Floyd in September 1999 and another storm in 2000. These disturbances may have offset any potential recovery from the drought at this site.

Fish communities can be strongly affected by warmer water temperatures and loss of habitat during a drought. At five of six sites at which fish sampling was conducted during all 3 years, the relative abundance of the single most-common species (dominance) was higher during the drought year than during normal-flow years (fig. 38D). A similar drought effect was seen in northern mid-Atlantic Index of Biotic Integrity (IBI) scores (Daniels and others, 2002), which were lower during 1999 than during 2000 and 2001.

Some natural factors may mitigate effects of the drought. For example, Raccoon Creek and Tulpehocken Creek had relatively little change in fish-community relative abundance, and lower noninsect invertebrate relative richness during the drought year than other sites. Both sites are in geologic settings where highly permeable underlying rocks allow for comparatively high streamflows to be maintained during the drought; these flows helped sustain the existing biological community. Additionally, good instream habitat and streamside vegetation seemed to mitigate effects of the drought at French Creek. Although streamflow was well below normal in 1999, the French Creek fish community was relatively diverse.

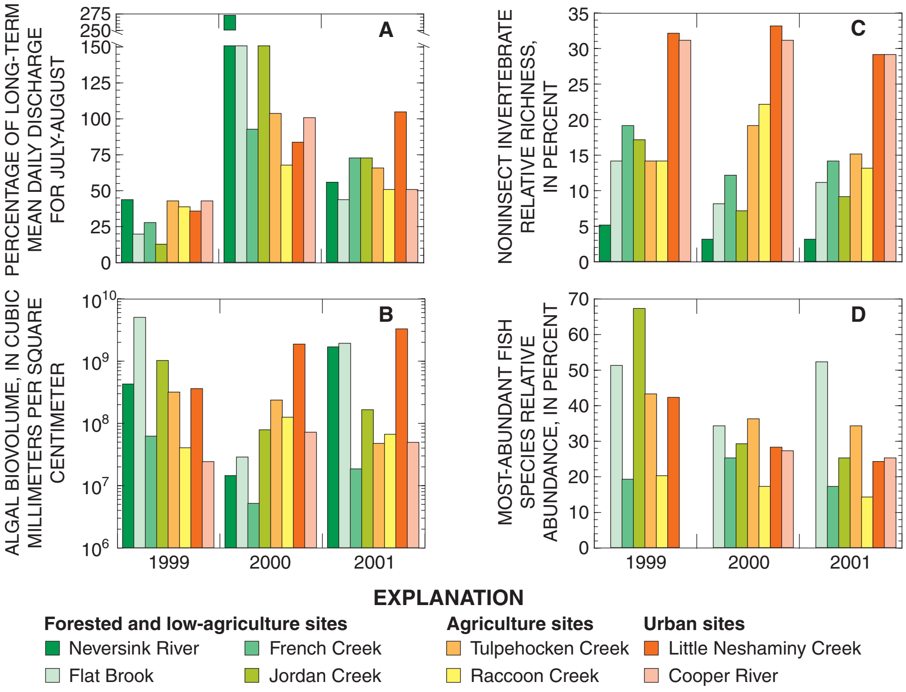


Figure 38. Physical and chemical stresses from low flows during the drought of 1999 affected algae, invertebrate, and (or) fish communities at most sites studied. Sites are placed from left to right in graphs in order of increasing road density, an indicator of human activity.

Study Unit Design

This study was designed to describe current water-quality and ecological conditions throughout the Delaware River Basin, document the occurrence and distribution of contaminants in water, sediment, and biota, and improve our understanding of the factors affecting water quality and ecological health (Gilliom and others, 1995).

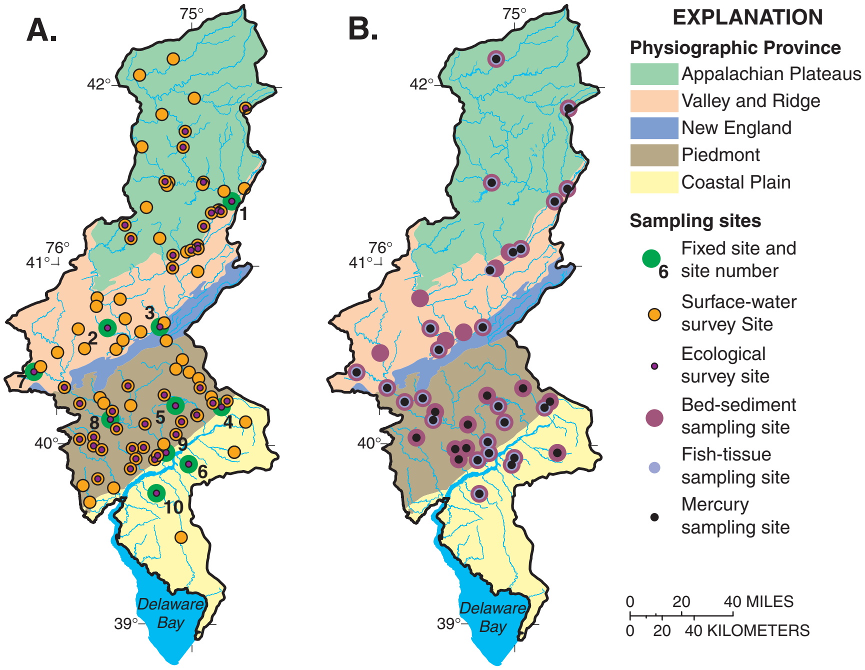
Surface-Water Studies

Surface-water studies were designed to assess the effects of natural factors and human activities on stream chemistry and ecological communities. Ten streams (fig. 39A) were sampled from 1998 to 2001 at regular intervals and during storms to examine variations in water quality and biological communities over time. Stream surveys were conducted at more than 80 sites (many in the Piedmont and Pocono regions) to describe spatial distributions of contaminants and examine relations among land use, water quality, and (for a subset of sites) biological communities. These sites were sampled only once or twice during the study period, at base flow.

Bed-sediment and fish-tissue samples were collected throughout the basin (fig. 39B) to document the distribution of metals, organochlorine pesticides, industrial compounds, and semivolatile organic compounds. A special study was conducted on mercury in water, sediment, and fish.

Ground-Water Chemistry

Water-quality studies were conducted on domestic (household) wells in three aquifer systems: the clastic-rock aquifer of the Piedmont Province, the clastic-rock aquifer of the Valley and Ridge Province, and the unconsolidated glaciofluvial aquifers that are interfingered through the Appalachian Plateaus, Valley and Ridge, and New England Provinces (fig. 40). Ground water in the Coastal Plain sediments or in the metamorphic rocks of the Piedmont was not sampled because data are available from previous NAWQA studies of the Long Island–New Jersey Coastal drainages and the Lower Susquehanna River Basin (Ayers and others, 2000; Lindsey and others, 1998).



1	Delaware River at Port Jervis, N.Y.	(I)	6	Cooper River at Haddonfield, N.J.	(U)
2	Jordan Creek near Schnecksville, Pa	(A)	7	Tulpehocken Creek near Bernville, Pa	(A)
3	Lehigh River at Glendon, Pa	(I)	8	French Creek near Phoenixville, Pa	(A)
4	Delaware River at Trenton, N.J.	(I)	9	Schuylkill River at Philadelphia, Pa	(I)
5	Little Neshaminy Creek near Neshaminy, Pa	(U)	10	Racoon Creek near Swedesboro, N.J.	(A)

(I) Integrator site; (A) Agricultural site; (U) Urban site

Figure 39. Stream-sampling sites included (A) surface-water routine sampling sites, water-quality survey sites, and ecological survey sites, and (B) streambed-sediment, fish-tissue, and mercury sampling sites.

