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Organic Compounds and Trace Elements in Fish Tissue and Bed Sediment in the Delaware River Basin, New Jersey, Pennsylvania, New York, and Delaware, 1998-2000

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By Kristin Romanok, Jeffrey M. Fischer, Karen Riva-Murray, Robin Brightbill, and Michael Bilger

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Foreword

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. (http://www.usgs.gov/). Information on the quality of the Nationís water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. (http://water.usgs.gov/nawqa/). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nationís streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nationís most important river basins and aquifers, referred to as Study Units. (http://water.usgs.gov/nawqa/nawqamap.html). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nationís major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nationís diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings. (http://water.usgs.gov/nawqa/natsyn.html).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide

you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nationís waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nationís water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD29).

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By Kristin Romanok, Jeffrey M. Fischer, Karen Riva-Murray, Robin Brightbill, and Michael Bilger

Abstract

As part of the National Water-Quality Assessment (NAWQA) program activities in the Delaware River Basin (DELR), samples of fish tissue from 21 sites and samples of bed sediment from 35 sites were analyzed for a suite of organic compounds and trace elements. The sampling sites, within subbasins ranging in size from 11 to 600 square miles, were selected to represent 5 main land-use categories in the DELR –forest, low-agricultural, agricultural, urban, and mixed use. Samples of both fish tissue and bed sediment were also collected from 4 "large-river" sites that represented drainage areas ranging from 1,300 to 6,800 square miles, areas in which the land is used for a variety of purposes.

One or more of the organochlorine compounds -DDT and chlordane metabolites, polychlorinated biphenyls (total PCBs), and dieldrin- were detected frequently in samples collected over a wide geographic area. One or more of these compounds were detected in fish-tissue samples from 92 percent of the sites and in bed-sediment samples from 82 percent of the sites. Concentrations of total DDT, total chlordanes, total PCBs, and dieldrin in whole white suckers and in bed sediment were significantly related to urban/industrial basin characteristics, such as percentage of urban land use and population density.

Semi-volatile organic compounds (SVOCs) –total polycyclic aromatic hydrocarbons (PAHs), total phthalates, and phenols- were detected frequently in bed-sediment samples. All three types of SVOCs were detected in samples from at least one site in each land-use category. The highest detection rates and concentrations typically were in samples from sites in the urban and mixed land-use categories, as well as from the large-river sites. Concentrations of total PAHs and total phthalates in bed-sediment samples were found to be statistically related to percentages of urban land use and to population density in the drainage areas represented by the sampling sites.

The samples of fish tissue and bed sediment collected throughout the DELR were analyzed for a large suite of trace elements, but results of the analyses for eight elements—arsenic, cadmium, chromium, copper, lead, nickel, mercury, and zinc- that are considered contaminants of concern are described in this report. One or more of the eight trace elements were detected in samples from every fish tissue and bed-sediment sampling site, and all of the trace elements were detected in samples from 97 percent of the bed-sediment sites.

The concentrations of organic compounds and trace elements in the DELR samples were compared to applicable guidelines for the protection of wildlife and other biological organisms. Concentrations of total DDT, total chlordanes, total PCBs, and dieldrin in fish-tissue samples from 14 sites exceeded one or more of the Wildlife Protective Guidelines established by the New York State Department of Environmental Conservation. Concentrations of one or more organic compounds in samples from 16 bed-sediment sites exceeded the Threshold Effects Concentrations (TEC) of the Canadian Sediment Quality Guidelines, and concentrations of one or more of the eight trace elements in samples from 38 bed-sediment sites exceeded the TEC. (The TEC is the concentration below which adverse biological effects in freshwater ecosystems are expected to be rare.) Concentrations of organic compounds in samples from some bed-sediment sites exceeded the Canadian Probable Effects Concentrations (PEC), and concentrations of trace elements in samples from 18 sites exceeded the PEC. (The PEC is the concentration above which adverse effects to biological organisms are expected to occur frequently).

Concentrations of organic compounds and trace elements in samples from the DELR were compared to similar data from other NAWQA study units in the northeastern United States and also data from the Mobile River (Alabama) Basin and the Northern Rockies Intermontane Basin study units. Median concentrations of total DDT, total chlordanes, and total PCBs found in fish tissue in the DELR were among the highest of those from all study units compared. The opposite was true, however, for the median concentrations of organic compounds in the bed sediment: the values from the DELR were the lowest of all the study units compared. Median concentrations of trace elements in fish livers from the DELR were lower than median concentrations in most of the other

study units, but the median concentrations of trace elements in bed-sediment samples from the DELR were higher than those in most of the other study units.

Comparisons of the data for sites at which samples of both fish tissue and bed sediment were collected showed significant statistical relations between the concentrations of organic compounds and trace elements in the sediment and the concentrations in fish tissue. The data also indicated that the fish were bioaccumulating certain organic compounds and trace elements.

Concentrations and the frequency of detection or organic compounds and trace elements differed among the different land-use categories. The fewest detections of organic compounds and trace elements were in samples from sites in the forest and low-agricultural areas. SVOCS, however, were detected more frequently and at higher concentrations in samples from forest areas than in samples from other land-use areas, except urban. Samples from urban areas accounted for the highest frequency of detections and highest median concentrations of most organic compounds in all land-use categories, probably a consequence of the long history of industry and urbanization in many parts of the Delaware River Basin.

Introduction

The National Water-Quality Assessment (NAWQA) Program is a long-term investigation by the U.S. Geological Survey (USGS) that is designed to evaluate the status of, and trends in, the quality of surface- and ground-water resources in the United States through an integrated approach of physical, chemical, and biological factors (Hirsch and others, 1988; Leahy and others, 1990; Gurtz, 1994; Gilliom and others, 1995). Started in 1991, NAWQA was designed to be conducted in more than 50 separate river basins and aquifer systems (study units) that account for about two-thirds of the water use and public water supply in the United States (Leahy and Wilber, 1991). These study units compose the framework for regional- and national-level assessments. Study units cycle through a 3 or 4 year high-intensity period about once every 10 years. The Delaware River Basin study unit in New Jersey, Pennsylvania, New York, and Delaware is one of 15 NAWQA study units in which investigations started in 1996.

Studies of trace elements and hydrophobic organic contaminants in streambed sediment and fish tissue are one aspect of the NAWQA program. Streambed sediment and fish tissue are studied for several reasons. Hydrophobic contaminants are easier to detect in sediment and tissue than in water (Foreman and others, 1995). The contaminants accumulate in sediment and tissue over time, whereas their concentrations in the dissolved phase fluctuate greatly and commonly are low, thus making them difficult to detect. Sediment-bound contaminants commonly enter the food chain when they are consumed by invertebrates and bioaccumulate at higher levels in the food chain. These contaminants can affect growth and reproduction in aquatic organisms and in terrestrial consumers of fish (humans and wildlife). Within a study unit, concentrations, detection frequencies, and spatial distributions of contaminants are used to assess which occur most frequently and why, and to assess potential effects on aquatic biota. The consistency of the NAWQA study and analytical methods allows results from the Delaware River Basin to be compared to results from other study units regionally and nationally.

The study described in this report was conducted to determine the occurrence of organochlorine compounds and trace elements in fish-tissue and bed-sediment samples, and semi-volatile organic compounds (SVOCs) in bed-sediment samples, and to examine the factors affecting their distribution throughout the Delaware River Basin NAWQA study unit during 1998–2000. Samples were collected from subbasins in New Jersey, Pennsylvania, and New York.

Purpose and Scope

This report presents the concentrations of organic compounds and trace elements in fish-tissue and bed-sediment samples collected in the Delaware River Basin NAWQA study unit during 1998-2000. Fish-tissue and bed-sediment samples were collected at 25 and 39 sites, respectively, throughout study unit. Samples were analyzed for seven classes of organic compounds—total DDT, total chlordanes, dieldrin, total polychlorinated biphenyls (PCBs), total polycyclic aromatic hydrocarbons (PAHs), total phthalates, and phenols—and eight trace elements—arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. The compounds were evaluated using graphical and statistical methods, and concentrations are compared to selected wildlife or environmental standards and guidelines. The presence and concentration of these compounds are compared with those of other studies regionally and nationally. The relation of reported compounds in bed sediment to those in fish tissue, where applicable, also is examined. Local variables and geology also are presented in selected cases.

Description of Study Area

The Delaware River Basin is about 300 mi long, 60 to 90 mi wide, and covers more than 12,700 mi^2 (fig. 1). More than 50 percent of the total basin area is in Pennsylvania, 23 percent in New Jersey, 19 percent in New York, and 8 percent in Delaware. The Delaware River originates in the Catskill Mountains of New York at an altitude of about 4,000 ft and flows 200 mi south to the Delaware Estuary. Major tributaries include the Lehigh and Schuylkill Rivers. The Delaware River Basin NAWQA study unit includes the entire Delaware Basin, except for 770 mi^2 of Coastal Plain in Delaware. According to the 2000 U.S. Census (U.S. Census Bureau, 2000), population in the study unit was greater than 7.2 million. Another 8 million people outside the basin rely on water from the Delaware River Basin for their drinking-water supplies.

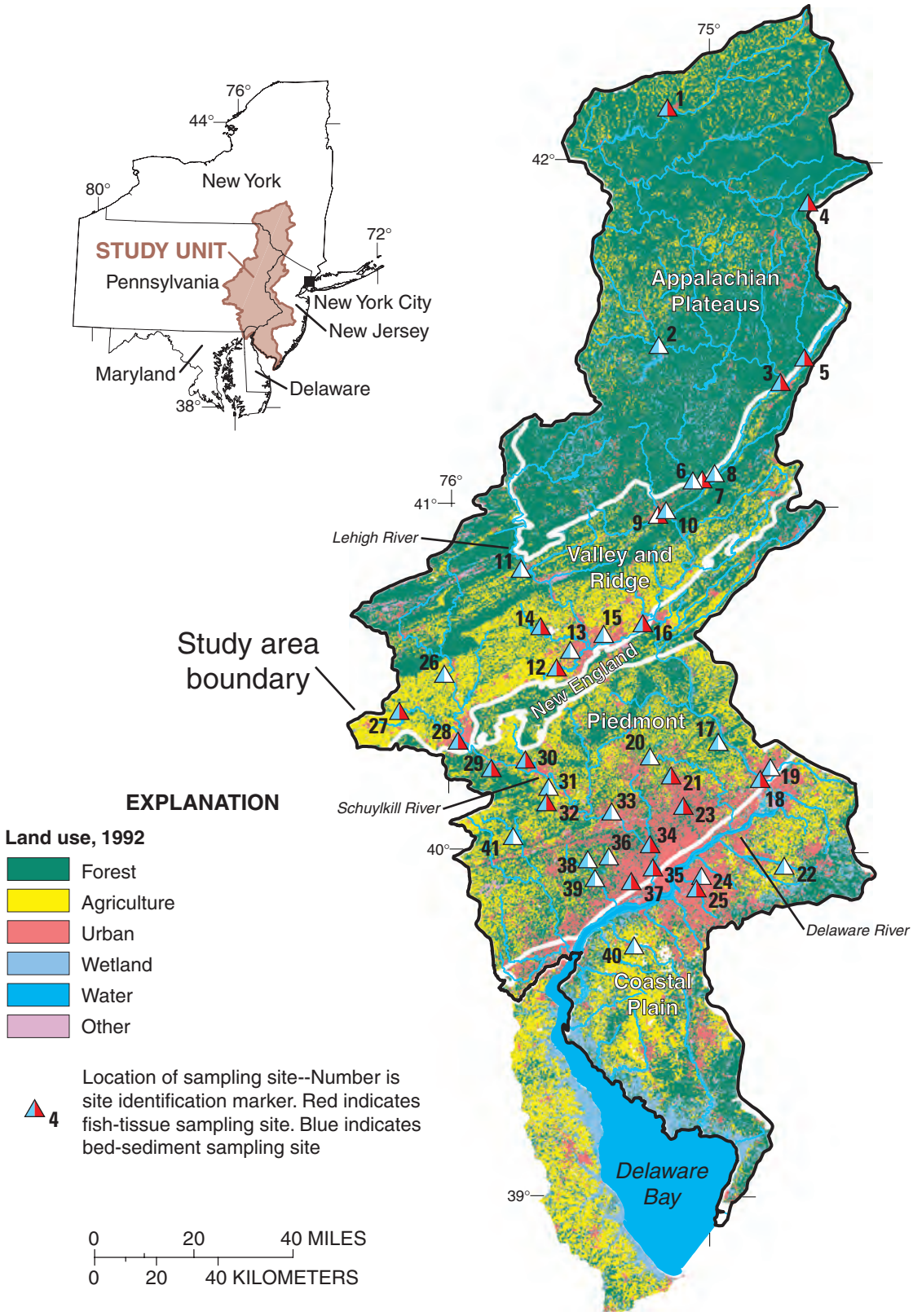

Figure 1. Locations of Delaware River Basin study unit, land use, and physiographic provinces, N.J., Pa., N.Y., and Del. (Site identification numbers correspond to numbers in table 1.)

There are five physiographic provinces within the Delaware River Basin: Appalachian Plateaus, Valley and Ridge, New England, Piedmont, and Coastal Plain. The Appalachian Plateaus Physiographic Province covers the northern one-third of the Delaware River Basin study unit but contains only 3 percent of the population in the study unit (fig. 1). The elevation of this region is higher than that of any other region and ranges from 2,000 to 3,000 feet above NGVD of 1929. Land use in this region is more than 85 percent forest, about 9 percent agriculture (mostly pasture for dairy farming), and less than 1 percent urban.

The Valley and Ridge, which has a long history of coal mining, and the New England provinces cover about 25 percent of the study unit. About 17 percent of the population resides in these two provinces. Land use in these provinces is about 55 to 60 percent forest, 30 to 35 percent agriculture, and less than 7 percent urban.

The Piedmont and Coastal Plain provinces make up the southern part of the study area and account for about 40 percent of the study area but contain more than 80 percent of the population. These provinces have a long history of agricultural use and urban development. The Piedmont accounts for 47 percent of the population (3.4 million people) and consists of 44 percent forest land, 34 percent agricultural land, and 19 percent urban land. The Coastal Plain accounts for 33 percent of the study unit's population and consists of 33 percent forest land, 29 percent agricultural land, and 22 percent urban land. This is the only province in which more than 10 percent of the area is water and wetlands.

Organic Compounds and Trace Elements in Aquatic Environments

Organochlorine compounds are manmade for many uses in industrial, residential, and agricultural practices. Semivolatile organic compounds (SVOCs) are both manmade and occur naturally in the environment. The source of SVOCs in the environment ranges from industrial uses, such as plasticizers, to incomplete combustion of materials during forest fires. Trace elements occur naturally, but their concentrations in the environment can be elevated by human activities, such as metal plating operations.

Organochlorine Compounds

Organochlorine insecticides (such as total DDT, dieldrin, and total chlordanes) and chlorinated industrial organic compounds (such as total PCBs) are all toxic manmade chemicals. They can enter streams directly from point-source discharges or indirectly from stormwater runoff or atmospheric deposition. Many of these contaminants are hydrophobic and preferentially sorb onto stream sediments. They then become bioavailable to organisms who feed on the sediment and the contaminants bioaccumulate (become more concentrated) as they move up the food chain when larger organisms prey on the smaller organisms (Dubrovsky and others, 1998). Because these compounds are lipophilic, they can be stored, long-term, in the fish. Also, most organochlorine compounds do not readily degrade; thus, they persist in the environment for many years. For these reasons most registered uses of total DDT, chlordane, total PCBs, and dieldrin have been cancelled in the United States for decades. Many of these toxic compounds are still being detected, however, in the water column, streambed sediment, and aquatic biota.

DDT, an insecticide, was used in agricultural practices before its use was cancelled in 1972. It also was used in urban/residential settings to control nuisance insects (Nowell and others, 1999). Other countries, however, continue to produce and use DDT in agricultural processes and disease control programs, and deposition can occur from atmospheric sources (U.S. Environmental Protection Agency (USEPA), 2002a). Also, because it persists so long in the environment there is currently a reservoir of contaminated terrestrial soils in many areas that continues to be a source of contamination to aquatic environments (Nowell and others, 1999). These sediments can be resuspended and transported during storms (USEPA, 2002a). DDT was marketed as technical grade DDT, which contained 77.1 percent *p, p'*-DDT, 14.9 percent *o,p'*-DDT, 4.0 percent *p,p'*-DDE, 0.1 percent *o,p'*-DDE, and 3.5 percent unidentified products (World Health Organization, 1989). DDT has been found to break down microbially into its transformation products, DDD and DDE, which also are toxic to wildlife (Nowell and others, 1999). Measurements of soil half-lives have been found to range from 2 to 16 years (Nowell and others, 1999). During this time, fish and other wildlife can bioaccumulate the compound, which can lead to genetic problems within the organism (USEPA, 2002a). DDD and DDE are similar to DDT: they are hydrophobic, toxic, and have similar bioaccumulation tendencies in aquatic biota (Larson and others, 1997).

Chlordane was used from 1948 to 1978 as an insecticide on agricultural crops, lawns, and gardens. In 1978, USEPA cancelled the registration for the use of chlordane on food crops, and over the next 5 years phased out all above-ground uses (USEPA, 2002b). From 1983 to 1988, the only approved use of chlordane was for the control of termites in homes, and after 1988, all uses were cancelled in the United States, although manufacturing for exportation continues (USEPA, 2002b).

PCBs are organic compounds used in electrical transformers, capacitors, switchgear, manufacturing machinery, printing inks, carbonless copy paper, heating coils, specialized cookware, fireproof panels, lubricating oils, resins, synthetic rubber, sealants and coatings, wax, waterproofing compounds, adhesives, and cutting oils (Steuer and others, 1999). They comprise 209 possible congeners and are very resistant to heat and degradation (Steuer and others, 1999). Mixtures of congeners were used under the trade names Aroclor and Askerel. PCBs are resistant to breakdown in the environment, thus they bioaccumulate in fish and other wildlife (USEPA, 2002c). Although the manufacture of PCBs was cancelled in

the United States in 1977, as much as 60 percent of previously manufactured PCBs are still in use today (Steuer and others, 1999).

Dieldrin is a manmade insecticide as well as an oxygenated metabolite of aldrin, another insecticide. Dieldrin and aldrin, which have similar chemical structures, were used to control insects on corn, cotton, and citrus crops, and to control locusts, mosquitoes, and termites (Agency for Toxic Substances and Disease Registry (ATSDR), 2002). They also are used as wood preservatives (USEPA, 2002d). Most uses of dieldrin were cancelled 1987, and it is no longer produced in the United States because of its harmful side effects on humans as well as fish and wildlife (USEPA, 2002d). Aldrin quickly changes to dieldrin when exposed to sunlight and bacteria. Dieldrin and aldrin bond tightly to soil particles and slowly evaporate into the air. Plants and animals, which bioaccumulate both aldrin and dieldrin from the soil, transform aldrin into dieldrin (ATSDR, 2002). Dieldrin is biomagnified through the food chain because animals store it in their body fat (ATSDR, 2002).

Semi-Volatile Organic Compounds

Semi-volatile organic compounds (SVOCs) such as PAHs, phthalates, and phenols have sources and behaviors similar to those of organochlorines in the environment. They are hydrophobic, bioaccumulate in aquatic organisms, and tend to persist in the environment. PAHs and phenols can be manmade or occur naturally, whereas all phthalates are manmade. Many of the SVOC compounds are thought to be toxic, although the only compound with a sediment-quality guideline is total PAH.

PAH's form during incomplete combustion of wood, gasoline, coal and fuel oil (Lopes and Furlong, 2000). They also are formed from the incomplete combustion of fossil fuels used in boilers, kilns, furnaces, open fires, and internal combustion engines such as automobile, buses, trucks, and other motorized vehicles (Golomb and Barry, 1999). Other sources of PAHs include spillage or seepage of petroleum, discharge of domestic and industrial wastes, fallout or rainout from air, and runoff from land (Neff, 1985). PAHs can enter the environment through dry or wet depositional processes (Golomb and Barry, 1999). Depending on the depositional source, PAHs can either be deposited locally, from dry deposition, or regionally, from wet deposition (Golomb and Barry, 1999). Once PAHs enter the water, they are quickly adsorbed onto particulate matter and deposited on lake or stream bottoms, where they become quite stable and persistent, thus remaining relatively close to the point of entry (Neff, 1985).

Phthalates are used as non-reactive plasticisers, in resin compounds, in the fabrication of polyvinyl chloride products, and in the production of adhesives, plastisols, and coatings. Releases into the environment occur from the use and disposal of material containing phthalates during the useful lifetime of the product, during incineration, or from landfills (Kohli and others,1992).

Phenols are used in industrial settings as disinfectants. They also are used in agricultural processes and can occur in vehicle exhaust, coal, petroleum, and wood (Lopes and Furlong, 2001). They have been used to manufacture nylon and other synthetic fibers, as well as slimicides, disinfectants, antiseptics, and medicinal preparations. (ATSDR, 1999a). *P*-cresol is a crystal that is soluble in organic solvents and volatile in steam (California Air Resources Board (ARB), 1999). It has been detected in emissions from motor vehicle exhaust, wood pulping, brewing, and tobacco smoke and is the photo-oxidation product of toluene (California ARB, 1999). Small quantities of p-cresol are known to originate from natural sources (Howard, 1989). Natural sources include chemical odors emitted from plants and odors from manure and (or) dung (Pineda, 2000; Wright and others, undated). The calculated half-life of cresols, including *p*-cresol, in the atmosphere is 4 to 6 hours, and the lifetime is 5 to 8 hours (California ARB, 1999). Wet deposition is thought to be a minor loss process from the atmosphere due to the short half-lives and lifetimes of cresols (California ARB, 1999).

Trace Elements

Although many elements are present in the environment at very low, or trace, concentrations, their concentrations can be substantially increased by human activities such as mining, industrial discharges, or combustion of fuels and waste. Once introduced into the environment, trace elements can remain biologically unavailable, transform into more or less toxic forms, or become bioavailable (Carter and Anderholm, 1997). Some trace elements are essential to animal and plant nutrition (for example, copper and zinc); however, in high concentrations, they can be harmful.

Arsenic, which was once used as a component of pesticides, can enter streams through waste disposal or agricultural drainage. In New Jersey from 1900 to 1980, about 49 million pounds of lead arsenate and 18 million pounds of calcium arsenate were applied to soils as pesticides (Murphy and Aucott, 1998). In the western parts of the New Jersey Coastal Plain, from 1900 to 1980, about one million pounds of arsenic were applied to the soils in the form of pesticides (Murphy and Aucott, 1998). Inorganic arsenic compounds are used mainly as wood preservatives (ATSDR, 2001a). Arsenic also can occur naturally in volcanic gases and phosphate rocks or can be released during the burning of coal and the smelting of ores (Hem, 1992). During the Civil War until about 1910, arsenic was used as the main ingredient in embalming fluids in some areas and can enter the environment in water leaching through old cemeteries (Konefes and McGee, accessed 2001). The U.S. Environmental Protection Agency (USEPA) maximum contaminant level (MCL) for arsenic in drinking water was recently (2005) set at 0.010 mg/L (USEPA, 2005). According to the Pesticide Action Network North America (PAN), many registrations for products containing arsenic have been cancelled in the United States (PAN, 2004).

Cadmium can be a byproduct of the smelting and refining of copper ores and is used in electroplating, paints, printing ink, and plastics. It is used as a stabilizer for polyvinyl chloride, in electrical batteries (nickel-cadmium batteries), and in fluorescent and video tubes. It can enter the environment as a leachate from buried wastes, through vaporization and atmospheric deposition, from metallurgical processes, and from the combustion of fossil fuels (Hem, 1992). Once in the environment, cadmium can be bioaccumulated and biomagnified by animals and fish (ATSDR, 1999b).

Chromium, in various forms, is used in many industrial applications, such as chrome plating operations (Hem, 1992). It also is used in leather tanning processes and wood preserving (ATSDR, 2001b). It can enter the environment through fossil-fuel combustion, waste incineration, and cement-plant emissions (Shelton, undated). Once in the environment, chromium adheres strongly to soil particles; little is dissolved in water and taken up by fish (ATSDR, 2001b).

Copper is widely used for plumbing purposes, can be added as a salt to water-supply reservoirs to suppress algal growth, is a component in agricultural pesticides, and can be a byproduct of acid mine drainage (Hem, 1992). Copper is naturally occurring in rocks, soil, water, and air, as well as in plants and animals (ATSDR, 1999c). It can be introduced into the environment after being dissolved from plumbing pipes and fixtures, in stormwater runoff in agricultural settings, and in copper smelting. Upon entering the water, copper dissolves rapidly and binds to suspended particles; some can be taken up by plants and animals (ATSDR, 1999c).

Lead was used in plumbing pipes and as an aid for combustion of gasoline (tetraethyl lead) (Hem, 1992). It could be found in solder used to joint copper fittings, in pipes in water-distribution service lines, and in brass and bronze fixtures (Shelton, undated). Hem (1992) stresses the importance of dry and wet deposition of particulate lead as a major source of lead into the environment. Lead, bound to particulates, can be washed into streams after storms and adheres to soil particles. Health concerns have caused a decrease in the amount of lead used in gasoline, paints, ceramic products, caulking, and pipe solder (ATSDR, 1999d)

Mercury was widely used as a biocide for the treatment of seed grain, in the form of organomercuric compounds, until its registration was cancelled in the 1960's. Prior to the 1970's, mercury was used in the electrolysis of molten sodium chloride. Other sources of mercury are electrical equipment such as batteries, lamps, switches, and rectifiers (which convert alternating current to direct current); smelting; fossil-fuel combustion; and mining operations (Shelton, undated; Hem, 1992). Mercury can enter the environment from atmospheric deposition, improper waste disposal, and stormwater runoff. Mercury is usually found in two forms, elemental mercury and methylmercury, which is produced through bacterially mediated processes. Elemental mercury is not usually bioavailable to fish, so although mercury concentrations can be high in bed sediment, if it is not methylmercury, it is unlikely to be bioaccumulated and detected in the fish livers (ATSDR, 1999e; Brightbill and others, 2004).

Nickel currently is used in the production of stainless steel and other corrosion resistant alloys (Hem, 1992). Nickel can enter the environment after being leached from metal alloys or by dry or wet deposition from smoke stacks where metal alloys are made, from power plants, or from trash incinerators. Though it does not readily collect in fish, plants, or animals, it can be leached into the ground or surface water where it may become available to humans at toxic levels (ATSDR, 1997).

Zinc is a common element found in the earth's crust, as well as in the air, soil, and water. It is also found in all foods. Zinc is widely used as a constituent of brass and bronze and for galvanizing steel, as well as a white pigment in paint and rubber (Hem, 1992). Zinc also is used to make ointments, dyes, and wood preservatives (ATSDR, 1995). Many forms of zinc, including zinc chloride, zinc oxide, zinc sulfate, and zinc sulfide, are found in hazardous waste sites (ATSDR, 1995). Zinc enters the environment as a leachate. Although most zinc binds tightly to soil particles, small amounts can be taken up by fish (ATSDR, 1995).

Methods of Sample Collection and Analysis

The following section describes the methods used in site selection, data collection and field processing, and laboratory and data analyses for organic compounds and trace elements in both fish tissue and bed sediment.

Site Selection

Streambed-sediment and fish-tissue samples were collected from sites on tributaries and large rivers (draining watersheds greater than 1,000 mi^2) throughout the Delaware River Basin. Sites were selected in a variety of land-use settings within each physiographic province and across the study unit (fig. 1 and table 1). Sites typically drain an area less than 600 mi^2 and were selected to represent forest, low-agricultural, agricultural, mixed, and urban land-use categories (table 5, further along in report). Fish samples were collected from 25 sites, and bed-sediment samples were collected from 39 sites (fig. 1). For comparisons across media, sites were selected so that organic compounds or trace elements were likely to be present in fish tissue and bed sediment. Samples from 23 of the sites contained organic compounds in both fish tissue and bed sediment, and samples from 19 sites contained trace elements in both media.

Table 1. Land-use characteristics in basins draining to bed-sediment and fish-tissue sampling sites, Delaware River Basin study unit, 1998-2000.

[Map number is shown in figure 1; mi^2, square miles]

Map location	Station name	Station number	Drainage area (mi^2)	Land-use category	Land use (in percent)			
					Urban	Agricultural	Forest	Impervious surface
1	West Branch Delaware River at Walton, N.Y.	01423000	332	Low agricultural	.9	23.1	75.4	2.3
2	Lackawaxen River at Hawley, Pa.	01431500	290	Low agricultural	1.0	18.8	74.7	4.9
3	Delaware River at Port Jervis, N.Y.	01434000	3,070	Large river	1.0	10.6	84.4	4.6
4	Neversink River near Claryville, N.Y.	01435000	66.6	Forest	.1	.4	99.3	1.7
5	Neversink River at Godeffroy, N.Y.	01437500	307	Forest	3.0	2.9	89.2	6.4
6	Bush Kill at Shoemakers, Pa.	01439500	117	Forest	.5	.4	87.2	3.9
7	Bush Kill at Bushkill, Pa.	01439550	124	Forest	1.0	.6	86.8	4.2
8	Flat Brook near Flatbrookville, N.J.	01440000	64.0	Forest	.6	7.1	87.9	2.8
9	Brodhead Creek at Stroudsburg, Pa.	01442110	257	Forest	3.9	2.8	87.6	5.5
10	Brodhead Creek at Minisink Hills, Pa.	01442500	259	Forest	4.5	7.4	83.1	5.7
11	Lehigh River at Lehighton, Pa.	01449000	591	Forest	2.4	3.3	83.3	6.5
12	Little Lehigh Creek at East Texas, Pa.	01451425	51.2	Agricultural	7.4	68.0	23.4	6.7
13	Cedar Creek above Lake Muhlenberg at Allentown, Pa.	01451624	13.7	Urban	41.0	39.7	17.0	27.7
14	Jordan Ck near Schnecksville, Pa.	01451800	53.0	Agricultural	1.1	65.3	33.0	2.5
15	Monocacy Creek at Bethlehem, Pa.	01452500	44.5	Mixed	10.3	67.3	19.1	9.7
16	Lehigh River at Glendon, Pa.	01454700	1,359	Large river	6.7	23.3	63.0	8.6
17	Pidcock Creek near New Hope, Pa.	01462100	12.1	Agricultural	.7	38.5	59.0	2.2
18	Delaware River at Trenton, N.J.	01463500	6,780	Large river	3.3	16.5	74.6	6.2
19	Shabakunk Creek near Lawrenceville, N.J.	01463810	11.7	Urban	59.7	14.5	17.5	36.8
20	Pine Run at Chalfont, Pa.	01464710	11.6	Mixed	13.8	47.0	37.2	10.8
21	Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	01464907	26.8	Urban	25.6	32.3	35.7	17.9

Table 1. Land-use characteristics in basins draining to bed-sediment and fish-tissue sampling sites, Delaware River Basin study unit, 1998-2000.—Continued

[Map number is shown in figure 1; mi², square miles]

Map location	Station name	Station number	Drainage area (mi²)	Land-use category	Land use (in percent)			
					Urban	Agricultural	Forest	Impervious surface
22	North Branch Rancocas Creek at Pemberton, N.J.	01467000	118	Mixed	8.9	4.0	62.1	10.3
23	PennyPack Creek at Paper Mill, Pa.	01467040	23.7	Urban	63.3	4.6	23.2	40.7
24	South Branch Pennsauken Creek at Cherry Hill, N.J.	01467081	9.0	Urban	66.9	12.0	14.3	41.7
25	Cooper River at Haddonfield, N.J.	01467150	17.0	Urban	58.1	7.2	24.0	39.0
26	Schuylkill River at Berne, Pa.	01470500	355	Mixed	4.1	14.8	72.3	10.0
27	Tulpehocken Creek near Bernville, Pa.	01470779	66.5	Agricultural	3.6	82.2	13.0	4.4
28	Wyomissing Creek at West Reading, Pa.	01471520	15.6	Urban	30.4	25.5	43.3	20.8
29	Hay Creek near Birdsboro, Pa.	01471668	20.8	Low agricultural	.4	21.3	75.6	3.3
30	Manatawny Creek near Pottstown, Pa.	01471980	85.5	Agricultural	1.6	41.0	55.8	3.0
31	Pigeon Creek near Parker Ford, Pa.	01472100	14.0	Agricultural	3.2	46.4	50.2	3.4
32	French Creek near Phoenixville, Pa.	01472157	59.1	Agricultural	.9	34.3	63.1	2.5
33	Stony Creek at Steriger Street at Norristown, Pa.	01473470	20.4	Urban	35.2	30.4	31.5	22.9
34	Wissahickon Creek below Walnut Lane near Manayunk, Pa.	01473990	61.4	Urban	41.9	11.7	40.4	27.1
35	Schuylkill River at Philadelphia, Pa.	01474500	1,893	Large river	10.0	37.9	48.2	10.0
36	Darby Creek at Foxcroft, Pa.	01475430	15.7	Urban	34.8	13.0	50.1	21.4
37	Darby Creek near Darby, Pa.	01475510	37.4	Urban	51.3	7.3	38.0	32.6
38	Crum Creek at Goshen Road near Whitehorse, Pa.	01475845	12.5	Mixed	16.9	20.6	60.0	11.1
39	Ridley Creek near Media, Pa.	01476470	27.3	Mixed	11.5	28.6	59.0	8.1
40	Raccoon Creek near Swedesboro, N.J.	01477120	26.9	Agricultural	4.3	63.9	27.0	4.3
41	East Branch Brandywine Creek near Dorlan, Pa.	01480665	33.4	Agricultural	1.0	52.6	45.0	3.1

Collection and Field Processing of Samples

Fish were collected by electrofishing with backpack, tote barge, or boat with pulse direct current from sites in the Appalachian Plateaus, Piedmont, Valley and Ridge, and Coastal Plain physiographic provinces of the Delaware River Basin during 1998-2000. Fish were collected using methods outlined in Crawford and Luoma (1993). Whole white suckers (*Catostomus commersoni*) were collected to assess distributions of contaminants across the basin (table 2). Whole common carps (*Cyprinus carpio*) were collected at five sites to assess differences between species, and smallmouth bass fillets (*Micropterus dolomieu*) were collected at four sites to assess the potential effects on human health (table 2). Once collected, specimens were weighed and measured (total and standard length), and gender was determined. For laboratory analyses for organochlorine compounds, 4 to 10 specimens of whole-white sucker, whole-common carp, or skin-on fillets of smallmouth bass were collected (table 2). Whole fish specimens were wrapped in foil, bagged, and frozen. For smallmouth bass a single fillet was collected from each specimen (according to methods described in Crawford and Luoma, (1993)), wrapped in foil, bagged, and frozen. For laboratory analyses for trace elements, 5 to 10 common carp or white-sucker livers were collected (table 3). Five to 10 grams of liver tissue was excised (using methods described in Crawford and Luoma, (1993)) from specimens different from those collected for analysis for organochlorine compounds. Livers were composited in a pre-cleaned glass jar and frozen on dry ice. All fish samples were shipped to the National Water-Quality Laboratory (NWQL), in Arvada, Colorado, where they were composited prior to analysis.

