Water Quality in the Long Island-New Jersey Coastal Drainages

New Jersey and New York, 1996–98

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

Circular 1201

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Front Cover: Based on the power of the Great Falls of the Passaic River at Paterson, N.J., Alexander Hamilton founded his Society for the Establishment of Useful Manufactures. Supported by private investors, this business venture was an 18th-century industrial park that Hamilton hoped would demonstrate the ability of the United States to be successful in manufacturing. It grew into one of the first centers of heavy industry in the United States (modified from: *A biography of Alexander Hamilton, 1755–1804* at http://odur.let.rug.nl/~usa/B/hamilton/hamilxx.htm, July 2000). *(Photograph by Timothy Reed.)*

Opposite Page: False color, thematic mapping satellite image of the study area, 1992. *(Digital image provided by Stephen Howard, Land Cover Applications Center, Raytheon, USGS EROS Data Center, Sioux Falls, S.Dak.)*

Back Cover: Photograph lower left, sampling the fish community on the Saddle River at Ridgewood, N.J., with a barge electrofisher; and lower right, sampling a ground-water monitoring well in southern New Jersey. *(Photographs by Mark Ayers.)*

Water Quality in the Long Island–New Jersey Coastal Drainages, New York and New Jersey, 1996–98

By Mark A. Ayers, Jonathan G. Kennen, *and* Paul E. Stackelberg

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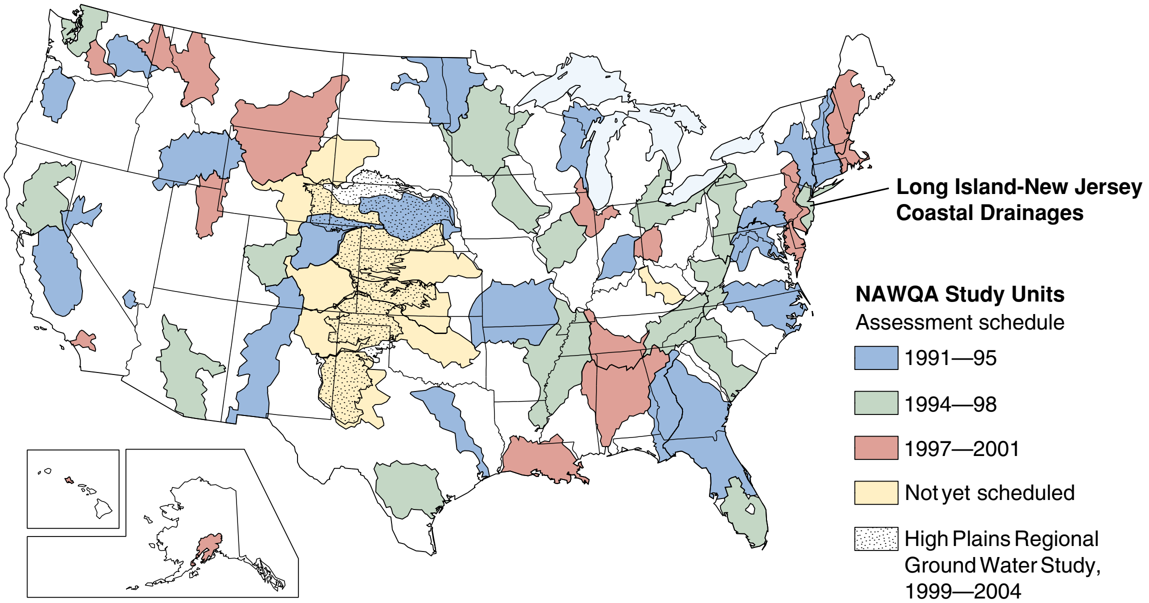
CONTENTS

NATIONAL PERSPECTIVES ON WATER-QUALITY CONDITIONS—

THIS REPORT summarizes major findings about water quality in New Jersey and on Long Island, N.Y., that emerged from an assessment conducted between 1996 and 1998 by the National Water-Quality Assessment (NAWQA) Program. Water quality is discussed in terms of local and regional issues and compared to conditions found in all 36 NAWQA study areas, called Study Units, assessed to date. Findings also are explained in the context of selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms. The NAWQA Program was not intended to assess the quality of the Nation's drinking water, such as by monitoring water from household taps. Rather, the assessments focus on the quality of the resource itself, thereby complementing many ongoing Federal, State, and local drinking-water monitoring programs. The comparisons made in this report to drinking-water standards and guidelines are only in the context of the available untreated resource. Finally, this report includes information about the status of aquatic communities and the condition of instream habitats as elements of a complete water-quality assessment.

Many topics covered in this report reflect the concerns of officials of State and Federal agencies, water-resource managers, and members of stakeholder groups who provided advice and input during the LINJ assessment. Long Island and New Jersey residents who wish to know more about water quality in the areas where they live will find this report informative as well.

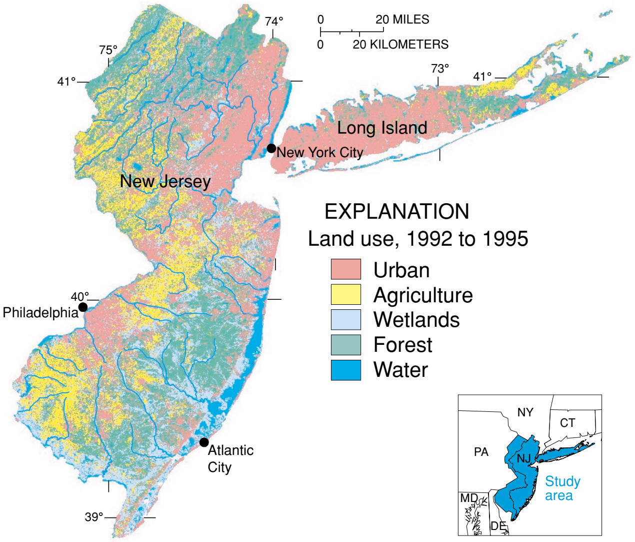


THE NAWQA PROGRAM of the U.S. Geological Survey (USGS) seeks to improve scientific and public understanding of water quality in the Nation's major river basins and ground-water systems. Better understanding facilitates effective resource managment, accurate identification of water-quality priorities, and successful development of strategies that protect and restore water quality. Guided by a nationally consistent study design and shaped by ongoing communication with local, state, and Federal agencies, NAWQA assessments support the investigation of local issues and trends while providing a firm foundation for understanding water quality at regional and national scales. The ability to integrate local and national scales of data collection and analysis is a unique feature of the USGS NAWQA Program.

The Long Island–New Jersey Coastal Drainages (LINJ) is one of 51 water-quality assessments initiated since 1991, when the U.S. Congress appropriated funds for the USGS to begin the NAWQA Program. As indicated on the map, 36 assessments have been completed, and 15 more assessments will conclude in 2001. Collectively, these assessments cover about one-half of the land area of the United States and include water resources that are available to more than 60 percent of the U.S. population.

Stream and River Highlights

Human activities associated with urban and agricultural land use are the primary factors that affect the quality of streams and the health of aquatic life throughout Long Island and New Jersey (see map on right). Although concentrations of most chemical constituents detected in stream samples generally meet Federal and State water-quality guidelines, current guidelines do not address many of these chemicals nor the combinations (mixtures) of pesticides, fertilizers, and industrial and fuel-related compounds (volatile organic compounds, or VOCs) that were commonly detected in all streams. Concentrations of trace elements and organic compounds in streambed sediment in urban areas commonly failed to meet guidelines for protection of aquatic life, but sediment quality did not appear to be as influential as other human-related factors in affecting aquatic community health. Rather, study findings indicate that urban and suburban development, especially when it replaces forest and wetlands, results in changes in the natural flow of streams, habitat degradation, reduction in biological diversity, and a shift toward species more tolerant of disturbance. These factors together likely have a greater effect on impairment of aquatic life than on drinking-water quality in highly urbanized areas.



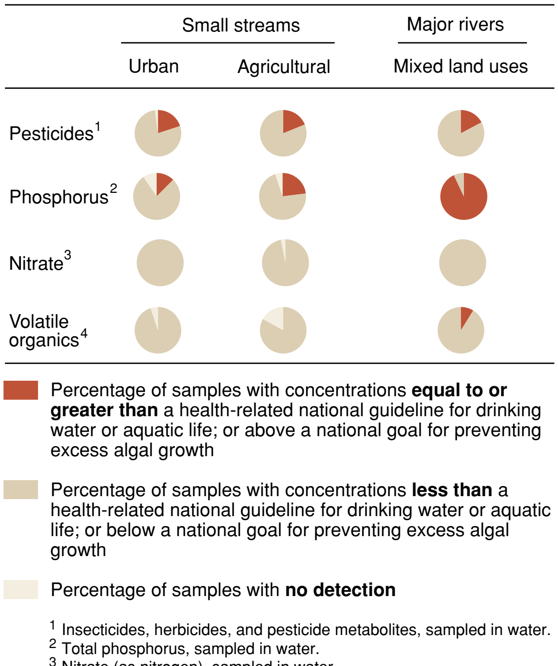
Land use is a primary factor affecting the quality of water resources in the Long Island–New Jersey Coastal Drainages study area.

- Impaired aquatic communities in urban areas were related to increases in impervious surfaces, in the amount and fluctuation in storm runoff, and in chemical use; impairment also was related to decreases in base flow, in forest and wetland area, and in stream-habitat quality (p. 8).
- Widespread historical use and environmental persistence of chlordane, dieldrin, DDT, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs), particularly in urban areas, have resulted in frequent detection of these compounds in streambed and lake sediments and, except for PAHs, in fish tissue (p. 9 and 14).
- Concentrations of most trace elements in streambed and lake sediments were elevated in urban watersheds relative to those in less developed watersheds (p. 10).
- Concentrations of nitrate generally were lower in streams than in ground water (p. 15). Modeling analysis indicates that this is a result of microbial, physical, and (or) chemical processes in or near the stream (p. 16).
- Elevated concentrations of nitrate and widespread low concentrations of pesticides were detected in streams in agricultural and urban areas (p. 15 and 18).
- Concentrations of pesticides in some agricultural streams during periods of high runoff in late spring and early summer, soon after crop application, exceeded drinking-water guidelines (p. 18).
- Nonpoint urban contaminant sources, especially in commercial and industrial areas, were major contributors to the widespread presence of VOCs at low concentrations in streams (p. 21).

Trends in Stream Quality

- Stream quality, as indicated by fish-community measures, improved from the 1970s to the 1990s largely as a result of wastewater-treatment-plant upgrades implemented under provisions of the Clean Water Act (p. 5).
- Concentrations of lead, DDT, PCBs, chlordane, and dieldrin in lake-sediment cores have declined since regulatory actions discontinued their production and use; however,

Selected indicators of stream-water quality



[1] Insecticides, herbicides, and pesticide metabolites, sampled in water.
[2] Total phosphorus, sampled in water.
[3] Nitrate (as nitrogen), sampled in water.
[4] Solvents, refrigerants, fumigants, and gasoline compounds sampled in water.

concentrations of zinc and PAHs in urban lake-sediment cores have steadily increased over time as a result of their association with increasing vehicular traffic and fossil-fuel use, respectiviely (p. 14).

Major Influences on Stream Quality

- Increased human activity/density and paved surfaces
- Increased surface runoff and chemical use
- Decreased base flow, forested area, and wetlands

Ground-Water Highlights

About 40 percent of the domestic (household) and public drinking-water supply in the study area is obtained from ground water that is replenished by precipitation that infiltrates the soil and drains to the water-table (surficial) aquifer. Elevated concentrations of nitrate and the frequent detection of pesticides and VOCs in water samples from surficial aquifers indicate that the aquifers are vulnerable to chemicals used in agricultural and urban areas.

Concentrations of nitrate in samples of shallow ground water underlying agricultural areas in southern New Jersey and agricultural and suburban areas on Long Island frequently exceeded drinking-water guidelines. The use of nitrogen fertilizers to support crop production and the use of septic systems in these areas, combined with the presence of well-drained and aerated soils, favor the formation of nitrate and its movement to ground water. Pesticide and VOC concentrations in water samples from surficial aquifers in New Jersey generally were low and rarely exceeded drinking-water guidelines; concentrations generally were greater in samples from the Long Island surficial aquifer system. Drinking-water standards or guidelines have been established for only 29 and 34 percent of the pesticides and VOCs detected, respectively.

Although human activities associated with agricultural and urban land uses are the principal sources of contaminants in ground water, factors other than land use can affect ground-water quality. For example, some pesticides that are known to be used extensively were not detected in ground water because they degrade readily or are not mobile. Additionally, some constituents, such as arsenic and radium, were detected in water where surficial sediments or geologic formations are known to contain these elements.

- Arsenic was frequently detected in samples from domestic wells in the Piedmont Physiographic Province (p. 12).
- Radium concentrations in one-third of 177 water samples from the surficial aquifer system in southern New Jersey exceeded the Federal drinking-water guideline (p. 13).
- The median concentration of nitrate in samples of shallow ground water underlying agricultural areas in the Coastal Plain of New Jersey was the highest nationwide among 47 similar ground-water surveys conducted to date by the NAWQA Program (p. 15).
- The most frequently detected pesticide compounds were herbicides and their breakdown products (p. 18); however, the most commonly used pesticides were not necessarily the most frequently detected in ground water (p. 20).
- VOCs were detected more frequently, and at higher concentrations, in samples of shallow ground water underlying urban areas than in those from agricultural or undeveloped areas (p. 23), and in samples of untreated water from public-supply wells than in those from shallow monitoring or domestic wells (p. 24).
- Nearly all samples from public-supply wells contained two or more pesticides and (or) VOCs (p. 25). Drinking-water guidelines do not address exposure to multiple compounds.

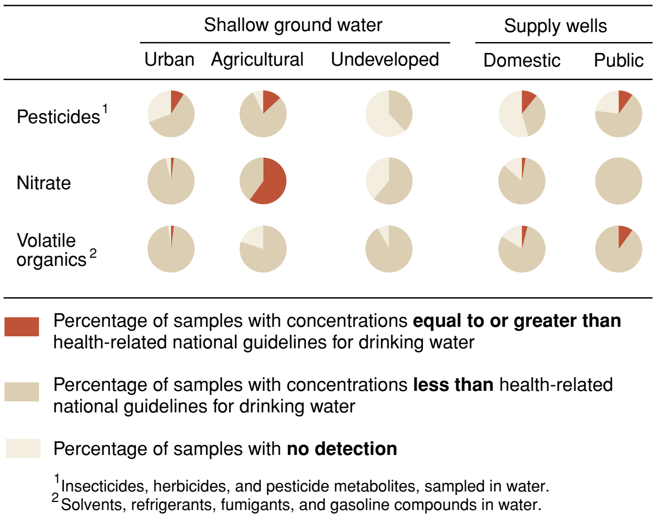
Trends in Ground-Water Quality

- A computer model study of the surficial aquifer system in southern New Jersey indicates that the concentration of nitrate in streams and public-supply wells is related to the type of land use in the recharge area and the time required for the recharge water to reach the stream or well (p. 16).
- Model results also indicate that years or even decades will be required before reduction in nitrate use will produce substantial decreases in the concentrations of nitrate in streams and ground water. If nitrate use remains at current levels, nitrate concentrations in streams and ground water in agricultural and urban parts of the study area will continue to increase for several decades (p. 17).

Major Influences on Ground-Water Quality

- Agricultural and urban land use
- Use and properties of chemicals
- Properties of soil and aquifer materials

Selected indicators of ground-water quality



Environmental Setting and Hydrologic Conditions

The study area covers 6,000 square miles (mi^2) of the LINJ Study Unit plus an additional 3,300 mi^2 in western New Jersey (fig. 1). About 15 million people (fig. 2) live in the study area, which includes some of the most densely populated metropolitan centers of the Nation. For more than two centuries, a prosperous commercial and industrial economy has centered on the seaports of New York City and Philadelphia. In the early 1970s, 22 percent of the study area was developed as urban residential, commercial, or industrial. By the mid-1990s, urban land use had grown to 33 percent of the area (fig.1), with a corresponding 11-percent decrease in forest and agricultural land. Population growth for the same period was about 8 percent overall, despite a slight population decline on Long Island (fig. 2).

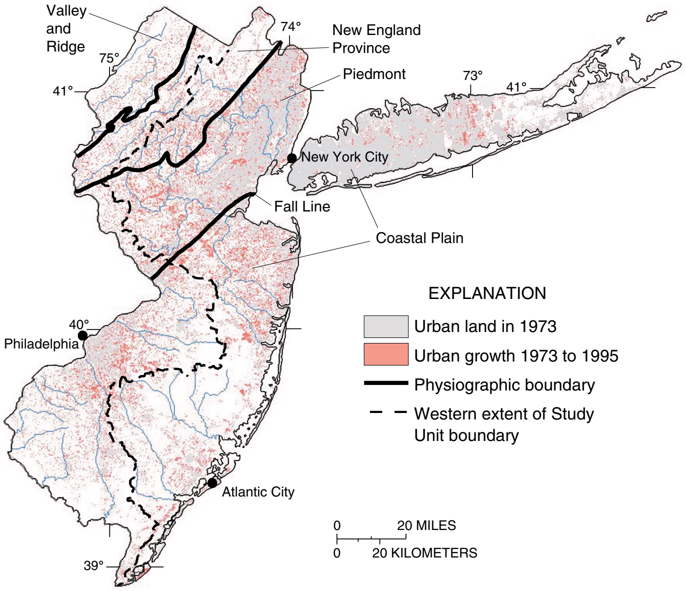


Figure 1. Urban land and associated human activities have a major influence on water quality and aquatic life.

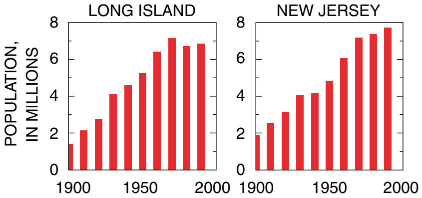


Figure 2. The population of Long Island and New Jersey is more than four times larger than it was in 1900.

The cost of land and the pressure for development have reduced agricultural activities in the area. For example, agriculture constituted nearly 60 percent of the land use in 1900. By the mid-1990s, agriculture accounted for only 14 percent of the land use. The more intensive agricultural areas that still remain are in eastern Long Island and in western and southern New Jersey. The remaining 53 percent of the study area in the mid-1990s was undeveloped land, principally forest (31 percent), wetlands (16 percent), and water (6 percent). As demonstrated since the 1970s, however, agricultural and undeveloped areas are rapidly becoming urbanized.

About two-thirds of the study area is in the Coastal Plain (fig. 1), which is characterized by flat to gently rolling topography developed on unconsolidated sedimentary (New Jersey and Long Island) and glacial deposits (Long Island only). The other one-third, north of the Fall Line, is characterized by rolling to hilly topography of weathered bedrock with glacial deposits in the northernmost part. As much as 80 percent of the streamflow in the Coastal Plain is derived from ground-water discharge, whereas response to rainfall in northern New Jersey is dominated by surface runoff. Most of western Long Island, northeastern New Jersey, and the corridor between New York City and Philadelphia consists of heavily urbanized and thus relatively impervious areas that yield runoff rapidly. Ground-water pumping considerably reduces base flow in streams on the western part of Long Island.

Water-supply systems in the study area are highly connected, and transfer of water across drainage divides and among basins is common. For example, about 100 million gallons per day (Mgal/d) is transferred from the Delaware River Basin to the Raritan River Basin in the Delaware and Raritan Canal. The Kirkwood-Cohansey aquifer system and the outcrop of the Potomac-Raritan-Magothy aquifer system are the principal surficial aquifers in the New Jersey Coastal Plain. Glacial deposits of sand and gravel overlie most of Long Island and form the surficial aquifer. To a large extent, the surficial aquifer is underlain by and hydraulically connected to the deeper Magothy aquifer, the principal source of water for Long Island.

Total freshwater withdrawals in the study area for all uses in 1995 were greater than 1,600 Mgal/d (Clawges and others, 1999). Almost 80 percent of that amount was either from surface-water sources (streams, canals, or lakes) or from surficial ground-water sources (fig. 3); **all of these sources are highly vulnerable to contamination** (Clawges and others, 1999). Most of the water-supply sources in the study area, therefore, are highly vulnerable to contamination from overlying and upstream human activities.

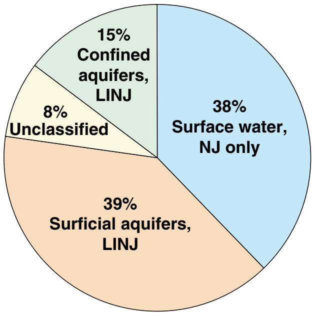


Figure 3. Nearly 80 percent of the study-area drinking-water supply is from a vulnerable surficial aquifer or surface-water source.

Annual precipitation and runoff during the NAWQA water-quality sampling years (1996–98) were above normal compared to their 40-year mean (table 1). The months of higher than normal precipitation and runoff, however, were mainly from October 1995 through December 1996. Precipitation and runoff were generally near normal after December 1996, except for the summer months in 1997 and 1998 (fig. 4).

Water-Quality Issues

The advisory committee for the LINJ NAWQA study identified two major water-quality concerns: (1) the effects of nonpoint-source runoff on streams, lakes, and estuaries, including aquatic biological communities, and (2) the vulnerability of public and domestic water supplies to contamination resulting from urban and agricultural activities. A wealth of data was available on contaminants such as VOCs, pesticides, nutrients, and trace elements, which are known to be related to high population density, urban and industrial development, and agricultural activities. Information on the processes governing contaminant occurrence, movement, and biological effects, however, was limited. Therefore, the LINJ study design (p. 28–29) focused on collection of data that would help describe these processes as well as add to the current knowledge of contaminant occurrence. Modeling approaches were used to help in the design of data collection and analyses of environmental factors and trends.

Table 1. Precipitation and runoff (in inches) during the 1996–98 sampling period were above the 40-year means

	40-year mean	1996	1997	1998
Precipitation	47.4	59.9	52.0	48.8
Runoff	20.6	28.5	26.6	20.8

Although hydrology and geology differ among parts of the study area, analyses of available chemical and biological data indicate that land use is the primary differentiating factor for much of the water-quality variability across the study area. The LINJ study design, therefore, focused considerable attention toward understanding the specific aspects of land use that control observed water quality and aquatic biological communities.

New information derived from the LINJ study is presented here to increase the understanding of (1) the effect of changing landscapes on stream aquatic life, (2) the occurrence of trace elements, nitrate, pesticides, and VOCs and other organic compounds in streams and aquifers, especially those used for drinking-water supply, and (3) implications of potential trends in water quality and aquatic biological communities in urban and agricultural areas.