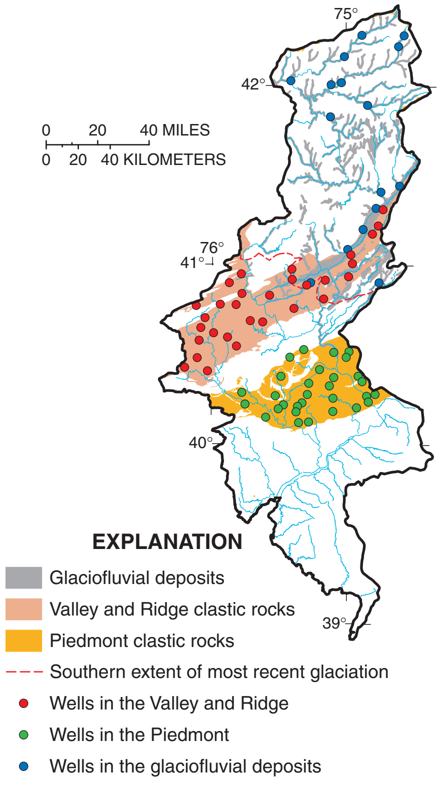


Figure 40. Ground-water sampling sites included domestic-supply (household) wells in the Piedmont clastic-rock and Valley and Ridge clastic-rock aquifers and the unconsolidated glaciofluvial aquifers.

Study component	What data are collected and why	Number and types of sites sampled	Sampling frequency and period
Stream and River Chemistry			
Fixed sites	Streamflow, field parameters,* major ions, nutrients, organic carbon, suspended sediment, 53 pesticides, and 85 volatile organic contaminants (VOCs). Sampled to determine how concentrations vary over time. Indicator sites also examine land-use and regional differences.	10 sites: 4 large (>1,000 mi^2) integrator basins with a mix of land uses, and 6 smaller indicator basins in the three most developed physiographic regions. Sites shown in figure 39.	Monthly and storm events: November 1998 – August 2001. VOCs sampled quarterly, no pesticides winter of 2000–2001.
Intensive fixed sites	Same data collection as above, but sampled more frequently for pesticides and VOCs.	3 fixed sites: Schuylkill River, Little Neshaminy Creek, and Tulpehocken Creek.	Biweekly to monthly, and storm events. April 1999 – August 2000.
Basinwide synoptic survey	Same as fixed sites, except no VOCs. To assess distribution of contaminants throughout the basin.	21 sites with a wide variety of land uses distributed throughout the basin.	Once in spring and once in summer 1999.
Urban stream synoptic surveys	Same as fixed sites, except no VOCs. Sites selected to assess effects of urban land use on water quality. Integrated with ecological synoptic surveys.	30 sites in the Piedmont and 20 in the Poconos. Sites range from undeveloped to highly urbanized.	Once in spring and once in summer. Piedmont (2000) and Poconos (2001).
Agricultural synoptic survey	Same as fixed sites, except no VOCs. Sites selected to assess effects of agriculture on water quality.	10 sites. Primarily agricultural land use in the Valley and Ridge.	Once in spring 2000.
Contaminants in bed sediments	32 organochlorine pesticides, 63 semivolatile organic compounds (SVOCs), and 44 trace elements in bed sediment. Sites sampled to look at basinwide distributions and land-use effects.	39 sites (including all 10 fixed sites). Forested, agricultural, urban, and mining sites located throughout the basin.	Once in July–August 1998, July–August 1999, or June 2000.
Contaminants in fish tissue	30 organochlorine pesticides in whole fish and 24 trace elements in fish livers. Sites sampled to look at basinwide distributions and land-use effects.	25 sites (including all 10 fixed sites). Forested, agricultural, and urban sites located throughout the basin.	Each site sampled once in July–August 1998 or 1999.
Mercury in sediment, fish, and water	Total and methylmercury in fish fillets, bed sediment, and water. To look at basinwide distributions and effects of human and natural factors.	31 fish-tissue, 30 streambed-sediment, and 24 water column sites throughout the basin.	Each site sampled once in summer of 1998, 1999, 2000, or 2001.
Stream and River Ecology			
Fixed indicator sites	Surveys of fish, macroinvertebrates, algae, and riparian habitat. To assess ecological conditions, determine yearly variations, and assess land-use effects.	Six sites representative of agricultural and urban land uses (see chemistry fixed indicator sites).	Once each year in 1999, 2000, and 2001.
Fixed integrator sites	Surveys of macroinvertebrates and algae. To assess ecological conditions at large river sites.	Four fixed integrator sites (see chemistry fixed indicator sites).	Once in July 1999 or September 2001.
Urban stream synoptic survey	Surveys of macroinvertebrates, algae, and riparian habitat. To look at effects of urbanization on stream biota and habitat.	24 Piedmont and 16 Poconos sites selected along gradients of urban development. Subset of chemistry sites.	Once in July-September 2000 (Piedmont) and 2001 (Poconos).
Ground-Water Chemistry			
Aquifer survey Piedmont clastic rocks	Field parameters,* turbidity, major ions, nutrients, organic carbon, 17 trace elements, 53 pesticides, 85 VOCs, and radionuclides. To provide broad overview of water quality.	30 wells — primarily existing open-hole domestic wells 63 to 500 feet deep.	Once, June–November 1999.
Aquifer survey Valley and Ridge clastic rocks	Field parameters,* turbidity, major ions, nutrients, organic carbon, 21 trace elements, 53 pesticides, 85 VOCs, and radionuclides. To provide broad overview of water quality.	30 wells — primarily existing open-hole domestic wells 65 to 500 feet deep.	Once, April–July 2000.
Aquifer survey glaciofluvial deposits	Field parameters,* turbidity, major ions, nutrients, organic carbon, 21 trace elements, 53 pesticides, 85 VOCs, and radionuclides. To provide broad overview of water quality.	16 wells — primarily existing open-ended or screened domestic wells 22 to 213 feet deep.	Once, July–August 2001.

* Field parameters include dissolved oxygen, pH, alkalinity, specific conductance, and temperature.

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Glossary

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.

Aquatic-life guidelines Specific levels of water quality which, if reached, may adversely affect aquatic life. These are nonenforceable guidelines issued by a governmental agency or other institution.

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 guidelines and Water-quality criteria.

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

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

Basin See Drainage basin.

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

Bed sediment The material that temporarily is stationary in the bottom of a stream or other watercourse.

Benthic invertebrates Insects, mollusks, crustaceans, worms, and other organisms without a backbone that live in, on, or near the bottom of lakes, streams, or oceans.

Bioaccumulation The net accumulation of a substance by an organism as a result of uptake from all environmental sources, including gills, epithelial tissues, and dietary sources.

Biota The animal and plant life of a particular region.

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-}).

Clastic Rock or sediment composed principally of broken fragments that are derived from preexisting rocks that have been transported from their place of origin, as in sandstone.