Bed-sediment samples were collected at each site at 5 to 10 depositional locations along the sampling reach, using methods outlined in Shelton and Capel (1994). Samples were scooped from the top 2.54 cm of sediment, which were assumed to be recent depositional zones. The collected sediment was composited in a glass bowl until a total volume of approximately 1.5 L of sediment was obtained. For analyses for trace elements, an aliquot of the composited sediment sample was sieved through a plastic 63-μm sieve and collected in a 500-mL, acid-rinsed, plastic jar. For analyses for organic compounds, a separate aliquot of the composited sediment sample was wet sieved through a 2.0-mm metal sieve, and the collected fines were placed in a 500-mL, methanol rinsed, glass jar. All samples then were packed on ice for shipment to the NWQL.

Laboratory Processing and Analyses of Samples

Whole fish and fillet samples were analyzed for concentrations of organochlorine compounds (table 13, farther on in report). Fish samples for single species were sent to the NWQL for analysis for organochlorine compounds. Whole fish or fillet samples for a single species from a site were homogenized into a single composite sample from which an aliquot was taken. This aliquot was analyzed by gas chromatography and mass spectrometry for organochlorines (Leiker and others, 1995). Lipid content also was determined from a separate aliquot.

Fish livers were analyzed for trace-element concentrations (table 22, farther on in report). Fish-liver samples for a single species from a single site were composited, dried, digested, and filtered prior to analysis (Arbogast, 1996). Laboratory analyses for all trace elements except mercury were conducted using inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma atomic emission spectrometry (Arbogast, 1996). Mercury concentrations were determined using cold vapor atomic absorption spectrophotometry (Hoffman, 1996). Lipid content was determined in a separate aliquot.

Streambed-sediment samples were analyzed for concentrations of organochlorine compounds, SVOCs, and trace elements (tables 13, 19, and 22, farther on in report). Arbogast (1996) and Foreman and others (1995) give detailed descriptions of the protocols for the determination of concentrations of trace elements and organic compounds in bed sediments. Detailed descriptions of laboratory methods for the analyses of SVOCs in bed sediment can be found in Furlong and others (1996). Organic and total carbon content, percent fines (<63 μm), also were determined in a subsample.

Data Analyses

The following section describes the methods used in the compilation and censoring of the fish-tissue and bed-sediment data, as well as the statistical and graphical analyses used to determine the differences among basin characteristics. The guidelines and advisories used to compare the data to environmental and human-health hazards also are described.

Compilation and Censoring of Data

Not all organic or trace-element compounds for which the samples were analyzed and that were detected (tables 13, 19, and 22 farther on in report) are listed and discussed in this report. Only those compounds and trace elements that were frequently detected and are of environmental concern are discussed. The organochlorines discussed include the sum of the DDT metabolites, the sum of the chlordane metabolites, PCBs, and dieldrin. For SVOCs, PAHs, phthalates, and phenols are discussed. The trace elements discussed include arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc.

In order to make statistically valid comparisons between categories of data, it was necessary to censor data to a common reporting limit. Data censoring was required because of elevated and variable reporting levels above the standard minimum reporting levels (MRLs) reported by the NWQL for particular constituents. Ranges in MRLs and censoring levels for all constituents are listed in tables 4a and 4b. The

Table 2. Weight, length, and number of fish specimens collected for analysis for organochlorine compounds, Delaware River Basin study unit, 1998-2000.

Station name	Weight (grams)			Length (millimeters)			Number of specimens
	Minimum	Median	Maximum	Minimum	Median	Maximum	
Whole white suckers (*Catostomus commersoni*)							
West Branch Delaware River at Walton, N.Y.	427	487	824	346	369	423	8
Lackawaxen River at Hawley, Pa.	87	160	214	194	242	261	6
Delaware River at Port Jervis, N.Y.	624	887	1,096	389	443	492	8
Neversink River near Claryville, N.Y.	580	626	739	385	402	421	6
Neversink River at Godeffroy, N.Y.	655	786	999	383	413	435	7
Bush Kill at Bushkill, Pa.	65	80	101	181	191	202	8
Flat Brook near Flatbrookville, N.J.	87	512	678	201	382	415	5
Brodhead Creek at Stroudsburg, Pa.	583	772	1,455	391	422	512	7
Little Lehigh Creek at East Texas, Pa.	361	516	824	334	365	442	8
Jordan Ck near Schnecksville, Pa.	212	437	644	278	359	412	8
Lehigh River at Glendon, Pa.	696	830	1,223	395	418	475	8
Delaware River at Trenton, N.J.	220	394	1,311	265	318	487	8
Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	168	224	420	254	280	331	10
Pennypack Creek at Paper Mill, Pa.	246	294	397	272	292	340	9
South Branch Pennsauken Creek at Cherry Hill, N.J.	72	102	357	185	211	320	7
Cooper River at Haddonfield, N.J.	231	371	485	272	321	359	7
Tulpehocken Creek near Bernville, Pa.	206	310	701	291	310	492	10
Wyomissing Creek at West Reading, Pa.	216	289	740	270	298	399	7
Hay Creek near Birdsboro, Pa.	142	174	259	267	278	310	8
Manatawny Creek near Pottstown, Pa.	610	625	845	379	401	433	8
French Creek near Phoenixville, Pa.	342	471	668	318	358	400	8
Wissahickon Creek below Walnut Lane near Manayunk, Pa.	243	263	766	272	292	389	4
Schuylkill River at Philadelphia, Pa.	322	548	1,000	305	394	473	8
Darby Creek near Darby, Pa.	332	468	622	303	343	368	8
Raccoon Creek near Swedesboro, N.J.	183	314	589	262	316	392	8
Common carp (*Cyprinus carpio*)							
Lehigh River at Glendon, Pa.	2,548	2,933	3,857	550	608	650	5
Delaware River at Trenton, N.J.	2,208	2,812	5,000	551	583	681	8
Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	1,991	3,683	3,976	522	625	634	5
Cooper River at Haddonfield, N.J.	1,100	1,500	2,900	365	455	569	6
Schuylkill River at Philadelphia, Pa.	2,298	2,828	3,554	545	588	630	8
Smallmouth bass (*Micropterus dolomieu*)							
Delaware River at Port Jervis, N.Y.	252	279	368	254	281	290	4
Lehigh River at Glendon, Pa.	259	357	444	272	297	326	5
Delaware River at Trenton, N.J.	310	795	1,209	292	400	446	5
Schuylkill River at Philadelphia, Pa.	280	324	354	294	305	325	5

Table 3. Weight, length, and number of fish specimens collected for analysis for trace elements, Delaware River Basin study unit, 1998-2000.

Station name	Weight (grams)			Length (millimeters)			Number of specimens
	Minimum	Median	Maximum	Minimum	Median	Maximum	
Whole white suckers (*Catostomus commersoni*)							
West Branch Delaware River at Walton, N.Y.	397	497	614	275	299	323	8
Delaware River at Port Jervis, N.Y.	620	860	1,200	381	443	496	8
Neversink River near Claryville, N.Y.	761	939	1,114	411	465	481	6
Neversink River at Godeffroy, N.Y.	572	901	1,273	394	432	486	7
Brodhead Creek at Stroudsburg, Pa.	548	816	1,069	380	415	449	6
Little Lehigh Creek at East Texas, Pa.	320	397	802	313	335	431	8
Jordan Ck near Schnecksville, Pa.	322	573	905	323	385	446	8
Lehigh River at Glendon, Pa.	395	754	1,559	310	390	520	8
Delaware River at Trenton, N.J.	351	477	1,039	304	352	485	8
Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	138	174	275	235	259	296	9
Pennypack Creek at Paper Mill, Pa.	237	288	486	273	298	355	8
Cooper River at Haddonfield, N.J.	190	238	350	261	285	320	8
Tulpehocken Creek near Bernville, Pa.	239	301	477	290	308	370	10
Wyomissing Creek at West Reading, Pa.	207	283	455	273	297	345	8
Hay Creek near Birdsboro, Pa.	104	147	170	225	248	257	10
Manatawny Creek near Pottstown, Pa.	503	646	1,078	364	393	465	8
French Creek near Phoenixville, Pa.	340	407	943	322	343	443	8
Wissahickon Creek below Walnut Lane near Manayunk, Pa.	276	331	346	288	293	302	4
Schuylkill River at Philadelphia, Pa.	652	782	1,284	390	428	488	8
Darby Creek near Darby, Pa.	284	446	858	289	341	405	8
Common carp (*Cyprinus carpio*)							
Lehigh River at Glendon, Pa.	3,506	4,435	6,081	611	640	711	5
Delaware River at Trenton, N.J.	1,332	2,525	4,200	462	580	670	8
Cooper River at Haddonfield, N.J.	844	1,178	1,739	383	442	503	6
Schuylkill River at Philadelphia, Pa.	2,225	3,139	6,200	520	619	754	8

goal of censoring was to create a balance between the greatest number of samples that could be used for statistical analyses and the lowest possible reporting limit. Each constituent was censored by raising the detection level for each sample to the highest MRL among all samples for that constituent. The above censoring method left a few samples with elevated reporting limits; these were handled in the following manner: (1) for constituents that were detected at 5 percent or fewer sites, statistical analyses were not performed; (2) for mercury in fish liver, data for two sites (01464907 and 01471668) were removed; and (3) for total PCB in bed sediment, data for two sites (01462100 and 01475845) were removed.

At sites where samples were collected for more than one year, only those data obtained from the initial sample were used in statistical analyses; however, if that sample contained concentrations elevated above the reporting limits, then data from a sample collected in another year were substituted, if available. For the fish-tissue dataset, white sucker data were used exclusively for statistical analyses because of the low number of samples of smallmouth bass and common carp.

For some organic compounds it was necessary to sum the concentrations of individual compounds to obtain a total concentration for that class of compounds, in order to track the mass balance as the compound degrades. Total concentrations for total chlordanes, total DDT, phenols, phthalates, and PAHs were calculated in this manner (individual constituents are listed in tables 4a and 4b). Constituents with concentrations less than the censoring level for any given sample were set to zero before summation. Compounds with concentrations remarked as having been estimated, which were greater than

Table 4a. Censoring levels of organochlorine compounds and trace elements in bed-sediment and fish-tissue samples collected in the Delaware River Basin study unit, 1998-2000.

[<, less than; µg/kg, micrograms per kilogram; µg/g, microgram per gram; NA, not applicable; n, number of samples]

Constituent	Minimum reporting limits		Censoring level	
	Bed sediment	Fish tissue[1]	Bed sediment	Fish tissue[1]
Organochlorine compounds (µg/kg, wet weight)				
o,p'-DDD	<1 - <8	<5 - <21	<8	<21
o,p'-DDE	<1 - <10	<5 - <8	<10	<8
p,p'-DDT	<2 - <6	<5	<6	<5
p,p'-DDD	<1 - <3	<5	<3	<5
p,p'-DDE	<1	<5	<1	<5
cis-chlordane	<1 - <3	<5	<3	<5
cis-nonachlor	<1 - <3	<5	<3	<5
Oxychlordane	<1 - <3	<5	<3	<5
trans-chlordane	<1 - <3	<5	<3	<5
trans-nonachlor	<1 - <3	<5	<3	<5
PCB[2]	<50 - <150	<50	<100	<50
Dieldrin	<1 - <3	<5	<3	<5
Trace elements (µg/g, dry weight)				
Arsenic	NA	<.2 - <1	NA	<.4
Cadmium	<.1	<.3	<.1	<.3
Chromium	NA	<.5	NA	<.5
Copper	NA	NA	NA	NA
Lead	NA	<.2 - <1	NA	<.4
Mercury[3]	NA	<.1 - <.4	NA	<.2
Nickel	NA	<.2 - <1	NA	<.4
Zinc	NA	NA	NA	NA

[1] Trace elements were determined in fish livers; organochlorine compounds were determined in whole fish samples.

[2] n = 37

[3] n = 19

Table 4b. Censoring levels of semi-volatile organic compounds in bed-sediment samples collected at 39 sites in the Delaware River Basin study unit, 1998-2000.

[<, less than; all concentrations in micrograms per kilogram, dry weight; ND, not detected]

Constituent	Minimum reporting limits	Censoring level
Polycyclic aromatic hydrocarbons		
1,2-Dimethylnaphthalene	<50 - <200	<200
1,6-Dimethylnaphthalene	<50 - <200	<200
1-methyl-9H-fluorene	<50 - <200	<100
1-Methylphenanthrene	<50 - <140	<100
1-Methylpyrene	<50 - <140	<140
2,3,6-Trimethylnaphthalene	<50 - <200	<200
2,6-Dimethylnaphthalene	<50	<50
2-Ethylnaphthalene	<50 - <200	<200
2-Methylanthracene	<50 - <140	<100
4H-cyclopenta(def)phenanthrene	<50 - <100	<100
9H-Fluorene	<50 - <140	<140
Acenaphthylene	<50 - <100	<100
Acenapthene	<50 - <140	<100
Anthracene	<50 - <100	<100
Benz(a)anthracene	<50 - <100	<100
Benzo(a)pyrene	<50	<50
Benzo(b)fluoranthene	<50	<50
Benzo(ghi)perylene	<50 - <100	<100
Benzo(k)fluoranthene	<50	<50
Chrysene	<50	<50
Dibenz(AH)anthracene	<50 - <140	<140
Dibenzothiophene	<50 - <140	<140
Fluoranthene	<50	<50
Indeno(1,2,3-cd)pyrene	<50	<50
Naphthalene	<50 - <200	<200
Phenanthrene	<50	<50
Pyrene	<50	<50
Phthalates		
bis(2-ethylhexyl)phthalate	<50	<100
Butylbenzyl phthalate	<50	<100
Diethyl phthalate	<50 - <200	<200
Dimethyl phthalate	<50 - <200	<200
Di-n-butyl phthalate	<50 - <100	<100
Di-n-octyl phthalate	<50 - <200	<200
Phenols		
2-Chlorophenol	<50 - <200	All ND
3,5 Dimethyl phenol	<50 - <200	All ND
4-Chloro-3-methylphenol	<50 - <200	All ND
p-cresol	<50	<50
Phenol	<50 - <200	<200

the censoring level, were included in the summed values. Values can be denoted as "estimated" for the following reasons: results were extrapolated above the calibration curve, data quantification was not performed according to method-specific criteria, performance of the analyte did not meet acceptable method-specific criteria, deviations from standard operating procedure occurred at the laboratory, some losses occurred in sample preparation but were not quantifiable, and moderate matrix interferences occurred (Oblinger-Childress and others, 1999). Despite these caveats, estimated values are considered valid detections and are commonly used in non-parametric statistical analyses.

Non-Parametric Analysis of Basin Characteristics

Basins upstream from the sampling site were characterized for land use and population density using a geographic information system. Basins were delineated using 30-m digital elevation data. Land use in each basin was determined from 1992 Landsat Satellite Thematic Mapper Imagery, and population was estimated from 2000 United States census data (U.S. Census Bureau, 2000). Impervious surface was calculated from the satellite data to facilitate in distinguishing differences between urban sites (McMahon and Cuffney, 2000). Sites were characterized as forest, low-agriculture, agricultural, mixed, and urban land uses (table 5). Sites on rivers that are 1,000 mi^2 or larger were classified as "large-river" sites because they integrate a combination of smaller watersheds and multiple land uses, and may have different processes affecting contaminant uptake from smaller rivers.

Whole white sucker, white sucker liver, and bed-sediment data were analyzed using graphical analyses and non-parametric statistical procedures. Median concentrations and frequency of detections were calculated for all the data and each land-use category. Kruskal-Wallis Rank Sum test (Zar, 1984), a non-parametric one-way ANOVA, was used to determine if there were statistically significant differences between concentrations in different land-use categories. Results of this test were considered significant if $p < 0.050$. If a statistically significant difference was found between categories, a non-parametric multiple-comparison, the Dunn test (Daniel, 1990), was performed to find which land-use categories had significantly different concentrations. Finally, Spearman's rank correlation (Zar, 1984) was used on the data set (except large-river sites) to determine relations between constituent concentrations and basin characteristics, including population density and impervious surface, and agricultural, forest, and urban land-use percentages. Large-river sites were not selected because they incorporate many different land uses and, therefore, are not indicative of any individual land use. Results from Spearman's rank correlation test were considered significant if $p<0.050$.

A comparison of concentrations of organochlorine compounds in fish tissue to those in bed sediment, as well as a comparison of concentrations of trace elements in fish livers to those in bed sediment were performed to see whether bioaccumulation was occurring. Those comparisons were done only for sites that had detections in both media.

Statistical analyses also were conducted to determine if normalizing the fish-tissue data to lipid content, or the streambed-sediment data to organic carbon content would improve the ability to relate land use to contaminant concentrations. Non-parametric correlation and ANOVAs were performed on both lipid-normalized and non-normalized data for whole white suckers and white sucker livers, and on organic carbon normalized and non-normalized data for bed sediment. Results of the comparison indicated no large differences between the normalized and non-normalized data for all constituents in any media. For this reason only non-normalized data are discussed in this report.

Bioaccumulation has been shown, in some studies, to be a function of the lipid solubility of the fish, and normalization of contaminants to lipid content has been shown to decrease the variability between species (Nowell and others, 1999). Lipid normalization, however, also has been shown not to lessen the variability in contaminant levels.

Table 5. Land-use and large-river site criteria based on Anderson Level Classification calculated using 1992 Landsat satellite Thematic Mapper Imagery, Delaware River Basin study unit, 1998-2000.

[mi^2, square miles]

Land use category	Criterion
Forested	Greater than 80 percent forested land
Low-agricultural	15-25 percent agricultural land, with greater than 65 percent forested land
Agricultural	Greater than 25 percent agricultural land, with less than 8 percent impervious surface
Mixed	Greater than or equal to 8 percent, but no more than 15 percent impervious surface
Urban	Greater than 15 percent impervious surface
Large-river sites	Draining watersheds greater than 1,000 mi^2, incorporating multiple land uses

Comparison with Guidelines

Constituent concentrations were compared with guidelines, criteria, and (or) action levels, where applicable. These levels, considered to be protective of human or wildlife health, have been developed by various agencies, using a variety of approaches. Guidelines, criteria, and action levels referred to in this study are shown in tables 6-9.

Constituent concentrations in whole-fish samples were compared with levels established by New York State Department of Environmental Conservation (NYSDEC) for the protection of fish-eating wildlife (Newell and others, 1987) (table 6). Constituent concentrations in smallmouth bass fillet samples were compared with the U.S. Food and Drug Administration (USFDA) action levels and advisory levels used by Pennsylvania Department of Environmental Protection (PaDEP) for total PCBs (tables 7 and 8) (U.S. Food and Drug Administration, 2000; Pennsylvania Fish and Boat Commission, 2000).

Data on organic compounds and trace elements in bed sediment were compared to Consensus-Based Sediment Quality Guidelines (SQG) (MacDonald and others, 2000) (table 9). Threshold Effects Concentrations (TEC) are concentration

Table 8. Pennsylvania Department of Environmental Protection Polychlorinated Biphenyls Advisory Levels.

[µg/kg, microgram per kilogram; Advisory levels from Pennsylvania Fish and Boat Commission, 2000]

Concentration ranges (µg/kg)	Advisory levels for edible fish flesh	Percentage of smallmouth bass within concentration range (n=4)
<50	Unrestricted	25
60 - 200	Eat no more than one meal per week	25
210 - 1,000	Eat no more than one meal per month	50
1,100 - 1,900	Eat no more than six meals per year	0
>1,900	Do not eat	0

Table 6. New York State Department of Environmental Conservation Wildlife Protection Guidelines for total DDT, total chlordanes, total polychlorinated biphenyls (PCBs), and dieldrin.

[µg/kg, micrograms per kilogram; Wildlife Protective Guidelines from Newell and others, 1987]

Organochlorine	Guideline (µg/kg)
Total DDT	200
Total chlordanes	500
Total PCBs	110
Dieldrin	120

Table 7. U.S. Food and Drug Administration Action Levels for Commercial Transport and Sale of Fish for total DDT, total chlordanes, polychlorinated biphenyls (PCBs), and dieldrin.

[µg/kg, microgram per kilogram; Action Levels from U.S. Food and Drug Administration, 2000]

Organochlorine	Action level (µg/kg)
Total DDT	5,000
Total chlordanes	500
Total PCBs	2,000
Dieldrin	300

Table 9. Consensus-Based Sediment Quality Guidelines Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC) for organic compounds and trace elements in bed sediment.

[µg/kg, micrograms per kilogram; mg/kg, milligrams per kilogram; PCBs, polychlorinated biphenyls; PAHs, polycyclic aromatic hydrocarbons; Consensus-based Sediment Quality Guidelines from MacDonald and others, 2000]

Constituent	TEC	PEC
Organic compounds (µg/kg)		
Total DDT	5.28	572
Total chlordane	3.24	17.6
Dieldrin	1.9	61.8
Total PCBs	59.8	676
Total PAHs	1,610	22,800
Trace elements (mg/kg)		
Arsenic	9.79	33
Cadmium	.99	4.98
Chromium	43.4	111
Copper	31.6	149
Lead	35.8	128
Mercury	.18	1.06
Nickel	22.7	48.6
Zinc	121	459

levels below which adverse biological effects in freshwater ecosystems are expected to be rare; Probable Effects Concentrations (PEC) are concentration levels above which adverse biological effects in freshwater ecosystems are expected to be frequent. Concentrations between TECs and PECs are levels at which adverse biological effects occasionally occur. These guidelines are for whole-sediment samples. Samples collected for analyses for trace elements were sieved to less than 63 μm to remove the sand-sized fraction, which is not likely to sorb trace elements. Therefore, use of samples for analyses that contain a lower percentage of fine material could result in an overestimation of the toxicity when compared to that of a whole-sediment sample. The minimum percentage of fines in this study was 10 percent; the maximum was 88 percent, with a median of 36 percent.

Although not included in this report, USEPA Human-health and Aquatic-life Benchmarks for many organic compounds are available on the World Wide Web at URL *http://www.epa.gov/* .

Many studies have been conducted on various species of fish to determine the effects of organic compounds on fish systems. From these studies, the following effects were observed: thyroid dysfunction, decreased fertility, decreased hatching success, birth deformities, compromised immune systems, feminization of males, and defeminization of females (Larson and others, 1997). Such deformities and defects could result in a decline in population of fish species in many rivers. Guidelines are in place to help protect fish and other wildlife that feed on fish, but it is important to stress that those guidelines are for individual compounds. The synergistic effects of multiple compounds are not taken into consideration and likely are more problematic to aquatic biota, as well as to humans and other terrestrial animals. A recent study assesses the potential effects of these mixtures (Gilliom and others, 2006).

Quality Assurance

Split replicate samples were collected for analysis of organic compounds and trace elements in fish tissue and bed sediment to determine variability between samples. Fish-tissue split replicates were collected from one site, and bed-sediment split replicates were collected from two sites.

Fish Tissue

For organic compounds in fish tissues, 11 of 13 constituents were not detected in either sample, which provides confidence in the results (table 10). For the two detected organic compounds, p, p'-DDE and total PCBs, the percent differences in concentrations between the environmental samples and the replicate samples were 54 percent and 35 percent, respectively. These results could indicate some environmental variability or greater variability in the analytical method at the low concentrations in the samples. For trace elements, the percent differences in concentrations were within expected limits for five of the eight trace elements (less than 20 percent); however, the differences for cadmium, mercury, and nickel might be exaggerated as a result of high variability at the low concentrations reported for each trace element.

Table 10. Results of quality-assurance analyses of environmental and split replicate samples for organochlorine compounds in whole white suckers and trace elements in white sucker livers collected at West Branch Delaware River at Walton, N.Y., August 16, 1999.

[<, less than; μg/kg, micrograms per kilogram; μg/g, micrograms per gram; E, estimated; ND, no detection in both samples; nd, no detection one sample; PCBs, polychlorinated biphenyls]

Constituent	Environmental sample	Split replicate sample	Percent difference
Organochlorine compounds (µg/kg)			
o,p'-DDD	<5	<5	ND
o,p'-DDE	<5	<5	ND
o,p'-DDT	<5	<5	ND
p,p'-DDD	<5	<5	ND
p,p'-DDE	9.8	E4.5	54
p,p'-DDT	<5	<5	ND
cis-chlordane	<5	<5	ND
cis-nonachlor	<5	<5	ND
oxychlordane	<5	<5	ND
trans-chlordane	<5	<5	ND
trans-nonachlor	<5	<5	ND
Total PCBs	75	E49	35
Dieldrin	<5	<5	ND
Trace elements (µg/g)			
Arsenic	.4	.4	0
Cadmium	2	1.5	25
Chromium	<.5	<.5	ND
Copper	34	36	-5.9
Lead	<.3	<.3	ND
Mercury	.4	.3	25
Nickel	1	<.3	nd
Zinc	83	87	-4.8

Bed Sediment

Concentrations of *o, p'*-DDE and *o, p'*-DDT in the environmental bed-sediment sample and split replicate sample were less than the MRL at both sites (table 11). The percent difference for *p,p'*-DDT in a sample collected at Cooper River at Haddonfield, N.J., and that for *p,p'*-DDD collected at Manatawny Creek near Pottstown, Pa., (fig. 1, map locations 25 and 30) could indicate some environmental variability or greater variability in the analytical method at low concentrations. The results were not duplicated between sites, however. Differ-

Table 11. Results of quality-assurance analyses of environmental and split replicate samples for organochlorine compounds and semi-volatile organic compounds (SVOCs) in bed-sediment samples collected at Cooper River at Haddonfield, N.J., June 22, 1999, and Manatawny Creek near Pottstown, Pa., August 19, 1998.

[<, less than; E, estimated; µg/kg, micrograms per kilogram, ND, no detection in both samples; nd, no detection in one sample; PCBs, polychlorinated biphenyls]

Constituent	Cooper River at Haddonfield, N.J.			Manatawny Creek near Pottstown, Pa.		
	Environmental sample	Split replicate sample	Percent difference	Environmental sample	Split replicate sample	Percent difference
Organochlorine compounds (µg/kg)						
o,p'-DDD	E4.3	5.7	-32	<1.0	<1.0	ND
o,p'-DDE	<2.0	<2.0	ND	<1.0	<1.0	ND
o,p'-DDT	<4.0	<4.0	ND	<2.0	<2.0	ND
p,p'-DDD	E12	E17	-42	<1.0	2.2	nd
p,p'-DDE	11	15	-36	2.8	4	-43
p,p'-DDT	E5.8	18	-210	<2.0	2.4	nd
cis-chlordane	18	29	-61	<1.0	<1.0	ND
cis-nonachlor	4.5	6.5	-31	<1.0	<1.0	ND
oxychlordane	3.6	4.8	-33	<1.0	<1.1	ND
trans-chlordane	14	22	-57	<1.0	1.1	nd
trans-nonachlor	9.3	15	-61	<1.0	<1.0	ND
Total PCBs	E73	98	-34	<50	<50	ND
Dieldrin	6.1	8.1	-33	1.1	1.2	-9
SVOCs (µg/kg)						
1,2-Dimethylnaphthalene	<130	<150	ND	<50	<50	ND
1,6-Dimethylnaphthalene	E15	E22	-46.7	<50	<50	ND
1-methyl-9H-fluorene	<130	<150	ND	<50	<50	ND
1-Methylphenanthrene	E85	E92	-8.2	E12	E15	-25
1-Methylpyrene	E32	E32	0	<50	E9.2	nd
2,3,6-Trimethylnaphthalene	<130	<150	ND	<50	<50	ND
2,6-Dimethylnaphthalene	E52	E68	-30.8	65	53	18.5
2-Chloronaphthalene	<130	<150	ND	<50	<50	ND
2-Ethylnaphthalene	<130	<150	ND	<50	<50	ND
2-Methylanthracene	E52	E50	3.8	<50	E18	nd
4H-cyclopena(def)phenanthrene	E130	170	-30.8	E4.8	E11	-129
9H-Fluorene	E52	E68	-30.8	<50	<50	ND
Acenaphthylene	E64	E67	-4.7	E19	E29	-52.6
Acenapthene	E29	E44	-51.7	<50	<50	ND
Anthracene	160	180	-12.5	E27	E33	-22
Benz(a)anthracene	610	800	-31.1	81	110	-35.8
Benzo(a)pyrene	560	820	-46.4	97	120	-23.7
Benzo(b)fluoranthene	990	1,400	-41.4	94	110	-17

Table 11. Results of quality-assurance analyses of environmental and split replicate samples for organochlorine compounds and semi-volatile organic compounds (SVOCs) in bed-sediment samples collected at Cooper River at Haddonfield, N.J., June 22, 1999, and Manatawny Creek near Pottstown, Pa., August 19, 1998.—Continued

[<, less than; E, estimated; µg/kg, micrograms per kilogram, ND, no detection in both samples; nd, no detection in one sample; PCBs, polychlorinated biphenyls]

Constituent	Cooper River at Haddonfield, N.J.			Manatawny Creek near Pottstown, Pa.		
	Environmental sample	Split replicate sample	Percent difference	Environmental sample	Split replicate sample	Percent difference
Benzo(ghi)perylene	E250	E560	-124	58	72	-24.1
Benzo(k)fluoranthene	E780	1100	-41	100	120	-20
Chrysene	880	1,300	-47.7	91	140	-53.8
Dibenz(AH)anthracene	E98	200	-104	<50	<50	ND
Dibenzothiophene	E4	E11	-175	<50	<50	ND
Fluoranthene	1,500	2,200	-46.7	180	260	-44.4
Indeno(1,2,3-cd)pyrene	E320	E820	-156	66	81	-22.7
Naphthalene	<130	<150	ND	<50	<50	ND
Phenanthrene	690	920	-33.3	54	78	-44.4
Pyrene	1,200	1,700	-41.7	140	200	-42.8
bis(2-ethylhexyl)phthalate	980	1,500	-53.1	86	78	9.3
Butylbenzyl phthalate	180	230	-27.8	E29	E24	17.2
Di-n-butyl phthalate	E50	E49	2	E49	E33	32.6
P-cresol	E45	E55	-22	E40	140	-250

ences in concentrations of trace elements, except arsenic and mercury, in environmental samples and split replicate samples were less than 5 percent (table 12). The percent difference for mercury may be exaggerated as a result of the small concentrations reported. The difference between the environmental samples and replicate samples for concentrations of total PAHs was 48 percent; p-Cresol, 50 percent; and total phthalates, 49 percent.

