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# WATER-QUALITY ASSESSMENT OF THE LOWER SUSQUEHANNA RIVER BASIN, PENNSYLVANIA AND MARYLAND: SOURCES, CHARACTERISTICS, ANALYSIS, AND LIMITATIONS OF NUTRIENT AND SUSPENDED-SEDIMENT DATA, 1975-90

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http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html

## 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 specific contamination problems; 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 U.S. 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 59 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 59 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.

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## CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

| | Multiply | by | To obtain |
|---|---|---|---|
| **Length** | | | |
| | inch (in.) | 25.4 | millimeter |
| | foot (ft) | 0.3048 | meter |
| | mile (mi) | 1.609 | kilometer |
| **Area** | | | |
| | square mile ($mi^2$) | 2.590 | square kilometer |
| | acre | 0.4047 | square hectometer |
| **Volume** | | | |
| | gallon (gal) | 3.785 | liter |
| **Flow** | | | |
| | cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second |
| | million gallons per day (Mgal/day) | 0.003785 | million cubic meters per day |
| **Mass** | | | |
| | pound (lb) | 0.4545 | kilogram |
| | pounds per acre per year (lb/acre/yr) | 1.123 | kilograms per hectare per year |
| | ton (short, 2,000 pounds) | 0.9072 | megagram (metric ton) |
| | ton per acre [(ton/acre)] | 3.6712 | metric ton per square kilometer |
| **Temperature** | | | |
| | degree Fahrenheit (°F) | °C=5/9 (°F-32) | degree Celsius |

Chemical concentrations and water temperature used in this report are given in metric units. Chemical concentration is given in milligrams per liter (mg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

# WATER-QUALITY ASSESSMENT OF THE LOWER SUSQUEHANNA RIVER BASIN, PENNSYLVANIA AND MARYLAND:

## Sources, Characteristics, Analysis, and Limitations of Nutrient and Suspended-Sediment Data, 1975-90

*by Robert A. Hainly and Connie A. Loper*

**ABSTRACT**

This report describes analyses of available information on nutrients and suspended sediment collected in the Lower Susquehanna River Basin during water years 1975-90. Most of the analyses were applied to data collected during water years 1980-89. The report describes the spatial and temporal availability of nutrient and suspended-sediment data and presents a preliminary concept of the spatial and temporal patterns of concentrations and loads within the basin. Where data were available, total and dissolved forms of nitrogen and phosphorus species from precipitation, surface water, ground water, and springwater, and bottom material from streams and reservoirs were evaluated. Suspended-sediment data from streams also were evaluated.

The U.S. Geological Survey National Water Information System (NWIS) database was selected as the primary database for the analyses. Precipitation-quality data from the National Atmospheric Deposition Program (NADP) and bottom-material-quality data from the National Uranium Resource Evaluation (NURE) were used to supplement the water-quality data from NWIS.

Concentrations of nutrients were available from 3 precipitation sites established for long-term monitoring purposes, 883 wells (854 synoptic areal survey sites and 29 project and research sites), 23 springs (17 synoptic areal survey sites and 6 project and research sites), and 894 bottom-material sites (840 synoptic areal survey sites and 54 project and research sites). Concentrations of nutrients and (or) suspended sediment were available from 128 streams (36 long-term monitoring sites, 51 synoptic areal survey sites, and 41 project and research sites).

Concentrations of nutrients and suspended sediment in streams varied temporally and spatially and were related to land use, agricultural practices, and streamflow. A general north-to-south pattern of increasing median nitrate concentrations, from 2 to 5 mg/L, was detected in samples collected in study unit streams. In streams that drain areas dominated by agriculture, concentrations of nutrients and suspended sediment tend to be elevated with respect to those found in areas of other land-use types and are related to the amount of commercial fertilizer and animal manure applied to the area drained by the streams. Animal manure is the dominant source of nitrogen for the streams in the lower, agricultural part of the basin.

