Water-quality Assessment Of The Hudson River Basin In New York And Adjacent States –

Analysis of available nutrient, pesticide, volatile organic compound, and suspended-sediment data, 1970-90

By Patrick J. Phillips and Dorothea W. Hanchar

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch,
Chief Hydrologist

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	by	To Obtain
	Length	
inch (in)	2.540	centimeter
feet (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
square mile (mi^2)	0.0259	hectare
	Volume	
gallon (gal)	3.785	liter
	Flow	
million gallons per day (Mgal/d)	3.785	million liters per day
billion gallons per day (Bgal/d)	3.785	billion liters per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Temperature	
degree Fahrenheit (°F)	0.5556(°F - 32)	degree Celsius

Other Abbreviations

tons per year (ton/yr)

micrograms per kilogram (µg/kg)

milligrams per liter (mg/L)

micrograms per liter (µg/L)

tons per day per square mile ($[ton/d]/mi^2$)

inches per year (in/yr)

pounds per square mile (lb/mi^2)

Water Year

The 365-day period from October 1 through September 30 of the following year. The water year is designated by the calendar year in which it ends.

Water-Quality Assessment of the Hudson River Basin in New York and adjacent States

Analysis of Available Nutrient, Pesticide, Volatile Organic Compound and Suspended-Sediment Data, 1970-90.

By Patrick J. Phillips and Dorothea W. Hanchar

ABSTRACT

The Hudson River basin encompasses about 13,300 mi^2 in parts of eastern New York, Vermont, New Jersey, Massachusetts, and Connecticut. More than 60 percent of the basin is forested, and about 25 percent is agricultural; only 7.8 percent is urban. This report presents analysis of data from the U. S. Geological Survey NWIS (National Water Information System) collected during 1970-90 as part of several water-quality studies.

The ground-water data analysis given herein represents nutrient concentrations at 100 wells and pesticide and volatile organic compound concentrations at 11 wells; well-depth and hydrogeologic information are available for all wells used in the analysis. The distribution of wells for which water-quality data are available is uneven throughout the study area. Nitrate concentrations in water from unconsolidated aquifers range from less than the analytical detection limit of 0.1 mg/L (milligram per liter) to 16 mg/L, with a median concentration of 0.23 mg/L, and those from bedrock aquifers range from less than 0.1 to 11 mg/L, with a median concentration of 0.3 mg/L. Nitrate concentrations decrease with depth in unconsolidated aquifers, but not in bedrock. Concentrations of all pesticides and volatile organic compounds in samples from the 11 wells with data were at or below the analytical detection limits, except for diazinon, which was detected at concentrations below 0.04 µg/L (micrograms per liter) at one well (in Schenectady County, N.Y.). Data are insufficient for correlation of nutrient and pesticide concentrations in ground water with land use in the Hudson River basin.

Data on nutrient concentrations in surface water are sufficient for an assessment of water-quality conditions in large watersheds (greater than 200 mi^2) dominated by agriculture and forest cover and in two watersheds dominated by urban, residential, or industrial land. Pesticide data are sufficient for analysis for DDT, chlordane, and aldrin in streambed sediments, and for 2,4-D in the water column. Most of the pesticide analyses were done during 1972-77.

In general, median nutrient concentrations in streams that drain urban watersheds (those that are more than 7.8 percent urban, residential, and industrial land and less than 20 percent agricultural land) and agricultural watersheds (those that are more than 25 percent agricultural land and less than 11.5 percent urban land) exceed those in streams that drain forested watersheds (those that are more than 78 percent forest). Nutrient yields (mass transported per year per unit area) during 1970-80 differ among streams depending on land use. The highest yields for dissolved nitrate, total nitrogen, and total phosphorus were in streams that drain agricultural and urban watersheds; these yields exceeded 3,200 lb/mi^2 (pounds per square mile) for dissolved nitrate, 4,200 lb/mi^2 for total nitrogen, and, 450 lb/mi^2 for total phosphorus. The lowest nutrient yields were from streams that drain large forested watersheds (drainage areas greater than 2,000 $mi^{2)}$ and the two sites dominated by agricultural land on Schoharie Creek; dissolved nitrate yields at these two sites were less than 1,700 lb/mi^2, and total nitrogen yields were generally less than 3,400 lb/mi^2. Total phosphorous yields from the large forested watersheds were less than 150 lb/mi^2, but those from Schoharie Creek sites

were somewhat higher (231 and 396 lb/mi^2, respectively). The low yields from the Schoharie Creek sites could be the result of water diversions from the upper reaches of the creek to reservoirs.

Estimated nutrient inputs from fertilizer, manure, sewage, and atmospheric deposition to each watershed indicate that (1) the major sources of nitrogen and phosphorus in Hudson River watersheds correspond to the predominant land use, and (2) the largest inputs result from agricultural activities. Most of the nitrogen and phosphorus inputs to agricultural watersheds were derived from manure and fertilizer, and most of the nitrogen input to forested watersheds was derived from atmospheric deposition; nitrogen inputs to urban watersheds could not be attributed to any predominant source. Phosphorus input was mostly from agricultural sources at all sites except those in urban-watersheds. These results indicate that nutrient inputs to the largest streams in the Hudson River basin were largely derived from nonpoint agricultural sources.

Sediment concentrations and transport rates reflect land use. The lowest median suspended-sediment concentrations and transport rates were in forested watersheds; in contrast, the highest median suspended-sediment concentration (26 mg/L) and transport rates (0.36 tons per day per square mile) were at the outlet of the Mohawk River basin, a watershed with little forest cover.

The available pesticide data indicate that pesticide concentrations can be related to spatial patterns of application. DDT was applied to agricultural, urban, and forested areas during 1940-72 and was detected at nearly all sites from which data were available, regardless of predominant land use. In contrast, chlordane has been applied primarily to urban lands since 1945 and was detected primarily at sites in urban watersheds.

INTRODUCTION

In 1991, the U. S. Geological Survey (USGS) implemented the National Water Quality Assessment (NAWQA) Program to:

1. Provide a nationally consistent database on the present chemical quality of the Nations's major surface-water and ground-water resources,
2. Define long-term trends (or lack of trends) in water quality, and
3. Identify, describe, and explain, to the extent possible, the major factors that affect the observed water-quality conditions and trends.

The NAWQA Program is designed to integrate water-quality data collected from areas of many sizes. To this end, data are being collected in 60 "study units" across the nation that, together, represent between 60 and 70 percent of the nations's ground-water and surface-water resources. The study units include most major river basins and aquifer systems, or large parts of aquifers, and encompass 1,200 to more than 50,000 mi^2. The Hudson River basin was one of the first 20 study units selected for investigation when the NAWQA program began in 1991. Results from the study units are to be used as part of a national synthesis to describe the nation's water-quality conditions.

An initial effort of each study-unit project entailed compiling, screening, and analyzing (1) the available water-quality data for nutrients (nitrogen and phosphorus), suspended sediment, pesticides, and volatile organic compounds, and (2) pertinent hydrologic, land-use, and land-cover information to provide an initial description of surface-water and ground-water quality.

Purpose and Scope

This report presents results of analyses of data from NWIS (National Water Inventory System) of the USGS and selected data from other agencies in the Hudson River basin. It (1) describes the hydrologic environment of the basin, (2) summarizes the approach, the data bases, and site characteristics, and (3) presents analyses of nutrient, pesticide, and volatile organic compounds in ground water and of nutrients, pesticides, and sediment in surface water, in relation to land use. It also defines temporal trends.

Acknowledgments

Special thanks are given to members of the liaison committee of the Hudson River basin project for their continuous support during this effort. The authors also thank Douglas A. Freehafer and Gary R. Wall of the U.S. Geological Survey for their work on maps and graphs in the report. Technical reviews were provided by Douglas A. Burns and Mark Ayers of the U.S. Geological Survey.

HUDSON RIVER BASIN

The Hudson River basin encompasses about 13,300 mi^2 and lies in parts of eastern New York, Vermont, New Jersey, Massachusetts, and Connecticut (fig. 1A). It contains a diversity of geologic, topographic, climatic, and hydrologic settings that are reflected in the patterns of land use. The basin consists of three major subbasins –the upper Hudson, the Mohawk, and the lower Hudson (fig. 1A). The upper Hudson subbasin includes the Hudson River drainage above the confluence of the Hudson and Mohawk River and has an area of more than 4,600 mi^2. The Mohawk subbasin consists of the drainage of the entire Mohawk River above its confluence with the Hudson River and has an area of about 3,500 mi^2. The lower Hudson subbasin, the largest of the three subbasins, consists of the Hudson River drainage below the confluence of the Hudson and Mohawk Rivers and has an area of about 5,200 mi^2. These three subbasins include parts of more than 35 counties (fig. 1B).

Environmental Setting

The Hudson River basin contains a wide variety of land uses and environmental settings. The amount of urban, agricultural, and forested land in each of the three subbasins, and the predominant land uses in each, are summarized in table 1. The land-use classification used in this report is based on digitized land-use maps made from high-altitude photography and satellite imagery obtained in the mid 1970s (U.S. Geological Survey, 1979a, b c, d;1980a, b). Because many areas have probably undergone land-use changes since then, especially those near urban areas, the land-use classifications may be inaccurate in places. The environmental settings, termed ecozones, reflect landforms, topography, bedrock geology, soil productivity, climate, and forest type and are delineated in Figure 1C. The generalized bedrock is indicated in figure 1D, and the physiographic provinces in figure 1E.

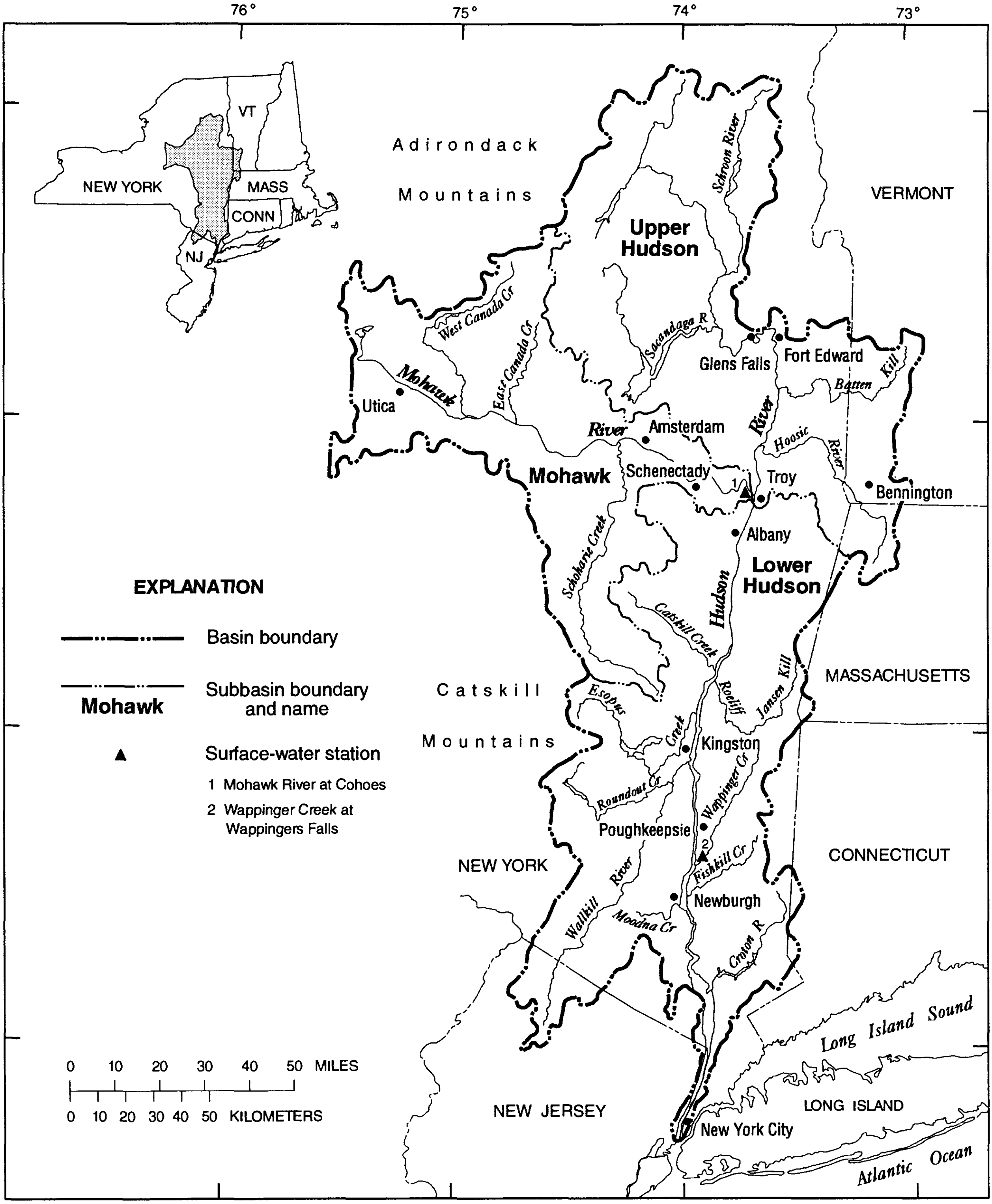
The upper Hudson subbasin, which forms the northern part of the study area (fig. 1A), covers about one-third of the Hudson River basin. Most of the subbasin is in the Adirondack Highlands–the Taconic Highland and Hudson Valley make up the rest (fig. 1C). Major rivers (those that drain more than 10 percent of the subbasin area) in the upper Hudson subbasin include the Hudson, Sacandaga, Schroon, Battenkill, and Hoosic Rivers. About 76 percent of the subbasin is forest, and 15 percent is farmed; only 3.4 percent is urban (table 1). Agricultural land is generally concentrated in the southeastern part of the subbasin, and most urban areas are along the Hudson River (Glens Falls and Troy) and along the upper reaches of the Hoosic River (North Adams, Mass., and Bennington, Vt). The 40-mi section of the Hudson River south of Fort Edward has been designated a "Superfund" site by the U.S. Environmental Protection Agency (USEPA) because its bed sedi-ments contain PCBs (polychlorinated biphenyls) (Limburg, 1985). This subbasin is underlain primarily by crystalline rocks, including anorthosite, gneiss, and granodiorite (fig. 1D). Relief is greatest in the Adirondack Mountains, where altitudes exceed 3,000 ft. locally.

The Mohawk River subbasin, in the west-central part of the study unit, covers about a quarter of the study area (fig. 1A). It lies mostly in the Mohawk Valley but extends into the Appalachian Plateau, Adirondack Mountain, Tug Hill, and Great Lakes Plain (fig. 1C). Major rivers in the Mohawk River subbasin include the Mohawk River, Schoharie Creek, and West Canada Creek. About 55 percent of the subbasin is forested, nearly 40 percent is farmed, and 6.2 percent is urban. Agricultural land is generally concentrated within 20 mi of the Mohawk River and lower reaches of Schoharie Creek. Urban areas, including Utica, Amsterdam, and Schenectady, are along the Mohawk River. The subbasin is underlain predominantly by clastic rocks–mostly shale and sandstone (fig. 1D). Relief is greatest in the Catskill Mountains (fig. 1E), where altitudes exceed 3,000 ft locally.

Table 1. Area and land-use characteristics of the Hudson River basin and its three subbasins in New York and adjacent States.

[Locations are shown in fig. 1]

Subbasin	Area (square miles)	Percentage of area		
		Urban	Agricultural	Forest
Upper Hudson	4,620	3.4	15	76
MohawkRiver	3,450	6.2	34	55
Lower Hudson	5,230	13	29	55
Entire Basin	13,300	7.8	25	62



Base from U.S. Geological Survey digital data 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29° 30' and 45° 30', central meridian -74°

Figure 1A. Surface drainage and subbasin boundaries in the Hudson River basin in New York and adjacent States.

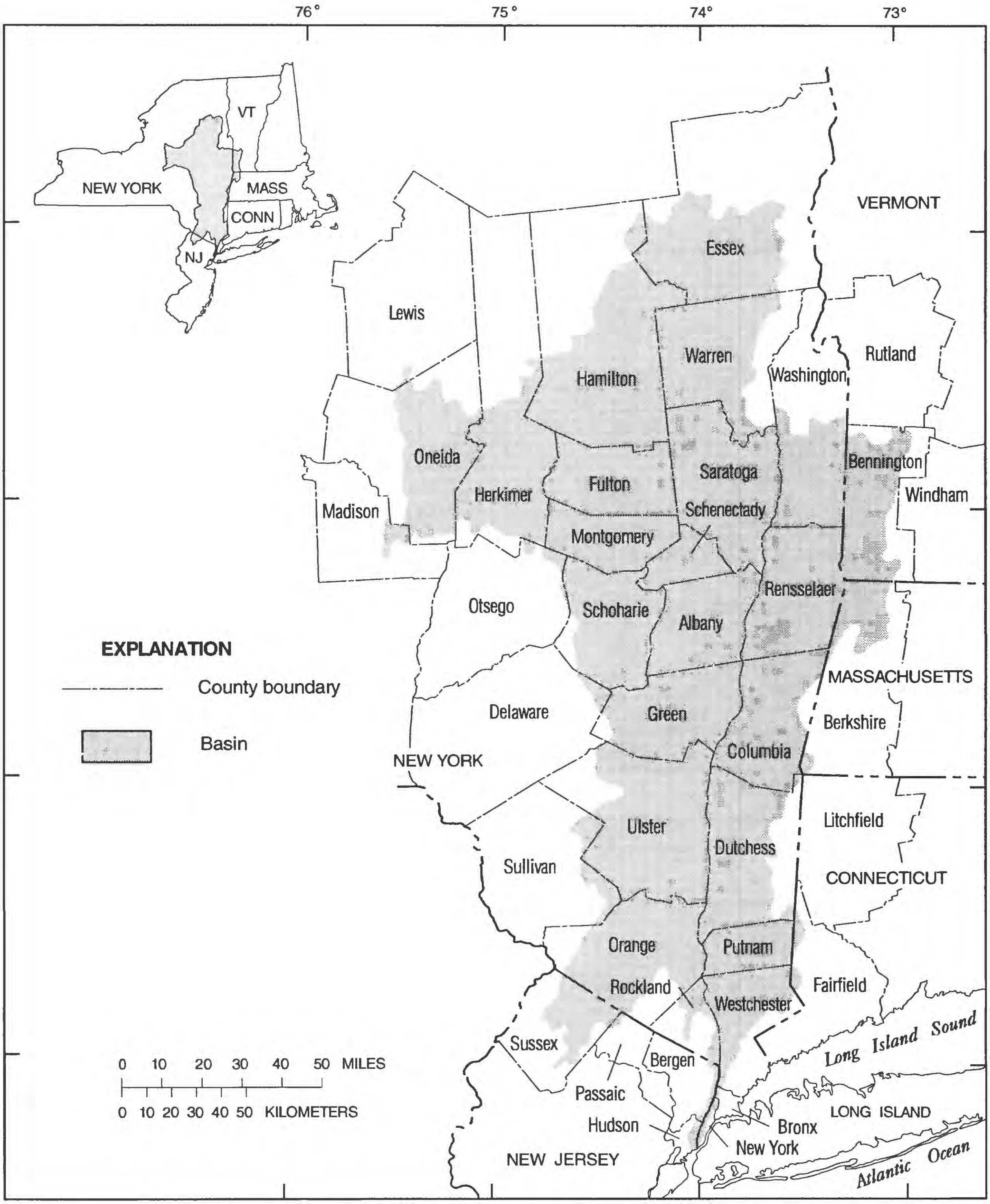


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Figure 1B. County boundaries in the Hudson River basin in New York and adjacent States.

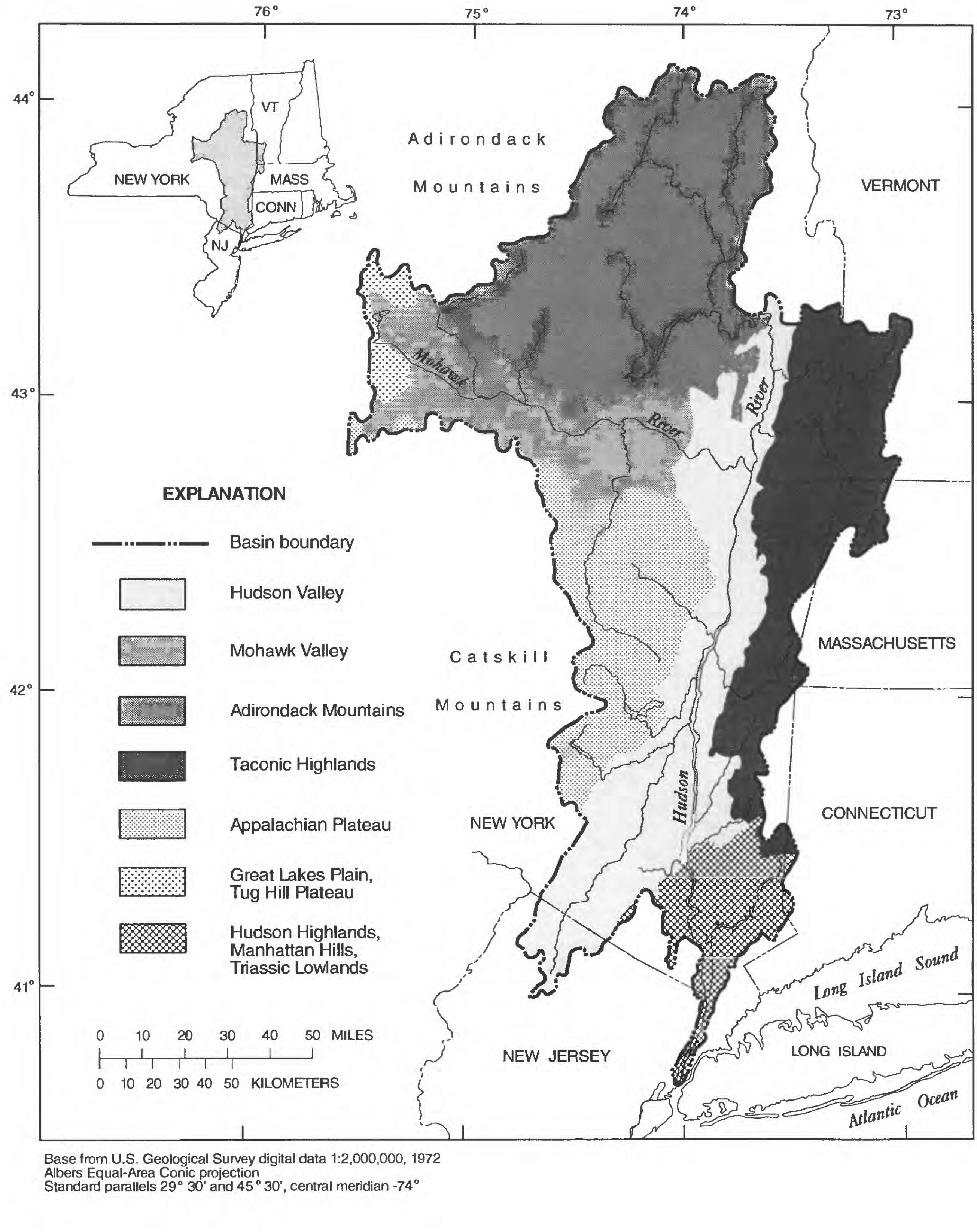
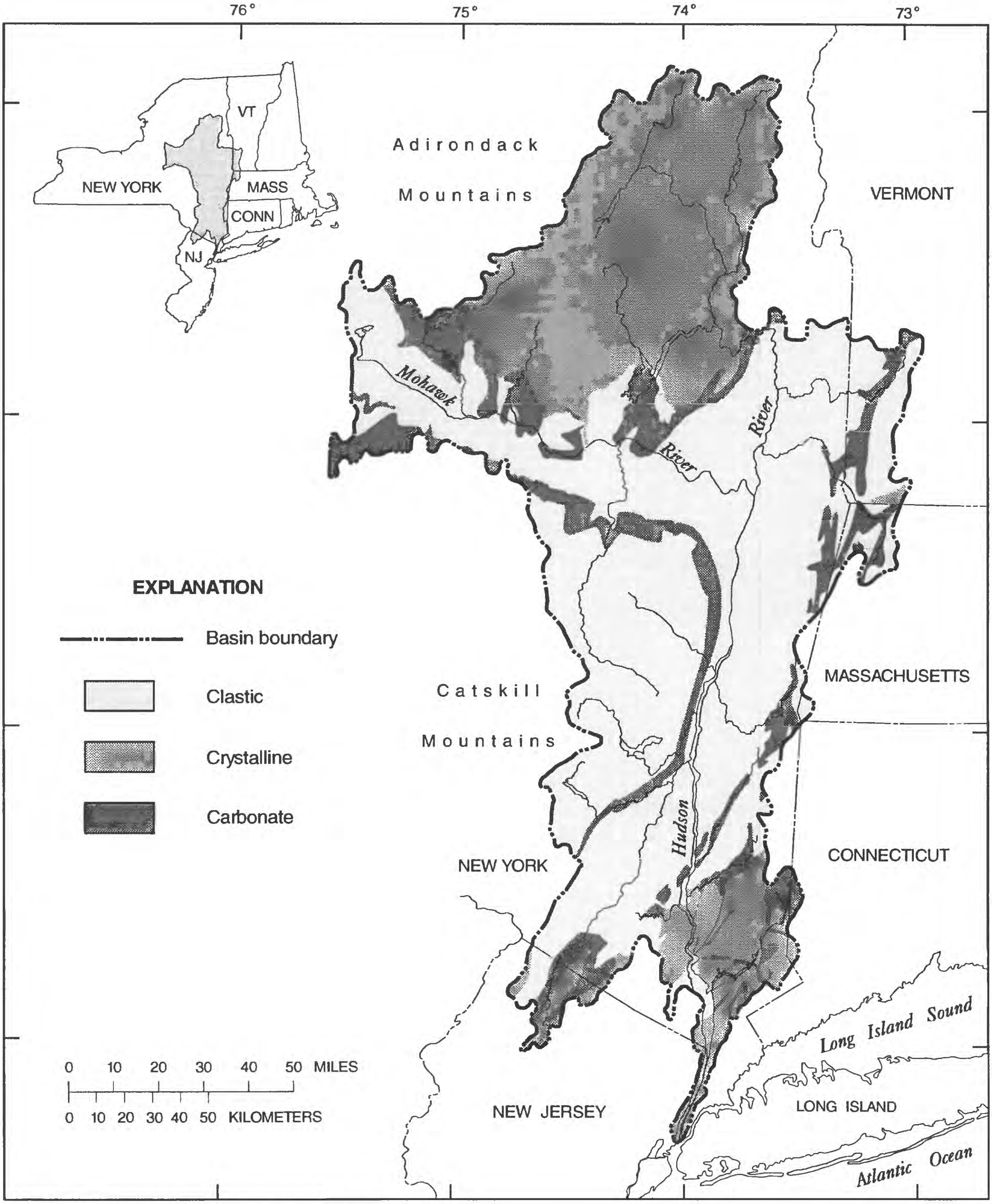


Figure 1C. Ecozone boundaries in the Hudson River basin in New York and adjacent States. (Modified from Will and others, 1982, fig. 2)



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Albers Equal-Area Conic projection
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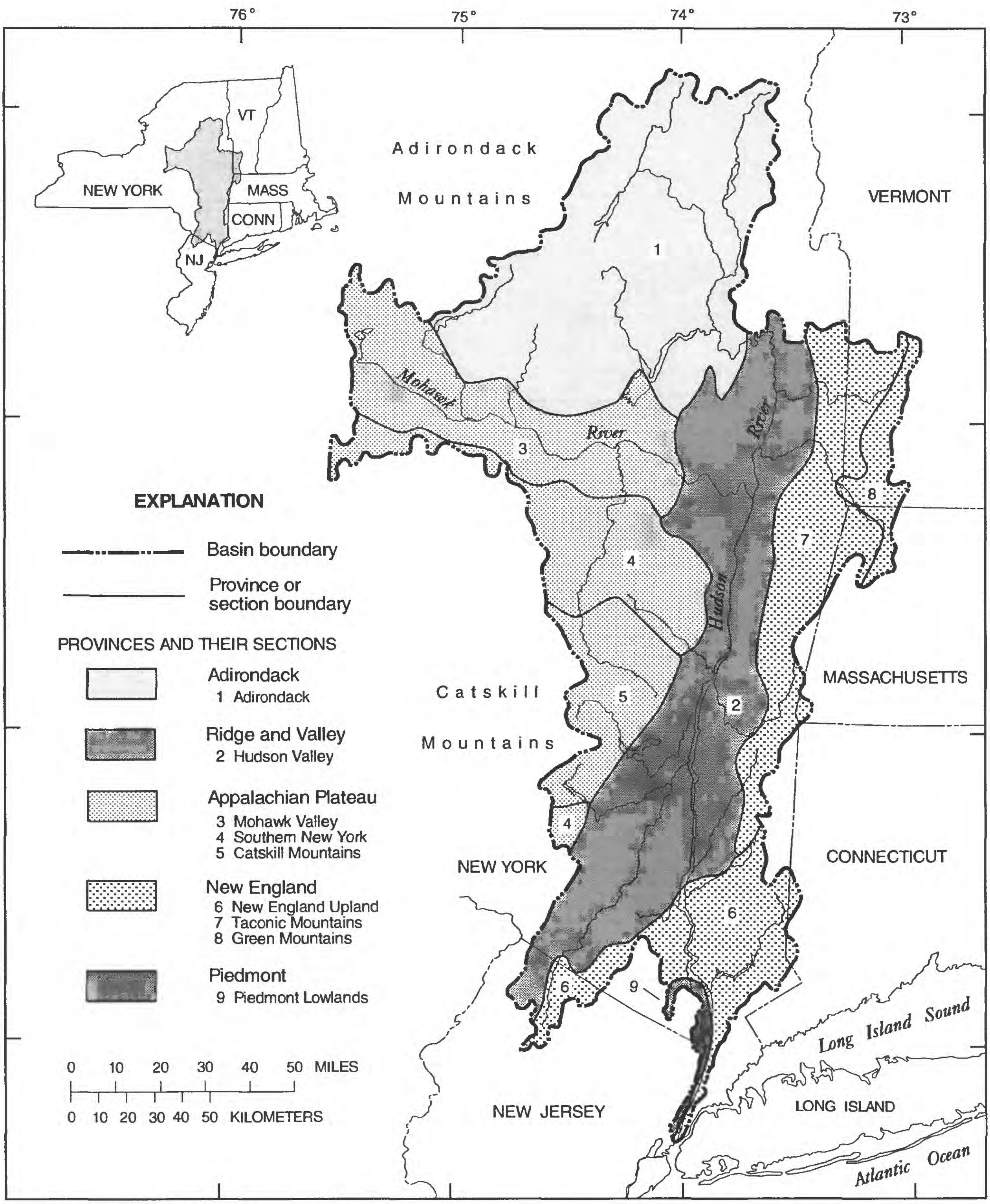
Figure 1D. Figure 1D. Generalized bedrock geology in the Hudson River basin in New York and adjacent States. (Modified from Hammond and others, 1978.)



Base from U.S. Geological Survey digital data 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29° 30' and 45° 30', central meridian -74°

Figure 1E. Generalized physiographic province boundaries in the Hudson River basin in New York and adjacent States. (Modified from Fenneman, 1938, plate 1.)

The lower Hudson subbasin, in the south-central part of the study area, occupies almost 40 percent of the study area (fig. 1A, table 1). It is mainly in the Hudson River valley but extends into the Appalachian Plateau, Taconic Highlands, Hudson Highlands, Manhattan Hills, and Triassic Lowlands (fig. 1C). Major rivers include the Hudson River (which is tidal south of Albany) and Roeliff Jansen Kill, Wallkill River, and Rondout Creek. About 55 percent of the land is forested, 29 percent is farmed, and 13 percent is urban (table 1). The agricultural land is mainly within 20 mi of the Hudson River and in the Wallkill River basin. Urban areas include New York City, Albany, Poughkeepsie, and Newburg, all of which are on the Hudson River. Much of the subbasin is underlain by clastic rocks–mostly shale and sandstone (fig. 1C), and relief is greatest in the Catskill Mountains and the Hudson Highlands
(figs. 1E and 1C).

Precipitation and Runoff

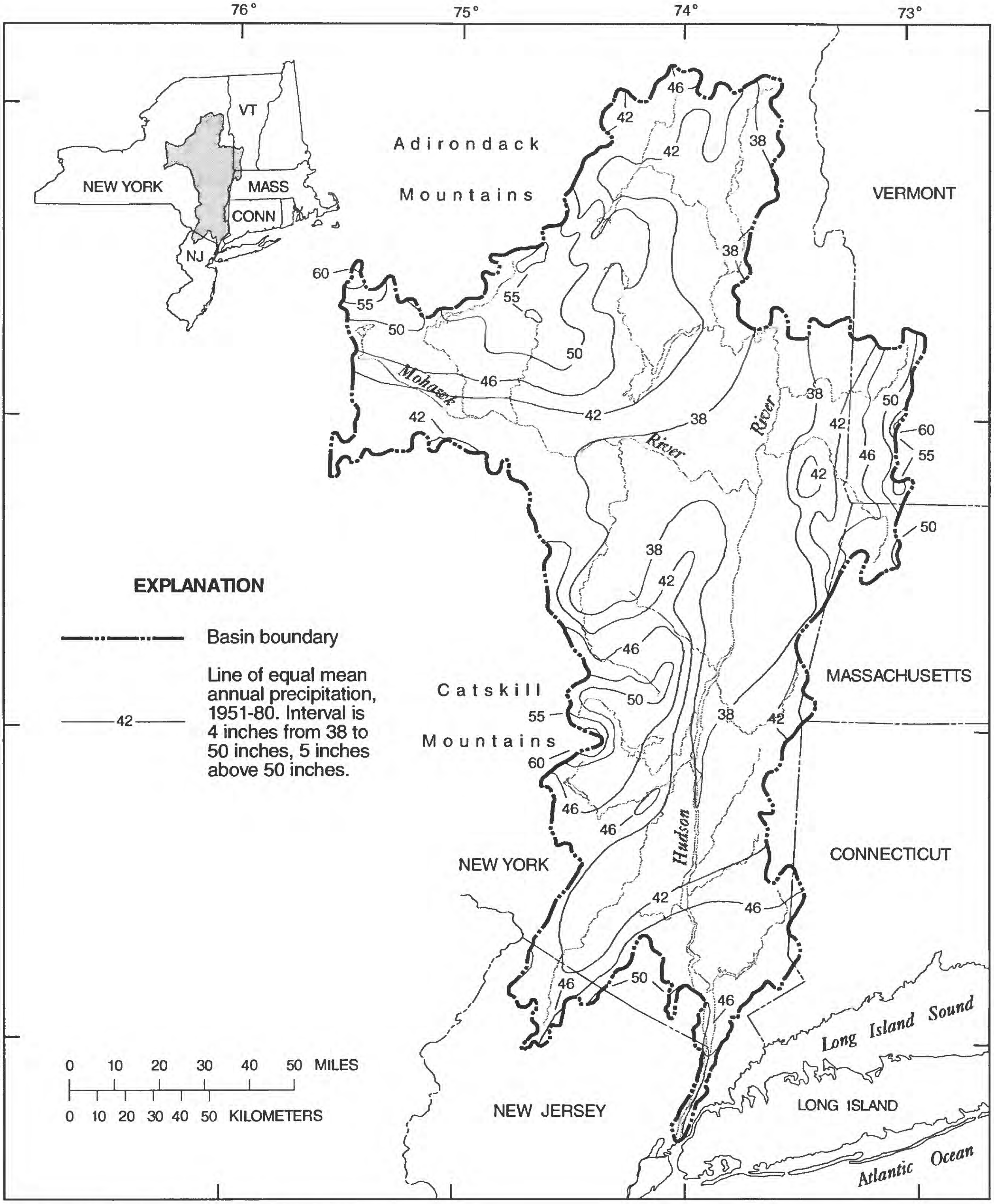
The distribution of precipitation and runoff in the Hudson River basin is related to relief. The largest precipitation amounts, in excess of 50 in/yr, fall in (1) the upper elevations of the Taconic Highlands, the Adirondack Mountains, and the Catskill Mountains, (2) in small areas on the northwestern edge of the Mohawk River subbasin, and (3) in the southeastern part of the study unit near the Atlantic Ocean (fig. 2A) (Randall, 1996). The smallest amounts (less than 40 in/yr) fall in the low-lying areas next to the Mohawk and Hudson rivers. Runoff patterns also largely correspond to relief. For example, the greatest runoff (in excess of 30 in/yr) is in the Adirondack Mountains, Taconic Highlands, and the Catskill Mountains (fig. 2B); the smallest amounts (less than 22 in/yr) are in low-lying areas along the Mohawk and Hudson Rivers (Randall, 1996).

Seasonal and annual patterns of runoff in the Hudson River basin were calculated from daily discharge data from the Mohawk River at Cohoes and Wappinger Creek near Wappinger Falls (fig. 1A) obtained from the NWIS database of the USGS. In general, seasonal and yearly fluctuations in monthly and annual discharge from the Mohawk River at Cohoes, which drains more than 3,400 mi^2, are typical of conditions in larger rivers in the northern part of the study unit, and those of Wappinger Creek near Wappingers Falls, which drains about 180 mi^2, is typical of smaller rivers in the south-central part of the study unit. A statistical summary of daily discharge on a monthly basis for these two stations is shown in figure 3A; annual mean discharges are given in figure 3B.

The median monthly discharge of the Mohawk River at Cohoes for 1929-91 ranges from less than 2,000 ft^3/s in August to over 10,000 ft^3/s in April (fig. 3A). Discharge typically increases from October through December, as temperatures decrease and the growing season ends. Discharges for January and February, when temperatures decline and much of the precipitation falls as snow, are typically lower than those for December; and median daily discharge typically peaks in March and April, during spring snowmelt. Discharges generally decline from May through August as snowmelt ceases and temperatures and infiltration increase.

The median monthly discharge of Wappinger Creek near Wappingers Falls for 1929-91 ranges from less than 30 ft^3/s in September to more than 400 ft^3/s in March (fig. 3A). Unlike the Mohawk River discharge at Cohoes, Wappinger Creek discharge near Wappingers Falls increases from October through March and generally does not decline during January and February; it generally is highest in March and declines from April through September. The seasonal differences in discharge between these two sites are related to climatic differences between the two drainage basins. Wappinger Creek is in the southern part of the study unit, which is less mountainous than the Mohawk River watershed and, thus, has generally warmer winters. Therefore, discharge in Wappinger Creek does not decrease during January and February, and spring snowmelt generally occurs in March.

Annual mean discharges for the Mohawk River at Cohoes and Wappinger Creek near Wappingers Falls for 1970-90 indicate that annual mean discharge in the early- to mid-1970s was higher than that for 1929-91; annual mean discharge of the Mohawk River exceeded the average for 1929-91 in each of the 9 years from 1971 through 1979. The highest annual mean annual discharge of the Mohawk River at Cohoes was recorded in 1972, and the second highest was in 1976. Flow conditions returned to normal after 1979, and the annual mean discharge exceeded the average for 1929-91 less than half the time.



Base from U.S. Geological Survey digital data 1:2,000,000, 1972
Albers Equal-Area Conic projection
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Figure 2A. Mean annual precipitation in the Hudson River basin in New York and adjacent States. (Modified from Randall, 1996.)