Laboratory blank set data indicated no systematic contamination problems for any compound analyzed for except SVOCs in bed sediment, including phenol, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, di-n-butylphthalate, and diethylphthalate. Quality-control data for these analytes indicated relatively frequent low-level contamination of samples during processing for analyses. Censoring of the data required raising the MRLs for these compounds to remove false detections. In all cases the raised MRL was less than the censoring level that previously had been applied to the data. Thus the low-level laboratory contamination had no effect on study results because potentially biased data had already been removed during data censoring.

Table 12. Results of quality-assurance analyses of environmental and split replicate samples for trace elements in bed-sediment samples collected at French Creek near Phoenixville, Pa., June 24, 1999.

[µg/g, micrograms per gram]

Constituent	Environmental sample (µg/g)	Split replicate sample (µg/g)	Percent difference
Arsenic	5.6	5.3	5.4
Cadmium	.6	.6	0
Chromium	72	72	0
Copper	51	49	3.9
Lead	44	43	2.3
Mercury	.12	.1	16.7
Nickel	30	30	0
Zinc	200	200	0

Occurrence of Organic Compounds and Trace Elements

One or more organic compounds or trace elements were detected in samples collected from every site in the Delaware River Basin study unit selected for this study.

Organochlorine Compounds in Fish Tissue and Bed Sediment

Of the 33 organic compounds for which samples were analyzed by the NWQL, 17 were detected in either bed-sediment or fish-tissue samples (table 13). Ten of those constituents (DDT compounds, chlordane compounds, dieldrin, and total PCBs) were detected frequently and are discussed in this report (table 14). Three DDT compounds were not frequently detected (*o'p*-DDT, o,p'-DDE, and *o'p*-DDD) but are included in the discussion for the sake of comparison with other DDT compounds (table 14 and fig. 2). Other less-frequently detected constituents are *p,p'*-methoxychlor (detected only at Tulpehocken Creek near Bernville, Pa. (fig.1, map location 27)), heptachlor epoxide, pentachloroanisole, hexachlorobenzene, and alpha endosulfan (table 13). Aldrin, the parent product of dieldrin, was not detected at any site in the Delaware River Basin study unit. This may be indicative of the rapid transformation of aldrin into dieldrin. Data on other organochlorine compounds not reported here (listed in table 13) are published in the U.S. Geological Survey water-quality data reports for water years 1999 and 2000 (DeLuca and others, 2000, and DeLuca and others, 2001). Total DDT, total chlordane, total PCBs, and dieldrin in fish-tissue and bed-sediment samples are listed by site in appendixes 1 and 2.

One or more organochlorine compound were detected in samples from 92 percent of fish-tissue sample collection sites and in samples from 82 percent of bed-sediment sample collection sites (apps. 1 and 2). The median number of organochlorine compounds detected in fish-tissue samples from all fish-tissue sampling sites was seven, and in bed-sediment samples from all bed-sediment sampling sites was one. The greatest number compounds detected at each of two fish-tissue sites in the urban land-use category was 11, and 11 compounds also were detected at one bed-sediment site in the urban land-use category. In general, detections of organic compounds were greater in fish-tissue samples than in bed-sediment samples (fig. 2). This indicates that although many organic compounds are present in bed sediment at concentrations less than the laboratory MRL, they can bioaccumulate in fish to detectable levels.

Total DDT

Total DDT was detected frequently in fish-tissue and bed-sediment samples collected at sites in most land-use categories. There was, for both fish tissue and bed sediment, a

Table 13. Organochlorine compounds analyzed for and detected in fish-tissue and (or) bed-sediment samples collected at one or more sites in the Delaware River Basin study unit, 1998-2000.

[x, detected compound (before censoring); **X**, compound detected and used in analyses (after censoring); ND, compound not detected (before censoring); NA, not analyzed for]

Constituent	Bed sediment	Fish tissue
Aldrin	ND	ND
alpha-BHC	ND	ND
alpha-endosulfan	x	NA
beta-BHC	ND	ND
cis-Chlordane	**X**	**X**
cis-Nonachlor	**X**	**X**
cis-Permethrin	ND	NA
Chloroneb	ND	NA
DCPA	ND	ND
delta-BHC	NA	ND
Dieldrin	**X**	**X**
Endrin	ND	ND
Heptachlor	ND	ND
Heptachlor epoxide	x	x
Hexachlorobenzene	x	NA
Isodrin	ND	NA
Lindane	ND	ND
Mirex	ND	ND
o,p'- methoxychlor	ND	ND
o,p'-DDD	**X**	ND
o,p'-DDE	**X**	**X**
o,p'-DDT	ND	ND
Oxychlordane	**X**	**X**
p,p'-DDD	**X**	**X**
p,p'-DDE	**X**	**X**
p,p'-DDT	**X**	**X**
p,p'-Methoxychlor	x	x
PCBs (polychlorinated biphenyls)	**X**	**X**
Pentachloroanisole	x	x
Toxaphene	ND	ND
trans-Chlordane	**X**	**X**
trans-Nonachlor	**X**	**X**
trans-Permethrin	ND	NA

Table 14. Percent detections, minimums, medians, and maximums of organochlorine compounds and trace elements, bed-sediment and fish-tissue data, collected in the Delaware River Basin study unit, 1998-2000.

[ND, not detected; µg/kg, micrograms per kilogram; µg/g, micrograms per gram; n, number of samples]

Constituent	Percent detections at censoring level		Concentration					
			Bed sediment			Fish tissue[1]		
	Bed sediment (n=39)	Fish tissue[1] (n=25)	Minimum	Median	Maximum	Minimum	Median	Maximum
Organochlorines (µg/kg)								
o,p'-DDT	0	0	ND	ND	ND	ND	ND	ND
o,p'-DDD	8	0	ND	ND	17	ND	ND	ND
o,p'-DDE	2.5	8	ND	ND	13	ND	ND	11
p,p'-DDT	18	64	ND	ND	44	ND	8	34
p,p'-DDD	31	64	ND	ND	48	ND	7	120
p,p'-DDE	82	92	ND	2	24	ND	61	240
Total DDT	82	92	ND	2	133	ND	75	385
cis-chlordane	25	52	ND	ND	25	ND	5	120
cis-nonachlor	13	32	ND	ND	6	ND	ND	21
Oxychlordane	13	48	ND	ND	5	ND	ND	34
trans-chlordane	20.5	36	ND	ND	22	ND	ND	33
trans-nonachlor	20.5	68	ND	ND	15	ND	8	62
Total Chlordanes	25.5	72	ND	ND	73	ND	15	270
PCB	21.5	84	ND	ND	220	ND	130	890
Dieldrin	23	60	ND	ND	65	ND	12	530
Trace elements (µg/g)								
Arsenic	100	60	5.2	9.1	57	ND	.4	.6
Cadmium	97.4	75	ND	.9	12	ND	1.5	5.8
Chromium	100	10	42	72.5	190	ND	ND	.6
Copper	100	100	19	50.5	180	22	33	80
Lead	100	5	31	69	380	ND	ND	.4
Mercury	100	42	.05	.1	.7	ND	.2	.4
Nickel	100	35	12	33.5	190	ND	.2	1
Zinc	100	100	100	240	2,100	65	89.5	170

[1] Trace elements were determined in fish livers; organochlorine compounds were determined in whole fish samples.

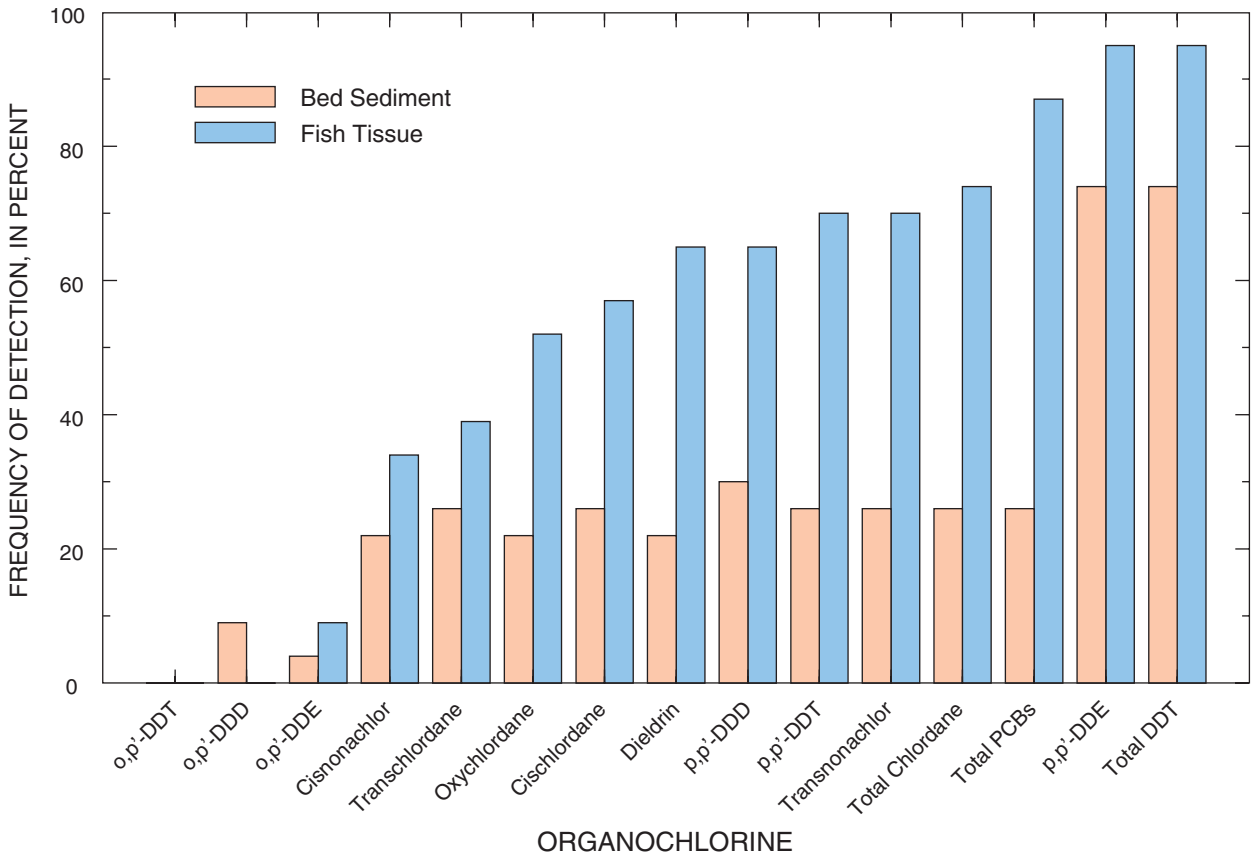

Figure 2. Frequency of detection of organic compounds in samples of whole white suckers and bed sediment from the 23 sites where both were collected, Delaware River Basin study unit, 1998-2000.

significant positive correlation between total DDT concentrations and urban land-use percent and a significant negative correlation with forest land-use percent.

Fish Tissue

In the Delaware River Basin, *p,p'*-DDE, a degradation product of DDT, was the most frequently detected DDT compound in whole white suckers (92 percent of the samples), followed by *p,p'*-DDD and *p,p'*-DDT (table 14). This is an indication that there have been few recent influxes of total DDT into the basin (Bilger and others, 1999); however, at two urban sites, Darby Creek near Darby, Pa., and South Branch Pennsauken Creek at Cherry Hill, N.J., (fig. 1, map locations 37 and 24) the ratio of *p,p*'DDE to *p,p*'DDT in whole white suckers and bed sediment indicated that there have been more recent influxes of DDT at these sites than at other sites. *P,p*'DDE was detected less frequently in bed sediment than in fish tissue, which is likely due to bioaccumulation (fig. 2).

The least frequently detected DDT compounds include *o,p'*-DDE and *o,p'*-DDD (table 14). The DDT compound *o,p'*-DDT was not detected at any site where whole white sucker samples were collected.

One or more DDT compounds were detected at 92 percent of the sites where whole white sucker samples were collected (table 14). Total DDT also was detected in 80 percent of the common carp samples and 75 percent of the bass samples. In whole white suckers, total DDT concentrations ranged from less than the censoring level to 385 μg/kg, with a median of 75 μg/kg (fig. 3). The median concentration of total DDT in common carp samples was 674 μg/kg and in smallmouth bass fillets was 14 μg/kg. Total DDT in fish-tissue samples, exceeded the NYSDEC wildlife protective guidelines of 200 μg/kg in six samples (table 15).

Total DDT detection frequencies and concentrations varied with land use. Total DDT was always detected in whole white suckers from agricultural, urban, and large-river sites (fig. 4). Sites in the agricultural and urban land-use categories and the large-river sites had the highest median concentrations (fig. 3). Total DDT was not detected at all of the sites in the low-agricultural and forest land-use categories but still was detected frequently (66 to 80 percent of the sites, respectively). The median concentrations of total DDT for these two land-use categories were lower than for other categories (fig. 3). The Kruskal-Wallis test was used to determine that there were significant differences among land-use catego-

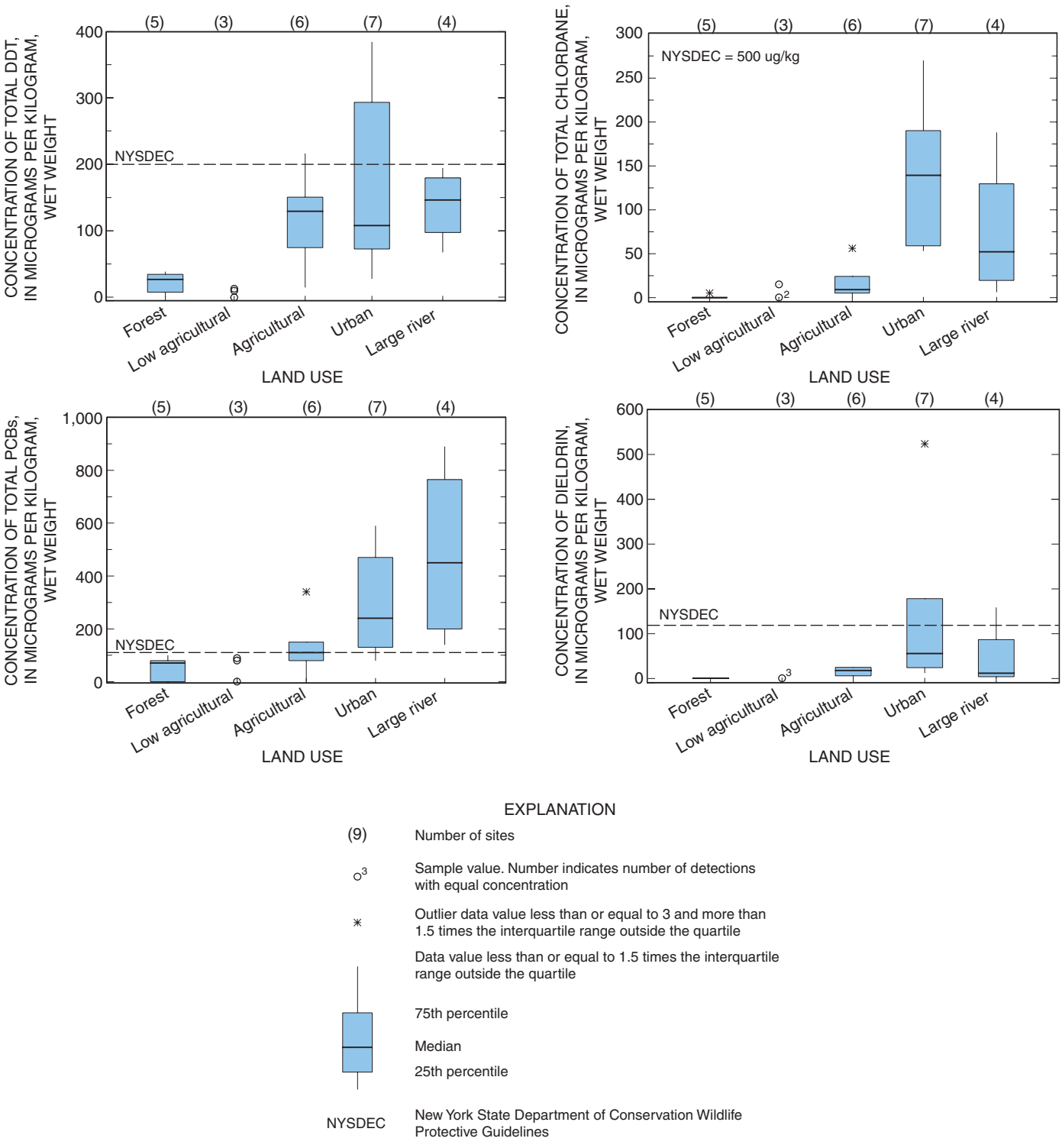

Figure 3. Relation of the concentrations of total DDT, total chlordane, total polychlorinated biphenyls (PCBs), and dieldrin in fish-tissue samples to land use, Delaware River Basin study unit, 1998-2000, with New York State Department of Environmental Conservation Wildlife Protective Guidelines. (All values below detection limit were set to zero.)

Table 15. Sites where fish tissue collected exceeded the New York State Department of Environmental Conservation Wildlife Protective Guidelines, U.S. Food and Drug Administration Action Levels for Commercial Transport and Sale of Fish, or Pennsylvania Department of Environmental Protection PCB Advisory Levels for organochlorine compounds in samples of whole white suckers, whole common carp, and smallmouth bass fillets, Delaware River Basin study unit, 1998-2000.

[µg/kg, micrograms per kilogram; PCB, polychlorinated biphenyls; NE, no exceedances]

Station name	Land-use category	Fish species	Organic compounds (µg/kg)		
			Total DDT	Total PCBs	Dieldrin
West Branch Delaware River at Walton, N.Y.	Low agricultural	Whole white sucker	NE	80[c]	NE
Delaware River at Port Jervis, N.Y.	Large river	Whole white sucker	NE	140[a,c]	NE
Neversink River at Godeffroy, N.Y.	Forest	Whole white sucker	NE	80[c]	NE
Flat Brook near Flatbrookville, N.J.	Forest	Whole white sucker	NE	70[c]	NE
Brodhead Creek at Stroudsburg, Pa.	Forest	Whole white sucker	NE	100[c]	NE
Little Lehigh Creek at East Texas, Pa.	Agricultural	Whole white sucker	NE	150[a,c]	NE
Lehigh River at Glendon, Pa.	Large river	Whole common carp	NE	900[a,c]	NE
Lehigh River at Glendon, Pa.	Large river	Smallmouth bass fillet	NE	80[c]	NE
Lehigh River at Glendon, Pa.	Large river	Whole white sucker	NE	640[a,c]	NE
Delaware River at Trenton, N.J.	Large river	Whole common carp	423[a]	1100[a,c]	NE
Delaware River at Trenton, N.J.	Large river	Smallmouth bass fillet	NE	370[a,c]	NE
Delaware River at Trenton, N.J.	Large river	Whole white sucker	NE	260[a,c]	NE
Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	Urban	Whole common carp	360[a]	570[a,c]	NE
Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	Urban	Whole white sucker	NE	240[a,c]	NE
Pennypack Creek at Paper Mill, Pa.	Urban	Whole white sucker	NE	130[a,c]	NE
South Branch Pennsauken Creek at Cherry Hill, N.J.	Urban	Whole white sucker	294[a]	200[a,c]	180[a]
Cooper River at Haddonfield, N.J.	Urban	Whole common carp	NE	320[a,c]	NE
Cooper River at Haddonfield, N.J.	Urban	Whole white sucker	385[a]	590[a,c]	NE
Tulpehocken Creek near Bernville, Pa.	Agricultural	Whole white sucker	NE	130[a,c]	NE
Wyomissing Creek at West Reading, Pa.	Urban	Whole white sucker	NE	80[c]	NE
Hay Creek near Birdsboro, Pa.	Low agricultural	Whole white sucker	NE	90[c]	NE
Manatawny Creek near Pottstown, Pa.	Agricultural	Whole white sucker	NE	340[a,c]	NE
French Creek near Phoenixville, Pa.	Agricultural	Whole white sucker	NE	80[c]	NE
Wissahickon Creek below Walnut Lake near Manayunk, Pa.	Urban	Whole white sucker	NE	470[a,c]	120[a]
Schuylkill River at Philadelphia, Pa.	Large river	Whole common carp	950[a]	4000[a,c]	NE
Schuylkill River at Philadelphia, Pa.	Large river	Smallmouth bass fillet	NE	250[a,c]	NE
Schuylkill River at Philadelphia, Pa.	Large river	Whole white sucker	NE	890[a,c]	160[a]
Darby Creek near Darby, Pa.	Urban	Whole white sucker	NE	360[a,c]	530[a,b]
Raccoon Creek near Swedesboro, N.J.	Agricultural	Whole white sucker	217[a]	90[c]	NE

[a] New York State Department of Environmental Conservation Wildlife Protective Guidelines

[b] U.S. Food and Drug Administration Action Levels for Commercial Transportation and Sale of Fish (for reference only, advisory levels are for edible portions.)

[c] Pennsylvania Department of Environmental Protection PCB Advisory Levels (for reference only in whole white suckers and whole common carp, advisory levels are for edible portions.)

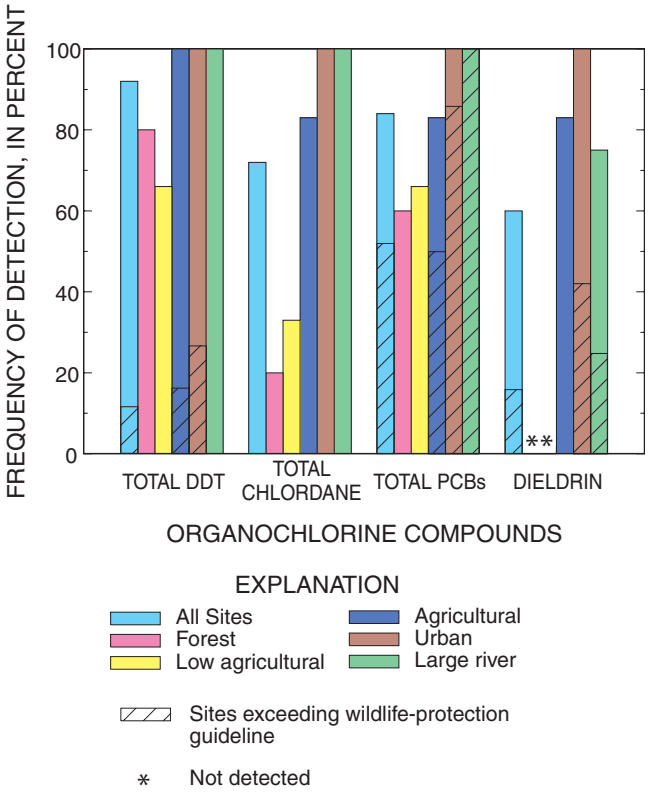

Figure 4. Frequency of detection of total DDT, total chlordane, total polychlorinated biphenyls (PCBs), and dieldrin in fish-tissue samples by land use, Delaware River Basin study unit, 1998-2000, with New York State Department of Environmental Conservation Wildlife Protective Guidelines.

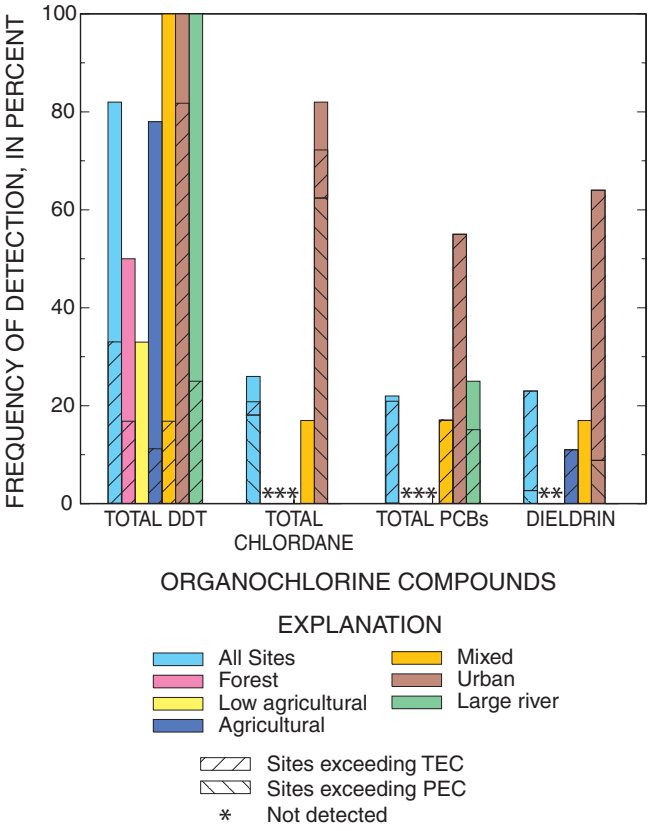

Figure 5. Frequency of detection of total DDT, total chlordane, total polychlorinated biphenyls (PCBs), and dieldrin in bed-sediment samples by land use, Delaware River Basin study unit, 1998-2000, with Consensus-Based Sediment Quality Guidelines Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC).

ries (p = .0078), and results of the multiple comparison test indicated that the mean rank of concentrations for the sites in agricultural and urban land-use categories, as well as large-river sites, were statistically different from those in the low agricultural and forest land-use categories. Supporting that, Spearman's rank correlation indicated that concentrations in whole white suckers had a significant positive correlation with urban land-use percent and a significant negative correlation with the forest land-use percent (table 16).

Two white sucker samples from sites in the urban land-use category and one white sucker sample in the agricultural land-use category contained concentrations of total DDT that exceeded the NYSDEC wildlife protective guidelines (table 15). Concentrations in one common carp sample from the urban land-use category and three common carp samples collected at large-river sites also exceeded this guideline (table 15). None of the smallmouth bass samples collected at three large-river sites contained concentrations of total DDT that exceeded the USFDA action levels for human consumption.

Bed Sediment

Total DDT was detected in samples from 82 percent of the sites where bed sediment was collected (fig. 5). Concentrations ranged from less than the censoring level to 133 µg/kg, with a median of 2 µg/kg (table 14). Total DDT in bed sediment from 33 percent of the sites exceeded the Consensus-Based SQG TEC (fig. 5).

As in the fish-tissue data, *p,p'*-DDE was the most frequently detected DDT compound in bed sediment, followed by *p,p'*-DDD and *p,p'*-DDT (fig. 2). The least frequently detected DDT compounds were *o,p'*-DDE, *o,p'*-DDD, and *o,p'*-DDT (fig. 2).

Total DDT was always detected in bed-sediment samples from urban, mixed, and large-river sites (fig. 5). Agricultural sites had a 78-percent detection rate. Agricultural, urban, and large-river sites also had the highest median concentrations (fig. 6). Total DDT was detected less frequently, and with lower median concentrations, at sites in low-agricultural and forest land-use categories (fig. 6).

Table 16. Results of Spearman's rank correlation test on relation of concentrations of organochlorine compounds in whole white suckers and trace elements in white sucker livers to land-use percent and population density, Delaware River Basin study area, 1998-2000.

[Large-river sites not included; blue indicates statistically significant values; PCBs, polychlorinated biphenyls]

Constituent	Urban land use (in percent)		Agricultural land use (in percent)		Forest land use (in percent)		Population density	
	Spearman's rho	p-value	Spearman's rho	p-value	Spearman's rho	p-value	Spearman's rho	p-value
Organochlorine compounds								
Total DDT	0.6623	0.0031	0.4163	0.063	-0.6865	0.0021	0.3423	0.1265
Total Chlordanes	.8086	.0003	.1841	.4119	-.6765	.0025	.7021	.0017
PCBs	.7271	.0021	.1648	.4628	-.5690	.0108	.6677	.0028
Dieldrin	.8197	.0002	.2063	.3577	-.7549	.0007	.6081	.0066
Trace elements								
Arsenic	-.3430	.1821	.3491	.1782	.0063	.9849	-.4443	.0842
Cadmium	-.3843	.1351	-.3767	.1430	.4591	.0763	-.3723	.1477
Chromium	-.3402	.1856	-.1508	.5553	.3246	.2106	-.3400	.1860
Copper	.2945	.2563	.3399	.1899	-.4930	.0555	.2693	.2996
Lead	.1961	.4508	.1400	.5915	-.0280	.9091	.1400	.5915
Mercury	-.3079	.2465	-.5768	.0304	.5749	.0320	-.0922	.7248
Nickel	-.4508	.0798	.2797	.2812	-.0845	.7390	-.5204	.0432
Zinc	.2160	.4059	.3124	.2284	-.4952	.0544	.1046	.6895

Median total DDT concentrations in bed sediment were considerably higher for sites in the urban category than any other land-use category (fig. 6). In other land-use categories, the median concentrations gradually decreased from highest at large-river sites through mixed and agricultural land use sites, and were lowest at forest and low-agricultural sites (fig. 6). The exceedances of the SQG TEC occurred at sites in the urban, agricultural, forest, and mixed land-use categories and one large-river site (fig. 5 and table 17). Notably, the urban land-use category accounted for more than 80 percent of the detections of total DDT greater than the SQG TEC; there were no exceedances of the PEC at any sites (fig. 5).

Results of the Kruskal-Wallis test indicated there was a significant difference for concentrations of total DDT between land-use categories ($p = 0.0009$), and the multiple comparison test indicated that concentrations of total DDT in samples from the urban land-use category were significantly different from those from all other land-use categories. Similar results were demonstrated by Spearman's rank correlation; total DDT concentrations in bed sediment had a significant positive correlation with urban land-use percent and had a significant negative correlation with forest land-use percent (table 18). Concentrations in bed sediment of total DDT and population density showed a significant positive correlation.

Total Chlordanes

Total chlordanes were detected most frequently in fish tissue and bed sediment from sites in the urban land-use category. In both fish tissue and bed sediment, significant positive correlations were indicated between the concentrations of total chlordanes and urban land-use percent and significant negative correlations between total chlordanes and forest land-use percent.