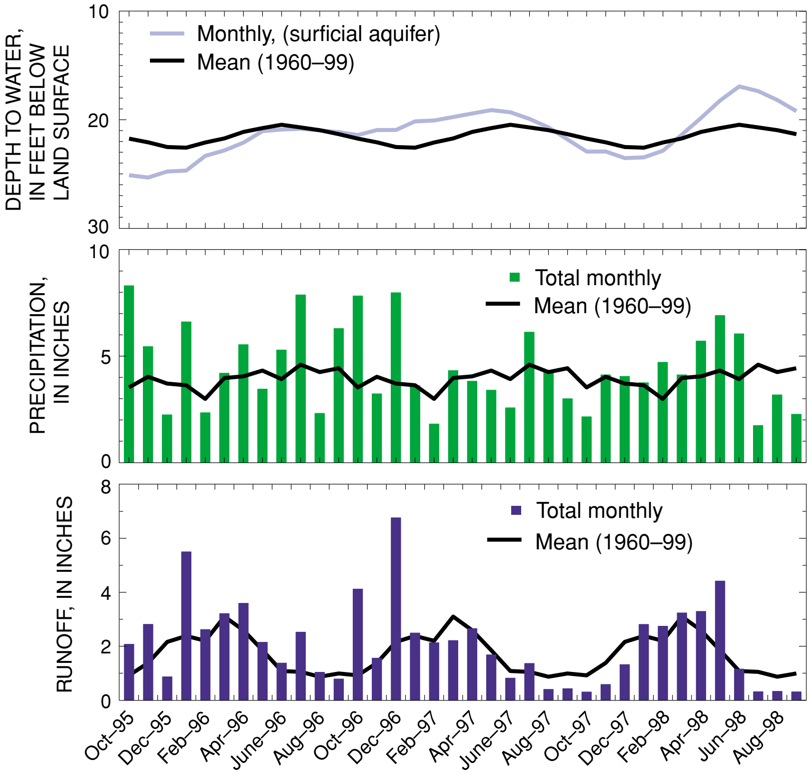


Figure 4. Hydrologic conditions during the study period (water years 1996–98). Water-level data are for a monitoring well in the Kirkwood-Cohansey aquifer system; precipitation and runoff are for the Raritan River Basin.

Stream Conditions for Fish Have Improved Since the 1970s

Fish are useful indicators of environmental changes in drainage basins because they are sensitive to a wide variety of stresses including changes in water chemistry and flow, modifications in habitat and food, and landscape alterations resulting from urbanization and other human-related activities. Moreover, fish accumulate certain contaminants within their tissues over their entire life span (Fausch and others, 1990; Karr and others, 1987, Chang and others, 2000). One way to identify environmental changes in watersheds is to assess changes in stream condition by use of an Index of Biotic Integrity (IBI; blue text box below). **On the basis of IBI results, conditions for fish in streams of the Delaware, Passaic, and Raritan River Basins have improved since the 1970s** (fig. 5; table 2) (Chang and others, 2000).

Of the 88 sites assessed, stream condition improved at 46 percent, worsened at only 13 percent, and remained the same at 41 percent from the 1970s to the 1990s (fig. 5). **Many factors, especially the improved treatment of wastewater discharges during the 1980s and changes in land-use practices, may have contributed to the statistically significant increase in IBI scores in all three basins** (table 2). Nonpoint sources were less of a factor than were point-source improvements; but as discussed on pages 7 and 8, urban nonpoint influences are still significant. The Delaware River Basin reflected the greatest improvement in stream condition, moving from a condition category of fair up to good (table 2).

A change in stream condition also can be assessed by comparing the percentage composition of the fish families (fig. 6). For example, the highly contaminant-tolerant white suckers made up a greater percentage of the fish communities in all basins during the 1970s than in the 1990s, especially in streams in the Delaware River Basin. In addition, during the 1990s, darters, of which many species (for example, the shield darter) are highly intolerant of human disturbance and habitat modification, increased

Index of Biotic Integrity (IBI)—Ten community measures (often called biometrics) based on the number of fish species, feeding habits, abundance, and health are used to evaluate the biological integrity of streams. A score of 1, 3, or 5 is assigned to each community measure on the basis of overall similarity to an appropriate regional reference site, 5 indicating most similar and 1 indicating least similar to reference conditions. Scores for individual community measures at each sampling location are then summed to produce a total score, which is assigned a condition category. The maximum score a site can receive is 50 and the minimum is 10. The four condition categories are excellent (44–50), good (37–43), fair (29–36), and poor (10-28) (Kurtenbach, 1993). The IBI serves as an integrated analysis because individual biological measures provide differing levels of sensitivity to changes in biological condition (Barbour and others, 1999).

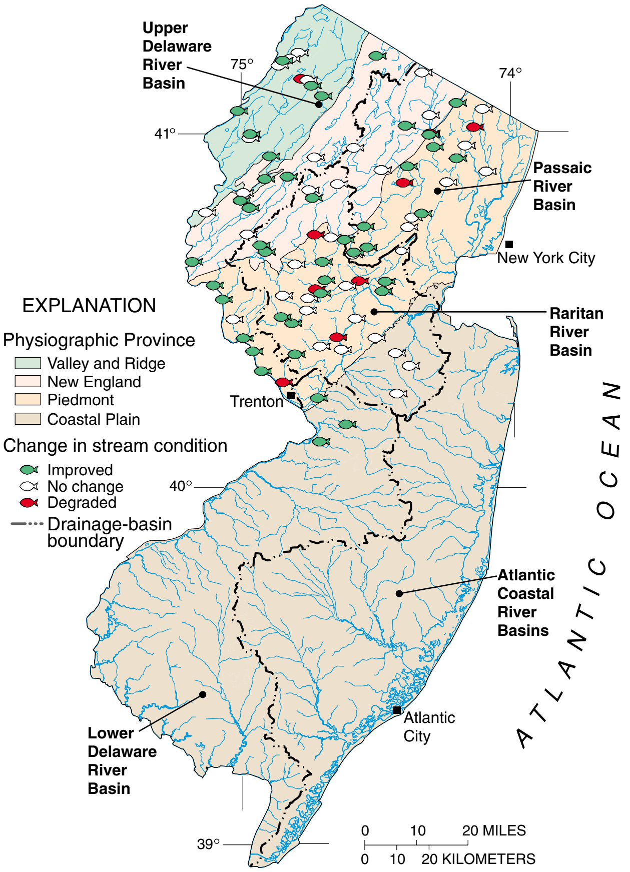
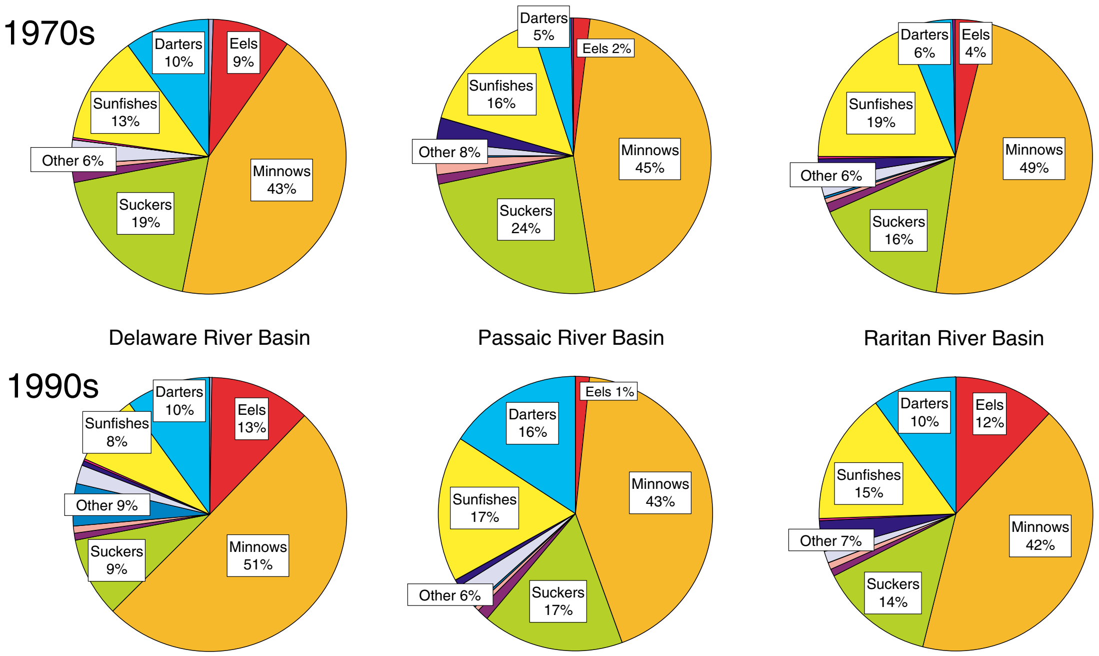


Figure 5. Stream conditions for fish communities have improved from the 1970s to the 1990s at 41 of 88 sites in northern New Jersey.

Table 2. The mean Index of Biotic Integrity (IBI) scores for streams of the Delaware, Passaic, and Raritan River Basins have increased significantly from the 1970s to the 1990s. [n, the number of stream sites assessed; * indicates a significant change in mean IBI score (Chang and others, 2000)]

Index	Delaware River (n=32)		Passaic River (n=24)		Raritan River (n=32)	
	1970s	1990s	1970s	1990s	1970s	1990s
Mean Index of Biotic Integrity score	34	40*	30	35*	33	36*
Condition rating	fair	good	fair	fair	fair	fair

Figure 6. Changes in the percentage of fish families (that is, a decrease in suckers and a general increase in darters) captured in streams of the Delaware, Passaic, and Raritan River Basins during the 1970s (top) and the 1990s (bottom) indicate that stream conditions have improved.



in abundance in streams in the Passaic and Raritan River Basins and remained unchanged in streams in the Delaware River Basin.

Many minnow species are indicators of good stream condition because they rely directly on the availability of aquatic insects for survival. Thus, as streams become degraded and insects and their larvae become scarcer, the numbers of insect-eating minnows often decrease. Minnows made up greater than 42 percent of the community during the 1970s and 1990s in all three river basins (fig. 6). The percentage of minnows increased in Delaware River streams. Minnows decreased slightly in the Passaic and Raritan River streams, however, an indication that these two basins may still reflect some degree of impairment.

These differences, perhaps, may explain why the mean IBI score for streams in the Delaware River Basin increased slightly more than that for streams in the Passaic or Raritan River Basins (table 2). Other fishes (such as eels) were not included in this comparison because they are found over a large range in water-quality and habitat conditions, thus limiting their use as aquatic indicators (Kurtenbach, 1993). Chang and others (2000) provide information on collection methods, fish taxonomy, and variability between the 1970s and 1990s collections.

Aquatic Invertebrate Communities Differ Naturally Across the Study Area

The New Jersey Department of Environmental Protection (1994b) established 43 reference or benchmark sites whose drainage basins have been minimally disturbed by human activity. A comparison of these sites indicates that the **aquatic invertebrate communities in the southern New Jersey Coastal Plain are distinctly different from those in the north as a consequence of natural differences in environmental and physical conditions** (table 3). Thus, natural variability in aquatic invertebrates needs to be taken into account when assessing communities across the entire study area. This finding helped focus our data-collection efforts toward gaining a

Table 3. Differences in aquatic-invertebrate communities in reference streams between northern and southern (Coastal Plain) New Jersey can be explained by natural differences in environmental conditions

	Northern New Jersey	Southern New Jersey
Most abundant aquatic invertebrates	Mayflies, stoneflies, caddisflies, and riffle beetles	Worms, freshwater clams, black flies, midges, caddisflies, and stoneflies
Environmental characteristics	Steeper channels and higher dissolved oxygen content	Low pH and low dissolved solids and nutrient content
Streambed characteristics	Mainly rock and cobble	Mainly sand and other fine sediments

better understanding of urban influences on northern New Jersey communities. In addition, analysis of LINJ NAWQA data indicates that aquatic-invertebrate communities on Long Island closely resemble New Jersey Coastal Plain communities because of similar physiographic and habitat conditions.

Fish and Aquatic Invertebrate Communities Are Impaired in Urban Areas

Despite some overall improvements in stream condition (p. 5), **fish and aquatic-invertebrate communities are commonly impaired in the urbanized parts of New Jersey** (figs. 7 and 8; see also fig. 1 on p. 3 for a comparison with urban area). Community-impairment scores at more than 150 fish-sampling sites (Kurtenbach, 1993) and more than 700 aquatic-invertebrate sampling sites (for example, New Jersey Department of Environmental Protection,

New Jersey Department of Environmental Protection's Ambient Biomonitoring Network (AMNET) is a statewide network of more than 700 aquatic-invertebrate sampling sites that was designed to monitor the condition of aquatic-invertebrate communities in five water-management areas on a 5-year rotational basis. This sampling frequency is considered to be realistic for evaluating long-term environmental changes. Sampling locations (fig. 7), which were chosen in a stratified-random design to monitor all nontidal streams at approximately 3-mile intervals, include 43 reference sites. In addition, this network was designed to incorporate, wherever possible, existing USGS and NJDEP cooperative water-quality monitoring stations to maximize the integration of water-quality and biological information. Level of community impairment (non-impaired, moderately impaired, and severely impaired) is based on a modification of the USEPA Rapid Bioassessment Protocol II (Plafkin and others, 1989).

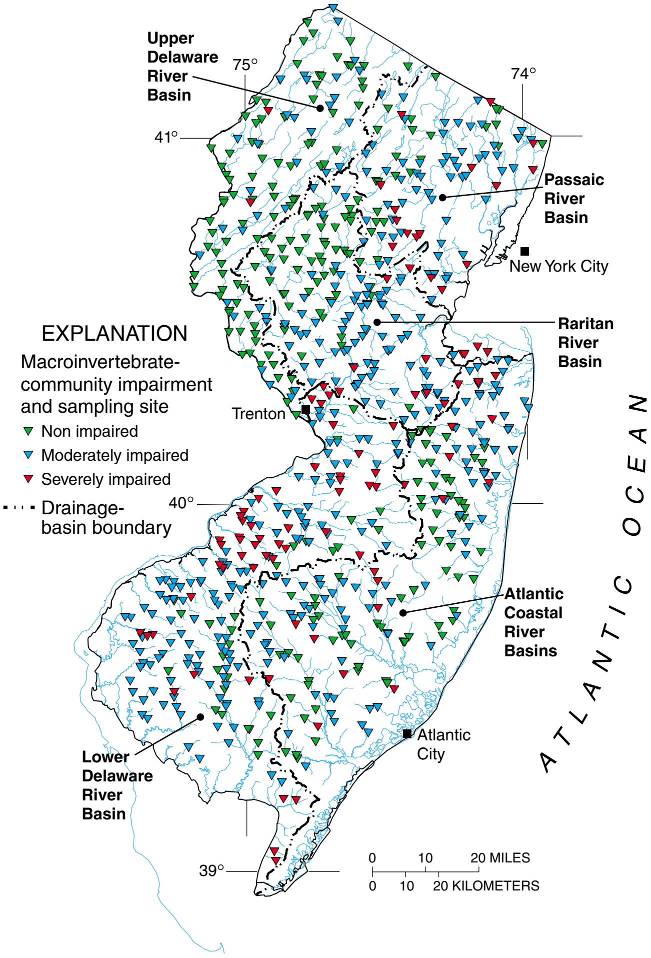


Figure 7. Aquatic-invertebrate-community data at more than 700 New Jersey AMNET sites (blue text box above) commonly indicate moderate to severe impairment in higher density urban areas (gray areas in fig. 1, p. 3).

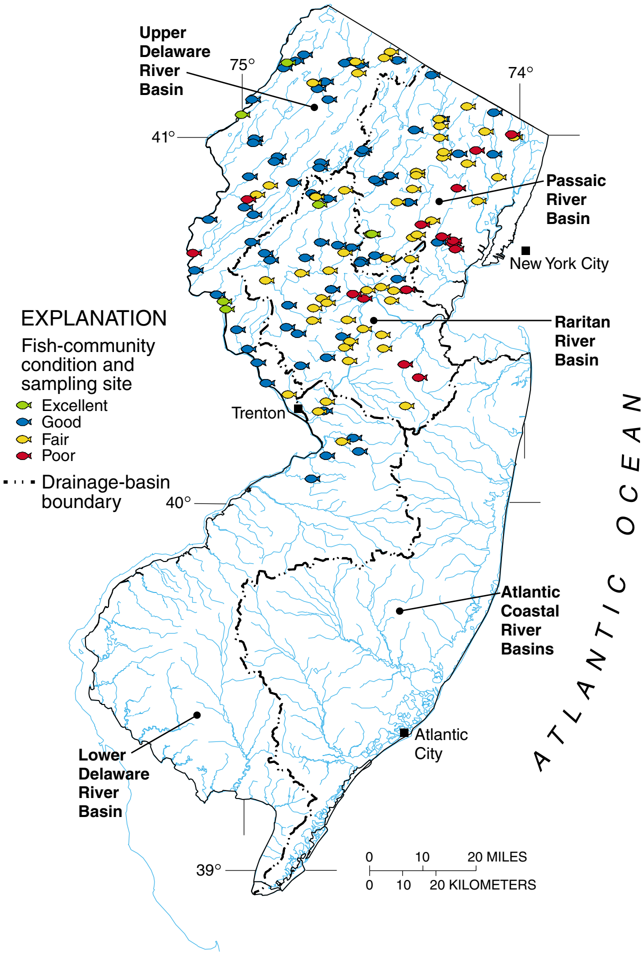


Figure 8. Fish-community data at more than 150 sampling sites in northern New Jersey indicate that streams in urban areas are in poor to fair condition (based on IBI scores; blue text box on p. 5).

1994a) in New Jersey were examined with respect to land use and other basin characteristics. The northwestern part of the State is less developed and consequently was least likely to reflect moderately or severely impaired aquatic communities (figs. 7 and 8).

The percentage of urban area in the drainage basin and the amount of treated wastewater flows upstream from sampling sites were the primary factors related to a severely impaired aquatic-invertebrate community (Kennen, 1999). **Total amount of forest land in the basin, however, was a strong mitigating factor and increased the likelihood of an unimpaired aquatic-invertebrate community. Similarly, total population in proximity to the sampling site and the amount of urban land in a basin were found to be most highly related to poor fish-community conditions**.

The following section describes an extension of these analyses of available data through an integrated study of the specific factors that affect biological communities in urban environments.

Characteristics of Urban Landscapes That Affect Aquatic Communities

More than 400 landscape and environmental variables were aggregated for comparison with data describing fish, invertebrate, and algal communities at 36 streams in New Jersey and Long Island. Sites were chosen with drainage basins that ranged from 3 to 96 percent urban land.

Table 4. Environmental factors that were highly related to impairment of fish, aquatic-invertebrate, and algal communities along an urban land-use gradient. Green shading indicates factors that were more favorable to healthy aquatic communities and red shading indicates factors that were less favorable. [NS, No statistically significant effect on aquatic community]

	Response of aquatic community		
Watershed characteristic	Fish	Aquatic invertebrates	Algae
Area of forest and wetlands	NS	Positive	NS
Ability to maintain base flow	NS	Positive	NS
Percentage of cobble substrate	Positive	Positive	NS
Median sulfate concentration	NS	Positive	Positive
Median total phosphorus concentration	Negative	NS	Positive
Mean annual flood	Negative	Negative	Negative
Flashiness of streamflow	Negative	NS	NS
Impervious area, road area only	Negative	Negative	Negative
Impervious area, nonroad area only	NS	Negative	NS
Population density	Negative	Negative	Negative
Total urban area in 1986	Negative	NS	NS
Urban area growth from 1986 to 1995	NS	Negative	NS
Commercial and industrial area in 1986	NS	Negative	Negative
Total point-source flow	NS	Negative	NS

Analyses of these data indicated that increasing impairment of fish, aquatic-invertebrate, and algal communities was statistically related to components of the urban gradient (table 4; refer also to "Glossary," p. 31). **Environmental factors such as annual peak discharge, amount of impervious road area, and population density were related to impairment in all three types of aquatic communities** (negative in table 4). Some environmental factors such as point-source flow, urban growth during 1986–95, and impervious nonroad area were related to impairment in the aquatic-invertebrate community only (negative in table 4). In addition, total urban area in 1986 appeared to be important only for the fish community. Other studies have found that historical changes in land use may have significant implications for longer-lived organisms such as fish.

The presence of cobble substrate was a factor contributing to healthier fish and aquatic-invertebrate communities (positive in table 4). Degradation of cobble and other stream habitat in urban systems likely is related to increases in

Figure 9. Unregulated impervious-area runoff directly affects water quality, habitat, and aquatic communities in streams and is exemplified by a storm-sewer pipe (left) that drains directly into the Saddle River at Ridgewood, N.J.

flow, channel erosion, and sedimentation common to minimally controlled urban stormwater runoff (fig. 9). In fact, **changes in hydrologic factors (such as decreases in base flow and increases in peak discharge and the flashiness of streamflow) play a major role in influencing the types and condition of aquatic communities present in a stream** (table 4, fig. 10), in large part, by the way these changes in flow affect stream habitat. As a result, stream communities are continually stressed and rarely reach stable population levels in urban systems. Conversely, reductions in base flow resulting from changes in water-use and wastewater distribution practices greatly influence the suitability of a stream for many types of organisms (Klein 1979).

The area of forest and wetlands in the drainage basin was a positive factor in the health of aquatic-invertebrate communities (tables 4 and 5). Forests and wetlands play a major role in maintaining a healthy supply of water, food, and habitat for disturbance-intolerant and highly desired species. Thus, forest and wetlands are able to help mitigate the undesirable effects of other human-induced landscape alterations.

Figure 10. Reductions in base flow of streams resulting from changes in up stream land-use and water-use practices affect the distribution of aquatic species in streams. For example, the difference in wetted habitat for median-flow conditions (upper photograph) and low-flow conditions (bottom photograph) at Neshanic River at Reaville, N.J., is substantial, although not entirely related to human activities.

Organochlorine Compounds Were Detected in Streambed Sediment and in Fish Tissue

Even though the use of many organochlorine compounds has been discontinued, the widespread historical application and the environmental persistence of compounds such as chlordane, dieldrin, DDT, and PCBs have led to frequent detection in streambed sediment and in whole-fish tissue samples in Long Island and New Jersey (Stackelberg, 1997; Long and others, 2000). Analyses of available bed-sediment chemical data for nearly 300 sites (Stackelberg, 1997) indicate that chlordane and dieldrin concentrations in bed sediments were highest in urban areas, reflecting their past use for termite control. Concentrations of DDT and PCBs were highest in urban and industrial areas, reflecting their principal historical use as an insecticide and an industrial chemical (in hydraulic lubricants and heat-resistant oils in electrical transformers), respectively. No significant relations were found, however, between chlorinated hydrocarbon concentrations in bed-sediment and whole-fish samples (white sucker, the chosen target species for this analysis) or between those in whole-fish samples and land use (Long and others, 2000).