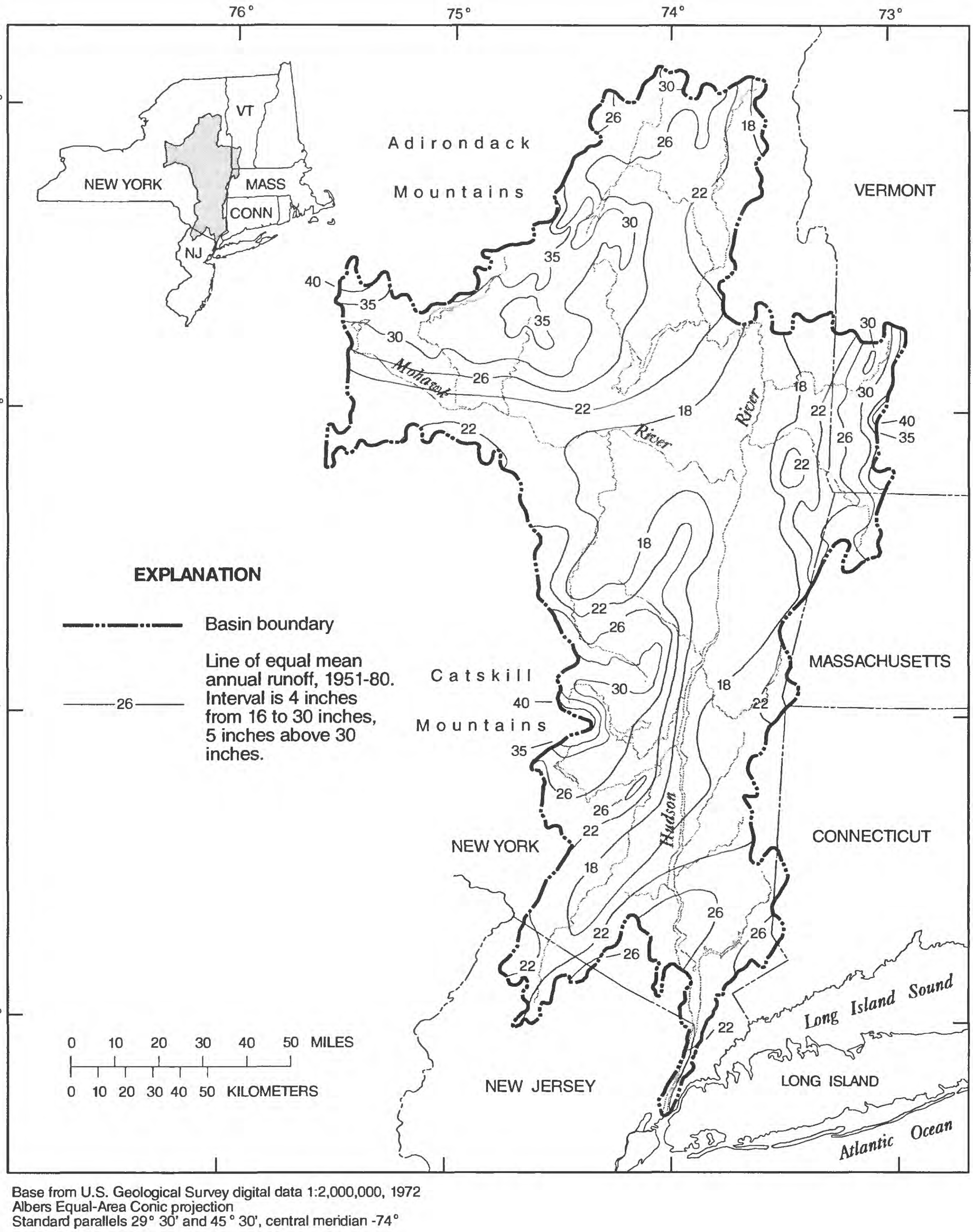


Figure 2B. Mean annual runoff in the Hudson River basin in New York and adjacent States. (Modified from Randall, 1996.)

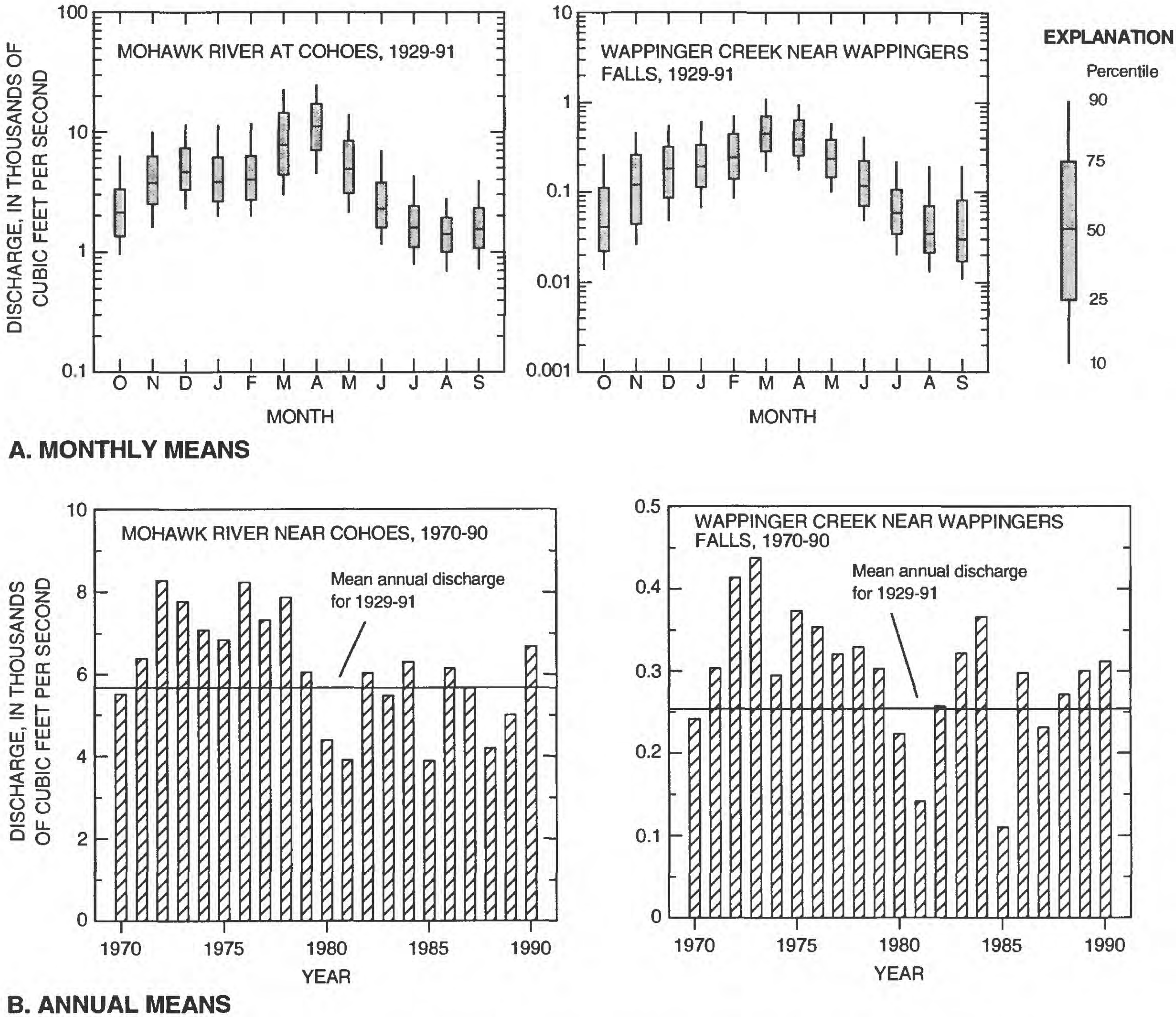
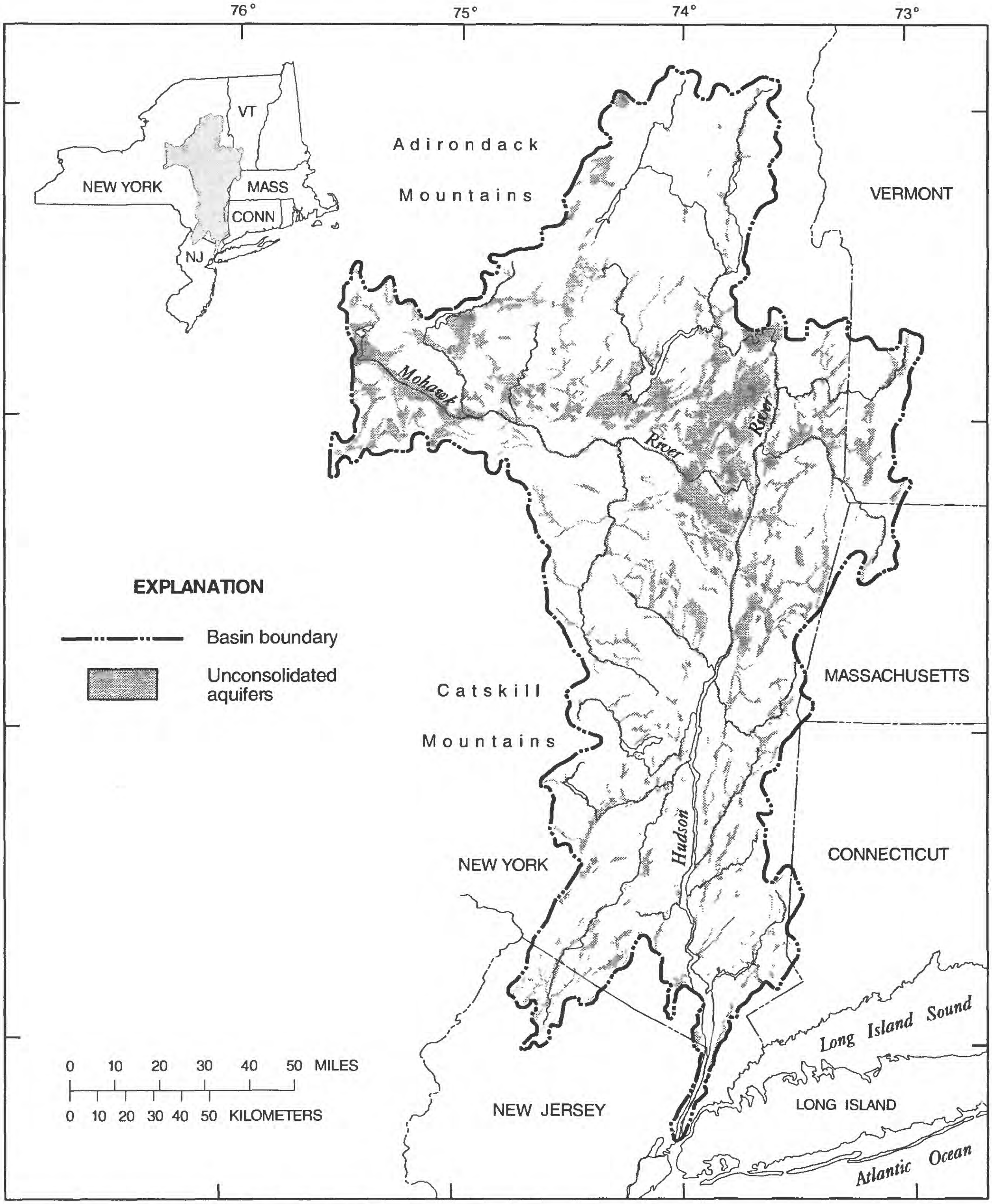


Figure 3. Mean flows of Mohawk River at Cohoes, N.Y. and Wappinger Creek near Wappingers Falls, N.Y. A. Monthly mean discharge, by month, 1929-91. B. Annual mean discharge, 1970-90

Aquifers

All significant aquifers in the Hudson River basin consist of unconsolidated glacial deposits or bedrock. Unconsolidated deposits of thick sand and gravel underlie flood plains and terraces along the larger tributaries to the Hudson River and occupy many valleys (fig. 4). Ground water in valley-fill aquifers can be in hydraulic connection with overlying streams but can be confined locally. Induced infiltration from streams to underlying aquifers commonly occurs where pumped wells are close to the streams (Waller and Finch, 1982). In some areas, particularly in Albany, Schenectady, and Saratoga Counties, sand deposits derived from glacial-lake sand and beach sand form significant aquifers. Four aquifers in the Hudson River basin are designated as Primary-Water-Supply Aquifers by the New York State Department of Environmental Conservation (NYSDEC); they are Fishkill/ Sprout Creek aquifer, Clifton Park/Halfmoon aquifer, Croton-on-Hudson aquifer, and the Schenectady aquifer (New York State Department of Health, 1981). The Schenectady aquifer is also designated as a sole-source aquifer by the USEPA (New York State Department of Health, 1981). All shallow, unconfined unconsolidated aquifers (water-table aquifers) are highly susceptible to contamination from surface sources.



Base from U.S. Geological Survey digital data 1:2,000,000, 1972
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Figure 4. Locations of unconsolidated aquifers in the Hudson River basin in New York and adjacent States. (Modified from Bugliosi and others, 1988 and Bugliosi and Trudell, 1988a, 1988b.)

Bedrock aquifers in the study unit consists of consolidated clastic (sandstone and shale) and carbonate (limestone and dolomite) rocks, some of which have been metamorphosed (fig. 1C). Ground-water movement in bedrock aquifers is principally along secondary openings such as fractures or bedding planes. The shales in much of the study area generally form aquifers that are adequate for domestic water supply (Hammond and others, 1978; Rogers, 1988).

Reservoirs

Major rivers of the Hudson River basin contain several reservoirs, dams, and locks. These structures store sediment as well as river water and thereby affect the movement of nutrients and sediment in the basin. All of the large reservoirs in the basin are in areas dominated by forests and, therefore, would not be expected to receive large amounts of nutrients or sediments because these are derived mostly from agricultural or urban areas. Regulation by dams and diversion of flows could decrease nutrient and sediment yields downstream, however.

Upper Hudson Subbasin

Major reservoirs in the upper Hudson subbasin include Great Sacandaga Lake and Indian Lake (fig. 5). Great Sacandaga Lake impounds flow from the uppermost 1,044 mi^2 of the Sacandaga River, and Indian Lake impounds flow from the uppermost 131 mi^2 of the Indian River basin. These reservoirs store water for flood control, low-flow augmentation, and power generation. Great Sacandaga Lake has a usable capacity of 29.7 billion ft^3, and Indian Lake has a usable capacity of 4.7 billion ft^3. These capacities represent about 12 in. of runoff at Great Sacandaga Lake and about 15 in. of runoff at Indian Lake. These reservoirs probably receive and store only small amounts of nutrients and sediment, however, because their mean annual inflow is small relative to their total capacity and because they are in extensively forested areas.

Mohawk River Subbasin

The Mohawk River subbasin contains three major reservoirs –Schoharie Reservoir, Hinckley Reservoir, and Delta Reservoir (fig 5). Schoharie Reservoir receives discharge from the uppermost 315 mi^2 of the Schoharie Creek watershed and has a usable capacity of 2.62 billion ft^3; this represents about 3.6 in. of runoff. All stored water is diverted from Schoharie Reservoir to Esopus Creek for the New York City water supply, except in periods of uncontrolled spillage. The annual mean diversion for 1992 was 475 ft^3/s. The diversion of water from Schoharie Creek probably has little direct effect on nutrient and sediment concentrations in Schoharie Creek because much of the watershed above Schoharie Creek is forested; yet, by decreasing discharge, the diversion could decrease the transport of nutrients and sediment in the watershed.

Hinckley Reservoir receives flow from the uppermost 372 mi^2 of West Canada Creek (fig. 5) and has a usable storage capacity of 3.3 billion ft^3; this capacity equals 3.8 in. of runoff. Minor amounts of water are diverted from Hinckley Reservoir for municipal water use in Utica. Delta Reservoir receives flow from the upper 148 mi^2 of the Mohawk River (fig. 5) and has a usable storage capacity of 2.8 billion ft^3–about 8.1 in. of runoff. Minor amounts of water are diverted from Delta Reservoir for canal navigation purposes (Firda and others, 1993). About 25 percent of the watershed draining to Delta Reservoir is agricultural; thus, the reservoir could decrease nutrient and sediment concentrations in downstream parts of the Mohawk River.

Lower Hudson Subbasin

The lower Hudson subbasin contains two major reservoirs–Ashokan and Rondout Reservoirs (fig. 5), both of which are in highly forested headwater areas. Ashokan Reservoir, which lies in the uppermost 256 mi^2 of the Esopus Creek watershed, receives flow from Esopus Creek plus diverted waters from Schoharie Creek and has a usable capacity of 17.1 billion ft^3–equal to more than 25 in. of runoff. The annual mean diversion of water from Ashokan Reservoir to the New York City water-supply system for 1992 was 886 ft^3/s (Firda and others, 1993).

Rondout Reservoir drains the uppermost 95.4 mi^2 of the Rondout Creek watershed (fig. 5) and has a usable capacity of 6.68 billion ft^3–more than 25 in. of runoff. Rondout Reservoir receives water diverted from three other reservoirs in the upper reaches of the Delaware River. The annual mean diversion from Rondout reservoir to the New York City water-supply system in 1992 was 1,101 ft^3/s (Firda and others, 1993).

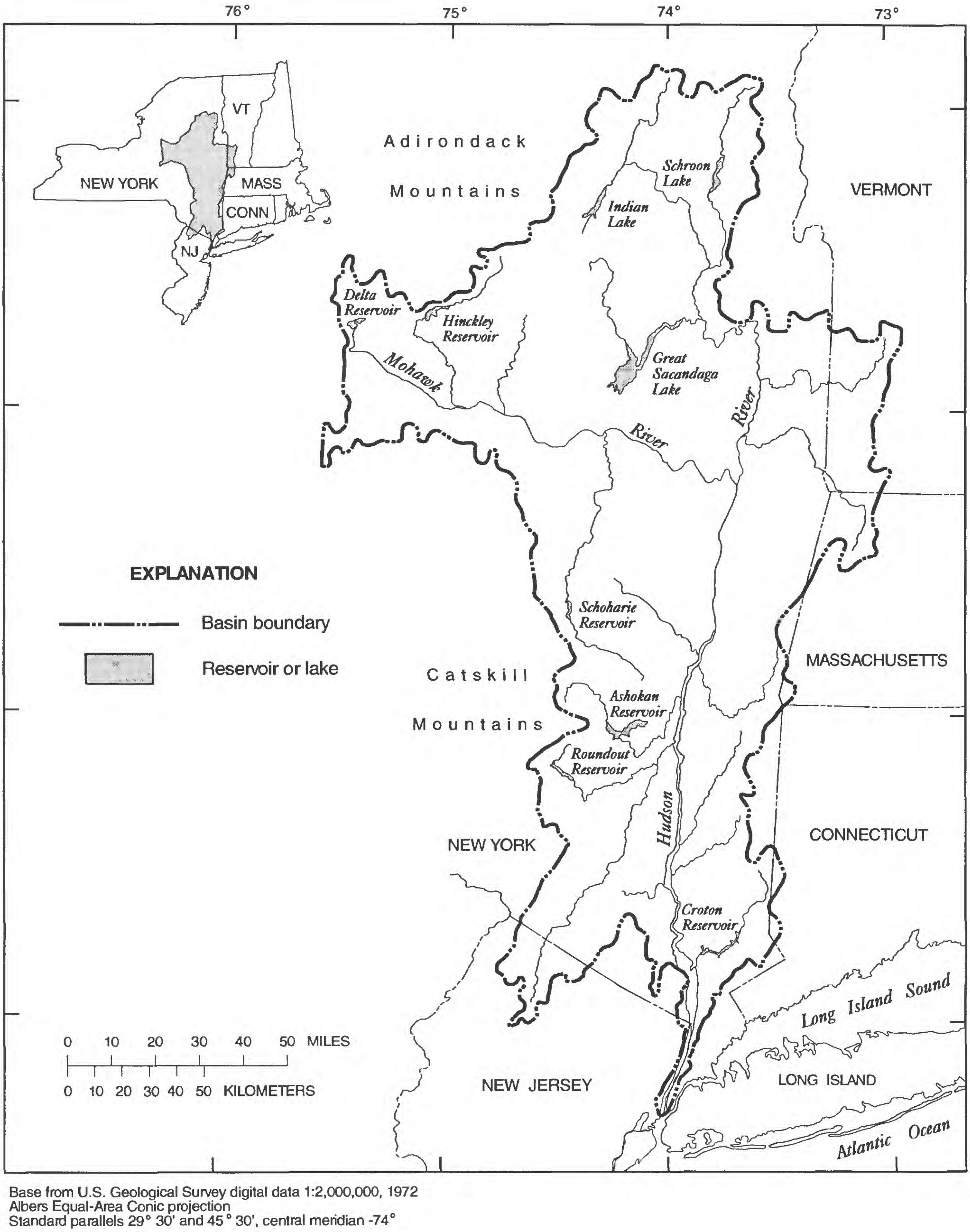


Figure 5. Locations of major reservoirs in the Hudson River basin in New York and adjacent States.

Water Use

Treated wastewater can be a significant source of nitrogen and phosphorus inputs into surface-water bodies in the Hudson River basin. Public-supply withdrawals become treated wastewater and, thus, can affect the concentration and movement of nutrients within the basin.

Total ground-water and surface-water withdrawals for water supply in the Hudson River basin in 1985 were about 1 Bgal/d (table 2) (Solley and others, 1988). Nearly 90 percent of the withdrawals for public water supply are from surface water; the vast majority of households not served by public water supply use ground water. Rates of total industrial withdrawals in 1985 were about 400 Mgal/d; two thirds of the water was surface water. Withdrawals for electric power generation from the estuarine part of the Hudson River exceed 2 Bgal/d, two-thirds of which are for cooling in nuclear powerplants; the remaining third is used for cooling in fossil-fuel thermoelectric plants.

Pesticide Use

Estimated application rates of commonly used pesticides enable comparison of pesticide use with pesticide concentrations in ground water, surface water, and streambed sediment. This comparison can help identify locations at which future collection of ground-water, surface-water, and streambed-sediment samples for pesticide analysis should be focused. Estimates of the application rates are available for two types of pesticide compounds in the Hudson River basin–persistent organochlorine compounds (including chlordane and DDT [dichlorodiphenyltrichlorethane]) that were widely used 20 or more years ago, and compounds that have been in wide use since 1980, including atrazine, alachlor, metiram, methyl parathion, cyanazine chlorothalonil, carbaryl, metolachlor, carbofuran, and 2,4-D ([2,4-dichlorophenoxy] acetic acid). Rod (1989) estimated chlordane and DDT applications from data compiled by Ayres and others (1988). National average rates of pesticide application, as estimated by Ayres and others (1988) from pesticide-export data, were apportioned to agricultural areas on the basis of crop acreage, and to urban and forested lands according to the land-use acreage, by subbasin.

Gianissi and Puffer (1988) used 1986 national estimates of pesticide-application rates, by crop type, in conjunction with county estimates of crop acreage, to estimate application rates, by county, for a variety of pesticides, including atrazine, alachlor, metiram, methyl parathion, cyanazine, chlorothalonil, carbaryl, metolachlor, carbofuran, and 2,4-D. Their results do not include pesticide applications in urban or forested areas; thus, the application rates estimated for compounds such as carbaryl that are widely used for insect control on lawns (Ware, 1989) could be substantially lower than the actual rates.

DDT-application patterns differed from chlordane-application patterns across the Hudson River basin. DDT was applied in a wide variety of settings, including urban, agricultural, and forested areas (Rod, 1989). In urban areas it was used to control a variety of insects; in agricultural areas it was used to control insects on potatoes, vegetables, and orchards; and in forested areas it was used to control gypsy moth and blackfly populations. Use of DDT in the Hudson and Raritan River basins peaked in 1957 and subsequently decreased until the compound was banned in the early 1970's (fig. 6A). This report gives the combined applications for both River basins because Rod (1989) did not calculate separate annual application estimates for the Hudson River basin. The peak DDT use in 1957 reflects a short-term increase in DDT use within forested areas in the Adirondack Mountains. Overall, DDT use in the Hudson and Raritan River basins during the 1950's and 1960's was highest in the Mohawk River subbasin and the northernmost parts of the lower Hudson subbasin.

Chlordane was applied in fewer types of settings than DDT in the Hudson River basin; it was largely used for the control of termites and other insects in suburban and urban settings and was used only to a

Table 2. Estimated water use in the Hudson River basin in New York and adjacent States, 1985.

[Data from U.S. Geological Survey Aggregated Water Use Data System. All values are in millions of gallons per day. Dashes indicate no data].

Use	Fresh Ground water	Surface-water Withdrawals		Consumptive Use	
		Fresh	Saline	Fresh-water	Saline Water
Water Supply	73.3	926	-	-	-
Commercial	9.44	25.4	-	17.3	-
Domestic	65.8	-	-	45.8	-
Industrial	110	201	-	70.0	-
Fossil Fuel	-	1280	726	12.8	7.26
Nuclear Power	-	-	1480	-	1340
Mining	-	27.3	-	2.73	-
Livestock	2.27	1.22	-	3.13	-
Irrigation	1.53	6.57	-	8.10	-

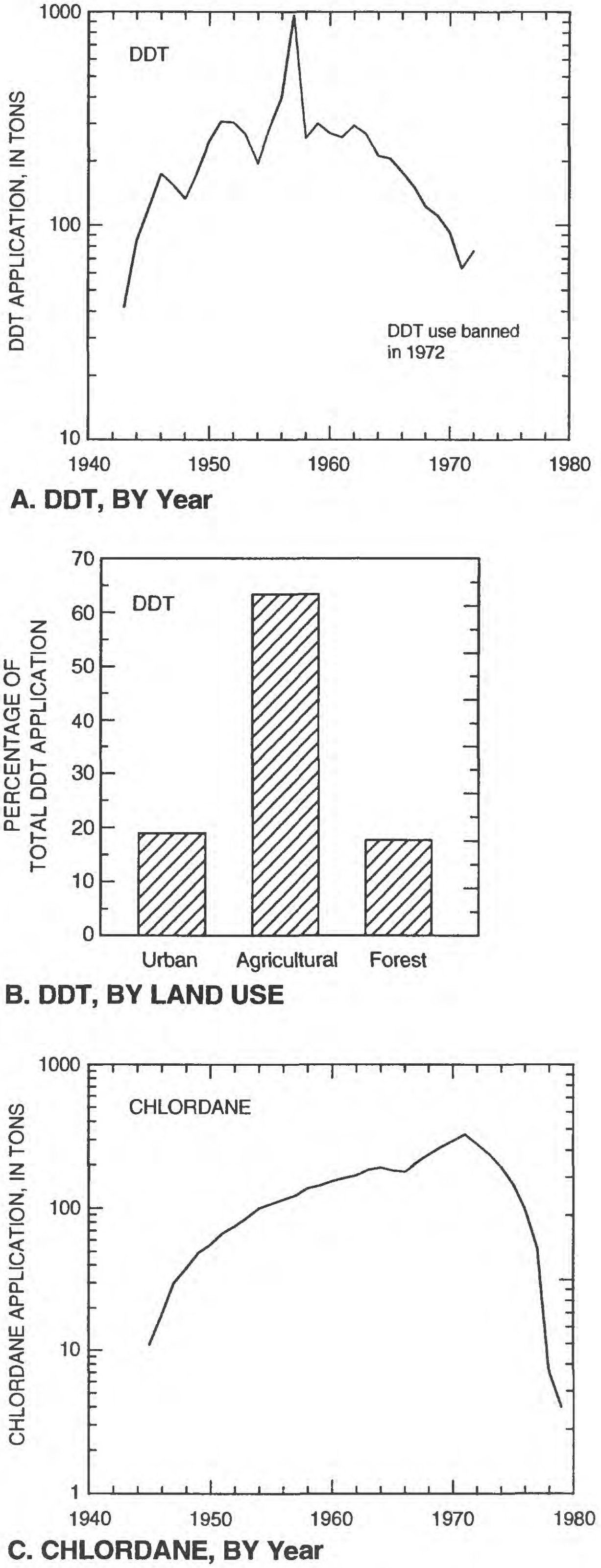


Figure 6. Estimated pesticide application in Hudson River basin, N.Y., and Raritan River basin, N.J., 1940-80. A. DDT application rate, by year. B. DDT application, by land-use category. C. Chlordane- application rate, by year. (Modified from Rod, 1989, figs. 8-6 and 8-4.)

small degree in agricultural and forested areas (Rod, 1989). Chlordane use in the Hudson and Raritan River basins increased steadily from 1945 to about 1972, then declined sharply during 1973-78 (fig. 6C). The areas with large populations, such as the southernmost part of the lower Hudson subbasin, had the highest chlordane use; chlordane use in areas dominated by agricultural or forested, land such as the Schoharie Creek watershed and the Adirondack Mountains, was almost negligible (Rod, 1989).

Of the 10 most extensively used agricultural pesticides, the two that were applied at the highest rates in 1986 (table 3) were atrazine—a triazine herbicide (Ware, 1989), and alachlor–an acetanelite herbicide (Ware, 1989). The patterns of atrazine and alachlor use are generally similar to those of four other widely used pesticides –cyanazine, metolachlor, carbofuran, and 2,4-D. In general, the greatest use of these pesticides is in the Mohawk Valley and Hudson Valley ecozones (fig. 1C); for example, the largest applications of atrazine and alachlor were in Washington, Columbia, Madison, and Montgomery Counties, N.Y. (fig. 7). The general application patterns for carbaryl, a carbamate compound used as an insecticide (Ware, 1989), are similar to those for metiram, a dithiocarbamate used as a fungicide (Ware, 1989), and methyl parathion, a phenyl derivative used as an insecticide (Ware, 1989). The highest rates of carbaryl application are in Columbia and Ulster counties (fig. 7). The highest application rates of chlorothalonil, a substituted aromatic used as a fungicide, are in the lower Hudson subbasin (fig. 7).

Table 3. Estimated agricultural use of selected pesticide compounds in the Hudson River basin, N.Y., and adjacent States, 1986.

[Units in thousands of pounds. Data from Gianissi and Puffer, 1988.]

Pesticide	Application Rate	Pesticide	Application Rate
Atrazine	257	Chlorothalonil	62.2
Alachlor	177	Carbaryl	60.6
Metiram	164	Metolachlor	56.8
Methyl Parathion	141	Carbofuran	53.6
Cyanazine	90.7	2,4-D	50.0

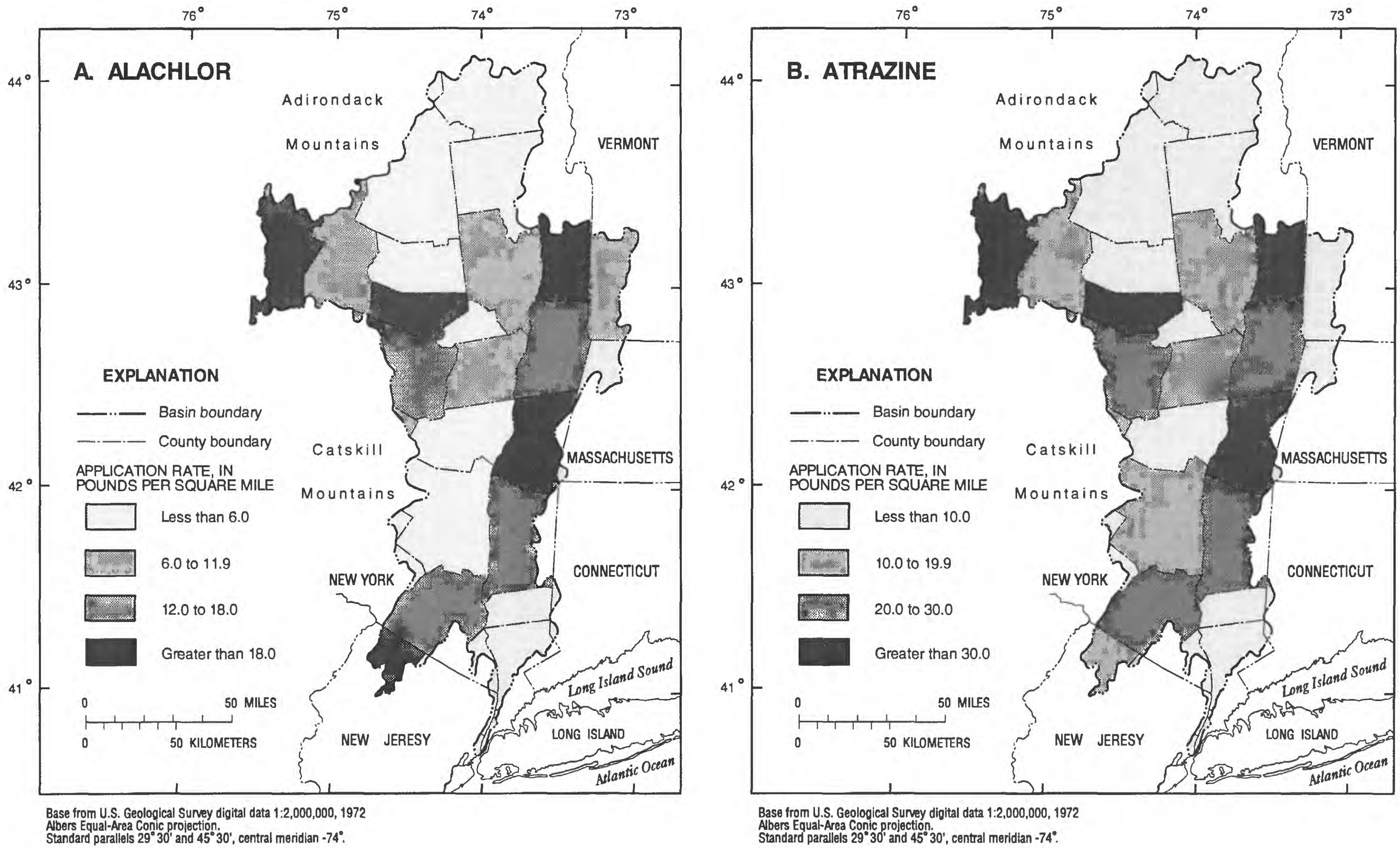
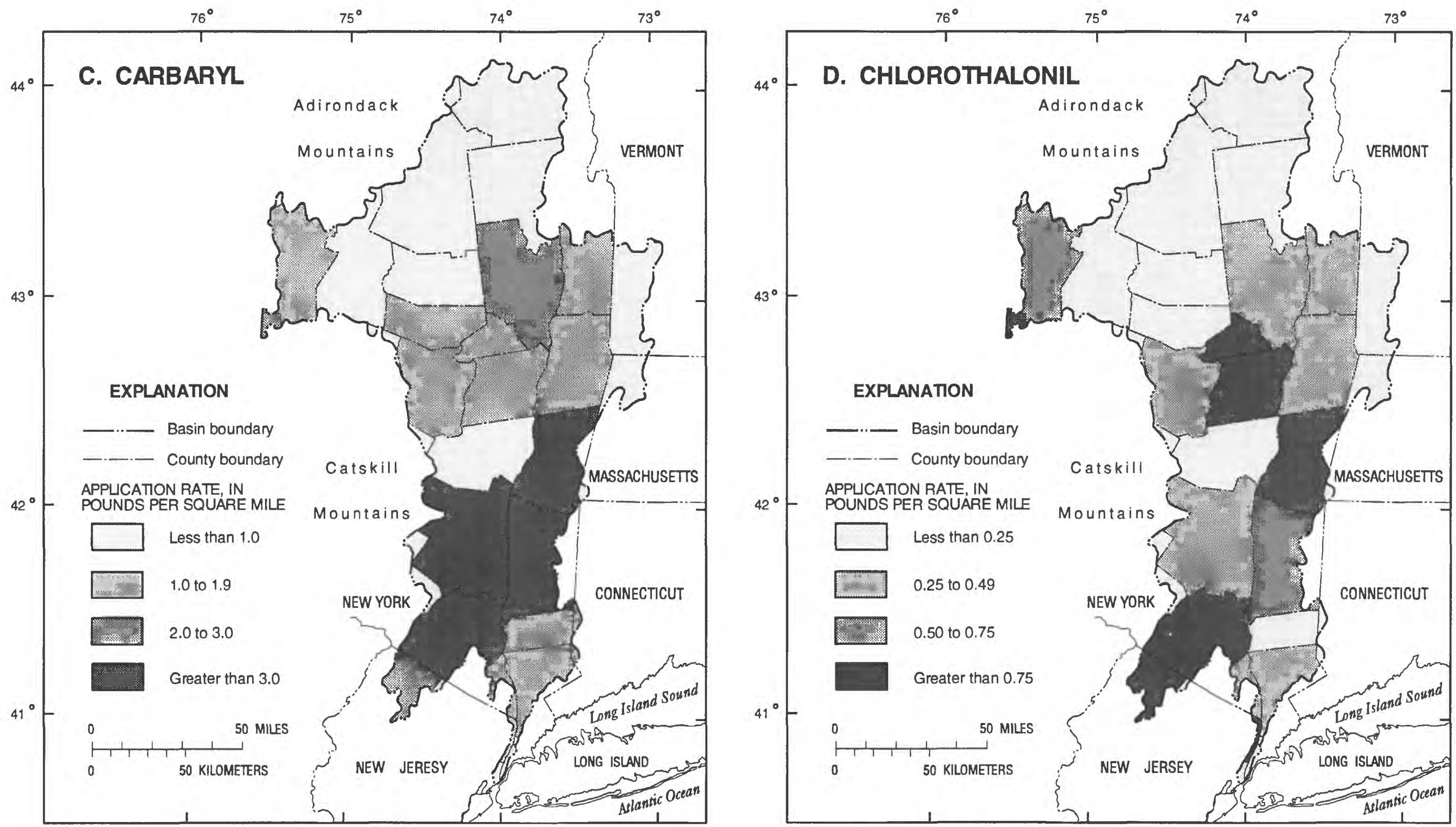


Figure 7. Estimated 1988 rates of pesticide application in the Hudson River basin in New York and adjacent States, by county. (Data from Gianissi and Puffer, 1988.): A. Alachlor. B. Atrazine. (County names are shown in fig. 1B.)



Base from U.S. Geological Survey digital data 1:2,000,000, 1972
Albers Equal-Area Conic projection.
Standard parallels 29°30' and 45°30', central meridian -74°.

Base from U.S. Geological Survey digital data 1:2,000,000, 1972
Albers Equal-Area Conic projection.
Standard parallels 29°30' and 45°30', central meridian -74°.

Figure 7. Estimated 1988 rates of pesticide application in the Hudson River basin in New York and adjacent States, by county. (Data from Gianissi and Puffer, 1988.): C. Carbaryl. D. Chlorothalonil. (County names are shown in fig. 1B.)

WATER-QUALITY ASSESSMENT

Basinwide assessment of ground-water and surface-water quality in the Hudson River basin began with a compilation and evaluation of available chemical and ancillary data. The data on most constituents discussed herein are derived from USGS studies, and most of the data are suitable for a basin-wide comparisons because the samples were collected and analyzed by uniform methods. Data from some non-USGS studies are included where appropriate to provide additional information on spatial, temporal, or other trends in nutrient or pesticide concentrations.

Approach

The analyses of available ground-water and surface-water quality data in this report are based mostly on data available in the NWIS database. These data were collected through cooperative studies between the USGS and several State and local agencies. USGS data were used because they (1) are available in computerized form, (2) can be associated with a geographic location, and (3) are from sites for which hydrologic, geologic, and other ancillary data are available.

Ground-Water Data

The ground-water data used in this report represent the results of projects in many areas and at differing spatial scales. Because quality-assurance data were not routinely collected as part of these investigations, the quality of the data is not quantifiable. Where more than one sample was available from a given well, only the most recent analysis for a given constituent was used, to avoid biasing data toward sites with multiple analyses. The assessment of ground-water quality is limited to dissolved nitrate and selected pesticides and VOCs (volatile organic compounds) in water from wells for which information on well depth and aquifer type was available.