Fish Tissue

Total chlordanes were detected in samples from 72 percent of the sites where whole white suckers were collected (fig. 4). The most frequently detected chlordane compounds were *trans*-nonachlor and *cis*-chlordane, which signifies that chlordane degradation is taking place and few recent influxes of chlordane into the basin have occurred (Bilger and others, 1999). Total chlordanes concentrations in whole white suckers ranged from less than the censoring level to 270 μg/kg, with a median of 15 μg/kg (table 14). The median concentration in common carp was 149 μg/kg and in smallmouth bass was less than the censoring level. No exceedances of the NYSDEC wildlife protective guidelines or USFDA Action Levels were observed for any site where whole fish or fillet samples were collected.

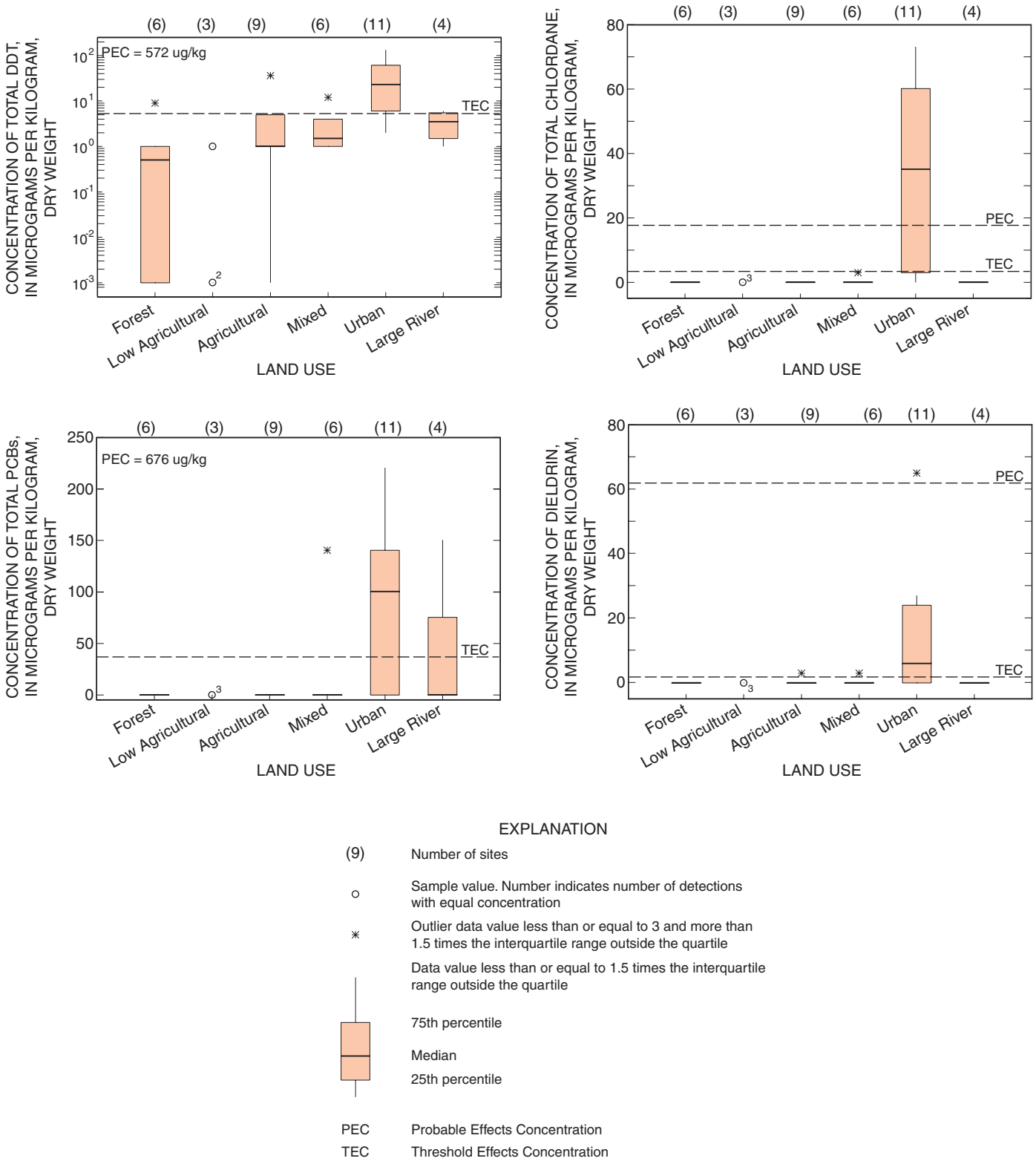

Figure 6. Relation of the concentrations of total DDT, total chlordane, total polychlorinated biphenyls (PCBs), and dieldrin in bed-sediment samples to land use, Delaware River Basin study unit, 1998-2000, with Consensus-Based Sediment Quality Guidelines Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC).

Table 17. Exceedances of Consensus-Based Sediment Quality Guidelines Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC) for organic compounds and trace elements in bed sediment, Delaware River Basin study unit, 1998-2000.

[NE, no exceedance; µg/kg, micrograms per kilogram; µg/g, micrograms per gram; PCBs, polychlorinated biphenyls; PAH, polycyclic aromatic hydrocarbons; As, arsenic; Cd, cadmium; Cr, chromium; Cu, copper; Pb, lead; Hg, mercury; Ni, nickel; Zn, zinc; values in **bold** indicate exceedances of PEC; Consensus-Based Sediment Quality Guidelines from MacDonald and others, 2000]

Station name	Land-use category	Organic compounds (µg/kg)					Trace elements (µg/g)							
		Total DDT	Total chlordanes	Total PCBs	Dieldrin	Total PAHs	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
West Branch Delaware River at Walton, N.Y.	Low agricultural	NE	NE	NE	NE	**107,090**	15	NE	66	**150**	92	NE	32	340
Lackawaxen River at Hawley, Pa.	Low agricultural	NE	NE	NE	NE	2,450	NE	1.6	52	34	80	NE	NE	190
Delaware River at Port Jervis, N.Y.	Large river	NE	NE	NE	NE	5,960	12	1	55	33	56	NE	32	240
Neversink River at Claryville, N.Y.	Forest	NE	NE	NE	NE	NE	NE	NE	44	NE	42	NE	NE	160
Neversink River at Godeffroy, N.Y.	Forest	NE	NE	NE	NE	5,980	NE	1.6	NE	43	77	NE	NE	320
Flat Brook near Flatbrookville, N.J.	Forest	NE	NE	NE	NE	NE	NE	1.1	**150**	64	67	NE	34	430
Brodhead Creek at Minisink Hills, Pa.	Forest	NE	NE	NE	NE	NE	NE	1	63	48	66	NE	27	280
Lehigh River at Lehighton, Pa.	Forest	9	NE	NE	NE	**34,390**	21	**6.3**	78	**180**	**170**	NE	**180**	**1,600**
Little Lehigh Creek at East Texas, Pa.	Agricultural	NE	NE	NE	NE	NE	14	NE	74	38	50	NE	47	200
Cedar Creek above Lake Muhlenberg at Allentown, Pa.	Urban	11	NE	NE	NE	13,120	12	1	70	62	96	.28	36	300
Jordan Creek near Schnecksville, Pa.	Agricultural	NE	NE	NE	NE	3,990	NE	NE	70	38	40	NE	33	190
Monocacy Creek at Bethlehem, Pa.	Mixed	NE	NE	NE	NE	15,840	NE	NE	63	50	62	NE	33	240
Lehigh River at Glendon, Pa.	Large river	NE	NE	NE	NE	12,270	13	**12**	97	98	**150**	.23	**63**	**2,100**
Pidcock Creek near New Hope, Pa.	Agricultural	NE	NE	NE	NE	NE	11	NE	72	36	NE	NE	30	NE
Delaware River at Trenton, N.J.	Large river	6	NE	NE	NE	8,240	13	4.4	84	61	110	.23	47	**910**
Shabakunk Creek near Lawrenceville, N.J.	Urban	97	35	220	12	**37,390**	NE	1.5	78	82	**210**	.21	32	400
Pine Run at Chalfont, Pa.	Mixed	NE	NE	NE	NE	1,980	NE	NE	79	34	42	NE	32	150
Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	Urban	NE	NE	100	NE	2,050	NE	NE	72	59	47	NE	29	160
North Branch Rancocas Creek at Pemberton, N.J.	Mixed	12	NE	NE	NE	NE	13	NE	57	60	**160**	.23	NE	NE
Pennypack Creek at Paper Mill, Pa.	Urban	7	16	130	5	15,360	NE	1	66	55	71	NE	24	270
South Branch Pennsauken Creek at Cherry Hill, N.J.	Urban	133	63	NE	24	**32,810**	**33**	2.2	**140**	76	120	.26	36	**480**
Cooper River at Haddonfield, N.J.	Urban	29	49	NE	6	8,070	**57**	3	**150**	69	**180**	.34	43	**480**
Schuylkill River at Berne, Pa.	Mixed	NE	NE	140	NE	4,400	16	2.2	66	85	**380**	.25	**190**	**810**
Tulpehocken Creek near Bernville, Pa.	Agricultural	NE	NE	NE	NE	NE	27	NE	69	32	38	NE	35	150
Wyomissing Creek at West Reading, Pa.	Urban	61	42	220	NE	**38,320**	NE	1.2	88	110	**160**	.69	43	380
Hay Creek near Birdsboro, Pa.	Low agricultural	NE	NE	NE	NE	3,070	10	NE	63	48	47	NE	39	170

Table 17. Exceedances of Consensus-Based Sediment Quality Guidelines Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC) for organic compounds and trace elements in bed sediment, Delaware River Basin study unit, 1998-2000.—Continued

[NE, no exceedance; µg/kg, micrograms per kilogram; µg/g, micrograms per gram; PCBs, polychlorinated biphenyls; PAH, polycyclic aromatic hydrocarbons; As, arsenic; Cd, cadmium; Cr, chromium; Cu, copper; Pb, lead; Hg, mercury; Ni, nickel; Zn, zinc; values in **bold** indicate exceedances of PEC; Consensus-Based Sediment Quality Guidelines from MacDonald and others, 2000]

Station name	Land-use category	Organic compounds (µg/kg)					Trace elements (µg/g)							
		Total DDT	Total chlordanes	Total PCBs	Dieldrin	Total PAHs	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Manatawny Creek near Pottstown, Pa.	Agricultural	NE	NE	NE	NE	NE	NE	NE	73	40	45	NE	29	170
Pigeon Creek near Parker Ford, Pa.	Agricultural	NE	NE	NE	NE	NE	NE	NE	67	NE	38	NE	30	NE
French Creek near Phoenixville, Pa.	Agricultural	NE	NE	NE	NE	NE	NE	NE	72	51	44	NE	30	200
Stony Creek at Steriger Street at Norristown, Pa.	Urban	NE	NE	NE	NE	15,800	NE	NE	75	42	90	NE	30	220
Wissahickon Creek below Walnut Lake near Manayunk, Pa.	Urban	43	60	100	27	25,340	NE	1.1	85	130	170	.56	39	340
Schuylkill River at Philadelphia, Pa.	Large river	NE	NE	150	NE	9,870	13	1.7	130	110	150	NE	92	610
Darby Creek at Foxcroft, Pa.	Urban	6	34	NE	14	14,860	NE	NE	170	53	77	.36	96	230
Darby Creek near Darby, Pa.	Urban	23	73	140	65	48,550	10	1.9	100	95	160	.46	48	420
Crum Creek at Goshen Road near Whitehorse, Pa.	Mixed	NE	NE	NE	3	4,840	NE	NE	120	36	51	NE	77	200
Ridley Creek near Media, Pa.	Mixed	NE	NE	NE	NE	3,520	NE	NE	140	42	46	NE	100	160
Raccoon Creek near Swedesboro, N.J.	Agricultural	36	NE	NE	3	NE	42	2.7	190	36	55	NE	42	300
East Branch Brandywine Creek near Dorlan, Pa.	Agricultural	NE	NE	NE	NE	NE	NE	NE	72	NE	49	NE	28	170

Table 18. Results of Spearman's rank correlation test on relation of concentrations of organic compounds and trace elements in bed-sediment samples to percent land use and population density, Delaware River Basin study unit, 1998-2000.

[Large-river sites not included; orange indicates statistically significant values]

Constituent	Urban land use (in percent)		Agricultural land use (in percent)		Forest land use (in percent)		Population density	
	Spearman's rho	p-value	Spearman's rho	p-value	Spearman's rho	p-value	Spearman's rho	p-value
Organochlorine compounds								
Total DDT	0.7488	0	-0.077	0.6527	-0.5782	0.0007	0.6	0.005
Total Chlordanes	.7594	.0000	-.2991	.0809	-.4437	.0096	.4953	.0039
PCBs	.4841	.0048	-.1941	.2573	-.2330	.1740	.5751	.0008
Dieldrin	.6691	.0001	-.2915	.0890	-.4052	.0181	.4050	.0182
Semi-volatile organic compounds								
Total PAHs	.6036	.0004	-.2824	.0994	-.2639	.1235	.6584	.0001
Total Phthalates	.7342	.0000	-.3612	.0351	-.3182	.0634	.6886	.0001
p-Cresol	.0776	.6575	-.3554	.0381	.1903	.2673	.3049	.0755
Trace elements								
Arsenic	.0157	.9286	-.0161	.9255	-.1904	.2734	.0842	.6291
Cadmium	.2813	.1062	-.5377	.0020	-.0001	.9986	.5556	.0014
Chromium	.4406	.0114	.0251	.8857	-.3241	.0624	.0537	.7583
Copper	.4136	.0175	-.4845	.0054	-.0219	.8990	.6581	.0002
Lead	.5226	.0027	-.5561	.0014	-.0587	.7352	.7722	.0000
Mercury	.3329	.0559	-.5819	.0008	.0746	.6688	.4559	.0088
Nickel	.2856	.1010	.0723	.6782	-.1777	.3068	.1664	.3393
Zinc	.3553	.0413	-.4556	.0088	-.0481	.7815	.5309	.0023

Total chlordanes detections and median concentrations were highest in the urban land-use category and at large-river sites. Total chlordanes were detected at all sites in the urban land-use category and large-river sites where whole white sucker samples were collected. It was detected least often and had the lowest median concentration at forest and low-agricultural land-use sites (figs. 3 and 4). Results of the Kruskal-Wallis test indicated that there were significant differences among land uses (p = 0.0013), and the multiple comparison test indicated that the mean rank of concentrations in whole white sucker samples from urban land-use sites and large-river sites were statistically different from those from the agricultural, low-agricultural, and forest land-use sites. Results of Spearman's rank correlation showed significant positive correlations between total chlordanes concentrations and urban land-use percent, and population density for whole white suckers (table 16). A significant negative correlation was demonstrated between total chlordanes concentrations and forest land-use percent (table 16).

Bed Sediment

Total chlordanes were detected in samples from 26 percent of the sites sampled for bed sediment (fig.5). The most frequently detected chlordane compounds were *cis*-chlordane, *trans*-chlordane, and *trans*-nonachlor. Concentrations ranged from less than the censoring level to 73 μg/kg, with a median less than the censoring level (fig. 6). The SQG TEC and PEC were exceeded at 21 percent and 18 percent of the sites sampled, respectively (fig. 5).

In bed sediment, total chlordanes were detected only at sites in the mixed and the urban land-use categories (fig. 5). The median concentration was less than the censoring level for the sites in the mixed land-use category and was 35 μg/kg for the sites in the urban land-use category. Sites in the urban land-use category had the largest number of exceedances of both the SQG TEC and PEC, 73 and 63 percent, respectively (fig. 5). Kruskal-Wallis results indicated that there was a difference between concentrations by land-use category (p = 0.0001), and further testing showed that the mean rank of concentrations for the urban land-use category was significantly different from that of all other land-use categories. Spearman's rank correlation results showed significant

positive correlations between total chlordanes concentrations in bed sediment and urban land-use percent and population density (table 18). A significant negative correlation was demonstrated between total chlordanes and forest land-use percent (table 18).

Total Polychlorinated Biphenyls

Total PCBs in fish tissue were detected frequently in samples from sites in all land-use categories and most frequently in bed sediment at sites in mixed and urban land-use categories and large-river sites. For fish-tissue and bed-sediment samples, there was a significant positive correlation between concentrations of total PCBs and urban land-use percent.

Fish Tissue

Total PCBs were detected in fish-tissue samples from 84 percent of sites where whole white sucker samples were collected (fig. 4). Total PCB concentrations in whole white suckers ranged from less than the censoring level to 890 μg/kg, with a median concentration of 130 μg/kg (table 14). The median concentration of total PCBs in common carp was 900 μg/kg, and in smallmouth bass was 250 μg/kg. Total PCBs exceeded the NYSDEC wildlife protective guideline in 20 fish-tissue samples (table 15). Three smallmouth bass fillets contained concentrations high enough to have eating restrictions according to the PaDEP PCB Advisory Levels for edible portions (table 8).

Total PCBs in whole white suckers were detected in samples from 60 percent or more of the sites in each land-use category (fig. 4). They were always detected at sites in the urban land-use category and at large-river sites, which also had the highest median concentrations (fig. 3). Concentrations in samples from all four of the large-river sites exceeded the NYSDEC wildlife protective guidelines, as did those from 86 percent of the sites in the urban land-use category and 50 percent of the sites from the agricultural land-use category. Results of the Kruskal-Wallis test indicated a difference among land uses ($p = 0.0072$), and further testing showed that the mean rank of concentrations for sites in the urban land-use category and large-river sites were statistically different from that of the sites in the low-agricultural and forest land-use categories. Spearman's rank correlation analysis further showed that for whole white suckers a significant positive correlation occurred between total PCB concentrations and urban land-use percent, and population density (table 16). For whole white suckers, a significant negative correlation was determined between total PCBs and forest land-use percent.

Bed Sediment

Total PCBs were detected in samples from 22 percent of sites where bed sediment was collected (table 14). Concentrations ranged from less than the censoring level to 220 μg/kg, with a median concentration less than the censoring level (table 14). Concentrations of total PCBs exceeded the SQG TEC at 21 percent of the sites (fig. 5).

Total PCBs were not detected at sites in the forest, low-agricultural, or agricultural land-use categories (fig. 5). Total PCBs were, however, detected at sites in the mixed and urban land-use categories and at large-river sites. Except for the urban land-use sites, median concentrations at all other land-use sites were less than the censoring level (fig. 6). Concentrations in samples from 55 percent of the sites in the urban land-use category, one large-river site, and one site in the mixed land-use category exceeded the SQG TEC (fig. 5 and table 17). Kruskal-Wallis results indicated that there was a difference between land-use categories ($p = 0.0379$), and the multiple comparison test showed that the mean rank of concentrations for the urban land-use category were significantly different from that of the agricultural and forest land-use categories. Spearman's rank correlation analysis further showed that for bed sediment there was a significant positive correlation between total PCB concentrations and urban land-use percent, and population density (table 18).

Dieldrin

Sites in the urban land-use category, had the most detections of dieldrin in fish-tissue and bed-sediment samples. For both fish tissue and bed sediment, there was a significant positive correlation between dieldrin concentrations and urban land-use percent, and a negative correlation with forest land-use percent.

Fish Tissue

Dieldrin was detected in samples from 60 percent of the sites where whole white sucker samples were collected (fig. 4). Concentrations ranged from less than the detection limit to 530 μg/kg, with a median concentration of 12 μg/kg. The median concentration of dieldrin in common carp was 13 μg/kg and in smallmouth bass was less than the censoring level. Concentrations of dieldrin exceeded the NYSDEC wildlife protective guideline in five fish-tissue samples (table 15).

Sites in the urban land-use category had the most detections and highest median concentrations of dieldrin in whole white suckers (figs. 3 and 4). Concentrations of dieldrin exceeded the NYSDEC wildlife protective guidelines at 43 percent of the urban sites (fig. 4). The agricultural land-use category had the second highest detection frequency and median concentration; however, no exceedances of the NYDEC wildlife protective guidelines were observed. Results of the Kruskal-Wallis test indicated that there was a difference among land uses ($p = 0.0024$), and further testing showed that the mean rank of concentrations for the forest land-use category was significantly different from that for the agricultural and urban land-use categories, and the large-river sites. Also, the mean rank of concentrations for the low-agricultural land-use category was significantly different from that for the urban land-use category. Results of Spearman's rank correla-

tion analysis indicated that in fish tissue there was a significant positive correlation between dieldrin concentrations and urban land-use percent, and population density (table 16). A significant negative correlation between dieldrin concentrations and forest land-use percent was observed (table 16).

Bed Sediment

Dieldrin was detected at 23 percent of the sites where bed-sediment samples were collected (fig. 5). Concentrations ranged from less than the censoring level to 65 µg/kg, with a median concentration less than the censoring level (fig. 6). Dieldrin concentrations exceeded the SQG TEC at 23 percent of the sites sampled for bed sediment and exceeded the PEC at 2.5 percent of the sites (fig. 5).

Dieldrin was not detected in any bed-sediment sample from the forest or low-agricultural land-use categories, or from any of the large-river sites (fig. 6). The urban land-use category had the highest detections and median concentrations in bed-sediment samples (figs. 5 and 6). Concentrations at 64 percent of the sites in the urban land-use category exceeded the SQG TEC, as did the concentrations at one site in the agricultural land-use category and one site in the mixed land-use category (table 17). Also, concentrations in samples from Darby Creek near Darby, Pa., (fig. 1, map location 37) an urban site, exceeded the SQG PEC (table 17). Results of the Kruskal-Wallis test indicated that there was a difference among land-use categories ($p = 0.0061$), and further testing showed that the mean rank of concentrations of the urban land-use category was significantly different from that of all other land-use categories and large-river sites. Spearman's rank correlation results indicated that for bed-sediment samples there were significant positive correlations between dieldrin concentrations and urban land-use percent, and population density (table 18). Also a significant negative correlation was observed between concentrations and forest land-use percent (table 18).

Semi-Volatile Organic Compounds in Bed Sediment

Of the 66 SVOC compounds analyzed for in bed sediment, 51 were detected before censoring (table 19). Thirty-eight of the detected SVOCs were total PAHs, total phthalates, or phenols, and after censoring, 26 were statistically evaluated in this study (table 19). The remaining 12 detected SVOCs are categorized as chloro-aromatics, azaarenes, nitro-aromatics, chloro-ethers, nitro-amines, quinones, bromo-ethers, and other SVOCs (table 19). Anthraquinone, carbazole, and acridine were detected most frequently after censoring (at 64, 41, and 10 percent, of the sites, respectively). Every site sampled had at least one or more detection of a PAH, phthalate, or phenol. The highest number of detections per site for total PAHs, total phthalates, and phenols combined was 24. The most frequently detected PAHs were pyrene, fluoranthene, and benzo(b)fluoranthene (fig. 7). The most frequently detected phthalate was bis(2-ethylhexyl)phthalate; *p*-cresol was the most frequently detected phenol (table 20). Data on other SVOCs not reported here (listed in table 19) are published in the U.S. Geological Survey water resources data reports on water quality for water years 1999 and 2000 (DeLuca and others, 2000, and DeLuca and others, 2001). Total PAHs, total phthalates, and phenol in bed-sediment samples are listed by site in appendix 3.

Total Polycyclic Aromatic Hydrocarbons

Eight PAH compounds were detected in bed sediment samples from more than 75 percent of the sites (fig. 7). Four compounds were detected at 50 to 75 percent of the sites, and five compounds were not detected at any site (table 4b). The most frequently detected PAH compound was pyrene, which was detected in 87 percent of the samples. Total PAH concentrations ranged from less than the censoring level to 107,090 µg/kg, with a median concentration of 4,400 µg/kg (fig. 8). Total PAHs exceeded the SQG TEC at 67 percent of the sites sampled and the PEC at 18 percent of sites sampled (fig. 9).

Total PAHs were detected in 90 percent of bed-sediment samples collected (fig. 9). They were detected at 100 percent of the sites in all land-use categories, except for the agricultural land-use category where it was detected only at 55 percent of the sites. Median concentrations were highest in the urban land-use category and at large-river sites, followed by the mixed, low-agricultural, and forest land-use categories (fig. 8). The lowest median concentration, 440 µg/kg, was present in a bed-sediment sample from the agricultural land-use category. The highest concentration of total PAHs was present in a sample from a low-agricultural land-use site. The SQG TEC was exceeded at some sites in all land-use categories (table 17). This includes 11 percent of the agricultural, 33 percent of the forest, 83 percent of the mixed, 100 percent of the low-agricultural, and 100 percent of the urban sites (fig. 9). The PEC was exceeded at 17 percent of forest, 33 percent of low-agricultural, and 45 percent of urban sites (fig. 9). Results of the Kruskal-Wallis test indicated that there was a difference between land-use categories ($p = 0.0004$). Further analysis showed that the mean rank of concentrations from the agricultural land-use category was significantly different from that of all other land-use categories. The mean rank of concentrations for the urban land-use category also was significantly different from that of the forest and mixed land-use categories. Spearman's rank correlation results indicated a significant positive correlation between total PAH concentration and urban land-use percent, and population density (table 18).

Further study shows that concentrations of individual PAHs that were detected at more than 18 percent of the sites sampled, with the exception of acenaphthylene which was detected at 38 percent of the sites, were statistically related to urban land-use percent and impervious surface percent. Spearman's rank correlation indicated that concentrations of

Table 19. Semi-volatile organic compounds (SVOCs) analyzed for and detected in bed-sediment samples from one or more sites in the Delaware River Basin study unit, 1998-2000.

[x, detected compound (before censoring); **X**, compound detected and used in analyses (after censoring); ND, compound not detected; * not analyzed statistically in this report]

Constituent	Bed sediment
Polycyclic aromatic hydrocarbons	
1,2-Dimethylnaphthalene	x
1,6-Dimethylnaphthalene	x
1-Methyl-9H-fluorene	x
1-Methylphenanthrene	**X**
1-Methylpyrene	**X**
2,3,6-Trimethylnaphthalene	x
2,6-Dimethylnaphthalene	**X**
2-Ethylnaphthalene	x
2-Methylanthracene	**X**
4H-cyclopenta(def)phenanthrene	**X**
9H-Fluorene	**X**
Acenaphthylene	**X**
Acenapthene	**X**
Anthracene	**X**
Benz(a)anthracene	**X**
Benzo(a)pyrene	**X**
Benzo(b)fluoranthene	**X**
Benzo(ghi)perylene	**X**
Benzo(k)fluoranthene	**X**
Chrysene	**X**
Dibenzothiophene	**X**
Fluoranthene	**X**
Indeno(1,2,3-cd)pyrene	**X**
Naphthalene	**X**
Phenanthrene	**X**
Pyrene	**X**
Dibenz(ah)anthracene	**X**
Phthalates	
bis(2-Ethylhexyl) phthalate	**X**
Butylbenzyl phthalate	**X**
Diethyl phthalate	x
Dimethyl phthalate	x
Di-n-butyl phthalate	**X**
Di-n-octyl phthalate	x
Nitro-amines*	
N-Nitrosodi-n-propyamine	ND
N-Nitrosodiphenylamine	x

Constituent	Bed sediment
Phenols	
2,4,6-Trichlorophenol	x
2-Chlorophenol	ND
3,5-Dimethylphenol	x
4-Chloro-3-methylphenol	ND
p-Cresol	**X**
Pentachlorophenol	x
Phenol	x
Chloro-aromatics*	
1,2,4-Trichlorobenzene	ND
1,2-Dichlorobenzene	ND
1,3-Dichlorobenzene	x
1,4-Dichlorobenzene	x
2-Chloronaphthalene	ND
Pentachloronitrobenzene	ND
Nitro-aromatics*	
2,4-Dinitrotoluene	ND
2,6-Dinitrotoluene	ND
Azobenzene	x
Nitrobenzene	ND
Azaarenes*	
2,2’-Biquinoline	x
Acridine	x
Benzo[c]cinnoline	x
Isoquinoline	x
Phenanthridine	x
Quinoline	x
Quinones*	
Anthraquinone	x
Chloro-ethers*	
bis(2-chloroethoxy)methane	ND
4-Chlorophenyl-phenylether	ND
Bromo-ethers*	
4-Bromophenyl-phenylether	ND
Other SVOCs*	
3’5-Xylenol	x
bis(2-chloroethyl)ether	ND
Carbazole	x
Isophorone	ND

Table 20. Percent detections, minimum, median, and maximum of semi-volatile organic compounds in bed-sediment data, collected at 39 sites in the Delaware River Basin study unit, 1998-2000.

[All concentrations in micrograms per kilogram, dry weight; ND, not detected]

Constituent	Percent detection at censoring level	Concentrations		
		Minimum	Median	Maximum
Polycyclic aromatic hydrocarbons				
1,2-Dimethylnaphthalene	0	ND	ND	ND
1,6-Dimethylnaphthalene	0	ND	ND	ND
1-methyl-9H-fluorene	0	ND	ND	ND
1-Methylphenanthrene	28.2	ND	ND	670
1-Methylpyrene	10.2	ND	ND	420
2,3,6-Trimethylnaphthalene	0	ND	ND	ND
2,6-Dimethylnaphthalene	17.9	ND	ND	330
2-Ethylnaphthalene	0	ND	ND	ND
2-Methylanthracene	20.5	ND	ND	330
4H-cyclopenta(def)phenanthrene	41.0	ND	ND	1,600
9H-Fluorene	23.1	ND	ND	990
Acenaphthylene	38.5	ND	ND	340
Acenapthene	15.4	ND	ND	1,200
Anthracene	53.8	ND	120	2,000
Benz(a)anthracene	71.8	ND	360	7,900
Benzo(a)pyrene	76.9	ND	350	7,400
Benzo(b)fluoranthene	84.6	ND	380	6,500
Benzo(ghi)perylene	66.7	ND	180	4,800
Benzo(k)fluoranthene	82.0	ND	320	7,100
Chrysene	82.0	ND	420	8,300
Dibenz(AH)anthracene	33.3	ND	ND	1,200
Dibenzothiophene	12.8	ND	ND	730
Fluoranthene	84.6	ND	850	20,000
Indeno(1,2,3-cd)pyrene	71.8	ND	220	5,100
Naphthalene	2.6	ND	ND	300
Phenanthrene	76.9	ND	500	14,000
Pyrene	87.2	ND	680	17,000
Total PAHs	89.7	ND	4,400	107,090
Phthalates				
bis(2-ethylhexyl)phthalate	66.7	ND	200	2,600
Butylbenzyl phthalate	46.2	ND	ND	2,800
Diethyl phthalate	0	ND	ND	ND
Dimethyl phthalate	0	ND	ND	ND
Di-n-butyl phthalate	7.7	ND	ND	500
Di-n-octyl phthalate	0	ND	ND	ND
Total phthalates	71.8	ND	320	4,800
Phenols				
2-Chlorophenol	0	ND	ND	ND
3,5 Dimethyl phenol	0	ND	ND	ND
4-Chloro-3-methylphenol	0	ND	ND	ND
p-cresol	53.8	ND	150	4,400
Phenol	0	ND	ND	ND

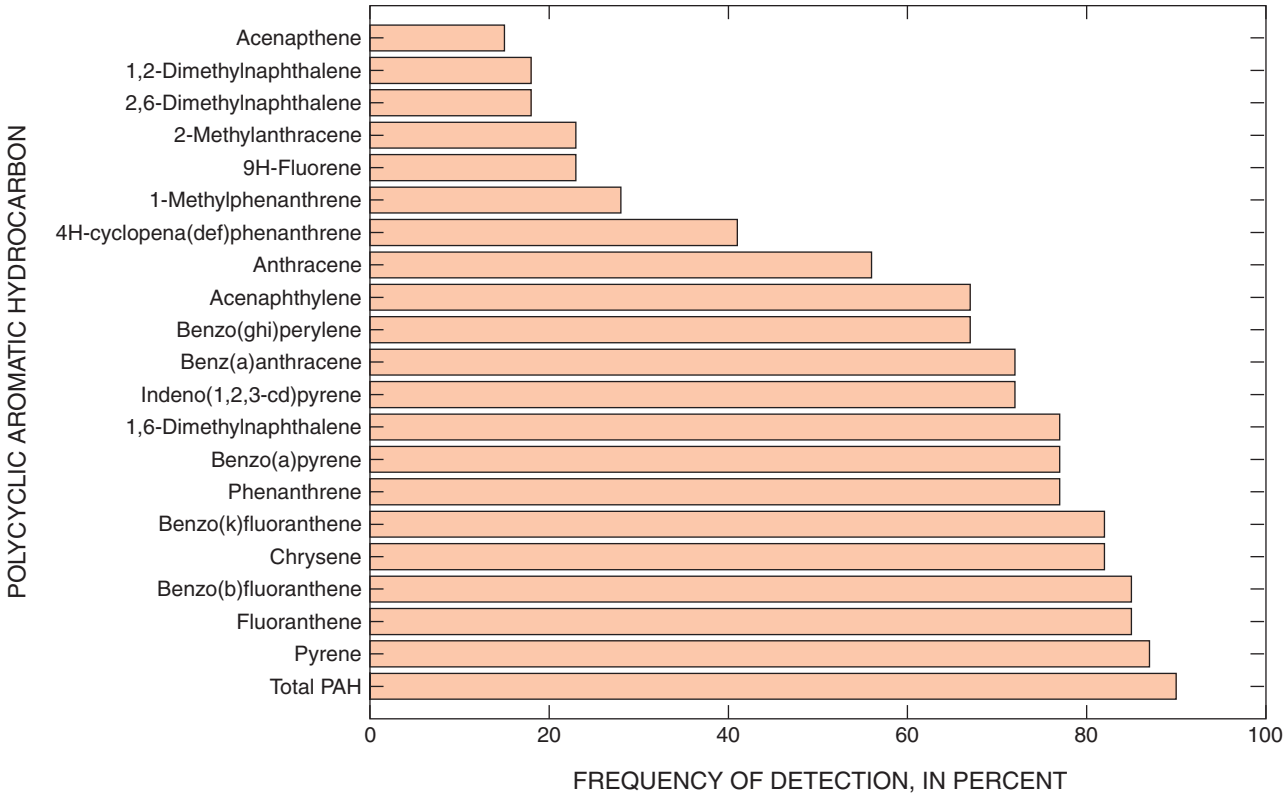

Figure 7. Frequency of detection of polycyclic aromatic hydrocarbons (PAHs) in bed-sediment samples, Delaware River Basin study unit, 1998-2000. (Only compounds detected at one or more sites are included.)