Of the eight streams sampled in fall 1997, one-half of all bed-sedi-

Organochlorine pesticides in the environment—Following discovery of the tremendous insecticidal properties of DDT in the 1940s, numerous organochlorine insecticides (for example, dieldrin, chlordane, heptachlor, and DDT) were developed and used extensively for the control of agricultural pests as well as termites in residential and commercial settings. DDT was also used historically to control mosquito and gypsy moth populations in residential and forested areas. The use of these insecticides peaked in the 1960s, but because of concerns over their toxic effects and tendency to bioaccumulate, restrictions on their use began in the 1970s; all uses of these organochlorine insecticides were discontinued by the mid-1980s. The residues of organochlorine insecticides are, however, extremely persistent in the environment. Once introduced into the aquatic environment, the lipophilic (“fat-loving”) nature of these compounds allows them to bioaccumulate and ascend through the food chain, often resulting in adverse effects on many aquatic species and fish-eating birds and wildlife.

ment samples contained concentrations of chlordane, DDT, and PCBs that exceeded threshold effect levels (fig. 11; blue text box on p. 12; Long and others, 2000). Concentrations of chlordane and PCBs in whole-fish samples from many of the sites exceeded established guidelines for fish-eating wildlife. Some of the detected compounds are known to pose human health risks; however, concentrations in whole-fish samples from this study are not directly comparable to concentrations in edible portions (fillets) that are used to establish U.S. Food and Drug Administration (FDA) action levels for human consumption (U.S. Food and Drug Administration, 1992). Nonetheless, the FDA action levels for human consumption of total chlordane [300 µg/kg (micrograms per kilogram)], total DDT (5,000 µg/kg), and total PCBs (2,000 µg/kg) in edible portions of fish were not exceeded in the whole-body samples at any of the sites. Organochlorine compounds in lake-sediment cores and in water samples are discussed on pages 14 and 20, respectively.

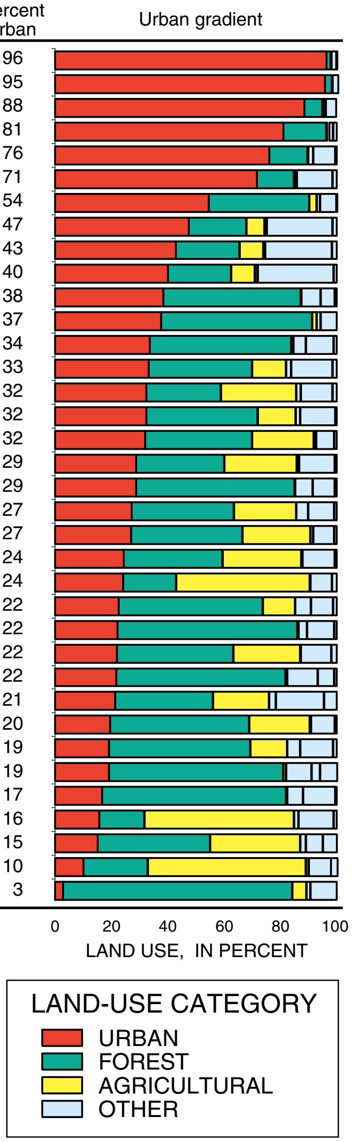
Trace-Element Concentrations Were Elevated in Streambed Sediment, Fish Tissue, and Ground Water

Human activities have accelerated the release of trace elements to aquatic environments through point- and nonpoint-source contamination (blue text box below). Analyses of available bed-sediment chemical data for nearly 300 sites

Trace elements in the environment–Geologic weathering accounts for natural releases of trace elements to aquatic environments. Human activities, however, have accelerated the release through point- and nonpoint-source contamination. Historically, industrial and other point sources were significant, as were releases from fossil-fuel burning and use of trace-element-based pesticides. More commonly now, trace elements from atmospheric deposition, vehicular traffic, and other activities accumulate on urban surfaces and are subsequently carried in runoff to streams. When introduced into aquatic environments, trace elements adsorb to fine-grained sediments (Forstner and Wittman, 1983). Trace elements can accumulate in sediments and may affect the health of bottom-dwelling (benthic) organisms and higher trophic-level species (fish) that rely on benthic organisms for food. Although some trace elements such as copper, iron, manganese, selenium, and zinc are vital to the metabolic processes of aquatic organisms, they can still be toxic at high concentrations.

Table 5. Comparison of biological status at 36 Long Island–New Jersey stream sites to 140 NAWQA sites nationwide indicates that the high scores relative to other NAWQA sites are associated with urban watersheds. Sites are ordered from top to bottom in descending percentage of urban land (urban gradient)

Stream name	Invertebrate status	Algal status	Percent urban
Elizabeth R at Hillside, N.J.	🟧	🟧	96
Saddle R at Upper Saddle River, N.J.	🟨	🟨	95
Saddle R at Ridgewood, N.J.	🟨	🟨	88
Rahway R at Washington Park, N.J.	🟧	🟧	81
Hohokus Brook at Allendale, N.J.	🟨	🟨	76
Bound Brook at Middlesex, N.J.	🟨	🟧	71
Whippany R at Morristown, N.J.	🟨	🟨	54
Passaic R near Chatham, N.J.	🟧	🟧	47
Great Egg Harbor R near Sicklerville, N.J.	🟪	🟨	43
Passaic R near Millington, N.J.	🟧	🟨	40
Wanaque R at Pompton Lakes, N.J.	🟨	🟪	38
Whippany R near Brookside, N.J.	🟪	🟨	37
Rockaway R at Boonton, N.J.	🟪	🟪	34
Lamington R near Pottersville, N.J.	🟪	🟪	33
Raritan R at Queens Bridge	🟨	🟨	32
SB Raritan R at Arch St	🟪	🟪	32
NB Raritan R near Raritan, N.J.	🟪	🟨	32
Stony Brook at Princeton, N.J.	🟨	🟨	29
Pequannock R at Pompton Lakes, N.J.	🟨	🟪	29
SB Raritan R at Darts Mill, N.J.	🟪	🟨	27
Lamington R at Burnt Mills, N.J.	🟪	🟨	27
Beden Brook near Rocky Hill, N.J.	🟨	🟧	24
Neshanic R at Reaville, N.J.	🟨	🟨	24
Musconetcong R at Hampton, N.J.	🟪	🟨	22
Rockaway R near Longwood Valley, N.J.	🟨	🟨	22
Mulhockaway R at Van Syckel, N.J.	🟪	🟨	22
Wanaque R near Awosting, N.J.	🟨	🟪	22
Paulins Kill at Lafayette, N.J.	🟨	🟨	21
Spruce Run near Glen Gardner, N.J.	🟪	🟪	20
Wallkill R near Sussex, N.J.	🟨	🟨	19
Musconetcong R at Hackettstown, N.J.	🟨	🟪	19
Pequannock R at Riverdale, N.J.	🟪	🟪	17
Doctors Creek at Allentown, N.J.	🟧	🟨	16
Paulins Kill at Augusta, N.J.	🟪	🟨	15
Paulins Kill at Blairstown, N.J.	🟪	🟨	10
Flat Brook near Flatbrookville, N.J.	🟪	🟪	3



INVERTEBRATE AND ALGAL STATUS

🟪 Lowest 25 percent nationally [least degraded sites]

🟨 Middle 50 percent nationally

🟧 Highest 25 percent nationally [most degraded sites]

Aquatic-Community Status in a National Context

Comparisons of invertebrate and algal status at 36 LINJ sites to their status at 140 selected NAWQA sites nationwide were made using nationally derived indicators (described in blue text box below). These indicators were selected because of their ability to discriminate, in a predictable way, human influences on the environment. These indicators also have the desirable characteristic of sensitivity to environmental stressors and a low dependency on natural variability such as elevation, stream size, and ecoregion. The results discussed in this section are for the sole purpose of a national comparison and refer only to a population of NAWQA Program sampling sites. They are not designed to be used as benchmarks for other State, regional or national studies because the aquatic community indicators have not been calibrated for such purposes.

Biological indicators of water quality in a national context—The selected biological indicators respond to changes in stream degradation. Degradation can result from a variety of factors that modify habitat or other environmental features such as land use, water chemistry, and streamflow. **Algal status** focuses on changes in the percentage of certain algae in response to increasing siltation and often appears to correlate closely with increasing nutrient concentrations. **Invertebrate status** is the average of 11 invertebrate biometrics that summarize changes in richness, tolerance, trophic conditions, and dominance associated with water-quality degradation. **Fish status**, which sums the scores of four fish metrics (percent tolerant, omnivorous, nonnative individuals, and percent individuals with external anomalies), was not used for this national comparison because values for the full suite of sites were not available. For all these indicators, higher values indicate a more degraded system.

About one-half of LINJ status scores ranked in the middle one-third (yellow squares, table 5) of the 140 NAWQA sites sampled during 1996–98. Some LINJ status scores (orange squares), however, were in the upper one-third, and a few sampling sites such as the Elizabeth River at Hillside, Rahway River at Washington Park, and Passaic River near Chatham, N.J., were among the highest scores nationally for algae and invertebrates. All these sites fell in the upper part of the urban gradient, or in basins with greater than 47 percent urban land use. These sites were dominated by disturbance-tolerant aquatic invertebrates such as worms and midges and supported few if any disturbance-sensitive invertebrates such as mayflies, stoneflies, and caddisflies. In addition, highly silt-tolerant algae made up from 86 to 98 percent of the overall community abundance. The presence of these tolerant forms reflect significant levels of disturbance and highly degraded instream and riparian habitat.

About 35 percent of the LINJ status scores were among the lowest one-third nationally (blue squares, table 5). The Rockaway River at Boonton (figure top right), Lamington River near Pottersville, South Branch Raritan River at Arch Street, Spruce Run at Glen Gardner, Pequannock River at Riverdale, and Flat Brook near Flatbrookville, N.J., had some of the lowest scores nationally for algae and invertebrates (table 5). Land use in the basins of these sites is less than 34 percent urban. These sites were among the most diverse sampled in the LINJ study; 50 to 79 percent of the invertebrate community was composed of intolerant organisms such as mayflies, stoneflies, and caddisflies. In addition, silt-tolerant algae made up less than 19 percent of the algal community abundance at all sites.


Sampling aquatic invertebrates in the Rockaway River at Boonton, N.J.

Two sites, Beden Brook near Rocky Hill and Doctors Creek at Allentown, N.J., were among the sites with the highest status scores nationally (most degraded) for algae and invertebrates, respectively (table 5), yet corresponding basins had relatively little urban land (less than 25 percent). In addition to nonpoint-source influence, these sites likely reflect additional degradation resulting from wastewater-treatment-plant effluent. Doctors Creek also has a high proportion of agricultural land and far less forest than many of the sites on the lower end of the urban gradient. Agricultural land is known to produce high levels of sedimentation in surface water and high levels of nutrients in surface water and ground water (see section on nitrate concentrations, p. 15), which have historically been linked to aquatic-community degradation (Culp and others, 1986).

(O'Brien, 1997) indicated that trace-element concentrations in bed sediments were generally higher in the northern New Jersey physiographic provinces (related to urban development and geologic availability) and lower in the Coastal Plain (related to lower organic content of sediments, geologic availability, and stream-water pH). Higher copper, lead, and zinc concentrations were correlated with increased population density; zinc was correlated with wastewater-treatment-plant flows; higher arsenic was correlated with increased agricultural land use; and higher chromium was correlated with certain geologic deposits (especially in the New England Physiographic Province).

All eight of the streams sampled during fall 1997 were found to have at least two trace elements that exceeded TELs in bed sediment (fig. 11; Long and others, 2000; blue text box on TELs and PELs below). Concentrations of eight trace elements at Rahway River near Springfield (fig. 11) exceeded TELs; arsenic, cadmium, and copper also exceeded PELs.

Copper, manganese, mercury, and selenium were detected in fish livers at all sites. No significant relations were found between trace-element concentrations in fish livers and those in bed sediment or between concentrations in fish livers and any land-use category or population density (Long and others, 2000).

Arsenic was detected in 17 of 22 samples collected from domestic-supply (household) wells completed in fractured bedrock aquifers of the Piedmont Physiographic Province, where geologic formations are known to contain arsenic-bearing minerals. Concentrations ranged from 1 to 57 µg/L. The current drinking-water standard for

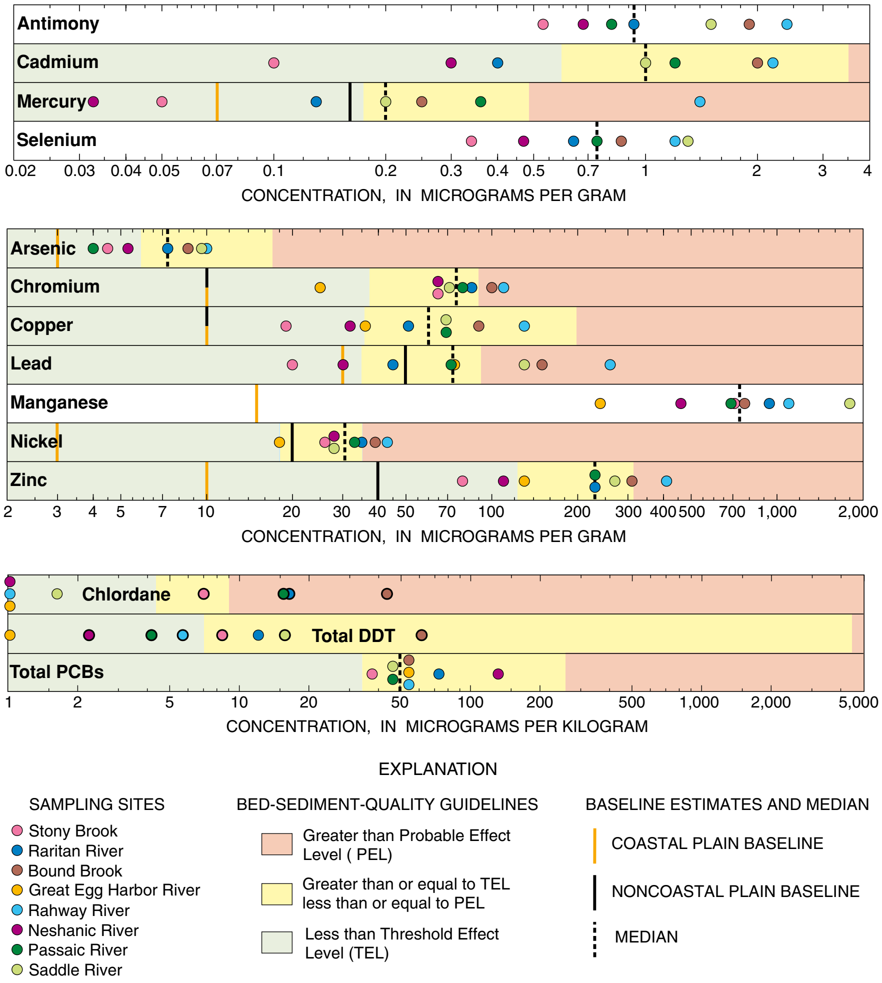
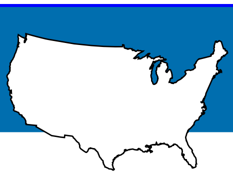


Figure 11. Concentrations of selected trace elements and organochlorine compounds in bed sediment commonly exceeded TEL and PEL guidelines, especially at urban sites. (Background concentrations were estimated using method of Velz (1984); see blue text box below concerning TELs and PELs.)

TELs and PELs—Currently, there are no U.S. standards for assessing the potential for adverse biological effects due to contaminated freshwater sediment. The Canadian Council of Ministers of the Environment (CCME) modified an approach by Long and Morgan (1991) to develop guidelines for marine and freshwater sediments. The CCME modified approach uses two assessment levels: (1) the threshold effect level (TEL), representing the concentration below which adverse effects are expected to occur rarely, and (2) the probable effect level (PEL), representing the concentration above which adverse effects are expected to occur frequently (Ecosystem Conservation Directorate Evaluation and Interpretation Branch, 1995). Concentrations between TEL's and PEL's are values at which occasional adverse biological effects are expected. Adverse biological effects are generally defined as effects that are considered to produce a negative response in an organism (for example, death, reduction in growth, or reduced reproductive success).



Mercury Concentrations in Fish Tissue Were Related to Methylmercury Concentrations in Water

During summer 1998, the LINJ study participated with 20 other NAWQA studies in a national survey (Krabbenhoft and others, 1999) in which bed sediment samples were analyzed for total mercury and methylmercury, and fish-muscle tissues (fillets) were analyzed for total mercury (assumed to be predominantly methylmercury). Four sites were sampled in the LINJ study area (map on p. 28).

Atmospheric deposition is the primary source of mercury to most aquatic ecosystems in the eastern United States; in some areas, however, urban, industrial, mining, volcanic, and (or) geothermal sources contribute to elevated concentrations of total mercury in bed sediment. In addition, past use of mercury-based pesticides on golf courses and certain agricultural crops are possible sources.

Mercury is readily methylated in the natural environment as a result of bacterially mediated sulfate reduction. Methylmercury is readily bioaccumulated and biomagnified, is the primary form of mercury in fish, and is a potent neurotoxin to humans and wildlife (fish, birds, and mammals).

At the LINJ sites, mercury concentrations in fish tissue (pickerel fillets) normalized by mean weight were positively related to methylmercury concentrations in water and negatively related to total mercury concentrations in bed sediment. These data indicate that mercury concentrations in fish tissue are more a function of methylmercury levels in water than in the sediment. This is consistent with results found nationally in fish tissue (Dennis Wentz, U.S. Geological Survey, written commun., 2000). The highest concentrations of mercury in fish tissue [near 0.5 µg/g (micrograms per gram) wet weight] were from the mixed-land-use site (Great Egg Harbor River), where relatively high percentages of wetlands may enhance methylation rates. Concentrations of mercury in fish tissue were intermediate in urban basins and lowest in the agricultural basin.

Nationally, background and mixed (agricultural and forested) basins had the highest mean mercury methylation efficiencies (as measured by the ratio of methylmercury to total mercury) in water. Mixed (agricultural and forested) basins had the highest mean methylation efficiencies in bed sediment; methylation efficiencies in background, agricultural, and urban basins were lower.

arsenic is 50 µg/L, but the USEPA has proposed a tenfold decrease in this standard to 5 µg/L. Six of the samples (27 percent) contained arsenic in concentrations equal to or greater than 5 µg/L.

Concentrations of radium (sum of Ra-226 and Ra-228) above the drinking-water standard were found in 33 percent of 170 wells sampled in the surficial aquifer system in southern New Jersey (Szabo and others, 1997). The highest radium levels were in areas where acidic waters are associated with surficial sediments that contain radium from geologic sources (primarily the Bridgeton Formation) and agricultural areas where use of nitrogen fertilizers and lime is heavy. The leaching and nitrification of applied fertilizers, which increase the dissolved-solids content and acidity of ground water, are likely mechanisms by which radium is mobilized from surficial sediments and transported to ground water. More recently, the short-lived isotope radium-224 was detected in samples from this surficial aquifer system in waters affected by the same chemical processes (Zoltan Szabo, U.S. Geological Survey, written commun., 2000).

In a 59-well subset of the 170 wells above, mercury was detected at concentrations above the drinking-water standard of 2 µg/L in about 10 percent of the samples. The source is suspected to be linked to past use of mercury-based pesticides. Mercury may have increased mobility as a result of the natural acidity of waters from the surficial aquifer in southern New Jersey, as well as widespread contamination of these waters with chloride from road salt, septic systems, and other discharges; but the mechanisms are as yet not well understood.

History of Chemical Use Is Evident in Lake-Sediment Cores

Analyses of lake sediment cores are an effective method for evaluating water-quality trends. (See blue text box below.) Cores were extracted from three lakes in northern New Jersey and one on Long Island as part of a national lake-coring study (Callender and Van Metre, 1997). Sediment was dated by use of cesium-137, a by-product of nuclear-weapons testing.

Trace elements (arsenic, cadmium, chromium, lead, mercury, nickel, and zinc) were detected throughout the cores of all four lakes, with concentrations of most elements elevated in the three urbanized basins relative to the largely forested Clyde Potts Reservoir basin. Until concentrations of lead peaked in the 1970s, lead and zinc concentrations were highly correlated over time with the population in the vicinity of the lake. Population is an indicator of vehicular traffic, which in turn is an indicator of gasoline use (a probable lead source) and tire wear (a probable zinc source). Removal of lead from gasoline by the Clean Air Act resulted in a general decrease in sedimentary concentrations of lead since the mid-1970s phaseout (fig. 12); however, lead concentrations remain elevated compared to detections at the base of the cores.

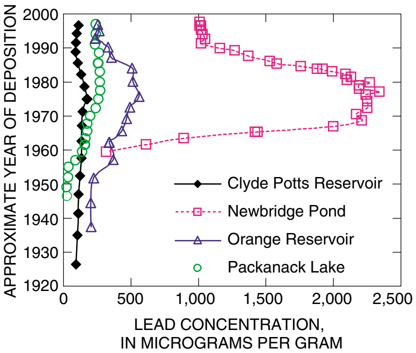


Figure 12. The mid-1970s phaseout of lead from gasoline as a result of the Clean Air Act has resulted in decreased basin inputs of lead concentrations in lake sediment.

Zinc concentrations are generally increasing in the three urban watersheds in response to increasing population and traffic density, but not in Clyde Potts Reservoir, which is least affected by traffic.

Detectable concentrations of chlordane, total DDT, total polycyclic aromatic hydrocarbons (PAHs) and total PCBs were found in all lake cores; dieldrin was detected in only two lake cores. **Generally, concentrations of organochlorine compounds began to decline after regulatory action discontinued organochlorine production and use in the 1970s and 1980s, but the persistence of these compounds may mean that a substantial amount of time must pass before they are purged from the basin. Concentrations of PAHs, however, are elevated and generally increasing over time in sediment cores (fig. 13), presumably as a result of increased vehicular and other fossil-fuel use associated with urban development.** Concentrations of PAHs were lowest in Clyde Potts Reservoir (least traffic influence). Of particular note are the low concentrations of PAHs in Packanack Lake sediments in the 1930s, when automobiles were comparatively rare and before the watershed was urbanized. These trends have been observed in other urban lake-sediment cores across the United States (Callender and Rice, 2000).

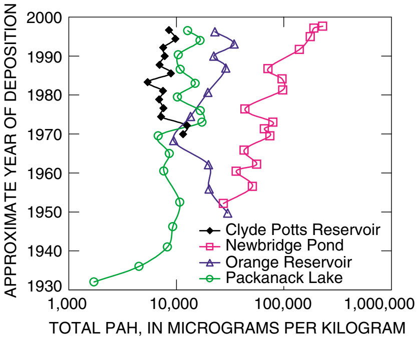


Figure 13. Concentrations of total polycyclic aromatic hydrocarbons (PAHs) are elevated and generally increasing in sediment cores as a result of increased vehicular traffic and fossil-fuel use.

Lake-sediment cores were useful for discerning chemical-use history—Lakes are more representative of a stable depositional environment than streams. Differences in sediment concentrations between the lake-sediment cores are related to differences in sedimentation rates and to factors affecting chemical inputs such as population density, traffic density, chemical use, and the extent of urban land use in the watershed. For example, even though the concentrations are different, the reduction of contaminants regulated by environmental legislation (chlordane, PCBs, DDT, and lead) is clearly evident in the sedimentary record for the three urban lakes. **Bed-sediment chemical data from streams, although useful for determining the relative effects of basin land use, had large within-site sample variability and were not particularly useful for trend detection, even with 25 years of data** (Stackelberg, 1997; O'Brien, 1997). This finding is typical of streambed-sediment data because sediments of different ages and different sources are continuously being mixed by changing hydrologic conditions.