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

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

Detection limit The minimum concentration of a substance that can be identified, measured, and reported within 99 percent confidence that the analyte concentration is greater than zero; determined from analysis of a sample in a given matrix containing the analyte.

Diatoms Microscopic algae having cell walls made of silica.

Discharge Rate of fluid flow passing a given point at a given moment in time, expressed as volume per unit of time.

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.

Drought Commonly defined as being a time of less-than-normal or less-than-expected precipitation.

Ecological studies Studies of biological communities and habitat characteristics to evaluate the effects of physical and chemical characteristics of water and hydrologic conditions on aquatic biota and to determine how biological and habitat characteristics differ among environmental settings in NAWQA Study Units.

Endocrine system The collection of glands in animals that secrete hormones which influence growth, gender, and sexual maturity.

Ground water In general, any water that exists beneath the land surface, but more commonly applied to water in fully saturated soils and geologic formations.

Glaciofluvial Pertaining to the meltwater streams flowing from wasting glacier ice, and especially to the deposits and landforms produced by such streams.

Habitat The part of the physical environment where plants and animals live.

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

Human health advisory 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.

Index of Biotic Integrity (IBI) An aggregated number, or index, based on several attributes or metrics of a fish community that provides an assessment of biological conditions.

Indicator sites Stream sampling sites located at outlets of drainage basins with relatively homogeneous land use and physiographic conditions; most indicator-site basins have drainage areas ranging from 20 to 200 square miles.

Insecticide A substance or mixture of substances intended to destroy or repel insects.

Integrator or Mixed-use site Stream sampling site located at an outlet of a drainage basin that contains multiple environmental settings. Most integrator sites are on major streams with relatively large drainage areas.

Invertebrate An animal having no backbone or spinal column. See also Benthic invertebrates.

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 mg/L.

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.

Periphyton Organisms that grow on underwater surfaces; periphyton include algae, bacteria, fungi, protozoa, and other organisms.

Pesticide A chemical applied to crops, rights-of-way, lawns, or residences to control weeds, insects, fungi, nematodes, rodents or other “pests.”

Physiography A description of the surface features of the Earth, with an emphasis on the origin of landforms.

Plankton Floating or weakly swimming organisms at the mercy of the waves and currents. Animals of the group are called zooplankton and the plants are called phytoplankton.

Relative abundance The number of organisms of a particular kind present in a sample relative to the total number of organisms in the sample.

Study Unit A major hydrologic system of the United States in which NAWQA studies are focused. Study Units are geographically defined by a combination of ground- and surface-water features and generally encompass more than 4,000 square miles of land area.

Surface water An open body of water, such as a lake, river, or stream.

Survey Sampling of any number of sites during a given hydrologic condition.

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.

Tolerant species Those species that are adaptable to (tolerant of) human alterations to the environment and often increase in number when human alterations occur.

Turbidity Reduced clarity of surface water because of suspended particles, usually sediment.

Unconsolidated deposit Deposit of loosely bound sediment that typically fills topographically low areas.

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.

Water-quality guidelines Specific levels of water quality which, if reached, may adversely affect human health or aquatic life. These are nonenforceable guidelines issued by a governmental agency or other institution.

Water-quality standards State-adopted and U.S. Environmental Protection Agency-approved ambient standards for water bodies. Standards include the use of the water body and the water-quality criteria that must be met to protect the designated use or uses.

Watershed See Drainage basin.

Appendix—Water-Quality Data from the Delaware River Basin in a National Context

Concentrations and detection frequencies of the most commonly detected constituents, constituents that exceed a drinking-water standard or aquatic-life guideline, or constituents that are of regulatory or scientific importance, are presented below. Plots of other pesticides, nutrients, VOCs, and trace elements assessed in the Delaware River Basin are available at our Web site at:

http://water.usgs.gov/nawqa/graphs

These summaries of chemical concentrations and detection frequencies from the Delaware River Basin are compared to findings from 51 NAWQA Study Units investigated from 1991 to 2001 and to water-quality benchmarks for human health, aquatic life, fish-eating wildlife, or prevention of nuisance plant growth. These graphical summaries provide a comparison of chemical concentrations and detection frequencies between (1) surface- and ground-water resources; (2) agricultural, urban, and mixed land uses; and (3) shallow ground water and aquifers commonly used as a source of drinking water.

CHEMICALS IN WATER

Concentrations and detection frequencies, Delaware River Basin, 1999–2001

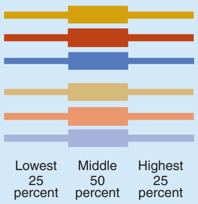
◆ Detected concentration in Study Unit

66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency

- - Not measured or sample size less than two

12 Study-unit sample size. For ground water, the number of samples is equal to the number of wells sampled

National ranges of detected concentrations, by land use, in 51 NAWQA Study Units, 1991–2001—Ranges include only samples in which a chemical was detected



Streams in agricultural areas
Streams in urban areas
Streams and rivers draining mixed land uses
Shallow ground water in agricultural areas
Shallow ground water in urban areas
Major aquifers

National water-quality benchmarks

National benchmarks include standards and guidelines related to drinking-water quality, criteria for protecting the health of aquatic life, and the desired goal for preventing nuisance plant growth due to phosphorus. Sources include the U.S. Environmental Protection Agency and the Canadian Council of Ministers of the Environment

| Drinking-water quality (applies to ground water and surface water)
| Protection of aquatic life (applies to surface water only)
| Prevention of nuisance plant growth in streams
* No benchmark for drinking-water quality
** No benchmark for protection of aquatic life

For example, the graph for prometon shows that in the Delaware River Basin (1) detections and concentrations are higher in urban streams than in steams in mixed-land-use areas or streams draining agricultural areas, (2) concentrations in both streams and ground water did not exceed the USEPA drinking-water standard, and (3) the rate of detection is lower in ground water than in streams.

NOTE to users:

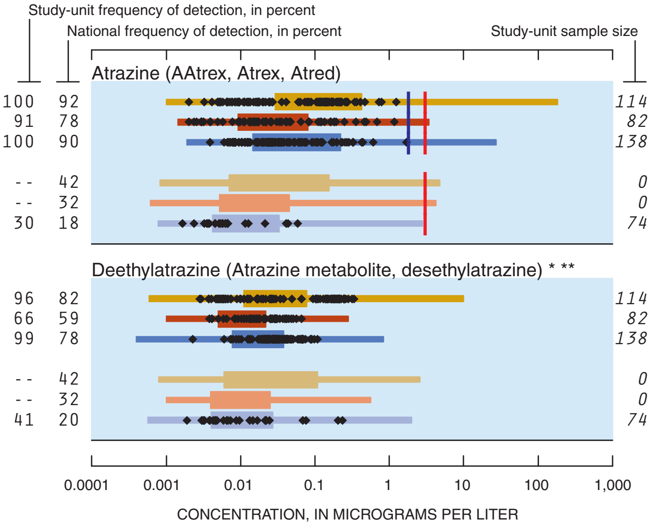
- The analytical detection limit varies among the monitored chemicals; thus, frequencies of detections are not comparable among chemicals.
- It is important to consider the frequency of detection along with concentration. For example, trichloromethane was detected more frequently in urban streams in the Delaware River Basin than in urban streams nationwide (80 percent compared to 60 percent) but generally was detected at lower concentrations.