17 individual PAHs were related to urban land-use percent and impervious surface percent (table 21).

Total Phthalates

Total phthalates were detected in samples from 72 percent of bed-sediment sites (fig. 9). Concentrations ranged from less than the censoring level to 4,800 µg/kg, with a median of 320 µg/kg (table 20). The most frequently detected of the six phthalates were *bis*(2-ethylhexyl)phthalate (detected in 67 percent of the samples) and butylbenzylphthalate (49 percent). Three of six phthalate compounds were not detected at greater than the censoring level in any sample (table 20).

Total phthalates were detected in samples from all of the sites in the mixed land-use category and the large-river sites and 91 percent of the sites in the urban land-use category (fig. 9). Sites from the urban land-use category had the highest median concentration, 1,990 µg/kg, followed by the large-river sites and mixed land-use category, 545 µg/kg and 438 µg/kg, respectively (fig. 8). The forest and low-agricultural land-use categories accounted for more than 50 percent of the detections, with median concentrations less than 200 µg/kg (figs. 8 and 9). The agricultural land-use category had the least detections, 33 percent, and the lowest median concentration. Kruskal-Wallis test results indicated that there was a difference between land-use categories ($p = 0.0006$). Further statistical analysis showed that the mean rank of concentrations for the agricultural land-use category was significantly different from that of the mixed and urban land-use categories, as well as the large-river sites. Also, the mean rank of concentrations for the urban land-use category was significantly different from that of the low-agricultural, forest, and mixed land-use categories. Spearman's rank correlation results indicated a significant positive correlation between phthalate concentrations and urban land-use percent and population density, and a significant negative correlation with agricultural land-use percent (table 18).

Further study of individual phthalates using Spearman's rank correlation ($a < .05$) showed that the concentration of *bis*(2-ethylhexyl)phthalate was significantly positively correlated with urban land-use percent and impervious-surface percent, 0.6900 and 0.7434, respectively. Additionally, butylbenzylphthalate was significantly positively correlated with urban land-use percent and impervious surface percent, 0.6823 and 0.6751. Butylbenzylphthalate also had a significant negative correlation with forest land-use percent, -0.4122.

Phenols

Of the five phenols analyzed for in bed-sediment samples, the only one detected, *p*-cresol (table 20), was present in 54 percent of the samples. Concentrations ranged from less

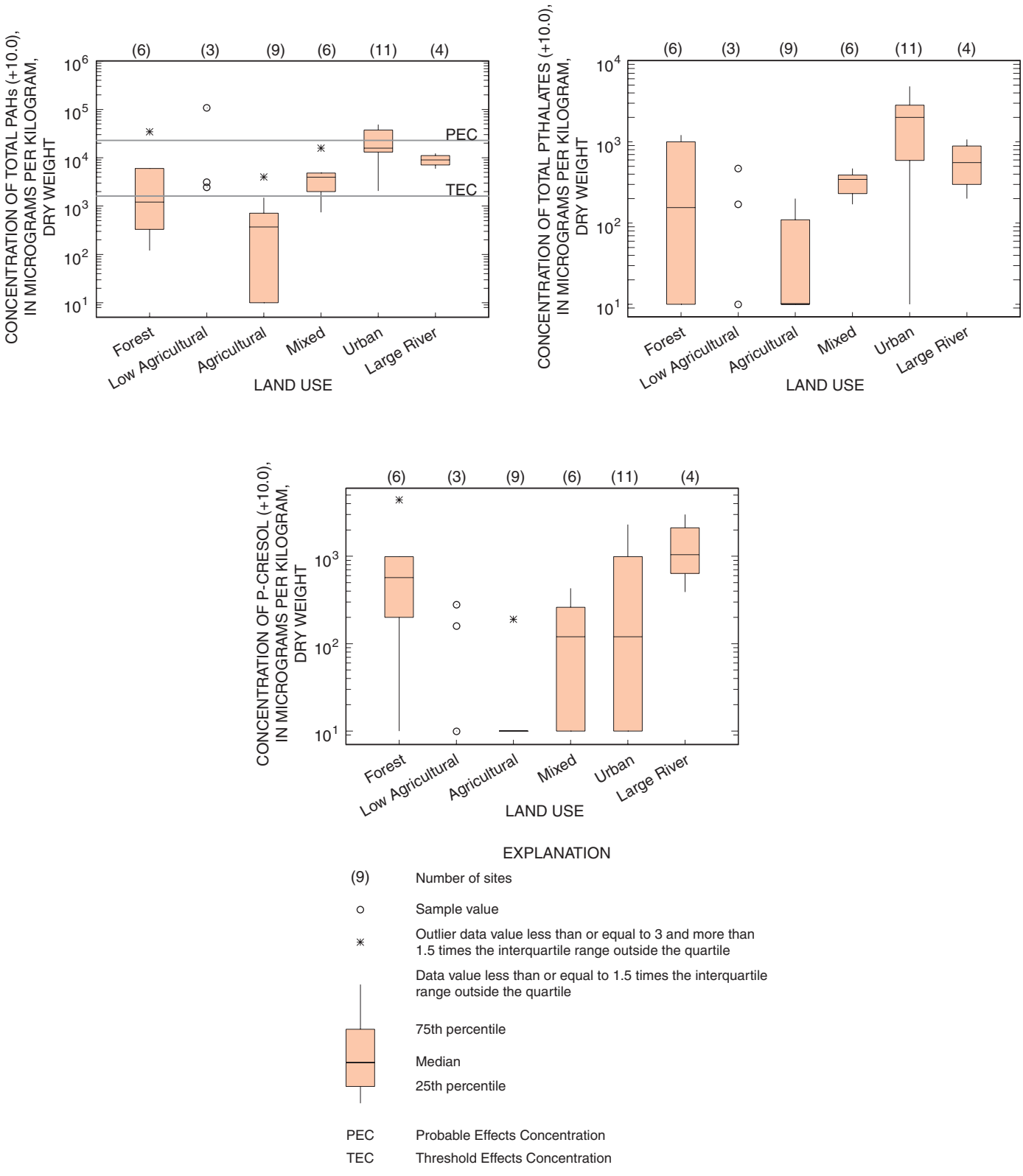

Figure 8. Relation of the concentrations of total polycyclic aromatic hydrocarbons (PAHs), total phthalates, and p-cresol in bed-sediment samples to land use, Delaware River Basin study unit, 1998-2000, with Consensus-Based Sediment Quality Guidelines Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC), where available. (All non-detections set to zero, 10.0 µg/kg added to all values for graphing purposes.)

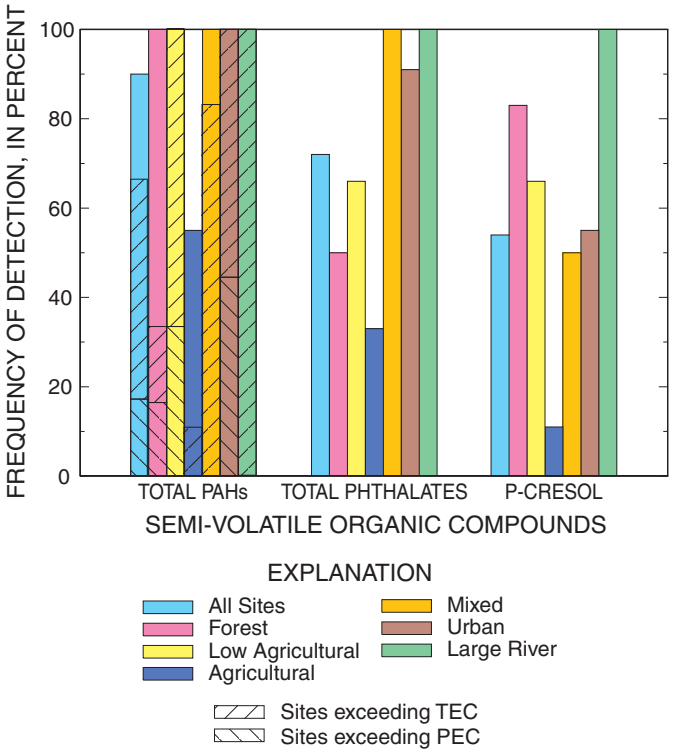

Figure 9. Frequency of detection of total polycyclic aromatic hydrocarbons (PAHs), total phthalates, and p-cresol in bed-sediment samples by land use, Delaware River Basin study unit, 1998-2000, with Consensus-Based Sediment Quality Guidelines Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC).

Table 21. Total polycyclic aromatic hydrocarbons (PAHs) statistically related to urban land-use percent and impervious surface percent, Delaware River Basin study unit, 1998-2000.

[NA, not applicable; Spearman's rank correlation was used to test relations at significance level = p <.05]

Total PAHs	Number of benzene rings	Rho-value for urban land-use percent	Rho-value for impervious surface percent
1-Methylphenanthrene	3	0.4716	0.4692
2,6-Dimethylnaphthalene	2	.3755	.3982
2-Methylanthracene	3	.3269	NA
4H-cyclopenta(def)phenanthrene	3	.4754	.5130
9H-Fluorene	3	.4020	.4051
Anthracene	3	.4053	.4589
Benz(a)anthracene	4	.5782	.6297
Benzo(a)pyrene	5	.5972	.6370
Benzo(b)fluoranthene	5	.5963	.6551
Benzo(ghi)perylene	6	.5573	.6170
Benzo(k)fluoranthene	5	.6051	.6517
Chrysene	5	.5980	.6552
Dibenz(ah)anthracene	5	.4951	.4911
Fluoranthene	4	.6051	.6550
Indeno(1,2,3-cd)pyrene	5	.6037	.6470
Phenanthrene	3	.5931	.6503
Pyrene	4	.5910	.6435

than the censoring level to 4,400 µg/kg, with a median concentration of 150 µg/kg (table 20).

P-cresol was detected in samples from 100 percent of the large-river sites; the highest median concentration, 1,035 µg/kg, was detected in one of these samples (figs. 8 and 9). *P*-cresol was frequently detected in sites from the forest and low-agricultural land-use categories, 83 percent and 66 percent, respectively. The median concentration was 560 µg/kg for the forest land-use category and 150 µg/kg for the low-agricultural land-use category. *P*-cresol was detected in samples from about 50 percent of the mixed and urban land-use sites, and both categories had median concentrations of 110 µg/kg. *P*-cresol was detected least frequently in the agricultural land-use category, in samples from 11 percent of the sites, and the median concentration was less than the censoring level. Kruskal-Wallis test results indicated that there was a difference between land-use categories (p = 0.0114). Further analysis showed that the mean rank of concentrations for the agricultural land-use category was significantly different from that of the forest and urban land-use categories and the large-river sites. Also, the mean rank of concentrations for the mixed land-use category was significantly different from the mean rank of concentrations for the large-river sites, which were significantly different from that of the urban land-use category. Results of the Spearman's rank correlation demonstrated a significant negative correlation between *p*-cresol concentration and agricultural land-use percent (table 18).

Trace Elements in Fish Livers and Bed Sediment

Of the 38 trace elements analyzed for in bed sediment, 37 were detected at one or more sites; 21 of the 22 trace elements analyzed for in fish livers were detected at one or more sites (table 22). Those not detected are listed in table 5. Eight trace elements are considered in this report: arsenic, cadmium, chromium, copper, lead, nickel, mercury, and zinc (table 22). These particular elements were chosen because they are considered, by the U.S. Environmental Protection Agency Code of Federal Regulations (1996), priority pollutants as a result of their toxicity to aquatic organisms at low concentrations. Trace elements were detected more frequently in bed-sediment than in fish-liver samples (fig. 10). One-hundred percent of the sites where fish tissue and bed sediment were collected had at least one detection. All eight trace elements were detected in samples from 97 percent of the bed-sediment sites. Data on other trace elements not reported here (listed in table 22)

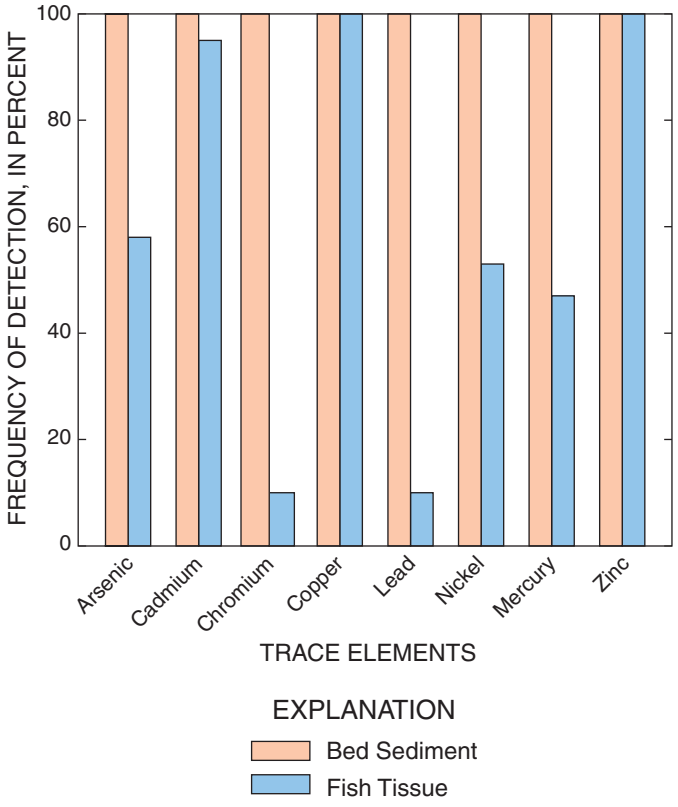

Figure 10. Frequency of detection of trace elements in whole white sucker liver and bed-sediment samples at 19 sites (18 for mercury) where both were detected, Delaware River Basin study unit, 1998-2000.

are published in the U.S. Geological Survey water resources data reports on water quality for water years 1999 and 2000 (DeLuca and others, 2000, and DeLuca and others, 2001). Trace elements in fish-liver and bed-sediment samples are listed by site in appendixes 4 and 5.

Arsenic

Arsenic was detected frequently in samples from the fish-liver and bed-sediment sites. No statistical relations were observed in either data set.

Fish Livers

Arsenic was detected in white sucker livers at 60 percent of the sites sampled (fig. 11a). Concentrations ranged from less than the censoring level to 0.6 μg/g, with a median of 0.4 μg/g (table 14).

Arsenic in white sucker livers was detected at 100 percent of the sites in the forest, low-agricultural, and agricultural land-use categories (fig. 11a). Median concentrations of arsenic in white sucker livers were highest at sites in the low-agri-

Table 22. Trace elements analyzed for and detected in fish-liver and (or) bed-sediment samples collected at one or more sites in the Delaware River Basin study unit, 1998-2000.

[x, detected compound (before censoring); **X**, compound detected and used in analyses; ND, compound not detected; NA, not analyzed for]

Constituent	Bed sediment	Fish tissue
Aluminum	x	x
Antimony	x	x
Arsenic	**X**	**X**
Barium	x	x
Beryllium	x	x
Bismuth	x	NA
Boron	NA	x
Cadmium	**X**	**X**
Cerium	x	NA
Chromium	**X**	**X**
Cobalt	x	x
Copper	**X**	**X**
Europium	x	NA
Gallium	x	NA
Gold	ND	NA
Holmium	x	NA
Iron	x	x
Lanthanum	x	NA
Lead	**X**	**X**
Lithium	x	NA
Manganese	x	x
Mercury	**X**	**X**
Molybdenum	x	x
Neodymium	x	NA
Nickel	**X**	**X**
Nobium	x	NA
Scandium	x	NA
Selenium	x	x
Silver	x	x
Strontium	x	x
Tantalum	x	NA
Thallium	ND	NA
Thorium	x	NA
Tin	x	NA
Titanium	x	NA
Uranium	x	ND
Vanadium	x	x
Ytterbium	x	NA
Yttrium	x	NA
Zinc	**X**	**X**

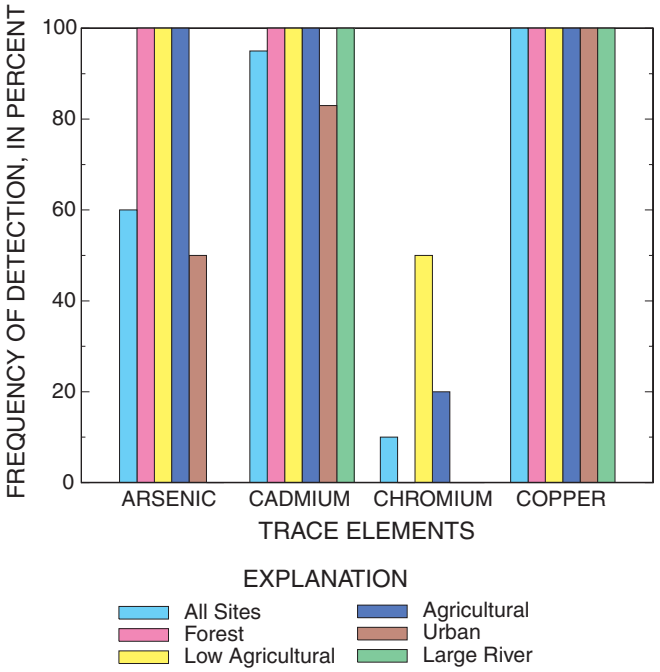

Figure 11a. Frequency of detection of arsenic, cadmium, chromium, and copper in white sucker liver samples in relation to land use, Delaware River Basin study unit, 1998-2000.

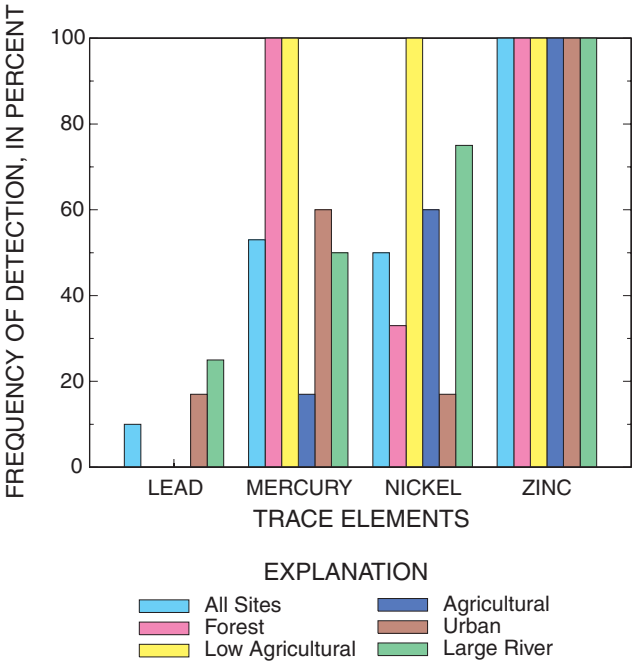

Figure 11b. Frequency of detection of lead, mercury, nickel, and zinc in white sucker liver samples in relation to land use, Delaware River Basin study unit, 1998-2000.

cultural, agricultural, and forest land-use categories (fig. 12a). For the urban land-use category, arsenic was detected at 50 percent of the sites; this group had the lowest median concentration. No detections of arsenic in white sucker livers were reported for the large-river sites (figs. 11a and 12a).

Bed Sediment

Arsenic was detected in bed-sediment samples from 100 percent of the sites sampled (fig. 13a). Concentrations ranged from 5.2 μg/g to 57 μg/g, with a median of 9.1 μg/g (table 14). Arsenic concentrations exceeded the consensus based SQG TEC at 47 percent of the sites and the SQG PEC at 8 percent of the sites (fig. 14a).

The median concentrations of arsenic in bed sediment were highest at large-river sites, followed in decreasing order by the low-agricultural, urban, mixed, forest, and agricultural land-use categories, although there was little difference in the median concentrations in the urban, mixed, forest, and agricultural land-use categories (fig. 14a). Arsenic concentrations exceeded the SQG TEC at 100 percent of the large-river sites and at many sites in the low-agricultural, agricultural, forest, urban, and mixed land-use categories (fig. 13a and table 17).

Cadmium

Cadmium was frequently detected in samples from the fish-liver and bed-sediment sites. No statistical relation was found between cadmium in fish livers and land use.

Fish Livers

Cadmium was detected at 95 percent of the sites where white sucker livers were collected (fig. 11a). Cadmium was not detected at only one urban site, Wissahickon Creek below Walnut Lake, near Manayunk, Pa. (fig. 1, map location 34). Concentrations ranged from less than the censoring level to 5.8 μg/g, with a median of 1.5 μg/g (table 14).

Median concentrations of cadmium in white sucker livers were highest for the forest land-use category (3.1 μg/g) and lowest for the urban category (0.75 μg/g). Cadmium was detected in 100 percent of the samples from the forest, low-agricultural, and agricultural land-use categories, as well as large-river sites (fig. 11a).

Bed Sediment

Cadmium was detected in samples from 97 percent of the sites where bed sediment was collected (fig. 13a). It was not detected in samples from only one site in the agricultural land-use category, Pigeon Creek near Parker Ford, Pa., (fig. 1, map location 31). Concentrations ranged from less than the detection level to 12 μg/g, with a median concentration of 0.9 μg/g (fig. 13a). Cadmium concentrations exceeded the Consensus-Based SQG TEC at 47 percent of the sites sampled, and exceeded the PEC at 5 percent of the sites (fig. 13a).

Median concentrations of cadmium in bed sediment were highest in samples from the large-river sites and lowest in those from the mixed category (fig. 14a). Concentrations exceeded the SQG TEC at all sites in the large-river category,

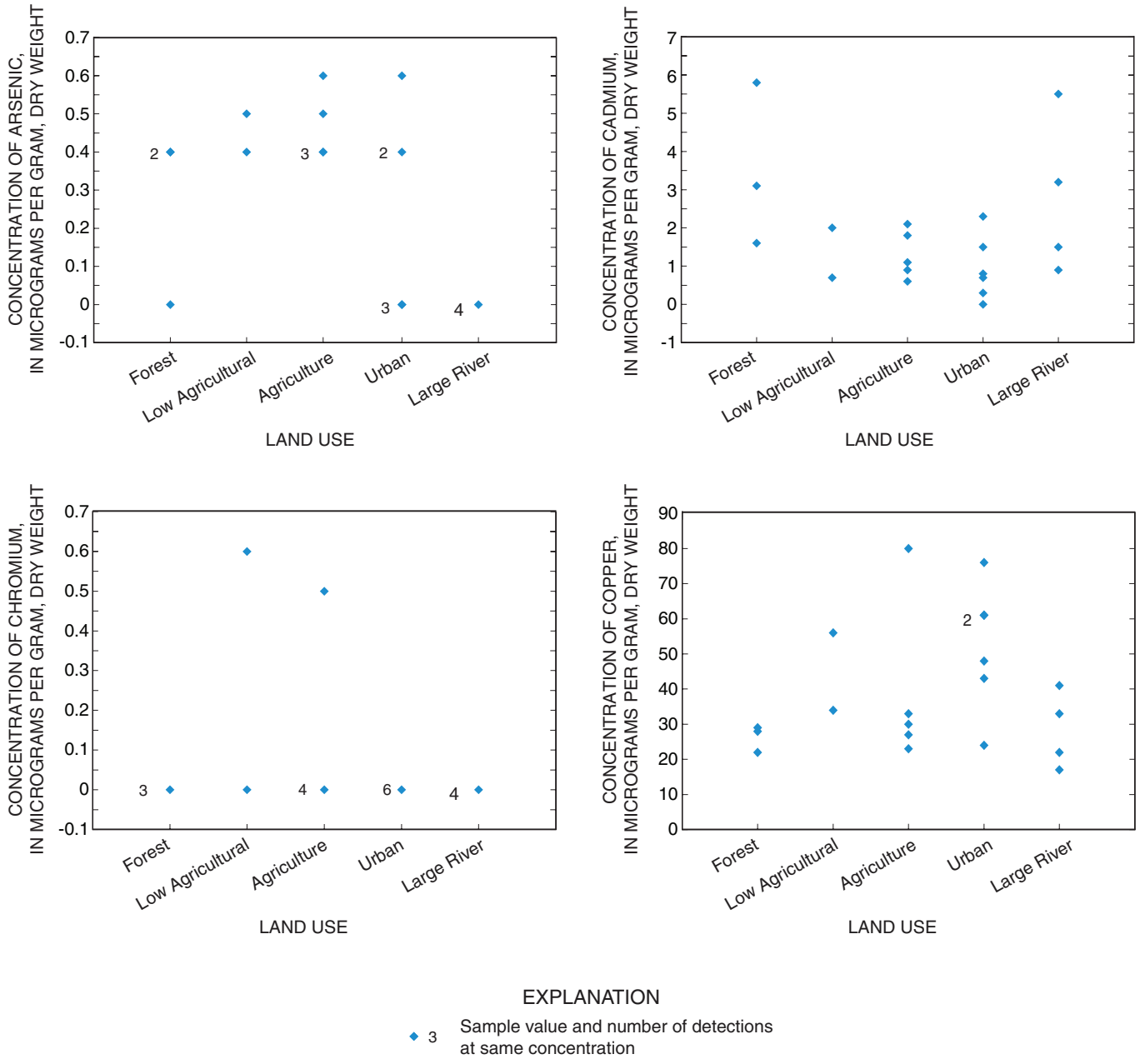

Figure 12a. Relation of the concentrations of arsenic, cadmium, chromium, and copper in white sucker liver samples to land use, Delaware River Basin study unit, 1998-2000.

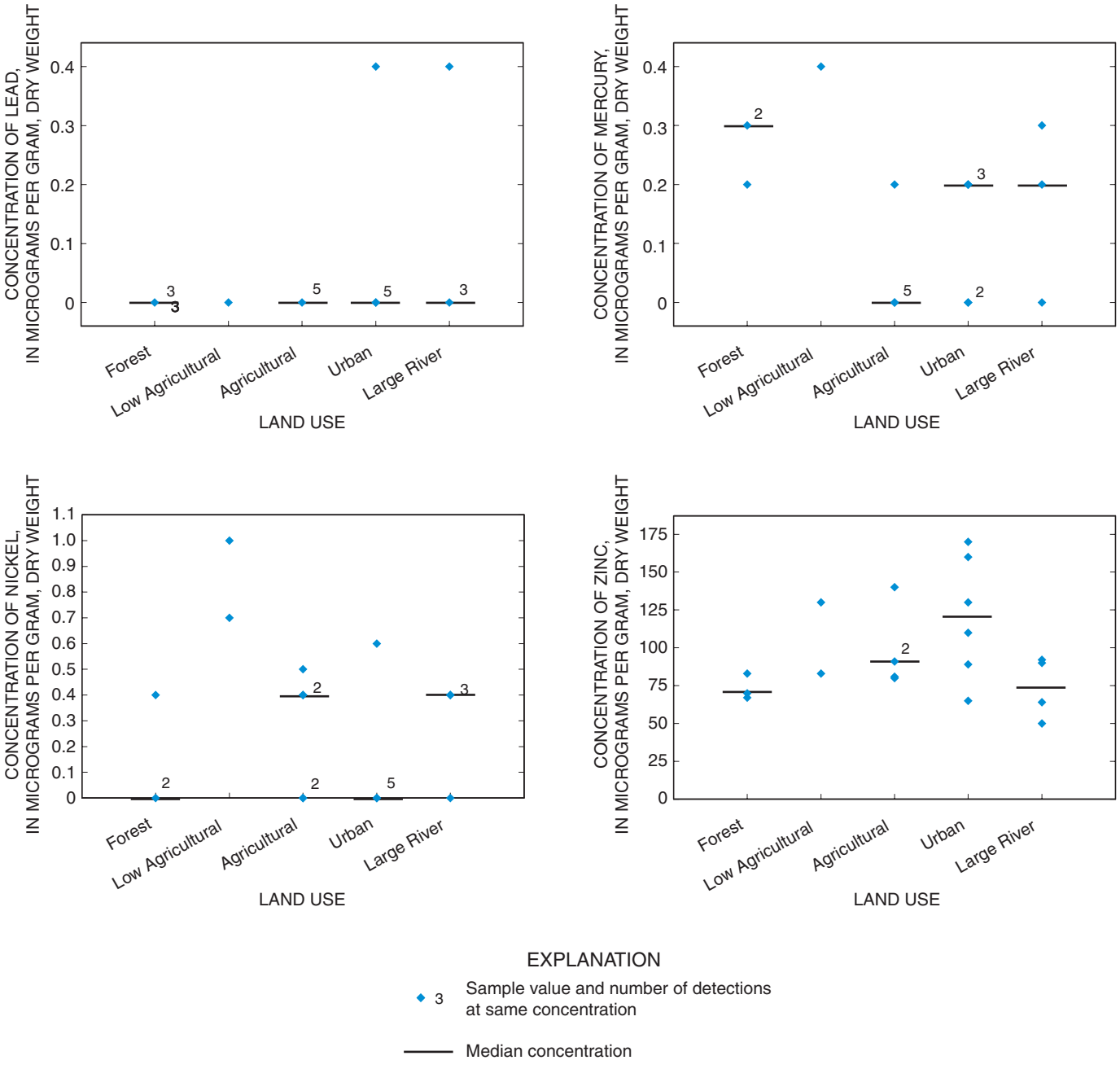

Figure 12b. Relation of the concentrations of lead, mercury, nickel, and zinc in white sucker liver samples to land use, Delaware River Basin study unit, 1998-2000.