Concentrations of nutrients in samples from wells varied with season and well depth and were related to hydrogeologic setting. Median concentrations of nitrate were 2.5 and 3.5 mg/L for wells drawing water at depths of 0 to 100 ft and 101 to 200 ft, respectively. The lowest median concentrations for nitrate in ground water from wells were generally

found in siliciclastic-bedrock, forested settings of the Ridge and Valley Physiographic Province, and the highest were found in carbonate-bedrock agricultural settings of the Piedmont Physiographic Province. Twenty-five percent of the measurements from wells in carbonate rocks in the Piedmont Physiographic Province exceeded the Pennsylvania drinking-water standard.

An estimate of mass balance of nutrient loads within the Lower Susquehanna River Basin was produced by combining the available information on stream loads, atmospheric-deposition loads, commercial-fertilizer applications, animal-manure production, private-septic-system nonpoint-source loads, and municipal and industrial point-source loads. The percentage of the average annual nitrate load carried in base flow of streams in the study unit ranged from 45 to 76 percent, and the average annual phosphorus load carried in base flow ranged from 20 to 33 percent. Average annual yields of nutrients and suspended sediment from tributary basins are directly related to percentage of drainage area in agriculture and inversely to drainage area. Information required to compute loads of nitrogen and phosphorus were available for all sources except atmospheric deposition, for which only nitrogen data were available. Atmospheric deposition is the dominant source of nitrogen for the mostly forested basins draining the upper half of the study unit.

The estimate of total annual nitrogen load to the study unit from precipitation is 98.8 million pounds. Nonpoint and point sources of nutrients were estimated. Nonpoint and point sources combined, including atmospheric deposition, provide a potential annual load of 390 million pounds of nitrogen and 79.5 million pounds of phosphorus. The range of percentages of the estimated nonpoint and point sources that were measured in the stream was 20 to 47 percent for nitrogen and 6 to 14 percent for phosphorus.

On the average, the Susquehanna River discharges 141,000 pounds of nitrogen and 7,920 pounds of phosphorus to the Lower Susquehanna River reservoir system each year. About 98 percent of the nitrogen and 60 percent of the phosphorus passes through the reservoir system.

Interpretations of available water-quality data and conclusions about the water quality of the Lower Susquehanna River Basin were limited by the scarcity of certain types of water-quality data and current ancillary data. A more complete assessment of the water quality of the basin with respect to nutrients and suspended sediment would be enhanced by the availability of additional data for multiple samples over time from all water environments; samples from streams in the northern and western part of the basin; samples from streams and springs throughout the basin during high base-flow or stormflow conditions; and information on current land-use, and nutrient loading from all types of land-use settings.

# INTRODUCTION

In 1985, the U.S. Geological Survey (USGS) proposed a National Water-Quality Assessment (NAWQA) Program designed to

1. provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources;
2. define long-term trends in water-quality data; and
3. identify, describe, and explain, to the extent possible, the major natural and human factors that affect observed water-quality conditions and trends.

The principal goal of the NAWQA program is to provide water-quality information that will assist policymakers and managers at the national, state, and local levels.

The program began in 1986, with pilot NAWQA studies at seven areas throughout the country. The pilot studies tested and refined approaches for large-scale water-quality assessments and evaluated the potential benefits and costs of a fully implemented nationwide program. After a thorough review of the pilot studies by the National Academy of Sciences (Engelbrecht and others, 1990), the implementation of a full-scale study at 59 separate study units was recommended. The 59 study units are river basins or aquifer systems that range in area from about 1,200 to 50,000 $mi^2$ and include about 60 to 70 percent of the Nation's water use.

The Lower Susquehanna River Basin was among the first 20 study units of the full-scale NAWQA program that began in 1991. The investigation of water quality in the study unit began in 1991 with planning and with analysis of available data. The bulk of the intensive water-quality sampling and interpretation was done during 1993-95. After completion of interpretive reports, low intensity water-quality sampling is scheduled for 4 years, after which a new cycle of intensive data collection will begin. The analysis of available information on nutrients and suspended sediment described in this report is one part of the general NAWQA objective to analyze available data.

## Purpose and Scope

This report describes the available information on nutrients and suspended sediment collected within the Lower Susquehanna River Basin. The report describes the spatial and temporal availability of nutrients and suspended-sediment data and presents a preliminary conceptual model of processes and the spatial and temporal patterns of concentrations and loads within the study unit.