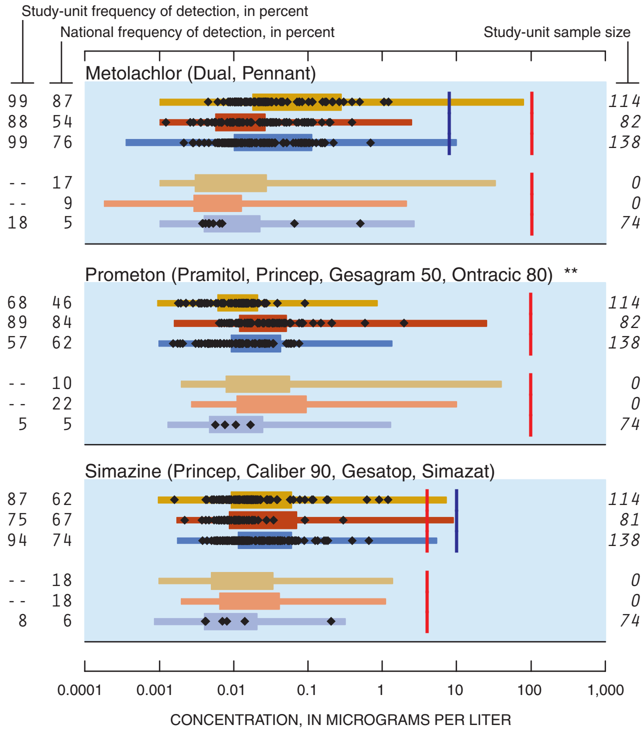
Data in this Appendix were compiled in a nationally consistent manner to facilitate comparisons among NAWQA Study Units. Some data presented in the body of this report may be compiled in a different manner to better describe variability in the Delaware River Basin Study Unit.

Quality-control data for these analytes indicate relatively frequent low-level contamination of samples during sample processing for analysis. Results for these analytes cannot, therefore, be presented using the generalized methods that were applied to other analytes in this Appendix. Analysis of results for analytes potentially affected by contamination requires special statistical treatment beyond the scope of this report. For more information about these analytes and how to interpret data on their occurrence and concentrations, please contact the appropriate NAWQA Study Unit.

Trace elements in ground water: aluminum, barium, boron, cadmium, chromium, cobalt, copper, lithium, nickel, strontium, zinc
SVOCs in bed sediment: phenol, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, di-*n*-butylphthalate, diethylphthalate
Insecticides in water: *p,p'*-DDE

Pesticides in water—Herbicides





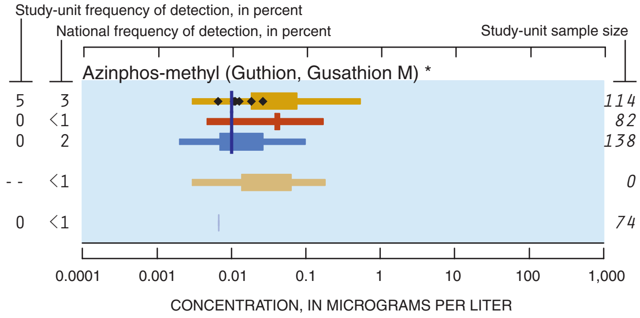
Other herbicides detected

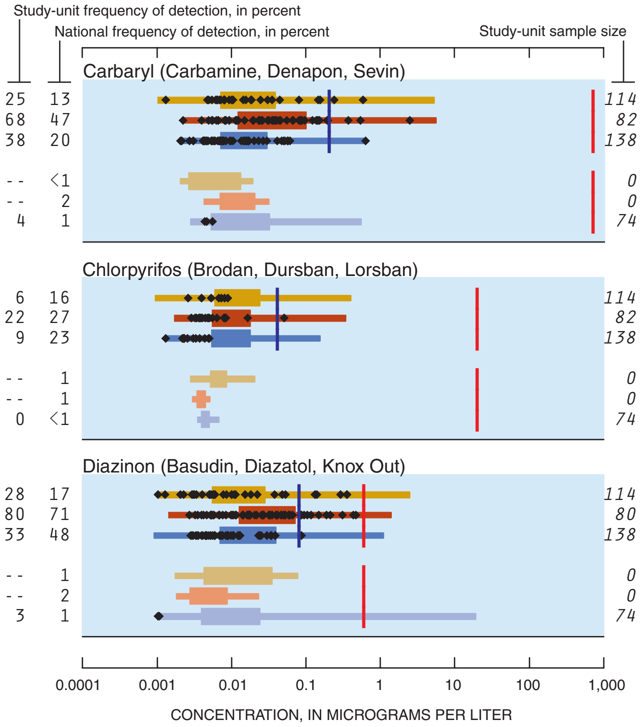
Acetochlor (Harness Plus, Surpass) * **
Alachlor (Lasso, Bronco, Lariat, Bullet) **
Benfluralin (Balan, Benefin, Bonalan, Benefex) * **
Cyanazine (Bladex, Fortrol)
DCPA (Dacthal, chlorthal-dimethyl) **
EPTC (Eptam, Farmarox, Alirox) * **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
Metribuzin (Lexone, Sencor)
Napropamide (Devrinol) * **
Pendimethalin (Pre-M, Prowl, Weedgrass Control, Stomp, Herbadox) * **
Pronamide (Kerb, Propyzamid) **
Propachlor (Ramrod, Satecid) **
Propanil (Stam, Stampede, Wham, Surcopur, Prop-Job) * **
Tebuthiuron (Spike, Tebusan)
Terbacil (Sinbar) **
Triallate (Far-Go, Avadex BW, Tri-allate) *
Trifluralin (Treflan, Gowan, Tri-4, Trific, Trilin)

Herbicides not detected

Chloramben, methyl ester (Amiben methyl ester) * **
Butylate (Sutan +, Genate Plus, Butilate) **
2,6-Diethylaniline (metabolite of Alachlor) * **
Ethalfluralin (Sonalan, Curbit) * **
Molinate (Ordram) * **
Pebulate (Tillam, PEBC) * **
Thiobencarb (Bolero, Saturn, Benthiocarb, Abolish) * **

Pesticides in water—Insecticides





Other insecticides detected

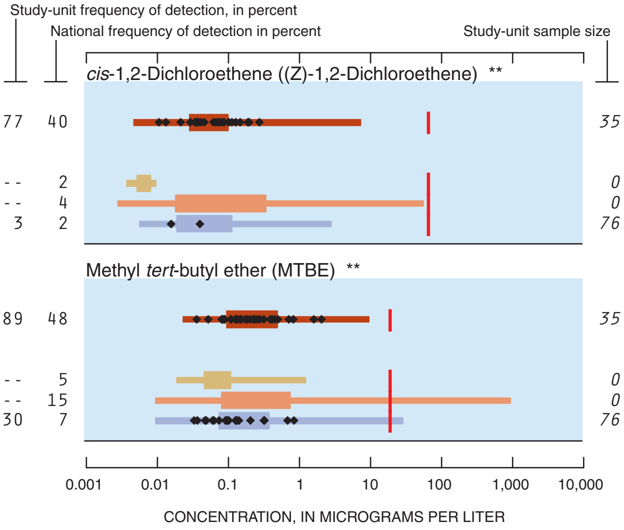
Carbofuran (Furadan, Curaterr, Yaltox)
Dieldrin (Panoram D-31, Octalox)
Fonofos (Dyfonate, Capfos, Cudgel, Tycap) **
gamma-HCH (Lindane, gamma-BHC, Gammexane)
Malathion (Malathion)