Nutrients Were Detected in Streams and Ground Water

Nitrate nitrogen was the most frequently detected nutrient species in 146 samples collected from 7 streams that drain areas with differing land-use settings (Reiser, 1999) and in 220 samples collected from 108 monitoring wells, 82 domestic wells, and 30 public-supply wells. (See study design on pages 28–29.)

Other nutrient species analyzed for during this study included nitrite, ammonia, and organic nitrogen; orthophosphate phosphorus; and phosphorus. These constituents were detected infrequently and at low concentrations in ground water (graphs on p. 36). In stream samples, these constituents were detected more frequently. Total phosphorus concentrations, for example, equaled or exceeded the New Jersey Department of Environmental Protection surface-water-quality criterion of 0.1 milligram per liter (mg/L) in nearly 40 percent of samples from the seven sites (p. 36). Phosphorus has been identified as a limiting nutrient that controls eutrophication (excessive growth of algae and vegetation) (fig. 14) in most New Jersey freshwater (New Jersey Department of Environmental Protection, 1998). Although phosphorus concentrations have declined in many locations throughout the State, exceedences of the phosphorus criterion are still common. Additional control of phosphorus to prevent or reduce eutrophication is being evaluated by water-resource managers and regulators.

Figure 14. Elevated concentrations of nutrients in streams and lakes can stimulate excessive growth of aquatic algae and vegetation and otherwise degrade water quality.

The highest median concentration of nitrate was for samples of ground water collected from shallow monitoring wells in agricultural settings in the Coastal Plain of New Jersey (fig. 15). In fact, the median nitrate concentration of 13 mg/L reported for these shallow agricultural monitoring wells was the highest of 47 similar surveys conducted to date across the Nation as part of the NAWQA Program. Intensive use of nitrogen fertilizers and manure to support crop production and the well-drained, aerated soils of the Coastal Plain combine to favor the formation, leaching, and recharge of nitrate to ground water. Nitrate concentrations exceeded the drinking-water standard in 60 percent of these samples. The median nitrate concentration in streams draining predominantly agricultural basins was less than 2.0 mg/L.

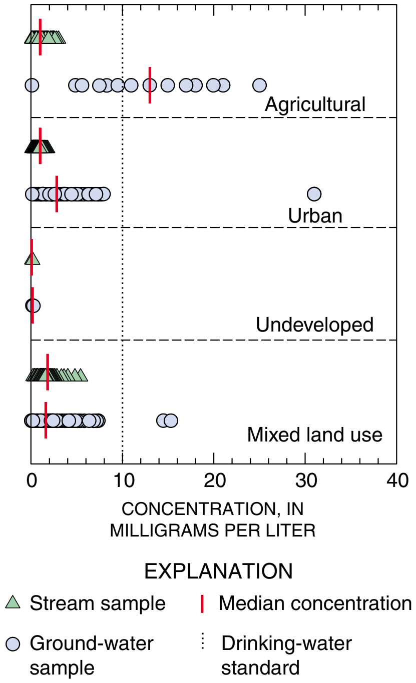


Figure 15. Nitrate concentrations are higher in ground water than in streams for most land-use categories.

The median concentration of nitrate in samples of shallow ground water underlying urban areas in the Coastal Plain of New Jersey was 2.8 mg/L as N (fig. 15). Again, the median nitrate concentration in streams draining predominantly urban basins was less than that of ground water. The median concentration of nitrate in samples of shallow ground water and streams in undeveloped areas of the Coastal Plain was less than 0.25 mg/L as N (fig. 15), reflecting a general absence of human inputs of nitrogen in these areas. In a similar study of shallow ground-water

Nitrate in the environment—Nitrate is a naturally occurring constituent in streams and ground water. Nitrate is formed by bacterial transformation of reduced (ammonia) and organic forms of nitrogen. It is introduced in excess of natural inputs to the environment through sources such as chemical fertilizers, manure, industrial wastes, sewage and septic-system effluents, and atmospheric deposition. Because nitrate is highly soluble and mobile, it enters streams in surface runoff and also leaches through permeable soils and recharges ground-water systems. The presence of nitrate in potable water supplies is of concern because ingestion of water with nitrate concentrations in excess of 10 mg/L as nitrogen (N) can sometimes lead to a blood disorder in infants commonly called blue-baby syndrome. The U.S. Environmental Protection Agency has established a Maximum Contaminant Level (MCL) of 10 mg/L as N for water delivered by public purveyors.

quality on Long Island, median nitrate concentrations were also highest in agricultural areas, intermediate in areas of suburban development, and lowest in undeveloped areas (Eckhardt and Stackelberg, 1995).

The median concentration of nitrate in water samples from domestic and public-supply wells in New Jersey (mixed land-use settings; fig. 15) was 1.6 mg/L as N. Domestic and public-supply wells sampled during this study are completed deeper in the aquifer than monitoring wells. Also, the domestic and public-supply wells are pumped at higher rates than the monitoring wells; thus, samples from these wells are less likely to have elevated nitrate concentrations than are samples from shallow monitoring wells in urban or agricultural areas.

The highest median and most variable concentrations of nitrate in streams were in large drainage basins that contain mixed land-use settings (fig. 15). These large drainage basins contain nonpoint sources of nitrate from agricultural and urban areas, as well as point sources such as effluent from wastewater-treatment plants.

Predicting Changes in Nitrate Concentrations in Streams and Wells

Difficulties in detecting water-quality changes (trends) in streams and ground water are linked to (1) the amount of time required for water to move through a drainage basin or aquifer system and discharge to a stream or well, (2) land-use and chemical-use changes over time, and (3) an inability to clearly separate hydrologic or water-quality trends from climatic variability. One approach to gaining a better understanding of potential trends is to use a computer model of the hydrologic system. A three-dimensional ground-water-flow model was developed to simulate the movement of nitrate from the water table, through the surficial aquifer system, to streams and public-supply wells in the surficial aquifer system in the Glassboro study area of southern New Jersey. The model integrates the hydraulic properties of the aquifer with land-use and nitrate-use changes over time to simulate nitrate concentrations at points of discharge (streams and wells).

In general, simulated nitrate concentrations matched concentrations measured in samples from public-supply wells in the study area, verifying that nitrate moves conservatively (that is, persists without being sorbed or chemically degraded) through the aquifer system. Simulated nitrate concentrations in three streams during base flow over a 9-year period, however, had to be multiplied by 0.6 to obtain a match with measured nitrate concentrations. **Because nitrate appeared to move conservatively to wells, the apparent loss of nitrate in streams indicates that about 40 percent of the nitrate in aquifer recharge is removed by denitrification in the aquifer near the streams and (or) by in-stream processes.** This finding is corroborated by the findings that median concentrations of nitrate in shallow ground water were consistently greater than those in streams draining similar land-use settings.

The model was also used to evaluate the effects of various hypothetical changes in nitrogen-use patterns on nitrate concentrations in streams and public-supply wells. The use of manure and nitrogen-based fertilizers has been steadily increasing since 1950 (Modica and others, 1998). In the year 2000, nitrate concentrations in recharge

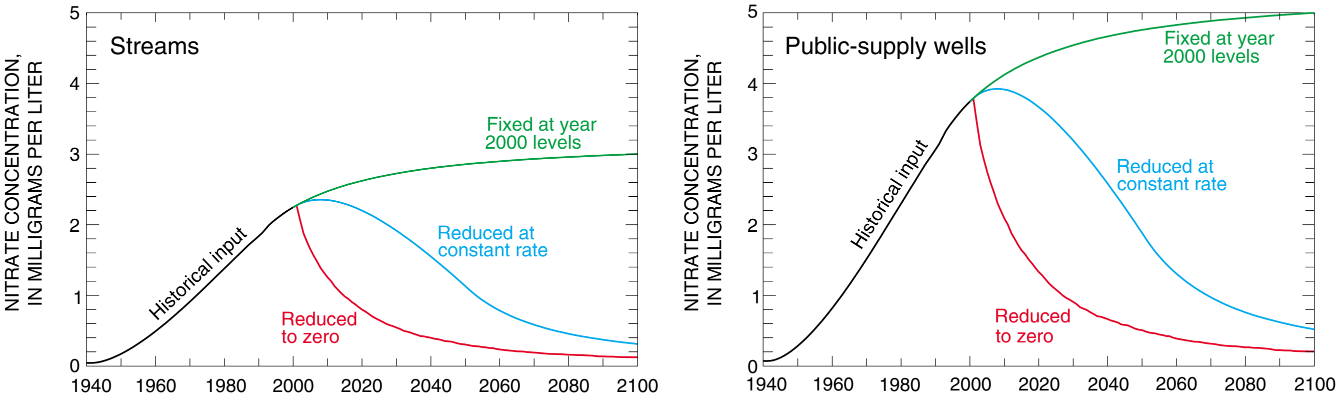


Figure 16. Simulated concentrations of nitrate in streams and public-supply wells for three hypothetical nitrogen-use patterns, Glassboro study area, New Jersey. A decrease in nitrate concentrations to half of the concentration in year 2000 will take 10 or more years because of the amount of time required for water introduced before 2000 to move through the aquifer system.

resulting from the hypothetical changes in nitrogen-use patterns were assumed to be (1) fixed at year 2000 levels, (2) reduced at a constant rate to zero in the year 2050, or (3) immediately reduced to zero (fig. 16).

The model shows that the response of nitrate concentrations in streams and public-supply wells differs depending on the nitrogen-use pattern, but that in each case, the concentration of nitrate in streams and public-supply wells will not decline immediately, primarily because of the amount of time required for water to move through the aquifer system and discharge to a stream or well (fig. 16). In fact, if nitrate concentrations in recharge remain at current (year 2000) levels, the concentration of nitrate in streams and public-supply wells will actually continue to increase for several decades before leveling off at a concentration corresponding to the amounts of nitrate applied to urban, agricultural, and undeveloped lands in recharge areas.

Even if nitrate concentrations in recharge are reduced at a constant rate to zero in the year 2050, nitrate concentrations in streams and public-supply wells will continue to increase for 5 to 10 years (fig. 16). This lag in response is equivalent to the average age of water discharging to streams and public-supply wells. Because public-supply wells sampled for this study are screened near the bottom of the aquifer system, they withdraw water that is on average older than water discharging to streams. Thus, streams will respond faster to changes in land use or chemical use than public-supply wells will.

Finally, if the concentration of nitrate in recharge that had been steadily increasing since 1950 could be immediately reduced to zero in the year 2000 (fig. 16), the concentration of nitrate in streams and public-supply wells would begin to decrease almost immediately as the result of the influx of young, uncontaminated ground water. The decrease in nitrate concentrations in streams and supply wells to one-half of the concentration in the year 2000, however, would still take 10 or more years because of the amount of time required for water introduced before 2000 to move through the aquifer system and discharge to a stream or well.

In addition to predicting changes in the concentration of nitrate in streams and public-supply wells over time, the model also was used to predict changes in nitrate concentrations at a depth (90 to 100 feet below land surface) at which many domestic wells in the study area are installed (fig. 17). **Simulation results show that nitrate concentrations at this depth will increase across the study area over the next 50 years and will likely exceed the drinking-water standard for nitrate in those areas where nitrogen fertilizer use is most intensive**.

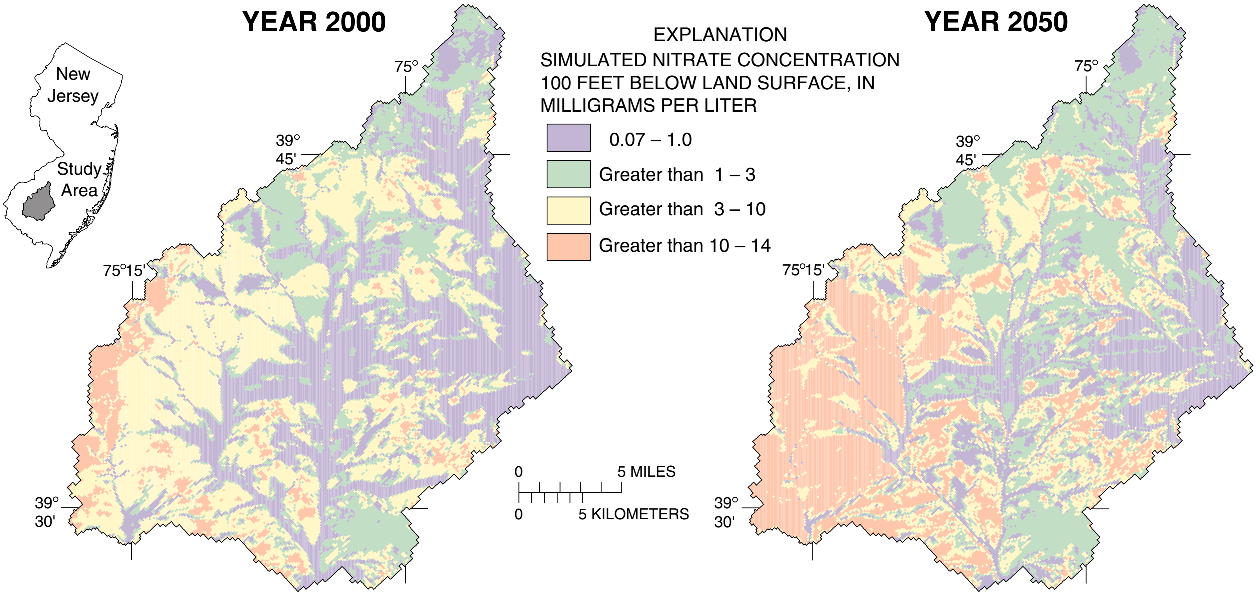


Figure 17. Domestic wells in the Kirkwood-Cohansey aquifer of southern New Jersey are commonly completed at a depth of 90-100 feet below land surface. Simulated nitrate concentrations at this depth in the Glassboro study area for the years 2000 and 2050 indicate that ground water in areas of intensive nitrogen fertilizer use is likely to exceed the drinking-water standard for nitrate of 10 mg/L by 2050. This simulation assumes nitrate inputs remain unchanged from year 2000.

Pesticides Were Detected in Streams and Ground Water

Pesticides were more prevalent in streams than in ground water. Concentrations in both water sources were generally low in the study area and rarely exceeded drinking-water standards (MCLs), drinking-water health advisories (HAs), or aquatic-life guidelines (AQLs) (fig. 18). MCLs, HAs, or AQLs have not been established, however, for 8 of the 41 pesticides detected in streams and 11 of the 38 pesticides detected in ground water. Overall, one or more pesticide compounds were detected in all but 1 of 146 stream samples (Reiser, 1999) and in 63 percent of 220 ground-water samples. **These findings are consistent with the** national findings to date from the NAWQA Program in which low-level concentrations of pesticides were detected in almost every stream sample and in about one-half of all ground-water samples (U.S. Geological Survey, 1999).

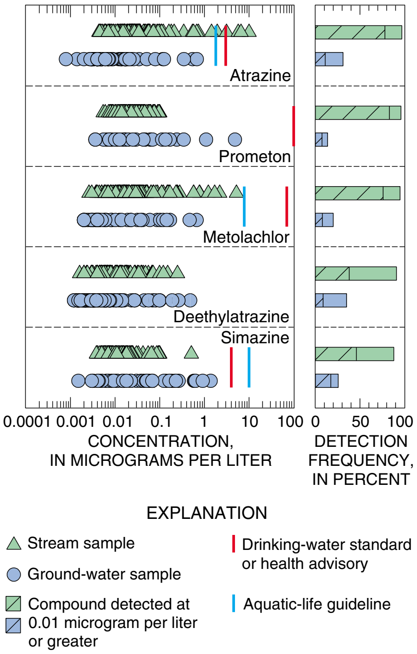


Figure 18. Pesticides occur more frequently in streams than in ground water, but concentrations in both rarely exceed drinking-water standards.

The five most frequently detected pesticides in stream and ground-water samples were herbicides and a herbicide metabolite (fig. 18). (Metabolites form when a parent compound degrades.) Atrazine and metolachlor are among the most heavily applied agricultural herbicides in New Jersey (fig. 19; blue text box below). Prometon and simazine, however, have little reported use by licensed applicators in New Jersey. These herbicides are available for purchase and use by nonlicensed applicators such as homeowners, and their frequent detection in this study likely reflects their use by the general public.

Pesticide Detections Vary by Season and in Response to Land Use

Concentrations of pesticides in streams vary throughout the year in response to seasonal patterns in pesticide applications (U.S. Geological Survey, 1999). Pesticide concentrations in samples collected from some agricultural streams during high flows soon after crop application (late spring to early summer) exceeded drinking-water guidelines (Reiser, 1999). For example, concentrations of the

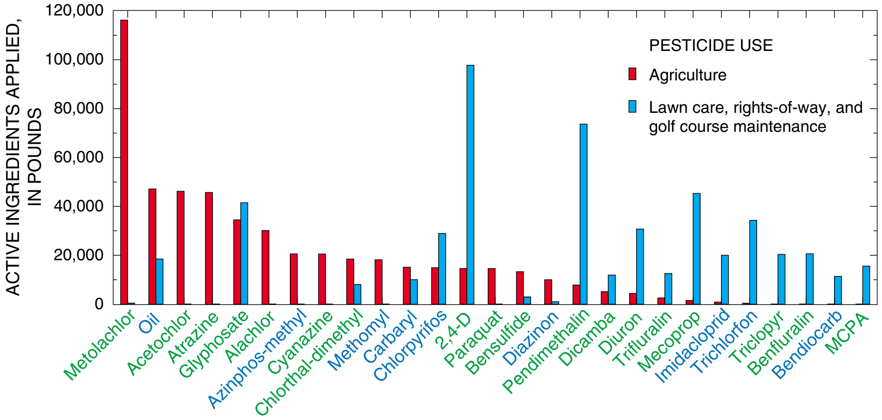


Figure 19. Metolachlor and chlorpyrifos are the herbicides and insecticides most heavily applied by licensed applicators in New Jersey, 1997-98. (Data from New Jersey Department of Environmental Protection, Pesticide Control Program, Trenton, N.J.)

Pesticide use--A pesticide is any substance or mixture of substances used to control pests, such as insects (**insecticides**), weeds (**herbicides**), and fungi (**fungicides**). Pesticides have long been used in agricultural settings, and their use in urban and undeveloped areas has increased in the last several decades (Barbash and Resek, 1996). More than 10,000 products containing more than 400 major active ingredients are currently registered for use as pesticides in New Jersey (Hamilton and Meyer, 1994). Agriculture accounts for the largest use of pesticides; more than 1.4 million pounds of active ingredients were applied by licensed applicators in 1997 (fig. 19). Residential lawn care accounts for the second largest use; more than 500,000 pounds of active ingredient (mostly herbicides) were applied by licensed applicators in 1998. Maintenance of golf courses and control of weeds in right-of-way areas account for most remaining pesticide use by licensed applicators.

herbicide atrazine increased as much as 500 percent in samples of Raritan River runoff during May-July (fig. 20). The Raritan River Basin is about 30 percent agricultural land on which atrazine is applied during the spring.

Herbicides such as atrazine and metolachlor that are used primarily for agricultural weed control were detected most frequently, and at highest concentrations, in samples from streams whose drainage basins contained about 25 percent or more agricultural land (fig. 21; Reiser and O'Brien, 1999) and in samples of shallow ground water underlying agricultural settings in New Jersey (fig. 22; Stackelberg and others, 1997). Atrazine and metolachlor are also frequently detected in shallow ground water underlying agricultural settings on Long Island (Phillips and others, 1999).

The herbicide prometon was detected most frequently in streams and shallow ground water associated with urban settings in New Jersey (fig. 22) and on Long Island (Phillips and others, 1999). Prometon is used in areas where total vegetation control is desired—for example, along roadways, rail ways, and other rights-of-way. Although prometon is not among the most commonly used herbicides by licensed applicators in New Jersey, it is available commercially and ranked 14th nationally for home and garden herbicide use (U.S. Geological Survey, 1999). In New Jersey, prometon was frequently detected in streams that drain mixed land-use areas, a reflection of its use along roadways and around homes.

The herbicide simazine, which is used in agricultural and nonagricultural settings, was detected in

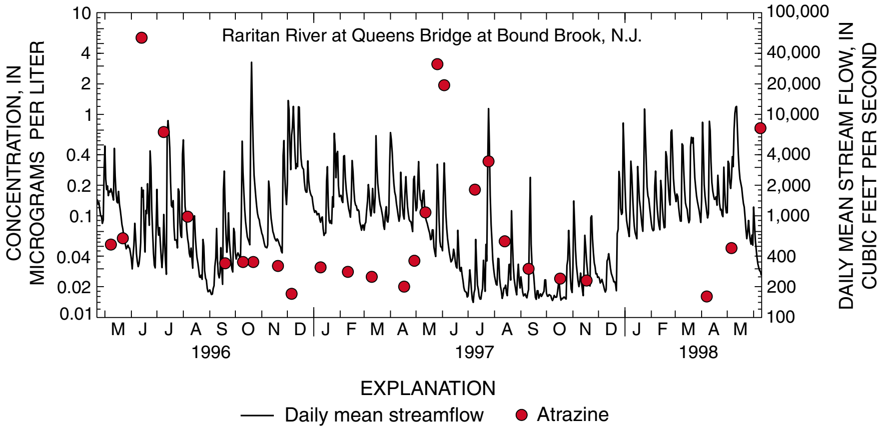


Figure 20. Concentrations of atrazine and other pesticides are highest during high streamflow in May–July following the April–June application period.

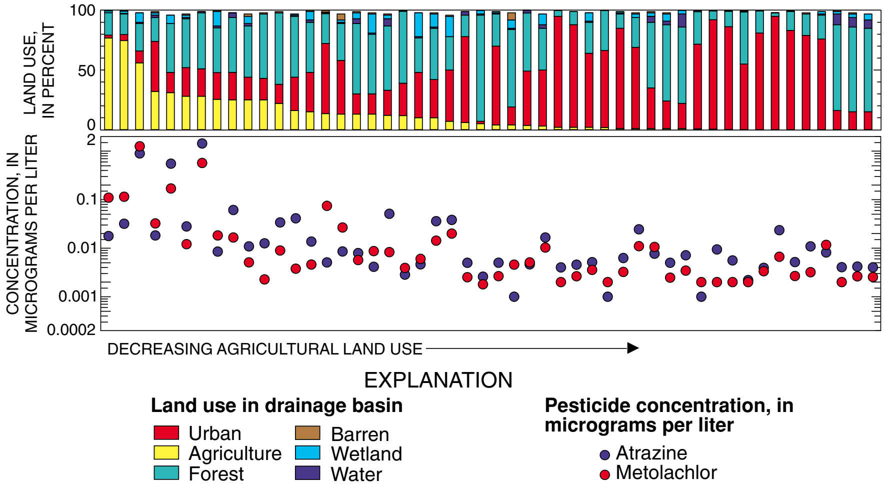


Figure 21. Concentrations of atrazine and metolachlor in samples from 50 stream sites were related to agricultural land use (from Reiser and O'Brien, 1999).