The scope of this report is limited to suspended-sediment and nutrient data collected during the water years 1975-90. (A water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends). The most complete analysis in the study was done on data collected during water years 1980-89. Results from this analysis were included in a national-level report on suspended sediment and nutrients in the 1980's (Mueller and others, 1995). Data for total and dissolved forms of nitrogen and phosphorus in precipitation, surface water, springwater, ground water, and bottom material and data for suspended sediment in surface water were evaluated. The primary nitrogen and phosphorus data analyzed in this study were dissolved nitrite plus nitrate and total phosphorus.

### Acknowledgments

Members of the Lower Susquehanna River Basin NAWQA thank all those who assisted in the retrieval and explanation of water-quality data from the various databases. Most of the assistance was received from personnel of the U.S. Environmental Protection Agency, the Pennsylvania Department of Environmental Protection, the Maryland Department of the Environment, the National Atmospheric Deposition Program, and USGS personnel from the Lemoyne, Pa., office and offices in surrounding states.

## DESCRIPTION OF THE STUDY UNIT

The Susquehanna River drains about 27,000 mi$^2$ in New York, Pennsylvania, and Maryland. About 80 percent of the Susquehanna's watershed is in Pennsylvania. From its headwaters near Cooperstown, N.Y., the Susquehanna River flows 447 mi to the Chesapeake Bay. In terms of total discharge at the mouth and its drainage area, the Susquehanna is the largest river on the eastern seaboard of the United States and 18th largest in the United States (Kammerer, 1987).

The study unit consists of 9,200 mi$^2$ of the basin from where the West Branch and main stem of the Susquehanna River join near Sunbury, Pa., downstream to Chesapeake Bay at Havre de Grace, Md. (fig. 1). The study unit also includes parts of the Northeast Creek and Elk River Basins upstream from the Fall Line. The Fall Line is an approximate boundary defined by the contact between the Piedmont and Coastal Plain Physiographic Provinces (fig. 2). Northeast Creek and Elk River drain directly into Chesapeake Bay and add about 150 mi$^2$ of watershed to the study unit. In this report, the term "Lower Susquehanna River Basin" includes this small area that drains directly to the bay. The study unit is bounded to the north by the upper basin of the Susquehanna River, to the south by the Fall Line and by the Potomac River Basin and small basins that drain directly into Chesapeake Bay, to the east by the Delaware River Basin, and to the west by the Allegheny River Basin (fig. 1).

### Physiography

Physiography affects water quality in the study unit by controlling the route that precipitation must follow through the flow system on its way to a discharge point on the Susquehanna River. Physiography also determines the amount of time the precipitation is in contact with materials such as soil, rock, and vegetative cover that affect the chemical content of surface and ground waters (Risser and Siwiec, 1996). The Lower Susquehanna River Basin contains parts of five physiographic provinces: the Appalachian Plateaus, Ridge and Valley, Blue Ridge, New England, and Piedmont (Berg and others, 1989). Together, the Ridge and Valley and Piedmont Physiographic Provinces account for 97 percent of the study unit (fig. 2).

The Ridge and Valley Physiographic Province, which accounts for the northwestern two-thirds of the study unit, is characterized by long, narrow ridges and valleys that trend southwest to northeast. The topography of the ridges and hillslopes creates rapid, direct runoff of precipitation to streams and a short contact time with interactive materials. Surface-water quality in the upland areas is generally influenced more by precipitation quality than by the local environmental factors, although the rapid runoff on barren or disturbed lands can produce high erosional and sedimentation rates. In some valleys, the volume of direct runoff is decreased by thick, rich soils and sinkholes. Evidence for this process is large springs and water quality reflective of local environmental factors.