Sites from which ground-water-quality data were available are classified in this report according to aquifer material, well depth (for screened and open-end wells), and land use in the well-site vicinity. Samples from unconsolidated aquifers represented in this report include those obtained from wells finished in unconsolidated aquifers, and samples from bedrock wells include those obtained from wells finished in bedrock aquifers, typically open-hole wells cased to competent bedrock. Data on well location, aquifer material, and well depth were obtained from the NWIS data base and were not field checked. Sites were classified as urban, agricultural, or forested, depending on the predominant land use within 1/2-mi radius of the well. The land-use category for each site was determined by overlaying digital land-use coverages (U.S. Geological Survey, 1979a,b,c,d; 1980a,b) on a digital coverage of well locations. The land-use data were not field checked.

Surface-Water Data

A variety of procedures described below were used to compile surface-water quality data and ancillary watershed data within the Hudson River basin.

Site Selection

Most of the nutrient and suspended-sediment analyses presented in this report are based on data collected at sites with daily discharge records. Most sites selected have dissolved nitrate, total nitrogen, or total phosphorus data for more than 25 samples. The availability of daily discharge data at these sites enables determination of: (1) the availability of water-chemistry data over the range of flow conditions, (2) the relation between concentration and discharge, and (3) solute- and sediment-transport rates at these sites. Discharge data for some ungaged sites were calculated from the discharge record of a nearby gaged site by multiplying the discharge at the gaged site by a ratio equal to the drainage area of the ungaged site, divided by the drainage area of the gaged site. Some sites that lack daily discharge data have 10 or more samples with dissolved nitrate, total nitrogen, or total phosphorus analyses; these sites were included in the analysis of nutrient concentrations in relation to land use.

Data from any two sites that were near one another were generally interpreted as one site. Nutrient data from stations whose drainage-area size was within 5 percent of a different station's drainage-area size were compared; if the data were similar, they were assigned to the station with the majority of data. This 5-percent criterion was used because a few sites with differing station-identification numbers in the NWIS database represent data from essentially the same site. Exceptions were nutrient samples from the Hudson River at Corinth, Glens

Falls, and Fort Edward; data for these three sites were not combined because Glens Falls, between Corinth and Fort Edward, is the first substantial urban area through which the Hudson River flows. Another exception was made for samples from two sites near the outlet of the Mohawk River–the Mohawk River at Crescent Dam and the Mohawk River at Cohoes. Samples from the Crescent Dam site were collected at the hydroelectric station 2.4 mi upstream from the Cohoes site. The effect of this difference in sampling location is unknown because few simultaneous samples were collected. The Crescent Dam site was included in this analysis because more than 90 percent of the data collected at the outlet of the Mohawk River were collected there.

Water-quality data from selected sites without daily discharge records were used with data from sites with daily discharge data in this study to make broad comparisons of median nutrient, suspended-sediment, and pesticide concentrations among sites that differ in land use, population density, and geologic characteristics. To avoid biasing the comparison of nutrient and pesticide concentrations among sites, data from sites with overlapping drainage areas were included only if no more than 50 percent of their drainage areas overlapped.

Data Sources

Most of the surface-water nutrient data analyzed in this report are from the NWIS database. Nutrient data from four sites in New Jersey were analyzed by the NJDEP (New Jersey Department of Environmental Protection), Division of Water Resources laboratories (Bauersfield and others, 1988) and stored in the USGS database. (The NJDEP sites were included because they represent urban watersheds, without which the comparison of median nutrient concentrations would have represented only one urban site). Discussions of temporal trends in nutrient and pesticide concentrations in surface water of primarily forested watersheds in the Hudson River basin are based on data collected by the NYCDEP (New York City Department of Environmental Protection); these data represent the only two sites in the Hudson River basin with long-term (greater than 30 years) water-quality records. Time trends for these data are reported by Murdoch and Stoddard (1992).

Suspended-sediment data represent sites from which 20 or more analyses were available in the NWIS system. Of those sites, only the ones for which daily discharge records were available were used to calculate sediment yield.

The pesticides discussed in this study are those with NWIS data from 10 or more sites and the three reported by Bopp and others (1982) from the lower Hudson River.

Methods of Analysis

A variety of maps, graphs, and nonparametric statistics are used in this report to depict the availability and statistical characteristics of nutrient, suspended-sediment, and pesticide concentrations and nutrient and sediment yields in streams of the Hudson River basin. The maps depict the spatial distribution of sites used for analysis. Bar charts depict the avail-ability of nutrient and sediment data for selected analyses by month, year, and percentile of flow. Maps and tables indicate the availability of pesticide data in streambed sediments and water samples over space and time.

The statistical range of nutrients, sediment, and pesticide concentrations at sites is depicted in boxplots and tables, and detection rates for pesticides are summarized in barcharts. Relations between concentration and discharge for nutrients and sediment are indicated by LOWESS (locally weighted scatterplot smooth) lines (Helsel and Hirsh, 1992). Statistical tests of trends over space and through time were done through nonparametric tests of association. Temporal trends in concentrations reported by Murdoch and Stoddard (1992) for two streams in the Catskill Mountains used analysis of covariance on ranks.

Median nutrient, sediment, and pesticide concentrations are compared among sites with differing land use through nonparametric tests of association, including Kruskall Wallace, Mann-Witney, and Tukey tests. Relations between nutrient concentrations and land use are depicted by nonparametric tests of association, including Spearman-rank correlations.

Yields of nutrient and sediments were calculated through a program that uses a minimum variance unbiased estimator (Cohn and others, 1989; Gilroy and others, 1990). The nutrient loads in this report are based on data for two periods–1970-80 and 1981-90–because concentration data were available from only certain periods. Loads for each of these periods were calculated from five variables–a constant, the log of instantaneous flow, the log of instantaneous flow squared, and the sine and cosine of the day of the year. Where instantaneous flow data were unavailable, mean daily discharge was used to estimate flow. Sediment loads for sites with daily sediment values were estimated through the program for days with missing data.

Because data availability is uneven, and flow conditions transient, transport yields in this report are reported as an average of 3 years representing a wide range of flows–one in which the annual mean flow was ranked in the upper 10 percent of the annual mean flows, one in which the annual mean flow was equal to the mean annual flow, and one in which the annual mean flow was ranked in the lower 10 percent of the annual mean flows. This averaging of transport rates over high, medium, and low-flow conditions improves the reliability of comparison of transport rates among stations. Sediment-transport rates also are reported for 1978, a year with high annual mean flow at most of the sites from which suspended-sediment data are available.

Ancillary Data

Ancillary data from a variety of sources (described below) were used in this study to obtain quantitative estimates of environmental factors and nutrient- and pesticide-application rates in the watersheds of selected sites. Environmental factors include geology, land use, population, rate of manure and fertilizer application, and rate of atmospheric deposition. Environmental factors were quantified by overlaying digitized watershed boundaries on digital coverages of ancillary data. Boundaries of most watersheds were delineated in this report by a 1:250,000-scale DEM (digital elevation model), and accuracy was checked through a comparison of the drainage area of the DEM-generated boundary with the drainage area recorded in files of the Troy, N.Y. office of the USGS. All drainage areas delineated by the DEM differed by less than 5 percent from those on record. Some of the watershed boundaries, particularly those for watersheds smaller than 20 mi^2, were manually digitized from 7.5-minute topographic maps.

Land Use.—Estimates of land use were made by overlaying the digitized basin boundaries on digitized land-use coverages compiled at a scale of 1:250,000 (U.S. Geological Survey, 1979a, b, c, d; 1980a, b). These data are based on high-altitude areal photographs taken during 1970-78 and, thus, represent land-use conditions of the 1970's and might not reflect present land-use conditions, especially in small watersheds near large urban areas. This generally should not be an obstacle in relating surface-water quality to land use patterns, however, because most of the available surface-water-quality data were collected during 1970-81. Estimates of geologic characteristics of watersheds are based on a digitized map compiled by Hammond and others (1978) at a scale of 1:500,000. The percentages of each watershed that are underlain by clastic (sandstone and shale), crystalline rock, and carbonate rock were obtained by a method similar to that used to determine land use. Basin-population estimates were obtained from digitized coverages of the centers of U.S. Census tracts; the population of a basin is the sum of populations of all the census tracts with centers within the watershed boundary.

Nutrient-Input Rates.—Estimated rates of nitrogen and phosphorus input from fertilizer, manure, treated-wastewater sources, and atmospheric deposition are based on varied data sources and time periods but represent the best available data and allow national comparisons of nitrogen- and phosphorus-input rates. Average fertilizer-application rates during 1970-79 were obtained from Alexander and Smith (1990) and are based on USDA (U. S. Department of Agriculture) Census of Agriculture data for county-level estimates of fertilized acreage. Average fertilizer-application rates for 1986-91 were estimated by W. Battaglin (U.S. Geological Survey, written commun., 1992) and are based largely on county-level fertilizer estimates calculated by USEPA (1990) from crop data. The fertilizer-application rates for 1970-79 used in this report are average yearly applications for 1970-79; similarly, the application rates used for 1986-90 represent average yearly applications for 1986-90. Manure-application rates are based on USDA Census of Agriculture data on livestock populations, by county, and were computed by W. Battaglin (U.S. Geological Survey, written commun., 1992) for 1982 and 1987. Fertilizer- and manure-application rates for the watershed for each site were calculated by first obtaining the rate of agricultural fertilizer or manure application (equal to the total amount of fertilizer or manure applied in a county, divided by the cropland plus pastureland acreage in the county), and multiplying the result by the number of acres of agricultural land use in a county that lies within the specified watershed. The sum of this product over all counties within the watershed yielded the total fertilizer or manure application of nitrogen or phosphorus for the watershed.

Inputs of nitrogen and phosphorus from treated wastewater are calculated from estimates of design-capacity flow from sewage-treatment plants. The discharge capacities estimated for New York State were based on data from NYDEC (1987); estimates for New Jersey, Massachusetts, and Vermont were based on the Permit Compliance System files compiled by USEPA. Estimates of treated-wastewater discharge from New York State plants were modified by D. S. Lumia (U.S. Geological Survey, written commun., 1993) and are on file at the USGS office in Troy, N.Y. Estimated inputs of nitrogen and phosphorus from treated wastewater were based on an average concentration of 15.1 mg/L for nitrogen and 11.1 mg/L for phosphorus; these values are typical for primary treated effluent (National Oceanic and Atmospheric Administration, 1993).

Rates of atmospheric deposition of nitrogen were estimated from precipitation-chemistry data collected at six sites by the National Atmospheric Deposition Program (NADP, 1992). These estimates were adjusted for dry deposition in the northeast United States, for wet and dry deposition in urban areas, and for droplet deposition for elevations above 1,850 ft (Sisterson, 1990). Nitrogen deposition rates discussed in this report are based on the annual averages for 1984-90.

Land-Use Categories

Each surface-water site was designated as representing one of four land-use categories to correlate land use with (1) surface-water quality, and (2) the availability of surface-water-quality data. The four categories, described below, are forested, agricultural, urban, and mixed; together they represent the range of land use within the Hudson River basin. The criteria used to categorize surface-water sites were (1) known correlations between water quality and land use, and (2) land-use characteristics of the Hudson River basin.

Forested watersheds are those that are more than 78 percent forest cover and less than 18 percent agricultural and urban land combined. The 78-percent criterion was selected because Murdoch and Stoddard (1992) found nitrate concentrations in a subbasin of Schoharie Creek that is about 80 percent forested to be unaffected by agricultural or urban activities. The Hudson River basin is 62 percent forested; therefore, the 78-percent criterion ensures that watersheds designated as forested have a larger proportion of forested land use than the Hudson River basin does. The second criterion–that watersheds designated as forest be less than 18 percent urban plus agricultural land–was used to exclude sites that are affected by urban or agricultural activities to ensure that the surface-water quality at sites representing forested watersheds reflects relatively pristine conditions.

Agricultural watersheds are those that are at least 25 percent farmland and less than 11.5 percent urban land. The Hudson River basin is 25 percent forested; therefore, the 25-percent criterion ensures that watersheds designated as agricultural have a larger proportion of agricultural land use than the Hudson River basin does. The 11.5-percent criterion was used to ensure that urban land in agricultural watersheds would not greatly affect the water quality at monitoring sites. Water quality at sites representing agricultural watersheds should reflect the presence of fertilizers and manure.

Urban watersheds are those in which more than 7.8 percent of the land is urban (including commercial, residential, and industrial land uses) and less than 20 percent is agricultural. The Hudson River basin is 7.8 percent urban; therefore, the 7.8-percent criterion ensures that watersheds designated as urban have a larger proportion of urban land than the Hudson River basin does. The criterion of less than 20 percent agricultural land was used to ensure that water quality at urban sites would not be significantly affected by agricultural activities and would largely reflect only the presence of sewage and other urban-associated sources of runoff.

Mixed land-use watersheds are those that did not match the criteria for the three preceding categories. Water quality at these sites would be expected to reflect a variety of land uses, including urban and agricultural activities.

Availability of Data, 1970-90

Assessment of water-quality conditions in the Hudson River basin requires data that (1) provide adequate spatial and temporal representation, and (2) reflect the current environmental conditions. The following sections discuss the availability of recent (1970-90) data on (1) nutrients in ground-water and surface water, (2) pesticides in ground water, surface water, and streambed sediments, and VOCs (volatile organic compounds) in ground water, and on (3) suspended sediment in surface water, with respect to space and time and over a range of environmental conditions.

Ground Water

Data on nutrient and pesticide concentrations in ground water in the Hudson River basin are limited. Although ground-water quality data were collected at 427 sites in the study area during 1970-90, nutrient and pesticide data were obtained at only 100 sites from which aquifer-type and well-depth information also are available.

Nutrients

The only nutrient discussed in relation to ground water is dissolved nitrate. Dissolved-nitrate analyses are available for 236 sites in the study area, 77 of which have no information on well depth or aquifer type, and another 59 of which have information on aquifer type, but not the recorded well depth. Of the 100 sites for which well depth and information on aquifer material are available (table 4), 63 are classified as unconsolidated-aquifer sites, and 37 are classified as bedrock-aquifer sites. Well-depth and aquifer data for these wells did not include records of the depth to water, nor sampling-depth interval. Wells completed in bedrock commonly are constructed with casing installed to competent bedrock, then completed as open hole; thus, water samples from these wells could be a mixture of water from water-bearing zones throughout the open interval. Because no data on depth of casing or open intervals are available, well depth is used for comparison purposes only.

Sites for which ground-water quality, well-depth, and aquifer-type data are available are distributed unevenly throughout the study area (fig. 8A)– many are clustered in three areas–(1) Albany County, N.Y., (2) Berkshire County, Mass., and (3) Westchester County, N.Y. and adjacent Fairfield County, Conn.; the rest are scattered across the study area. Ground-water quality data for most of the study area are unavailable. Statistical comparisons pertaining to aquifer type in this report are based on data from two areas –Albany County (unconsolidated aquifers) and Westchester County (bedrock aquifers).

The land use attributed to each well site is the dominant land use within a 1/2-mi radius of the well. By this criterion, 53 of the 100 sites are urban, 20 are agricultural, and 27 are forested. Of the 53 urban-site wells, 43 are completed in unconsolidated glacial sediments, and 10 are finished in bedrock; of the 20 agricultural-site wells, 9 are completed in unconsolidated sediments, and 11 are completed in bedrock. Of the 27 forested-site wells, 11 are completed in unconsolidated deposits, and 16 are completed in bedrock (table 4).

The paucity of data on depth, locations, and hydrogeologic characteristics of wells for which nitrate data are available, and the temporal distribution of data collection, limit the usefulness of these data for a basinwide assessment. The wells for which information is available also are unevenly distributed with respect to depth (fig. 9A, p. 29). Whereas 62 of the 63 samples from unconsolidated-aquifer sites are from wells completed at depths of 200 ft or less, only 21 of the 37 samples from bedrock aquifers are from depths less than 200 ft. Among the wells with depths 100 ft or less, 52 samples are from unconsolidated-aquifers, and only 10 are from bedrock. The temporal distribution of samples also is uneven; more than half of the 63 samples from unconsolidated aquifers were collected in 1979 (fig. 9B), and more than two-thirds of the samples from bedrock aquifers were collected during 1987 and 1988 (fig. 9B).

Pesticides and Volatile Organic Compounds

Only 11 wells in the Hudson River basin are represented by analyses for pesticides and VOC's from 1970 through 1990; six are in Fairfield County, Conn., one is in Schenectady County, N.Y., and four are in Sussex County, N.J. (fig. 8B and table 4).

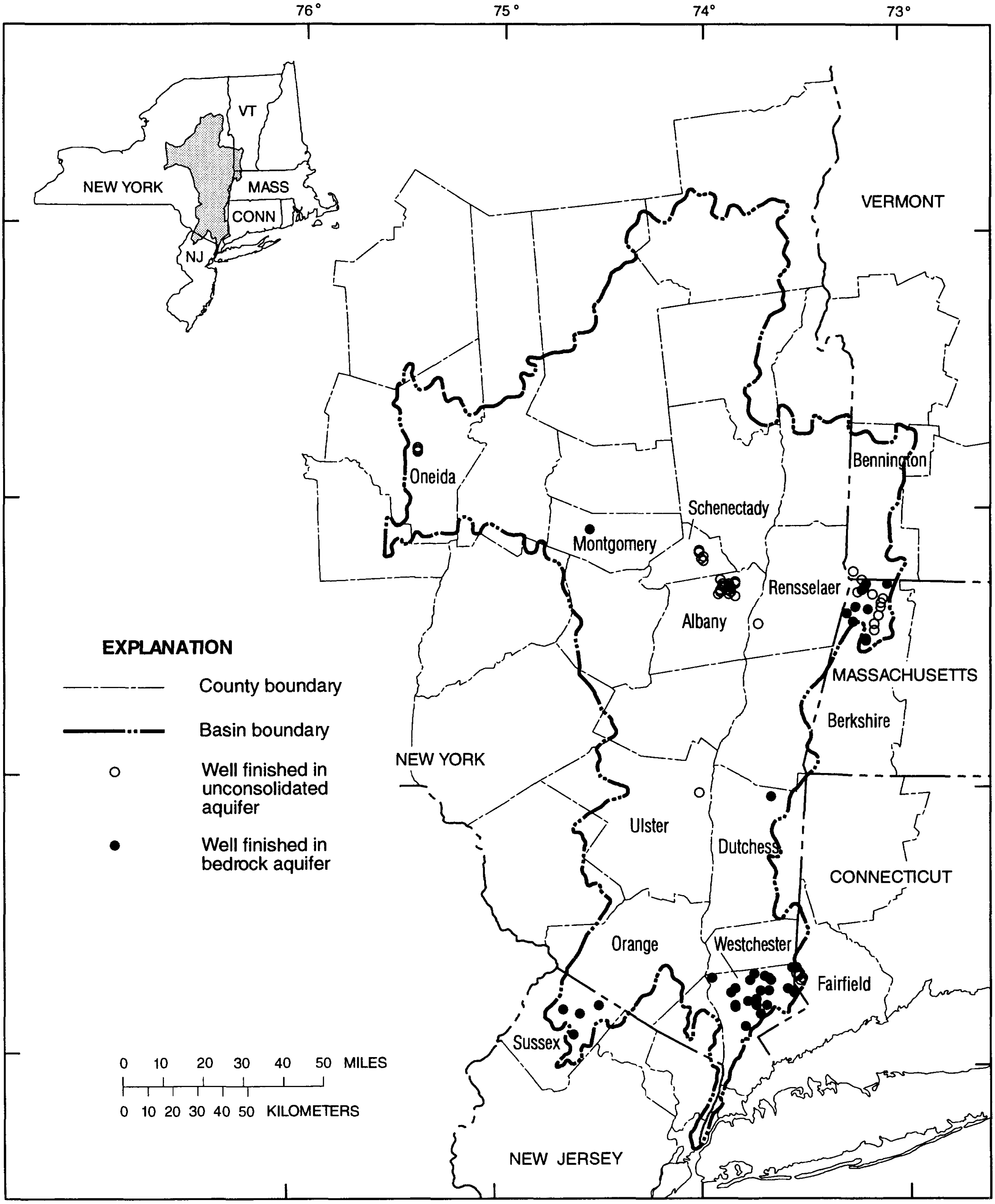
Surface Water

NWIS data on nutrients, sediment, and pesticides are available from 56 sites in the Hudson River Basin (table 5). The following sections describe (1) the availability of nutrient and sediment data in terms of location, time, and flow regime, and (2) the availabil-

Table 4. Characteristics of wells in the Hudson River basin for which 1970-90 water-quality data are available

[Unc., unconsolidated; B, bedrock. U, urban; F, forest; A, agricultural. All sites have dissolved nitrate data; those with an asterisk also have pesticide and volatile organic compound data]

Station-identification number	Depth, below land surface (feet)	Year of Sample collection	Type of aquifer	Principal land use
CONNECTICUT - Fairfield County				
411835073304001*	30	1984	Unc	U
411902073303601*	29.6	1984	Unc	U
411942073314201	18.4	1984	Unc	F
411947073314801*	32.7	1984	Unc	F
411951073315201	28.7	1984	Unc	F
411957073322301*	22.2	1984	Unc	F
411958073315901*	19.5	1984	Unc	F
412129073322201*	9.3	1989	Unc	F
MASSACHUSETTS - Berkshire County				
423134073112701	110	1970	B	A
423206073105901	182	1970	B	A
423359073084601	113	1969	Unc	F
423511073082901	103	1969	Unc	A
423554073143601	75	1969	B	F
423708073072601	85	1970	Unc	U
423737073164801	157	1969	B	A
423814073100801	200	1970	B	F
423840073064701	84	1969	Unc	U
423844073141001	240	1969	B	F
423955073063101	90	1969	Unc	U
424036073060501	110	1970	Unc	U
424149073091701	190	1969	Unc	U
424154073133301	65	1969	Unc	A
424224073115901	500	1969	B	U
424304073112301	150	1970	Unc	U
424309073113501	120	1969	Unc	U
424350073111701	300	1969	B	U
424403073043501	546	1970	B	U
424417073125201	80	1970	Unc	A
NEW JERSEY				
Sussex County				
410633074364601*	95	1988	B	A
411108074351901*	75	1988	B	A
411224074401201*	63	1988	B	A
411255074295101*	147	1988	B	A
Suffolk County				
424125073495701	30	1979	Unc	U
NEW YORK - Albany County				
424125073495702	25	1979	Unc	U
424125073495702	25	1979	Unc	U
424139073514501	35	1979	Unc	U
424139073514502	35	1979	Unc	U
424155073545001	20	1979	Unc	A
424215073505601	39	1979	Unc	U
424222073541301	70	1979	Unc	U
424231073514901	48	1979	Unc	U
424232073514901	49	1979	Unc	U
424232073515001	49	1979	Unc	U
424232073515002	22	1979	Unc	U
424241073535201	45	1979	Unc	U
424244073535301	40	1979	Unc	U
424247073515201	60	1979	Unc	F
424247073515301	69	1979	Unc	F
424247073515302	32	1979	Unc	F
424249073521801	30.8	1979	Unc	U
424250073521901	49	1979	Unc	U
NEW YORK - Albany County (cont.)				
424250073521902	25	1979	Unc	U
424313073511201	25	1979	Unc	U
424324073525501	25	1979	Unc	U
424325073513001	18	1979	Unc	U
424327073531101	30	1979	Unc	U
424347073525701	30	1979	Unc	U
424357073531201	30	1979	Unc	U
424359073493901	350	1979	Unc	A
424410073515301	30	1979	Unc	U
424422073493001	20	1979	Unc	A
424448073535201	35	1979	Unc	A
Dutchess County				
415818073393101	228	1975	B	A
Montgomery County				
425558074330701	625	1973	B	A
Oneida County				
431229075241401	21.5	1987	Unc	U
431233075242401	46	1987	Unc	U
431243075243201	35	1987	Unc	U
431244075241701	25	1987	Unc	U
431246075244101	41.5	1987	Unc	U
431252075243001	30.5	1987	Unc	U
431258075243701	25	1987	Unc	U
423534073423401	80.4	1982	Unc	U
Schenectady County				
424910073591701*	62	1973	Unc	U
424938073593101	60	1979	Unc	U
424957073590001	32	1979	Unc	U
425102074003601	75	1979	Unc	U
425118074000801	92	1979	Unc	A
Ulster County				
415850074003501	79	1972	Unc	F
Westchester County				
410833073465901	60	1971	B	U
411116073422301	500	1987	B	F
411240073493801	80	1988	B	F
411308073410001	300	1987	B	F
411310073494901	160	1988	B	F
411317073435601	50	1987	B	F
411411073461901	125	1988	B	F
411433073434901	200	1987	B	F
411542073323601	350	1987	B	F
411600073512201	300	1988	B	F
411618073395401	325	1987	B	U
411627073325701	180	1987	B	U
411629073423901	125	1987	B	F
411643073500101	90	1988	B	F
411651073342101	240	1987	B	A
411832073454201	205	1987	B	A
411839073393301	400	1987	B	U
411913073561801	180	1988	B	F
411915073400701	425	1987	B	U
411942073411201	80	1987	B	U
411946073443001	900	1987	B	U
412125073331801	750	1987	B	F
VERMONT - Bennington County				
424628073143401	58	1970	Unc	A



Base from U.S. Geological Survey digital data 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29° 30' and 45° 30', central meridian -74°

Figure 8A. Locations of wells in Hudson River basin in eastern New York and adjacent States for which 1970-90 dissolved nitrate data were available.

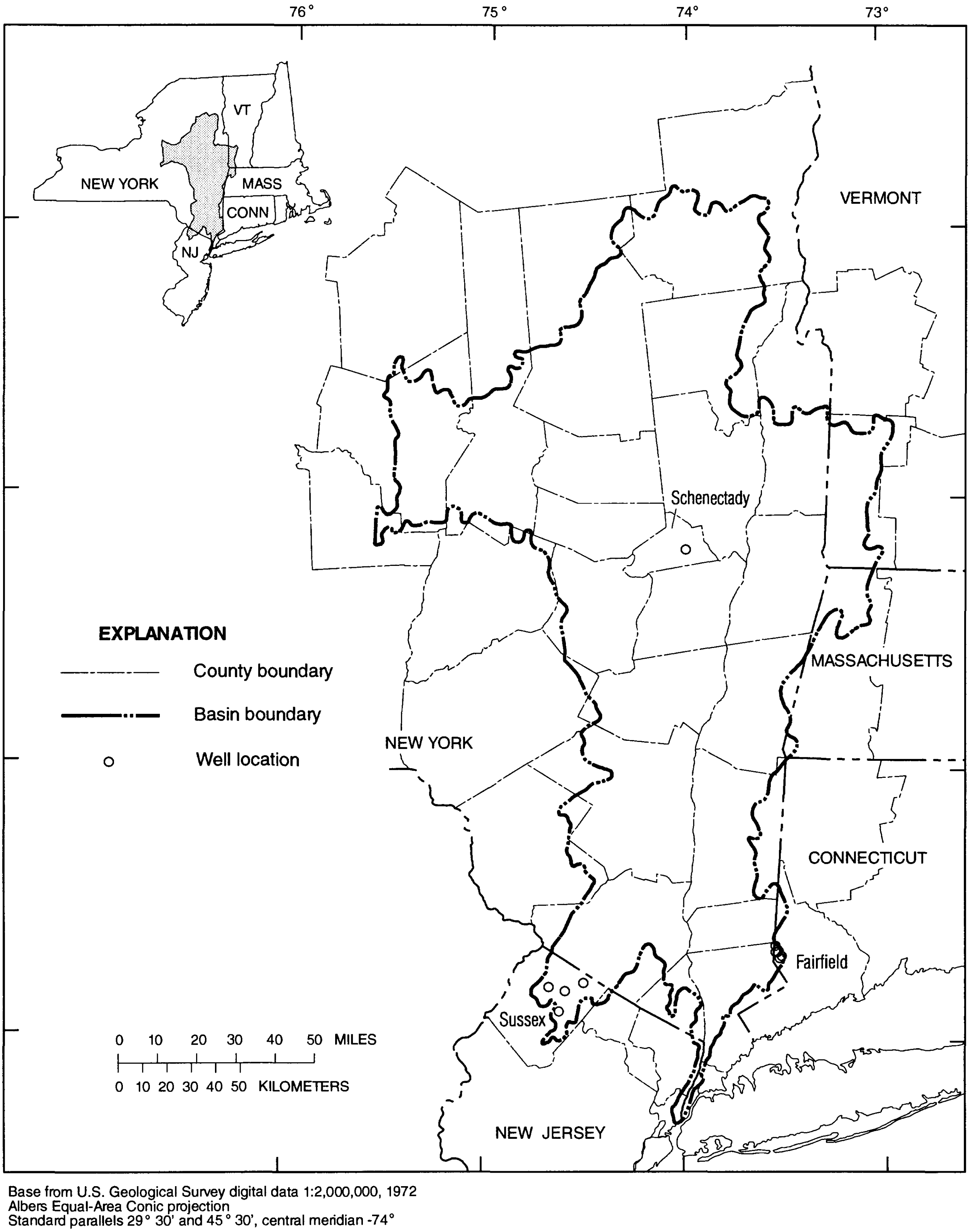


Figure 8B. Locations of wells in Hudson River basin in eastern New York and adjacent States for which 1970-90 pesticide and volatile organic compound data were available.

Table 5. Name, location and drainage area, and types of data available from surface-water sites in the U.S. Geological Survey National Water Inventory System database from which nutrient, suspended sediment, or pesticide data are available.

[Site locations are shown in fig. 10. N, nutrient data; S, suspended sediment data; P, pesticide data. Mi^2, square miles]

Site no.	U.S. Geological Survey no.	Site Name	Latitude	Longitude	Drainage Area (mi^2)	Types of data available
1	01315500	Hudson River at North Creek, NY	43°42'03"	73°59'02"	792	N
2	01317000	Schroon River at Riverbank, NY	43°36'34"	73°44'17"	527	N
3	01319000	East Branch Sacandaga River at Griffin, NY	43°28'25"	74°13'25"	114	N
4	01325005	Sacandaga River at Hadley, NY	43°18'50"	73°50'45"	1057	N
5	01325420	Hudson River at Corinth, NY	43°14'55"	73°49'57"	2755	N
6	01327600	Hudson River at Glens Falls, NY	43°18'20"	73°36'58"	2807	N,S
7	01327750	Hudson River at Fort Edward, NY	43°16'10"	73°35'47"	2817	N,S
8	01329640	Batten Kill at Middle Falls, NY	43°05'55"	73°31'32"	434	N
9	01329650	Hudson River at Schuylerville, NY	43°05'54"	73°34'25"	3440	S
10	01329907	Clover Mill Brook on Shaw Hill Rd near Rock City Falls, NY	43°04'09"	73°56'20"	44.3	N
11	01330770	Kayaderosseras Creek at Saratoga Springs, NY	43°02'37"	73°46'16"	165	N
12	01331095	Hudson River at Stillwater, NY	42°56'16"	73°39'04"	3770	S
13	01333300	Hoosic River below Williamstown, MA	42°44'28"	73°12'47"	204	N,P
14	01333360	Hoosic River at North Petersburg, NY	42°49'35"	73°19'21"	233	N,P
15	01334805	Hoosic River at Eagle Bridge, NY	42°57'05"	73°23'28"	571	N
16	01335770	Hudson River at Waterford, NY	42°47'19"	73°40'28"	4620	N,S,P
17	01342602	Mohawk River near Utica, NY	43°05'26"	75°09'27"	553	N
18	01343902	Utica Water Supply Intake on West Canada Creek, NY	43°18'39"	75°06'38"	372	N
19	01349520	Cayadutta Creek at Fonda, NY	42°57'13"	74°22'51"	62.7	N
20	01349527	Mohawk River above State Highway 30 at Fonda, NY	42°57'01"	74°22'21"	2120	N
21	01349858	Silver Lake Outlet at Hensonville, NY	42°17'43"	74°12'48"	6.66	S
22	01350180	Schoharie Creek at North Blenheim, NY	42°27'57"	74°27'45"	358	N
23	01350355	Schoharie Creek at Breakabeen, NY	42°32'13"	74°24'39"	444	N
24	01350500	Schoharie Creek at Middleburg, NY	42°35'58"	74°20'12"	534	N
25	01351500	Schoharie Creek at Burtonsville, NY	42°48'00"	74°15'48"	886	N
26	01354000	Mohawk River at Tribes Hill, NY	42°56'41"	74°17'19"	3090	N
27A	01357000	Mohawk River at Crescent Dam, NY	42°48'21"	73°43'24"	3440	N
27B	01357500	Mohawk River at Cohoes, NY	42°47'07"	73°42'29"	3450	N,S,P
28	01358000	Hudson River at Green Island, NY	42°45'08"	73°41'22"	8090	N,S,P
29	01359915	Hannacrois Creek at Dormansville, NY	42°29'49"	73°58'46"	13.5	S
30	01359918	Silver Creek at Dormansville, NY	42°29'17"	73°58'56"	2.90	S
31	01361750	Basic Creek at South Westerlo, NY	42°26'50"	74°01'37"	18.3	S
32	01362198	Esopus Creek at Shandaken, NY	42°06'59"	74°23'20"	59.5	N,S,P
33	01362342	Hollow Tree Brook at Lanesville ,NY	42°08'32"	74°15'55"	1.95	N
34	01364501	Esopus Creek at Saugerties, NY	42°04'16"	73°57'02"	425	N
35	01364959	Rondout Creek above Red Brook at Peekamoose, NY	41°56'13"	74°22'30"	5.36	N
36	01364974	Rhinebeck Water Plant Intake on Hudson River, NY	41°55'38"	73°56'52"	10,510	P
37	01367620	Wallkill River at Outflow of Lake Mohawk at Sparta, NJ	41°01'59"	74°38'36"	4.38	N,P
38	01367700	Wallkill River at Franklin, NJ	41°06'43"	74°35'21"	29.4	N,P
39	01367770	Wallkill River near Sussex, NJ	41°11'38"	74°34'32"	60.8	N,P
40	01367910	Papakating Creek at Sussex, NJ	41°12'02"	74°35'59"	59.4	N,P
41	01368950	Black Creek near Vernon, NJ	41°13'21"	74°28'33"	17.3	N,P
42	01372003	Wallkill River near Rosendale, NY	41°48'53"	74°03'33"	764	N
43	01372005	Rondout Creek at Eddyville, NY	41°53'39"	74°01'13"	1150	N
44	01372044	Twaalfskill near Highland, NY	41°41'42"	73°59'08"	3.59	N,P
45	01372500	Wappinger Creek near Wappingers Falls, NY	41°39'11"	73°52'23"	181	N
46	01372547	Chelsea Water Plant Intake on Hudson River, NY	41°33'49"	73°57'30"	11,800	P
47	01373500	Fishkill Creek at Beacon, NY	41°30'40"	73°56'55"	190	N
48	01373860	Moodna Creek near New Windsor, NY	41°27'32"	74°01'27"	175	N
49	01374300	Peekskill Hollow Creek at Van Cortlandtville, NY	41°19'04"	73°54'21"	46.6	P
50	01374398	Furnace Brook near Croton-on-Hudson, NY	41°13'51"	73°54'24"	7.21	P
51	01374963	Hallocks Mill Brook at Amawalk, NY	41°17'08"	73°45'58"	11.4	P
52	01376500	Saw Mill River at Yonkers, NY	40°56'11"	73°53'12"	25.6	P
53	411218-073434700	Kisco River trib. Green Sreet at Mount Kisco, NY	41°12'18"	73°43'47"	2.80	P
54	411707-073500901	Mill Pond Trib off Hunter Brook Road at Yorktown ,NY	41°17'07"	73°50'09"	2.40	P
55	431230-075241001	Three Mile Creek at Rome, NY	43°12'30"	75°24'10"	0.50	P
56	435703-074051302	Winebrook Hills Plant Intake on Hudson River, NY	43°57'03"	74°05'13"	8.00	N,P

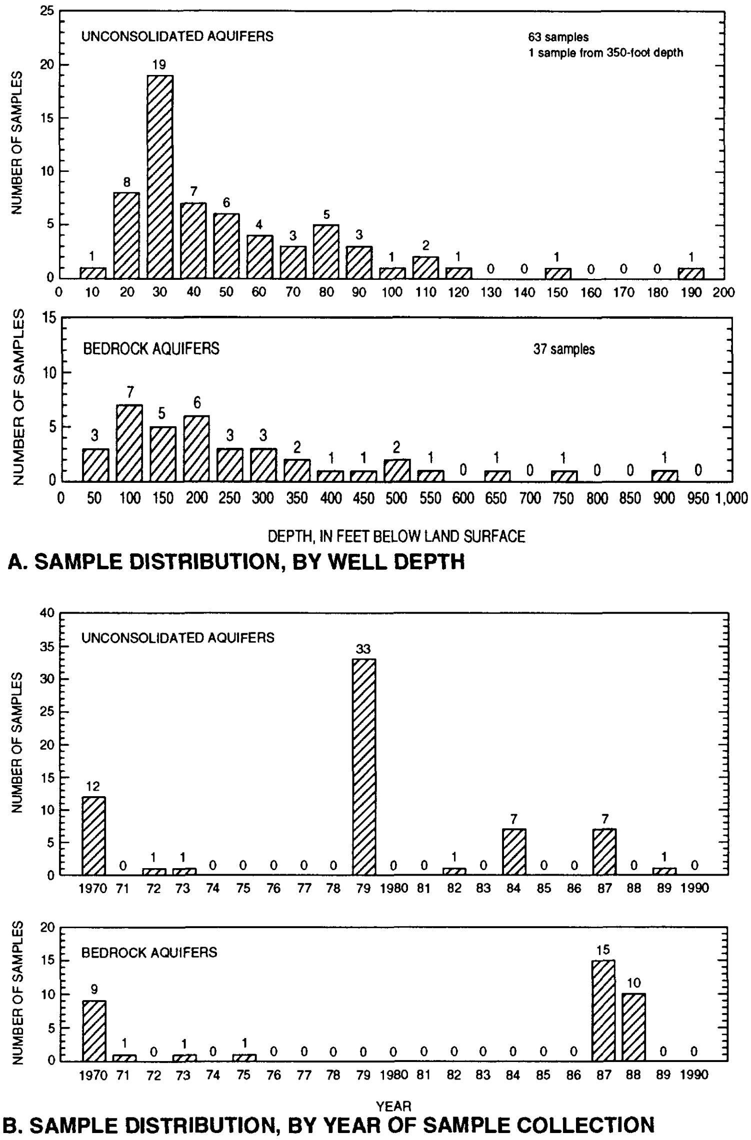
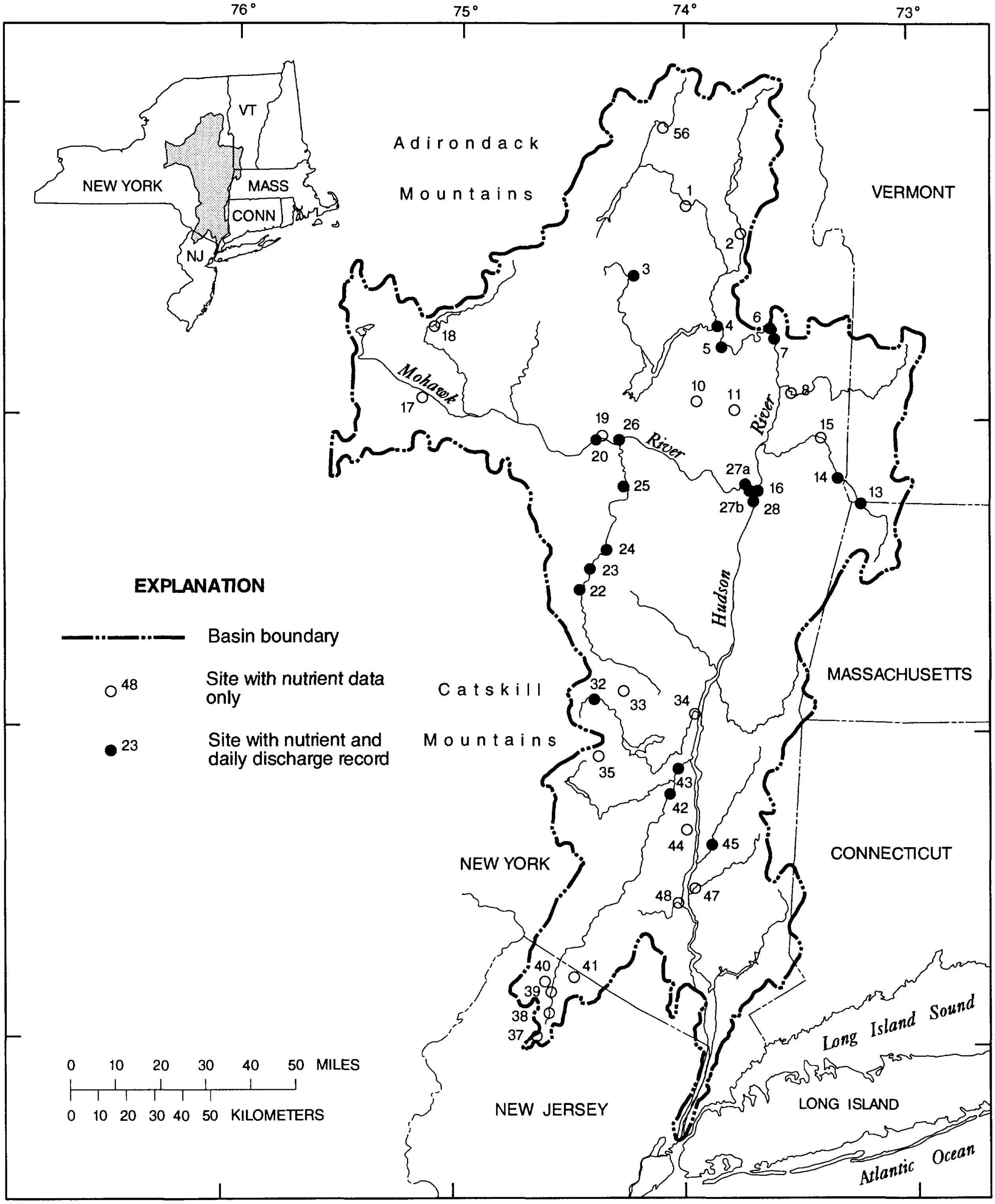


Figure 9. Time and well-depth distribution of dissolved-nitrate analyses for unconsolidated and bedrock aquifers in the Hudson River basin in eastern New York and adjacent States, 1970-90: A. Sample distribution, by well depth. B. Sample distribution, by year of collection.