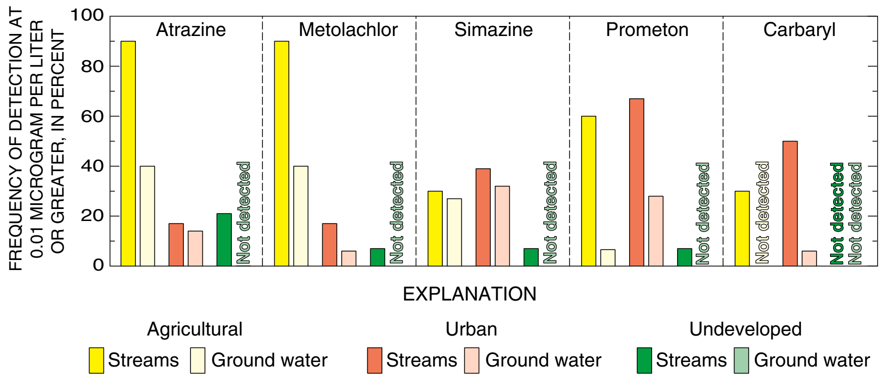


Figure 22. Pesticides are detected more frequently in streams and ground water in agricultural and urban areas than in undeveloped areas.

streams and shallow ground water underlying agricultural and urban areas in New Jersey (fig. 22) and on Long Island (Phillips and others, 1999). The insecticide carbaryl, which also is used in agricultural and nonagricultural settings, was detected almost exclusively in samples from streams. During this study, carbaryl was the fourth most commonly applied agricultural insecticide and the fifth most commonly applied lawn-care insecticide by licensed applicators in New Jersey. Carbaryl is also available commercially to nonlicensed applicators such as homeowners. Despite its high rate of use, carbaryl was infrequently detected in ground water in New Jersey or on Long Island (Phillips and others, 1999). This finding demonstrates that high application rates alone do not necessarily result in the detection of pesticides in ground water.

Pesticide Detections in Ground Water Are Related to Pesticide Properties

The most commonly used pesticides are not necessarily the most frequently detected in samples of shallow ground water. Various properties dictate pesticide persistence or mobility in the environment and make certain pesticides more likely to be detected in ground water and other pesticides less likely, regardless of the quantity applied at land surface. Vogue and others (1994) derived a movement rating for pesticide compounds in ground water based on expected persistence (soil half-life) and mobility or tendency to adsorb to soil particles (soil-sorption coefficient). Thirty-four pesticides analyzed during this study for which usage data are available were classified by the method of Vogue and others (1994) as having low to very low, moderate, or high to very high movement ratings. Pesticides with low to very low or moderate movement ratings were seldom detected (less than 5 percent) in samples of shallow ground water, even if applied in large quantities (fig. 23). In contrast, pesticides with high to very high movement ratings were detected more frequently (5 to 26 percent) even if applied in relatively small quantities.

Organochlorine Insecticides Were Detected in Streams and Ground Water

Even though the use of many organochlorine compounds has been discontinued, their widespread historical application and environmental persistence have led to frequent detection in streambed sediments (Stackelberg, 1997) and in whole-fish tissue samples (Long and others, 2000) (see blue text box and discussion on p. 9). During this study, the organochlorine insecticide dieldrin, which was used historically to control termite populations in residential settings and, to a lesser extent, to control insects in agricultural settings, was detected in 24 to 27 percent of samples from monitoring and public-supply wells in southern New Jersey (Stackelberg and others, 2000). Agricultural uses of dieldrin were discontinued in the 1970s, and its use as a termiticide was canceled in the mid-1980s, 10 years before the collection of these ground-water samples. Dieldrin was also detected in nearly 20 percent of samples from streams that drain agricultural areas during this study (Reiser and O'Brien, 1999).

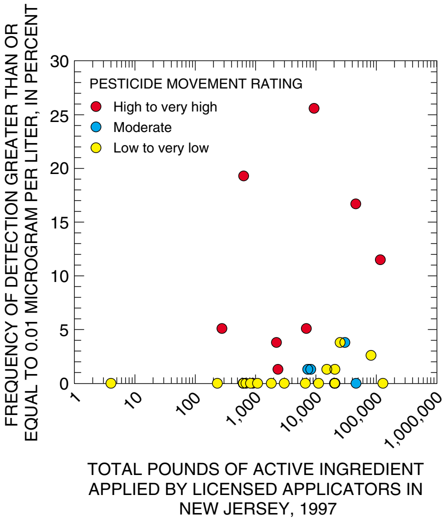


Figure 23. Pesticides with high to very high movement ratings have the highest detection frequency (5 to 26 percent) in ground water even when applied in relatively small quantities.

Organochlorine insecticides were detected in 52 and 100 percent of samples of shallow ground water underlying suburban and agricultural areas, respectively, in a similar study on Long Island in the mid-1980s (Eckhardt and Stackelberg, 1995). Dieldrin, chlordane, and heptachlor epoxide (a metabolite of heptachlor) were the most frequently detected organochlorine insecticides in areas of suburban development where they were used for termite control (fig. 24). Dieldrin and heptachlor epoxide, as well as DDT and its metabolites DDD and DDE, also were frequently detected in samples from agricultural areas where they were used historically to control potato beetles and other agricultural pests.

More recently, three organochlorine compounds were detected in samples from 50 wells in the surficial aquifer system on Long Island (Phillips and others, 1999). The metabolite DDE was detected in 30 percent of these samples 25 years after all uses of its parent compound DDT were canceled.

The frequent detection of organochlorine compounds in ground water 10 to 25 years after their use was discontinued demonstrates the environmental persistence of these compounds. The frequent occurrence of organochlorine insecticide metabolites such as heptachlor epoxide, DDD, and DDE also demonstrates the need to consider degradation products in assessments of pesticide occurrence in ground water.

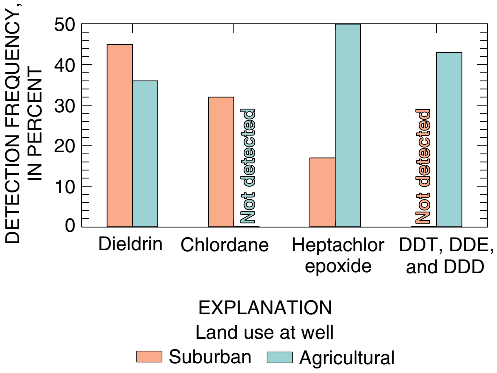


Figure 24. Detection frequency of the four most commonly detected organochlorine insecticides in shallow ground water on Long Island. (Data from LeaMond and others, 1992.)

Pesticide Metabolites Were Frequently Detected in Ground Water

Many pesticide compounds are unstable in soil and the unsaturated zone and thus readily degrade to other compounds (metabolites), some of which can be of equal or greater toxicity than the parent compound. Currently, Federal drinking-water standards and health advisories have not been established for pesticide metabolites. In southern New Jersey, deethylatrazine, a metabolite of atrazine, was the most frequently detected pesticide compound in samples from public-supply wells and the second most frequently detected pesticide in samples from monitoring wells (Stackelberg and others, 2000).

The presence of pesticide metabolites in ground water was more thoroughly evaluated on Long Island by Phillips and others (1999). Of the 25 pesticide compounds detected in samples from 50 wells in the surficial aquifer system on Long Island, 9 (36 percent) were pesticide metabolites. Furthermore, the highest pesticide concentrations reported by Phillips and others (1999) were generally those of herbicide metabolites.

VOCs Were Detected in Streams and Ground Water

Volatile organic compounds (VOCs; blue text box on next page) **were frequently present in streams and ground water. Concentrations, however, were generally low and rarely exceeded MCLs, HAs, or AQLs** (fig. 26). MCLs, HAs, and AQLs have not been established for 19 of the 47 VOCs detected in stream samples nor for 20 of the 58 VOCs detected in samples of ground water. Overall, one or more VOCs were detected in 93 percent of 112 stream samples (Reiser and O'Brien, 1998) and in 91 percent of 220 ground-water samples. **These findings are consistent with national findings to date from the NAWQA Program** in which VOCs shown in figure 26 were among the most frequently detected in samples of stream water

Sources of pesticides and VOCs in the environment—Because pesticides and VOCs are commonly used in modern society, there are numerous potential sources from which they may enter the environment. Sources that introduce contaminants to localized areas are called **point sources**. Examples of point sources include leaking underground storage tanks, discharge of effluent from industrial facilities and wastewater-treatment plants, leachate from landfills, accidental spills, and improper or illegal disposal. Although individual point sources generally contaminate only a small area, they may introduce a wide variety of chemicals to the environment at highly elevated concentrations. Widespread or diffuse sources of contaminants, called **nonpoint sources**, generally result in the introduction of low-level concentrations of specific compounds to the environment (fig. 25).

Figure 25. Examples of nonpoint sources include widespread application of fertilizers and pesticides over agricultural and urban areas (left), and vehicular and industrial emissions in urban areas (right).

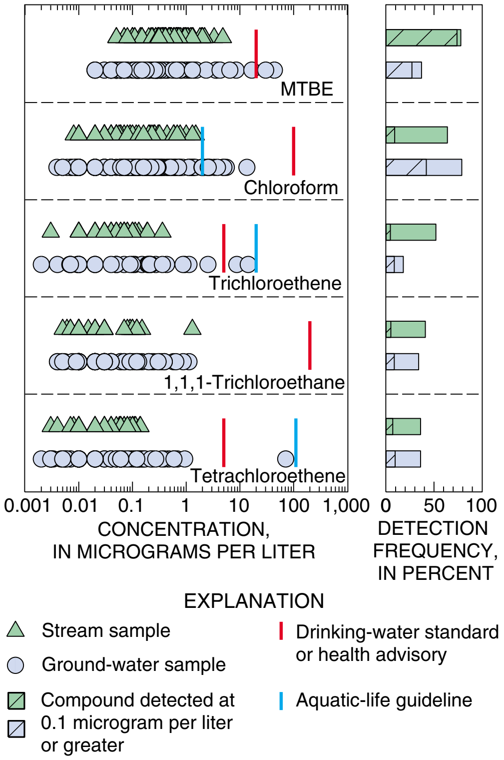


Figure 26. Volatile organic compounds (VOCs) occur frequently in streams and ground water, but concentrations are low and rarely exceed drinking-water standards.

and ground water (Squillace and others, 1999).

The most frequently detected VOCs in streams and ground-water samples are compounds used in gasoline or commercial and industrial processes, or are by-products of the chlorination of water (fig. 26; blue text box on p. 21). Methyl *tert*-butyl ether (MTBE) is a fuel oxygenate added to gasoline to enhance combustion and reduce atmospheric concentrations of carbon monoxide and ozone. Trichloromethane (chloroform) can form as a by-product of the chlorination of water, and it is also used as an industrial solvent, an extracting agent, and in the production of other synthetic compounds. Trichloroethene (TCE), 1,1,1-trichloroethane (TCA), and tetrachloroethene (PCE) are three of the most extensively used VOCs in commercial and industrial applications. These compounds were detected in shallow ground water on Long Island and in the Glassboro study area. Concentrations were greater in samples from Long Island (fig. 27) because suburban areas on Long Island were already heavily developed in the 1960s and early 1970s when use of these chlorinated solvents was greatest. Many parts of the Glassboro study area, however, were not developed until after use of these compounds was restricted.

Volatile Organic Compounds (VOCs)—VOCs are a class of organic compounds that are produced in large quantities for a multitude of uses. Products containing VOCs are used extensively in industry, commerce, and households. VOCs are present in fuels and the exhaust from their combustion. They are in many manufactured products including paint, adhesives, cleaning agents, deodorants, and polishing products. They also are used widely in commercial and industrial applications as solvent degreasers and refrigerants, in the dry-cleaning industry, in the manufacture of pharmaceutical products and plastics, and in agricultural applications as active and inactive components of pesticides and fumigants. Many VOCs have properties that make them likely to be mobile and persistent in the environment. Many VOCs are also known to be carcinogenic, mutagenic, and otherwise toxic to humans and aquatic organisms; therefore, their use, disposal, and concentration in drinking-water supplies are regulated.

VOC Detections Vary by Season and in Response to Land Use

Detection frequencies of the VOCs most frequently detected in streams were higher in samples collected during the cool months than during the warm months (fig. 28) (Reiser and O'Brien, 1998). This seasonal pattern may be attributable to the lower volatility and the greater partitioning of these compounds from air to water at cooler temperatures. Higher detection frequencies for MTBE also may result from increased amounts of MTBE added to gasoline during the winter in the study area.

In contrast, concentrations of chloroform were higher in the warm months than in the cool months at six of the seven streams. This seasonal pattern is likely attributable to a decrease in streamflow during warm months, when

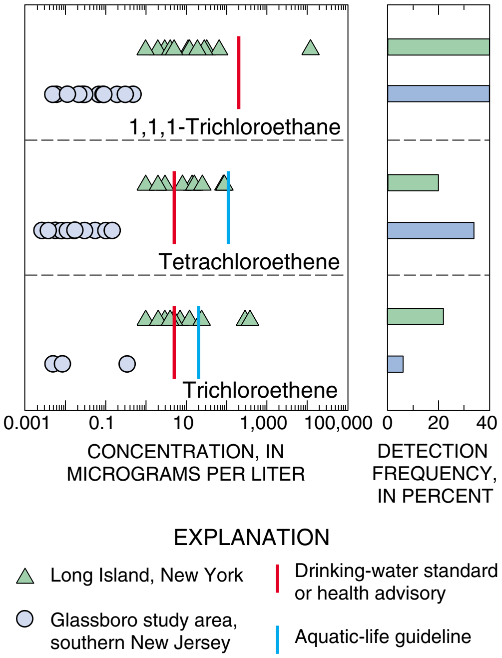


Figure 27. The concentrations of chlorinated solvents in ground water underlying urban areas were higher on Long Island than in southern New Jersey (Long Island data from LeaMond and others, 1992).

inputs of chlorinated water from wastewater-treatment plants, swimming pools, and other outdoor uses of chlorinated water are less diluted (Reiser and O'Brien, 1998).

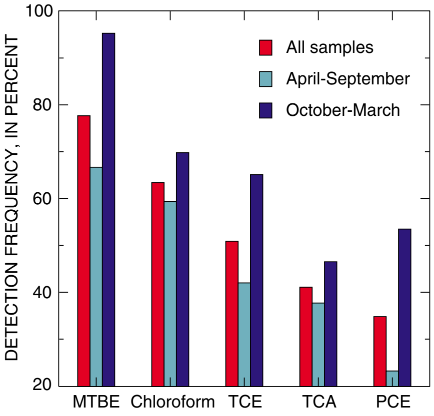


Figure 28. The detection frequency of volatile organic compounds most commonly detected in streams was higher in the cool months than in the warm months (from Reiser and O'Brien, 1998).

Fifty VOCs were detected in samples from 42 stream sites on Long Island and in New Jersey that drain basins with various land-use settings. **In general, the number and concentration of VOCs detected were highest in streams with the highest percentages of urban land use** (O'Brien and others, 1997; Terracciano and O'Brien, 1997) (fig. 29). A few exceptions were found at sites draining primarily forested land, an indication of unidentified point sources in these basins.

Thirty-eight VOCs were detected in 78 samples of shallow ground water collected in southern New Jersey (Stackelberg and others, 1997). Consistent with national findings to date, **detection frequencies and concentrations of the most frequently detected VOCs generally were highest in urban areas and lowest in agricultural and undeveloped areas** (fig. 30). This more frequent detection of VOCs is the result of increased human activity and greater VOC use in urban areas.

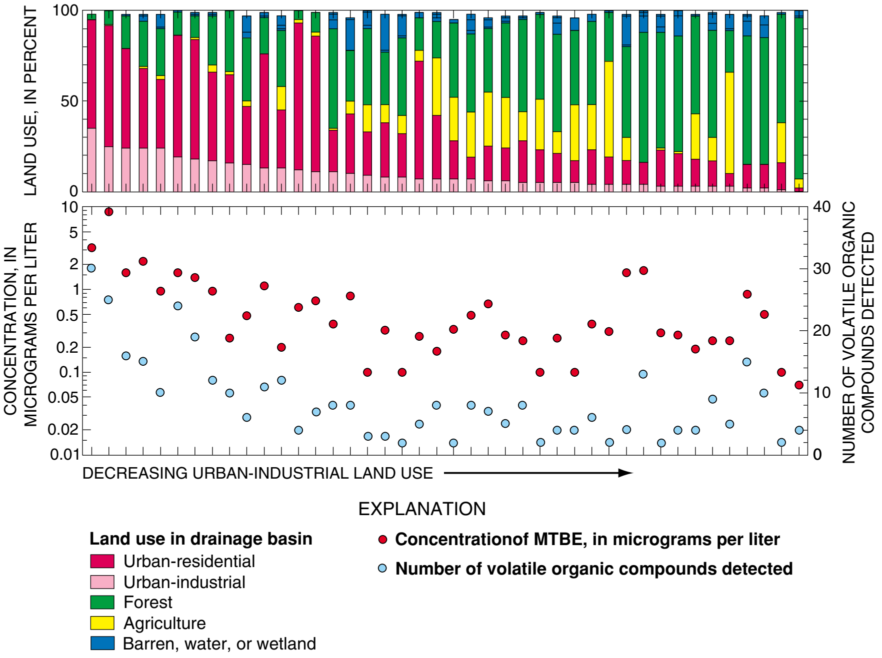


Figure 29.The concentration of methyl *tert*-butyl ether (MTBE) and the total number of volatile organic compounds (VOCs) generally were related to the amount of urban land use in the drainage basin (from O'Brien and others, 1997).

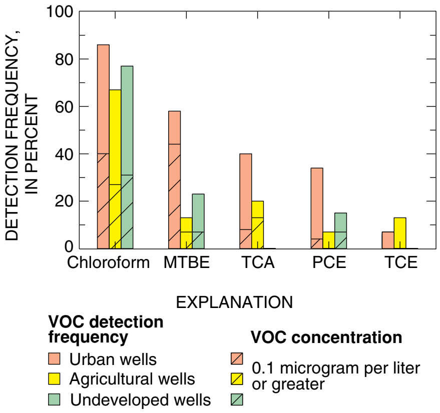


Figure 30. Detection frequencies of volatile organic compounds (VOCs) generally were highest in urban areas and lowest in agricultural and undeveloped areas.

The presence of VOCs in ground water underlying Long Island is also related to urban land use. Nearly all samples of ground water underlying Kings and Queens Counties, which form the New York City Boroughs of Brooklyn and Queens, contained one or more VOCs (Spinello and others, 2000). MTBE was the most frequently detected VOC, followed by chloroform, toluene, and TCA.

In samples of ground water underlying Nassau and Suffolk Counties on Long Island, VOCs were detected most frequently (54 percent detection greater than 1 µg/L) in areas of suburban development where industry and commercial services that use VOCs are interspersed with residential housing, and least frequently (3 percent) in agricultural and undeveloped areas (Eckhardt and Stackelberg, 1995).

Public-Supply Wells in Surficial Aquifers Are Vulnerable to VOCs

In the surficial Kirkwood-Cohansey aquifer system underlying the Glassboro study area, the number and total concentration of VOCs per sample were significantly greater in water from public-supply wells than in water from monitoring wells (Stackelberg and others, 2000) (fig. 31). VOCs in ground water can be derived from both point and nonpoint sources (blue text box, p. 21). Within the Glassboro study area, however, the atmosphere was determined not to be a nonpoint source for most VOCs (Baehr and others, 1999b; blue text box below). Point sources (such as spills) and nonpoint sources (such as urban stormwater runoff) are more common in urban areas and lead to spatially variable concentrations of VOCs near the water table.

Because much larger volumes of water are withdrawn from public-supply wells than from monitoring wells, their contributing areas are larger and, therefore, more likely to intercept water flowing from VOC sources, especially point sources. Additionally, results of ground-water-flow simulations indicate that public-supply wells in the Glassboro study area intercept relatively young water flowing along short paths, making the wells vulnerable to contamination by the VOCs that are frequently detected in recently recharged ground water. These public-supply wells, however, also intercept water flowing along longer paths associated with longer residence times. This water is more likely than water from shallow monitoring wells to contain VOCs derived from the degradation of parent compounds or VOCs that had significant historical use that has recently been reduced or phased out. Monitoring wells sampled during this study were completed at depths near the water table and, thus, intercept relatively short flow paths.

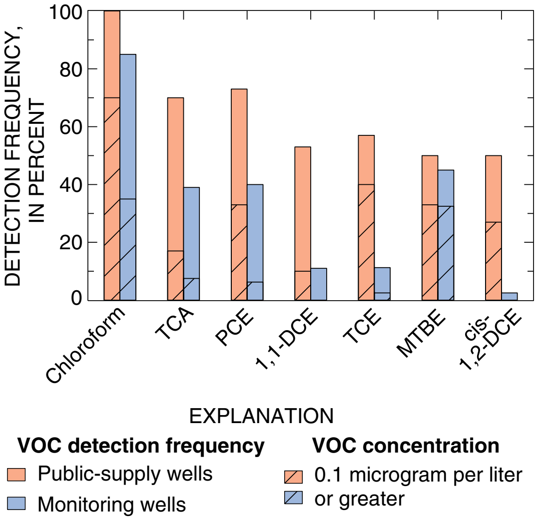


Figure 31. Volatile organic compounds (VOCs) were detected more frequently and in higher concentrations in samples from public-supply wells than from monitoring wells in the Glassboro study area, New Jersey.

Evaluating the sources of VOCs in ground water—Results of work done as part of the NAWQA Program indicate that VOCs are frequently detected at low-level concentrations in shallow ground water in urban areas across the Nation (Squillace and others, 1999). Consistent with this national finding, several VOCs including trichloromethane (chloroform), MTBE, TCA, PCE, and TCE were frequently detected at low concentrations in shallow ground water underlying the Glassboro study area (Stackelberg and others, 1997). To improve understanding of the source(s) of these compounds, samples of VOCs in the atmosphere and unsaturated-zone gas also were collected (Baehr and others, 1999a). Atmospheric concentrations of MTBE were high enough to explain all but seven of the ground-water detections. In contrast, the atmosphere was ruled out as a likely source for all other VOCs because their atmospheric concentrations were not high enough to explain even the lowest detection in ground water.

Concentrations of VOCs in unsaturated-zone gas provide further insight into the likely source(s) of these compounds (Baehr and others, 1999a). For example, at about 43 percent of the sites where MTBE was detected in both ground water and unsaturated-zone gas, the concentration in ground water was greater than could be explained by atmospheric or unsaturated-zone gas concentrations. At these sites, the movement of MTBE appears to be upward from ground water to the unsaturated zone. The likely source of MTBE at these sites is an upgradient gasoline source (such as a spill, urban runoff, or leaky underground storage tank) with MTBE migrating to the site as a solute in ground water. At 28 percent of the sites where MTBE was detected in both ground water and unsaturated-zone gas, the concentration in ground water was less than the water-equivalent concentration in the unsaturated-zone gas, but within the atmospheric concentration range, indicating a net movement of MTBE downward across the water table with the atmosphere being the likely source. At the remaining sites, the source of MTBE in ground water could be either the atmosphere or an upgradient source.

At sites where the other VOCs were detected in both ground water and unsaturated-zone gas, the concentration gradient indicates that these compounds are moving upward from ground water to the unsaturated zone and, thus, are likely derived from upgradient sources.