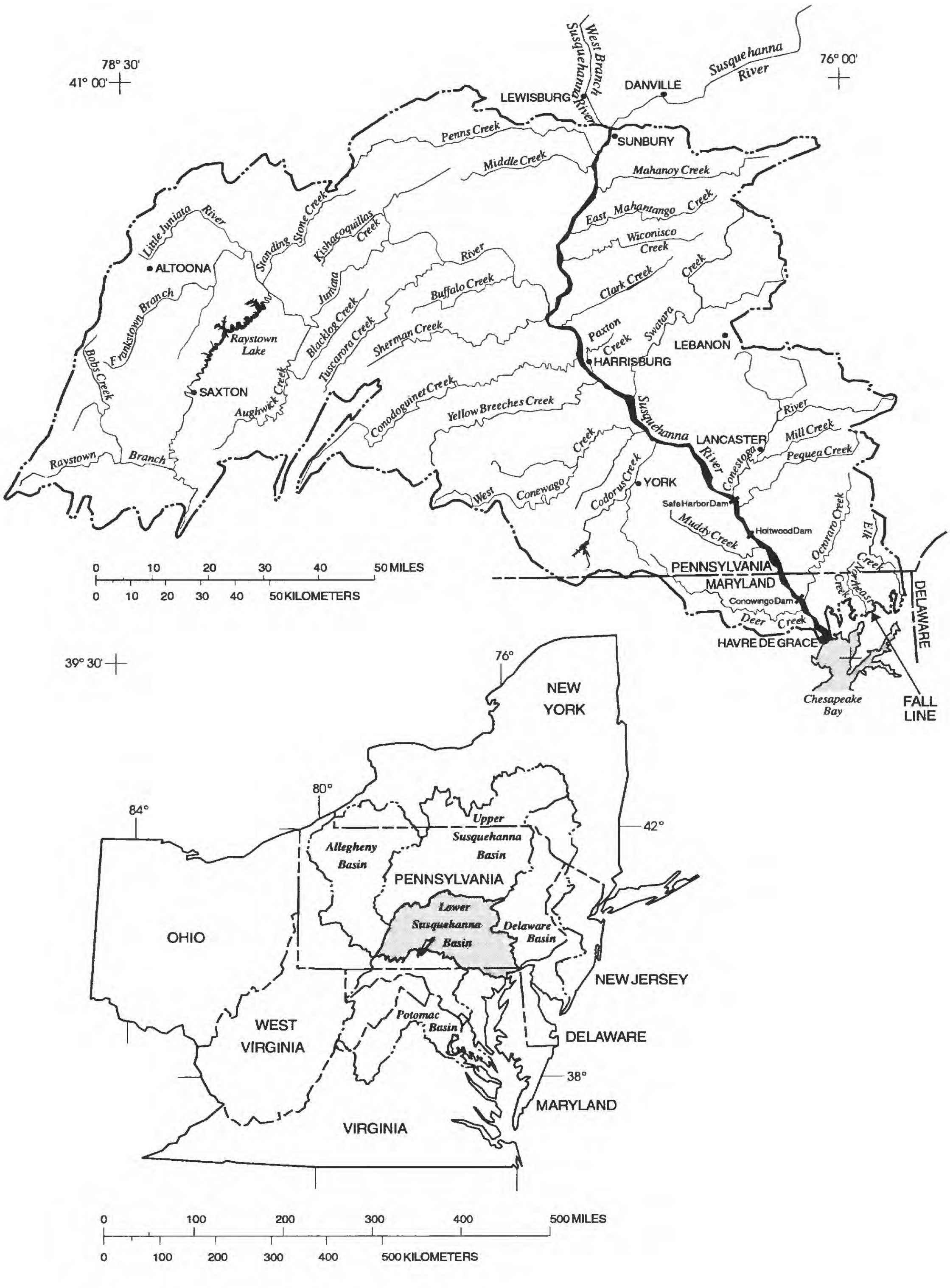



**Figure 1.** Location of the Lower Susquehanna River Basin.

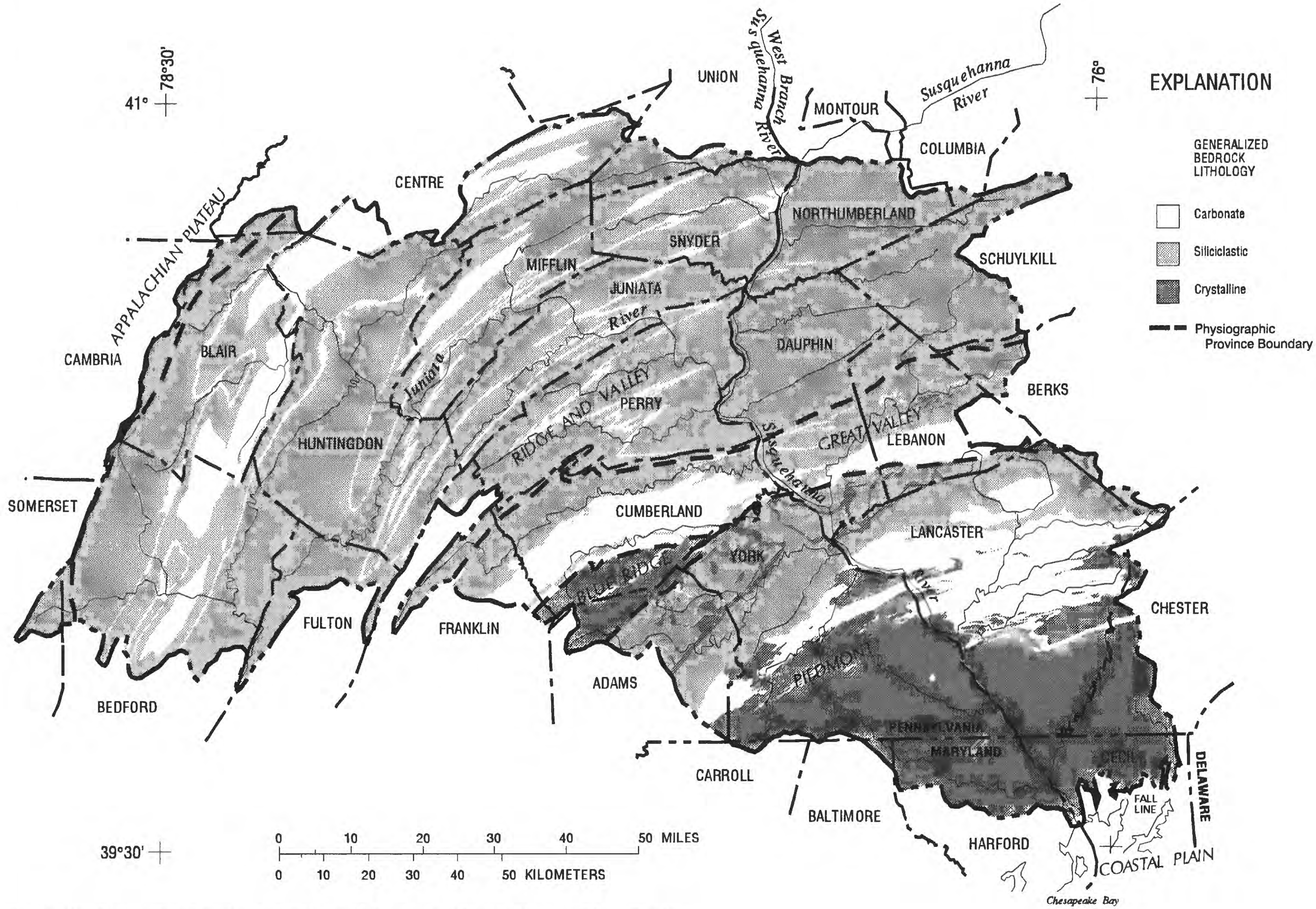



**Figure 2.** Generalized bedrock lithology of the Lower Susquehanna River Basin.

The Great Valley Section of the Ridge and Valley Physiographic Province is at the eastern edge of the province (fig. 2). The section, a broad 10- to 15-mi-wide valley, is unique in the province. This topography allows for slow runoff rates and long contact times with interactive materials. Water quality in this area is generally related to local environmental influences.

The Piedmont Physiographic Province, an area of low, rolling hills and broad valleys, makes up the southeastern third of the study unit (fig. 2). The topography and bedrock type in the northern part of this province allows generally slow-moving runoff to have a long contact time with interactive materials. Water quality in this part of the province is generally related to local environmental factors. Even though the runoff is slow-moving, high sediment erosion rates are common in the northern section of this province because of the exposure of thick, rich soils.