Nutrients

Data on dissolved nitrate, total nitrogen, dissolved ammonium, and total phosphorus in surface water were available from 42 sites (fig. 10 and table 6). All of these sites have data on dissolved nitrate, but not all have data on total phosphorus, total nitrogen, or dissolved ammonium. Of the 42 sites for which nutrient data are available, 21 also have daily discharge data (fig. 10). Only four sites with nutrient data are classified as urban, and only two of these (sites 13 and 14) have daily discharge records (table 6); both are on the upper parts of the Hoosic River downstream of Williamstown, within 10 mi of one another (fig. 10 and table 6). Of the remaining 19 sites with nutrient and daily-discharge data, seven are agricultural, six are forested, and six are mixed. Most of the agricultural sites with available nutrient and daily discharge data are in the Mohawk River basin and have drainage areas greater than 900 mi^2 (sites 20, 25, 26, 27A , 27B in fig. 10 and table 6). Only one agricultural site for which nutrient and daily discharge data are available (Wappinger Creek, site 45) has a drainage area of less than 200 mi^2.



Base from U.S. Geological Survey digital data 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29° 30' and 45° 30', central meridian -74°

Figure 10. Surface-water sites in Hudson River basin in eastern New York and adjacent States for which nutrient data, or nutrient and daily-discharge data, are available. (Site names are given in table 5).

Table 6. Land use and population density of watersheds represented by the 42 surface-water sites in Hudson River basin from which 1970-90 nutrient data were available.

[Site locations are shown in fig. 10; site names are shown in table 5; * denotes daily discharge data available] .

Site no.	Site Category	Land Use in Watershed area (in percent)			Watershed population (per square mile)	
		Urban	Agricultural	Forest	1980	1990
1	Forest	0.41	0.28	92.7	3.28	4.78
2	Forest	1.60	0.36	93.6	12.0	9.39
3*	Forest	0.00	0.00	94.3	0.00	14.1
4*	Forest	1.32	1.46	87.4	29.9	18.7
5*	Forest	1.12	1.03	91.1	18.9	15.8
6*	Forest	1.34	1.08	90.9	26.6	23.7
7*	Forest	1.36	1.12	90.8	27.0	24.3
8	Agricultural	1.23	35.7	62.3	34.4	41.8
10	Forest	0.900	9.5	89.6	101	78.2
11	Agricultural	6.55	26.1	66.3	196	218
13*	Urban	10.7	13.3	74.8	211	198
14*	Urban	9.89	15.5	73.7	195	183
15	Mixed	7.50	24.4	67.5	134	135
16*	Mixed	3.34	15.0	76.7	69.1	70.9
17	Agricultural	11.2	44.1	40.1	368	358
18	Forest	0.321	1.58	88.9	3.24	5.06
19	Mixed	11.7	36.0	48.1	345	512
20*	Agricultural	4.65	34.7	54.9	150	150
22*	Mixed	2.49	18.1	75.3	22.1	26.3
23*	Mixed	1.99	18.3	76.2	22.3	24.9
24*	Mixed	1.93	19.6	75.4	28.6	28.5
25*	Agricultural	2.17	30.1	64.8	40.8	46.3
26*	Agricultural	3.89	34.0	57.2	118	117
27a*	Agricultural	6.09	33.8	55.0	174	175
27b*	Agricultural	6.12	33.8	55.0	175	176
28*	Mixed	4.65	23.2	67.1	118	119
32*	Forest	1.65	0.33	94.4	7.76	13.9
33	Forest	0.00	0.00	100.00	0.00	0.00
34	Forest	6.35	7.50	82.6	152	154
35	Forest	0.00	0.00	100.00	0.00	0.00
37	Urban	44.7	0.00	29.8	1140	1710
38	Urban	21.1	12.6	57.9	417	442
39	Mixed	13.4	30.6	50.5	397	450
40	Agricultural	3.63	71.5	24.3	156	215
41	Mixed	22.5	29.5	42.2	342	350
42*	Agricultural	8.97	55.1	35.6	247	290
43*	Mixed	7.25	40.8	51.3	189	219
44	Agricultural	2.94	32.3	67.7	245	245
45*	Agricultural	4.58	35.6	58.1	174	129
47	Mixed	10.8	29.5	58.7	253	294
48	Mixed	15.2	40.1	42.5	283	364
56	Forest	0.00	0.00	94.5	0.00	0.00

Six sites (sites 13, 27A, 27B, 28, 32 and 45 in fig. 10) with daily-discharge data were chosen for an analysis of the number of samples available, the years represented, and the distribution of samples over the range of flow conditions for four nutrients during 1970-90; the patterns of nutrient-data availability at these sites is typical of sites across the Hudson River basin. The constituents most frequently sampled for are dissolved nitrate and total phosphorus (table 7). Dissolved nitrate is the most commonly sampled nutrient and, therefore, is used in this report to represent the availability of all nutrient data.

Most samples for dissolved-nitrate analysis were collected during 1970-80 at the six sites; only a few samples were collected during 1981-90 (table 8). Only two of the sites–Esopus Creek at Shandaken (site 32) and Hudson River at Green Island (site 28)–have nutrient data for each year of 1970-90, and even at these locations, the sampling frequency declined substantially during the 1980's (table 8). Samples were collected at the outlet of the Mohawk River at Crescent Dam (site 27A in fig. 10) for dissolved nitrate analysis during 1970-78; after 1978, the sampling location was shifted 2 mi downstream to Cohoes (site 27B), where most of the samples for dissolved nitrate analysis were collected after 1988 (table 8). The analysis of nutrient concentrations at the Mohawk River outlet in this report is based mostly on data collected from Crescent Dam (site 27A) because few data are available from the Cohoes site.The inconsistency of nutrient-data collection by year restricts the usefulness of the data for a basinwide assessment of current conditions and trends, and the lack of data after 1980 largely restricts the basinwide assessment of nutrient concentrations to 1970-80. The only available temporal-trend analyses of nutrients are those reported for dissolved nitrate at two forested sites in the Catskill Mountains by Murdoch and Stoddard (1992) from NYCDEP data. Wappinger Creek is a site with a monthly sampling pattern that is representative of most sites with more than 40 samples and shows an even distribution throughout the year (fig. 11A). Mohawk River at Crescent Dam is another representative site; the frequency of sample collection per month at this site is less consistent than at Wappinger Creek, however, because few samples were collected in the winter months, possibly because of ice conditions.

All sites with both nutrient and daily discharge data had at least one sample representing high flow conditions (discharge that is exceeded 10 percent of the time); therefore, nutrient data representing high-flow conditions are generally available–more than 20

Table 7. Number of samples collected at selected sites in Hudson River basin for nutrient analysis, 1970-90 .

[Site locations are shown in fig. 10; names are given in table 5]

Site no.	Site Name	Nutrient: Total nitrogen	Dissolved nitrate	Dissolved ammonium	Total phosphorus
13	Hoosic River below Williamstown MA	10	49	8	49
27A	Mohawk River at Crescent Dam ,NY	109	170	98	169
27B	Mohawk River at Cohoes, NY	32	34	1	20
28	Hudson River at Green Island, NY	131	162	102	159
32	Esopus Creek at Shandaken, NY	48	181	70	170
45	Wappinger Creek near Wappingers Falls, NY	37	72	50	67

Table 8. Number of samples collected for dissolved nitrate analyses from selected sites with discharge data in the Hudson River basin, 1970-90, by year.

[Site locations are shown in fig. 10, names are given in table 7. Dash indicates no data available]

Year	Number of Samples: Site 13	Site 27a	Site 27b	Site 28	Site 32	Site 45
1970	12	25	1	12	10	12
1971	12	26	-	12	11	14
1972	12	25	-	12	12	13
1973	12	22	-	13	11	13
1974	1	25	-	12	12	12
1975	-	18	-	10	11	8
1976	-	10	-	10	12	-
1977	-	8	-	8	12	-
1978	-	11	-	9	12	-
1979	-	-	13	9	11	-
1980	-	-	-	12	12	-
1981	-	-	-	12	12	-
1982	-	-	-	6	12	-
1983	-	-	-	4	7	-
1984	-	-	-	4	4	-
1985	-	-	-	4	4	-
1986	-	-	-	3	5	-
1987	-	-	-	1	2	-
1988	-	-	2	4	4	-
1989	-	-	11	3	3	-
1990	-	-	7	2	2	-

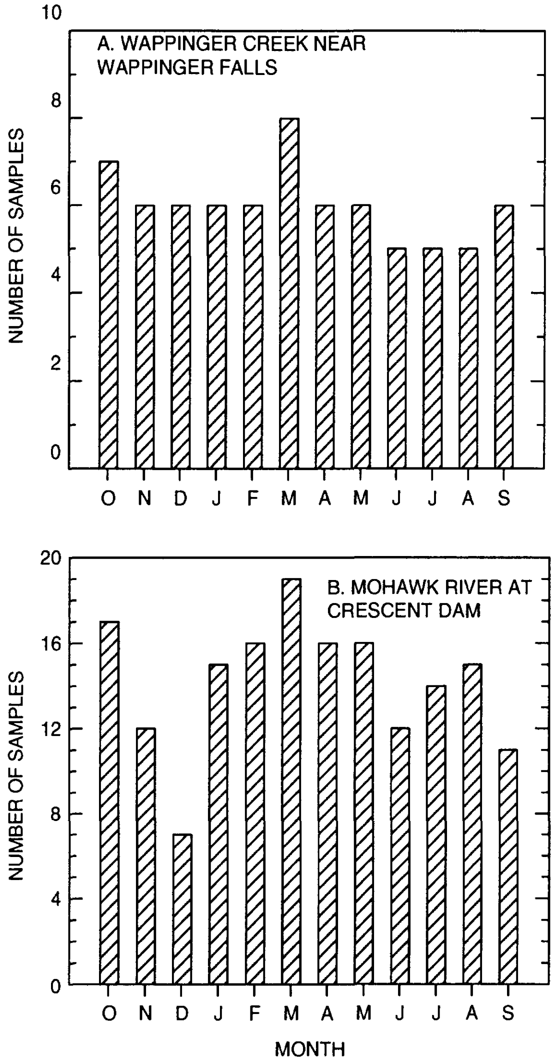


Figure 11. Number of water samples collected monthly at two sites in the Hudson River basin during 1970-90 for dissolved nitrate analysis, . (Locations are shown in fig. 10).

samples for dissolved nitrate analyses were collected at the Mohawk River at Crescent Dam during high-flow conditions (table 9). More than 10 samples were collected during low-flow conditions (discharges that were exceeded 80 percent of the time). The distribution of dissolved nitrate samples over the flow range at Wappinger Creek near Wappingers Falls is similar; 14 samples represent high-flow conditions, whereas only 9 represent low-flow conditions. In contrast, fewer samples were collected during high-flow conditions than during low-flow conditions at the Hoosic River below Williamstown and at Esopus Creek at Shandaken (table 9), although more than 5 samples represent high-flow conditions at these sites. The large percentage of samples representing high-flow conditions is likely attributable to high-flow conditions during 1970-80. Yet, the dissolved nitrate analyses represent a sufficiently wide range of flow conditions that the relations between discharge and nutrient concentration could be assessed. These results indicate that the distribution of data collected at sites with (1) daily discharge records and (2) analyses of more than 40 samples for nutrients, is generally adequate for plotting nitrate concentration as a function of discharge and for calculating nutrient yields.

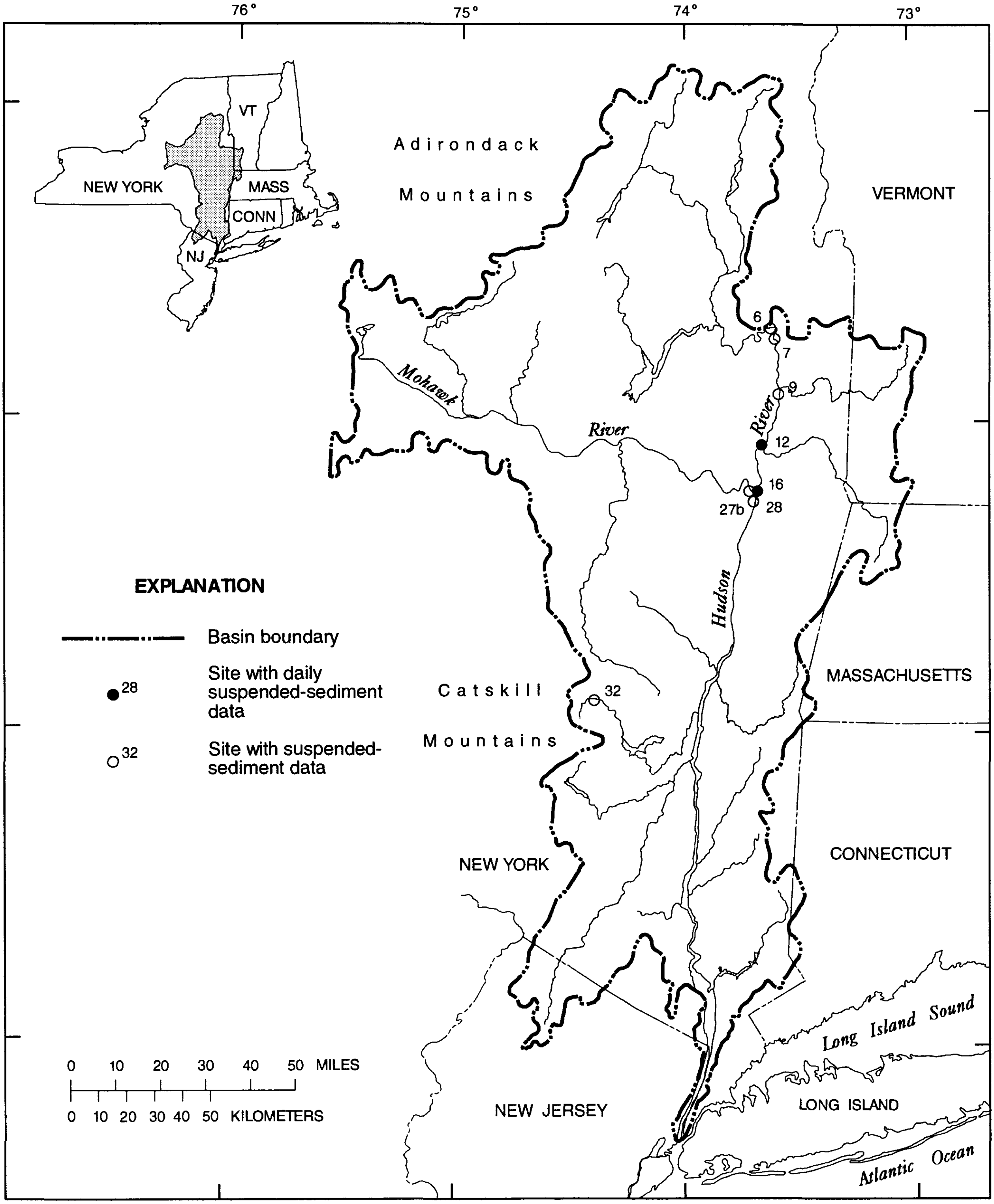
Table 9. Number of samples collected for dissolved nitrate analyses during high and low flows at select sites in the Hudson River basin, 1970-90.

[Locations are shown in fig. 10; names in table 5. High flow includes discharges exceeded 10 percent of the time or less; low flow includes discharges exceeded 80 percent of the time or more.

Site no.	Site name	Number of samples collected: High flow	Low flow
13	Hoosic River below Williams-town, Mass.	6	13
27A	Mohawk River at Crescent Dam	22	15
27B	Mohawk River at Cohoes N.Y.	7	4
28	Hudson River at Green Island, .	21	21
32	Esopus Creek at Shandaken, NY.	21	33
45	Wappinger Creek near Wappingers Falls NY.	14	9

Suspended Sediment

All suspended-sediment data used in the analysis herein are from the NWIS database. Eight of the 12 sites with suspended-sediment data have more than 40 samples and, thus, were considered suitable for analysis (fig. 12 and table 10), and all eight of these sites have more than 90 samples from 1970-90. Five of these sites are on the main stem of the upper Hudson River (sites 6, 7, 9, 12, 16; see fig. 12 and table 10) and were sampled by the USGS in cooperation with the NYSDEC as part of a long-term PCB-monitoring program; two of these sites have daily suspended-sediment data–site 12 (Hudson River at Stillwater) and site 16 (Hudson River at Waterford). Suspended-sediment samples also were collected from the Hudson River at Green Island (site 28) as part of the USGS NASQAN (National Stream-Quality Accounting Network) program, and at the Esopus Creek at Shandaken (site 32) as part of the USGS Hydrologic Benchmark program (Firda and



Base from U.S. Geological Survey digital data 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29° 30' and 45° 30', central meridian -74°

Figure 12. Locations of surface-water sites in Hudson River basin in eastern New York from which suspended-sediment data were available, 1970-90. (Site names are given in table 10).

Table 10. Data on numbers of samples collected at eight sites in the Hudson River basin, N.Y., that have discharge records and more than 40 suspended-sediment samples, 1970-90.

[Flow duration is percentage of time discharge was exceeded. Dashes indicate no data available. Site locations are shown in fig. 12]

A. Site number and name, land-use category, and high-flow data.

Site no.	Site Name	Predominant land use in watershed	Suspended-sediment samples: Total collected	Suspended-sediment samples: No. collected at high flow (discharge exceeded 10 percent of time or less)	Flow duration for sample representing highest discharge
6	Hudson River at Glens Falls	Forest	90	23	0.05
7	Hudson River at Fort Edward	Forest	423	132	0.03
9	Hudson River at Schuylerville	Forest	293	-	-
12*	Hudson River at Stillwater	Forest	3,297	415	0.04
16*	Hudson River at Waterford	Mixed	4,007	476	0.04
27B	Mohawk River at Cohoes	Agriculture	156	** 70	0.01
28	Hudson River at Green Island	Mixed	96	13	0.60
32	Esopus Creek at Shandaken	Forest	168	17	0.06

*Site with daily suspended-sediment values.

**Some samples were collected on same day

B. Number of suspended-sediment samples collected in 1970-90 by year and season

Year	Number ofsamples: Site 6	Site 7	Site 9	Site 12	Site 16	Site 27B	Site 28	Site 32
1970	-	-	-	-	-	-	-	8
1971	-	-	-	-	-	-	-	8
1972	-	-	-	-	-	-	-	12
1973	-	-	-	-	-	-	-	12
1974	-	-	-	-	-	-	-	8
1975	2	6	-	-	-	-	4	13
1976	-	4	2	-	-	20	11	14
1977	25	-	55	199	365	95	7	14
1978	50	28	16	365	365	2	9	12
1979	13	49	12	346	365	23	10	9
1980	-	63	13	335	366	-	12	12
1981	-	53	25	282	308	-	12	11
1982	-	66	35	213	308	-	6	10
1983	-	37	38	283	334	-	4	4
1984	-	2	1	206	274	-	4	4
1985	-	16	17	117	108	-	4	5
1986	-	7	5	217	249	-	4	3
1987	-	28	17	106	115	-	-	-
1988	-	31	20	246	296	2	4	3
1989	-	33	28	112	317	9	3	3
1990	-	-	9	270	237	5	2	2
Season								
Winter (Jan-Mar)	4	69	46	548	758	42	16	40
Spring (Apr-June)	31	152	115	984	1096	22	26	42
Summer (July-Sep)	23	143	93	941	1096	25	29	46
Fall (Oct-Dec)	32	59	39	824	1057	67	25	39

others, 1993). All eight of these sites except Hudson River at Schuylerville (site 9) have daily discharge records that enable calculation of sediment-transport rates. In general, these sites represent forested or mixed land-use watersheds; only one (site 27B, Mohawk River at Cohoes) is agricultural. No suspended-sediment data are available for urban watersheds.

The distribution of suspended-sediment data collection, by year, differs considerably among the sites. The sites with daily sediment records–Hudson River at Stillwater (site 12) and Hudson River at Waterford (site 16, fig. 12)–have average daily sediment-concentration and yield data for more than 250 days in each of most years during 1977-90 (table 10B). Most suspended-sediment samples were collected at the Hudson River at Fort Edward (site 7) and the Hudson River at Schuylerville (site 9) were collected during 1978-83. In contrast, all samples from the Hudson River at Glens Falls (site 6) were collected during 1975-79. More than half of the suspended-sediment samples from the Mohawk River at Cohoes were collected in 1977 (table 10B), and suspended-sediment data were not collected in most years. Although adequate numbers of suspended-sediment samples were collected at Esopus Creek at Shandaken (site 32) and the Hudson River at Green Island (site 28) (table 10B), the sampling frequency at these sites decreased by more than half after 1982.

The seasonal distribution of suspended-sediment data collection is uneven for some sites (table 10B). At most sites without daily sediment data, fewer than 15 percent of the suspended-sediment samples were collected in the winter (December, January and February), largely because ice cover makes sample collection difficult. For example, the number of winter samples collected at Fort Edward (site 7) is one-half to one-third of the number collected in other seasons (table 10B), and fewer samples were collected at Stillwater and Waterford (sites 12 and 16) in winter than in other seasons.

Suspended-sediment data are available over a wide range of flow conditions, including high flow conditions at all seven sites with daily discharge records (table 10B). These seven sites have 10 or more analyses for days of high flow, when the daily mean discharge was exceeded 10 percent of the time or less, and nearly all have analyses for discharges that are exceeded less than 0.1 percent of the time.

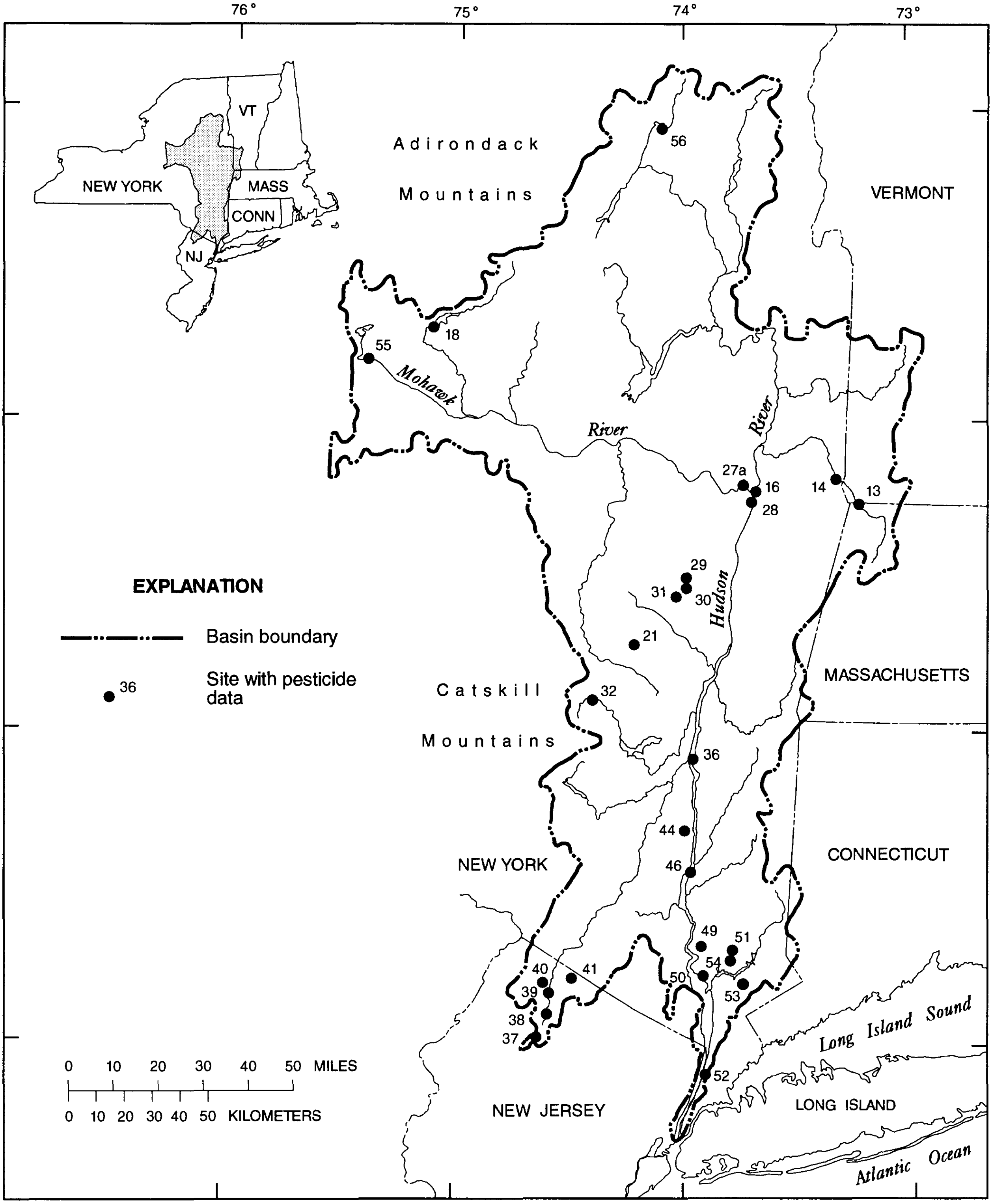
The distribution of suspended-sediment data by watershed and land-use category is inadequate for a basinwide assessment of suspended sediment. Even though sediment data for the mainstem of the upper Hudson River are plentiful, no data for tributaries to the upper Hudson or Mohawk Rivers are available; thus, neither the major sources of sediment to the Hudson and Mohawk Rivers, nor the relations between land use and suspended-sediment concentrations, can be identified. Assessment of current suspended-sediment conditions at the Mohawk River at Crescent Dam is also impossible because few samples for suspended-sediment analyses were collected there after 1977.

Pesticides

The pesticide data analyzed herein are largely from the NWIS database and are based on only a few samples. Only five pesticides in streambed samples have data from 10 or more sites in at least two watersheds–these are DDD (dichlorodiphenyldichloroethane), DDE (dichlorodiphenyldichloroethane), DDT, chlordane, and aldrin; only one compound dissolved in the water column (2,4-D) has data from 10 or more sites. All of these compounds except 2,4-D are persistent insecticides (Ware, 1989); 2,4-D is less persistent and more water soluble than the others. Locations of sites with pesticide data are shown in figure 13. In this report, the bed-sediment concentrations of DDT, DDE, and DDD are combined and reported as total DDT (fig. 14). Chlordane and aldrin data are available from 22 sites, total DDT from 21 sites, and 2,4-D from only 11 sites (table 11). Nearly half the sites with data for the first five pesticides represent urban watersheds; the remainder represent forested, agricultural, and mixed-use watersheds (fig. 14). The 2,4-D data are evenly distributed among the different types of sites (fig. 14).

All pesticide samples were collected during 1972-77 (table 11) except those from the upper Wallkill River basin, where chlordane, aldrin, and total DDT sampling (sites 37-41) was generally more recent (through 1990). No samples for 2,4-D analysis were collected after 1982.

In general, pesticide data are inadequate for a basinwide assessment of pesticide distribution in streambed sediment in the Hudson River basin. Few data on persistent pesticide compounds (such as chlordane and total DDT) are available for areas



Base from U.S. Geological Survey digital data 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29° 30' and 45° 30', central meridian -74°

Figure 13. Locations of surface-water sites in the Hudson River basin in eastern New York and adjacent States from which pesticide data are available. (Site names are given in table 5)

outside northern New Jersey after 1980 (table 11), and no water-column-concentration data on many widely used pesticides, including atrazine, alachlor, cyanazine, carbofuran, and carbaryl, are available. In addition, 2,4-D data are limited to one sample per site; thus, no information is available on 2,4-D concentrations under differing flow conditions or during different seasons. The lack of water-column data on pesticides and streambed sediment limit the analyses to (1) broad comparisons of detection rates, and (2) comparisons of median concentrations of a few persistent pesticides at sites in urban watersheds with those at nonurban watersheds.

Table 11. Years of pesticide-data collection in the Hudson River basin, 1970-90, by site.

[Locations are shown in fig. 13, names in table 5. Dashes indicate no data available.]

Site no.	Land-use Category	Pesticide Aldrin	Chlordane	DDD, DDT, DDE	2,4-D
13	Urban	-	-	-	1972-73
14	Urban	1972	1972	1972	1970-72
16	Mixed	-	-	-	1973-74
18	Forest	-	-	-	1974
21	Forest	1975	1975	1975	-
27A	Agricultural	1974	1974	1974	1973-77
28	Mixed	-	-	-	1982
29	Mixed	1978	1978	1978	-
30	Agricultural	1978	1978	1978	-
31	Agricultural	1978	1978	1978	-
32	Mixed	1970-82	1970-82	1970-82	1970-82
36	Estuary	-	-	-	1971-73
37	Urban	1980	1980	1980	-
38	Urban	1982-89	1982-89	1982-89	-
39	Mixed	1978-89	1978-89	1978-89	-
40	Urban	1978-90	1978-90	1978-90	-
41	Mixed	1978-90	1978-90	1978-90	-
44	Agricultural	1974	1974	1974	1974
46	Estuary	1974	1974	1974	1970
49	Urban	1976	1976	1976	-
50	Urban	1976	1976	1976	-
51	Urban	1976	1976	1976	-
52	Urban	1976-77	1976-77	1976-77	-
53	Urban	1976-77	1977	1976-77	-
54	Urban	1976	1976	1976	-
55	Urban	1987	1987	-	-
56	Forest	1974	1974	1974	1974

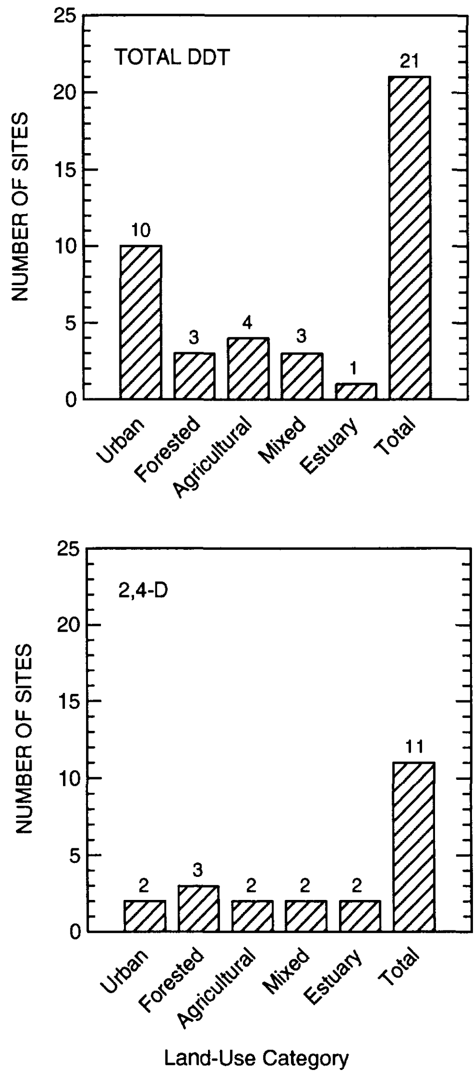


Figure 14. Number of sites in Hudson River basin, N.Y., with concentration data for total DDT or 2,4-D, by land-use category, 1970-90.

ANALYSIS OF NUTRIENT, PESTICIDE, VOLATILE ORGANIC COMPOUND, AND SUSPENDED-SEDIMENT DATA

The following analysis provides a preliminary basinwide ground-water and surface-water assessment. The ground-water section addresses nitrate, selected pesticides, and several VOC's; the surface-water section addresses nutrients, suspended-sediment, and pesticides. Both sections discuss (1) relations among nutrient concentrations, hydrologic conditions, and land use; and (2) pesticide concentrations and their relation to land use. The surface-water section also summarizes suspended-sediment concentrations at selected sites and gives computed yields of nutrients in surface water and suspended sediment.

Ground Water

The nutrient data discussed in this section are limited to nitrate because data on other nutrient species were sparse or lacking. Nitrate concentrations in ground water are compared with natural factors, such as type of aquifer material and well depth, as well as human factors, such as land use. Pesticide and VOC concentrations, by contrast, are compared only with human-derived factors.

Nitrate

Nitrate is the most soluble and mobile form of nitrogen in ground water. Previous investigations have indicated that all principal aquifers in New York State, both unconsolidated and bedrock, contain ground water with median nitrate concentrations as N (nitrogen) less than the 10-mg/L USEPA drinking-water standard (Rogers, 1988). (All references to concentrations of nitrogen in this report are expressed as N.) Elevated concentrations may be found, however, in shallow, unconfined systems that are susceptible to contamination from overlying sources of nitrate, such as fertilizers, underground sewage-disposal systems, animal waste, and landfills (Rogers, 1988).

Results of a study by Madison and Brunett (1984) indicate that background concentrations of nitrate are low (less than 0.2 mg/L) and that a threshold nitrate concentration indicative of human effects is 0.2 to 0.3 mg/L. A threshold concentration of 0.3 mg/L was estimated for this study from a probability distribution (SAS Institute, Inc., 1990) of the available nitrate data (fig. 15). The threshold was obtained through a qualitative determination that 0.3 mg/L corresponded to the steepest part of the dissolved nitrate probability plot and is interpreted as representing a point separating two populations of data.

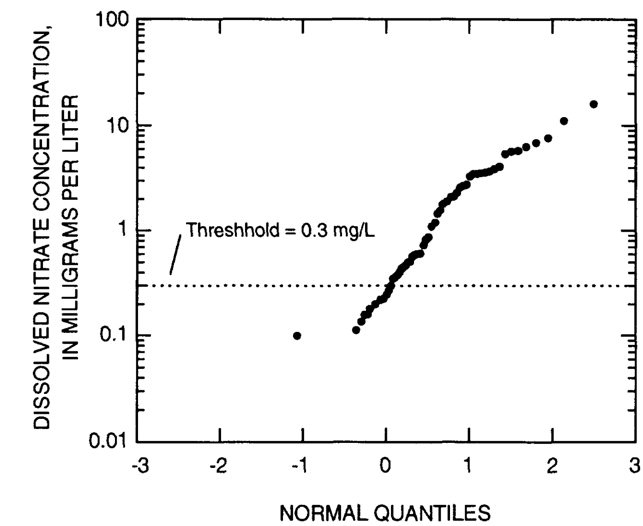


Figure 15. Dissolved nitrate concentrations in water from wells completed in bedrock and unconsolidated aquifers in the Hudson River basin in eastern New York and adjacent States, as a function of normal distribution, 1970-90.

Boxplots summarizing the concentrations of dissolved nitrate in ground-water samples from wells throughout the study area are given in figure 16A. Of the 100 ground-water samples represented in this report, 63 are from wells completed in unconsolidated glacial material, and 37 are from wells completed in bedrock. Two samples exceed the Federal and State maximum contaminant level of 10 mg/L–one is from an unconsolidated aquifer, and one from a bedrock aquifer. Nitrate concentrations in water from unconsolidated deposits range from less than the analytical detection limit of 0.1 mg/L to 16 mg/L, with a median concentration of 0.23 mg/L, and nitrate concentrations in water from bedrock range from less than 0.1 to 11 mg/L, with a median concentration of 0.3 mg/L. Depths of wells completed in unconsolidated deposits range from 9.35 to 350 ft below land surface, with a median of 35 ft, and depths of wells completed in bedrock aquifers range from 50 to 900 ft below land surface, with a median of 200 ft.

The effects of local differences in geology or other factors on nitrate concentration in ground water were evaluated through a comparison between two areas: one representing unconsolidated material (Albany and Schenectady Counties, 42 wells), the other

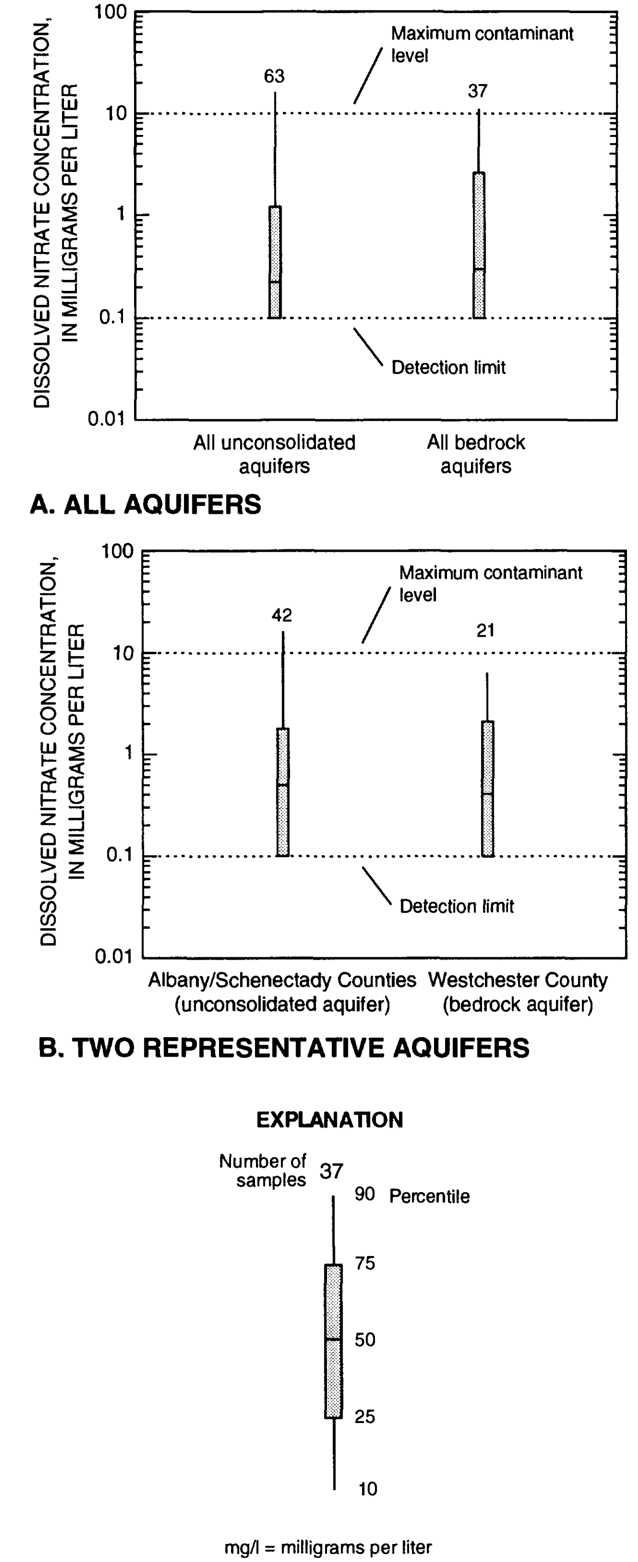


Figure 16. Range of dissolved nitrate concentrations in relation to aquifer type in the Hudson River basin in eastern New York and adjacent States, 1970-90: A. All aquifers, by aquifer type. B. Two representative unconsolidated aquifers in Albany and Schenectady Counties and bedrock aquifers in Westchester County.

representing bedrock (Westchester County, 21 wells). Nitrate concentrations in the unconsolidated-aquifer locality range from less than the reporting limit of 0.1 to 16 mg/L with a median of 0.48 mg/L, whereas those in the bedrock-aquifer locality range from less than 0.1 to 6.3 mg/L with a median of 0.43 mg/L. Boxplots summarizing nitrate concentrations in ground-water samples collected in these areas are given in figure 16B.