VOCs and Pesticides Occur Together in Ground Water

Drinking-water standards and guidelines described in this report are based on the toxicity of individual compounds and not on combinations of compounds. Results from this and other NAWQA studies, however, clearly indicate that most pesticides and VOCs found in streamwater or ground-water samples occur as mixtures of two or more compounds (Stackelberg and others, in press; U.S. Geological Survey, 1999; Squillace and others, 1999).

In this study, nearly all of 146 stream samples contained 5 or more pesticide compounds, and nearly 50 percent of these samples contained 9 or more pesticide compounds (Reiser, 1999). In addition, two or more pesticides and (or) VOCs were detected in more than 95 percent of samples collected from public-supply and monitoring wells in the Glassboro study area. **Total pesticide and total VOC concentrations per sample increased significantly as the number of detected compounds per sample increased** (fig. 32).

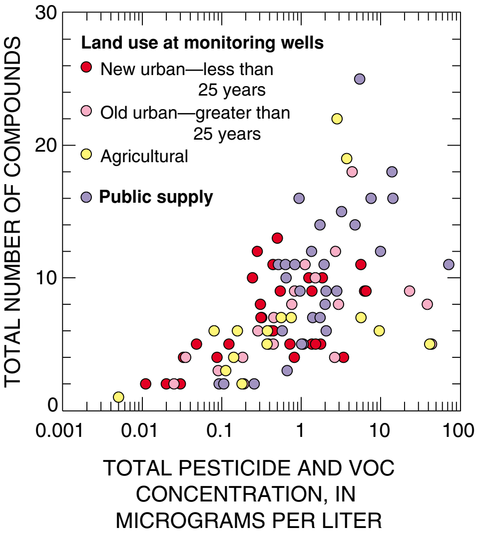


Figure 32. The total concentration of pesticides and volatile organic compounds (VOCs) in each sample increased significantly as the number of compounds detected in each sample increased.

Most pesticides and VOCs in samples from public-supply and monitoring wells in the Glassboro study area were detected at concentrations less than 1 µg/L (figs. 18 and 26). The sum of these organic compounds, however, was greater than 1 µg/L in 45 percent of these samples (fig. 32).

More than 400 combinations of pesticides and VOCs were detected in 20 percent or more of public-supply well samples in southern New Jersey. The most frequently detected pesticides and VOCs constitute the most frequently occurring combinations (fig. 33). Although certain pesticides and VOCs commonly occurred together in samples of water from public-supply and monitoring wells, other pesticides and VOCs were found to commonly occur together only in one or the other well network. As discussed previously, compared to samples from monitoring wells, samples from public-supply wells are more likely to contain constituents that (1) were used in greater quantities in the past, (2) were introduced from point sources, and (or) (3) were derived from the degradation of parent compounds along extended flow paths. For VOCs, samples from public-supply wells in the surficial aquifer system of southern New Jersey commonly contain more combinations more frequently than samples from monitoring wells.

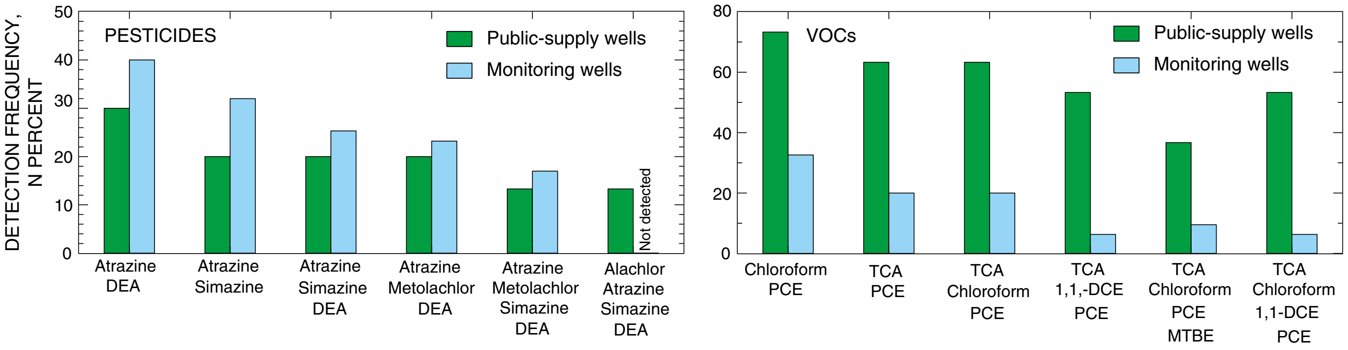


Figure 33. Certain mixtures of pesticides and volatile organic compounds were common in samples from public-supply and monitoring wells, Kirkwood-Cohansey aquifer system, Glassboro study area, New Jersey. [DEA=deethylatrazine; PCE= tetrachloroethene; TCA=1,1,1-trichloroethane; TCE=trichloroethene; 1,1-DCE=1,1-dichloroethene]

Implications of Findings for the Management of Water and Ecological Resources

Activities associated with urban and agricultural land use are the primary factors that affect the quality of streams and surficial aquifer systems and the health of aquatic life in the LINJ study area (fig. 34). The frequent detection of nutrients, synthetic organic compounds, and trace elements over a wide range of concentrations indicates a complex integration of the effects of current and historical point and nonpoint sources of these constituents. In addition, some constituents are present naturally in ground water in areas where surficial sediments or geologic formations are known to contain these constituents.

The restriction or cancellation of the use of some trace elements and synthetic organic compounds has been effective in reducing their concentrations in the environment, as evidenced by their declining concentrations in lake-sediment cores. Furthermore, stream quality, as determined by fish-community measures, improved from the 1970s to the 1990s largely as a result of wastewater-treatment-plant upgrades implemented under provisions of the Clean Water Act. In contrast, the concentrations of compounds whose uses have not been canceled, such as zinc and PAHs, continue to increase in urban lake sediments as a result of their association with increasing fossil-fuel use and vehicular traffic. In addition, findings from this study indicate that changes in the natural flow of streams, habitat degradation, reduction in biological diversity, and a shift toward species more tolerant of disturbance are associated with urban and suburban development.

The expected continued growth of population in the study area will likely continue to have a significant effect on stream- and ground-water quality and aquatic communities. Results of this study indicate that land development and management approaches that help maintain or increase base flow in flow-stressed streams and reduce flow variability during storms can promote improved water quality and stream health. For example, increasing recharge and otherwise reducing runoff in new or existing developments will likely increase stream base flow and reduce stream flashiness, both of which would benefit aquatic communities. Increased aquifer recharge also would benefit water supply if the quality of that recharge is not impaired. Furthermore, actions that prevent the loss of forests and wetlands, especially in riparian buffer areas, would also moderate the effects of development and provide improved habitat for native plants and animals.

Population growth in the study area has resulted in an increasing reliance on surface-water and surficial ground-water sources for public and domestic supply. Currently, 60 to 80 percent of the water supply in the study area is derived from these sources. The Safe Drinking Water Act provides regulatory oversights to maintain and monitor the quality of these vulnerable public-water supplies. Similar regulatory oversights are not currently in place for domestic (household) supplies, but results from domestic-well surveys in this study indicate that these systems are also vulnerable to contamination.

The Glassboro ground-water-flow model indicates that nitrate concentrations will increase significantly over the next 50 years in those parts of the Coastal Plain surficial aquifer system that underlie areas of intensive use of manure and nitrogen-based fertilizers. Furthermore, the model indicates that likely changes in land-management or chemical-use practices will not necessarily result in immediate improvements in the quality of water discharging to streams or being pumped from public-supply wells. Rather, the model indicates that nitrate concentrations will likely increase for several years following any changes in chemical use or land-management practices because of the length of time required for water to move through the aquifer system and discharge to streams or wells. The success of monitoring strategies designed to measure the effectiveness of stormwater management, chemical-use management, and other land-management, development, and restoration activities is reliant on incorporating this understanding of the hydrologic system.

Actions that would help to ensure safe and reliable sources of drinking water into the future and to protect stream habitats and aquatic communities include (1) adequate monitoring and assessment of water quantity and quality, and biological resources, (2) land-development and watershed-management approaches that mitigate the effects of urbanization on these resources, and (3) a close linkage of water- supply planning and development with land-use planning and watershed-management strategies that favor improvement of water quality and quantity. Given the prospect for continued population growth in the region, an increased vigilance in terms of monitoring and assessment of water and related resources likely is warranted.

Figure 34. New urban areas commonly are displacing agricultural and (or) forest land in the study area. Specifically, urban land area has grown from 22 percent of the study area in the early 1970s to 33 percent in 1995, with a corresponding 11-percent decrease in agricultural and forest land.

"*The need of wholesome water for household consumption, as also good water for use in the arts, has prompted many inquiries about the available sources from which steady and abundant supplies of such water may be had, and the large number of these inquiries has demonstrated the necessity of gathering all of the facts relative to the occurrence of waters on the surface and in the earthy and rocky beds under it... The importance of this question of water supply to our citizens, most of whom are dependent upon public water-supply systems, and its intimate relation to the general health, make it deserving of the time and space which has been allotted to it in this report. The subject is a growing one and the conditions are so rapidly changing that no report thereon can be considered final. The space here given to it is inadequate to its full discussion. It merely rounds out an epoch in the accumulation of information therein for public use.*"

(Taken from the preface by John C. Smock, New Jersey State Geologist, *in* Cornelius C. Vermeule, 1894, Water Supply—Water power, the flow of streams and attendant phenomena: Geological Survey of New Jersey Report, v. 3, 352 p.)

DESIGN OF THE LONG ISLAND–NEW JERSEY STUDY

The LINJ study design focused on collecting data (table 6) that would add to current knowledge of contaminants in water, sediment, and fish tissue and improve the understanding of their occurrence, their biological effects, and the processes governing their occurrence and movement (Gilliom and others, 1995).

Samples of stream water (over a range of flow conditions) and stream ecology (once each year) were collected at seven fixed sites (fig. 35a; basic and intensive, table 6). Samples for chemistry and ecology also were collected once at 45 synoptic sites (fig. 35b). Streambed sediments were sampled once at 14 sites (fig. 35a); samples of whole fish or fish livers were collected at 8 of these sites. Sediment cores were collected once from four lakes (fig. 35a). Streambed sediment and fish fillets were collected once for mercury and methylmercury at four stream sites (fig. 35a).

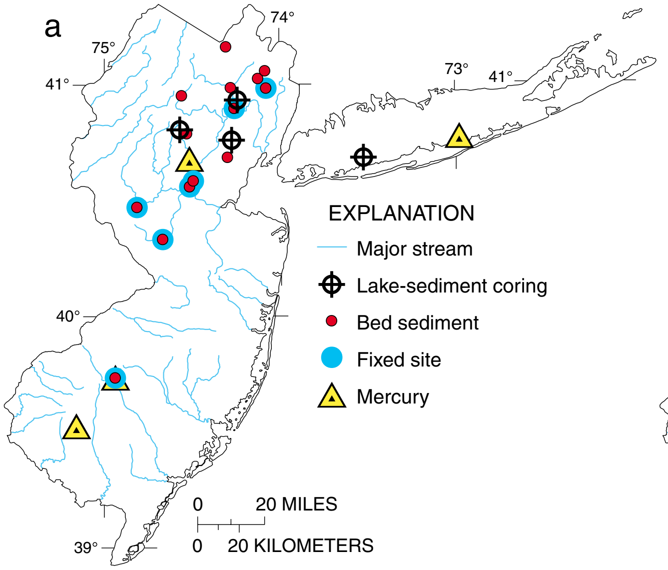


Figure 35. Stream-sampling sites included (a) fixed sites, bed-sediment and mercury synoptic sites, and lake-sediment coring sites, and (b) pesticide, VOC, and ecological synoptic sites.

Ground-water samples (table 6) were collected from 220 wells in surficial aquifers that are sources of drinking-water supply. Monitoring wells were installed in the Kirkwood-Cohansey aquifer system underlying 30 new urban (less than 25 years old), 20 old urban (greater than 25 years old), 15 agricultural, and 13 undeveloped land-use settings and each well was sampled once (fig. 36a). Water-quality data from these 78 wells, from 30 deeper monitoring wells collocated with urban monitoring wells, from 30 public-supply wells, and from 3 streams were used in a modeling analysis of how contaminants enter and move through the aquifer to water- supply wells and streams. Domestic-supply wells were sampled to assess water quality in three major aquifer systems—the Kirkwood-Cohansey aquifer system (30 wells) and the fractured-bedrock aquifer systems of the New England (30 wells) and Piedmont (22 wells) Physiographic Provinces (fig. 36b).

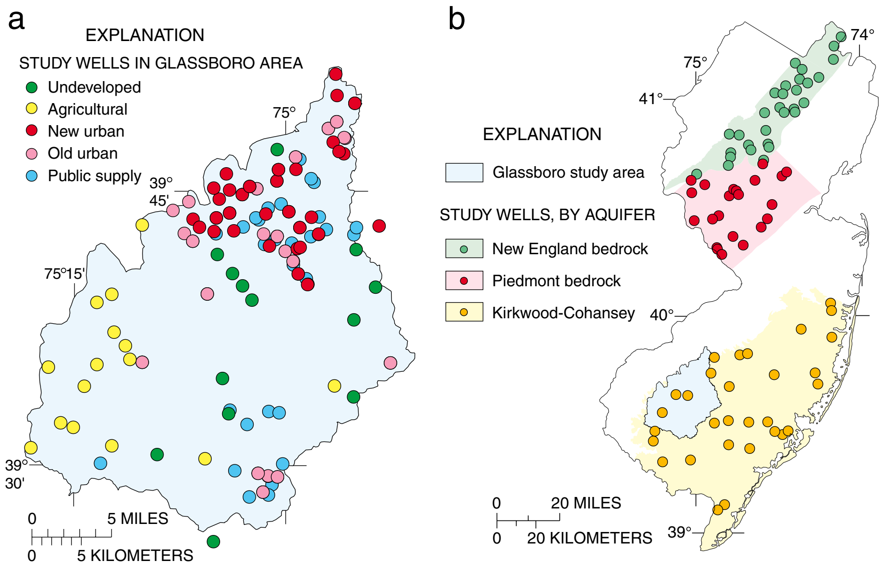


Figure 36. Ground-water sampling sites included (a) land-use monitoring wells and public-supply wells and (b) domestic-supply (household) wells.

Table 6. Summary of data collection in the Long Island–New Jersey Coastal Drainages study, 1996–98

Study component	What data were collected and **why**	Number and types of sites sampled	Sampling frequency and period
Stream Chemistry			
Basic-fixed sites	Nutrients, suspended sediment, major ions, organic carbon, field parameters (streamflow, dissolved oxygen, water temperature, pH, and specific conductance), and 1 year of 87 pesticides and 85 volatile organic compounds (VOCs). **Fixed sites measure how often and how much of a constituent is found, over time, due to different seasonal or land-use patterns.**	Includes 5 sites that represent typical urban, agricultural, and/or mixed land-use basins—3 smaller basins that are indicative of an intensive urban residential (Saddle River), a developing urban (Stony Brook), and an agricultural (Neshanic River) land use and 2 larger basins (Passaic and Raritan Rivers) that integrate mixed land uses. Drainage areas range from 20 to 804 square miles (mi^2) in size.	Monthly and storm events, 1996–98; flow and stream temperature measured hourly.
Intensive-fixed sites	Same as above but sampled more for pesticides and VOCs. **To determine how often and how much of a constituent is found, over time, due to different seasonal or land-use patterns**.	Includes 2 smaller (16–44 mi^2) sites. Bound Brook represents intensive urban residential/commercial land use in northern N.J. and Great Egg Harbor River represents urban/mixed land use in the Coastal Plain.	Biweekly to monthly and storm events, 1996–98; flow, stream temperature, and specific conductance measured hourly.
Long-term site	Same constituents as above. **To determine changes or trends in chemistry over time**.	Only 1 site, Raritan River at Queens Bridge (804 mi^2) that integrates mixed land uses in northern N.J.	Monthly, quarterly only for VOCs, 1999 to next cycle.
Synoptic sites	Nutrients, organic carbon, suspended sediment, field parameters, 47 pesticides, and 85 VOCs were sampled. **To measure how much a constituent changes, over the area, due to different land- or chemical-use patterns**.	Includes 45 sites over a full range (gradient) of urban land use (3–96 percent) and a range in drainage area from 16 to 180 mi^2.	Once; VOCs in January 1997; pesticides/nutrients—most in June 1997 but some in June 1998.
VOC-source surveys	Field parameters and 85 VOCs were sampled. **To evaluate VOC sources within selected basins for different flow conditions**.	Includes 11 sites within urban basins during winter base-flow conditions and 3 sites within the Bound Brook basin 4–6 times during a spring storm.	Once during base flow in January 1997, 3 sites 4–6 times during a storm in April 1998.
Stream Ecology, Fish Tissue, Streambed Sediments, and Lake Sediments			
Ecological fixed sites	Algal, benthic-invertebrate, and fish communities and the condition of stream habitat sampled. **To measure how much the communities vary due to land-use patterns, location, and time**.	Includes 7 sites that are collocated with the 7 chemistry fixed sites. Two of the 7 sites also had 2 additional samples upstream and downstream from these fixed sites.	Single stream reach (200–400 meters) once each year in August–October 1996–98; multiple reaches only in 1998.
Ecological synoptic sites	Same as stream ecology fixed sites above except reduced stream habitat and fish collected only at selected sites. **To measure how much the communities differ due to land use**.	Includes 43 sites that are collocated with the chemistry synoptic sites over a full range of urban land use (3–96 percent). Drainage area ranged from 16 to 180 mi^2. Fish data collected at 16 sites.	Single reach, only once, most in August–October 1996; Coastal Plain sites in 1997–98.
Streambed-sediment and fish tissue sites	Organochlorine pesticides and other hydrocarbons, in sieved sediments and whole fish tissue. Trace elements in sieved sediments and fish livers. **To measure how much a constituent changes due to different land- or chemical-use patterns**.	Includes 14 bed-sediment and 8 tissue sites—7 sites that are collocated with the 7 chemistry fixed sites and, to complement existing data, also with the synoptic sites, 7 sites for bed sediment and 1 for tissue.	Once in September–October 1997.
Lake-sediment coring sites	Organochlorine pesticides, other hydrocarbons, and trace elements at multiple depths in cored sediments. **To determine the changes (trend) in basin inputs over time due to different land- or chemical-use patterns**.	Includes 4 lakes. From least to most developed watershed—Clyde Potts Reservoir (undeveloped), Packanack Lake (urban residential), Orange Reservoir (urban residential and commercial), and Newbridge Pond (urban residential and commercial).	Once in September 1997.
Mercury synoptic sites	Mercury, methylmercury, and acid-volatile sulfides in bed sediment and fish fillets. **To evaluate factors for mercury occurrence and methylation potential nationwide**.	Includes 4 stream sites over a range in land use as part of a larger national mercury synoptic survey. From least to most urban—Muddy Run (agriculture), and Passaic, Great Egg Harbor, and Swan Rivers.	Once in July 1997.
Ground-Water Chemistry			
Land-use monitoring-well surveys	Nutrients, major ions, organic carbon, field parameters, 85 VOCs, 106 pesticides. **To measure the effects of land use on shallow ground-water quality**.	Installed 78 monitoring wells 10 feet below the water table underlying new urban (< 25 years), old urban (> 25 years), agricultural, and undeveloped land-use settings in the Kirkwood-Cohansey aquifer system of the 400-mi^2 Glassboro study area, N.J.	Once in fall 1996.
Flow-path monitoring wells	Same as land-use surveys above except 47 pesticides. **To evaluate the quality of ground water recharged in urban areas 10–20 years ago**.	Installed 30 monitoring wells 40-50 feet below the water table, collocated with 30 of the urban land-use monitoring wells.	Once in fall 1997.
Household (domestic) well surveys	Same as land-use surveys plus some trace elements (reduced to 87 pesticides; Piedmont, 47 pesticides). **To measure water quality representative of major aquifer subunits**.	Includes 82 household (domestic) wells in 3 major aquifer systems; 30 wells in the New England, 22 in the Piedmont fractured bedrock aquifers, and 30 in the Kirkwood-Cohansey aquifer system.	Once; New England and Piedmont in 1997, Kirkwood-Cohansey in 1998.
Community supply well survey	Same as land-use surveys. Used in a modeling analysis, along with land-use survey, flow-path survey, and stream data. **To better understand how contaminants enter and move through the aquifer to water-supply wells and streams**.	Includes 30 community (public)-supply wells in the Glassboro area (Kirkwood-Cohansey aquifer system).	Once in 1997 or 1998.

GLOSSARY

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

Algae—Chlorophyll-bearing nonvascular, primarily aquatic species that have no true roots, stems, or leaves; most algae are microscopic.

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

Aquatic invertebrates—Insects, worms, crayfish, snails, clams, and other organisms without a backbone that live in, on, or near lakes, streams, rivers, or oceans.

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

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

Basic-fixed site—A site on a stream where streamflow and water-quality data are collected to measure how often and how much of a constituent is found, over time, due to different seasonal, hydrologic, or land-use patterns.

Basin—See Drainage basin.

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

Benchmark site—See reference site.

Best management practices (BMPs)—Land-use practices that are effective and practical ways of preventing or reducing nonpoint-source pollution.

Blue-baby syndrome—A condition that can be caused by ingestion of high amounts of nitrate, resulting in the blood losing its ability to effectively carry oxygen. Most common in young infants and elderly people.

Confined aquifer—An aquifer that is completely filled with water under pressure and that is overlain by material that restricts the upward movement of water.

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

Contributing area—The area in a drainage basin that contributes water to streamflow or recharge to an aquifer.

Denitrification—A process by which oxidized forms of nitrogen such as nitrate (NO_3) are reduced to form nitrites, nitrogen oxides, ammonia, or free nitrogen, commonly brought about by the action of bacteria and usually resulting in the los of nitrogen to the air.

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

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

Ecological synoptic study—A short-term investigation to measure the differences in biologic communities, within all or part of a study area, due to different factors, such as land uses or contaminant sources.

Flow path—An underground route for ground-water movement, extending from a recharge area to a discharge area or point such as a shallow stream or pumping well.

Flowpath survey—Collection of data from a network of wells in an area to study the relations among land-use practices, ground-water flow, and contaminant occurrence and transport. These surveys are conducted in the area of one of the land-use surveys.

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

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

Indicator site—Stream sampling site located at an outlet of a drainage basin with relatively homogeneous land use and physiographic conditions; drainage areas range from 20 to 200 square miles.

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

Intensive-fixed site—A basic-fixed site at which sampling frequency is increased during selected seasonal periods.

Intolerant species—Species that are not adaptable to human alterations to the environment and thus decline in numbers where human alterations occur.

Land-use survey—Collection of data from a network of shallow wells in an area having a relatively uniform land use. These studies have the goal of relating the quality of shallow ground water to land use.

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

Major ions—Constituents commonly present in water at concentrations exceeding 1.0 milligram per liter. Generally includes the cations calcium, magnesium, sodium, and potassium; the anions, sulfate, chloride, fluoride, and nitrate; and those constituents contributing to alkalinity, most generally bicarbonate and carbonate.

Maximum contaminant level (MCL)—Maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are enforceable standards established by the U.S. Environmental Protection Agency.