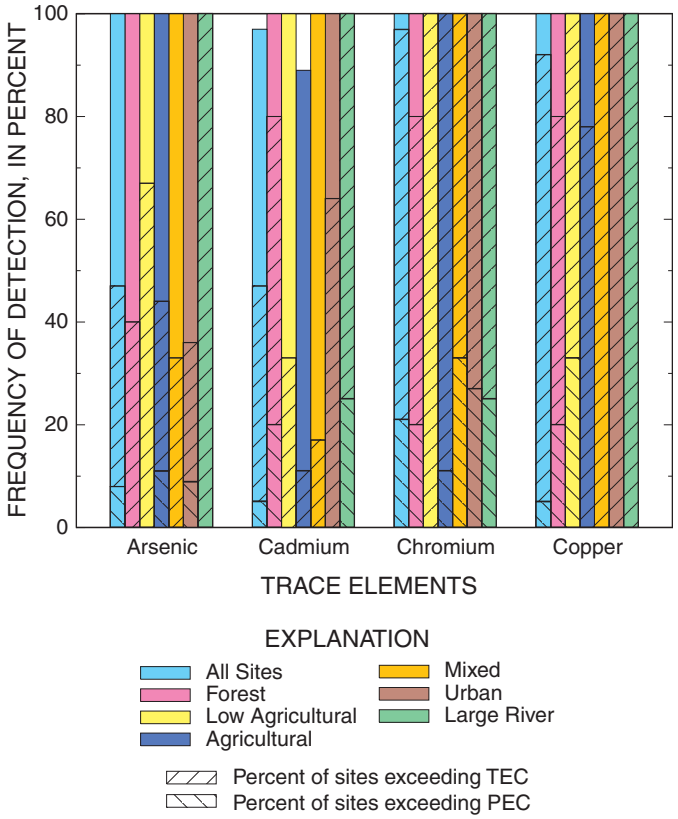

Figure 13a. Relation of frequency of detection of arsenic, cadmium, chromium, and copper in bed-sediment samples to land use, Delaware River Basin study unit, 1998-2000, with Consensus-Based Sediment Quality Guidelines Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC).

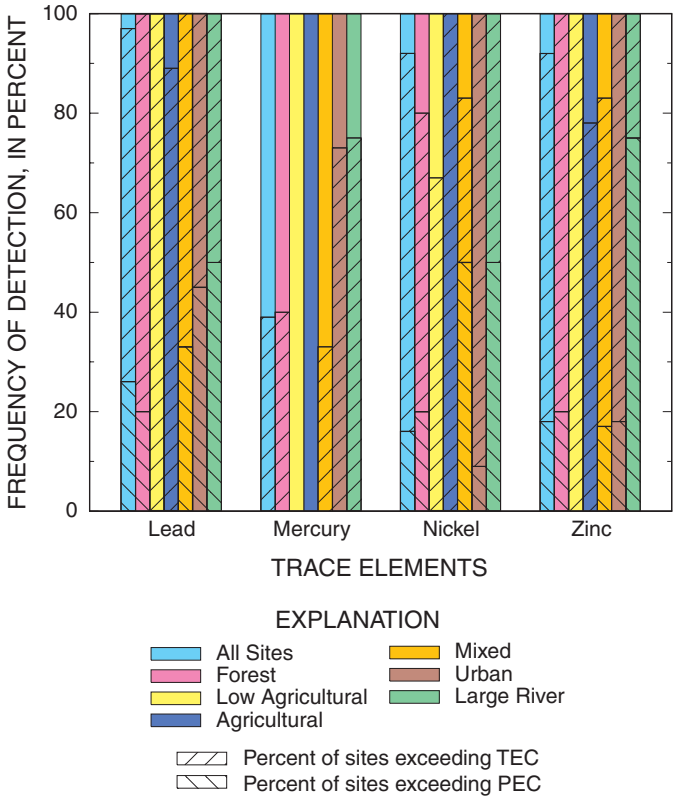

Figure 13b. Relation of frequency of detection of lead, mercury, nickel, and zinc in bed-sediment samples to land use, Delaware River Basin study unit, 1998-2000, with Consensus-Based Sediment Quality Guidelines Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC).

at 73 percent of the sites in the urban category, 60 percent in the forest category, 33 percent in the low-agricultural category, and 17 percent in the mixed category (fig. 13a). The Consensus-Based SQG PEC was exceeded at two sites on the Lehigh River: Lehigh River at Glendon, Pa., and Lehigh River at Lehighton, Pa., (fig. 1, map locations 16 and 11; table 17). Results of the Kruskal-Wallis test indicated that there was a difference between land-use categories ($p = 0.0135$). Multiple comparison tests showed that the mean rank of concentrations for the agricultural land-use category was statistically different from that of the forest and urban land-use categories, and from that of the large-river sites. Also, the mean rank of concentrations for the mixed land-use category was statistically different from that of the forest and urban land-use category, and the large-river sites. Results of Spearman's rank correlation further demonstrated a significant negative correlation between concentrations of cadmium in bed sediment and agricultural land-use percent, and a significant positive correlation between concentrations and population density (table 18).

Chromium

Chromium was detected more frequently in samples from the bed-sediment sites than in samples from the fish-liver sites. No statistical relation was observed between chromium in fish livers and land use.

Fish Livers

Chromium was detected in samples from 10 percent of the sites where white sucker livers were collected (fig. 11a). Concentrations ranged from less than the censoring level to 0.6 μg/g, with a median concentration less than the censoring level (table 14).

Chromium was detected in samples of white-sucker livers from 50 percent of the sites in the low-agricultural land-use category and from 20 percent of the sites in the agricultural land-use category (fig. 13a). Median concentrations of chromium in white sucker livers were highest in the low-agricultural category (0.3 μg/g) (fig. 12a). The median concentrations for all other land-use categories were less than the detection level.

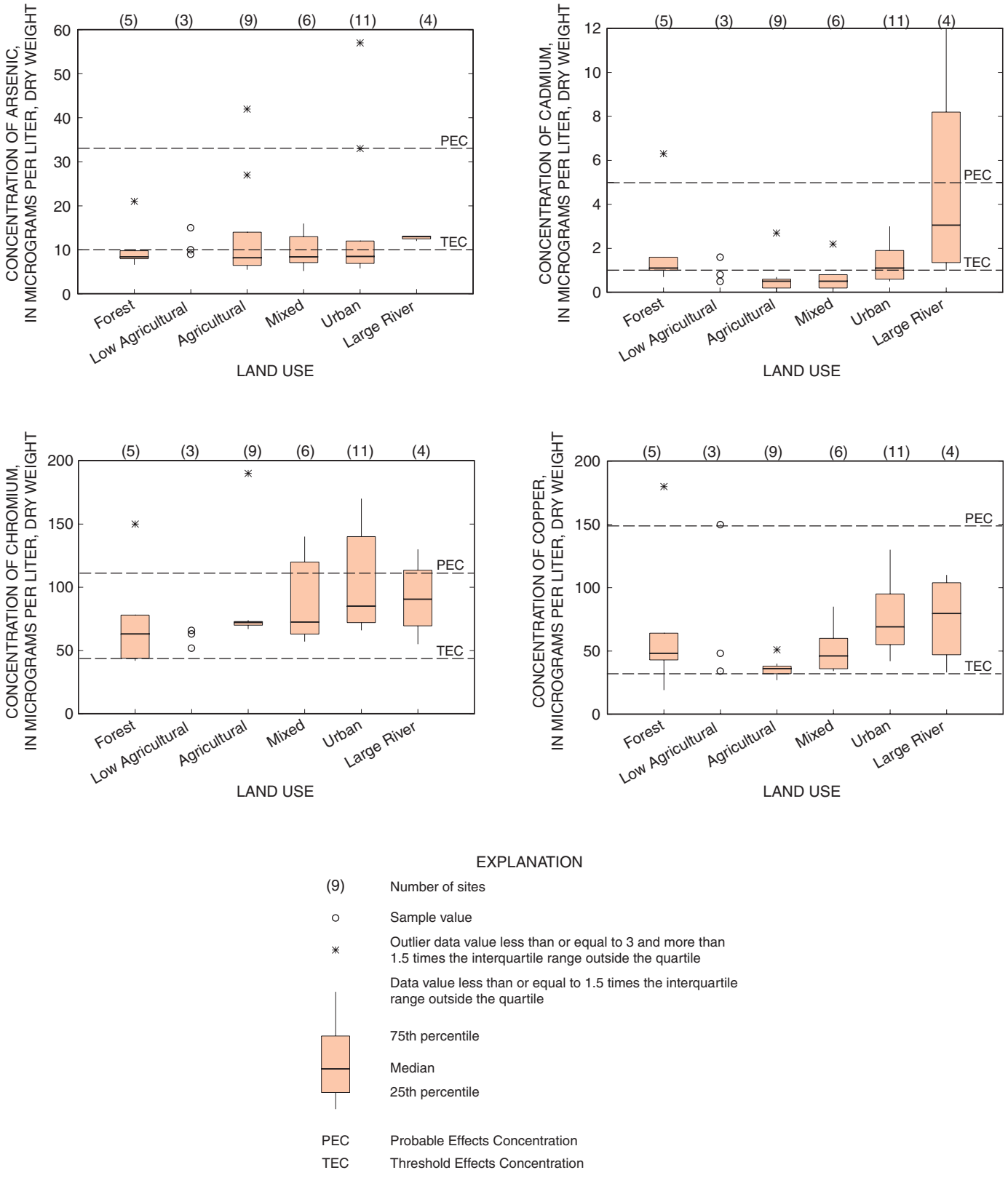

Figure 14a. Relation of the concentrations of arsenic, cadmium, chromium, and copper in bed-sediment samples to land use, Delaware River Basin study unit, 1998-2000, with Consensus-Based Sediment Quality Guidelines Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC).

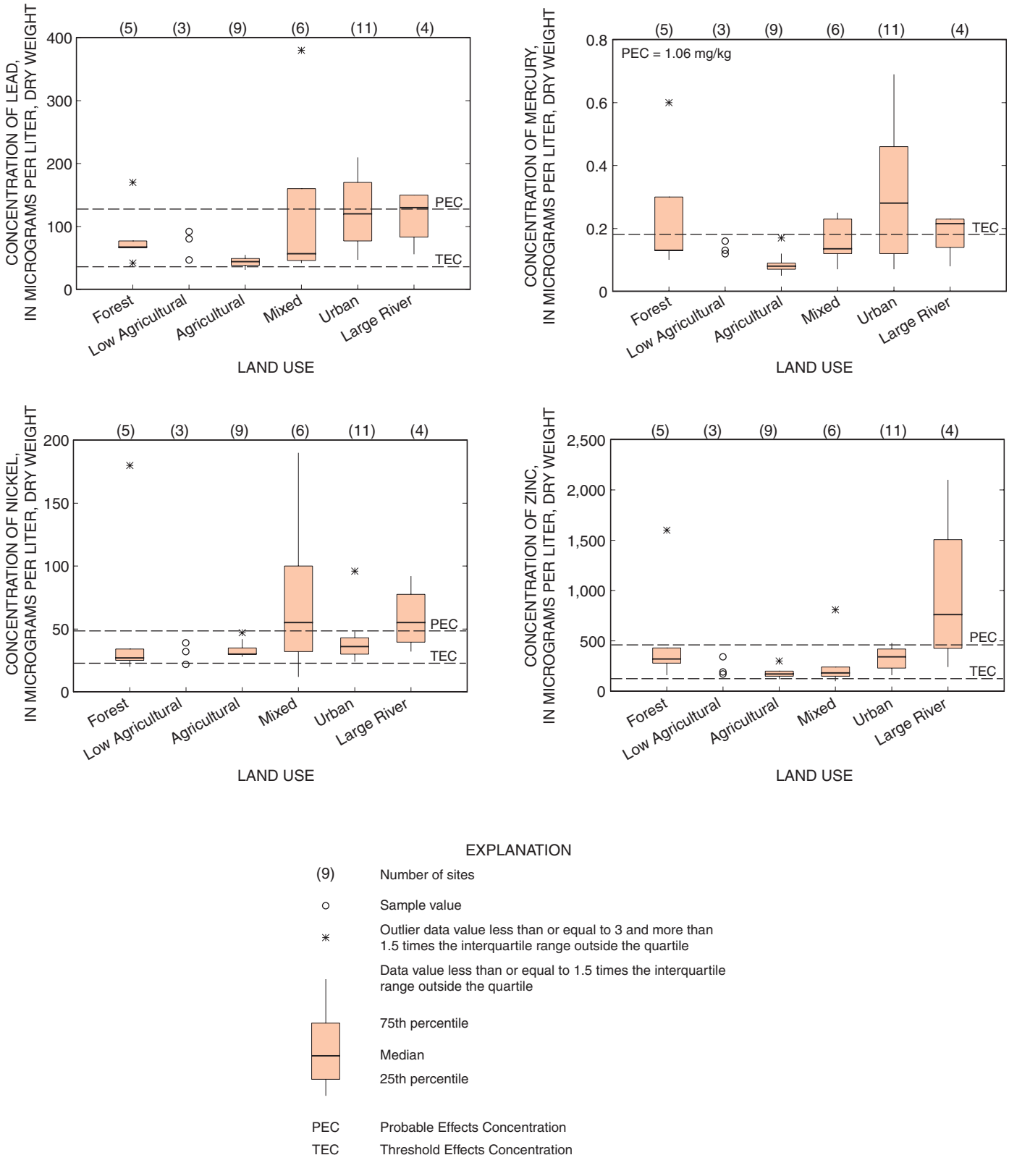

Figure 14b. Relation of the concentrations of lead, mercury, nickel, and zinc in bed-sediment samples to land use, Delaware River Basin study unit, 1998-2000, with Consensus-Based Sediment Quality Guidelines Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC).

Bed Sediment

Chromium was detected in bed-sediment samples from all sites (fig. 13a). Concentrations ranged from 42 µg/g to 190 µg/g, with a median concentration of 72.5 µg/g (table 14). Chromium exceeded the Consensus-Based SQG TEC in samples from 97 percent of the sites and exceeded the PEC in samples from 21 percent of the sites (fig. 13a).

Median concentrations of chromium in bed sediment were highest for the large-river sites (90 µg/g), followed in decreasing order by the urban, agricultural, and mixed sites (fig. 14a). The lowest median concentrations (63 µg/g) were in samples from sites in the forest and low-agricultural categories. Concentrations exceeded the SQG TEC at 100 percent of the sites in the low-agricultural, agricultural, mixed, and urban categories, and large-river sites, and in 80 percent of the forest sites (fig. 13a; table 17). Concentrations exceeded the SQG PEC in 33 percent of the sites in the mixed land-use category, 27 percent of the urban sites, 25 percent of the large-river sites, 20 percent of the forest sites, and 11 percent of the agricultural sites (fig. 13a; table 17). Spearman's rank correlation results demonstrated a significant positive correlation between concentrations of chromium in bed sediment and urban land-use percent (table 18).

Copper

Copper was detected in all samples from both the fish-liver and bed-sediment sites. No statistical relation was observed between copper concentrations in fish livers and land use.

Fish Livers

Copper was detected in samples from all sites where white sucker livers were collected (fig. 11a). Concentrations ranged from 22 µg/g to 80 µg/g, with a median concentration of 33 µg/g (table 14).

The highest median concentrations for copper in white sucker livers were in samples from sites in the urban category (54.5 µg/g), followed by the low-agricultural and agricultural categories. The lowest median concentrations for copper, 28 µg/g, were present in samples from the large-river sites and the forest land-use category.

Bed Sediment

Copper was detected in samples from all sites where bed-sediment samples were collected (fig. 13a). Concentrations ranged from 19 µg/g to 180 µg/g, with a median concentration of 50.5 µg/g (table 14). Copper concentrations exceeded the SQG TEC at 92 percent of the sites, and the PEC at 5 percent of the sites (fig. 13a).

Median concentrations of copper were highest in bed-sediment samples from large-river sites and urban land-use categories (80 and 69 µg/g, respectively) and lowest in samples in the agricultural land-use category (36 µg/g) (fig. 13a). Concentrations exceeded the SQG TEC in samples from all sites in the low-agricultural, mixed, and urban land-use categories, and large-river sites (fig. 13a; table 17), in 80 percent of the forest category, and 78 percent of the agricultural category. The Consensus-Based SQG PEC was exceeded at two sites: Lehigh River at Lehighton, Pa., and West Branch Delaware River at Walton, N.Y. (fig. 1, map locations 11 and 1; table 17). Results of the Kruskal-Wallis test indicated that there was a difference among land-use categories ($p = 0.0182$). Further statistical analysis showed that the mean rank of concentrations for the agricultural land-use category was significantly different from that of the forest and urban land-use categories and the large-river sites. Also, the mean rank of concentrations for the mixed land-use category was significantly different from that of the urban land-use category. Spearman's rank correlation results showed a significant positive correlation between copper in bed sediment and urban land-use percent, and population density, and a significant negative correlation between copper in bed sediment and agricultural land-use percent (table 18).

Lead

Lead was more frequently detected in samples from the bed-sediment sites than in samples from the fish-liver sites. No statistical relation was observed between lead in fish livers and land use.

Fish Livers

Lead was detected in samples from two of the sites (10 percent) where white sucker livers were collected (fig. 11b). These sites are Schuylkill River at Philadelphia, Pa., (01474500) and Wyomissing Creek at West Reading, Pa., (01471520) (fig. 1, map locations 28 and 35). Concentrations ranged from less than the censoring level to 0.4 µg/g, with a median concentration less than the censoring level (table 14).

Bed Sediment

Lead was detected in all of the bed-sediment samples (fig. 13b). Concentrations ranged from 31 µg/g to 380 µg/g, with a median concentration of 69 µg/g (table 14). Lead concentrations exceeded the Consensus-Based SQG TEC in samples from 97 percent of the sites sampled, and exceeded the PEC at 26 percent of the sites sampled (fig. 13b).

Median concentrations of lead in bed sediment were highest in samples from the large-river sites and those from the urban land-use category (130 and 120 µg/g, respectively), and lowest in those from the agricultural category (44 µg/g) (fig. 13b). Concentrations exceeded the SQG TEC at every site in the forest, low-agricultural, mixed, and urban land-use categories, and large-river sites, and 89 percent of the sites in the agricultural land-use category (fig. 13b and table 17). Concentrations exceeded the SQG PEC in 50 percent of the large-river sites, 45 percent of the urban sites, 33 percent of

the mixed sites, and 20 percent of the forest sites (fig. 13b; table 17). Results of Kruskal-Wallis test demonstrated that there was a significant difference between land-use categories ($p = 0.0033$). Further analysis showed that the mean rank of concentrations for the agricultural land-use category was significantly different from that of all other land-use categories and large-river sites. Spearman's rank correlation results showed a significant positive correlation between lead in bed sediment and population density and urban land-use percent (table 18). A significant negative correlation between concentrations of lead and agricultural land-use percent is evident (table 18).

Mercury

Mercury was detected more frequently in samples from bed-sediment sites than those from fish-liver sites.

Fish Livers

Mercury was detected in samples from 53 percent of the sites where white sucker liver samples were collected (fig. 11b). Concentrations ranged from less than the censoring level to 0.4 μg/g, with a median concentration of 0.2 μg/g (table 14).

Mercury was detected in samples from 100 percent of the sites in the forest and low-agricultural land-use categories, 50 to 60 percent of the sites in the urban land-use category and large-river sites, and less than 50 percent of the sites in the agricultural land-use category (fig. 11b). The highest median concentration (0.4 μg/g) of mercury in white sucker livers was in a sample from the low-agricultural category (fig. 12b). The lowest median concentration in white sucker livers was from the agricultural land-use category. Spearman's rank correlation results showed a significant positive correlation between concentrations in white-sucker livers and forest land-use percent, and a significant negative correlation between concentrations and agricultural land-use percent (table 16).

Bed Sediment

Mercury was detected in samples from all of the bed-sediment sampling sites (fig. 13b). Concentrations ranged from 0.05 μg/g to 0.7 μg/g, with a median concentration of 0.1 μg/g (table 14). Concentrations of mercury exceeded the SQG TEC at 39 percent of the sites sampled; no sample exceeded the PEC (fig. 13b).

The highest median concentration was in a bed-sediment sample from the urban land-use category (fig. 14b). The lowest median concentration was in a bed-sediment sample from a site in the agricultural land-use category. Mercury concentrations exceeded the SQG TEC in samples from 75 percent of the large-river sites, 73 percent of the urban sites, 40 percent of the forest sites, and 33 percent of the mixed sites (fig. 13b; table 17). Results of the Kruskal-Wallis test indicated that there was a difference among land-use categories ($p = 0.0138$). Further analysis showed that the mean rank of concentrations of the agricultural land-use category was significantly different from all the other land-use categories and large-river sites. Spearman's rank correlation indicated a significant positive correlation between concentrations of mercury in bed sediment and population density and a significant negative correlation between mercury and agricultural land-use percent (table 18).

Nickel

Nickel was more frequently detected in samples from bed-sediment sites than those from fish-liver sites. No statistical relation was observed between nickel concentrations in bed sediment and land use.

Fish Livers

Nickel was detected in samples from 50 percent of the sites where white sucker livers were collected (fig. 11b). Concentrations ranged from less than the censoring level to 1 μg/g, with a median concentration of 0.2 μg/g (table 14).

Nickel was detected in samples of white sucker livers from 100 percent of the low-agricultural sites. Samples from these sites had the highest median concentration (0.85 μg/g). Nickel also was detected in samples from 75 percent of the large-river sites, 60 percent of the agricultural sites, and less than 34 percent of the sites in the forest and urban land-use categories (fig. 11b). Median concentrations were lowest in samples from the forest and urban land-use categories (less than the detection limit) (fig. 12b). Spearman's rank correlation results showed a significant negative correlation between concentrations of nickel in white sucker livers and population density (table 16).

Bed Sediment

Nickel was detected in samples from all bed-sediment sites (fig. 13b). Concentrations ranged from 12 μg/g to 190 μg/g, with a median concentration of 33.5 μg/g (table 14). Nickel concentrations exceeded the SQG TEC at 92 percent of the bed-sediment sites and the PEC at 16 percent of the sites (fig. 13b).

The highest median concentration of nickel was present in a sample from a large-river site and a sample from the mixed land-use category (55 μg/g) (fig. 14b). The lowest median concentration was from a site in the forest land-use category (27 μg/g). Concentrations of nickel exceeded the SQG TEC at 100 percent of the agricultural and urban land-use categories, and large-river sites (fig. 13b; table 17). Concentrations also exceeded the SQG TEC in samples from 83 percent of the mixed sites, 80 percent of the forest sites, and 66 percent of the low-agricultural sites. The SQG PEC was exceeded by concentrations in samples from 50 percent of the sites in the mixed land-use category and large-river

sites and 20 percent of the sites in the forest land-use category (table 17).

Zinc

Zinc was detected frequently in samples from both the fish-liver and bed-sediment sites. No statistical relation was observed between zinc concentrations in fish livers and land use.

Fish Livers

Zinc was detected in samples from 100 percent of the white sucker liver sampling sites (fig. 11b). Concentrations ranged from 65 μg/g to 170 μg/g, with a median concentration of 89.5 μg/g (table 14).

The highest median concentrations of zinc in white sucker livers were present in samples from the urban land-use category (120 μg/g), and in decreasing order, low-agricultural and agricultural land-use categories (fig. 12b). The lowest median concentration of zinc in white sucker livers was present in a sample from a site in the forest land-use category.

Bed Sediment

Zinc was detected in samples from all of the bed-sediment sites (fig. 13b). Concentrations ranged from 100 μg/g to 2,100 μg/g, with a median concentration of 240 μg/g (table 14). Concentrations of zinc exceeded the SQG TEC at 92 percent of the sites and exceeded the PEC at 18 percent of the sites. (fig. 13b).

The highest median concentration of zinc in bed sediment, 760 μg/g, was present in a sample from a large-river site. The next highest concentrations were in samples from the urban and forest land-use categories, which had median concentrations of 340 and 320 μg/g, respectively (fig. 14b). The lowest median concentrations in bed sediment were in samples from sites in the agricultural, mixed, and low-agricultural land-use categories, and ranged from 170 to 190 μg/g. Concentrations exceeded the SQG TEC at 100 percent of the sites from the low-agricultural and urban land-use categories, and large-river sites (fig. 13b; table 17). In addition, concentrations exceeded the SQG TEC at 83 percent of sites in the mixed land-use category and 78 percent in the agricultural category. The SQG PEC was exceeded at 75 percent of the large-river sites, 20 percent of the forest sites, 18 percent of the urban sites, and 17 percent of the mixed sites (table 17). Kruskal-Wallis results indicated a difference among land-use categories ($p = 0.0084$). Further statistical analysis showed that the mean rank of concentrations for the agricultural land-use category was significantly different from that of the forest and urban land-use categories as well as the large-river sites. In addition, the mean rank of the concentrations for the mixed land-use category was significantly different from that for the urban land-use category and large-river sites. Results from Spearman's rank correlation showed a significant positive correlation between concentrations of zinc in bed sediment and urban land-use percent, and population density, and a significant negative correlation between concentrations and agricultural land-use percent (table 18).

Comparison of Concentrations and Detection Frequencies of Organic Compounds and Trace Elements in Fish Tissue and Bed Sediment

The concentrations and detection frequencies of organochlorine compounds (total DDT, total chlordanes, total PCB, and dieldrin) in fish tissue and bed sediment were compared for 23 sites where both media were collected to show the relation between concentrations of contaminants in the two media. The concentrations and detection frequencies of trace elements (arsenic, cadmium, chromium, copper, lead, nickel, and zinc) in fish livers and bed sediment also were compared for 19 sites where both media were collected (samples for mercury were collected jointly at only 17 sites). Spearman's rank correlation tests were performed on these data sets; large-river sites were not included because they encompass many land-use categories.

Organic compounds in bed sediment could be an important source for those compounds that accumulate in fish tissue. Fish may be exposed to low levels (below laboratory detection limits) of organochlorine compounds in the bed sediment, or the compounds may be transported to the stream water through overland run-off. At many sites sampled in this study, organic compound concentrations in bed sediment were too low to be detected; however, even when this was the case they were often detected in samples of whole white suckers (fig. 2). Ratios of concentrations of organic compounds in whole white suckers to concentrations of those same compounds in bed sediment shows that total DDT, total chlordanes, total PCB, and dieldrin are being bioaccumulated in whole white suckers (ratio >1), in some cases to levels exceeding the NYSDEC wildlife protective guidelines (fig. 15). Results of Spearman's rank correlation showed significant relations between concentrations of total DDT, total chlordanes, and dieldrin in whole white suckers and those same compounds in bed sediment (table 23), substantiating the connection of the two media.

Unlike organic compounds, most trace elements did not tend to bioaccumulate in fish livers. Trace elements were detected more frequently in bed sediment than in fish livers at the 19 sites where both types of samples were collected (fig. 10). For these sites, every trace element was detected in a bed-sediment sample from every site. A comparison of ratios of trace-element concentrations in fish livers to those in bed sediment showed that ratios for cadmium, copper, and mercury typically were close to one, which indicates that these compounds were not biomagnified in livers (fig. 16). In contrast, arsenic, nickel and zinc ratios were less than one. For arsenic

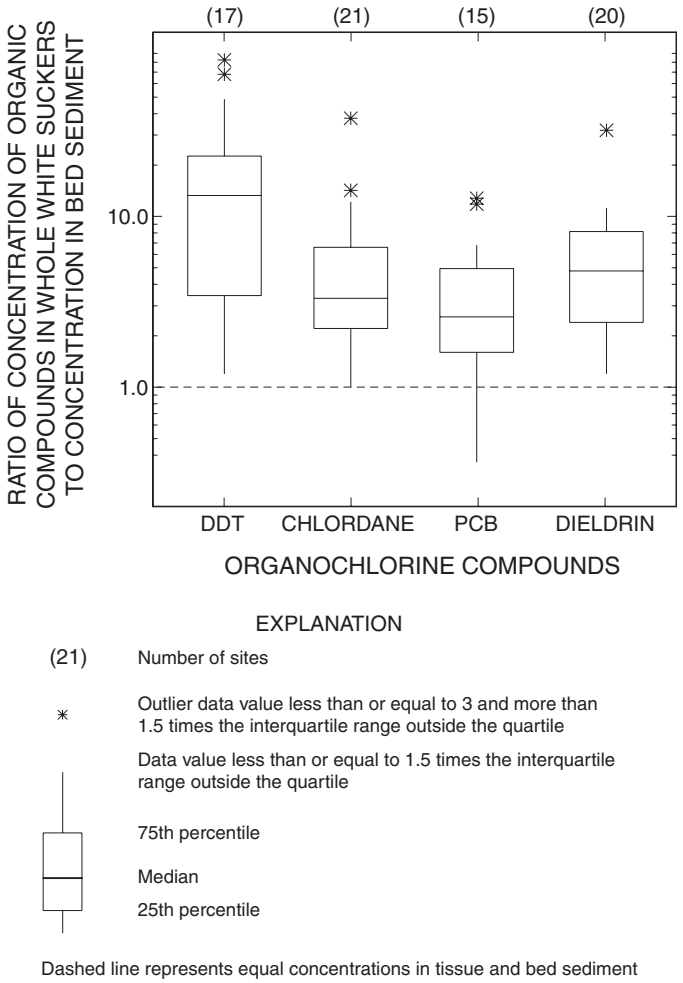

Figure 15. Distribution of ratios of concentrations of total DDT, total chlordane, total polychlorinated biphenyls (PCBs), and dieldrin in whole white sucker samples to concentrations in bed-sediment samples, Delaware River Basin study unit, 1998-2000.

Table 23. Results of Spearman's rank correlation test on relation of concentrations of organochlorine compounds and trace elements in bed-sediment samples to concentrations in fish-tissue samples, Delaware River Basin study unit, 1998-2000.

[Large-river sites not included; orange indicate statistically significant values]

Constituent	Spearman's rho	p-value
Organochlorine compounds		
Total DDT	0.7117	0.0026
Total Chlordane	.7822	.0009
PCB	.3455	.1436
Dieldrin	.7963	.0007
Trace elements		
Arsenic	.2078	.4407
Cadmium	.0568	.8367
Chromium	-.1149	.6624
Copper	.2683	.3186
Lead	.2788	.2999
Mercury	.2415	.4081
Nickel	.0048	.9908
Zinc	-.3108	.2421

and nickel, ratios were more than an order of magnitude lower than one. This indicates that fish may not bioaccumulate these compounds in the liver. Similar results were seen for arsenic, cadmium, copper, mercury, and nickel in the Clark Fork–Pend Oreille and Spokane River Basins in Washington State (Maret and Skinner, 2000). Results of Spearman's rank correlation test comparing trace elements detected in fish-liver samples to those detected in bed-sediment samples, indicated that no significant correlations occurred between the two media.

Fish livers were sampled because it is thought that trace elements can be stored in the livers of the fish. Constituent concentrations in fish livers, in general, indicate the contaminants the fish populations are exposed to. The bioavailability of trace elements to fish, however, depends on several physiochemical characteristics, including dissolved solids, dissolved organics, pH, hardness, and sediment load (Lindsey and others, 1998). The chemical form of trace elements can be altered by these stream characteristics and can affect their availability for uptake by fish and other organisms (Lindsey and others, 1998). Another factor of bioavailability is that sediment samples may have been collected from stream reaches where fish do not normally come in contact with the bed sediment (Lindsey and others, 1998). Bioavailability also can be affected by lipid composition, age and body size, season of collection, and reproductive state of fish (Nowell and others, 1999). In addition, fish may or may not metabolize all trace elements in their livers. Whole fish samples may be a better indicator of concentration levels and variations by land use.