The topography of the southern part of the Piedmont Physiographic Province is the same as that in the northern part but is underlain by a bedrock type that promotes more rapid runoff. Water quality in this area is not as heavily influenced by local environmental factors.

## Geology

The structurally complex and diverse bedrock in the Lower Susquehanna River Basin ranges in age from Precambrian to Triassic (Berg and others, 1980). Metamorphic and igneous crystalline rocks (for example, schist, gneiss, gabbro, and quartzite) crop out in the southeastern part of the basin. Carbonate rocks (limestone and dolomite) crop out predominantly in two east-west trending bands near the south-central part of the basin, in a southwest to northeast band in the northwestern part of the study unit, and in thin ribbons in the center of the study unit. The remaining area of the Lower Susquehanna River Basin is underlain by siliciclastic rocks consisting of sandstone, shale, and siltstone (fig. 2). The geology of the study unit is described in greater detail by Risser and Siwiec (1996).

Of the three rock types just described, carbonate rocks—which weather more readily than the other types—contribute most to ground-water chemistry. Ground water from carbonate rocks commonly is elevated in dissolved solids, hardness, and pH with respect to those found in ground water from siliciclastic or crystalline rock. The median hardness of ground-water samples from carbonate rocks is about three times that for siliciclastic rocks and about six times that for crystalline rocks (Taylor and Werkheiser, 1984). Median pH of ground water in carbonate-rock areas is 7.5, and in areas underlain by crystalline rock the median pH is 6.0. Some siliciclastic rocks are coal bearing and contain pyrite (iron sulfide). The sulfide weathering of pyrite results in surface waters and ground waters of low pH and high concentrations of dissolved metals and sulfur.

Unconsolidated sediments consisting of glacial and riverbed deposits and materials deposited from the weathering of surface features and underlying bedrock cover most of the study unit. These sediments provide a potentially rich supply of soluble minerals to water as it percolates through the deposits toward the underlying aquifer. The amount of material dissolved and transported to ground water depends on the chemical quality of the infiltrating water, the solubility of the minerals, and the percolating water's contact time with the deposited materials.

Glacial deposits are present only in the north-central part of the Lower Susquehanna River Basin. Riverbed deposits are mainly in the Juniata and Susquehanna River valleys. Material created by the weathering of surface features, found mainly at the base of hillslopes in the Ridge and Valley and Blue Ridge Physiographic Provinces, covers about 30 percent of the land surface in the Ridge and Valley Physiographic Province.

Most surficial deposits in the study unit are formed from the weathering of crystalline and carbonate bedrock. In the Piedmont Physiographic Province, thickness of deposits ranges from 20 to 90 ft (Dennis Low, U.S. Geological Survey, Lemoyne, Pa., written commun., 1991). In the Blue Ridge Physiographic Province, which occupies a small area in the south-central part of the study unit, a deposit as much as 450 ft thick along one of the ridges steadily releases water to the underlying aquifer.

## Hydrogeologic Setting

In the Lower Susquehanna River Basin, physiography defines and controls the local, shallow ground-water flow systems common to the basin. The five major hydrogeologic settings are (1) crystalline rocks in the Piedmont and Blue Ridge Physiographic Provinces, (2) carbonate rocks in the Piedmont Physiographic Province, (3) siliciclastic rocks in the Piedmont Physiographic Province, (4) carbonate rocks in the Ridge and Valley Physiographic Province, and (5) siliciclastic rocks in the Ridge and Valley Physiographic Province. The major difference between each setting is physiography and rock type. These two factors are major controls of the runoff and infiltration characteristics and the potential chemical quality of the ground water. The settings are described in greater detail by Risser and Siwiec (1996).

## Climate

The climate of the Lower Susquehanna River Basin is controlled by a prevailing westerly circulation of air and the proximity of the basin to the Atlantic Ocean. The western part of the study unit has a humid continental climate characterized by large seasonal temperature variations, whereas the eastern part of the study unit has a more coastal-type climate characterized by moderated temperatures (U.S. Geological Survey, 1991).