Metabolite—A substance produced as the result of the degradation of another compound.

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

Minimum reporting level (MRL)—The smallest measured concentration of a constituent that may be reliably reported as a result of use of a given analytical method.

Nonpoint source—A source that cannot be defined as originating from discrete points such as pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from runoff are types of nonpoint sources.

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

Organochlorine compound—Synthetic organic compounds containing chlorine. Examples include organochlorine insecticides, polychlorinated biphenyls, and some solvents containing chlorine.

Organochlorine insecticide—Organic insecticides containing a high percentage of chlorine. Includes dichlorodiphenylethanes (such as DDT), chlorinated cyclodienes (such as chlordane), and chlorinated benzenes (such as lindane). Use of most organochlorine insecticides was banned because of their carcinogenicity, tendency to bioaccumulate, and toxicity to wildlife.

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

Point source—A source that originates from a discrete location such as discharge pipe or ditch, well, concentrated livestock operation, leaky tank, or floating craft.

Polychlorinated biphenyls (PCBs)—A mixture of chlorinated derivatives of biphenyl, marketed under the trade name Aroclor. PCBs were used in transformers and capacitors for insulating purposes and in gas pipeline systems as a lubricant. Further sale for new use was banned by law in 1979.

Polycyclic aromatic hydrocarbon (PAH)—Organic compounds with a fused-ring aromatic structure. PAHs result from incomplete combustion of organic carbon, municipal solid waste, and fossil fuels, as well as from uncombusted coal and oil products.

Probable effect level (PEL)—Concentration of a contaminant above which adverse biological effects are expected to occur frequently.

Recharge—Water that infiltrates the ground and reaches the saturated zone or aquifer.

Reference site—A site whose contributing area is minimally disturbed, such as forest and other natural areas.

Riparian—Areas adjacent to rivers and streams with a high density, diversity, and productivity of plant and animal species relative to nearby uplands.

Runoff—Excess rainwater or snowmelt that is transported to streams by overland flow, tile drains, or ground water.

Sorption—General term for the interaction (binding or association) of a solute ion or molecule with a solid.

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

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

Subunit survey—Collection of data from a network of wells in a major aquifer system, based primarily existing wells and on data collected in other programs.

Synoptic site—A site sampled during a short-term investigation to measure differences in water quality, within all or part of a study area, due to different factors, such as land uses or contaminant sources.

Threshold effect level (TEL)—Concentration of a contaminant above which adverse biological effects are expected to occur rarely.

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

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

Unconfined aquifer—An aquifer whose upper surface is a water table. See confined aquifer.

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

Urban gradient study—A study designed to measure physical, chemical, and biological responses along gradients of urban land-use intensity and identify the factors most responsible for controlling water-quality conditions.

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

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

Watershed—See Drainage basin.

Water table—The point below land surface where ground water is first encountered and below which the earth is saturated. Depth to a water table varies widely.

Water year—The continuous 12-month period, October 1 through September 30, designated by the year in which it ends. September 30, 1980 is the "1980" water year.

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APPENDIX—WATER-QUALITY DATA FROM THE LONG ISLAND-NEW JERSEY COASTAL DRAINAGES IN A NATIONAL CONTEXT

For a complete view of Long Island - New Jersey Coastal Drainages data and for additional information about specific benchmarks used, visit our Web site at http://water.usgs.gov/nawqa/. Also visit the NAWQA Data Warehouse for access to NAWQA data sets at http://water.usgs.gov/nawqa/data.

This appendix is a summary of chemical concentrations and biological indicators assessed in the Long Island - New Jersey Coastal Drainages. Selected results for this Study Unit are graphically compared to results from as many as 36 NAWQA Study Units investigated from 1991 to 1998 and to national water-quality benchmarks for human health, aquatic life, or fish-eating wildlife. The chemical and biological indicators shown were selected on the basis of frequent detection, detection at concentrations above a national benchmark, or regulatory or scientific importance. The graphs illustrate how conditions associated with each land use sampled in the Long Island - New Jersey Coastal Drainages compare to results from across the Nation, and how conditions compare among the several land uses. Graphs for chemicals show only detected concentrations and, thus, care must be taken to evaluate detection frequencies in addition to concentrations when comparing study-unit and national results. For example, alachlor concentrations in Long Island - New Jersey streams draining mixed land-use areas were similar to the national distribution, but the detection frequency was much higher (83 percent compared to 45 percent).

CHEMICALS IN WATER

Concentrations and detection frequencies, Long Island - New Jersey Coastal Drainages, 1996–98—Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals

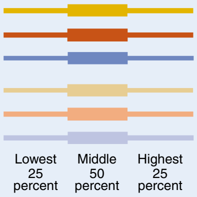
◆ Detected concentration in Study Unit

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

-- Not measured or sample size less than two

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

National ranges of detected concentrations, by land use, in 36 NAWQA Study Units, 1991–98—Ranges include only samples in which a chemical was detected



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

National water-quality benchmarks

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

| Drinking-water quality (applies to ground water and surface water)

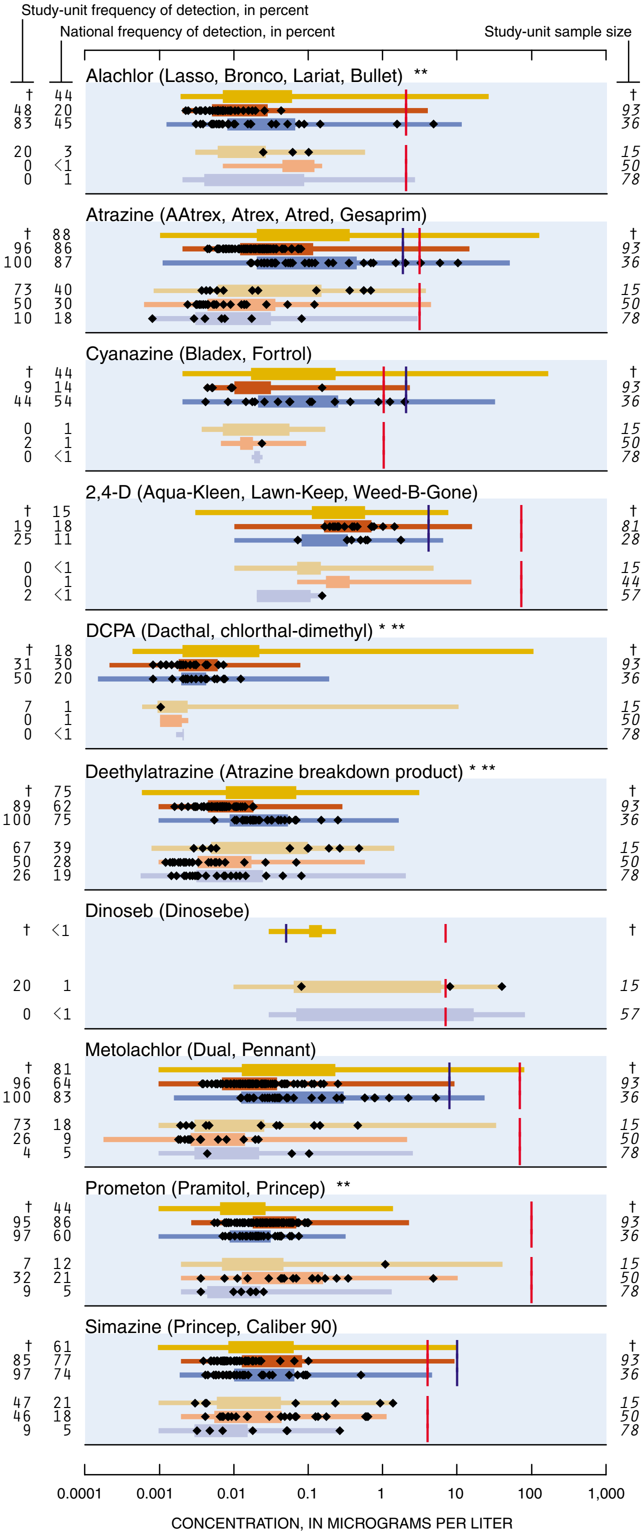
| Protection of aquatic life (applies to surface water only)

| Prevention of eutrophication in streams not flowing directly into lakes or impoundments

* No benchmark for drinking-water quality

** No benchmark for protection of aquatic life

Pesticides in water—Herbicides

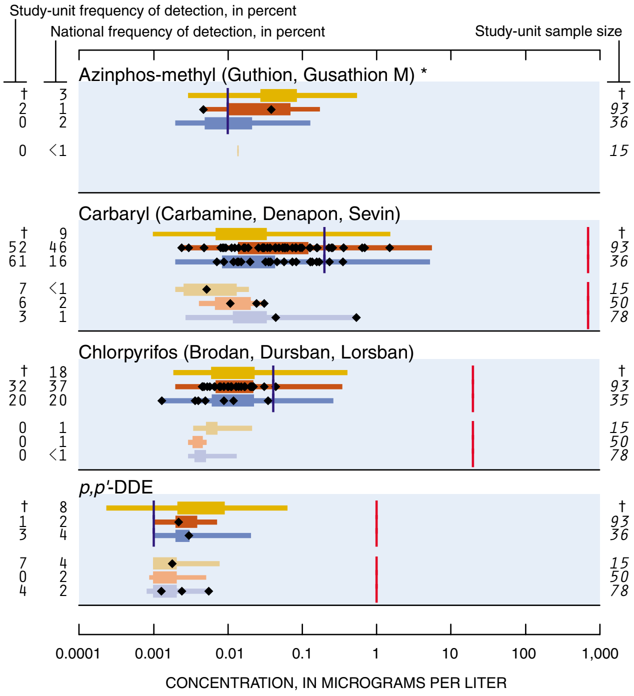


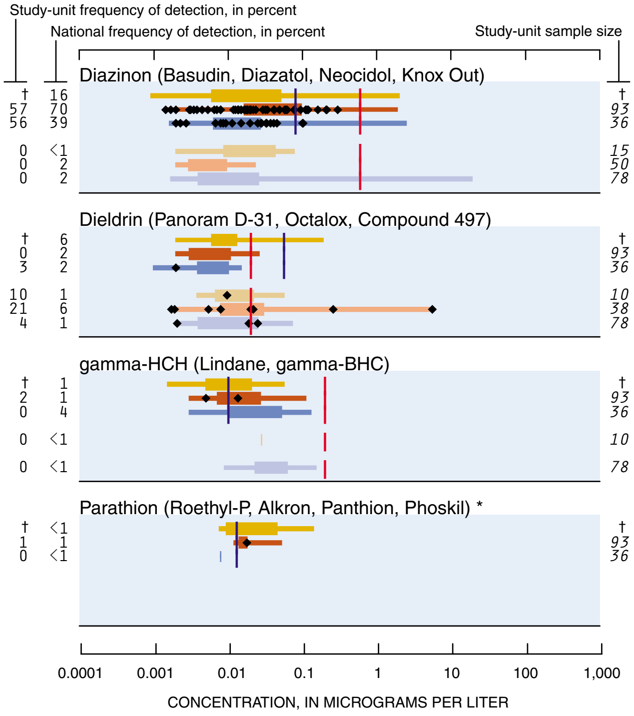
† Seven samples were collected at Neshanic River at Reaville, N.J., an agricultural site. The requirement of having a minimum of 6-months of data, however, was not met. See pages 18–20 for a discussion of pesticide findings.

Other herbicides detected
Acetochlor (Harness Plus, Surpass) * **
Acifluorfen (Blazer, Tackle 2S) **
Benfluralin (Balan, Benefin, Bonalan) * **
Bentazon (Basagran, Bentazone) **
Bromacil (Hyvar X, Urox B, Bromax)
Butylate (Sutan +, Genate Plus, Butilate) **
Dicamba (Banvel, Dianat, Scotts Proturf)
Diuron (Crisuron, Karmex, Diurex) **
EPTC (Eptam, Farmarox, Alirox) * **
Fenuron (Fenulon, Fenidim) * **
Fluometuron (Flo-Met, Cotoran) **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
MCPA (Rhomene, Rhonox, Chiptox)
Metribuzin (Lexone, Sencor)
Napropamide (Devrinol) * **
Norflurazon (Evital, Predict, Solicam, Zorial) * **
Pendimethalin (Pre-M, Prowl, Stomp) * **
Picloram (Grazon, Tordon)
Propachlor (Ramrod, Satecid) **
Propanil (Stam, Stampede, Wham) * **
2,4,5-TP (Silvex, Fenoprop) **
Tebuthiuron (Spike, Tebusan)
Terbacil (Sinbar) **
Trifluralin (Treflan, Gowan, Tri-4, Trific)

Herbicides not detected
Bromoxynil (Buctril, Brominal) *
Chloramben (Amiben, Amilon-WP, Vegiben) **
Clopyralid (Stinger, Lontrel, Transline) * **
2,4-DB (Butyrac, Butoxone, Embutox Plus, Embutone) * **
Dacthal mono-acid (Dacthal breakdown product) * **
Dichlorprop (2,4-DP, Seritox 50, Lentemul) * **
2,6-Diethylaniline (Alachlor breakdown product) * **
Ethalfluralin (Sonalan, Curbit) * **
MCPB (Thistrol) * **
Molinate (Ordram) * **
Neburon (Neburea, Neburyl, Noruben) * **
Oryzalin (Surflan, Dirimal) * **
Pebulate (Tillam, PEBC) * **
Pronamide (Kerb, Propyzamid) **
Propham (Tuberite) **
2,4,5-T **
Thiobencarb (Bolero, Saturn, Benthiocarb) * **
Triallate (Far-Go, Avadex BW, Tri-allate) *
Triclopyr (Garlon, Grandstand, Redeem, Remedy) * **

Pesticides in water—Insecticides





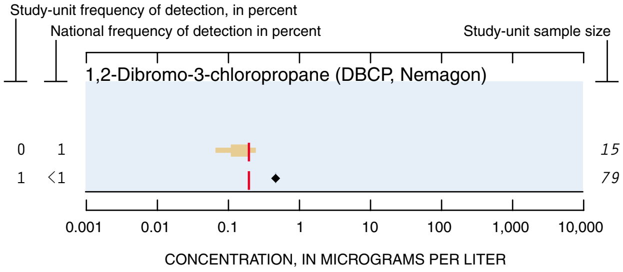
† Seven samples were collected at Neshanic River at Reaville, N.J., an agricultural site. The requirement of having a minimum of 6-months of data, however, was not met. See pages 18–20 for a discussion of pesticide findings.

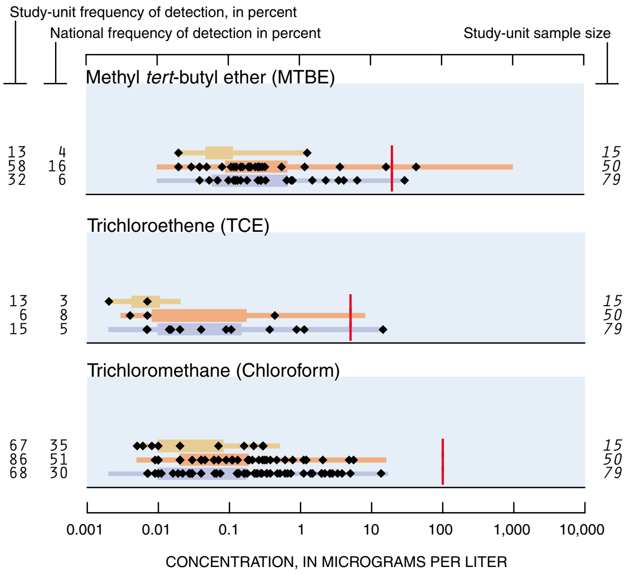
Other insecticides detected
Aldicarb (Temik, Ambush, Pounce)
Aldicarb sulfoxide (Aldicarb breakdown product)
Carbofuran (Furadan, Curaterr, Yaltox)
Fonofos (Dyfonate, Capfos, Cudgel, Tycap) **
Malathion (Malathion)
Methomyl (Lanox, Lannate, Acinate) **
Terbufos (Contraven, Counter, Pilarfox) **

Insecticides not detected
Aldicarb sulfone (Standak, aldoxycarb)
Disulfoton (Disyston, Di-Syston) **
Ethoprop (Mocap, Ethoprophos) * **
alpha-HCH (alpha-BHC, alpha-lindane) **
3-Hydroxycarbofuran (Carbofuran breakdown product) * **
Methiocarb (Slug-Geta, Grandslam, Mesurol) * **
Methyl parathion (Penncap-M, Folidol-M) **
Oxamyl (Vydate L, Pratt) **
cis-Permethrin (Ambush, Astro, Pounce) * **
Phorate (Thimet, Granutox, Geomet, Rampart) * **
Propargite (Comite, Omite, Ornamite) * **
Propoxur (Baygon, Blattanex, Unden, Proprotox) * **

Volatile organic compounds (VOCs) in ground water

These graphs represent data from 16 Study Units, sampled from 1996 to 1998

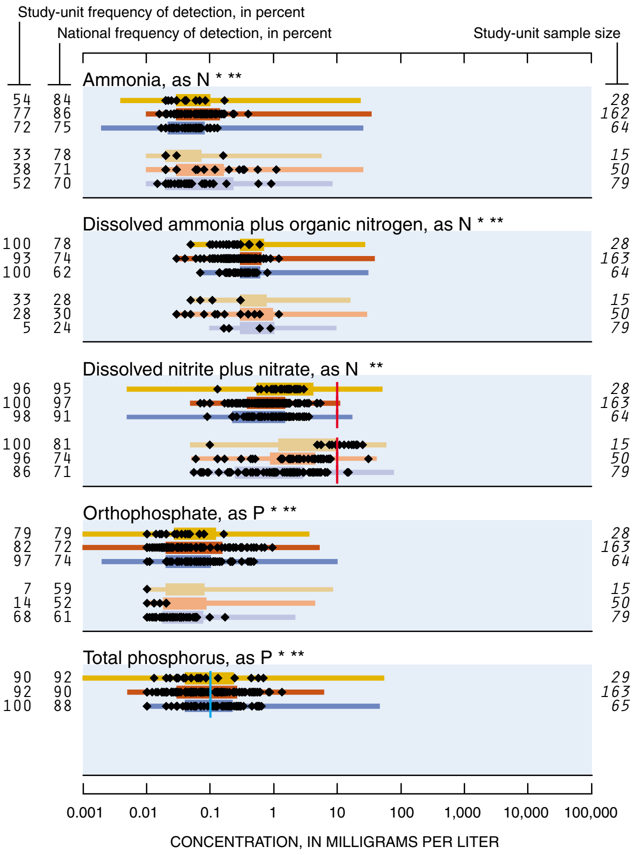




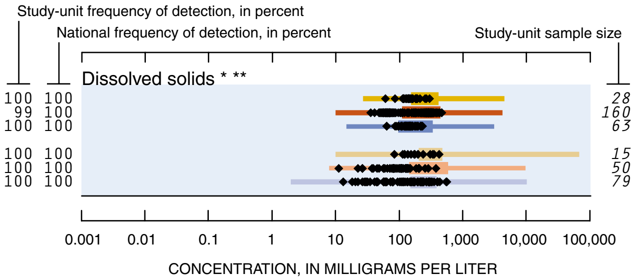
Other VOCs detected
tert-Amylmethylether (*tert*-amyl methyl ether (TAME)) *
Benzene
Bromodichloromethane (Dichlorobromomethane)
2-Butanone (Methyl ethyl ketone (MEK)) *
n-Butylbenzene (1-Phenylbutane) *
sec-Butylbenzene *
tert-Butylbenzene *
Carbon disulfide *
Chlorobenzene (Monochlorobenzene)
Chlorodibromomethane (Dibromochloromethane)
Chloroethane (Ethyl chloride) *
Chloroethene (Vinyl chloride)
Chloromethane (Methyl chloride)
1,2-Dichlorobenzene (*o*-Dichlorobenzene)
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene)
Dichlorodifluoromethane (CFC 12, Freon 12)
1,2-Dichloroethane (Ethylene dichloride)
1,1-Dichloroethane (Ethylidene dichloride) *
1,1-Dichloroethene (Vinylidene chloride)
cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene)
Dichloromethane (Methylene chloride)
1,2-Dichloropropane (Propylene dichloride)
Diethyl ether (Ethyl ether) *
Diisopropyl ether (Diisopropylether (DIPE)) *
1,2-Dimethylbenzene (*o*-Xylene)
1,3 & 1,4-Dimethylbenzene (*m*-&*p*-Xylene)
1-4-Epoxy butane (Tetrahydrofuran, Diethylene oxide) *
Ethenylbenzene (Styrene)
1-Ethyl-2-methylbenzene (2-Ethyltoluene) *
Ethylbenzene (Phenylethane)
Iodomethane (Methyl iodide) *
Isopropylbenzene (Cumene) *
p-Isopropyltoluene (*p*-Cymene) *
Methylbenzene (Toluene)
Naphthalene
2-Propanone (Acetone) *
n-Propylbenzene (Isocumene) *
Tetrachloroethene (Perchloroethene)
Tetrachloromethane (Carbon tetrachloride)
1,2,3,4-Tetramethylbenzene (Prehnitene) *
Tribromomethane (Bromoform)
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113) *
1,1,1-Trichloroethane (Methylchloroform)
Trichlorofluoromethane (CFC 11, Freon 11)
1,2,4-Trimethylbenzene (Pseudocumene) *
1,3,5-Trimethylbenzene (Mesitylene) *

VOCs not detected
Bromobenzene (Phenyl bromide) *
Bromochloromethane (Methylene chlorobromide)
Bromoethene (Vinyl bromide) *
Bromomethane (Methyl bromide)
3-Chloro-1-propene (3-Chloropropene) *
1-Chloro-2-methylbenzene (*o*-Chlorotoluene)
1-Chloro-4-methylbenzene (*p*-Chlorotoluene)
1,2-Dibromoethane (Ethylene dibromide, EDB)
Dibromomethane (Methylene dibromide) *
trans-1,4-Dichloro-2-butene ((Z)-1,4-Dichloro-2-butene) *
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene)
2,2-Dichloropropane *
1,3-Dichloropropane (Trimethylene dichloride) *
trans-1,3-Dichloropropene ((E)-1,3-Dichloropropene)
cis-1,3-Dichloropropene ((Z)-1,3-Dichloropropene)
1,1-Dichloropropene *
Ethyl methacrylate *
Ethyl *tert*-butyl ether (Ethyl-*t*-butyl ether (ETBE)) *
Hexachlorobutadiene
1,1,1,2,2,2-Hexachloroethane (Hexachloroethane)
2-Hexanone (Methyl butyl ketone (MBK)) *
Methyl acrylonitrile *
Methyl-2-methacrylate (Methyl methacrylate) *
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) *
Methyl-2-propenoate (Methyl acrylate) *
2-Propenenitrile (Acrylonitrile)
1,1,2,2-Tetrachloroethane *
1,1,1,2-Tetrachloroethane
1,2,3,5-Tetramethylbenzene (Isodurene) *
1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene *
1,1,2-Trichloroethane (Vinyl trichloride)
1,2,3-Trichloropropane (Allyl trichloride)
1,2,3-Trimethylbenzene (Hemimellitene) *