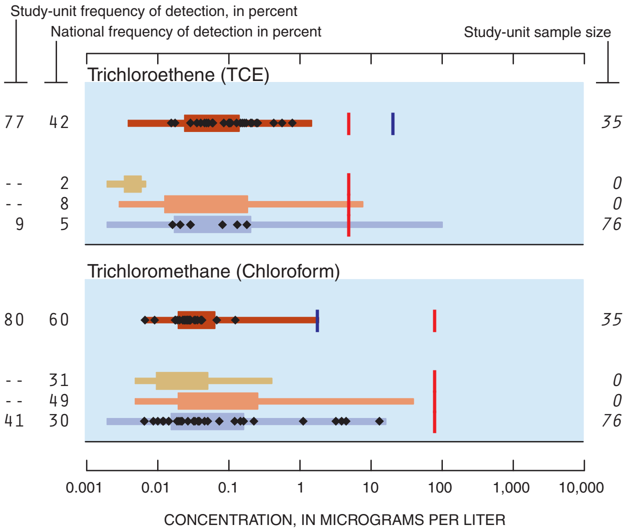
Insecticides not detected

Disulfoton (Disyston, Di-Syston, Frumin AL, Solvirex, Ethylthiodemeton) **
Ethoprop (Mocap, Ethoprophos) * **
alpha-HCH (alpha-BHC, alpha-lindane) **
Methyl parathion (Penncap-M, Folidol-M, Metacide, Bladan M) **
Parathion (Roethyl-P, Alkron, Panthion) *
cis-Permethrin (Ambush, Astro, Pounce) * **
Phorate (Thimet, Granutox, Geomet, Rampart) * **
Propargite (Comite, Omite, Ornamite) * **
Terbufos (Contraven, Counter, Pilarfox) **

Volatile organic compounds (VOCs) in water

These graphs represent data from 32 Study Units, sampled from 1994 to 2001





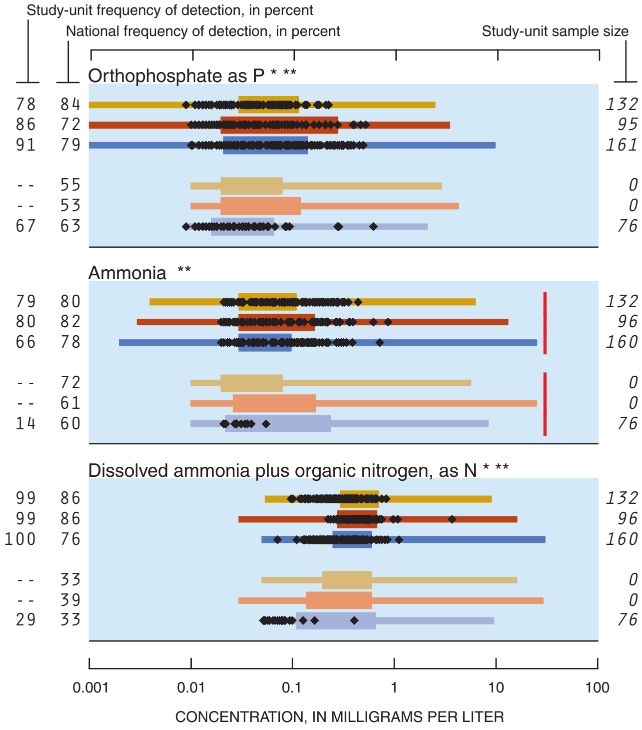
Other VOCs detected

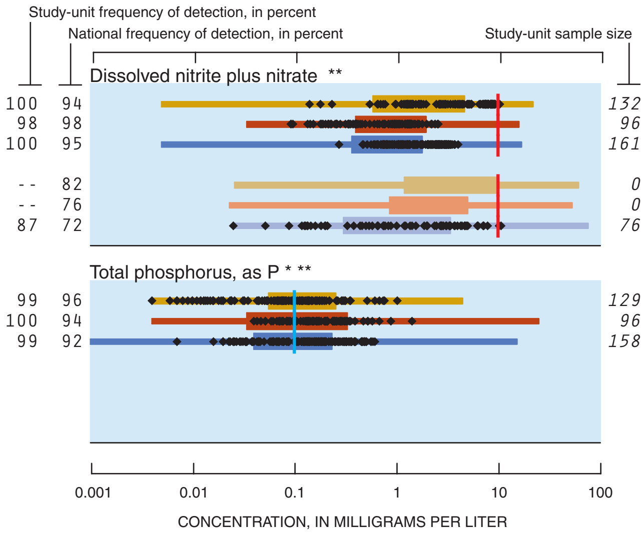
Acetone (Acetone) * **
Benzene
Bromodichloromethane (Dichlorobromomethane) **
2-Butanone (Methyl ethyl ketone (MEK)) **
Carbon disulfide * **
Chlorobenzene (Monochlorobenzene)
Chloroethane (Ethyl chloride) * **
Chloromethane (Methyl chloride) **
Dibromochloromethane (Chlorodibromomethane) **
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB)
Dichlorodifluoromethane (CFC 12, Freon 12) **
1,1-Dichloroethane (Ethylidene dichloride) * **
1,1-Dichloroethene (Vinylidene chloride) **
Dichloromethane (Methylene chloride)
1,2-Dichloropropane (Propylene dichloride) **
1,2-Dimethylbenzene (*o*-Xylene) **
1,3 & 1,4-Dimethylbenzene (*m*-&*p*-Xylene) **
Ethenylbenzene (Styrene) **
Ethyl *tert*-butyl ether (Ethyl-t-butyl ether (ETBE)) * **
Ethylbenzene (Phenylethane)
Iodomethane (Methyl iodide) * **
p-Isopropyltoluene (*p*-Cymene, 1-Isopropyl-4-methylbenzene) * **
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) * **
Methylbenzene (Toluene)
Naphthalene
Tetrachloroethene (Perchloroethene)
Tetrachloromethane (Carbon tetrachloride)
1,2,3,5-Tetramethylbenzene (Isodurene) * **
Tribromomethane (Bromoform) **
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113, CFC 113) * **
1,1,1-Trichloroethane (Methylchloroform) **
1,1,2-Trichloroethane (Vinyl trichloride) **
Trichlorofluoromethane (CFC 11, Freon 11) **
1,2,4-Trimethylbenzene (Pseudocumene) * **
tert-Amyl methyl ether (TAME) * **