Comparison with Other Studies

The results of the evaluations of organic compounds and trace elements collected at sites from the Delaware River Basin were compared with those in other NAWQA studies in the northeastern United States [Long Island–New Jersey Coastal Plain (LINJ); New England Coastal Basin (NECB); Connecticut, Housatonic, and Thames River Basins (CONN); Hudson River Basin (HDSN); and Lower Susquehanna River Basin (LSUS)] and two studies from the southern and western United States [Mobile River Basin (MOBL) and Northern Rockies Intermontane Basins (NROK)] (Long and others, 1999, Chalmers, 2002, Maret and Skinner, 2000, and Zappia, 2002. National statistics on organic compounds and trace ele-

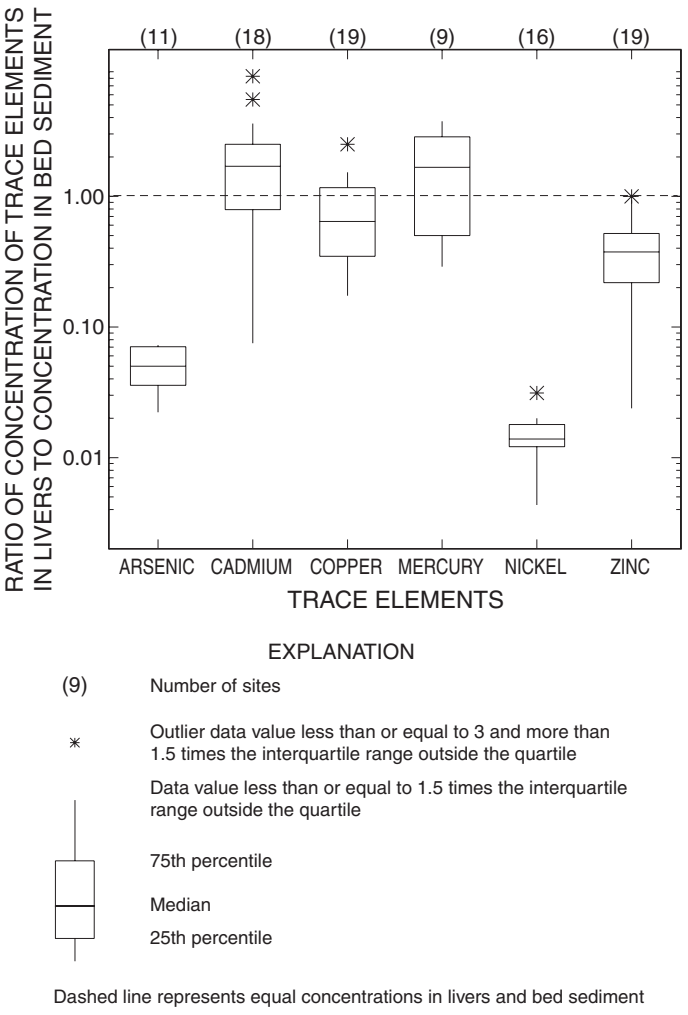

Figure 16. Distribution of ratios of concentrations of arsenic, cadmium, copper, mercury, nickel, and zinc in white sucker liver samples to concentrations in bed-sediment samples, Delaware River Basin study unit, 1998-2000.

Table 24. Median concentrations of total DDT, total chlordane, total polychlorinated biphenyls (PCBs), and dieldrin in bed sediment and fish-tissue samples, and total polycyclic aromatic hydrocarbons (PAHs) in bed-sediment samples, from selected National Water-Quality Assessment Program study units and national statistics.

[<, less than; NA, not available; µg/kg, micrograms per kilogram; DELR, Delaware River Basin; LINJ, Long Island-New Jersey; CONN, Connecticut, Housatonic, and Thames River Basins; HDSN, Hudson River Basin; LSUS, Lower Susquehanna River Basin; NECB, New England Coastal Basins; MOBL, Mobile River Basin; blue indicates highest value for fish-tissue samples; orange indicates highest value for bed-sediment samples; **bold** values indicate this study]

Study Unit	Total DDTs	Total Chlordanes	Total PCBs	Dieldrin	Total PAHs
Fish tissue (µg/kg, wet weight)					
DELR	**104**	**54.5**	**140**	**25**	**NA**
CONN[1]	76.8	23.4	250	NA	NA
HDSN[1]	68	<5	120	NA	NA
LINJ[2]	146	173	205	NA	NA
LSUS[1]	46.2	9.5	190	NA	NA
MOBL[3]	53.9	82.8	135	84	NA
NECB[1]	44.3	9	325	NA	NA
National[1]	20	<5	<50	NA	NA
Bed sediment (µg/kg, dry weight)					
DELR	**2**	**<3**	**<100**	**<3**	**4,400**
CONN[1]	3.7	<1	<50	NA	4,813
HDSN[1]	1.9	<1	<50	NA	2,819
LINJ[2]	7.7	4.65	<50	NA	[1]4,454
LSUS[1]	<2	<1	<100	NA	1,766
MOBL[3]	40	14	160	7	NA
NECB[1]	25.9	18	155	NA	21,764
National[1]	<2	<1	<50	1.9	267

[1] Chalmers (2002)

[2] Long and others (2000)

[3] Zappia (2002)

ment data from the NAWQA program, where available, also are compared (Chalmers, 2002 and Maret and Skinner, 2000).

Median concentrations of total DDT, total chlordanes, and total PCB in fish tissue in the Delaware River Basin were much higher than national medians and slightly higher than medians in other study units in the northeast, except LINJ (and NECB and CONN for total PCB) (table 24). Median concentrations of total DDT, total chlordanes, total PCB, and dieldrin in bed sediment in the Delaware River Basin generally were similar to median concentrations in other northeastern study units and national medians (table 24). Median concentrations of the sum of the 22 PAH compounds used in the statistical analyses for the Delaware River Basin study were about 5 times lower than those for the NECB study and about 16 times higher than the national median (table 24). High SVOC concentrations in the Delaware River Basin study specifically, and the northeast generally, relative to the concentrations in national statistics may be related to the density of urban development in the Delaware River Basin, associated transportation, and industrial combustion products, and to the persistence of these compounds once they have entered the aquatic environment.

Median concentrations of arsenic, cadmium, and mercury in fish liver samples from the Delaware River Basin were higher than the national medians, and median concentrations of chromium, copper, lead, nickel, and zinc were similar or lower (table 25). Differences in concentrations in fish livers among study units could be due to differences in species, age, and size of the fish collected (Maret and Skinner, 2000).

Table 25. Median concentrations of trace elements in bed-sediment and fish-liver samples from selected National Water-Quality Assessment Program study units and national statistics.

[<, less than; μg/g, micrograms per gram; DELR, Delaware River Basin; LINJ, Long Island-New Jersey; NROK, Northern Rockies Intermontane; CONN, Connecticut, Housatonic and Thames River Basins; HDSN, Hudson River Basin; MOBL, Mobile River Basin; blue indicates highest value in fish-liver samples; orange indicates highest value in bed-sediment samples; **bold** values indicate this study]

Study Unit	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Fish livers (μg/g, dry weight)								
DELR	**0.4**	**1.5**	**<.5**	**33**	**<.3**	**.2**	**.2**	**89.5**
LINJ[1]	NA	1.0	.6	57.6	.5	.05	NA	136
NROK[2]	0.6	1.8	.2	55	.2	.2	<.1	104
National[3]	0.4	1.5	.7	55.9	.3	.2	.4	123
Bed sediment (μg/g, dry weight)								
DELR	**9.1**	**.9**	**72.5**	**50.5**	**69**	**.1**	**33.5**	**240**
CONN[4]	5.9	1.1	91	55.5	80	.2	36.5	200
HDSN[4]	7	.7	64	33	38	.1	33	180
NECB[4]	19	2.1	99	92.5	190	.6	45	295
MOBL[3]	11	.2	78	22	26	.05	29	110
NROK[2]	9.7	.3	43	26	42	.1	18	98
National[4]	7.7	.5	63.5	28	25.9	.07	29	110

[1] Long and others (1999)

[2] Maret and Skinner (2000)

[3] Zappia (2002)

[4] Chalmers (2002)

Median concentrations of trace elements in bed sediment from the Delaware River Basin were higher than the national medians (table 25). The Delaware River Basin study bed-sediment samples generally had higher concentrations of trace elements than those in the HDSN, were similar to concentrations in the CONN, and lower than those in the NECB (table 25).

Factors Affecting Distribution of Organic Compounds and Trace Elements

Concentrations of organic compounds and trace elements differ among land uses and regions within the Delaware River Basin. The distributions of organic compounds and trace elements usually are related to the amount of agriculture or urban activity within a watershed but also can be related to atmospheric deposition and natural sources.

Forest and Low-Agricultural Land Uses

Most organochlorine compounds were negatively correlated with the percentage of forest land use in a basin, and the frequencies of detection and median concentrations of these compounds were lower for forested land than for all other land-use categories. For organochlorine compounds, few exceedances of any fish-tissue or bed-sediment guidelines were detected for sites in forested areas. DDT was the most frequently detected organochlorine in fish tissue (80 percent) and was the only organochlorine detected in bed sediment at forest sites (50 percent). It is not surprising that DDT was detected in forests because it was used in the past in most land-use settings to control insects. Nowell and others (1999) indicate that the long-term storage of DDT (and its degradation products) in the forest soil and in the bed sediment of rivers continues to contibute DDT compounds to streams. Frequent detections of PCBs in whole white suckers in forest settings (67 percent) were unexpected because PCBs were not widely used in forests. Their presence could be due to leakage from electrical transformers or low-level atmospheric deposition (Jaward and others, 2005). The presence of PCBs also could be due to bioaccumulation in fish. Chlordane was detected infrequently in fish from forest settings, and the presence of chlordane could be related to local use for insect control.

All SVOCs were detected frequently in samples from forested areas. Total PAHs were detected at every forest land-use site, but median concentrations were lower than those for all land-use categories except agriculture. PAHs are combustion products that can be deposited from local and remote

atmospheric sources (Golomb and Barry, 1999). An analysis of molecular masses and concentration ratios of different PAH compounds (Yunker and others, 2001) indicates a wide variety of PAH sources in forests of the Delaware River Basin. These include wood, coal, kerosene and other fuels, and oil. PAH ratios also indicated runoff from asphalt could be a source (Mahler and others, 2004), particularly on the West Branch of the Delaware River at Walton, N.Y., (107,090 μg/kg) and the Lehigh River at Lehighton, Pa., (34,390 μg/kg) (fig. 1, map locations 1 and 11), two sites with high total PAH concentrations that exceeded the SQG PEC.

Phthalates, which usually are associated with industrial processes involving plastics, also have been detected at more than half the sites in the forest land-use category (fig. 9). Median concentrations of phthalates were lower than those for all other land-use categories except agricultural. The source of total phthalates in the forest, although unclear, also may be atmospheric deposition. Studies have shown that atmospheric deposition of one particular phthalate, di-n-butyl phthalate, can be significant (Long and Meek, 1997). Di-n-butyl phthalate was detected at only one site in the forest land-use category, Lehigh River at Lehighton, Pa. (160 μg/kg).

The only phenol detected, *p*-cresol, was detected more frequently and at higher concentrations in forests than in all other land-use categories except large rivers. Because of the short half-life of *p*-cresol in air, only a few hours, it is likely that sources of *p*-cresol to streams are local.

Concentrations of trace elements in bed-sediment samples from forest and low-agricultural land-use categories tend to be comparable or lower than concentrations in samples from sites in other land-use categories, except agriculture, although detection frequencies in agricultural areas are high. One forest land-use site in particular, Lehigh River at Lehighton, Pa., yielded a bed-sediment sample with high concentrations of many trace elements (fig. 1, map location 11). Five trace elements at this site exceeded the SQG PEC. This site is downstream from a region where, more than 50 years ago, extensive mining was conducted, and more recently a zinc smelter was operated. Therefore, the median concentrations of trace elements were higher than would be expected in the absence of mining activity. Another site, Hay Creek near Birdsboro, Pa., yielded a bed-sediment sample with high concentrations of arsenic, chromium, copper, nickel, and zinc; none of the concentrations, however, exceeded the SQG PEC (fig.1, map location 29). This site is near trap-rock quarries.

Bed-sediment samples were collected from sites in forest and low-agricultural land-use settings to provide background information on contaminant levels relative to levels at other sites in the Delaware River Basin. A surprising number of organic and trace element compounds were detected. Also, concentrations of most contaminants in samples from forest sites were almost always greater than concentrations in samples from agricultural sites, but usually lower than those in samples from urban sites. The physical setting of forests and their proximity to urban areas in the Delaware River Basin could account for some of the greater frequencies of detection and higher concentrations of some compounds. Most forests cover ridges and highlands, which are more likely to be exposed to regional atmospheric sources of contaminants than are lowlands (which typically have been cleared for agricultural uses). In addition, many forests are at higher elevations than land used for other purposes. Elevation affects temperature, and temperature helps determine how readily contaminants partition between air and land or leaf surfaces (Jaward and others, 2005). Forests also have the ability to preferentially remove more contaminants from the atmosphere than do cleared areas at the same elevation because large areas of leaf surfaces are in contact with the atmosphere (Jaward and others, 2005).

Agricultural Land Use

Detection frequencies of organochlorine compounds in fish tissue and bed sediment from sites in the agricultural land-use category were similar to detection frequencies in the forest land-use category and less than those in other land-use categories (figs. 3 and 6). Concentrations of most organochlorines (particularly total DDT) in fish-tissue samples were greater than those in bed-sediment samples from sites in the forest land-use category, but less than those from other land-use categories. The low median concentrations of total DDT, total chlordanes, and dieldrin in bed sediment and lack of correlation with percentage of agricultural land-use were unexpected because of the nature of their use in agricultural settings. Because most uses of these products have been cancelled over the past 20 years, however, the data may indicate that there are no new sources in this region.

SVOCs were shown not to be associated with percentage of agricultural land-use. Total PAHs, total phthalates, and phenols were detected less often in areas of agricultural land use than in areas of other land uses because they are not used in agriculture. They are used in industrial processes, or they are produced as a result of incomplete combustion of wood, gasoline, coal, or fuel oil. Evaluation using molecular masses and concentration ratios (Yunker and others, 2002) indicate that potential sources of PAHs to the agricultural areas could be the combustion of wood or grass, number 2 fuel oil, diesel fuel and oil, wood soot, or kerosene.

Trace elements were detected in bed-sediment samples from all sites sampled; however, median concentrations for the agricultural land-use category were lower than those for most other land-use categories. The highest concentrations of arsenic, cadmium, chromium, mercury, and zinc compared to those from sites in all land-use categories were present in the sample from Raccoon Creek near Swedesboro, N.J. (fig.1, map location 40). This site is downstream from two sewage-treatment plants and has a history of industrial activity, which could affect the concentrations of trace elements in the bed sediment.

Mixed land use

All land uses are incorporated into the mixed land-use category; therefore, it is not surprising that organochlorines were detected. Many uses of organochlorines, such as insect control in urban and agricultural areas, as well as industrial sources of these compounds, can contribute to the presence of organochlorines in the environment. Although concentrations of organochlorines in bed sediment from sites in the mixed land-use category were similar to those in most other land-use categories within the basin, frequencies of detection were greater for mixed land-use sites than for forest and agricultural land-use sites. Only the urban land-use category, which accounted for the smallest percentage of land use at most mixed land-use sites, had higher concentrations and more detections of organochlorines (figs. 5 and 6). Only two sites in the mixed land-use category had exceedances of the SQG TEC—Schuylkill River at Berne, Pa., and Rancocas Creek at Pemberton, N.J (fig.1, map locations 26 and 22). No exceedances of the SQG PEC were observed.

Total PAHs and total phthalates were detected in bed sediment samples from all sites in the mixed land-use category. The highest frequencies of detection and median concentrations for all land-use categories, except the urban and large-river sites, occurred at sites in the mixed land-use category. Five of the six sites in the mixed land-use category had exceedances of the SQG TEC. *P*-cresol had the second lowest frequency of detection and lowest median concentration in samples from mixed land-use sites when compared to any of the other land uses. Evaluation of molecular masses and concentration ratios (Yunker and others, 2002) indicated that potential sources of PAHs could include the combustion of grass and wood, coal, and number 2 fuel oil, diesel or shale oil, kerosene, and wood soot.

All trace elements were detected in bed-sediment samples from all sites in the mixed land-use category. Median concentrations of trace elements in samples from these sites were comparable to those in samples from most other land-use sites (figs. 14a and b). The number of exceedances of the SQG TEC in the mixed land-use category ranged from 5 to 8, and exceedances of the SQG PEC ranged from 0 to 3. Of the mixed land-use sites, the Schuylkill River at Berne, Pa., (fig.1, map location 26) had the highest number of exceedances of the SQG TEC and the SQG PEC, 8 and 3, respectively. This site had the lowest percentage of urban land use and the highest percentage of forest land use compared to other sites in the mixed land-use category, so multiple exceedances were not expected. The multiple exceedances of trace elements, along with the exceedances of organochlorine compounds and PAHs, could be indicative of a local source of contamination.

Urban Land Use

Samples from sites in the urban land-use category had the highest frequencies of detection and greatest median concentrations of most of the organic compounds for which compounds were analyzed in this study. Sites in this land-use category are most at risk for multiple exceedances of water-quality guidelines by multiple compounds, of which the effects on fish and sediment-dwelling organisms are unknown. The number of exceedances of the NYSDEC wildlife protective guidelines for organochlorine compounds per site in the urban land-use category ranged from one to three. The number of exceedances of the SQG PEC per site ranged from zero to five. Samples from one site, South Branch Pennsauken Creek at Cherry Hill, N.J., (fig.1, map location 24) had the most exceedances for both sets of guidelines.

Many organic compounds have been used in urban/residential practices in the Delaware River Basin, more so potentially, than in agricultural practices. Urban land has been greatly affected by the use of these compounds. An example of this is chlordane; until 1988, chlordane was used for termite control in residential/urban areas. In 1980, 10 million pounds of chlordane was used, and in 1985, 3.0 to 3.5 million pounds of chlordane was used in residential/urban areas for this purpose (Nowell and others, 1999). In this study, total chlordanes were detected more frequently, and at higher concentrations, in urban areas than all other land uses (fig. 6 and apps. 1 and 2). Some of the highest median concentrations and detection frequencies of total DDT, total chlordanes, total PCBs, dieldrin, total PAHs, and total phthalates were present in bed-sediment and whole white sucker samples from urban land-use sites compared with those in samples from other land-use sites (figs. 3-6 and 9). Concentrations of total DDT, total chlordanes, total PCB, dieldrin, and total PAHs at more than 60 percent of the urban sites exceeded the SQG TEC (figs. 4 and 9). At more than 25 percent of the urban sites where fish-tissue samples were collected, concentrations exceeded the NYSDEC wildlife protective guidelines (fig. 4). At sites where concentrations exceeded the SQG TEC for total PAHs, the median urban land-use percent was 12.7, and at sites where concentrations exceeded the SQG PEC for total PAHs, the median urban land-use percent was 41.9 percent. In contrast, at sites that did not exceed either guideline for total PAHs, the median urban land-use percent was 2.4. These results are similar to those found in a national study by Lopes and Furlong (2001). Statistically, concentrations of total DDT, total chlordanes, total PCB, and dieldrin in bed-sediment and whole white sucker samples were significantly and positively related to percentage of urban land-use.

Concentrations of total PAHs and total phthalates in bed-sediment samples also were related to percentage of urban land-use (table 18). These patterns likely are the result of the extensive use of these compounds in urban/residential settings in this river basin. By evaluation of molecular masses and concentration ratios (Yunker and others, 2002), it was determined that sources of total PAHs in the urban land-use category are likely the burning of grass or wood and the combustion of fossil fuels including kerosene, gasoline, asphalt, number 2 fuel oil, and diesel oil. A study by Mahler and others (2003) in Austin, Texas, shows that high concentrations of total PAHs

were coming from coal-tar sealed parking lots. This may be a source in the Delaware River Basin as well. *P*-cresol concentrations did not correlate with urban land-use percent at sites where *p*-cresol is mainly used; this could result from the short half-life of p-cresol in the gaseous phase, ranging from 4 to 8 hours, which allows little time for deposition into streams (California Air Resources Board, 1999).

Four of the eight trace elements (chromium, copper, lead, and zinc) in bed sediment were statistically related to urban land-use percent (table 18). All four of these metals are used in processes associated with urbanization, including household and industrial pipe manufacturing, use, and jointing. Arsenic, cadmium, copper, mercury, and zinc were detected in more than 50 percent of fish-liver samples (figs. 11a and b), whereas all trace elements analyzed for were detected in 100 percent of bed-sediment samples from the all land-use categories. Median concentrations for most trace elements in bed sediment from urban areas were higher than medians for all other land-use categories but lower than those for the large-river sites (figs. 14a and b). More than 70 percent of the concentrations of all trace elements, except arsenic (36 percent), exceeded the SQG TEC, but few exceeded the PEC (figs. 14a and b).

Large-River Sites

Organochlorine compounds were detected in bed-sediment samples from large-river sites at frequencies similar to those for urban and mixed land-use sites, but at frequencies lower than at other land-use sites. Whole white sucker samples from large-river sites, however, had higher detection frequencies and median concentrations of total DDT and total PCBs than those from most other land-use categories (fig. 4). Possible reasons for this are the age, size, and (or) percent of lipid concentration of the specimens collected from the large-river sites. The lipid percentages of the specimens from these sites were the highest of all specimens collected. Another reason for the high detection frequencies and median concentrations could be that a constant flow of organic compounds, however small, in the large rivers increases the potential for bioaccumulation to occur. Large-river sites also accounted for more exceedances of the NYSDEC wildlife protective guidelines per site than any of the other land-use categories except urban (fig. 4). Concentrations of total DDT, total chlordanes, total PCBs, and dieldrin in fish-tissue samples were consistently higher than those in the bed-sediment samples obtained from the large-river sites (fig. 17). Similarly, frequencies of detection of organochlorine compounds in fish-tissue samples were higher than those in the bed-sediment samples, with the exception for total DDT, which was detected in samples from all the fish-tissue and bed-sediment sites sampled. Fish-tissue samples from the Schuylkill River at Philadelphia, Pa., (fig.1, map location 35) contained the highest concentrations of total DDT, total chlordanes, total PCB, and dieldrin compared with samples from all of the other large-river sites (fig. 17), which is indicative of the large percentage of urban land use surrounding this site (fig. 1). State advisories often state that humans should avoid consuming any fish from the lower Schuylkill River (Pennsylvania Fish and Boat Commission, 2006).

Bed-sediment samples from large-river sites had the highest median concentration of *p*-cresol in samples from all land-use categories and second highest median concentrations of total PAHs and total phthalates, which were highest for urban sites (fig. 8). The land-use category with the next highest concentration of *p*-cresol was forest. Forests accounts for a large percentage of land cover at the large-river sites. Concentrations of total PAHs exceeded the SQG TEC in samples from all four large-river sites; none exceeded the PEC. Not surprisingly, the lowest concentrations of total PAHs (5,960 μg/kg) and total phthalates (190 μg/kg) in samples from the large-river sites were in samples from the Delaware River at Port Jervis, N.Y., (fig. 1, map location 3) which also has the lowest percentage of urban land use (1 percent). The opposite is true for *p*-cresol; samples from the Delaware River at Port Jervis, N.Y., (fig. 1, map location 3) contained the highest concentration (3,000 μg/kg). A local source may be a contributing factor. An evaluation of molecular masses and concentration ratios (Yunker and others, 2002) indicated sources of total PAHs could include the combustion of wood or grass, coal, diesel fuel, number 2 fuel oil, or crude oil. Other sources that are indicated are diesel oil, wood soot, and road dust.

In most cases, the relation between trace elements in fish livers and bed sediment from large-river sites are opposite to the relation between organic compounds in fish tissue and bed sediment at large-river sites. Trace elements, which were frequently detected in bed sediment from large-river sites, were detected much less frequently in the fish livers (fig. 18). The reason for the lower frequencies of detection of trace elements in fish livers could be that, as previously mentioned, many of the trace elements analyzed for in this study are not in the bioavailable form, and therefore, are not taken up by fish. Some trace elements, such as mercury, do not readily accumulate in the liver, but do so in muscle tissue (Brightbill and others, 2004). The frequency of detection of trace elements in bed sediment from large-river sites is similar to that of organic compounds. Although concentrations of most trace elements at all four sites exceeded the SQG TEC (the exception was mercury at Delaware River at Port Jervis, Pa. (fig. 1, map location 3)), the concentrations in samples collected at the Delaware River at Port Jervis, Pa. (fig. 1, map location 3), were consistently lower than the concentrations in samples from the other three large-river sites. This may be indicative of the high value of forest land-use percent and low value of urban land-use percent at that site.

Mining and Smelter Facilities

The sites at Lehigh River at Lehighton, Pa., and Schuylkill River at Berne, Pa., are downstream from what was

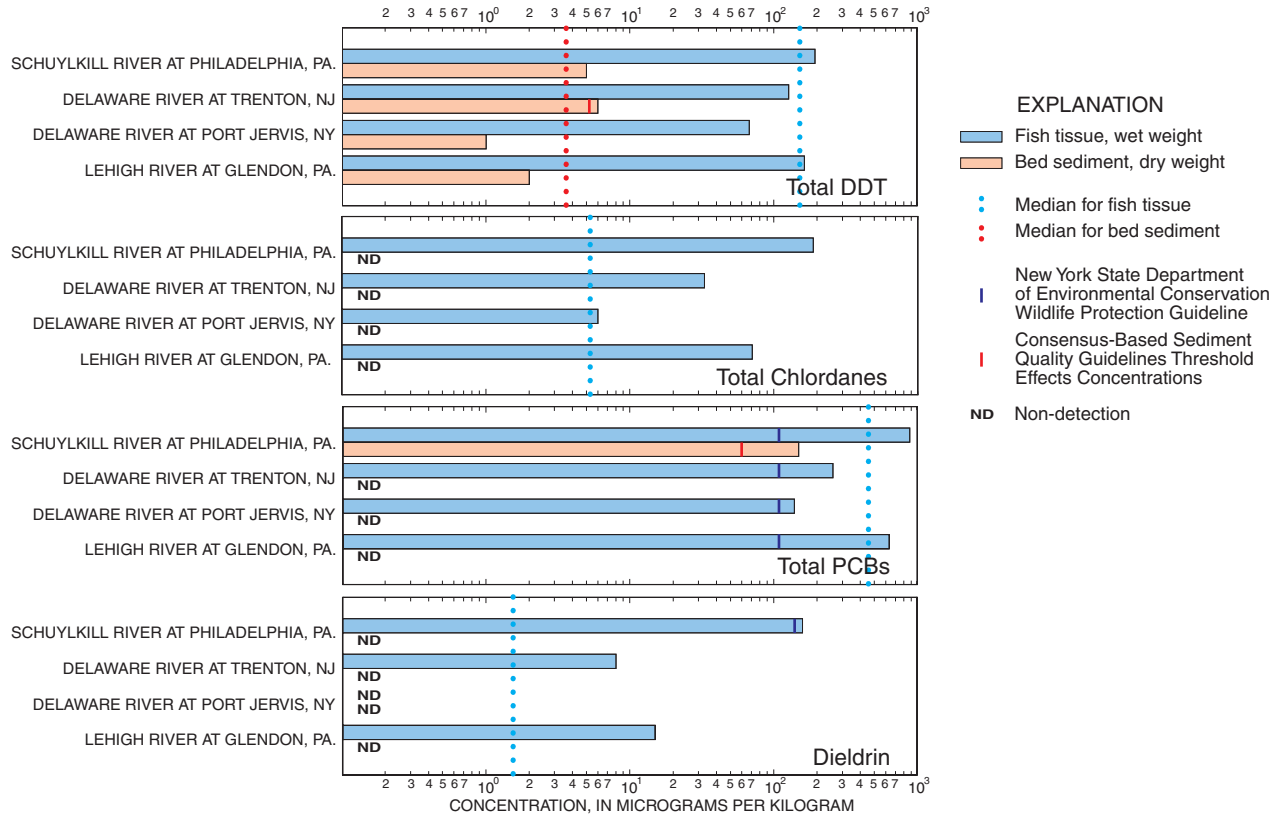

Figure 17. Concentrations of total DDT, total chlordane, total polychlorinated biphenyls (PCBs), and dieldrin in whole white sucker and bed-sediment samples from large-river sites, Delaware River Basin study unit, 1998-2000.

an extensive coal mining area more than 50 years ago (fig.1, map locations 11 and 26). This is reflected in the high concentrations of many trace elements in bed sediment from these sites. Sediment samples from the Lehigh River at Lehighton, Pa., (fig. 1, map location 11) had some of the highest concentrations of cadmium, copper, and zinc of any site sampled, and concentrations of arsenic and lead were also high (app. 5). The Schuylkill River at Berne, Pa., (fig. 1, map location 26) had some of the highest concentrations of lead (380 μg/g) and nickel (190 μg/g) as well as elevated concentrations of arsenic, cadmium, copper, and zinc (app. 5).

Another regional difference is that concentrations of cadmium and zinc in bed sediment were highest at the two Lehigh River sites (Lehigh River at Lehighton, Pa., and Lehigh River at Glendon, Pa., (fig. 1, map locations 11 and 16)) (app. 5), of any site sampled. Concentrations of both metals at both sites exceeded the PEC. These sites are near a former zinc smelter and current superfund site that contaminated a large local region through airborne processes (Carline and Jobsis, 1989). The site with the next highest concentrations of cadmium (4.4 μg/g) and zinc (910 μg/g) was the Delaware River at Trenton, N.J., (fig. 1, map location 18) (app. 5) which is downstream from the Lehigh River. No historical data were available for additional sites upstream and downstream from the smelter.

Geology

Some trace elements were not found to be related to land use, but were found to be related to a specific region of the Delaware River Basin. In particular, arsenic was found to be associated with geologic formations that crop out in the western part of the New Jersey Coastal Plain near the Delaware Bay (figs. 1 and 19). Three bed-sediment sites sampled in the Coastal Plain as part of the Delaware NAWQA study had the highest arsenic concentrations of any site in the basin (Raccoon Creek near Swedesboro, N.J. (42 μg/g); South Branch Pennsauken Creek at Cherry Hill, N.J. (33 μg/g); and Cooper River at Haddonfield, N.J. (57 μg/g)) (fig. 1, map locations 40, 24, and 25). To examine this finding in greater detail, additional Coastal Plain bed-sediment data from 153 sites (NJDEP/USGS cooperative monitoring program) and soil data from 213 sites sampled as part of the National Uranium Resource Evaluation Program (NURE) were examined to assess the spatial trends in arsenic (Grosz and others, 2000). Coastal Plain

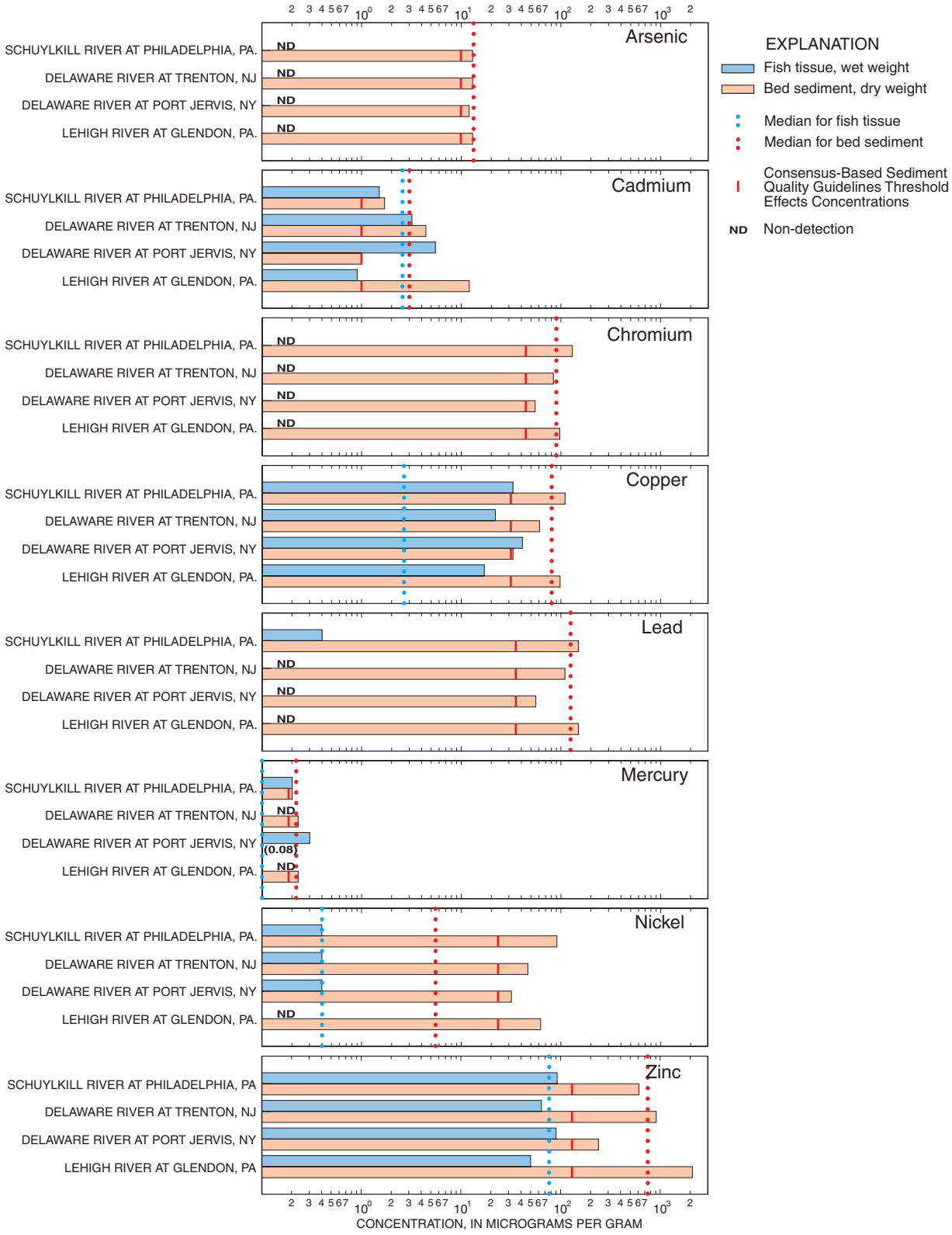

Figure 18. Concentrations of trace elements in white sucker liver and bed-sediment samples from large-river sites, Delaware River Basin study unit, 1998-2000.