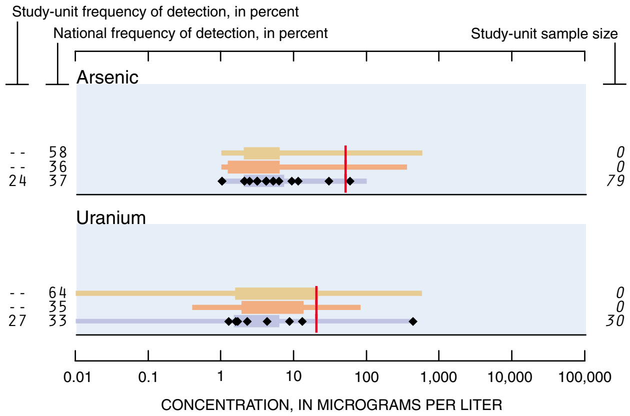
Nutrients in water

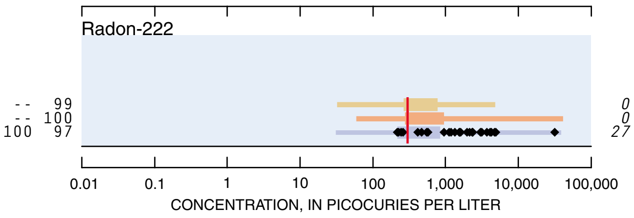


Dissolved solids in water



Trace elements in ground water

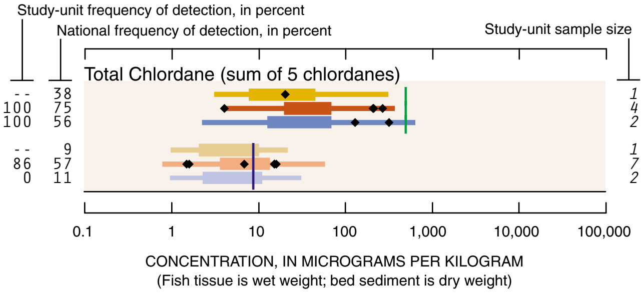




Other trace elements detected
Chromium
Lead
Selenium
Zinc

Trace elements not detected
Cadmium

Organochlorines in fish tissue (whole body) and bed sediment



CHEMICALS IN FISH TISSUE AND BED SEDIMENT

Concentrations and detection frequencies, Long Island - New Jersey Coastal Drainages, 1996–98—Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals. Study-unit frequencies of detection are based on small sample sizes; the applicable sample size is specified in each graph

◆ Detected concentration in Study Unit

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

-- Not measured or sample size less than two

12 Study-unit sample size

National ranges of concentrations detected, by land use, in 36 NAWQA Study Units, 1991–98—Ranges include only samples in which a chemical was detected

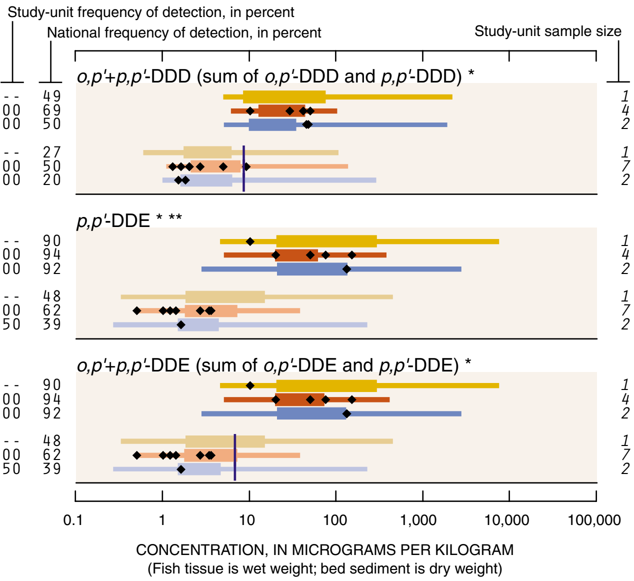
▬ Fish tissue from streams in agricultural areas
▬ Fish tissue from streams in urban areas
▬ Fish tissue from streams draining mixed land uses
▬ Sediment from streams in agricultural areas
▬ Sediment from streams in urban areas
▬ Sediment from streams draining mixed land uses

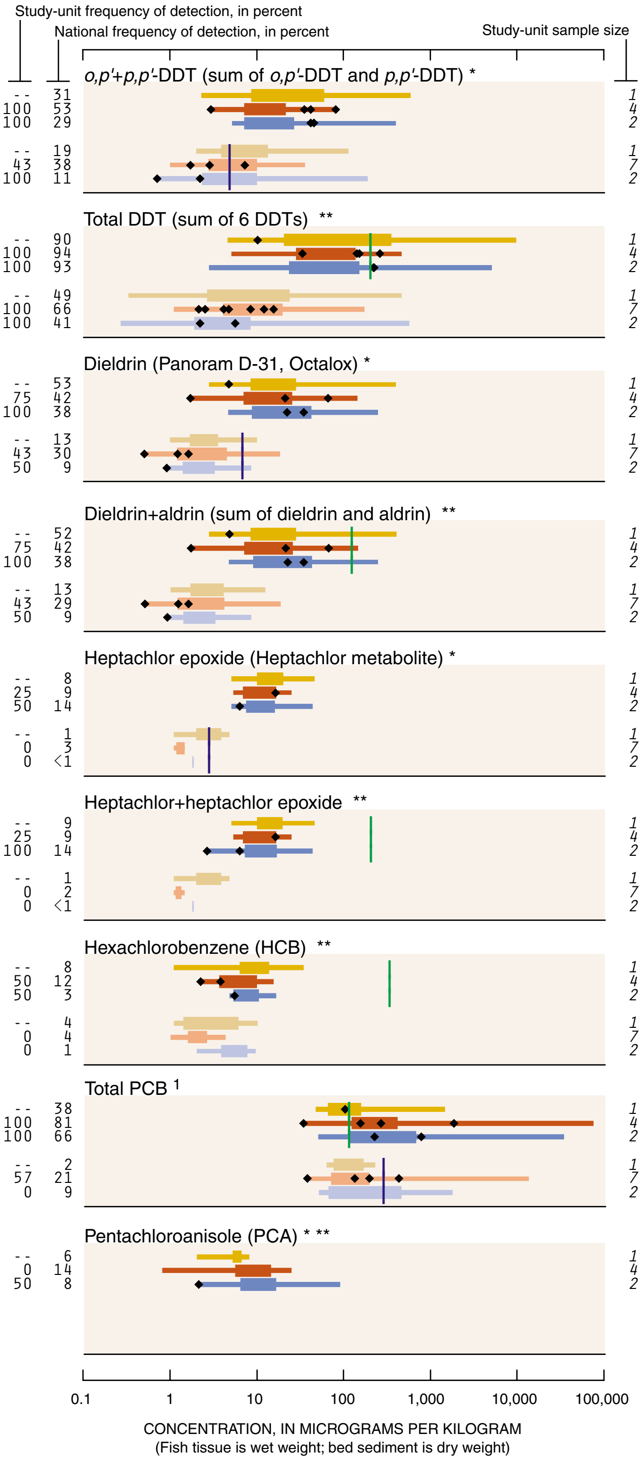
Lowest 25 percent | Middle 50 percent | Highest 25 percent

National benchmarks for fish tissue and bed sediment

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

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





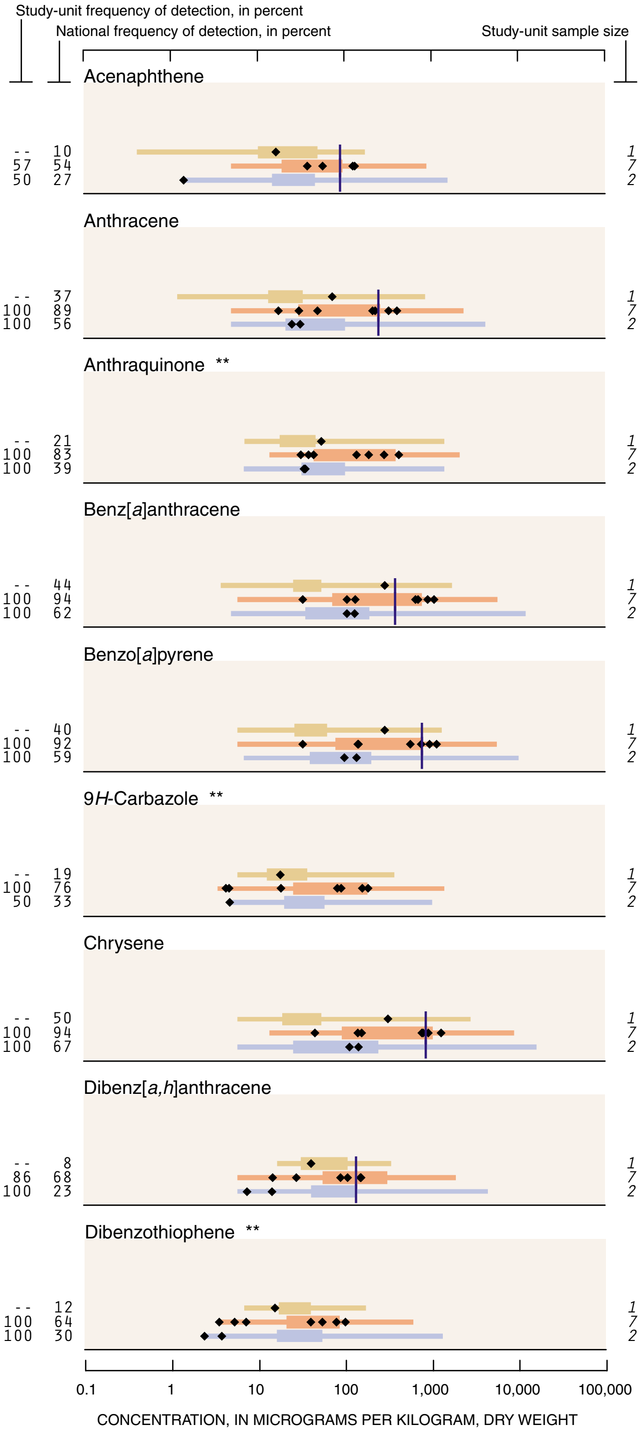
Other organochlorines detected

Mirex (Dechlorane) **

Organochlorines not detected

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

Semivolatile organic compounds (SVOCs) in bed sediment



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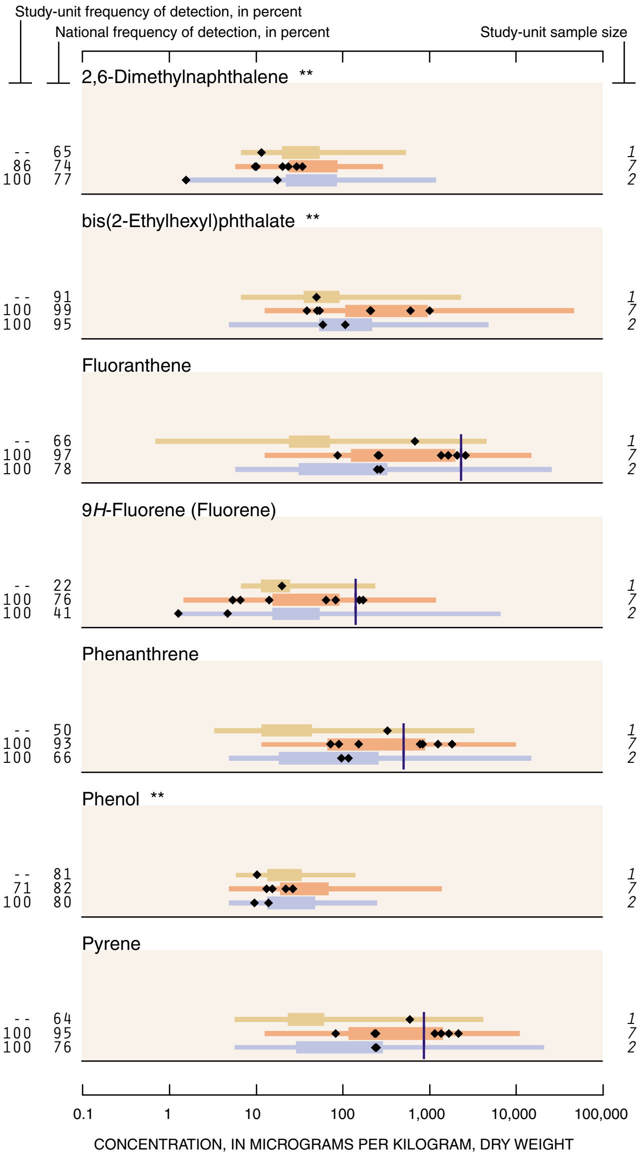
[1] The national detection frequencies for total PCB in sediment are biased low because about 30 percent of samples nationally had elevated detection levels compared to this Study Unit. See http://water.usgs.gov/nawqa/ for additional information.



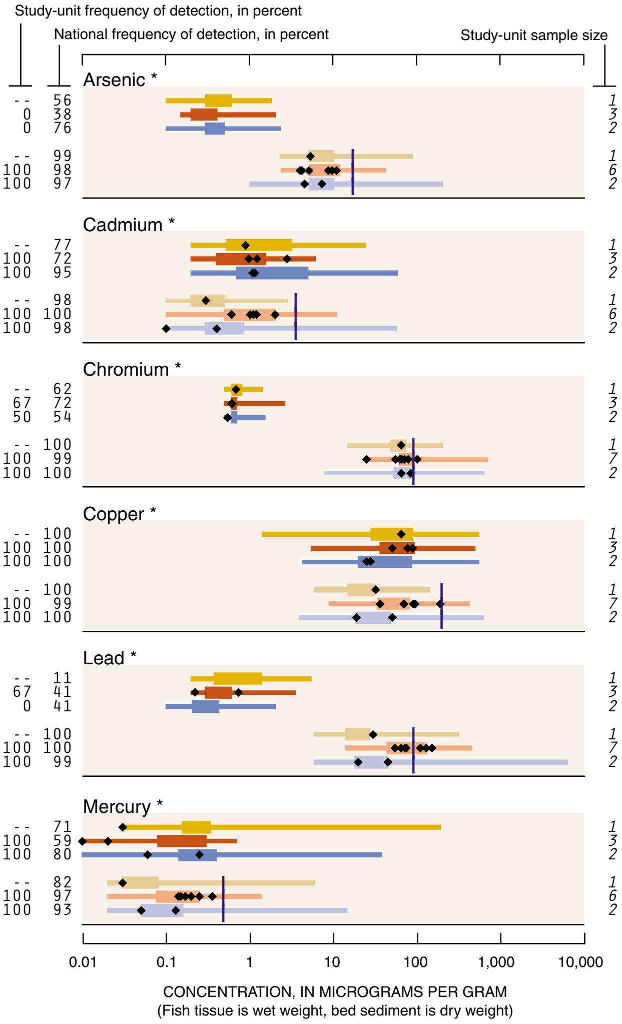
Other SVOCs detected

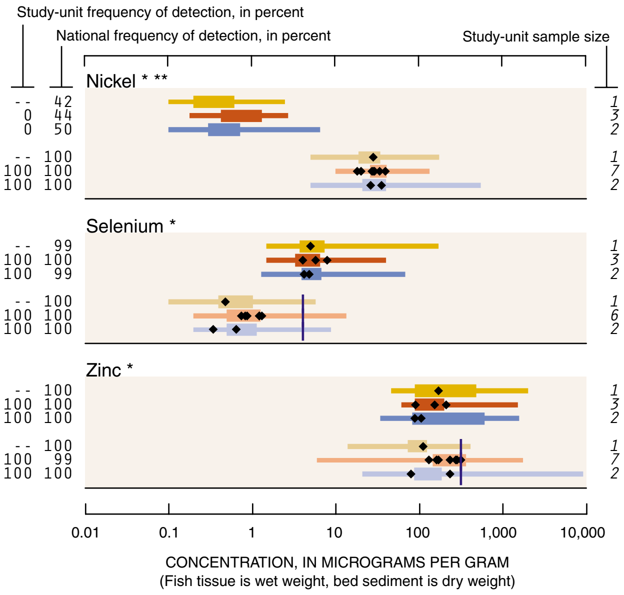
Acenaphthylene
Acridine **
Benzo[*b*]fluoranthene **
Benzo[*ghi*]perylene **
Benzo[*k*]fluoranthene **
Butylbenzylphthalate **
p-Cresol **
Di-*n*-butylphthalate **
Di-*n*-octylphthalate **
Diethylphthalate **
1,2-Dimethylnaphthalene **
1,6-Dimethylnaphthalene **
Dimethylphthalate **
Indeno[1,2,3-*cd*]pyrene **
1-Methyl-9*H*-fluorene **
2-Methylanthracene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
1-Methylpyrene **
Naphthalene
Phenanthridine **
1,2,4-Trichlorobenzene **
2,3,6-Trimethylnaphthalene **

SVOCs not detected

C8-Alkylphenol **
Azobenzene **
Benzo[*c*]cinnoline **
2,2-Biquinoline **
4-Bromophenyl-phenylether **
4-Chloro-3-methylphenol **
bis(2-Chloroethoxy)methane **
2-Chloronaphthalene **
2-Chlorophenol **
4-Chlorophenyl-phenylether **
1,2-Dichlorobenzene (*o*-Dichlorobenzene) **
1,3-Dichlorobenzene (*m*-Dichlorobenzene) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene) **
3,5-Dimethylphenol **
2,4-Dinitrotoluene **
2-Ethylnaphthalene **
Isophorone **
Isoquinoline **
Nitrobenzene **
N-Nitrosodi-*n*-propylamine **
N-Nitrosodiphenylamine **
Pentachloronitrobenzene **
Quinoline **

Trace elements in fish tissue (livers) and bed sediment





BIOLOGICAL INDICATORS

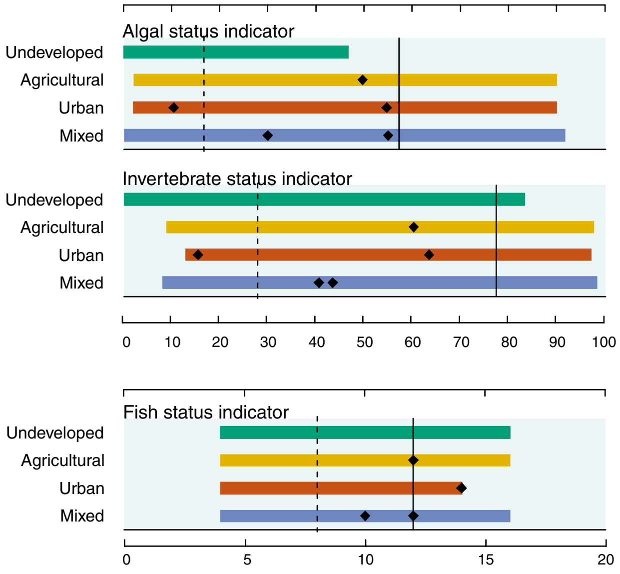
Higher national scores suggest habitat disturbance, water-quality degradation, or naturally harsh conditions. The status of algae, invertebrates (insects, worms, and clams), and fish provide a record of water-quality and stream conditions that water-chemistry indicators may not reveal. **Algal status** focuses on the changes in the percentage of certain algae in response to increasing siltation, and it often correlates with higher nutrient concentrations in some regions. **Invertebrate status** averages 11 metrics that summarize changes in richness, tolerance, trophic conditions, and dominance associated with water-quality degradation. **Fish status** sums the scores of four fish metrics (percent tolerant, omnivorous, non-native individuals, and percent individuals with external anomalies) that increase in association with water-quality degradation

Biological indicator value, Long Island - New Jersey Coastal Drainages, by land use, 1996–98

◆ Biological status assessed at a site

National ranges of biological indicators, in 16 NAWQA Study Units, 1994–98

🟩 Streams in undeveloped areas
🟨 Streams in agricultural areas
🟥 Streams in urban areas
🟦 Streams in mixed-land-use areas
— 75th percentile
- - - 25th percentile



A COORDINATED EFFORT

Coordination with agencies and organizations in the Long Island–New Jersey Coastal Drainages was integral to the success of this water-quality assessment. We thank those agencies and organizations who allowed their employees to serve as members of our liaison committee.

Federal agencies
National Park Service
U.S. Department of Agriculture-Natural Resources Conservation Service
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service
U.S. Forest Service

State agencies
New Jersey Department of Agriculture
New Jersey Department of Environmental Protection
New Jersey Geological Survey
New Jersey Pinelands Commission
New York Department of Environmental Conservation
New York Geological Survey

Local and regional agencies
Hunterdon County Planning Board
Long Island Regional Planning Board
Nassau County Department of Public Works
New York City Department of Environmental Protection
Ocean County Health Department
Suffolk County Department of Health
Suffolk County Water Authority

Universities
Rutgers University
Stony Brook University

Other public and private organizations
Farm Bureau of Long Island and New Jersey
Hackensack Meadowlands Development Committee
New Jersey State Soil Conservation Committee
New Jersey Water Resources Research Institute
Passaic River Coalition
Rutgers Agricultural Extension Service
The Nature Conservancy, L.I. Chapter
Upper Raritan Watershed Association

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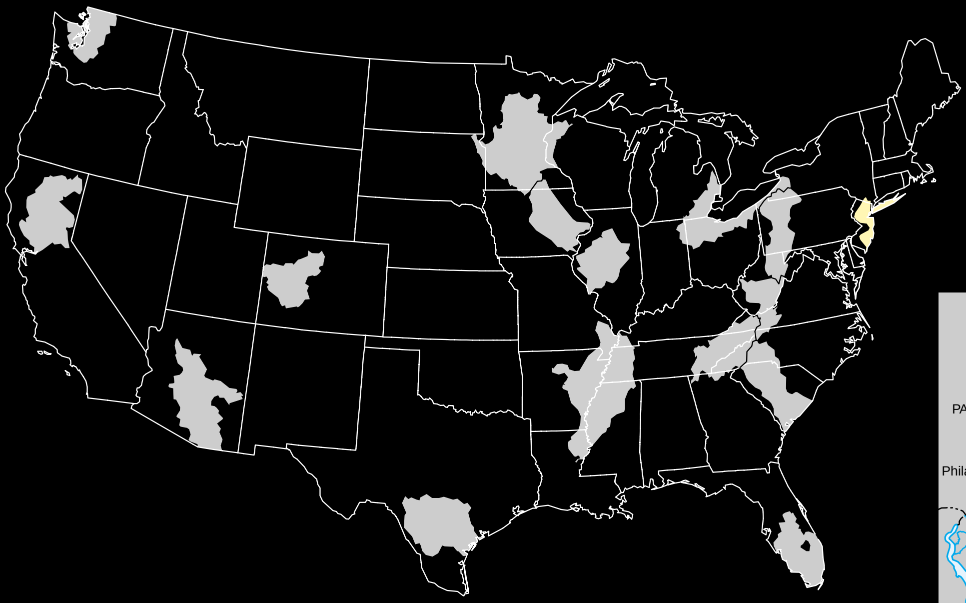
NAWQA

National Water-Quality Assessment (NAWQA) Program
Long Island-New Jersey Coastal Drainages



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