VOCs not detected

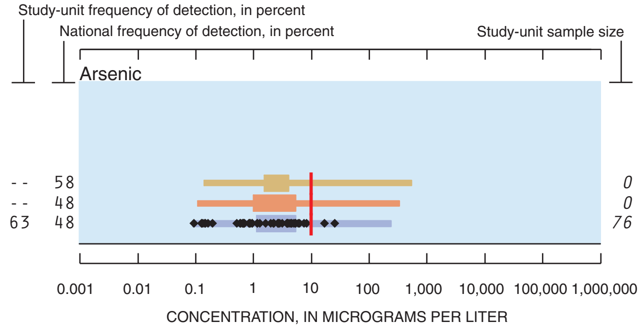
Bromobenzene (Phenyl bromide) * **
Bromochloromethane (Methylene chlorobromide) **
Bromoethene (Vinyl bromide) * **
Bromomethane (Methyl bromide) **
n-Butylbenzene (1-Phenylbutane) * **
sec-Butylbenzene ((1-Methylpropyl)benzene) * **
tert-Butylbenzene ((1,1-Dimethylethyl)benzene) * **
3-Chloro-1-propene (3-Chloropropene) * **
1-Chloro-2-methylbenzene (*o*-Chlorotoluene) **
1-Chloro-4-methylbenzene (*p*-Chlorotoluene) **
Chloroethene (Vinyl chloride) **
1,2-Dibromo-3-chloropropane (DBCP, Nemagon) **
1,2-Dibromoethane (Ethylene dibromide, EDB) **
Dibromomethane (Methylene dibromide) * **
trans-1,4-Dichloro-2-butene ((Z)-1,4-Dichloro-2-butene) * **
1,2-Dichloroethane (Ethylene dichloride)
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene) **
2,2-Dichloropropane * **
1,3-Dichloropropane (Trimethylene dichloride) * **
trans-1,3-Dichloropropene ((E)-1,3-Dichloropropene) **
cis-1,3-Dichloropropene ((Z)-1,3-Dichloropropene) **
1,1-Dichloropropene * **
Diethyl ether (Ethyl ether) * **
Diisopropyl ether (Diisopropylether (DIPE)) * **
Ethyl methacrylate (Ethyl methacrylate) * **
2-Ethyltoluene (*o*-Ethyltoluene) * **
1,1,2,3,4,4-Hexachloro-1,3-butadiene (Hexachlorobutadiene)
1,1,1,2,2,2-Hexachloroethane (Hexachloroethane) **
2-Hexanone (Methyl butyl ketone (MBK)) * **
Isopropylbenzene (Cumene) * **
Methyl acrylonitrile (Methacrylonitrile) * **
Methyl methacrylate (Methyl-2-methacrylate) * **
Methyl-2-propenoate (Methyl acrylate) * **
2-Propenenitrile (Acrylonitrile) **
n-Propylbenzene (Isocumene) * **
1,1,2,2-Tetrachloroethane **
1,1,1,2-Tetrachloroethane (1,1,1,2-TeCA) **
Tetrahydrofuran (Diethylene oxide) * **
1,2,3,4-Tetramethylbenzene (Prehnitene) * **
1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene (1,2,3-TCB) *
1,2,3-Trichloropropane (Allyl trichloride) **
1,2,3-Trimethylbenzene (Hemimellitene) * **
1,3,5-Trimethylbenzene (Mesitylene) * **

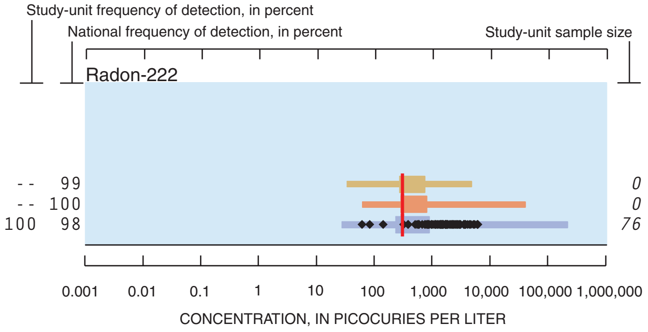
Nutrients in water





Trace elements in ground water





Other trace elements detected

Antimony
Lead
Manganese *
Molybdenum
Selenium
Thallium
Uranium
Vanadium *

Trace elements not detected

Beryllium
Silver

CHEMICALS IN FISH TISSUE AND BED SEDIMENT

Concentrations and detection frequencies, Delaware River Basin 1999–2001—Study-unit frequencies of detection are based on small sample sizes; the applicable sample size is specified in each graph

◆ Detected concentration in Study Unit

66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency

- - Not measured or sample size less than two

12 Study-unit sample size

National ranges of concentrations detected, by land use, in 51 NAWQA Study Units, 1991–2001—Ranges include only samples in which a chemical was detected

Fish tissue from streams in agricultural areas
Fish tissue from streams in urban areas
Fish tissue from streams draining mixed land uses
Sediment from streams in agricultural areas
Sediment from streams in urban areas
Sediment from streams draining mixed land uses

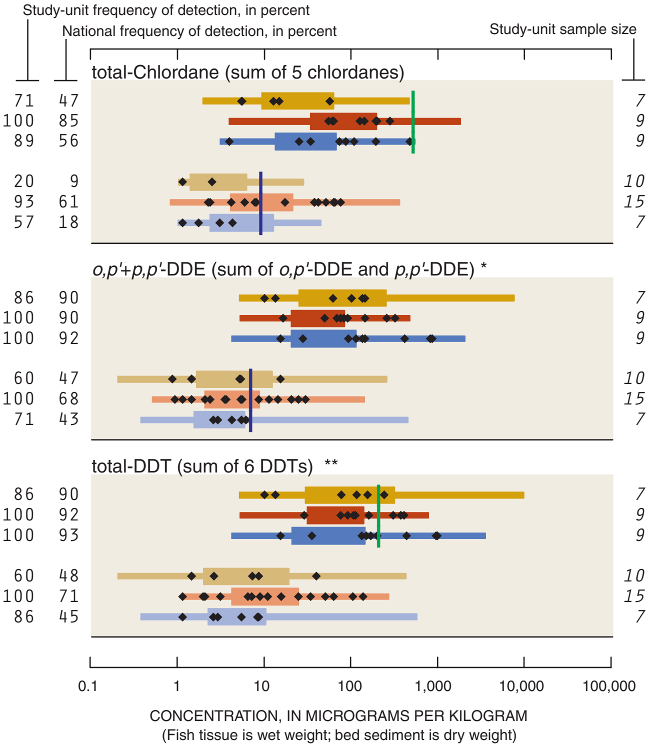
Lowest 25 percent
Middle 50 percent
Highest 25 percent

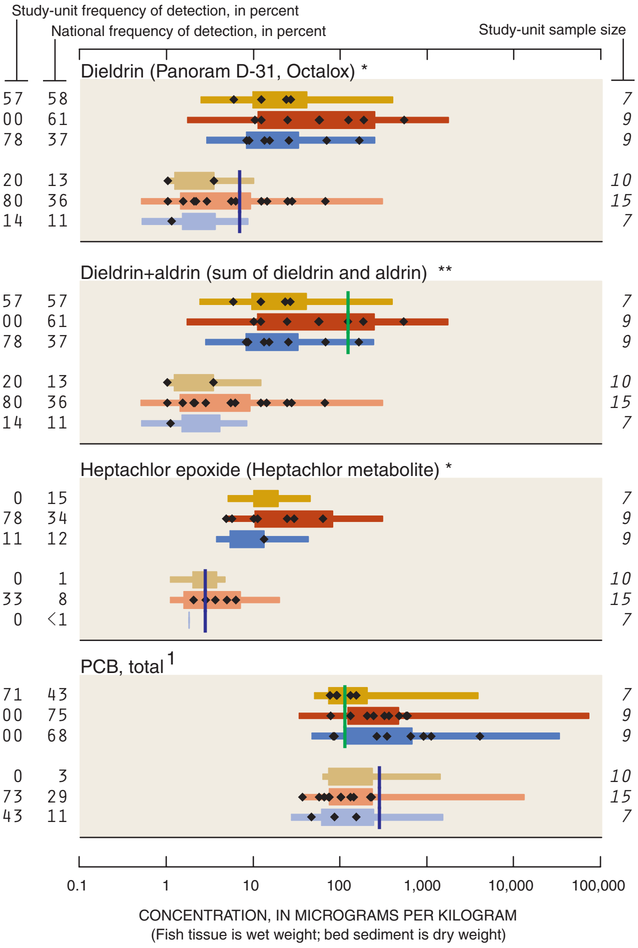
National benchmarks for fish tissue and bed sediment