The Wilcoxon rank sum test (SAS Institute, Inc., 1990) (a nonparametric statistical test) was used to determine whether nitrate concentrations in unconsolidated aquifers differ from those in bedrock aquifers. The alpha value, or level of significance, used in this test was 0.05. In this test, the null hypothesis was accepted with a probability value of 0.81, indicating no statistically significant difference between nitrate concentrations in unconsolidated aquifers of Albany and Schenectady Counties and those in bedrock aquifers of Westchester County.

In general, nitrate concentrations in ground water decreased with depth. The relation between nitrate concentration and well depth for wells screened in unconsolidated aquifers in the Hudson River basin (fig. 17A) indicates the expected decrease, but the plot for bedrock aquifers suggests some other control on nitrate concentrations (fig. 17A). The graph of nitrate concentrations in relation to depth in bedrock aquifers suggests two populations of data–those affected, and those unaffected; the controlling factor appears to be land use. Statistical tests were done on depth and land use to test whether these apparent controls are real or the result of chance differences.

Box plots of nitrate concentrations by well depth (fig. 17B) indicate a median nitrate concentration of 0.61 mg/L for unconsolidated aquifers in wells less than 35 ft deep, and 0.2 mg/L in wells more than 35 ft deep, confirming that nitrate concentrations decrease with depth. In bedrock aquifers, however, concentrations at depths less than 200 ft range from less than 0.1 to 11 mg/L with a median of 0.26 mg/L, and those at depths greater than 200 ft range from less than 0.1 to 3.6 mg/L, with a median of 0.43 mg/L. Ground water in bedrock aquifers flows along zones of secondary permeability, such as fractures and bedding-plane openings; thus, the high concentrations of nitrate at depth are probably the result of downward flow along fractures that could extend from land surface and provide a direct conduit for shallow ground-water flow into deep zones.

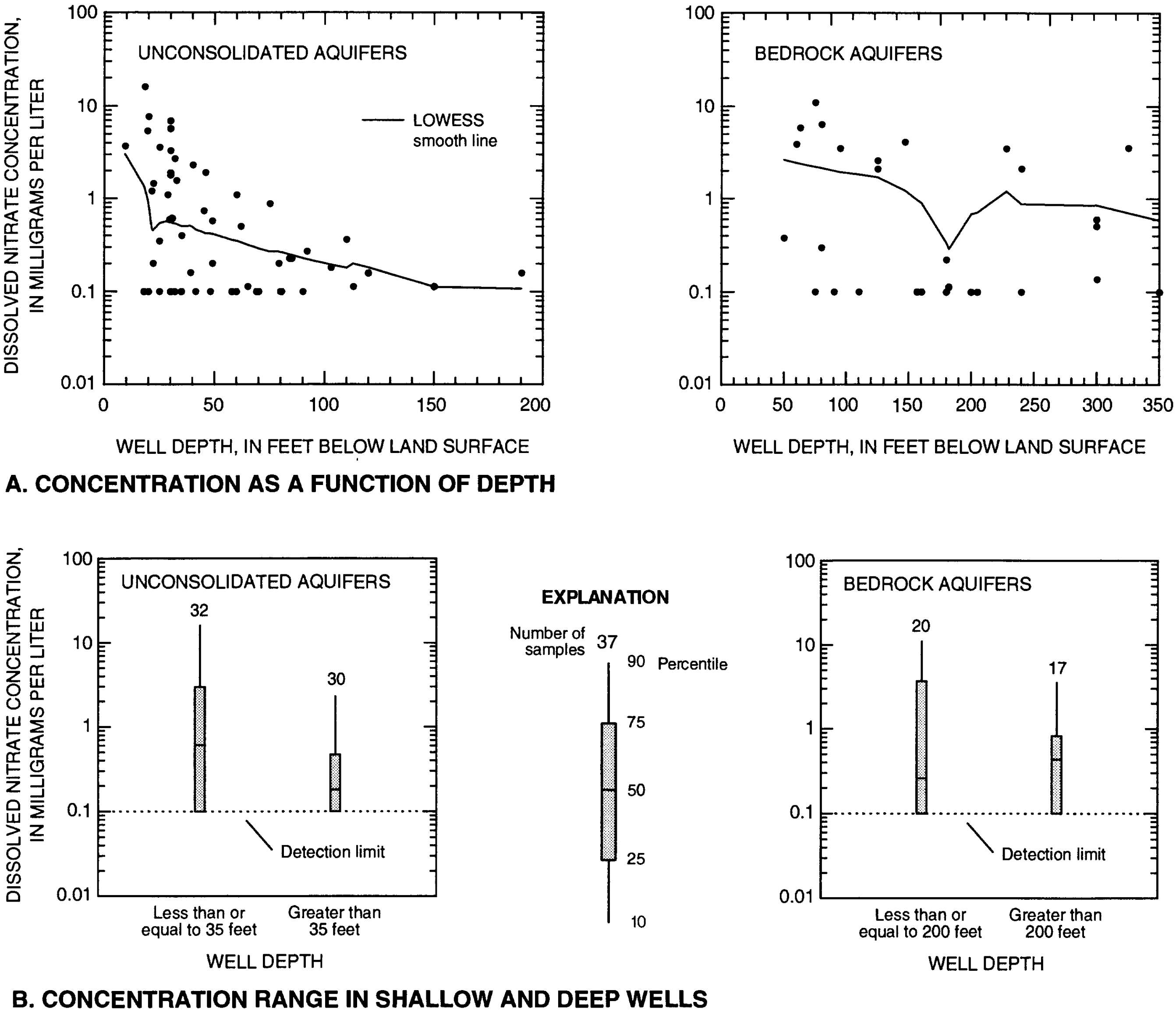


Figure 17. Dissolved nitrate concentrations in relation to well depth in unconsolidated and bedrock aquifers in the Hudson River basin in eastern New York and adjacent States, 1970-90. A. Concentration as a function of well depth. B. Concentration range in shallow and deep wells

The Wilcoxon rank sum test (SAS Institute, Inc., 1990) was used to indicate whether changes in nitrate concentration with depth in both types of aquifers result from chance variability or represent real differences. The alpha value used in this test was 0.05. In unconsolidated aquifers, the null hypothesis was rejected with a probability value of 0.04, indicating a statistically significant difference in the nitrate concentrations in samples from wells 35 ft deep or less, and in samples from wells more than 35 ft deep. In bedrock aquifers, a probability value of 0.74 indicates no statistically significant difference between samples from wells 200 ft deep or less and those from wells more than 200 feet deep.

Nitrate data for the unconsolidated and bedrock aquifers also were analyzed in relation to three categories of land use type; results are presented in boxplots in figure 18. Median concentrations for the three land use categories among unconsolidated aquifers range from less than 0.1 to 0.6 mg/L; the highest median concentration represents forest settings (fig. 18A). Median concentrations, by land use, in bedrock aquifers range from 0.2 to 2.81 mg/L; the highest median concentration (2.81 mg/L) represents an agricultural area (fig. 18B).

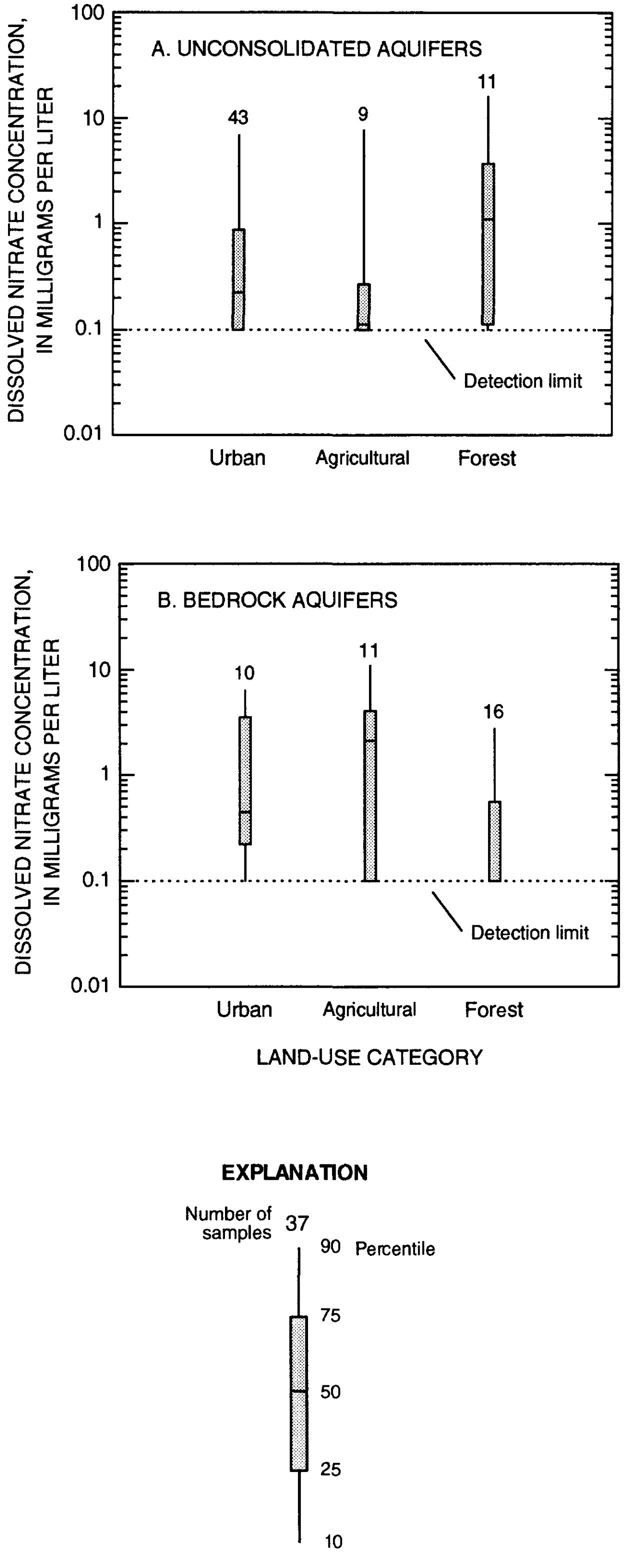


Figure 18. Range of dissolved nitrate concentrations in water from wells in the Hudson River basin in eastern New York and adjacent States, 1970-90, by land use and aquifer type: A. Unconsolidated aquifers. B. Bedrock aquifers.

The Kruskal-Wallis test (SAS Institute, Inc., 1990) is a nonparametric test used to determine whether all groups have (1) the same median, or (2) at least one median that differs from the rest. The null hypothesis of this test is that all groups of data have identical distributions. The alpha value used in this test is 0.05. A probability value smaller than or equal to the alpha value indicates that the groups differ significantly. Neither the samples from unconsolidated aquifers (probability value = 0.15), nor those from bedrock aquifers (probability value = 0.10) showed significant differences with respect to land-use category; therefore, no correlation between nitrate concentration and land use in the Hudson River basin can be made from available ground-water-quality data.

Two of the land-use categories were then combined in an effort to indicate the effect of land use on nitrate concentrations in bedrock aquifers. The agricultural and urban categories were combined as "developed" land and compared with forest or "undeveloped" land, and the data were reapplied. Results of the Wilcox rank sum test indicate a significant difference (probability value = 0.04), which indicates that the median concentration of nitrate in ground water beneath developed land is greater than that in ground water beneath undeveloped land. Therefore, land use is likely the major controlling factor on nitrate concentrations in bedrock aquifers.

Pesticides and Volatile Organic Compounds

Of the 100 sites represented in this report, 11 had samples for selected pesticides and VOC's during 1970-90. Six of these sites are in Connecticut, one is in New York, and four are in New Jersey. Concentrations of all compounds were at or below the analytical detection limits (table 12) except for diazinon, which was detected at a concentration of 0.03 µg/L at the New York site in an urban setting (Schenectady County).

Surface Water

This section presents results of the analyses of nutrient, suspended-sediment, and pesticide data from 56 surface-water sites. It includes nutrient-yield estimates for selected sites and relates them to rates of input from agricultural, atmospheric, geologic, and sewage sources; it also compares suspended-sediment concentrations and yields among the sites

Table 12. Detection limits of selected pesticides and volatile organic compounds for which ground-water samples from the Hudson River basin were analyzed, 1970-90.

[Detection limits are in micrograms per liter]

Constituent	Detection limit
Pesticides	
2, 4-D, Total	0.01
2, 4-DP, Total	0.01
2, 4, 5-T, Total	0.01
Aldrin, Total	0.001
Aldrin, Dissolved	0.01
AmetrynE	0.1
Atrazine, Total	0.1
Bromoform, Total	0.2
Chlordane Total	0.1
Chlordane, Dissolved	0.1
CYANAZINE	0.01
DDD, Total	0.001
DDD, Dissolved	0.01
DDE, Total	0.001
DDE, Dissolved	0.01
DDE, Dissolved	0.01
DDT, Total	0.001
DDT, Dissolved	0.01
Diazinon, Total	0.01
Dieldrin, Total	0.01
Dieldrin, Dissolved	0.01
Endosulfan I, Total	0.001
Endrin, Total	0.001
Endrin, Dissolved	0.01
Ethion, Total	0.01
Heptachlor, Dissolved	0.01
Heptachlor, Total	0.01
Heptachlor Epoxide, Dissolved	0.001
Heptachlor Epoxide, Total	0.01
Lindane, Dissolved	0.01
mirex, Dissolved	0.001
Mirex, Total	
Parathion Total	0.01
Perthane, Total	0.01
Prometone, Total	0.01
Prometryne, Total	0.01
Propazine	0.1
Silvex, Total	0.2
Simazine, Total	0.1
Simetryne, Total	0.1
Toxaphene, Total	0.1
Volatile Organic Compounds	
Chlorobenzene	0.2
Chlorodibromomethane, Total	0.1
Chloroethane	0.1
Dichlorobromomethane, Total	0.1
Methylchloride, Total	0.01
Methylene chloride, Total	0.01

that have adequate data and discusses pesticide-detection rates and median pesticide concentrations in relation to land use.

Nutrients

Nutrient concentrations in surface water are related to discharge, season, land use, and population density and are used to calculate yields (mass per area) and transport rates (mass per time unit). The following paragraphs present estimated yields for selected sites with daily discharge data; it also includes mass balances and yields for total nitrogen, dissolved nitrate, and total phosphorus for comparison with inputs from atmospheric and, agricultural sources, and from treated wastewater.

Concentration in Relation to Discharge

Plots of nutrient concentration in relation to discharge at sites representing differing land uses can help identify whether the nutrients are derived from point or nonpoint sources. If nutrient concentrations increase with increasing discharge, nonpoint sources are probably the main control, but if the concentrations decrease with increasing discharge, point sources are probably the main control. This section presents nutrient concentration-to-discharge relations for five sites representing:

1. a small (less than 250 mi^2) agricultural watershed (Wappinger Creek near Wappingers Falls, N.Y. site 45),
2. a large (greater than 1,000 mi^2) agricultural watershed (Mohawk River at Crescent Dam, N.Y. site 27a),
3. a small (less than 250 mi^2) urban watershed (Hoosic River below Williamstown, Mass. site 13),
4. a small (less than 100 mi^2) forested watershed (Esopus Creek at Shandaken, N.Y. site 32), and
5. a large (greater than 1,000 mi^2) forested watershed (Hudson River at Corinth, N.Y. site 5).

The Hoosic River site below Williamstown, Mass. has no data on total nitrogen; therefore, the Hoosic River site near North Petersburg, N.Y. (site 14) was used to represent urban conditions for total nitrogen. The following discussion focuses mainly on the relation between discharge and dissolved nitrate, total nitrogen, and total phosphorus concentrations at these five sites and also includes dissolved ammonium concentration at the five sites from which more than 30 samples were available.

Small Agricultural Watershed. Concentrations of most nutrient species in the small agricultural watershed (Wappinger Creek near Wappingers Falls, site 45) increase with increasing discharge. This watershed is about 36 percent agricultural land and has little urban area (less than 5 percent); most of the remaining watershed area is forested. In general, nitrate concentrations at this site increase with increasing discharge (fig. 19A), and the concentration-to-discharge relation shows little seasonal variability. The relation for total nitrogen at this site is similar to those for nitrate because dissolved nitrate constitutes most of the total nitrogen. In contrast, dissolved ammonium slightly increases with increasing discharge during discharges less than 200 ft^3/s and decreases with increasing discharges of 200 to 1,000 ft^3/s. Dissolved ammonium concentrations decrease with increasing discharge at this site and most other sites in the Hudson River basin, regardless of land use. The total phosphorus concentration at this site increases with increasing discharge at discharges greater than 300 ft^3/s. These results indicate that nutrient concentrations in surface water in this agricultural watershed are controlled largely by nonpoint sources.

The relations between nutrient concentrations and discharge in other agricultural watersheds that have daily-discharge records confirm this direct correlation; this pattern was observed for dissolved nitrate, total nitrogen, and total phosphorus at two of the other three agricultural watersheds: Mohawk River at Fonda (site 20) and Schoharie Creek at Burtonsville (site 25). The third site, the Wallkill River near

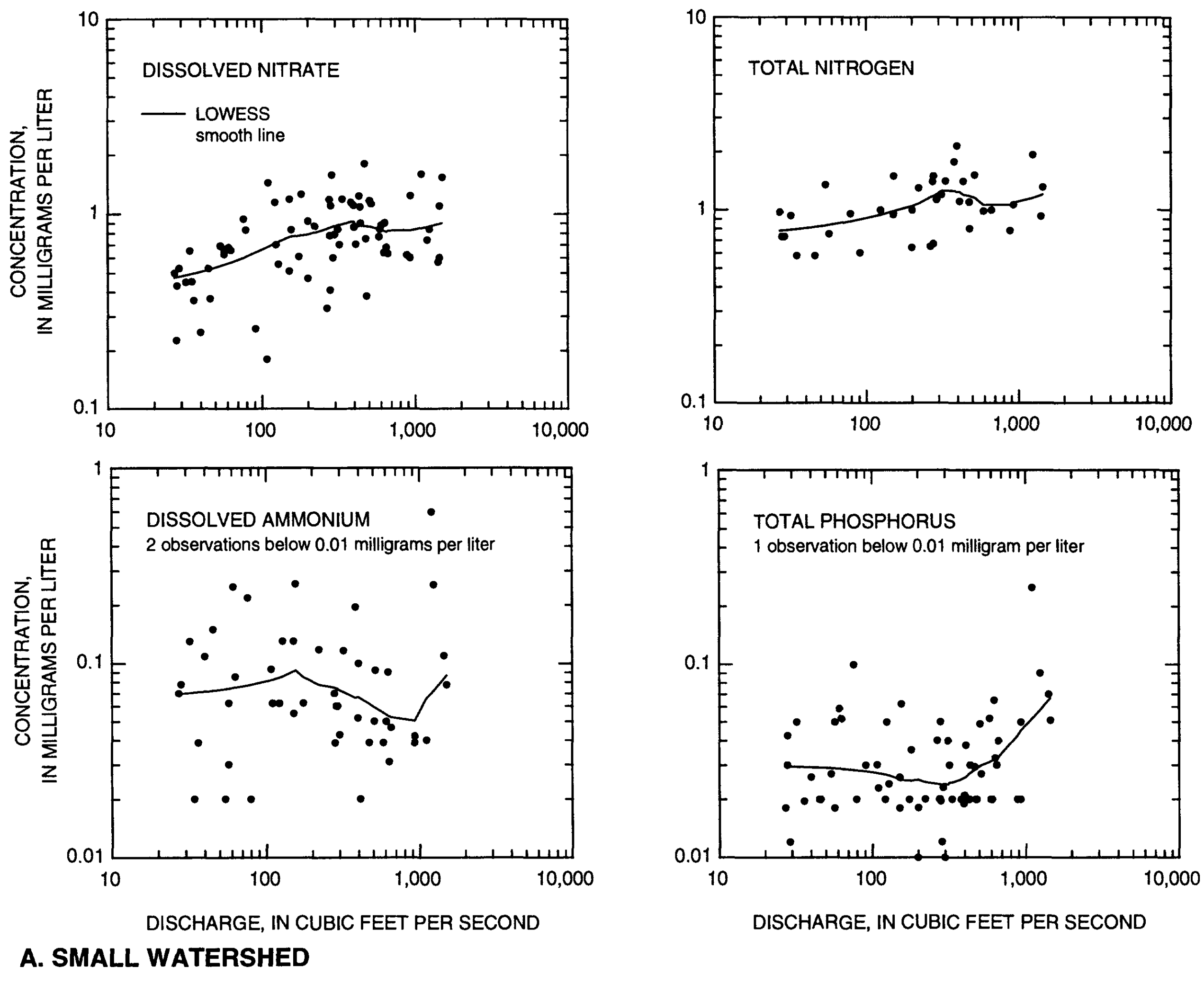


Figure 19A. Nutrient concentrations as a function of discharge in a small agricultural watershed (181 mi^2, Wappinger Creek near Wappinger's Falls, N.Y.), 1970-90.

Rosendale (site 42), differs from the other two agricultural sites in that more than 5 percent of its area is urban, its 1980 population density exceeded 200 per mi^2, and concentrations of dissolved nitrate, total nitrogen, and total phosphorus change little with increasing discharge. These results confirm that nutrients in streams draining agricultural watersheds are derived mainly from nonpoint agricultural sources, although they could be partly derived from urban point sources in agricultural watersheds with an elevated population density and extensive urbanization.

Large agricultural watershed. The Mohawk River at Crescent Dam drains a large area (greater than 3,000 mi^2) that is nearly 34 percent agricultural and about 6 percent urban; the rest is mainly forested land. Nutrient concentrations near the outlet of the Mohawk River (at site 27A, Mohawk River at Crescent Dam) are not strongly related to discharge. The LOWESS line for the relation between dissolved nitrate concentration and discharge is flat, as is the line for total nitrogen (fig. 19B). The LOWESS line for ammonium implies a direct correlation at discharges less than 3,000 ft^3/s; but the wide scatter of data makes any apparent trend difficult to discern. The line for total phosphorus has a mild U shape – at daily discharges of 4,000 to 10,000 ft^3/s, the concentration decreases with increasing discharges, and at discharges of 10,000 to 30,000 ft^3/s, it increases with increasing discharge. These results indicate that nutrients at this site are derived from a combination of point and nonpoint sources.

The relation between some nutrients and discharge at this site changes seasonally (fig. 20A). From November through February, dissolved nitrate concentration generally decreases with increasing discharge, whereas from March through June, it

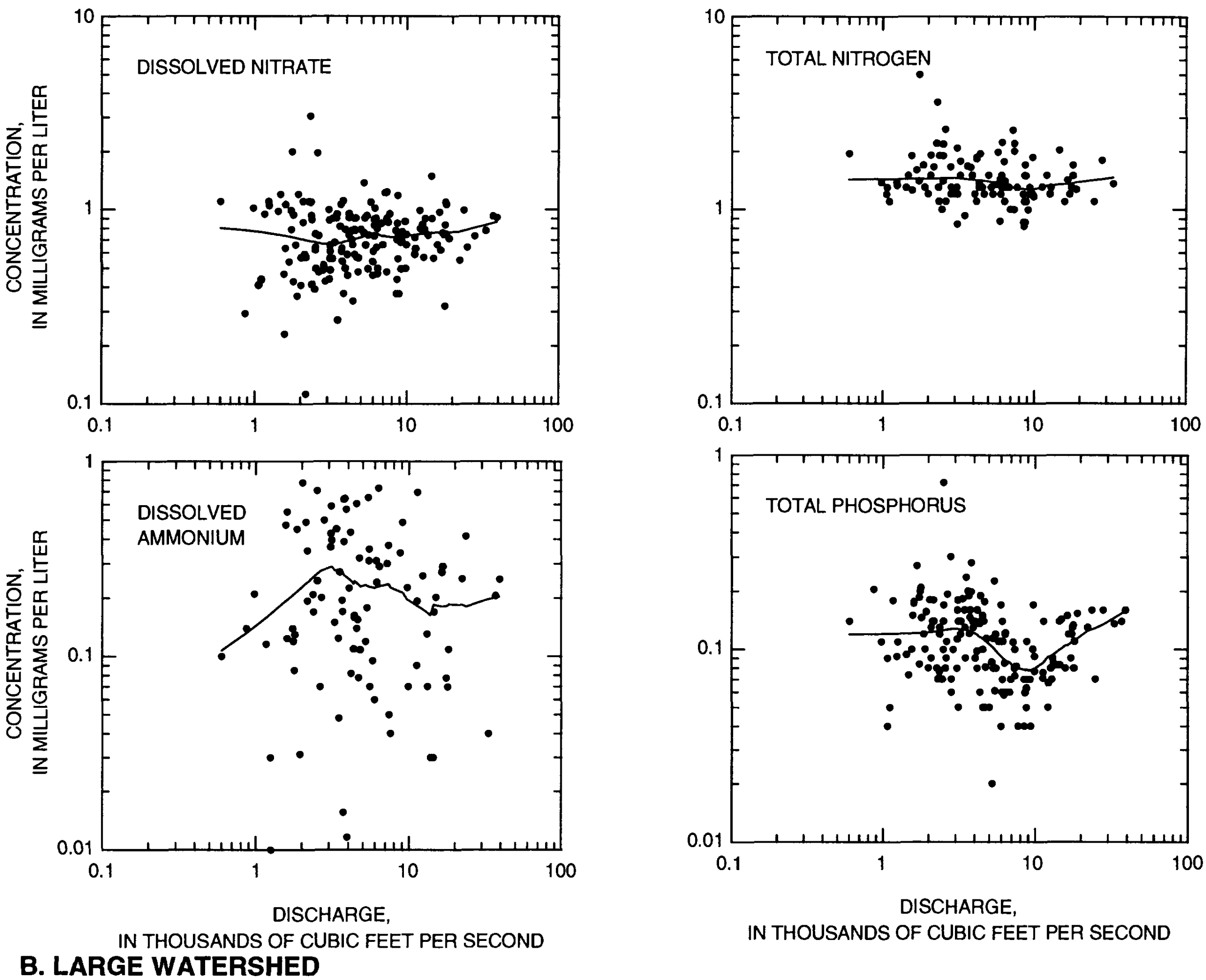


Figure 19B. Nutrient concentrations as a function of discharge in a large agricultural watershed (3,440 mi^2, Mohawk River at Crescent Dam, N.Y.), 1970-90.

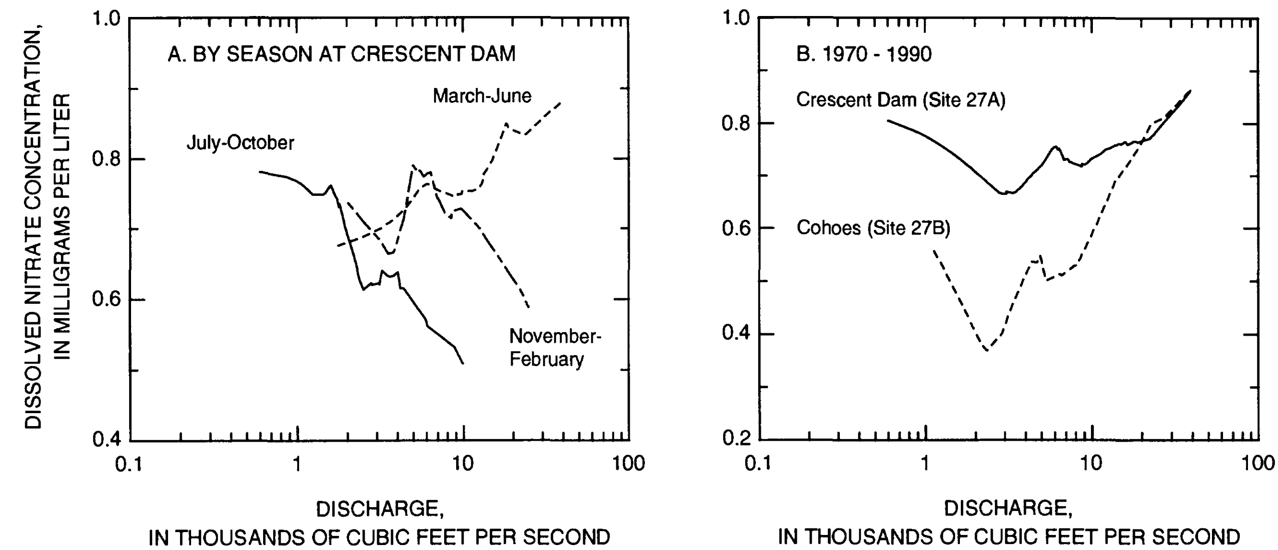
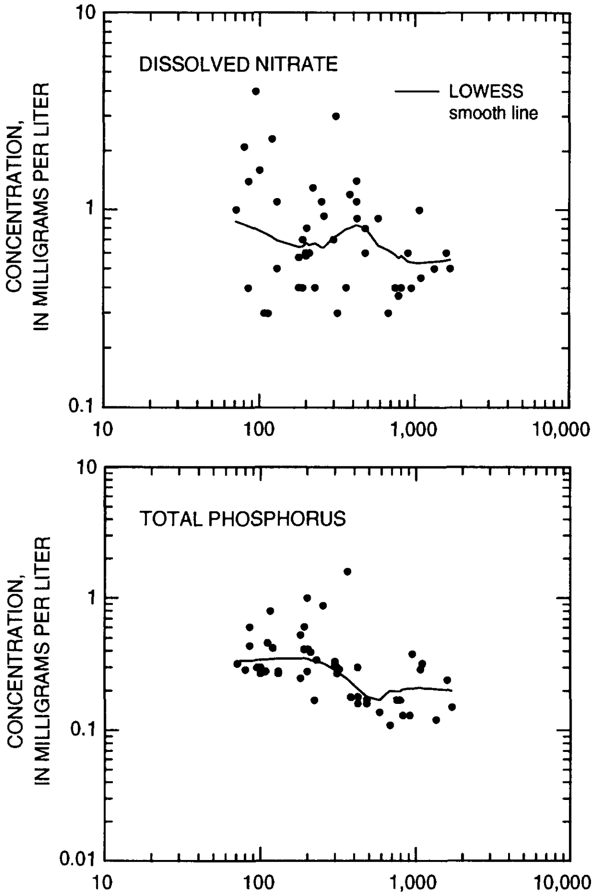


Figure 20. Dissolved nitrate concentration as a function of discharge at a large agricultural watershed site (Mohawk River outlet): A. At Crescent Dam, based on season, 1970-90; B. At Crescent Dam and Cohoes, based on all 1970-90 data.

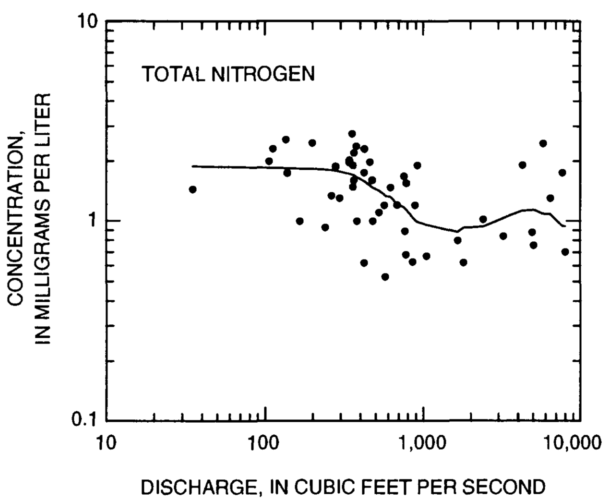
generally increases with increasing daily discharges. Dissolved nitrate concentration from March through June is also higher than the concentration observed from November through February at nearly all discharges. From July through October, the concentration generally decreases with increasing discharge, especially at discharges above 2,000 ft^3/s. The seasonal patterns of total nitrogen concentrations at this site are similar to those for dissolved nitrate, but the relations for dissolved ammonium and total phosphorus do not change seasonally. The cause of the seasonal variability in the dissolved nitrate-to-discharge relation at this site is uncertain, but the positive correlation from March through June could reflect the predominance of nonpoint agricultural runoff during the spring, whereas the negative correlation during the remaining months could reflect the predominance of urban point sources. These results indicate that nonpoint sources of nutrients have a greater effect on dissolved nitrate and total nitrogen concentrations from March through June at this site than at any other time.

The relation of dissolved nitrate to discharge at this site (site 27A) differs from the relation for the Mohawk River at Cohoes (site 27B), 2 mi upstream. At flows less than 20,000 ft^3/s, the dissolved nitrate concentration at Crescent Dam is higher than at Cohoes (fig. 20B). Only a few samples from the Mohawk River at Cohoes site were analyzed for dissolved ammonium, total nitrogen, or total phosphorus; thus, differences in the relation of concentration to discharge between the two sites could not be assessed. All Crescent Dam samples were collected before 1979, whereas nearly all of the Cohoes samples were collected after 1986; thus, the difference in nitrate concentration between these sites could reflect either a change in nitrate source between 1979-86 or differences in sampling locations over time.

Urban watershed. Nutrient concentrations generally decrease with increasing discharge at the two urban watersheds for which nutrient data were available – Hoosic River below Williamstown (site 13) and Hoosic River near North Petersburg (site 14). Dissolved nitrate and total phosphorus concentrations generally decrease with increasing discharge at the Williamstown site, although the concentration-to-discharge plot for nitrate shows considerable scatter (fig. 21A). Although total nitrogen data from this site are unavailable, the total nitrogen concentration at the North Petersburg site generally decreases with increasing discharge (fig. 21B). Because the Hoosic River watershed above these two sites is about 10 percent urban land and 15 percent agricultural land, with the remaining mostly forested land, these relations indicate that nutrient concentrations in the Hoosic River are probably associated with urban point sources. Turk and Troutman (1981) suggested that shale bedrock in the Hoosic River basin may contribute significant amounts of phosphorus to streams during periods of high discharge, but the general decrease in total phosphorus concentration with



A. HOOSIC RIVER BELOW WILLIAMSTOWN, MASS.



B. HOOSIC RIVER NEAR NORTH PETERSBURG, N.Y..

Figure 21. Nutrient concentration as a function of discharge in two urban watersheds, 1970-90: A. Dissolved nitrate and total phosphorus concentration at Hoosic River below Williamstown, Mass. (site 13). B. Total nitrogen at Hoosic River near North Petersburg, N.Y. (site 14).

increasing discharge indicates that nonpoint geologic sources have only a minor effect, if any, on total phosphorus concentrations in the Hoosic River.

Forested watersheds . Concentration of dissolved nitrate and total nitrogen generally increase with increasing discharge in both large and small forested watersheds in the basin, as exemplified by Esopus Creek at Shandaken (site 32), a small watershed dominated by forest in the Catskill Mountains, where dissolved nitrate and total nitrogen concentrations increase with increasing discharge (fig. 22A). Total phosphorus concentration, in contrast, shows little change with discharge, partly because the total phosphorus concentrations in nearly half the samples collected from this site were at or near the detection limit of 0.01 mg/L as P . These patterns are similar in large forested watersheds, as seen in the corresponding plots for samples from the Hudson River at Corinth (site 5), a large watershed dominated by forest in the Adirondack Mountains (fig 22B). As at site 32, dissolved nitrate and total nitrogen concentrations at this site generally increase with increasing discharge, and total phosphorus concentration changes little with increasing discharge, because most of the concentrations were at or below 0.01 mg/L. These relations indicate that nitrogen in streams that drain forested watersheds are derived mainly from nonpoint sources.

A similar pattern of increasing dissolved nitrate concentration with increasing discharge was found by Murdoch and Stoddard (1992) for small forested watersheds in the Catskill Mountains; dissolved nitrate concentrations at these sites tend to be highest during high flows in the late winter and early spring. Because agricultural and urban land generally constitutes less than 2 percent of these basins, Murdoch and Stoddard (1992) attributed the observed dissolved nitrate concentrations to atmospheric deposition, rather than to agricultural, urban, or residential sources.