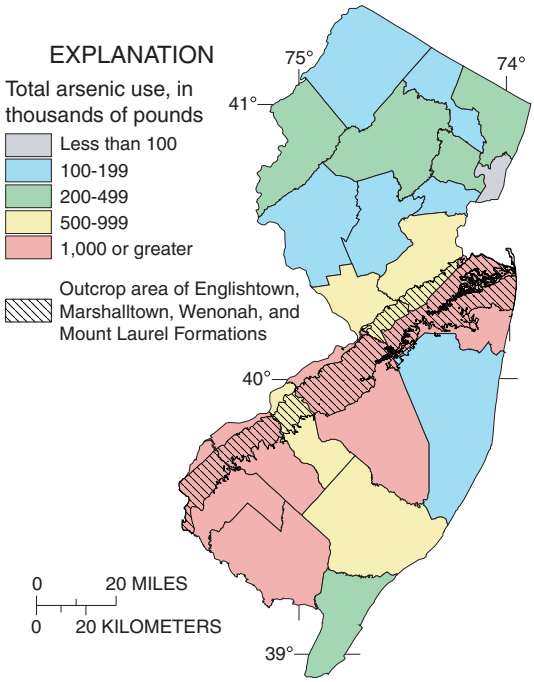

Figure 19. Total arsenic use in New Jersey, 1900-80. (Data from Murphy and Aucott, 1998)

bed-sediment data were retrieved using the U.S. Geological Survey National Water-Quality database (QWDATA, available on the World Wide Web at URL *http://waterdata.usgs.gov/nj/nwis/qw*). These data indicated arsenic concentrations were highest in streams in the western outcrops that parallel the Delaware River, in particular the Englishtown, Marshalltown, Wenonah, and Mount Laurel formations (fig. 19). High arsenic concentrations also were recorded in the fish-liver data from this area. High arsenic concentrations were not found farther east in the outcrop area of the Kirkwood and Cohansey Formations. Some of the formations in the western Coastal Plain may contain greater natural arsenic concentrations in the glauconitic clays or have a greater ability to bind arsenic. This addition of arsenic (as mentioned on page 5), along with the natural bonding ability of clays, could result in the high concentrations of arsenic seen in the sites previously mentioned.

Summary and Conclusions

From 1998 to 2000, fish-tissue and bed-sediment samples were collected as part of the National Water-Quality Assessment (NAWQA) Program studies in the Delaware River Basin. A survey was conducted to determine concentrations of organic compounds in fish tissue and bed sediment, trace elements in fish livers and bed sediment, and semi-volatile organic compounds in bed sediment. Bed-sediment samples were collected from 39 sites, whole white sucker samples were collected from 25 sites, and white sucker liver samples were collected from 20 sites. Data were analyzed to determine how frequently different compounds occurred, and concentrations were compared to established environmental, wildlife, and human-consumption guidelines. Comparisons also were made to data from other NAWQA studies across the Nation. Samples were assessed by forest, low-agricultural, agricultural, mixed, and urban land-use categories, as well as large-river sites, and concentrations and frequencies of detection were compared to determine whether particular compounds were associated with different land-use categories.

Organochlorine compounds such as total DDT, total polychlorinated biphenyls (PCBs), total chlordanes, and dieldrin were the most frequently detected compounds in the fish-tissue and bed-sediment samples from the Delaware River Basin. All of the compounds were detected more frequently in fish tissue than in bed sediment, which indicates they are being bioaccumulated or biomagnified. In fish tissue, total DDT was the most frequently detected compound (92 percent of sites), followed by total PCBs (84 percent), total chlordanes (72 percent), and dieldrin (60 percent). PCBs exceeded the wildlife-protective guidelines for whole white suckers, common carp, and smallmouth bass more frequently than any other compound (in 62 percent of the samples), followed by total DDT (22 percent), and dieldrin (16 percent). Concentrations of all four compounds in bed sediment exceeded the Sediment Quality Guidelines Threshold Effects Concentrations (SQG TEC) at more than 20 percent of the sites. The SQG Probable Effects Concentrations (PEC) was exceeded only by total chlordanes and dieldrin at 18 and 2.5 percent of sites, respectively. Constituent concentrations in bass fillets from 6 sites did not exceed the U.S. Food and Drug Administration Action Levels for Commercial Transport and Sale of Fish for any compound. Although the production of all these organochlorine compounds was banned more than 25 years ago, many of the compounds still persist in the environment and are recycled in aquatic ecosystems.

At least one or more semi-volatile organic compounds (SVOCs) were detected at every site sampled for bed sediment in the Delaware River basin. Total polycyclic aromatic hydrocarbons (PAHs) were the most frequently detected compounds (at more than 90 percent of sites) followed by total phthalates (72 percent) and phenols (54 percent). Total PAHs exceeded the TEC for bed sediment at 66 percent of the sites and the PEC at 18 percent of sites. Guidelines do not exist for other detected SVOC compounds.

All eight trace elements (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc) were detected in samples from 97 percent of the bed-sediment sites and in many of the white sucker liver samples. The TECs were exceeded at more than 90 percent of the sites by chromium, copper, lead, nickel, and zinc; the remaining trace elements exceeded the TECs at more than 40 percent of the sites. The PECs were exceeded most often by lead, chromium, zinc, and nickel (at 26, 21, 18, and 16 percent of the sites, respectively). Concentrations of arsenic, cadmium, and copper exceeded

the PECs at about 5 percent of the sites. Some of the highest concentrations of arsenic in sediment were those in samples from the western Coastal Plain where geologic formations containing arsenic crop out. In those areas the high concentrations of arsenic could be related to either natural deposits or to past applications of arsenical pesticides. Although trace elements are present at low concentrations in many geologic environments, their presence at high concentrations in many streams indicates that sediment-dwelling organisms may be at risk from high concentrations of multiple trace elements.

The effects of urbanization and human activity, past and present, are apparent within the Delaware River Basin. Most organic compounds and trace elements were detected more frequently and at higher concentrations in urban basins than in basins in other land-use categories. Many significant positive correlations were evident between the individual compound detections and concentrations (in bed sediment and fish tissue) and urban land-use percent or population density. Concentrations of the organic compounds total DDT, total PCBs, total chlordanes, dieldrin, total PAHs, and phthalates were correlated with urban land-use percent and (or) population density. Concentrations of the trace elements cadmium, chromium, copper, lead, mercury, and zinc also were shown to be positively correlated with population density or urban land-use percent. Concentrations of most organic compounds and many trace elements in bed-sediment samples from urban sites exceeded sediment quality guidelines or wildlife protective guidelines more often than those from other sites. For instance, concentrations of total DDT, total PCBs and dieldrin in whole white sucker samples from sites in the urban land-use category exceeded the wildlife protection guidelines more often than those from other land-use categories. Similarly, concentrations of dieldrin, total PAHs, chromium, lead, nickel, and zinc in bed-sediment samples from sites in the urban land-use category accounted for the greatest number of exceedances of the PECs. In combination, these findings indicate that fish and sediment-dwelling organisms are under stress from multiple contaminants in urban environments, which can have adverse effects for the entire ecosystem.

Large rivers tend to integrate the effects of all land uses. In the Delaware River Basin, most large-river sites, as well as mixed land-use sites, mirror many of the conditions at urban land-use sites. For example, concentrations of organic compounds and trace elements in many fish-tissue samples from large-river sites exceeded wildlife protection guidelines. Concentrations in bed sediment frequently exceeded the TECs, and PECs were exceeded at frequencies similar to those for urban sites. The Delaware River above Port Jervis, which remains primarily a forest basin, is the one large-river site in the Delaware River Basin at which concentrations of organic compounds or trace elements rarely exceeded a bed-sediment criteria or wildlife guideline. In contrast, sites on the Schuylkill and Lehigh Rivers, and the Delaware River downstream from its confluence with the Lehigh, still show the effects of current and past urban, mining, and industrial activities. For example, organochlorine concentrations in small mouth bass fillets collected at these sites indicate that humans should limit consumption of fish from the Lehigh and Delaware Rivers and avoid eating fish from the lower Schuylkill River (as is often indicated in State advisories) because of PCB contamination. In another instance, the highest concentrations of cadmium and zinc were present in bed-sediment samples from the Lehigh River (and a downstream site on the Delaware) and are likely related to mineral extraction and smelting activities.

In general, median concentrations and frequencies of detection of organic compounds and trace elements in white sucker and bed-sediment samples from forest and low-agricultural land-use sites were more often lower than median concentrations and frequencies of detections in samples from sites in all other land-use categories, except agricultural. Samples from sites in the forest land-use category had few exceedances of any guidelines. Compounds that were detected as frequently or more frequently in samples from forest land-use sites than in samples from agricultural sites include total PAHs, total phthalates, phenols, arsenic, cadmium, copper, and mercury. Total DDT was often detected, most likely because it was formerly used widely in all land-use settings to control insects. Total PAHs could be present because they result from incomplete combustion during forest fires or are contributed by runoff from roads. Atmospheric sources could account for elevated concentrations of total phthalates and phenols. Most forest sites are at higher elevations with lower temperatures than other land-use sites that favor condensation of chemicals, and the high surface area of leaves can increase scavenging of chemicals from the air. High concentrations of cadmium and zinc in samples from a Lehigh River site may be due to a local smelter.

Median concentrations and frequencies of detection of organic compounds and trace elements in samples of whole white suckers and bed sediment from agricultural lands were similar or lower than concentrations and frequencies in samples from other land-use categories. Total DDT, the one exception, was present in high concentrations that probably can be attributed to the former use of DDT in farming practices. Concentrations of total DDT and PCBs exceeded NYSDEC wildlife protective guidelines in samples from four agricultural land-use sites, PCB at three sites, and total DDT at one site. Even though many TECs for trace elements were exceeded, (except cadmium and mercury), there were few exceedances of the PEC. Only chromium exceeded the PEC; the exceedances occurred in samples from 11 percent of the sites.

The guidelines for organochlorine compounds, total PAHs, and trace elements used in this report are for single compounds. Exceedances of any one of the guidelines in itself is of concern because they indicate the potential threats not only to the aquatic ecosystem, but to higher level predators and even to humans that come in contact with that environment. The potential for synergistic effects that multiple contaminants could have on aquatic life, however, is largely unknown and could pose additional threats to the environment.

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Appendixes 1-5

Appendix 1. Organochlorine compounds in whole white sucker samples and land-use category at sample collection sites, Delaware River Basin study unit, 1998-2000.

[ND, non-detect; PCBs, total polychlorinated biphenyls; concentrations are in micrograms per kilogram]

Station number	Station name	Land-use category	Total DDT	Total chlordane	Total PCBs	Dieldrin
01423000	West Branch Delaware River at Walton, N. Y.	Low agricultural	10	ND	80	ND
01431500	Lackawaxen River at Hawley, Pa.	Low agricultural	ND	ND	ND	ND
01434000	Delaware River at Port Jervis, N.Y.	Large river	68	6	140	ND
01435000	Neversink River near Claryville, N.Y.	Forest	8	ND	ND	ND
01437500	Neversink River at Goddeffroy, N. Y.	Forest	27	ND	80	ND
01439550	Bush Kill at Bushkill, Pa.	Forest	ND	ND	ND	ND
01440000	Flat Brook near Flatbrookville, N.J.	Forest	39	ND	70	ND
01442110	Brodhead Creek at Stroudsburg, Pa.	Forest	35	5	100	ND
01451425	Little Lehigh Creek at East Texas, Pa.	Agriculture	113	13	150	6
01451800	Jordan Creek near Schnecksville, Pa.	Agriculture	151	5	ND	26
01454700	Lehigh River at Glendon, Pa.	Large river	165	71	640	15
01463500	Delaware River at Trenton, N.J.	Large river	128	33	260	8
01464907	Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	Urban	108	61	240	24
01467040	Pennypack Creek at Paper Mill, Pa.	Urban	28	53	130	56
01467081	South Branch Pennsauken Creek at Cherry Hill, N.J.	Urban	294	139	200	180
01467150	Cooper River at Haddonfield, N.J.	Urban	385	190	590	55
01470779	Tulpehocken Creek near Bernville, Pa.	Agriculture	75	56	130	12
01471520	Wyomissing Creek at West Reading, Pa.	Urban	73	59	80	12
01471668	Hay Creek near Birdsboro, Pa.	Low agricultural	13	15	90	ND
01471980	Manatawny Creek near Pottstown, Pa.	Agriculture	146	24	340	25
01472157	French Creek near Phoenixville, Pa.	Agriculture	15	ND	80	ND
01473990	Wissahickon Creek below Walnut Lake near Manayunk, Pa.	Urban	148	188	470	120
01474500	Schuylkill River at Philadelphia, Pa.	Large river	195	188	890	160
01475510	Darby Creek near Darby, Pa.	Urban	104	270	360	530
01477120	Raccoon Creek near Swedesboro, N.J.	Agriculture	217	5	90	23

Appendix 2. Organochlorine compounds in bed-sediment samples and land-use category at sample collection sites, Delaware River Basin study unit, 1998-2000.

[ND, non-detect; PCBs, polychlorinated biphenyls; all concentrations are in micrograms per kilogram]

Station number	Station name	Land-use category	Total DDT	Total chlordane	Total PCBs	Dieldrin
01423000	West Branch Delaware River at Walton, N.Y.	Low agricultural	ND	ND	ND	ND
01431500	Lackawaxen River at Hawley, Pa.	Low agricultural	1	ND	ND	ND
01434000	Delaware River at Port Jervis, N.Y.	Large river	1	ND	ND	ND
01435000	Neversink River Near Claryville, N.Y.	Forest	ND	ND	ND	ND
01437500	Neversink River at Godeffroy, N.Y.	Forest	ND	ND	ND	ND
01439500	Bush Kill at Shoemakers, Pa.	Forest	1	ND	ND	ND
01440000	Flat Brook near Flatbrookville, N.J.	Forest	ND	ND	ND	ND
01442500	Brodhead Creek at Minisink Hills, Pa.	Forest	1	ND	ND	ND
01449000	Lehigh River at Lehighton, Pa.	Forest	9	ND	ND	ND
01451425	Little Lehigh Creek at East Texas, Pa.	Agriculture	5	ND	ND	ND
01451624	Cedar Creek above Lake Muhlenberg at Allentown, Pa.	Urban	11	3	ND	ND
01451800	Jordan Creek near Schnecksville, Pa.	Agriculture	5	ND	ND	ND
01452500	Monocacy Creek at Bethlehem, Pa.	Mixed	4	ND	ND	ND
01454700	Lehigh River at Glendon, Pa.	Large river	2	ND	ND	ND
01462100	Pidcock Creek near New Hope, Pa.	Agriculture	1	ND	ND	ND
01463500	Delaware River at Trenton, N.J.	Large river	6	ND	ND	ND
01463810	Shabakunk Creek near Lawrenceville, N.J.	Urban	97	35	220	12
01464710	Pine Run at Chalfont, Pa.	Mixed	1	ND	ND	ND
01464907	Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	Urban	5	ND	100	ND
01467000	North Branch Rancocas Creek at Pemberton, N.J.	Mixed	12	ND	ND	ND
01467040	Pennypack Creek at Paper Mill, Pa.	Urban	7	16	130	5
01467081	South Branch Pennsauken Creek at Cherry Hill, N.J.	Urban	133	63	ND	24
01467150	Cooper River at Haddonfield, N.J.	Urban	29	49	ND	6
01470500	Schuylkill River at Berne, Pa.	Mixed	2	ND	140	ND
01470779	Tulpehocken Creek near Bernville, Pa.	Agriculture	ND	ND	ND	ND

Appendix 2. Organochlorine compounds in bed-sediment samples and land-use category at sample collection sites, Delaware River Basin study unit, 1998-2000.—Continued

[ND, non-detect; PCBs, polychlorinated biphenyls; all concentrations are in micrograms per kilogram]

Station number	Station name	Land-use category	Total DDT	Total chlordane	Total PCBs	Dieldrin
01471520	Wyomissing Creek at West Reading, Pa.	Urban	61	42	220	ND
01471668	Hay Creek near Birdsboro, Pa.	Low agricultural	ND	ND	ND	ND
01471980	Manatawny Creek near Pottstown, Pa.	Agriculture	3	ND	ND	ND
01472100	Pigeon Creek near Parker Ford, Pa.	Agriculture	1	ND	ND	ND
01472157	French Creek near Phoenixville, Pa.	Agriculture	1	ND	ND	ND
01473470	Stony Creek at Steriger Street st Norristown, Pa.	Urban	2	ND	ND	ND
01473990	Wissahickon Creek below Walnut Lake near Manayunk, Pa.	Urban	43	60	100	27
01474500	Schuylkill River at Philadelphia, Pa.	Large river	5	ND	150	ND
01475430	Darby Creek at Foxcroft, Pa.	Urban	6	34	ND	14
01475510	Darby Creek near Darby, Pa.	Urban	23	73	140	65
01475845	Crum Creek at Goshen Road near Whitehorse, Pa.	Mixed	1	3	ND	3
01476470	Ridely Creek near Media, Pa.	Mixed	1	ND	ND	ND
01477120	Raccoon Creek near Swedesboro, N.J.	Agriculture	36	ND	ND	3
01480665	East Branch Brandywine Creek near Dorlan, Pa.	Agriculture	ND	ND	ND	ND

Appendix 3. Semi-volatile organic compounds in bed-sediment samples and land-use category at sample collection sites, Delaware River Basin study unit, 1998-2000.

[ND, non-detect; PAHs, polycyclic aromatic hydrocarbons; all values in micrograms per kilogram]

Station number	Station name	Land-use category	Total PAHs	Phenols	Total phthalates
01423000	West Branch Delaware River at Walton, N.Y.	Low agricultural	107,090	270	107,360
01431500	Lackawaxen River at Hawley, Pa.	Low agricultural	2,450	150	2,600
01434000	Delaware River at Port Jervis, N.Y.	Large river	5,960	3,000	8,960
01435000	Neversink River Near Claryville, N.Y.	Forest	1,000	190	ND
01437500	Neversink River at Godeffroy, N.Y.	Forest	5,980	920	6,900
01439500	Bush Kill at Shoemakers, Pa.	Forest	320	980	ND
01440000	Flat Brook near Flatbrookville, N.J.	Forest	110	ND	ND
01442500	Brodhead Creek at Minisink Hills, Pa.	Forest	1,410	200	1,610
01449000	Lehigh River at Lehighton, Pa.	Forest	34,390	4,400	38,790
01451425	Little Lehigh Creek at East Texas, Pa.	Agriculture	1,480	ND	ND
01451624	Cedar Creek above Lake Muhlenberg at Allentown, Pa.	Urban	13,120	1,800	14,920
01451800	Jordan Creek near Schnecksville, Pa.	Agriculture	3,990	ND	3,990
01452500	Monocacy Creek at Bethlehem, Pa.	Mixed	15,840	420	16,260
01454700	Lehigh River at Glendon, Pa.	Large river	12,270	1,200	13,470
01462100	Pidcock Creek near New Hope, Pa.	Agriculture	ND	180	180
01463500	Delaware River at Trenton, N.J.	Large river	8,240	380	8,620
01463810	Shabakunk Creek near Lawrenceville, N.J.	Urban	37,390	840	38,230
01464710	Pine Run at Chalfont, Pa.	Mixed	1,980	ND	1,980
01464907	Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	Urban	2,050	ND	ND
01467000	North Branch Rancocas Creek at Pemberton, N.J.	Mixed	730	ND	730
01467040	Pennypack Creek at Paper Mill, Pa.	Urban	15,360	ND	15,360
01467081	South Branch Pennsauken Creek at Cherry Hill, N.J.	Urban	32,810	110	32,920
01467150	Cooper River at Haddonfield, N.J.	Urban	8,070	ND	8,070
01470500	Schuylkill River at Berne, Pa.	Mixed	4,400	220	4,620
01470779	Tulpehocken Creek near Bernville, Pa.	Agriculture	700	ND	ND

Appendix 3. Semi-volatile organic compounds in bed-sediment samples and land-use category at sample collection sites, Delaware River Basin study unit, 1998-2000.—Continued

[ND, non-detect; PAHs, polycyclic aromatic hydrocarbons; all values in micrograms per kilogram]

Station number	Station name	Land-use category	Total PAHs	Phenols	Total phthalates
01471520	Wyomissing Creek at West Reading, Pa.	Urban	38,320	2,300	40,620
01471668	Hay Creek near Birdsboro, Pa.	Low agricultural	3,070	ND	ND
01471980	Manatawny Creek near Pottstown, Pa.	Agriculture	520	ND	ND
01472100	Pigeon Creek near Parker Ford, Pa.	Agriculture	ND	ND	ND
01472157	French Creek near Phoenixville, Pa.	Agriculture	ND	ND	ND
01473470	Stony Creek at Steriger Street st Norristown, Pa.	Urban	15,800	ND	15,800
01473990	Wissahickon Creek below Walnut Lake near Manayunk, Pa.	Urban	25,340	240	25,580
01474500	Schuylkill River at Philadelphia, Pa.	Large river	9,870	870	10,740
01475430	Darby Creek at Foxcroft, Pa.	Urban	14,860	ND	14,860
01475510	Darby Creek near Darby, Pa.	Urban	48,550	980	49,530
01475845	Crum Creek at Goshen Road near Whitehorse, Pa.	Mixed	4,840	250	5,090
01476470	Ridely Creek near Media, Pa.	Mixed	3,520	ND	3,520
01477120	Raccoon Creek near Swedesboro, N.J.	Agriculture	ND	ND	ND
01480665	East Branch Brandywine Creek near Dorlan, Pa.	Agriculture	360	ND	ND

Appendix 4. Trace elements in white sucker liver samples and land-use category at sample collection sites, Delaware River Basin study unit, 1998-2000.

[ND, non-detect; NU, not used; As, arsenic; Cd, cadmium; Cr, chromium; Cu, copper; Pb, lead; Hg, mercury; Ni, nickel; Zn, zinc; all concentrations in micrograms per gram]

Station number	Station name	Land use category	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
01423000	West Branch Delaware River at Walton, N. Y.	Low agricultural	0.4	2.0	ND	34	ND	0.4	1.0	83
01434000	Delaware River at Port Jervis, N.Y.	Large river	ND	5.5	ND	41	ND	.3	.4	90
01435000	Neversink River near Claryville, N.Y.	Forest	.4	5.8	ND	29	ND	.3	.4	83
01437500	Neversink River at Goddeffroy, N. Y.	Forest	ND	3.1	ND	22	ND	.3	ND	70
01442110	Brodhead Creek at Stroudsburg, Pa.	Forest	.4	1.6	ND	28	ND	.2	ND	67
01451425	Little Lehigh Creek at East Texas, Pa.	Agriculture	.5	1.1	0.5	27	ND	ND	ND	91
01451800	Jordan Creek near Schnecksville, Pa.	Agriculture	.4	1.8	ND	23	ND	.2	.4	91
01454700	Lehigh River at Glendon, Pa.	Large river	ND	.9	ND	17	ND	ND	ND	50
01463500	Delaware River at Trenton, N.J.	Large river	ND	3.2	ND	22	ND	ND	.4	64
01464907	Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	Urban	.4	.8	ND	61	ND	NU	ND	160
01467040	Pennypack Creek at Paper Mill, Pa.	Urban	.4	2.3	ND	76	ND	.2	ND	170
01467150	Cooper River at Haddonfield, N.J.	Urban	ND	.3	ND	24	ND	ND	.6	65
01470779	Tulpehocken Creek near Bernville, Pa.	Agriculture	.6	.6	ND	80	ND	ND	.5	140
01471520	Wyomissing Creek at West Reading, Pa.	Urban	.6	.7	ND	48	.4	.2	ND	110
01471668	Hay Creek near Birdsboro, Pa.	Low agricultural	.5	.7	0.6	56	ND	NU	.7	130
01471980	Manatawny Creek near Pottstown, Pa.	Agriculture	.4	.9	ND	30	ND	ND	.4	81
01472157	French Creek near Phoenixville, Pa.	Agriculture	.4	2.1	ND	33	ND	ND	ND	80
01473990	Wissahickon Creek below Walnut Lake near Manayunk, Pa.	Urban	ND	ND	ND	43	ND	ND	ND	89
01474500	Schuylkill River at Philadelphia, Pa.	Large river	ND	1.5	ND	33	.4	.2	.4	92
01475510	Darby Creek near Darby, Pa.	Urban	ND	1.5	ND	61	ND	.2	ND	130

Appendix 5. Trace elements in bed-sediment samples and land-use category at sample collection sites, Delaware River Basin study unit, 1998-2000.

[ND, non-detect; As, arsenic; Cd, cadmium; Cr, chromium; Cu, copper; Pb, lead; Hg, mercury; Ni, nickel; Zn, zinc; all concentrations are in micrograms per gram]

Station number	Station name	Land-use category	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
01423000	West Branch Delaware River at Walton, N.Y.	Low agricultural	15	0.8	66	150	92	0.16	32	340
01431500	Lackawaxen River at Hawley, Pa.	Low agricultural	9	1.6	52	34	80	0.12	22	190
01434000	Delaware River at Port Jervis, N.Y.	Large river	12	1	55	33	56	0.08	32	240
01435000	Neversink River Near Claryville, N.Y.	Forest	9.8	0.7	44	19	42	0.6	20	160
01437500	Neversink River at Godeffroy, N.Y.	Forest	6.6	1.6	42	43	77	0.1	25	320
01440000	Flat Brook near Flatbrookville, N.J.	Forest	8	1.1	150	64	67	0.13	34	430
01442500	Brodhead Creek at Minisink Hills, Pa.	Forest	8.4	1	63	48	66	0.13	27	280
01449000	Lehigh River at Lehighton, Pa.	Forest	21	6.3	78	180	170	0.3	180	1,600
01451425	Little Lehigh Creek at East Texas, Pa.	Agriculture	14	0.7	74	38	50	0.09	47	200
01451624	Cedar Creek above Lake Muhlenberg at Allentown, Pa.	Urban	12	1	70	62	96	0.28	36	300
01451800	Jordan Creek near Schnecksville, Pa.	Agriculture	8.2	0.5	70	38	40	0.07	33	190
01452500	Monocacy Creek at Bethlehem, Pa.	Mixed	8.8	0.8	63	50	62	0.15	33	240
01454700	Lehigh River at Glendon, Pa.	Large river	13	12	97	98	150	0.23	63	2,100
01462100	Pidcock Creek near New Hope, Pa.	Agriculture	11	0.1	72	36	31	0.05	30	120
01463500	Delaware River at Trenton, N.J.	Large river	13	4.4	84	61	110	0.23	47	910
01463810	Shabakunk Creek near Lawrenceville, N.J.	Urban	9.2	1.5	78	82	210	0.21	32	400
01464710	Pine Run at Chalfont, Pa.	Mixed	8	0.2	79	34	42	0.07	32	150
01464907	Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	Urban	7.1	0.5	72	59	47	0.07	29	160
01467000	North Branch Rancocas Creek at Pemberton, N.J.	Mixed	13	0.7	57	60	160	0.23	12	100
01467040	Pennypack Creek at Paper Mill, Pa.	Urban	5.8	1	66	55	71	0.12	24	270
01467081	South Branch Pennsauken Creek at Cherry Hill, N.J.	Urban	33	2.2	140	76	120	0.26	36	480
01467150	Cooper River at Haddonfield, N.J.	Urban	57	3	150	69	180	0.34	43	480
01470500	Schuylkill River at Berne, Pa.	Mixed	16	2.2	66	85	380	0.25	190	810
01470779	Tulpehocken Creek near Bernville, Pa.	Agriculture	27	0.3	69	32	38	0.07	35	150
01471520	Wyomissing Creek at West Reading, Pa.	Urban	8.5	1.2	88	110	160	0.69	43	380

Appendix 5. Trace elements in bed-sediment samples and land-use category at sample collection sites, Delaware River Basin study unit, 1998-2000.—Continued

[ND, non-detect; As, arsenic; Cd, cadmium; Cr, chromium; Cu, copper; Pb, lead; Hg, mercury; Ni, nickel; Zn, zinc; all concentrations are in micrograms per gram]

Station number	Station name	Land-use category	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
01471668	Hay Creek near Birdsboro, Pa.	Low agricultural	10	0.5	63	48	47	0.13	39	170
01471980	Manatawny Creek near Pottstown, Pa.	Agriculture	5.5	0.5	73	40	45	0.09	29	170
01472100	Pigeon Creek near Parker Ford, Pa.	Agriculture	8.2	ND	67	29	38	0.06	30	120
01472157	French Creek near Phoenixville, Pa.	Agriculture	5.6	0.6	72	51	44	0.12	30	200
01473470	Stony Creek at Steriger Street st Norristown, Pa.	Urban	7.1	0.5	75	42	90	0.1	30	220
01473990	Wissahickon Creek below Walnut Lake near Manayunk, Pa.	Urban	6.9	1.1	85	130	170	0.56	39	340
01474500	Schuylkill River at Philadelphia, Pa.	Large river	13	1.7	130	110	150	0.2	92	610
01475430	Darby Creek at Foxcroft, Pa.	Urban	6.7	0.6	170	53	77	0.36	96	230
01475510	Darby Creek near Darby, Pa.	Urban	10	1.9	100	95	160	0.46	48	420
01475845	Crum Creek at Goshen Road near Whitehorse, Pa.	Mixed	7.1	0.3	120	36	51	0.12	77	200
01476470	Ridely Creek near Media, Pa.	Mixed	5.2	0.1	140	42	46	0.12	100	160
01477120	Raccoon Creek near Swedesboro, N.J.	Agriculture	42	2.7	190	36	55	0.17	42	300
01480665	East Branch Brandywine Creek near Dorlan, Pa.	Agriculture	6.5	0.2	72	27	49	0.08	28	170

For additional information, write to:
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