National benchmarks include standards and guidelines related to criteria for protection of the health of fish-eating wildlife and aquatic organisms. Sources include the U.S. Environmental Protection Agency, other Federal and State agencies, and the Canadian Council of Ministers of the Environment.

| Protection of fish-eating wildlife (applies to fish tissue)
| Protection of aquatic life (applies to bed sediment)
* No benchmark for protection of fish-eating wildlife
** No benchmark for protection of aquatic life

Organochlorines in fish tissue (whole body) and bed sediment





[1] The national detection frequencies for total PCB in sediment are biased low because about 30 percent of the samples nationally had elevated detection limits compared to this Study Unit. See http://water.usgs.gov/nawqa/ for additional information.

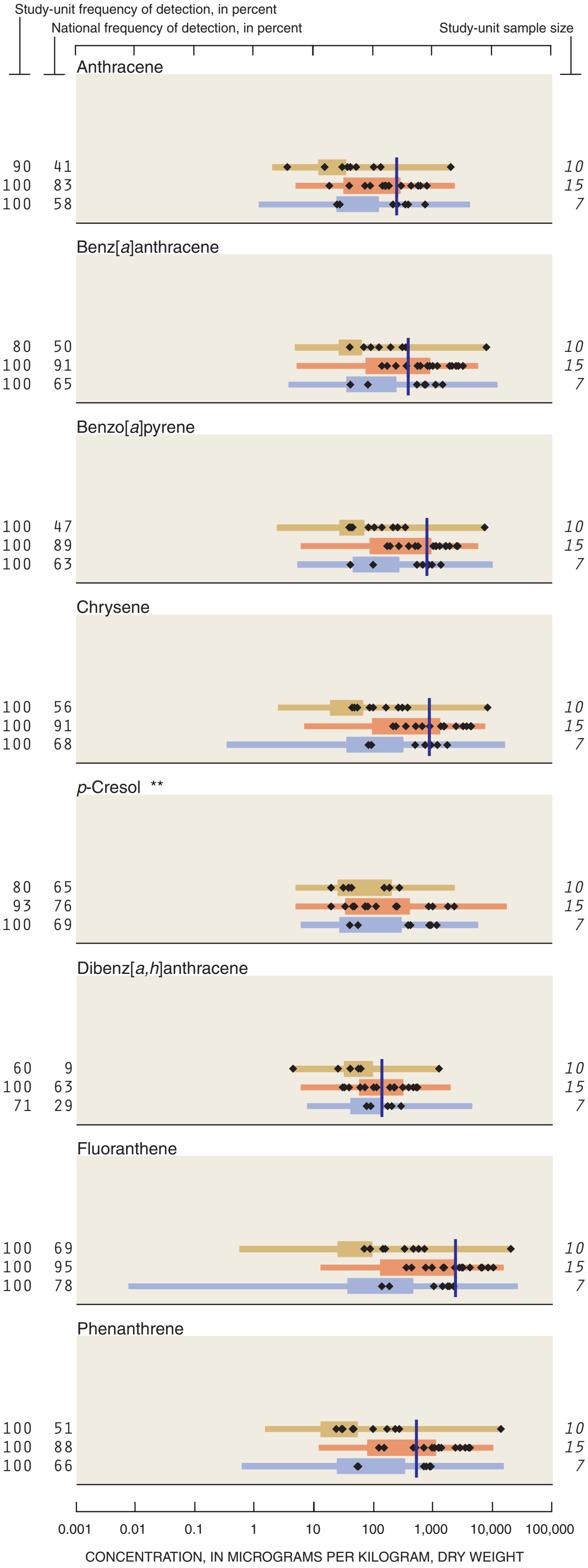
Other organochlorines detected

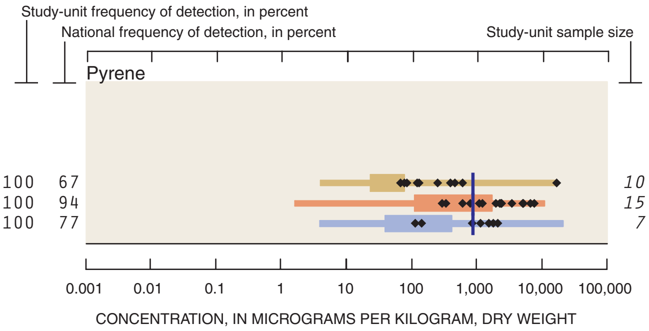
o,p'+*p,p'*-DDD (sum of *o,p'*-DDD and *p,p'*-DDD) *
p,p'-DDE * **
o,p'+*p,p'*-DDT (sum of *o,p'*-DDT and *p,p'*-DDT) *
Endosulfan I (alpha-Endosulfan, Thiodan) * **
Heptachlor+heptachlor epoxide **
Hexachlorobenzene (HCB) **
p,p'-Methoxychlor (Marlate, methoxychlore) * **
Pentachloroanisole (PCA, pentachlorophenol metabolite) * **

Organochlorines not detected

Chloroneb (chloronebe, Demosan) * **
DCPA (Dacthal, chlorthal-dimethyl) * **
Endrin (Endrine)
gamma-HCH (Lindane, gamma-BHC, Gammexane) *
Total HCH (sum of alpha, beta, gamma, and delta-HCH) **
Isodrin (Isodrine, Compound 711) * **
o,p'-Methoxychlor * **
Mirex (Dechlorane) **
cis-Permethrin (Ambush, Astro, Pounce) * **
trans-Permethrin (Ambush, Astro, Pounce) * **
Toxaphene (Camphechlor, Hercules 3956) * **