Concentration in Relation to Time

Nitrate concentrations in streams draining small forested watersheds in the Catskill Mountains increased gradually during 1920-70 and sharply after 1970 (Murdoch and Stoddard, 1992), as indicated by the trend line for two representative streams with long-term records (fig. 23). Much of

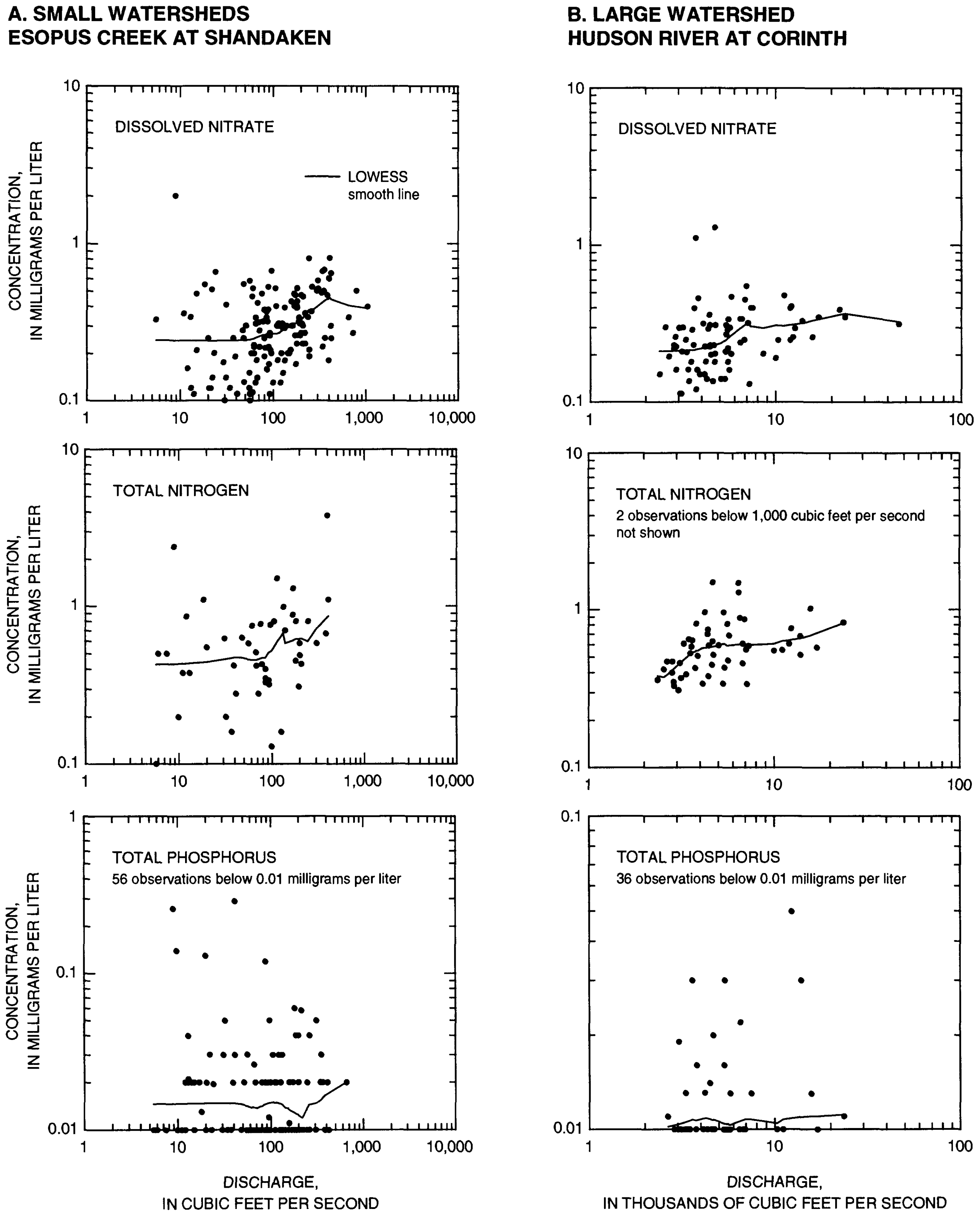


Figure 22. Concentration of dissolved nitrate, total nitrogen, and total phosphorus as a function of discharge at two forested watersheds, 1970-90: A. Esopus Creek at Shandaken, N.Y. (59.5 mi^2). B. Hudson River at Corinth, N.Y. (2,755 mi^2)

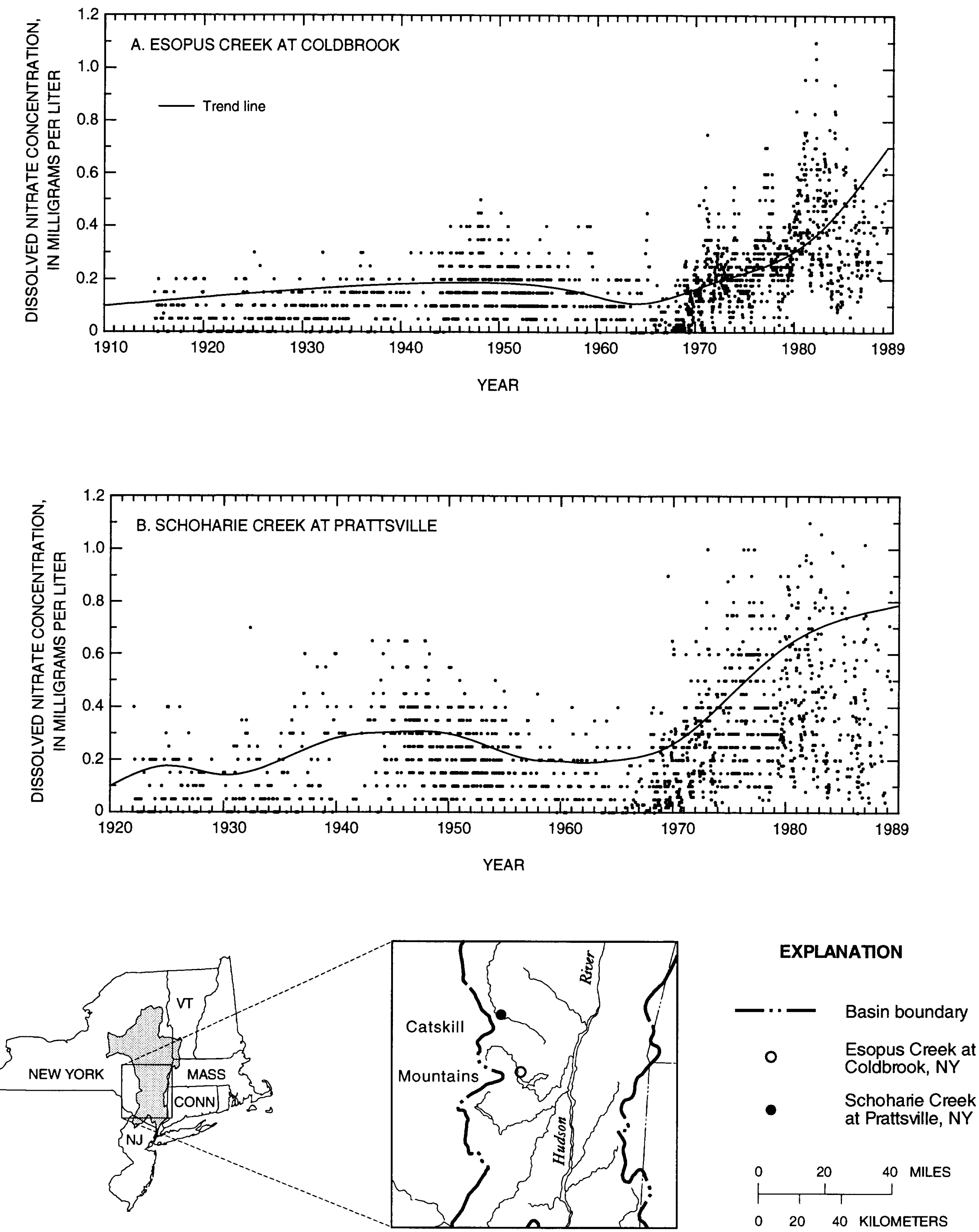


Figure 23. Dissolved nitrate concentrations in two Catskill Mountain streams of eastern New York. A. Esopus Creek at Coldbrook. B. Schoharie Creek at Prattsville (Modified from Murdoch and Stoddard, 1992, fig. 4.)

the increase at these sites is attributed by Murdoch and Stoddard (1992) to the increase in nitrate concentrations during storms; changes in nitrate concentrations during low discharges have been insubstantial. These data indicate that nitrate concentrations in streams draining small (less than 250 mi^2) forested watersheds have increased over time. The sparsity of data for other types of sites (including agricultural, urban, and mixed) and for large watersheds prevents basinwide assessment of time trends for nutrients.

Concentration in Relation to Land Use and Population Density

The relation between nutrient concentrations and land use is discussed in this section through statistical comparisons of median nutrient concentrations at (1) six selected sites with daily discharge records, and (2) a larger group of sites, some with daily discharge records and some without. The median values are compared among land-use categories and correlated with population density.

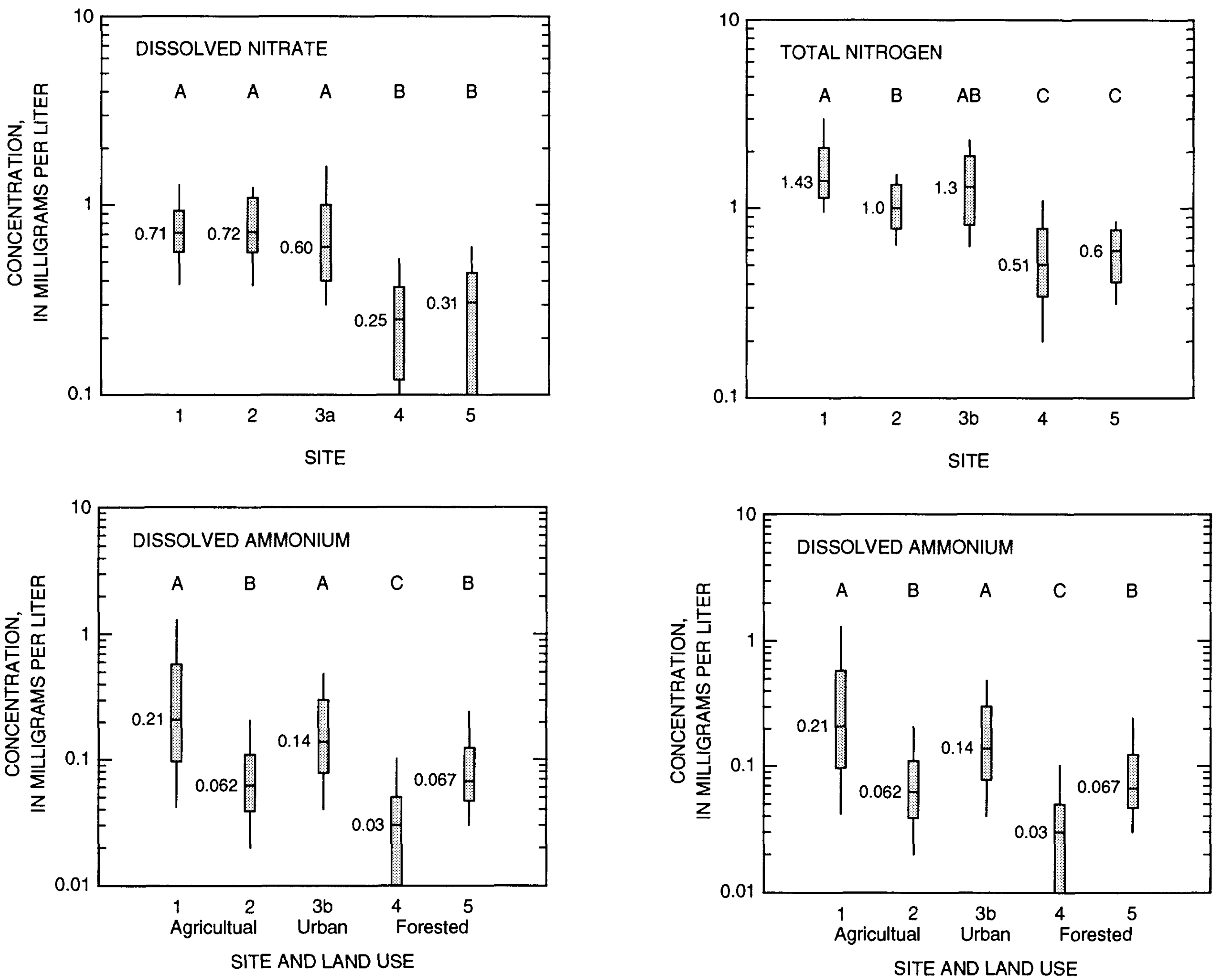
The sites selected for land-use and population correlations represent (1) two agricultural watersheds–the Mohawk River at Fonda (site 20) and Wappinger Creek (site 45) for four nutrients (dissolved nitrate, total nitrogen, dissolved ammonium, and total phosphorus), (2) two urban watersheds–Hoosic River below Williamstown, Mass. (site 13) for dissolved nitrate and total phosphorus, and Hoosic River at North Petersburg (site 14) for dissolved ammonium and total nitrogen, and (3) two forested watersheds–Esopus Creek at Shandaken (site 32) and East Branch of the Sacandaga River (site 3) for all four nutrients. These sites together represent the major land uses and environmental settings within the study area.

The median concentrations of dissolved nitrate and total nitrogen for agricultural or urban watershed sites are twice to three times the median concentrations for the forested watersheds (fig. 24), as are the median dissolved ammonium concentrations for the Mohawk River at Fonda (agricultural) and Hoosic River at North Petersburg (urban) sites. The median concentration of dissolved ammonium for Wappingers Creek (agricultural) is similar to that for East Sacandaga River (forested), however. Median total phosphorus concentrations for the Mohawk River at Fonda (agricultural) and Hoosic River at North Petersburg (urban) are 10 to 30 times higher than those for the two forested sites. In summary, median concentrations of all nutrients (except dissolved ammonium) for the agricultural- and urban- watershed sites greatly exceed those medians for the forested watershed sites.

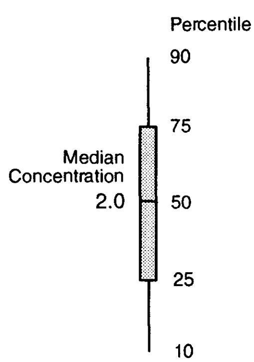
The purpose of the basinwide comparison of median nutrient concentrations is to show broad trends among watersheds that differ in land use and population density. Sites that were included in the basinwide comparison were those for which 10 or more analyses for a constituent were available (site locations are shown in fig. 25; nutrients represented at each site are listed in table 13). If the drainage areas of two sites selected overlapped by 50 percent or more, the site with the larger drainage area was excluded. Because only a few urban or mixed sites had sufficient data, results from these sites were combined for the analysis.

Comparison of median dissolved nitrate, total nitrogen and total phosphorus concentrations among agricultural, urban/mixed, and forested sites indicates that median concentrations of total nitrogen and total phosphorus at agricultural and urban/mixed sites are similar to one another and exceed the median concentrations at forested sites by a factor of 2 for total nitrogen and a factor of 7 for total phosphorus. Median concentrations of dissolved nitrate, in contrast, do not differ significantly among sites (fig. 26).

Nonparametric Spearman-rank correlations between median dissolved nitrate, total nitrogen, and total phosphorus concentrations and site characteristics (including predominant land use and population density in the watershed) indicate the characteristic with which all nutrients are most closely related is population density. Median concentrations of all nutrients are significantly (at the 0.05 level) and positively related to percent agricultural land and population density and negatively related to percent forest (table 14); median total nitrogen and total phosphorus concentrations are significantly and positively related to percent urban land. The highest correlations are for the relation between population density and (1) median total nitrogen and (2) median total phosphorus. Population density also is positively correlated with percent urban land and percent agricultural land, and negatively correlated with percent forest land (table 14).



EXPLANATION



SITES

Agricultural
1. Mohawk River at Fonda, NY
2. Wappinger Creek near Wappingers Falls, NY

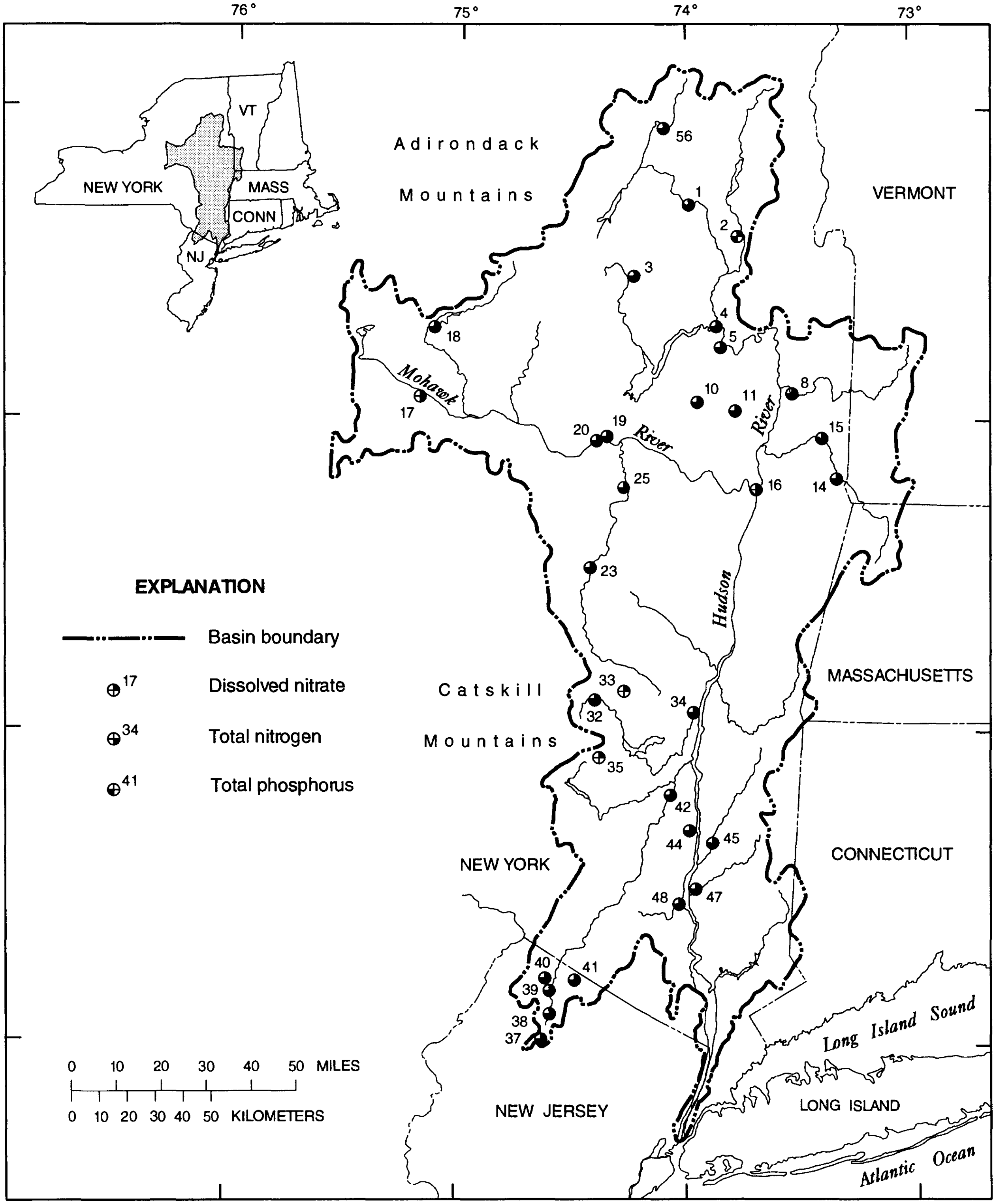
Urban
3a. Hoosic River below Williamstown, MA
3b. Hoosic River near North Petersburg, NY

Forested
4. Esopus Creek at Shandaken, NY
5. East Sacandaga River at Griffin, NY

A B AB C — differing letters indicate significant difference in median concentrations, according to Kruskal-Wallis test

< — less than

Figure 24. Median and range of dissolved nitrate, total nitrogen, dissolved ammonia, and total phosphorus concentrations at five sites in the Hudson River basin in eastern New York and adjacent States, by land use, 1970-90.



Base from U.S. Geological Survey digital data 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29° 30' and 45° 30', central meridian -74°

Figure 25. Locations of surface-water sites from which data were available for basinwide comparison of nutrient concentrations. (Site names are given in table 13).

Table 13. Sites used for basinwide comparison of median nutrient concentrations.

[DN = dissolved nitrate, TN = total nitrogen, TP = total phosphorus. Site locations are shown in fig. 25]

Site no.	Site Name	Land Use	Nutrients for which data are available
1	Hudson River at North Creek N.Y.	Forest	DN,TN,TP
2	Schroon River at Riverbank N.Y.	Forest	DN,TP
3	East Branch Sacandaga River at Griffin N.Y.	Forest	DN,TN,TP
4	Sacandaga River at Hadley N.Y.	Forest	DN,TN,TP
5	Hudson River at Corinth N.Y.	Forest	DN,TN,TP
8	Batten Kill at Middle Falls N.Y.	Agricultural	DN,TN,TP
10	Clover Mill Brook on Shaw Hill Rd near Rock City Falls N.Y.	Forest	DN,TN,TP
11	Kayaderosseras Creek at Saratoga Springs N.Y.	Agricultural	DN,TN,TP
14	Hoosic River at North Petersburg N.Y.	Urban	DN,TN,TP
15	Hoosic River at Eagle Bridge N.Y.	Mixed	DN,TN,TP
16	Hudson River at Waterford N.Y.	Mixed	DN,TN
17	Mohawk River near Utica N.Y.	Agricultural	DN,TN
18	Utica Water Supply Intake on West Canada Creek N.Y.	Forest	DN,TN,TP
19	Cayadutta Creek at Fonda N.Y.	Mixed	DN,TN,TP
20	Mohawk River above State Highway 30 at Fonda N.Y.	Agricultural	DN,TN,TP
23	Schoharie Creek at Breakabeen N.Y.	Mixed	DN,TN,TP
25	Schoharie Creek at Burtonsville N.Y.	Agricultural	DN,TN,TP
32	Esopus Creek at Shandaken N.Y.	Forest	DN,TN,TP
33	Hollow Tree Brook at Lanesville N.Y.	Forest	DN
34	Esopus Creek at Saugerties N.Y.	Forest	DN,TN,TP
35	Rondout Creek above Red Brook at Peekamoose N.Y.	Forest	DN
37	Wallkill River at Outflow of Lake Mohawk at Sparta N.J.	Urban	DN,TN,TP
38	Wallkill River at Franklin N.J.	Urban	DN,TN,TP
39	Wallkill River near Sussex N.J.	Mixed	DN,TN,TP
40	Papakating Creek at Sussex N.J.	Agricultural	DN,TN,TP
41	Black Creek near Vernon N.J.	Mixed	DN,TN,TP
42	Wallkill River near Rosendale N.Y.	Agricultural	DN,TN,TP
44	Twaalfskill near Highland N.Y.	Agricultural	DN,TN,TP
45	Wappinger Creek near Wappingers Falls N.Y.	Agricultural	DN,TN,TP
47	Fishkill Creek at Beacon N.Y.	Mixed	DN,TN,TP
48	Moodna Creek near New Windsor N.Y.	Mixed	DN,TN,TP
56	Winebrook Hills Plant Intakeon Hudson River N.Y.	Forest	DN,TN,TP

Median nutrient concentrations generally increase with increasing population density at sites representing watersheds with a population less than 250 per mi^2 (fig. 27). Although the median nutrient concentrations for watersheds with a population density exceeding 300 per mi^2 appear to be lower than those for watersheds with intermediate population densities (150 to 250 per mi^2), only six watersheds have a population density greater than 300 per mi^2. Four of the six sites with population density in excess of 300 per mi^2 are in the upper reaches of the Wallkill River (in northern New Jersey), where the low nutrient concentrations are probably the result of land use, hydrologic or geologic conditions, or use of non-USGS analytical methods. The available data are insufficient for estimation of

Table 14. Spearman nonparametric correlation coefficients for correlation of basinwide median nutrient concentrations with land use and population density.

[Number in parentheses is significance level. Coefficient for population density is based on sites with dissolved nitrate analyses.]

Basin characteristic	Spearman non-parametric correlation coefficient with basin characteristic			
	Dissolved Nitrate	Total Nitrogen	Total Phosphorus	Population density
Percent urban	0.31 (0.083)	0.73 (<0.01)	0.76 (<0.01)	0.95 (<.01)
Percent agricultural	0.63 (<0.01)	0.66 (<0.01)	0.74 (<0.01)	0.62 (<0.01)
Percent forested	-0.47 (<0.01)	-0.76 (<0.01)	-0.77 (<0.01)	-0.87 (<.01)
Population density	0.38 (0.033)	0.76 (<0.01)	0.79 (<0.01)	-

median nutrient concentrations for watersheds with population densities greater than 300 per mi^2.

A comparison of median nutrient concentrations for the six selected sites that have daily discharge records – Mohawk River at Fonda, Wappinger Creek at Wappinger Falls, Esopus Creek at Shandaken, East Branch of the Sacandaga River at Griffen, Hoosic River below Williamstown (for dissolved nitrate and total phosphorus), and Hoosic River at North Petersburg–with medians for sites used in the basinwide comparison indicates that the median nutrient concentrations for the six sites are generally representative of the entire basin. Both groups of sites show the same general trend of increasing dissolved nitrate, total nitrogen, and total phosphorus concentrations with increasing population density.

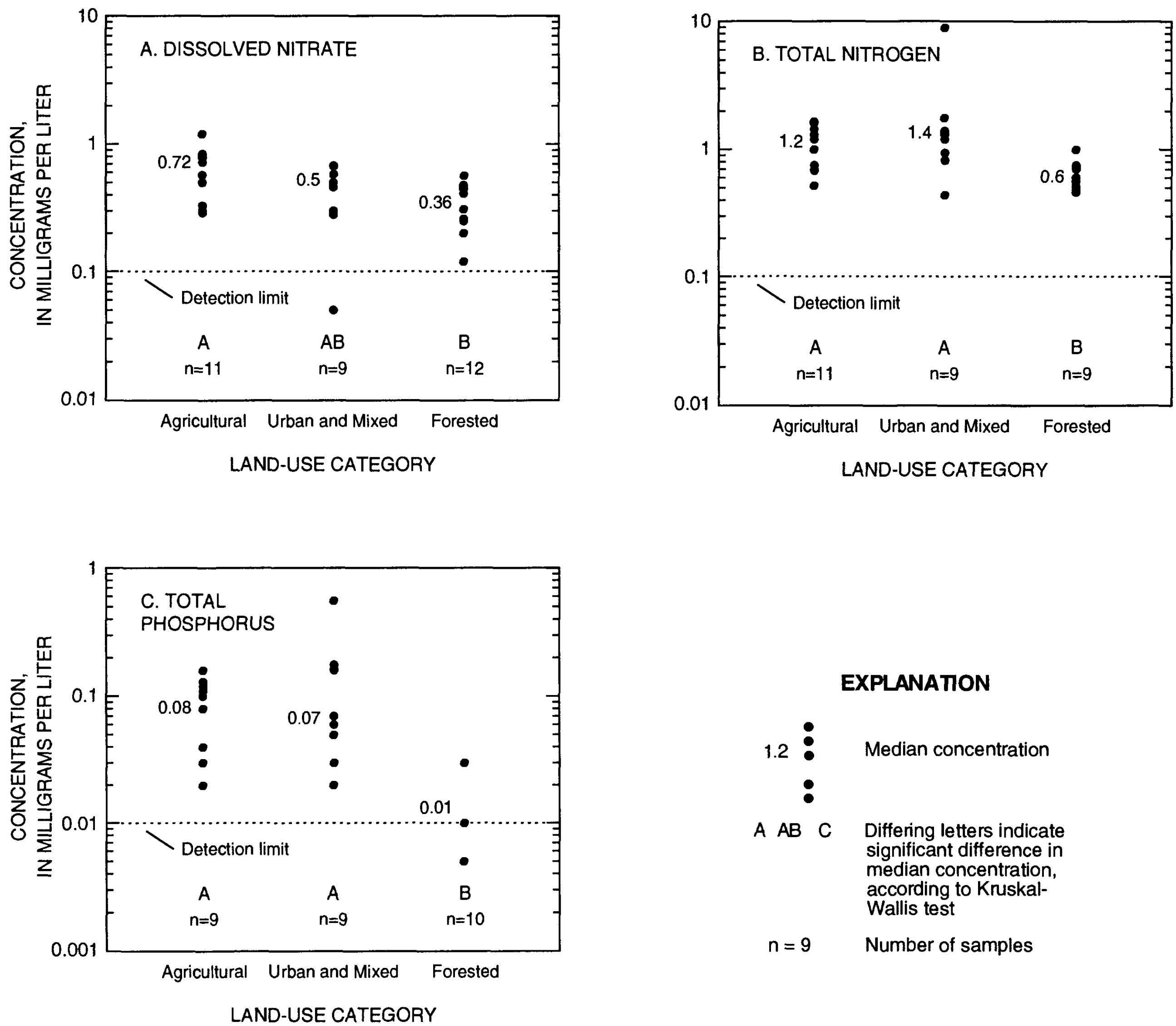


Figure 26. Range of dissolved nitrate, total nitrogen, and total phosphorus concentrations among sites grouped by land use for basinwide comparison.

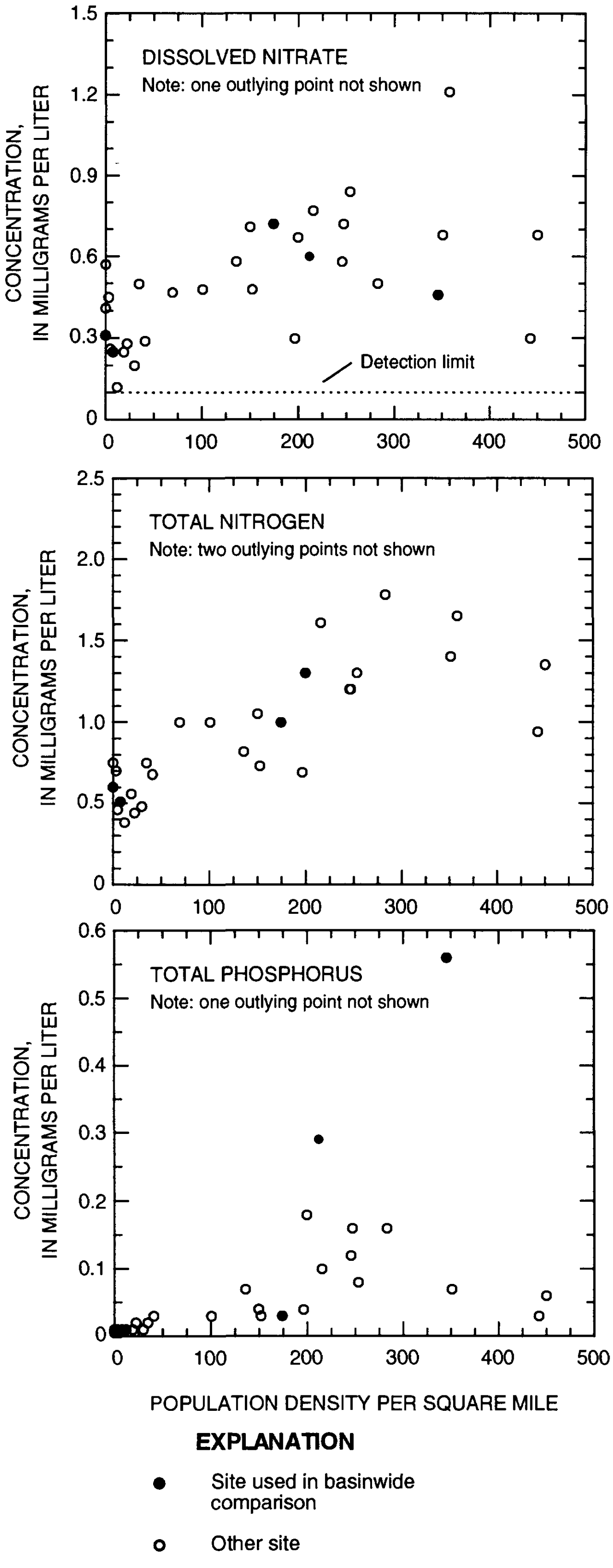


Figure 27. Median concentration of dissolved nitrate, total nitrogen, and total phosphorus in relation to watershed population at surface-water sites in the Hudson River basin.

Yields

Nitrogen and phosphorus yields (mass per unit area) from watersheds were calculated and related to the rates of inputs to illustrate the major patterns of nutrient movement through the Hudson River basin. The effects of treated wastewater, agricultural, and atmospheric sources on nutrient yield also were evaluated. Average annual yields were calculated for 16 sites from data collected during 1970-80; additional yield estimates were also calculated for three of these sites from data collected during 1981-1990 (table 15, fig. 28). The yields discussed here are based on the averages for 3 years–one in which the annual mean flow was ranked in the upper 10 percent of all annual mean flows, one in which the annual mean flow was equal to the long-term mean annual flow, and one in which the annual mean flow was ranked in the lower 10 percent of all annual mean flows. The discussion is based largely on yields calculated for 1970-80 because nearly all the data were collected during this period. Two yields were calculated for the three sites with data collected during 1970-90; the first is based on data collected during 1970-80, the second on data collected during 1981-90. The yield reported for 1970-80 for site 25 (Schoharie Creek at Burtonsville) is based on samples collected during 1970-90; the additional samples collected at this site from 1981-90 were needed to ensure a sufficient number of samples for computation of yields.

Yields generally are calculated from data representing a wide range of flow conditions, including high flows. Nearly all of the yields presented here are based on data sets representing four or more samples collected during a flow with an exceedence probability of less than 10 percent; most estimates include samples collected in the upper 1 percent of flow duration (table 15). The estimates for most sites are based on 20 or more samples, and the standard errors of rate estimate are generally less than 25 percent (tables 15, 16). One exception is site 23 (Schoharie at Breakabeen), at which all the standard errors of prediction exceed 25 percent (table 16); therefore, the estimated yields for this site were used only for comparison with a downstream site (site 25, Schoharie Creek at Burtonsville). Similarly, the estimated yields for site 20 (Mohawk at Fonda) are based on only 13 samples collected during 1981-90, but they allow some comparison with the yields calculated for this site from 1970-80 data.

Table 15. Number and flow characteristics of samples used to calculate average annual yields.
[Site locations are shown in fig. 28.]

Site Number	Constituent	Number of Samples: Total	Number of Samples: Representing discharge exceeded less than 10 percent of time	Exceedence Probability for samples representing: Maximium Discharge	Exceedence Probability for samples representing: Minimum Discharge	Years: Of sample collection	Years: Used in computation of transport rates
A. DATA BASED ON 1970-80 SAMPLING							
5	Dissolved nitrate	66	12	.68	83	1970-75	1978, 75, 81
	Total phosphorus	do.	do.	do.	do.	do.	do.
	Dissolved ammonium	49	9	do.	do.	do.	do.
6	Total nitrogen	60	15	.11	85	1972-78	1978, 75, 81
	Dissolved nitrate	69	19	do.	do.	do.	do.
	Total phosphorus	do.	do.	do.	do.	do.	do.
7	Total nitrogen	88	17	.38	85	1971-79	1978, 75, 81
	Dissolved nitrate	147	28	do.	do.	do.	do.
	Total phosphorus	145	27	do.	do.	do.	do.
	Dissolved ammonium	92	15	do.	do.	do.	do.
13	Dissolved nitrate	49	7	3.00	91	1970-74	1973, 77, 81
	Total phosphorus	do.	do.	do.	do.	do.	do.
14	Total nitrogen	40	5	.52	92	1971-75	1973, 77, 81
	Dissolved nitrate	103	17	.25	91	do.	do.
	Total phosphorus	100	16	.52	do.	do.	do.
16	Total nitrogen	101	29	.38	99.8	1977-80	1978, 82, 81
	Dissolved nitrate	do.	do.	do.	do.	do.	do.
	Total phosphorus	do.	do.	do.	do.	do.	do.
20	Total nitrogen	37	5	.11	92	1971-75	1978, 89, 88
	Dissolved nitrate	67	9	do.	94	1970-75	do.
	Total phosphorus	do.	do.	do.	do.	do.	do.
23	Total nitrogen	24	4	0.36	98.7	1971-76	1979, 76, 81
	Dissolved nitrate	29	6	0.24	do.	1974-76	do.
	Total phosphorus	24	4	0.36	do.	do.	do.
25	Total nitrogen	32	6	0.92	99.9	1971-90	1978, 70, 81
	Dissolved nitrate	do.	8	do.	do.	do.	do.
	Total phosphorus	29	6	0.90	do.	1970-90	do.
26	Total nitrogen	80	12	1.80	93	1973-79	1978, 70, 81
	Dissolved nitrate	do.	do.	do.	do.	do.	do.
	Total phosphorus	do.	do.	do.	do.	do.	do.
27A	Total nitrogen	108	10	0.62	98	1971-78	1978, 83, 81
	Dissolved nitrate	169	24	do.	do.	do.	do.
	Total phosphorus	168	do.	do.	do.	do.	do.
	Dissolved ammonium	97	17	do.	do.	do.	do.
28	Total nitrogen	87	16	0.65	97	1970-80	1978, 83, 81
	Dissolved nitrate	118	21	do.	98	do.	do.
	Total phosphorus	116	20	do.	do.	do.	do.
	Dissolved ammonium	58	9	2.00	97	do.	do.
32	Dissolved nitrate	125	13	1.70	99	1970-80	1972,71,81
	Total phosphorus	121	10	2.50	do.	do.	do.

Table 15. Number and flow characteristics of samples used to calculate average annual yields (cont.).

Site Number	Constituent	Number of Samples: Total	Number of Samples: Representing discharge exceeded less than 10 percent of time	Exceedence Probability for samples representing: Maximium Discharge	Exceedence Probability for samples representing: Minimum Discharge	Years: Of sample collection	Years: Used in computation of transport rates
42	Total nitrogen	21	2	5.6	88.5	1971-75	1972, 71, 81
	Dissolved nitrate	32	do.	.53	do.	1970-75	do.
	Total phosphorus	33	5	do.	do.	do.	do.
43	Total nitrogen	22	1	10.0	90.91	1971-75	1972, 71, 81
	Dissolved nitrate	30	4	.50	do.	do.	do.
	Total phosphorus	30	do.	do.	do.	do.	do.
45	Total nitrogen	36	6	1.33	86.3	1971-75	1975, 82, 81
	Dissolved nitrate	71	14	1.15	do.	1969-75	do.
	Total phosphorus	66	11	1.33	do.	do.	do.
B. DATA	**BASED ON 1981-90 SAMPLING**						
20	Total nitrogen	13	7	.45	98	1988-90	1978, 89, 88
	Dissolved nitrate	do.	do.	do.	do.	do.	do.
28	Total nitrogen	42	5	.65	96	1981-90	1978, 83,81
	Dissolved nitrate	do.	do.	do.	do.	do.	do.
	Dissolved ammonium	do.	do.	do.	do.	do.	do.
	Total phosphorus	do.	do.	do.	do.	do.	do.
32	Total nitrogen	45	4	6.7	99	1981-90	1972, 71, 81
	Dissolved nitrate	54	7	1.1	do.	do.	do.
	Total phosphorus	45	4	6.7	do.	do.	do.
	Dissolved ammonium	46	do.	do.	do.	do.	do.

The relations among average annual yield and watershed characteristics indicate that nutrient yield is a function of agricultural land use and population density. Average annual yields of dissolved nitrate, total nitrogen, and total phosphorus based on 1970-80 data generally increase with increasing percent agricultural area and with increasing population density (fig. 29, p. 59). The highest average annual nutrient yields were in watersheds with the largest amount of agricultural land and the highest population densities, including sites 20 (Mohawk River at Fonda), 13 (Hoosic River below Williamstown, Mass.), 14 (Hoosic River at North Petersburg), and 42 (Wallkill River at Rosendale). The calculated average annual yields at these four sites exceed 3,200 lb/mi^2 for dissolved nitrate, 4,200 lb/mi^2 for total nitrogen, and 450 lb/mi^2 for total phosphorus (table 16). Sites 20 and 42 are more than 34 percent agricultural, and sites 13, 14, and 42 have population densities exceeding 180/mi^2

The lowest nutrient yields were in forested watersheds that are less than 5 percent agricultural— sites 5,6, 7, and 32 (fig. 28) and the two watersheds on Schoharie Creek – sites 23 (mixed) and 25 (agricultural). The calculated average annual yields of dissolved nitrate at all six of these sites were less than 1,700 lb/mi^2, and the yields for total nitrogen were generally less than 3,400 lb/mi^2. Total phosphorus yields for sites 5, 6, 7 and 32 were less than 150 lb/mi^2, and those for sites 23 and 25 were higher (396 and 231 lb/mi^2, respectively). The average annual dissolved nitrate and total nitrogen yields for sites 23 and 25 were lower than expected (fig. 29A), possibly because these sites are downstream of Prattsville Reservoir, where much of the flow in Schoharie Creek is diverted to Esopus Creek; the low nutrient yields at these two sites could be due to water export and smaller discharge per basin area than at other sites.