Semivolatile organic compounds (SVOCs) in bed sediment





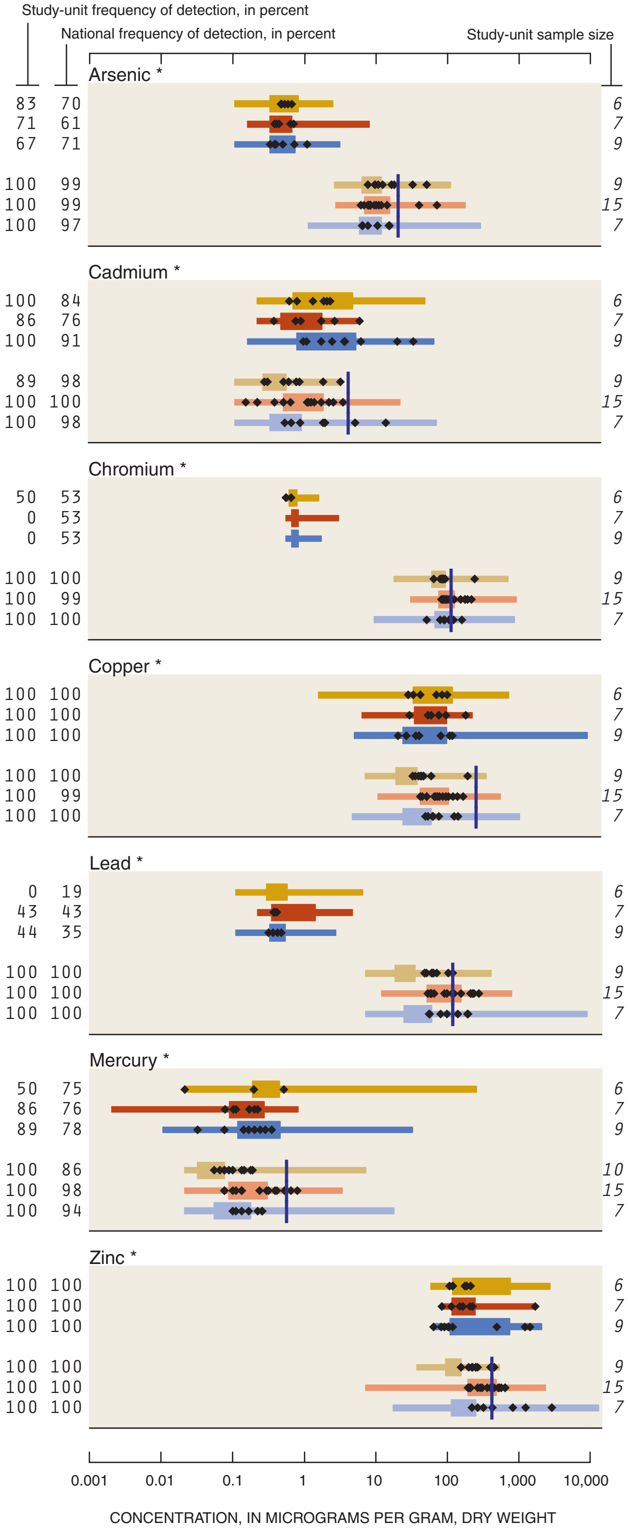
Other SVOCs detected

Acenaphthene
Acenaphthylene
Acridine **
Anthraquinone **
Azobenzene **
Benzo[*b*]fluoranthene **
Benzo[*c*]cinnoline **
Benzo[*g,h,i*]perylene **
Benzo[*k*]fluoranthene **
2,2-Biquinoline **
9*H*-Carbazole **
Di-*n*-octylphthalate **
Dibenzothiophene **
1,3-Dichlorobenzene (*m*-Dichlorobenzene) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB) **
1,2-Dimethylnaphthalene **
1,6-Dimethylnaphthalene **
2,6-Dimethylnaphthalene **
3,5-Dimethylphenol **
Dimethylphthalate **
9*H*-Fluorene (Fluorene)
Indeno[1,2,3-*c,d*]pyrene **
Isoquinoline **
1-Methyl-9*H*-fluorene **
2-Methylanthracene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
1-Methylpyrene **
Naphthalene
Nitrobenzene **
N-Nitrosodiphenylamine **
Phenanthridine **
Quinoline **
2,3,6-Trimethylnaphthalene **

SVOCs not detected

C8-Alkylphenol **
4-Bromophenyl-phenylether **
4-Chloro-3-methylphenol **
bis (2-Chloroethoxy)methane **
bis (2-Chloroethyl)ether **
2-Chloronaphthalene **
2-Chlorophenol **
4-Chlorophenyl-phenylether **
1,2-Dichlorobenzene (*o*-Dichlorobenzene, 1,2-DCB) **
2,4-Dinitrotoluene **
Isophorone **
N-Nitrosodi-*n*-propylamine **
Pentachloronitrobenzene **
1,2,4-Trichlorobenzene **

Trace elements in fish tissue (livers) and bed sediment



Other trace elements detected

Nickel * **
Selenium *

Coordination with agencies and organizations in the Delaware River Basin was integral to the success of this water-quality assessment. We thank those who served as members of our liaison committee:

Federal Agencies

National Park Service (NPS)
Natural Resources Conservation Service (NRCS)
U.S. Army Corp of Engineers (USACE)
U.S. Environmental Protection Agency (USEPA)
U.S. Fish and Wildlife Service (USFWS)
USDA Forest Service (USFS)

State Agencies

Delaware Department of Natural Resources and Environmental Control (DNREC)
Delaware Geological Survey
New Jersey Department of Agriculture
New Jersey Department of Environmental Protection (NJDEP)
New Jersey Geological Survey
New York State Department of Environmental Conservation (NYSDEC)
New York State Department of Health
Pennsylvania Department of Environmental Protection (PADEP)
Pennsylvania Fish and Boat Commission (PFBC)
Pennsylvania Geological Survey

Local Agencies

Chester County Water Resources Authority
Delaware Estuary Program
Delaware River Basin Commission (DRBC)
Delaware Valley Regional Planning Commission
Lehigh County Authority
Monroe County Planning Commission
New Jersey Pinelands Commission
New York City Department of Environmental Protection (NYCDEP)
Philadelphia Water Department
Pike County Conservation District
Upper Delaware Council
Water Resources Agency of New Castle County

Universities

Drexel University
University of Delaware

Other Public and Private Organizations

The Academy of Natural Sciences
Berks County Conservancy
Delaware Riverkeeper Network
The Heritage Conservancy
The Nature Conservancy
Public Service Electric and Gas Co. (PSE&G)
PECO Energy
Wildlands Conservancy

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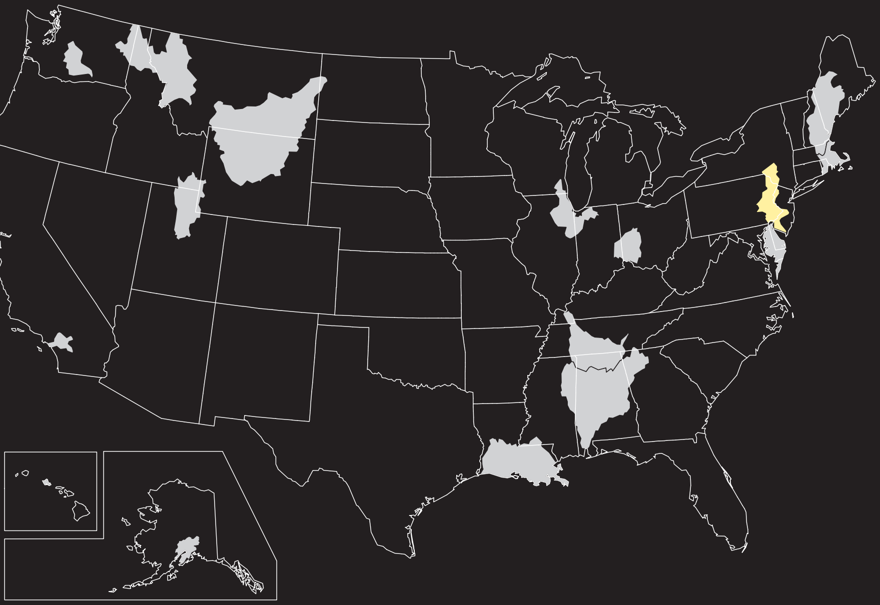
NAWQA

National Water-Quality Assessment (NAWQA) Program
Delaware River Basin



Fischer and others—Water Quality in the Delaware River Basin
U.S. Geological Survey Circular 1227

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