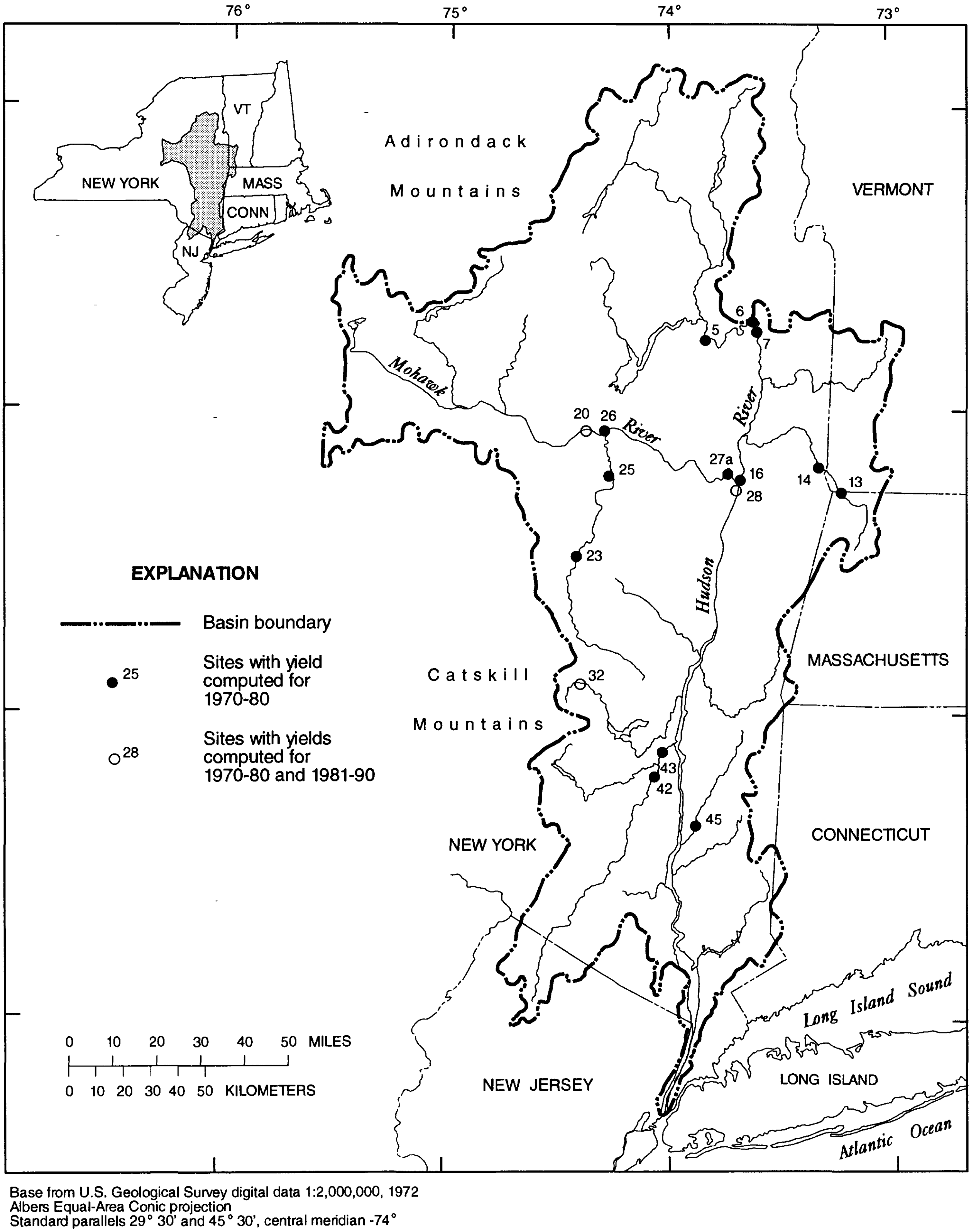
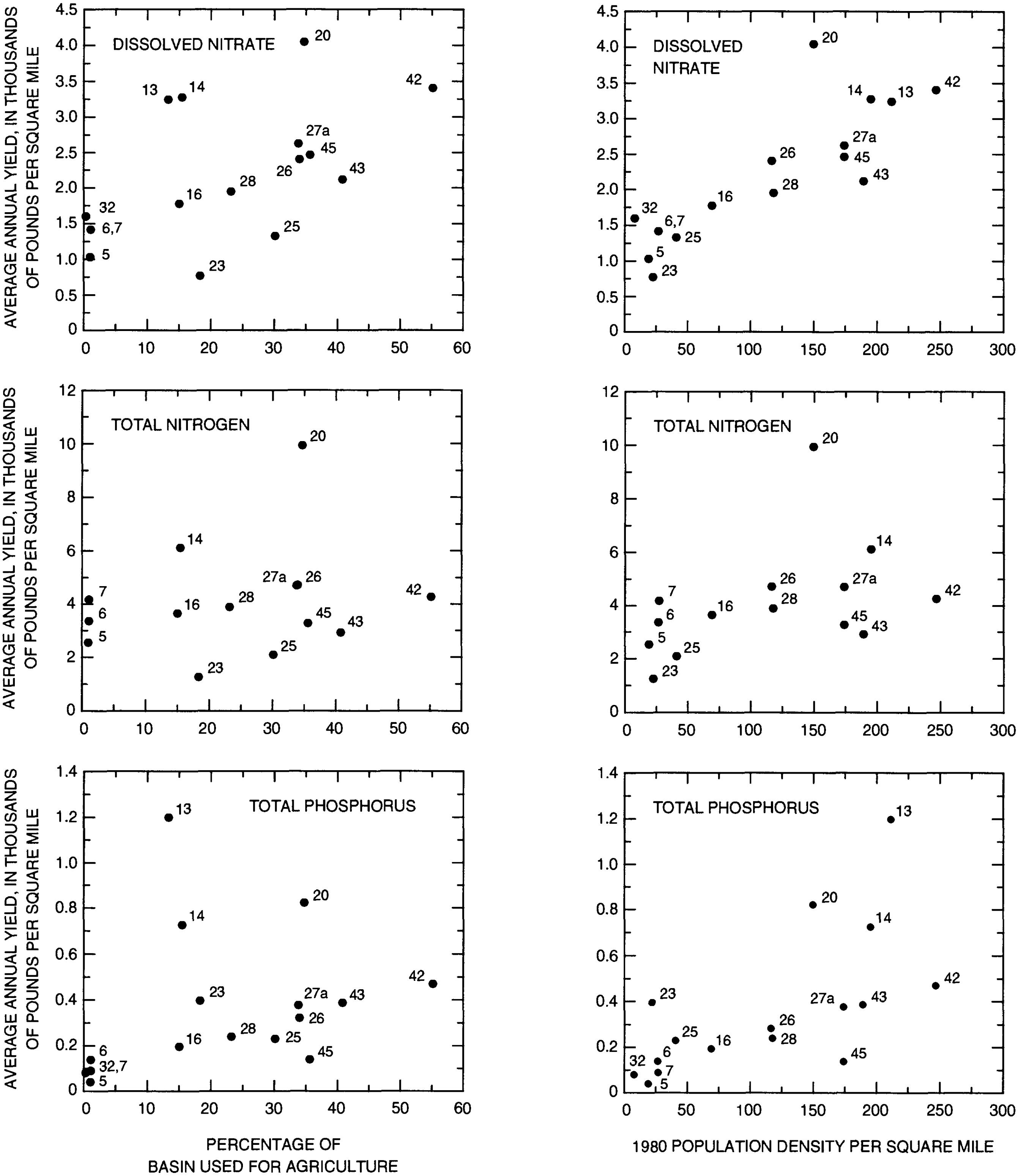


Figure 28. Locations of surface-water sites for which nutrient yields in 1970-80 and 1981-90 were computed. (Site names are listed in table 5.)



EXPLANATION

● 25 SAMPLING SITE AND NUMBER names are listed in table 5 and locations are shown in figure 28

Figure 29. Nutrient yield as a function of agricultural land use and population density in Hudson River basin watersheds.

The range of dissolved nitrate, total nitrogen, and dissolved ammonia yields indicates that dissolved nitrate and ammonia can account for half to three-quarters of the total nitrogen load (right column in table 16). Total organic nitrogen yields, estimated as total nitrogen minus the inorganic component (dissolved nitrate and dissolved ammonium) range from 431 lb/mi^2 at site 5 (Hudson River at Corinth) to 4,230 lb/mi^2 at site 20 (Mohawk River at Fonda). The organic nitrogen yield represents 26 to 43 percent of the total nitrogen yield at sites for which organic nitrogen yield was estimated; the total organic nitrogen component likely represents algae and other particulate organic matter. Although the high error of estimate associated with the dissolved ammonia yields (table 16) indicates that the actual organic nitrogen yield could be as much as 20 percent higher or lower than these estimates, these patterns indicate that organic nitrogen is an important part of the total nitrogen budget in the Hudson River basin. Published investigations of nitrogen cycling in the Hudson River basin, such as Murdoch and Stoddard (1992) and Howarth and others (1991), emphasized only dissolved nitrate, however, and might not accurately reflect total nitrogen yield.

Nutrient Inputs. Nutrient inputs were calculated for the 16 watersheds that contain sites for which nutrient yields were available, to relate nutrient yields to their principal sources in each watershed. The sources used in this analysis were fertilizer, manure, atmospheric deposition and treated waste-water. The calculated inputs do not represent the actual amounts of nutrients reaching the stream but, rather, the amount applied to each watershed. Not all of the amount applied to a

Table 16. Annual nutrient yields and standard errors of estimate at sites for which data are adequate for analysis, 1970-90.
[Site locations shown in fig. 28. Yields are in thousands of pounds per square mile. Standard errors are in percent. Dash indicates no data.]

	Constituent								
	Dissolved nitrate		Total nitrogen		Total phosphorus		Dissolved ammonia		
Site Number	Annual Yield	Standard Error	Annual Yield	Standard Error	Annual Yield	Standard Error	Annual Yield	Standard Error	Ratio of organic yield[1] to total nitrogen yield
A. DATA BASED ON 1970-80 SAMPLING									
5	1.03	6.23	2.54	6.98	0.0410	7.63	0.431	18.1	0.416
6	1.42	6.40	3.36	5.94	.138	15.00	-	-	-
7	1.42	6.63	4.18	4.59	.0901	7.30	1.47	17.7	.310
13	3.24	19.80	-	-	1.20	15.90	-	-	-
14	3.28	7.91	6.12	8.03	.727	10.10	-	-	-
16	1.78	4.85	3.65	3.74	.195	8.74	-	-	-
20	4.05	7.30	9.94	9.40	.822	12.30	1.66	20.3	.426
23	.77	28.80	1.26	32.60	.396	50.10	-	-	-
25	1.33	14.60	2.09	11.90	.231	35.50	-	-	-
26	2.40	6.42	4.72	4.39	.284	10.90	-	-	-
27a	2.62	6.49	4.71	4.60	.377	6.51	.869	14.8	.258
28	1.95	4.11	3.90	4.20	.240	9.62	.829	22.3	.289
32	1.60	13.30	-	-	.0813	23.20	-	-	-
42	3.40	21.70	4.27	16.50	.471	10.90	-	-	-
43	2.12	13.00	2.92	10.80	.386	10.80	-	-	-
45	2.46	6.56	3.27	7.41	.138	17.10	-	-	-
B. DATA BASED ON 1981-90 SAMPLING									
20	3.39	10.20	5.42	21.80	-	-	-	-	-
28	2.24	10.40	4.42	6.58	.199	12.10	.439	13.4	.384
32	1.89	15.20	3.75	28.90	.0901	43.30	.0958	33.4	.470

1 Organic nitrogen calculated as total nitrogen yield minus dissolved nitrate yield minus total ammonia yield.

watershed reaches the stream because many processes can interfere. For example, nitrogen can be lost through the volatilization of ammonium in manure and fertilizer; also nitrogen and phosphorus can be lost through uptake by plants and through storage in organic debris or stream sediment. The proportion of nutrient input to the watershed that enters a stream is probably greater for treated wastewater than for other sources. Estimates of nutrient inputs from the several sources are useful in defining the relative importance of each source in a given watershed.

The largest annual inputs of nitrogen (exceeding 12,800 lb/mi^2) and phosphorus (exceeding 3,000 lb/mi^2) are in agricultural areas along the Mohawk River (sites 20, 26, 27A) and on the Wallkill River (site 42); about three-quarters of the nitrogen and phosphorus inputs in these areas are derived from fertilizer and manure (table 17; fig. 30). The input rates for nitrogen and phosphorus in the other two agricultural watersheds (sites 25 and 45, on Schoharie Creek and Wappinger Creek, respectively) are somewhat lower than those along the Mohawk River and Wallkill Rivers, but the predominant sources of nutrients at these sites are still derived from agricultural activities.

In contrast, forested watersheds in the upper Hudson River basin that drain the Adirondack Mountains–the Hudson River at Corinth (site 5), Hudson River at Glens Falls (site 6), and Hudson River at Fort Edward (site 7)–have the lowest nitrogen input rates (less than 3,200 lb/mi^2) and phosphorus (less than 130 lb/mi^2) of the 16 sites for which yields were calculated (table 17 and fig. 30). More than 90 percent of the nitrogen input to these watersheds are from the atmosphere. Although the watershed above site 32, a forested watershed in the Catskill Mountains, has a higher nitrogen-input rate (875 lb/mi^2) than the Adirondack watersheds (sites 5, 6, and 7), more than 95 percent of the nitrogen input to this watershed is also from atmospheric deposition (table 17). Estimates of phosphorus inputs indicate that, for these forested watersheds, the predominant source of phosphorus can be either agricultural areas or treated wastewater.

Nitrogen and phosphorus input rates for the two urban watersheds (Hoosic River sites 13 and 14) are more than 9,500 lb/mi^2 and 210 lb/mi^2, respectively (fig. 30; table 17). Most of the nitrogen inputs in these watersheds are derived is from a combination of atmospheric and agricultural sources. The urban sites are the only ones where more than 15 percent of the nitrogen inputs and 50 percent of the phosphorus inputs are derived from treated wastewater (fig. 30, table 17).

Watersheds above sites with mixed land use (sites 16, 23, 28, and 43) have a wide range of nitrogen inputs (6,100 to 10,000 lb/mi^2) and phosphorus inputs (about 1,000 to 2,640 lb/mi^2) (fig. 30, table 17). The predominant source of nitrogen at all sites but 23 (Schoharie Creek at Breakabeen) is agricultural activities; at site 23, the predominant source is atmospheric deposition (table 17). Atmospheric deposition is also an important source of nitrogen at site 16 (Hudson at Waterford) and site 28 (Hudson River at Green Island) – 42 and 27 percent of total nitrogen input, respectively (fig. 30). The predominant source of phosphorus input to these sites is agriculture; treated wastewater contributes less than 25 percent (fig. 30).

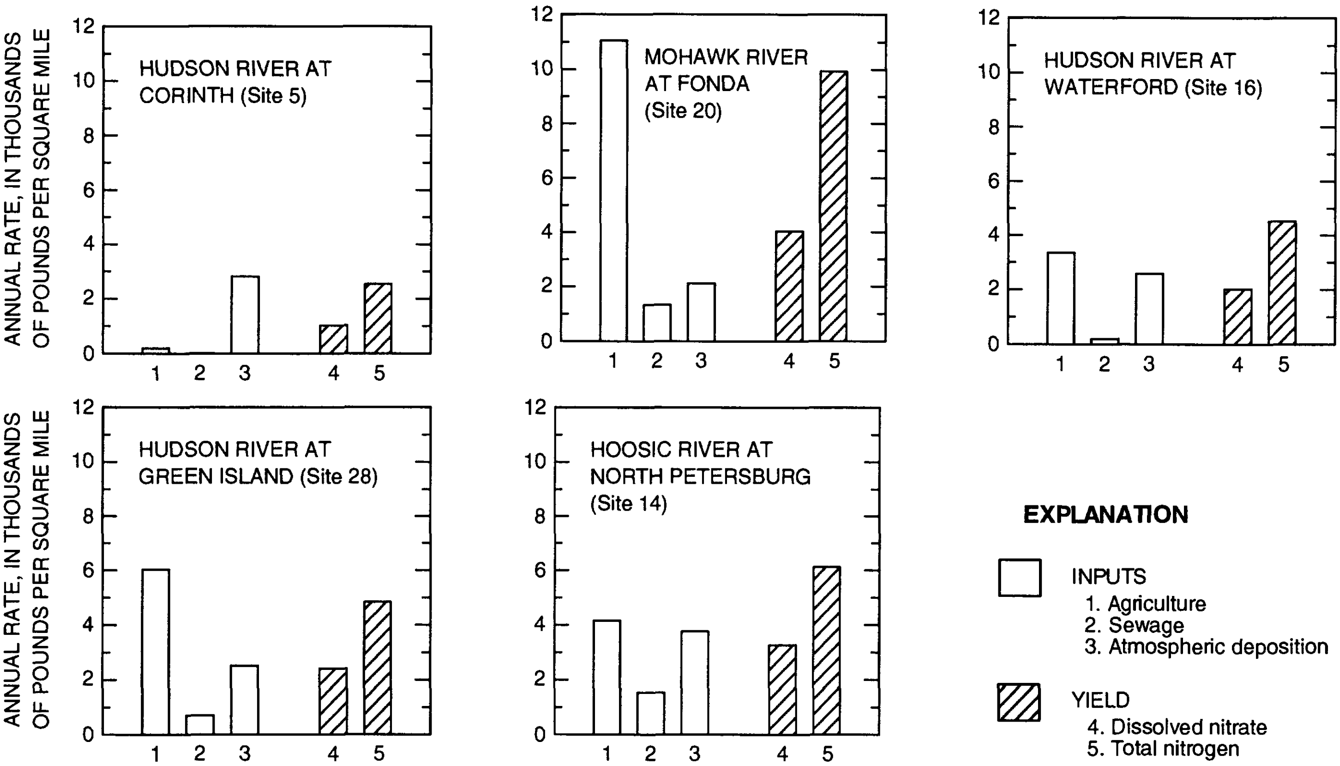
These results indicate that the nutrient inputs to the two largest nontidal tributaries to the Hudson River (sites 28, Hudson River at Green Island and 43, Rondout Creek at Eddyville) are largely derived from nonpoint agricultural sources. Although considerable error is likely in the estimates of nitrogen and phosphorus inputs, the high percentage of nitrogen derived from agriculture and atmospheric deposition (greater than 90 percent) indicate the importance of nonpoint sources of nutrients to large watersheds in the Hudson River basin. Patterns of nutrient input, by source for 1980-91, are similar to those for 1970-80 (table 17).

Ratios of nitrogen yield to nitrogen input can indicate (1) the fate of nitrogen inputs, or (2) whether nitrogen-input estimates are accurate. Any comparison of yield with input rate for a given watershed should be qualified by the statistical errors associated with each. Despite the potential for error, some general patterns are evident from these ratios: (1) ratios of total-nitrogen yields to input rates greater-than 0.8 are generally restricted to forested watersheds in the Upper Hudson River basin (sites 5, 6, and 7), and (2) ratios less than 0.3 are limited to the two sites on Schoharie Creek (site 23, mixed land use and site 25, agricultural). The high yield-to-input ratios at sites 5, 6, and 7 could indicate that input rates for these sites are underestimated–partly through underestimation of industrial discharges of nutrients into the Hudson River in the Glens Falls and Fort Edward vicinity, and partly through underestimation of nitrogen input from atmospheric deposition, because the

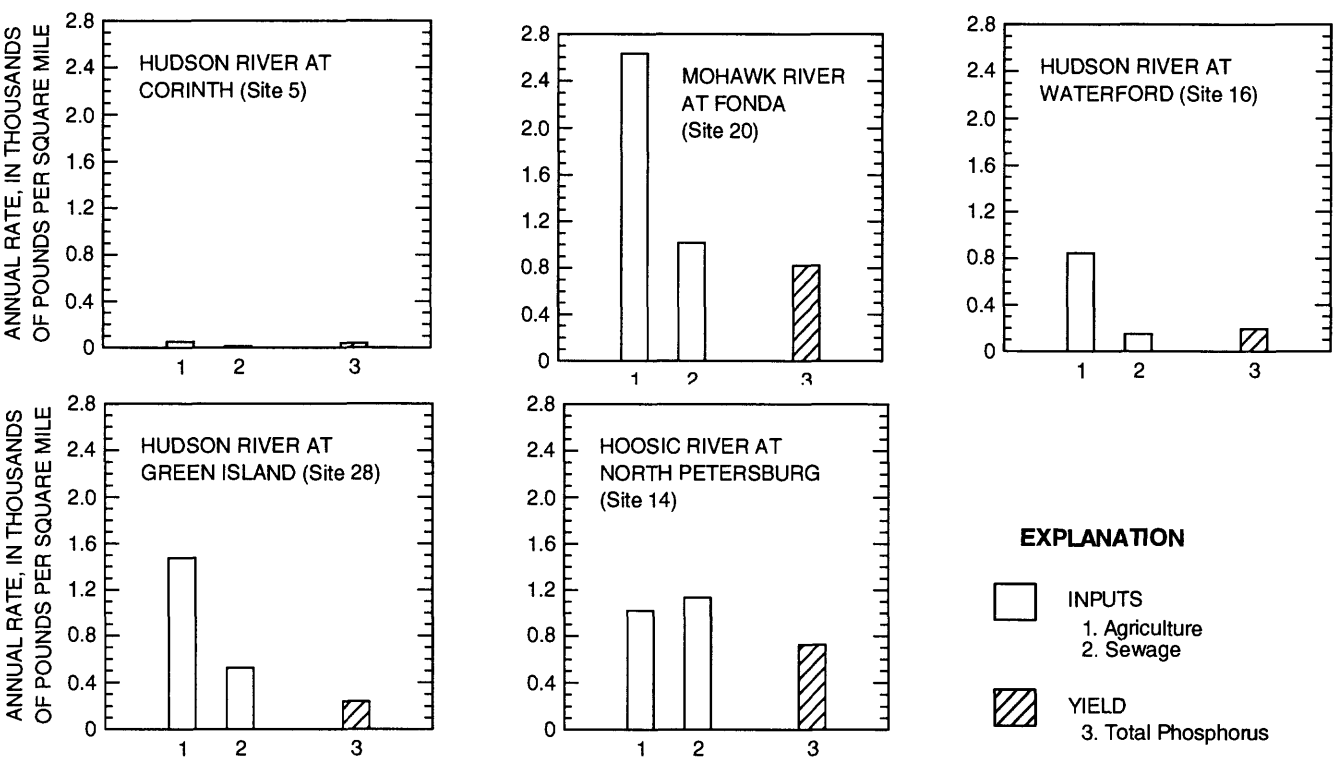
Table 17. Average annual nitrogen and phosphorus inputs, source of input, average annual yield, and ratio of yield to total input for sites in the Hudson River basin for which sufficient data are available for analysis.

[Input rates and yields are in thousands of pounds per square mile. Dashes indicate no value calculated. Site locations are shown in fig. 28]

Site No.	Average Yearly total input	Source of input, in percent: Fertilizer	Manure	Treated wastewater	Atmospheric deposition	Average Annual Yield	Ratio of yield to total input
A. BASED ON 1970-80 DATA							
Nitrogen							
5	3.01	2.20	4.07	0.553	93.2	2.54	0.844
6	3.03	2.23	4.12	1.09	92.6	3.37	1.11
7	3.10	2.25	4.13	3.09	90.5	4.18	1.35
13	10.1	19.2	20.7	17.8	42.4	-	-
14	9.51	19.8	24.0	16.5	39.7	6.12	0.643
16	6.14	19.1	35.6	3.30	42.0	3.65	0.595
20	14.6	23.3	52.5	9.70	14.6	9.94	0.681
23	9.59	12.4	30.3	2.56	54.8	1.26	0.132
25	9.78	20.3	46.5	1.85	31.4	2.09	0.214
26	13.4	23.1	51.9	7.73	17.3	4.72	0.352
27A	13.5	22.3	49.3	10.3	18.2	4.71	0.350
28	9.27	21.1	44.0	7.70	27.2	3.90	0.421
32	8.90	0.516	0.412	1.67	97.4	-	-
42	12.9	35.8	48.0	5.15	11.1	4.27	0.332
43	10.0	33.9	45.7	4.87	15.5	2.92	0.291
45	8.26	36.6	51.1	1.24	11.1	3.28	0.397
Phosphorus							
5	0.0615	45.2	34.9	19.9	-	0.0410	0.666
6	0.0746	38.1	29.4	32.5	-	0.138	1.85
7	0.122	24.0	18.4	57.6	-	0.0901	0.738
13	2.30	26.5	16.4	57.1	-	1.120	0.521
14	2.17	28.2	18.8	53.0	-	0.727	0.334
16	0.994	48.7	36.3	15.0	-	0.195	0.196
20	3.67	38.7	33.0	28.3	-	0.822	0.224
23	1.18	42.4	42.3	15.3	-	0.396	0.336
25	1.74	47.7	44.7	7.66	-	0.231	0.133
26	3.18	40.9	35.2	24.0	-	0.284	0.089
27	3.34	37.6	32.0	30.5	-	0.377	0.113
28	2.00	40.7	33.1	26.2	-	0.240	0.120
32	0.137	14.1	6.48	79.5	-	0.0813	0.592
42	3.50	53.0	33.1	13.9	-	0.471	0.135
43	2.64	52.3	34.1	13.6	-	0.386	0.146
45	2.09	60.6	35.8	3.60	-	0.138	0.0660
B. BASED ON 1981-90 DATA							
Nitrogen							
20	14.6	27.7	47.8	9.94	14.6	5.42	0.372
28	9.26	25.3	39.6	7.90	27.2	4.42	0.477
32	8.90	0.576	0.368	1.71	97.4	3.75	0.421
Phosphorus							
28	1.977	43.44	30.02	26.54	-	0.1988	0.101
32	0.136	13.90	5.995	80.10	-	0.0901	0.662



A. NITROGEN



A. PHOSPHORUS

Figure 30. Annual nutrient inputs and yield at five sites in the Hudson River basin, N.Y., as calculated from samples collected during 1970-80. A. Nitrogen. B. Total phosphoorus.

ratio for the uppermost site (site 5, Hudson River at Corinth, above Glens Falls and Fort Edward) also is high. The high yield-to-input ratios at these forested sites could also be due to the failure of the forest ecosystem in these watersheds to retain atmospherically deposited nitrogen–a phenomenon known as nitrogen saturation (Murdoch and Stoddard, 1992). Nitrogen saturation is avoided in other watersheds, particularly those dominated by agriculture, by the removal of nitrogen through the harvest of plant or animal matter. The rate of plant or animal harvest at these three forested sites is presumably much less than at the other sites, thus, nitrogen saturation is possible.

Most of the forested sites have a high ratio of phosphorus yield to input (greater than 0.55). This could indicate underestimation of phosphorus-input rates; one reason could be the omission of input from geologic sources.

The two sites with the lowest ratios of nitrogen yield to input (less than 0.22) were on Schoharie Creek sites (sites 23 and 25) (table 17). The low ratios could be due to the export of water from the upper 215 mi^2 (35 percent) of the watershed, which significantly decreases the flow at sites 23 and site 25. For example, the mean annual flow at Schoharie Creek at Prattsville above the diversion at the Schoharie Reservoir for 1950-92 was 1.98 $(ft^3/s)/mi^2$, whereas the flow of Schoharie Creek at Burtonsville, below the diversion, is only 1.19 $(ft^3/s)/mi^2$, or 40 percent less than at Prattsville. Because the transport of nutrients is controlled to a large degree by discharge, the low nitrate and total nitrogen yields and low ratio of yield to input for sites 23 and 25 could be attributable to the diversion of water. The decreased discharge could also result in greater storage of nutrients in the flood plain of Schoharie Creek and increased uptake by plants. The ratios of phosphorus yield to input for the two Schoharie Creek sites are below 0.4, which is not significantly lower than that for other sites.

Although the nitrogen yields for the two Schoharie Creek sites (23 and 25) seem consistent with the population densities of this watershed, the low ratio of yield to input indicates that the correlation between population density and yield may be weaker than indicated by the scatterplot in figure 29. Because agricultural activities are the major sources of nutrient inputs to streams in the Hudson River basin, the close relation between population density and nutrient yields indicated by these plots could be spurious. Many of the sites lie along the mainstem of the Hudson River (sites 5, 6,7, 16 and 28); thus, the apparent correlation between nutrient yield and population density could largely reflect conditions along the mainstem, not the smaller tributaries.

Mass Balance. Mass-balance calculations were done for nine sites as a check of nutrient yields; results indicate that much of the mass of nutrients transported from the combined drainages of the upper Hudson and Mohawk River subbasins (represented at site 28, Hudson River at Green Island) is derived from the upper 2,100 mi^2 drainage of the Mohawk River basin (site 20). The mass balances are based on yields calculated for 1977- 81, the only 5-year period before 1982 with yield data available for the outlet of the Upper Hudson River basin (Hudson River at Waterford, site 16). Mean annual flows for this period at all sites were equal to or greater than mean annual flows for the 30-year period 1960-89; therefore, the yields for 1977-81 also are probably somewhat higher than average.

The sum of the mass of nutrients transported past the Mohawk River subbasin outlet (site 27A, Mohawk River at Crescent Dam) and the upper Hudson subbasin outlet (site 16, Hudson River at Waterford) is approximately equal to the total mass transported past site 28 (Hudson River at Green Island), just downstream from these sites. The mass of dissolved nitrate (17.2 million lb), total nitrogen (33.8 million lb), and total phosphorus (2.17 million lb) transported past sites 27A and site 16 during 1977-1981 is 5.5 percent, 3.7 percent, and 6.8 percent higher, respectively, than was transported past site 28 (table 18). These differences are similar to the standard error of estimate for the yields (table 16), indicating that the yields calculated for sites 16 and 27A are consistent with those calculated for site 28. In contrast, the average mass of nutrients transported past site 20 (Mohawk River at Fonda) during 1977-81 is significantly greater than was transported past site 26 (Mohawk River at Tribes Hill), 5 mi downstream. Site 26 is 0.3 mi downstream from Schoharie Creek; hence, the combined masses transported past site 20 and site 25 (Schoharie Creek at Burtonsville) should approximate the masses transported past site 26. However, the masses of dissolved nitrate (9.5 million lb), total nitrogen (21.8 million lb) and total phosphorus (1.94 million lb) calculated for site 20 are 21, 38, and 85 percent higher than the masses calculated for site 26 (7.85 million lb, 15.7 million lb, and 1.05 million lb, respectively). These differences are more than twice the standard error estimates (table 16); hence, either some storage or uptake of nutrients occurs in the 5-mi reach between Fonda and Tribes Hill, or the nutrient masses calculated for site 20 are overestimated.

Dissolved nitrate and total nitrogen yields for site 20 during 1981-90 are 16 percent and 45 percent less than those for 1970-80 (table 16); these differences exceed the standard error for 1981-90, suggesting that yields for 1970-80 are overestimated. One possible reason for the overestimate could be that the water samples collected at site 20 during 1970-80 were collected from a dock on the northern side of the Mohawk River, 0.2 mi downstream and on the same side as the mouth of Cayadutta Creek. From 1970-80 Cayadutta Creek had elevated nutrient concentrations caused by discharge of incompletely treated wastewater from sewage-treatment facilities (Bode and others, 1992). Thus, the elevated rates of nutrient transport past site 20 could reflect incomplete mixing of the two waters and a disproportionate amount of water from Cayadutta Creek. The 1981-90 samples probably are more representative of conditions in the Mohawk River because they were collected by multivertical sampling at a bridge 0.2 mi downstream from the previously used dock. Therefore, a corrected estimate of nutrient transport past site 20 was computed as the mass transported past site 25 minus the mass transported past site 26 (table 18).

Most of the nutrient mass transported past the outlet of the combined Upper Hudson and Mohawk River subbasins (site 28) are derived from the Mohawk subbasin. The mass of dissolved nitrate, total nitrogen, and total phosphorus transported at site 27A (Mohawk River at Crescent Dam) represents 58.3 percent, 50.9 percent, and 66 percent of the mass transported past site 28, even though the drainage area upstream from site 27A represents only 42 percent of the drainage area upstream from site 28.

Nutrient yields calculated for site 20 (the Mohawk River at Fonda, an agricultural watershed) represent a disproportionate amount of nutrients within the Mohawk River drainage. Although the drainage area upstream of this site represents only 26 percent of the drainage area upstream from site 28, the mass of dissolved nitrate (6.26 million lb), total nitrogen (13.3 million lb), and total phosphorus (0.728 million lb) transported past site 20 is 38 percent, 41 percent, and 36 percent of the corresponding masses transported past Green Island (site 28, table 18). The high nutrient-transport rates calculated for site 20 are most likely due to the high input rates of nitrogen and phosphorus in this watershed; 40 percent of the total nitrogen and 48 percent of the total phosphorus inputs in the watershed upstream from site 28 originated within the Mohawk River watershed above Fonda (site 20). These results are further evidence that agricultural sources contribute the bulk of nitrogen and phosphorus inputs to streams of the Hudson River basin.

Table 18. Average mass of nutrients transported at selected sites in the Upper Hudson and Mohawk River subbasins, 1977-80.

[Mass in millions of pounds. Numbers in parentheses are standard error of estimate, in percent. Discharges are in cubic feet per second. Dash indicates no data available. Site locations are shown in fig. 28. Mass value based on yields for samples collected during 1970-80].

Site no.	Constituent mass: Dissolved nitrate	Constituent mass: Total nitrogen	Constituent mass: Total phosphorus	Drainage area (square miles)	Mean annual discharge: 1960-89	Mean annual discharge: 1977-81
Upper Hudson Subbasin						
5	2.93 (6.78)	6.86 (7.02)	0.113 (7.89)	2,755	5,050	5,290
16	7.61 (4.85)	17.2 (3.77)	0.818 (8.81)	4,620	-	8,113
Mohawk Subbasin						
20	9.50 (9.91)	21.8 (10.7)	1.94 (16.1)	2,118	4,570	4,730
20*	6.26 -	13.3 -	0.728 -	2,118	4,570	4,730
25	1.59 (16.4)	2.37 (13.4)	0.322 (48.3)	886	1,060	1,270
26	7.85 (7.77)	15.7 (5.42)	1.05 (15.5)	3,090	-	-
27a	9.50 (7.74)	16.6 (5.31)	1.35 (7.50)	3,438	5,720	5,906
Upper Hudson-Mohawk Outlet						
28	16.3 (4.12)	32.6 (4.23)	2.03 (9.63)	8,090	13,600	14,500
Lower Hudson Subbasin						
43	2.54 (14.5)	3.28 (12.4)	0.483 (13.3)	1,150	1,610	1,690
45	0.478 (7.19)	0.622 (7.78)	0.0234 (15.3)	181	264	264

*Estimate for site 20 based on mass at site 26 minus mass at site 25

Suspended Sediment

Nutrients, organic compounds (including pesticides), and metals can sorb to suspended sediment and, therefore, can affect the transport of a wide variety of constituents. Suspended-sediment concentration and yields in the Hudson River basin are related to land use.

Concentration

The relation between suspended-sediment concentration and discharge varies spatially . For example, the sediment concentration-to-discharge relations for site 12 (Hudson River at Stillwater, a site typical of conditions in the Upper Hudson River basin) and from site 27B (Mohawk River at Cohoes) (fig. 31) show considerable scatter, but sediment concentration generally increases with discharge. Sediment concentrations at main-stem Hudson River sites are usually less than 10 mg/L when discharge is less than 10,000 ft^3/s but generally increase at an increasing rate to 50 mg/L at discharges of more than 35,000 ft^3/s (fig. 31). Sediment concentrations at site 27B (Mohawk River at Cohoes), by contrast, are generally 6 to 25 mg/L at discharges less than 10,000 ft^3/s but typically increase to more than 150 mg/L at discharges of 35,000 ft^3/s (fig. 31).

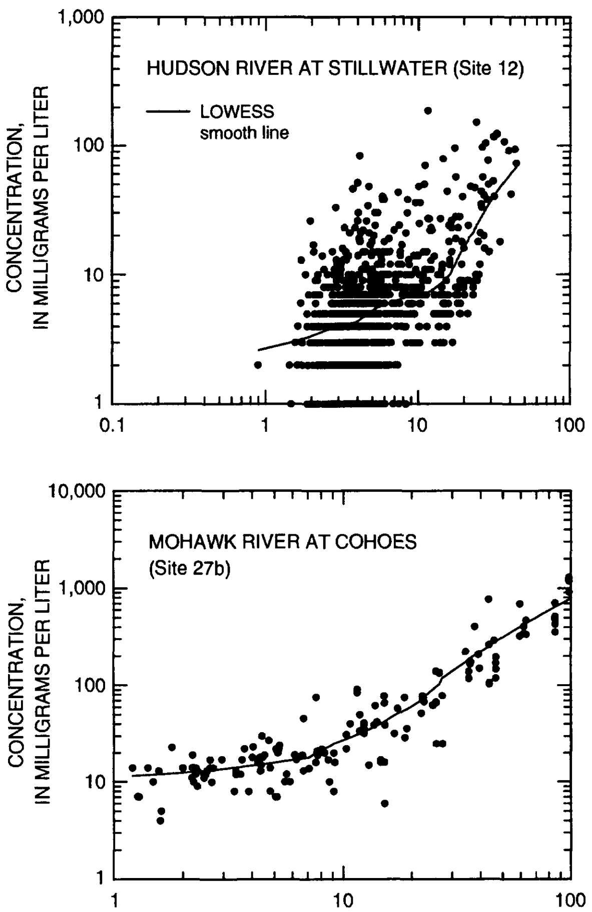


Figure 31. Suspended-sediment concentration as a function of discharge for Hudson River at Stillwater, N.Y., and Mohawk River at Cohoes, N.Y., 1970-90. (Locations are shown in fig. 12).

The lowest median suspended-sediment concentrations are at sites representing forested watersheds. For example, site 32 (Esopus Creek at Shandaken, in the Catskill Mountains) has the lowest median suspended sediment concentration (3.0 mg/L) of the eight sites with suspended-sediment data (fig. 32); it also represents the most heavily forested watershed of the eight sites (98 percent of the drainage area). In contrast, site 27B (Mohawk River at Cohoes) has the highest median suspended-sediment concentration (26 mg/L) of the eight sites, and its watershed is the least forested (55 percent of the drainage area). Median suspended-sediment concentrations for sites in the Upper Hudson River basin (sites 6, 7, 9, 12, and 16) range from 4 to 7.5 mg/L (fig. 32). Forest cover at these sites ranges from more than 90 percent of the drainage area upstream from site 6 to less than 80 percent of the drainage area upstream from site 16. The median suspended-sediment concentration at site 28 (Hudson River at Green Island, 67 percent forest cover, 11 mg/L) is between the median suspended-sediment concentration for each of the two sites that lie just upstream (sites 16 and 27B). These results indicate that suspended-sediment concentrations in the Hudson River basin are inversely proportional to percent forest cover. The effect of urbanization on suspended-sediment concentrations cannot be assessed, however, because no data are available from sites in urban watersheds.

Yields

Sediment transport in the Hudson River basin is highly variable over time and space, and the sparsity of data from all sites except those in the Upper Hudson River subbasin makes estimation of sediment yields difficult. The sparsity of data also is a major hindrance to interpretation of suspended-sediment transport because most of the annual sediment load for a site can be transported in just a few days and,

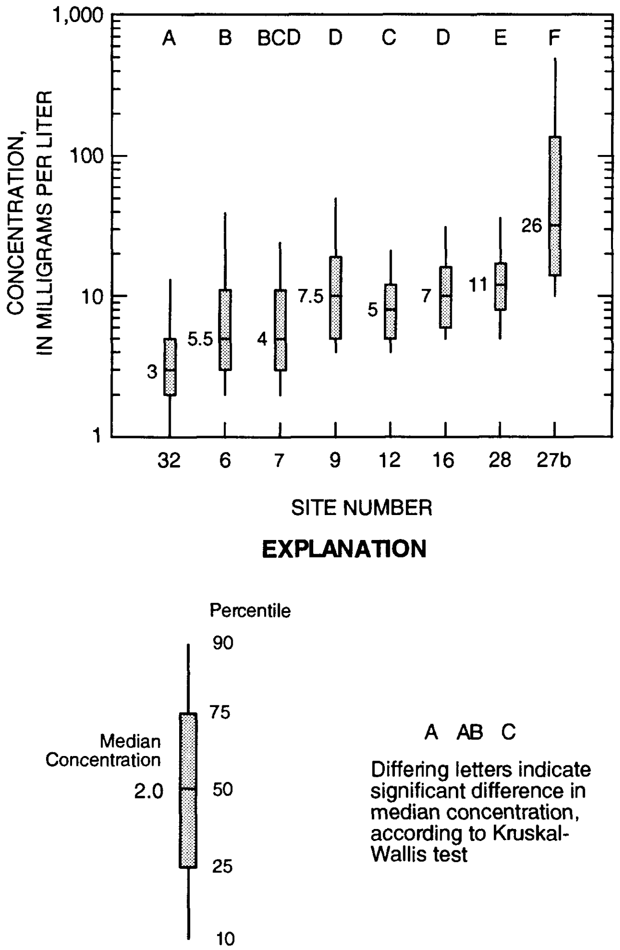


Figure 32. Range of suspended-sediment concentrations at sites in the Hudson River basin for which 1970-90 sediment data are available. (Site locations are shown in fig. 12.)

therefore, could easily be overlooked. For example, in an average year, about half of the total annual sediment load at site 16 (Hudson River at Waterford, a daily-values sediment station) is transported in the 18 days with the highest discharges. Hence, the accuracy of yield estimates depends on the number and availability of samples collected during high flows, and the suspended-sediment yields calculated for the two daily-values sites (sites 12 and 16, Hudson River at Stillwater and at Waterford) are generally more reliable than those calculated for other sites.

As mentioned previously, two types of yield are discussed in this report: (1) an average of the sediment yield for 3 years–a year in which the annual mean flow was ranked in the upper 10 percent of the annual mean flows, a year in which the annual mean flow was equal to the mean annual flow, and a year in which the annual mean flow was ranked in the lower 10 percent of the annual mean flows (table 19); and (2) sediment yield for 1978. Estimates of sediment-transport rates for each site are based on analyses of more than 90 samples and include samples collected during a discharge that was exceeded less than 1 percent of the time (table 19). Of the 156 suspended-sediment samples collected at site 27B (Mohawk River at Cohoes), nearly all were collected in 1976; hence, the calculated sediment yields for this site largely reflect conditions during 1976. For sites 12 and 16 (the sites with daily sediment data), daily suspended sediment data were missing for only 15 and 7.2 percent of the days, respectively, of the 3 years used to calculate the average transport rate. No days had missing values for 1978.

The standard error for computed yields ranges from 11 to 30 percent. Most of the errors are between 15 and 30 percent (table 20). The largest error is for site 32, Esopus Creek at Shandaken; this may reflect the variable concentration-to-discharge relation for this small watershed. Comparison of sediment transport

Table 19. Discharge characteristics represented by samples used to calculate suspended-sediment yields in Hudson River basin.

[Site locations shown in fig. 12.]

Site no.	No. samples used for estimate	No. high-flow samples (taken at a discharge exceeded 10 percent of time or less)	Percent of time discharge was exceeded for sample with:		Years of sample collection	Years of flow data used for 3- year average yield estimate*
			Highest dischage	Lowest discharge		
6	90	23	0.05	95	1975-79	1978, 1981, 1983
7	423	126	0.03	98	1975-83	1978, 1981, 1983
27B	156	65	0.01	92	1976-79	1978, 1981, 1983
28	96	15	0.60	96	1970-90	1978, 1981, 1983
32	168	17	0.06	99	1980-90	1972, 1971, 1928

*Years of flow data used represent discharge from years with high, medium, and low mean annual flows.

Table 20. Suspended-sediment yield calculated for sites in the Hudson River basin.

[Yields are in tons per day per square mile. SE (standard error of estimate) in percent. A dash indicates missing data. Site locations are shown in fig. 12. Asterisk denotes sites with daily values. Average yield is based on 3 years.]

Site no.	Site name	Predominant land use in watershed	Average Yield estimate		1978 Estimate	
			Yield	SE	Yield	SE
6	Hudson River at Glens Falls	Forest	0.053	22	0.078	14
7	Hudson River at Fort Edward	Forest	.044	12	.058	9.5
12*	Hudson River at Stillwater	Forest	.066	-	.080	-
16*	Hudson River at Waterford	Mixed	.097	-	.13	-
27B	Mohawk River at Cohoes	Agricultural	.25	11	.36	9.3
28	Hudson River at Green Island	Mixed	.22	21	.28	28
32	Esopus Creek at Shandaken	Forest	.076	30	-	-

rates among sites 27B (Mohawk River at Cohoes), site 16 (Hudson River at Waterford), and site 28 (Hudson at Green Island), suggests that, the estimates of sediment transport at these sites are reasonably consistent. For example, the 1978 value for site 28, estimated as the sum of 1978 values for sites 16 and 27B, is 1,820 (ton/d)/mi^2–about 17 percent lower than the 2,240 ton/yr estimated from 1978 site 28 data alone. The 3-year average sediment yield calculated for site 28 from site 16 and site 27B data combined (1,330 (ton/d)/mi^2) is 26 percent lower than the 3-year estimate made from site 28 data alone. Thus, the estimates based on the sum of sediment transported at sites 16 and 27B are within a standard error of estimate for both the 3-year and 1978 periods.

Sediment yield is related to watershed land use and drainage area. The relations between sediment yield and land use are similar to those for sediment concentration; for example, annual sediment yield generally decreases with increasing forest cover for both the 3-year averages and the 1978 estimates (table 20, fig. 33). The one exception is the somewhat higher average sediment yield for site 32 (Esopus Creek at Shandaken) than for Upper Hudson basin sites with similar forest cover (sites 6 and 7); this may be attributable to the small size of the watershed represented by site 32 (less than 7 percent of the drainage area of sites 6 and 7) because, in general, sediment yield also decreases with increasing watershed drainage area (Ritter, 1978). Watershed land use in the Upper Hudson subbasin has a greater effect than drainage area on sediment yield. For example, the drainage area of the Hudson River from Glens Falls (site 6, about 2,800 mi^2) to Green Island (site 28, about 8,000 mi^2) increases nearly threefold, and the sediment yield increases over fourfold, from 0.053 (ton/d)/mi^2 to 0.22(ton/d)/mi^2. This can probably be attributed to the decrease in the proportion of forest cover from the watershed above site 6 downstream to the watershed above site 28.

A comparison of sediment-transport rates indicates that most of the sediment transported at site 28 (Hudson River at Green Island) originates in the Mohawk River basin rather than in the Upper Hudson

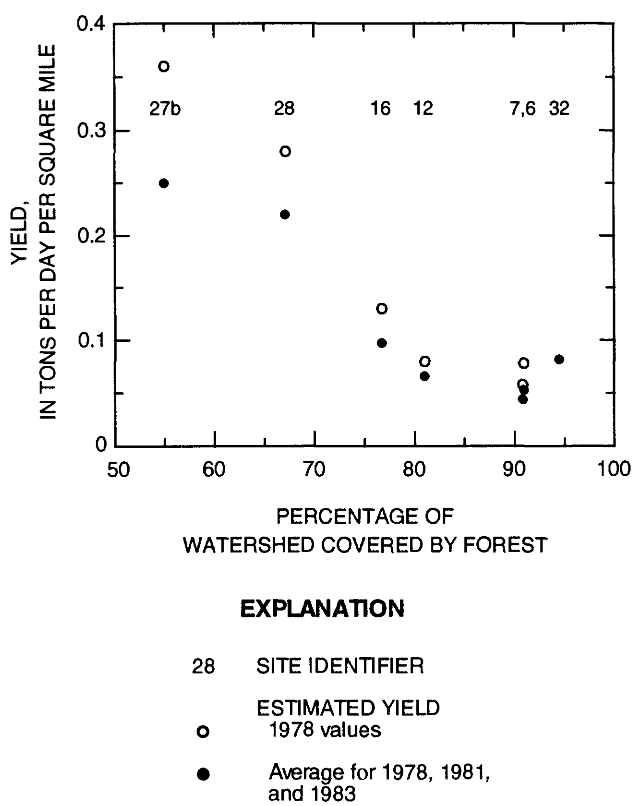


Figure 33. Relation of suspended-sediment yield, 1970-90, to percentage of watershed in the Hudson River basin that is forested. (Site locations are shown in fig. 12.)

basin, even though the Mohawk River basin constitutes about 40 percent of the combined drainage area. The mass of sediment transported past site 27B constitutes 66 percent of the summed mass of sites 27B and 16 (Hudson River at Waterford) as calculated from the 3-year average, and 68 percent of the summed yield of these sites as calculated from the 1978 data. Thus, the Mohawk River basin contributes a disproportionate amount of the sediment in the combined Upper Hudson and Mohawk River subbasin drainages, presumably because it contains considerably more agricultural land than the heavily forested Upper Hudson basin.

The sparsity of sediment data for Mohawk River sites 20 and 25, upstream from Cohoes, makes further assessment of suspended-sediment yield in the Mohawk River basin impossible, and the sparsity of sediment data from sites downstream of the Hudson River at Green Island makes estimation of sediment yield in the Lower Hudson subbasin difficult.

Pesticides

Local variability in pesticide-application rates, as indicated by reported patterns of DDT, chlordane, and 2,4-D use, suggest that rates of pesticide detection and median pesticide concentrations in water-column and streambed sediments also should vary locally. Because half of the sites from which pesticide data are available are in urbanized watersheds, most of the discussion of pesticide-detection rates and concentrations in this report pertain to comparisons of urban watersheds with nonurban watersheds. Because the data presented here were collected largely in the late 1970's, the following interpretations may not reflect current (1996) conditions and indicate only general relations between pesticide concentrations and land use. Data on all pesticides but 2,4-D are from streambed-sediment samples; 2,4-D data are from water-column samples.

The bed-sediment data do not indicate that the patterns of DDT detection and median DDT concentrations differ among the land-use categories. Total DDT was detected in streambed sediment in concentrations above 0.1 µg/kg in all but 1 of the 21 watersheds (fig. 34A); thus, a chi-square analysis indicated no significant difference in percent detection between urban and nonurban watersheds. Similarly, a Mann-Whitney analysis of variance on ranks confirmed that the median streambed-sediment concentrations for urban sites (5.8 µg/kg) was not significantly higher than the median concentration for nonurban sites, (3.0 µg/kg) (fig. 34B). Total DDT concentrations exceeding 50 µg/kg were detected in one urban watershed (site 52, Sawmill River at Yonkers) and in one agricultural watershed (site 27A, Mohawk River at Crescent Dam).

Unlike DDT, chlordane was detected more frequently at urban-watershed sites than elsewhere, and median chlordane concentrations for urban-watershed sites exceed those for nonurban-watershed sites. Chlordane concentrations in more than 80 percent of the samples from urban sites exceeded the detection limit of 2 µg/kg (fig. 34A); concentrations at fewer than 20 percent of the nonurban sites exceeded the detection limit. A chi-square statistical analysis confirms that these differences in detection between urban and nonurban watersheds is statistically significant at the 0.05 level. A Mann-Whitney analysis of variance on ranks confirmed that the median streambed-sediment concentration for urban watersheds, 5.0 µg/kg, is also significantly higher (at the 0.05 level) than the median concentration for nonurban watersheds, less than 2 µg/kg (fig. 34B). The highest chlordane concentration in streambed sediment, greater than 90 µg/kg, was in a highly urbanized watershed (site 52, Sawmill River at Yonkers, N.Y.). Aldrin was not detected in any streambed-sediment samples.

The small number of sites with 2,4-D data (11 sites) makes a relation between 2,4-D detection and land use difficult to confirm. 2,4-D was detected in about half the water-column samples from sites in all land use-categories (fig. 34A), but no statistical comparison of median 2,4-D concentrations could be made between urban and nonurban watersheds because only two samples from urban watersheds were available. The highest 2,4-D concentration, 0.04 µg/L, was in a sample from site 44 (Twaalfskill Creek), in an agricultural watershed (fig. 34B).

The spatial distribution of pesticide detections and concentrations indicates that pesticide concentrations are partly related to land use. Some general conclusions can be given about total DDT and chlordane that are based on differences in detection rates and concentrations according to land use. For example, DDT was detected in nearly all streambed-sediment samples, including those from nonurban watersheds, and the median DDT concentration did not differ significantly between urban and nonurban sites (fig. 34). The widespread occurrence of DDT reflects the

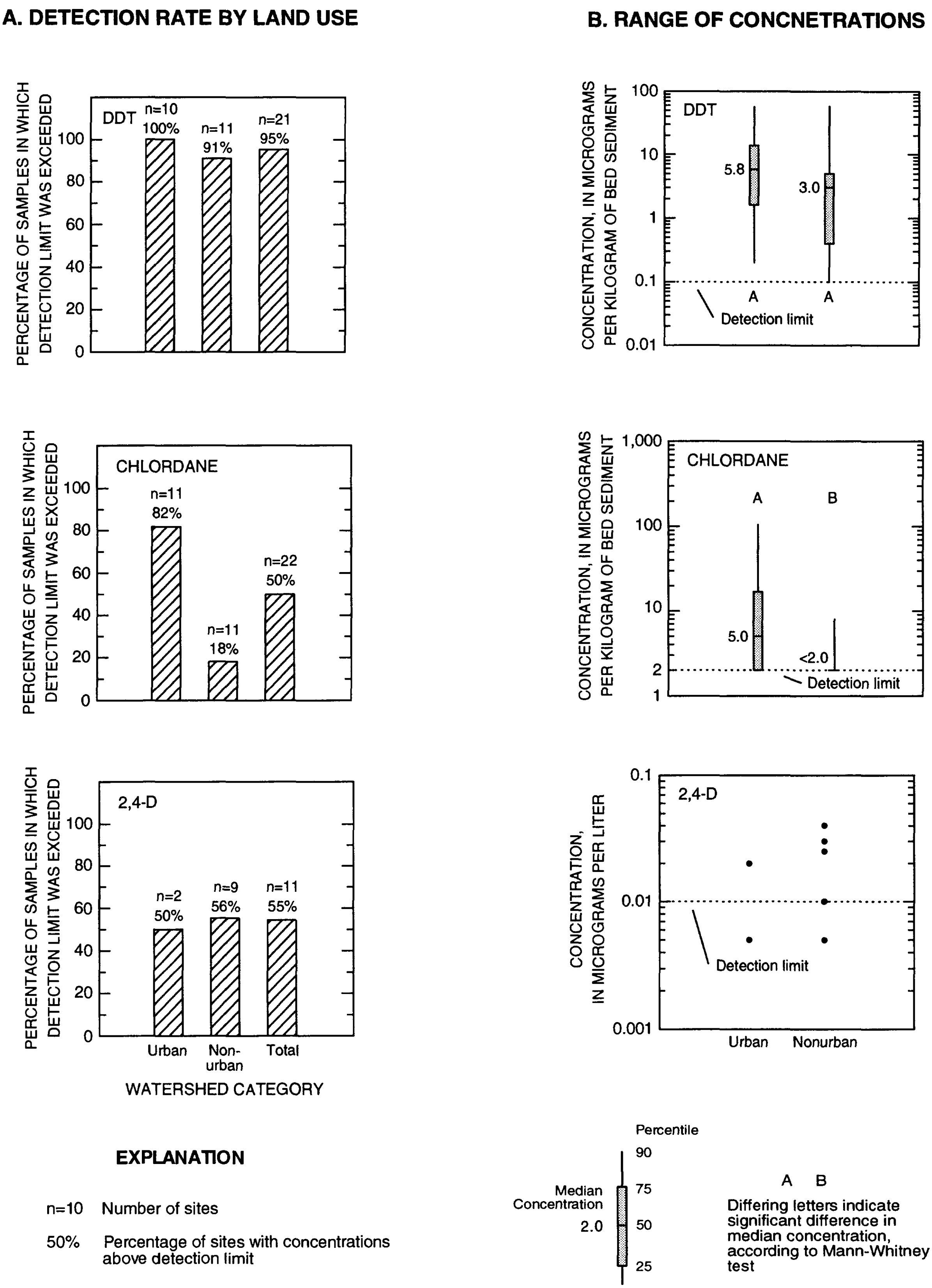


Figure 34. Detection rate and pesticide-concentration range in streambed-sediment samples (DDT and chlordane) and water column samples (2, 4, -D) from sites in urban and nonurban watersheds in the Hudson River basin in eastern New York and adjacent states,1970-90. A. Detection rate for DDT, Chlordane, and 2,4-D. B. Range of DDT,

application of DDT in urban, forested, and agricultural areas as reported by Rod (1989). Chlordane, by contrast, was detected much more frequently in urban watersheds than nonurban watersheds (fig. 34), and the median concentrations for urban watersheds were significantly greater than the median concentration for nonurban watersheds. The pattern of chlordane detection parallels the pattern of chlordane use, as chlordane was applied mainly in urban settings.

Rod (1989) concluded that breakdown products of DDT would be detected in Hudson River sediments longer than chlordane. Rod's estimates are based largely on detailed analyses of three cores collected in the tidal sections of the Hudson River by Bopp and others (1982), who collected p,p′-DDD samples at depth intervals ranging from 1 to 4 cm (2.5 to 10 in.) from three sites along the tidal reaches of the Hudson River, and chlordane samples at intervals from 5 to 7 cm (13 to 18 in.) at one site near New York City. Bopp and others (1982) also found that p,p′-DDD constituted about 80 percent of total DDT in these cores; hence, p,p′-DDD concentrations should be similar to total DDT concentrations. Ages of core sections were determined from radionuclide-activity tests; the relation between p,p′-DDD concentration and age differs among the three cores. For example, the concentration of p,p′ DDD peaked first at site C (near Newburgh) around 1960, and subsequently peaked at site E (near Manhattan Island) in the early 1960s (fig. 35). Concentrations of p,p′-DDD at site B (near Kingston) remained fairly constant from around 1960 to the mid-1970s. Rod attributed the large decrease in p,p′-DDD concentrations at site E after 1963 to increased sediment transport and accelerated DDT degradation in urban settings in the southern part of the Hudson River basin and concluded from these patterns that, although DDT use was banned in 1972, detectable concentrations of DDD would persist in agricultural and forested watersheds in the Hudson River basin well into the 1990s.

The distribution of chlordane concentrations with depth in Hudson River sediments indicates that chlordane is less persistent than DDD and that chlordane concentrations declined even before chlordane use was phased out in the early 1980s (Rod, 1989). Concentrations of chlordane in core E from the lower Hudson River (near Manhattan Island, N.Y.) peaked in the 1960s and early 1970s (fig. 36) and declined substantially thereafter (Bopp and others, 1982). Rod (1989) concluded that, at this rate of decline, chlordane concentrations in bed sediments in tidal sections of the Hudson River should be below 20 μg/kg by the early 1990s.

In general, few data on such commonly used pesticides as atrazine and alachlor are available; hence, the relation between pesticide concentrations and land use across the Hudson River basin cannot be assessed.

Despite the lack of data on all but a few pesticides in Hudson River basin streams, the trends for two persistent compounds–DDT and chlordane–in streambed sediments indicate that pesticide detection and concentration correlate with land use and past patterns of pesticide use. As DDT and chlordane degrade with time, the relation between the concentrations of these compounds and land use will presumably become obscure.

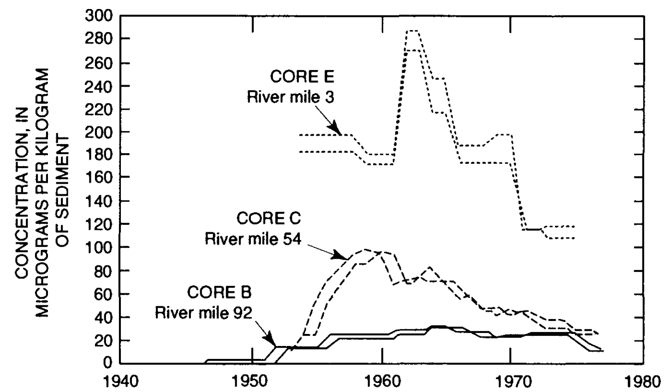


Figure 35. pp′-DDD concentration in Hudson River sediment cores collected by Bopp and others (1982). River miles measured from the southern tip of Manhattan Island. Double lines reflect uncertainty in data. (Modified from Rod, 1989, fig. 8-8).

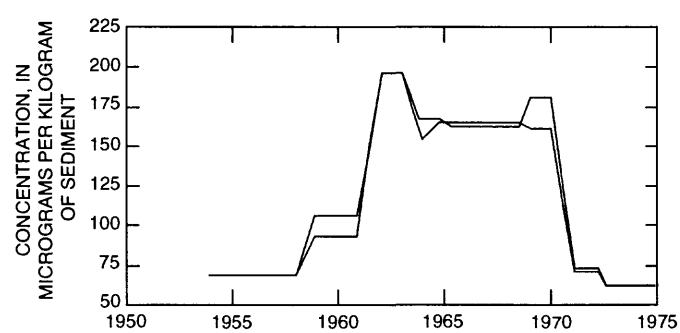


Figure 36. Chlordane concentration as a function of time in Hudson River sediment core E, collected at river mile 3 near Manhattan Island by Bopp and others (1982). (Modified from Rod, 1989, fig. 8-4).

SUMMARY AND CONCLUSIONS

The purpose of this study was to (1) compile, screen, and analyze the available water-quality data on nutrients (nitrogen species and phosphorus), suspended sediment, pesticides, and volatile organic compounds in the Hudson River basin (which covers more than 13,400 mi^2 and encompasses parts of eastern New York, Vermont, New Jersey, Massachusetts, and Connecticut), and relate these data to pertinent hydrologic factors and land use in the Hudson River basin, and (2) interpret these data to provide a general description of surface-water and ground-water quality conditions in the basin and indicate information gaps.

The predominant land use in the basin is forest (62 percent); 25 percent of the land is categorized as agricultural, and 7.8 percent as urban or residential. Most of the urban and agricultural areas are in valley lowlands and areas within 20 mi of large rivers in the western and central parts of the basin.

Ground water

Ground-water-sampling sites are characterized in this report by (1) aquifer type–either unconsolidated material that consists of bedrock or glacially derived sediments, and (2) the predominant land use within a 0.5-mi radius of each site. Land use at each well is classified as urban, agricultural, or forest.

Nutrient-data analysis are limited to nitrate concentrations, many of which lack supporting well-depth and aquifer-material information. Only 100 wells in the study area that have records of nitrate concentrations for the period of interest (1970-90) also have information have well-depth and aquifer material; 63 of these wells tap unconsolidated aquifers, and 37 tap bedrock aquifers. Most of these data were collected during 1979 and 1986-1988. All nutrient data were collected by the U.S. Geological Survey.

Nitrate concentrations in water from unconsolidated deposits range from less than 0.1 mg/L (the analytical detection limit) to 16 mg/L, with a median concentration of 0.23 mg/L, and the concentrations in water from bedrock aquifers range from less than 0.1 to 11 mg/L, with a median concentration of 0.3 mg/L. Nitrate concentrations in water samples from unconsolidated aquifers do not differ significantly from those in samples from bedrock aquifers. Although nitrate concentrations appear to decrease with well depth in unconsolidated aquifers and bedrock aquifers, those decreases were significant only in unconsolidated aquifers. No statistically significant difference in nitrate concentrations in unconsolidated aquifers or bedrock aquifers could be identified among differing land-use categories.

Only 11 ground-water-sampling sites in the Hudson River basin have pesticide or volatile-organic-compound data for the period of interest (1970-90). Water from only one of these sites, in Schenectady County, N.Y., contained a compound (diazinon) in concentrations greater than the detection limit 0.02 µg/L.

These results suggest that the ground-water-quality data for the Hudson River basin that are available in NWIS are not adequate to assess current nutrient and pesticide concentrations in the Hudson River basin and their relation to land use.

Surface water

Each surface-water site represented in this report was assigned to one of four land-use categories, depending on the predominant land use in the drainage basin above the site. Watersheds that are more than 25 percent agricultural and less than 11.5 percent urban were termed agricultural, and watersheds that are more than 8 percent urban and less than 20 percent agricultural were termed urban. Watersheds that are more than 78 percent forested and less than 18 percent agricultural were classified as forest. Sites not included in any of these three categories were classified as mixed.

Most of the nutrient data were collected during 1970-80. Data for 1981-90 are limited, and only two sites have more than 30 samples for that period. In general, the data represent an even distribution of flow conditions, season, and land use. Of the 19 sites with nutrient data and daily discharge data for 1970-80, only two are more than 9.5 percent urban; thus, the data for urban sites are extremely sparse.

Suspended-sediment data are available for eight sites; because these data were collected during 1970-80, assessment of current conditions at many of the sites is not possible. Six of the sites are on the upper Hudson River, above the Mohawk River outlet, one is at the outlet of the Mohawk River, and one is in a small forested watershed in the Catskill Mountains. Assessment of suspended-sediment concentrations and yields is limited because of the sparsity of data for agricultural watersheds, and lack of data for urban watersheds.

Pesticide data also are insufficient for a basinwide assessment of current conditions in either the water column or bed sediment. Bed-sediment concentrations of five compounds (DDE, DDD, DDT, chlordane, and aldrin) are available at about 20 sites, half of which represent urban watersheds. Most of the streambed-sediment samples were collected before 1980 and, therefore, do not necessarily reflect current conditions. The only pesticide for which water-column data are available is 2,4-D; these data were collected at 11 sites. Because only one sample was collected from each site, data cannot be used to establish the relation between 2,4-D concentration and discharge. Virtually no information on concentrations of other commonly used pesticides in the Hudson River basin, such as atrazine and alachlor, is available.

Concentrations of nutrients in surface waters in the Hudson River basin can be related to agricultural and urban activities. In most farmed watersheds, dissolved nitrate, total nitrogen, and total phosphorus concentrations are directly related to stream discharge, indicating a predominance of nonpoint sources in these regions. In contrast, the concentrations of these constituents in farmed watersheds that are more than 5 percent urban and that have a population density exceeding 200 per mi^2 do not increase with increasing discharge, indicating a mix of point and nonpoint sources. Concentrations of these constituents in two urban watersheds are inversely related to discharge, suggesting a predominance of point sources in urban areas.

Dissolved nitrate and total nitrogen concentrations at sites draining both small and large forested watersheds are directly related to discharge, suggesting that nitrogen from nonpoint sources predominates in waters of forested watersheds. Total phosphorus concentrations are not strongly related to discharge at forested sites, and the total-phosphorus concentrations at many forested-watershed sites were below the detection limit of 0.01 mg/L; hence, the predominant control on phosphorus concentrations is unknown.

The sparsity of long-term nutrient data in the Hudson River Basin limits analysis of temporal trends in nutrient concentrations to a few sites. Long-term records for two forested watersheds in the Catskill Mountains indicate that dissolved nitrate concentrations increased four- to five-fold during 1970-90.

Agricultural and urban watersheds generally have higher median concentrations of dissolved nitrate, dissolved ammonium, total nitrogen, and total phosphorus than watersheds in the forested or mixed-land-use category. Median dissolved nitrate and median total nitrogen concentrations at sites with daily discharge data range from 0.71 mg/L and 1.43 mg/L, respectively at the Mohawk River at Fonda (agricultural) to 0.25 mg/L and 0.51 mg/L, respectively at Esopus Creek at Shandaken (forested). Median total phosphorus concentrations at sites with daily discharge data range from 0.29 mg/L for the Hoosic River at North Petersburg (urban) to less than 0.01 mg/L at East Sacandaga River at Griffith (forested).

Analysis of nutrient data from 32 surface-water sites indicates that lowest median nutrient concentrations are at sites representing forested watersheds: the median nitrate concentrations range from 0.72 mg/L in agricultural watersheds to 0.36 mg/L in forested watersheds; median total nitrogen concentrations range from 1.4 mg/L in urban and mixed watersheds to 0.6 mg/L in forested watersheds; and the median total phosphorus concentrations range from 0.08 mg/L in agricultural watersheds to less than 0.01 mg/L in forested watersheds. Median nutrient concentrations in this data set also are directly related to population density and increase with increasing population density in watersheds with a population density less than 300 per mi^2.

Nutrient yields (mass per year per area) during 1970-80 and predominant sources of nutrient input differ with land use. The highest yields of dissolved nitrate and total phosphorus were from agricultural watersheds and in urban watersheds with population densities exceeding 150 per mi^2. Annual yields for dissolved nitrate, total nitrogen, and total phosphorus exceeded 3,200 lb/mi^2, 4,200 lb/mi^2, and 450 lb/mi^2, respectively, from drainage areas upstream from four sites - Mohawk River at Fonda (agricultural), Hoosic River below Williamstown (urban), Hoosic River at North Petersburg (urban), and Wallkill River near Rosendale (agricultural). The lowest dissolved nitrate yields (less than 1,600 lb/mi^2) and total nitrogen yields (3,400 lb/mi^2) were from forested watersheds and from parts of the Schoharie Creek watershed at sites below significant water diversions. The lowest total phosphorus yields (less than 150 lb/mi^2) were from forested watersheds.

The predominant source of nitrogen and phosphorus inputs to a watershed site reflects the land use in the watershed. Estimated nutrient inputs represent the total amount of nutrients applied to each watershed not the actual amounts of nutrients reaching the stream. In forested watersheds, 90 percent of the nitrogen input is from atmospheric deposition, whereas in farmed watersheds, more than 70 percent is from fertilizer and manure; in the two urban watersheds, 40 percent of the nitrogen input was from treated wastewater. At the mixed land use watersheds (including the Hudson River at Green Island), 50 to 70 percent of the nitrogen input was from fertilizer or manure, and the balance was generally split equally between atmospheric deposition and treated wastewater. The predominant source of phosphorus input in all but the two urban watersheds and two forested watersheds is fertilizer and manure. A mass balance based on nutrient transport (yield multiplied by watershed area) using data for watersheds upstream of the Hudson River at Green Island, indicates that between 50 and 60 percent of the mass of nutrients transported past Green Island comes from the Mohawk River basin, even though that basin represents only about 40 percent of the drainage area of the Green Island site; this indicates that the Mohawk River basin is an important source of nutrients to the Hudson River estuary.

Suspended-sediment concentrations and yields in the Hudson River basin also are related to land-use characteristics. The highest median suspended-sediment concentration (26 mg/L) and the highest sediment yield (0.36 (ton/d)/mi^2) were at the Mohawk River site at Cohoes; the watershed above this site also represents the smallest percentage of forest cover of the eight sites with suspended-sediment data. Similarly, watersheds above sites representing the highest percentage of forest cover had the lowest median suspended-sediment concentrations (less than 5 mg/L) and lowest yields (less than 0.08 (ton/d)/mi^2).

Detection rates for selected persistent pesticide compounds in streambed sediment also are related to land use. DDT was applied to agricultural, urban, and forested watersheds from the 1940's through the early 1970's, and total DDT was detected in streambed-sediment at concentrations exceeding 0.1 µg/kg at all but one of the 21 sites with available data. Median total DDT streambed-sediment concentrations at the urban sites did not differ significantly from those at the other sites. Chlordane, by contrast, was applied primarily in urban areas from the 1940's through the 1970's, and was detected at concentrations equal to or greater than 2 µg/kg at more than 80 percent of the 11 urban sites and at less than 20 percent of the 11 non-urban sites. In contrast to DDT, median chlordane bed-sediment concentrations at urban sites were significantly higher than those at nonurban sites.

The above results demonstrate that local differences in concentrations of nutrients and suspended sediment in surface-water samples and of selected pesticides in streambed sediment can be related to land-use patterns and the sources and locations of nutrient and pesticide inputs. These relations are based on data collected during 1970-80, however, and do not necessarily reflect current water-quality conditions. In addition, the lack of nutrient and suspended-sediment data from urban sites makes the assessment of water-quality conditions in urban streams difficult.

REFERENCES CITED

Alexander, R. B., and Smith, R. A., 1990, County-level estimates of nitrogen and phosphorus fertilizer use in the United States, 1945-1985, U. S.Geological Survey Open-File Report 90-130, 12 p.

Ayres, R. U., Ayres, L. W., McCurley, J. Small, M., Tarr, J. A., and Widgery, R. C., 1988, An historical reconstruction of major pollutant levels in the Hudson-Raritan Basin - 1880-1980 [3 volumes], National Ocean Service, National Oceanic and Atmospheric Administration, Rockville, Md., NOS OMA 43, 139 p.

Bauersfeld, W. R., Moshinsky, E. W., Pustay, E. A., and Jones, W. D., 1988, Water Resources Data - New Jersey, Water Year 1987, volume 1. Atlantic Slope Basins, Hudson River to Cape May: U. S. Geological Survey Water-Data Report NJ-87-1, 347 p.

Bode, R. W., Novak, M. A. and Abele, L. E., 1992, Biological stream assessment of Cayadutta Creek, N. Y.: Albany, N.Y., New York State Department of Environmental Conservation, Bureau of Monitoring and Assessment, Albany, N.Y., 24 p.

Bopp, R. F., Simpson, H. J., Olsen, C. R., Treier, R. M., and Kostyk, Nadia, 1982, Chlorinated hydrocarbons and radionuclide chronologies in sediments of the Hudson River and Estuary, New York: Environmental Science and Technology 16, no. 10, p. 666-676.

Bugliosi, E. F., and Trudell, R. A., 1988a, Potential yields of wells in unconsolidated aquifers in upstate New York—lower Hudson sheet: U.S. Geological Survey Water-Resources Investigations Report 87-4274, 1 sheet, scale 1: 250,000.

____ 1988b, Potential yields of wells in unconsolidated aquifers in upstate New York-- Adirondack sheet: U.S. Geological Survey Water-Resources Investigations Report 87-4276, 1 sheet, scale 1:250,000.

Bugliosi, E. F.,Trudell, R. A., and Casey, G. D., 1988, Potential yields of wells in unconsolidated aquifers in upstate New York—Hudson-Mohawk sheet: U.S. Geological Survey Water-Resources Investigations Report 87-4275, 1 sheet, scale 1: 250,000.

Cohn, T. A., DeLong, L. L., Hirsch, R. M., and Wells, D. K., 1989, Estimating constituent loads: Water Resources Research, v. 25, no. 5, p. 837-942.

Fenneman, N. M., 1938, Physiography of eastern United States: New York, McGraw-Hill, 691 p.

Firda, G. D., Lumia, Richard, and Murray, P. M., and Freeman, W. O., 1993, Water Resources Data - New York, water year 1993, Volume 1. Eastern New York excluding Long Island: U. S. Geological Survey Water-Data Report NY-93-1, 452 p.

Gianissi, L. P., and C. M. Puffer, 1988, Use of selected pesticides for agricultural crop production in the United States, 1982-1985: Washington D.C., Resources for the Future, 490 p.

Gilroy, E. J., Hirsch, R. M., and Cohn, T. A., 1990, Mean square error of regression-based constituent transport estimates: Water Resources Research, v. 26, no. 9, p. 2069-2077.

Hammond, D. S., Heath, R. C., and Waller, R. M., 1978, Ground-water data on the Hudson River Basin, New York: U. S. Geological Survey Open File Report 78-710, 18 p.

Helsel, D. R., and Hirsch, R. M., 1992, Statistical Methods in Water Resources: New York, Elsevier, 552 p.

Howarth, R. W., Fuci, J. R. and Sherman, Diane, 1991, Inputs of sediment and carbon to an estuarine ecosystem - Influence of land use: Ecological Applications v. 1, no. 1, p. 27-39.

Limburg, K. E., 1985, PCBs in the Hudson, *in* Limburg, K. E., Moran, M. A, and McDowell, W. H., eds., The Hudson River Ecosystem: New York, Springer-Verlag, p. 82-130

Madison, R.J., and Brunett, J.O., 1984, Overview of the occurrence of nitrate in ground water of the United States, *in* National water summary, 1984 – hydrologic events, selected water-quality trends, and ground- water resources: U.S. Geological Survey Water-Supply Paper 2275 p. 93-105.

Murdoch, P. S., and Stoddard, J. L., 1992, The role of nitrate in the acidification of streams in the Catskill Mountains of New York: Water Resources Research v. 28, no. 10, p. 2707-2720.

National Atmospheric Deposition Program (NRSP-3)/National Trends Network 1992 Report, 1992: NADP/NTN Coordination Office: Fort Collins Colo., Colorado State University, Natural Resource Ecology Laboratory.

New York State Department of Environmental Conservation, 1987, Descriptive data of sewage treatment systems in New York State: Albany, N. Y., 82 p.

New York State Department of Health, 1981, Report on ground-water dependence in New York State: Albany, N.Y., New York State Department of Health, Bureau of Public Water Supply, 49 p.

National Oceanic and Atmospheric Administration, 1993, Point-source methods document: Silver Spring, Md., National Ocean Service, Pollution Sources Characterization Branch, 224 p.

Hammond, D. S., Heath, R. C., and Waller, R. M., 1978, Ground-water data on the Hudson River Basin, New York: U. S. Geological Survey Open File Report 78-710, 18 p.

Randall, A. D., 1996, Mean annual runoff, precipitation, and evapotranspiration in the glaciated northeastern United States, 1951-80: U. S. Geological Survey Open-File Report 96-395, 2 pl., 1:250,000.

Ritter, D. F., 1978, Process Geomorphology: Dubuque, Iowa, William C. Brown, 603 p.

Rod, S. R., 1989, Estimation of historical pollutions trends using mass balance principles—selected metals and pesticides in the Hudson-Raritan basin, 1880-1980: Pittsburgh, Pa., Carnegie-Mellon University, Unpublished dissertation, 212 p.

Rogers, R. J., 1988, New York ground-water quality, *in* Moody, D. W., Carr, Jerry, Chase, E. B., and Paulson, R. W, (compilers), National water summary 1986 – hydrologic events and ground-water quality: U.S. Geological Survey Water-Supply Paper 2325, p. 385-392.

SAS Institute, 1990, SAS/STAT User's guide (release 6, Fourth edition): Cary, N.C., SAS Institute, 1689 p.

Sisterson, D. L., 1990, Detailed SOx-S and NOx-N mass budgets for the United States and Canada. in Acidic Deposition—State of Science and Technology, Appendix 8A: Washington, D.C., National Acid Precipitation assessment Program, p. 8A-1 through 8A-10.

Turk, J. T., and D. E. Troutman, 1981, Relationship of water quality of the Hudson River, New York, during peak discharges to geologic characteristics of contributing subbasins: U. S. Geological Survey Water Resources Investigations 80-108, 15 p.

U.S. Geological Survey, 1979a, Land use and land cover, 1970-76, Hartford, Connecticut; New York; New Jersey; Massachusetts: U.S. Geological Survey Land-Use Map Series, Map L-79, scale 1:250,000.

_____, 1979b, Land use and land cover, 1974, Newark, New Jersey; Pennsylvania; New York: U.S. Geological Survey Land-Use Map Series, Map L-33, scale 1:250,000.

_____, 1979c, Land use and land cover, 1972-73, New York; New Jersey; Connecticut: U.S. Geological Survey Land-Use Map Series, Map L-82, scale 1:250,000.

_____, 1979d, Land use and land cover, 1974, Scranton Pennsylvania; New York; New Jersey: U.S. Geological Survey Land-Use Map Series, Map L-35, scale 1:250,000.

_____, 1980a, Land use and land cover, 1972, Glens Falls, New York; New Hampshire; Vermont: U.S. Geological Survey Land-Use Map Series, Map L-185, scale 1:250,000.

_____, 1980b, Land use and land cover, 1975-78, Albany, New York; Massachusetts; New Hampshire; Vermont: U.S. Geological Survey Land-Use Map Series, Map L-134, scale 1:250,000.

Waller, R. M., and Finch, A. J., 1982, Atlas of eleven selected aquifers in New York: U.S. Geological Survey Water-Resources Investigations, Open-File Report 82-553, 255 p.

Ware, G. W., 1989, The pesticide book: Fresno, Calif., Thomson Publications, 336 p.

Will, G. B., Staminal, F. D., Gotie, R. F., and Smith, E. S., 1982, The ecological zones of northern New York: New York Fish and Game Journal, v. 29 no. 1, p. 1-25.