Mean annual air temperature ranged from 46° to 55°F in the study unit during 1951-80. Mean daily air temperatures vary widely throughout the year, ranging from the low 20's in January to the mid 70's in July. The length of the growing season varies from 160 days in the north to 200 days in the south.

Mean annual precipitation ranged from 38 to 48 in. throughout the study unit during 1951-80. The mean annual precipitation is about 40 in. Areas that generally receive the most precipitation are the western edge and the southeastern part of the basin, primarily because of the mountain ridges and the Atlantic Ocean, respectively. On the average, slightly more than one-half of the annual precipitation falls during the nongrowing season (October through March); because evapotranspiration is at a minimum during these months much of this quantity is available for ground-water recharge. Additional detail on the climate of the study unit is given in Risser and Siwiec (1996, figs. 13 and 14).

## Surface-Water Hydrology

The Susquehanna River enters the study unit at Sunbury just downstream from the West Branch Susquehanna River confluence. The main stem above this confluence is known locally as the North Branch Susquehanna River. The West and North Branches provide about two-thirds of the outflow from the study unit. The Juniata River, a major tributary within the Lower Susquehanna River Basin, drains about one-third of the study unit and provides about 10 percent of the outflow. The study unit contains 31 tributary streams whose drainage areas are greater than 100 $mi^2$.

Runoff in inches indicates the depth to which the contributing watershed would be covered if all the streamflow for a given time period were uniformly distributed on it. Runoff in the Lower Susquehanna River Basin, as indicated by the flow measured at the streamflow-gaging site on the Susquehanna River at Conowingo, Md., near the mouth, averaged about 18 in. annually for the periods 1980-89 and 1951-80, an indication that streamflows during the 1980's were near normal. The period 1951-80 was used for the comparison because it was the latest 30-year climatological summary available. During 1980-89, runoff ranged from 13 to 27 in., and during 1951-80, it ranged from 16 to 26 in. Risser and Siwiec (1996, fig. 21) provide more information on this subject. Daily mean streamflows and summary statistics for all streamflow-monitoring sites in the Susquehanna River Basin are published in Annual Water Resources Data Reports for Pennsylvania (U.S. Geological Survey, 1980, 1981b, 1982b; Buchanan, 1983; Buchanan and others, 1984; Loper and others, 1985-91; Durlin and Schaffstall, 1992) and Maryland (U.S. Geological Survey, 1981a, 1982a; James and others, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990).

Annual streamflows at five selected streamflow-gaging sites for 1951-80 varied among the sites (fig. 3). Streamflow at sites near Harrisburg closely follows precipitation recorded during the same period at the meteorological site at Harrisburg (U.S. Department of Commerce, 1951-80). "Wet year" and "dry year" periods appear to have followed a decadal pattern during the 30-year period. In the 1950's, streamflows appear to have varied equally above and below the mean for the 30 years; in the 1960's, flows were generally below the average (a series of dry years); and in the 1970's, flows were generally above average (a series of wet years).

Natural streamflows also vary seasonally or monthly (fig. 4). In general, streamflows are highest during March and April. About 60 percent of streamflow is from February through May (Risser and Siwiec, 1996). Evapotranspiration during the growing season months of July, August, and September reduces streamflow to a minimum for the year. During these months, streamflow is primarily from ground water. According to analyses of 24 streamflow-gaging sites in the study unit, 55 to 88 percent of annual streamflow is from ground water.

## Water Use

Water use affects water quality by changing characteristics of the return water such as temperature, suspended solids, and concentrations of chemical constituents. In the Lower Susquehanna River Basin, the major water withdrawals are for power generation, industrial uses, and water supply for municipalities, livestock, and domestic use. Power generation accounts for 87 percent of the 3,820 Mgal/d of water used in the study unit. About 10 percent of this water is lost through evaporation from thermoelectric powerplants. The remaining water withdrawals are for nonpower uses and are drawn nearly evenly from surface- and ground-water sources. Of the 266 municipal supply systems in the study unit, 185 (70 percent) use ground water as their major source (Hollowell and others, 1991). The source of most agricultural water-supply systems in the study unit is ground water.

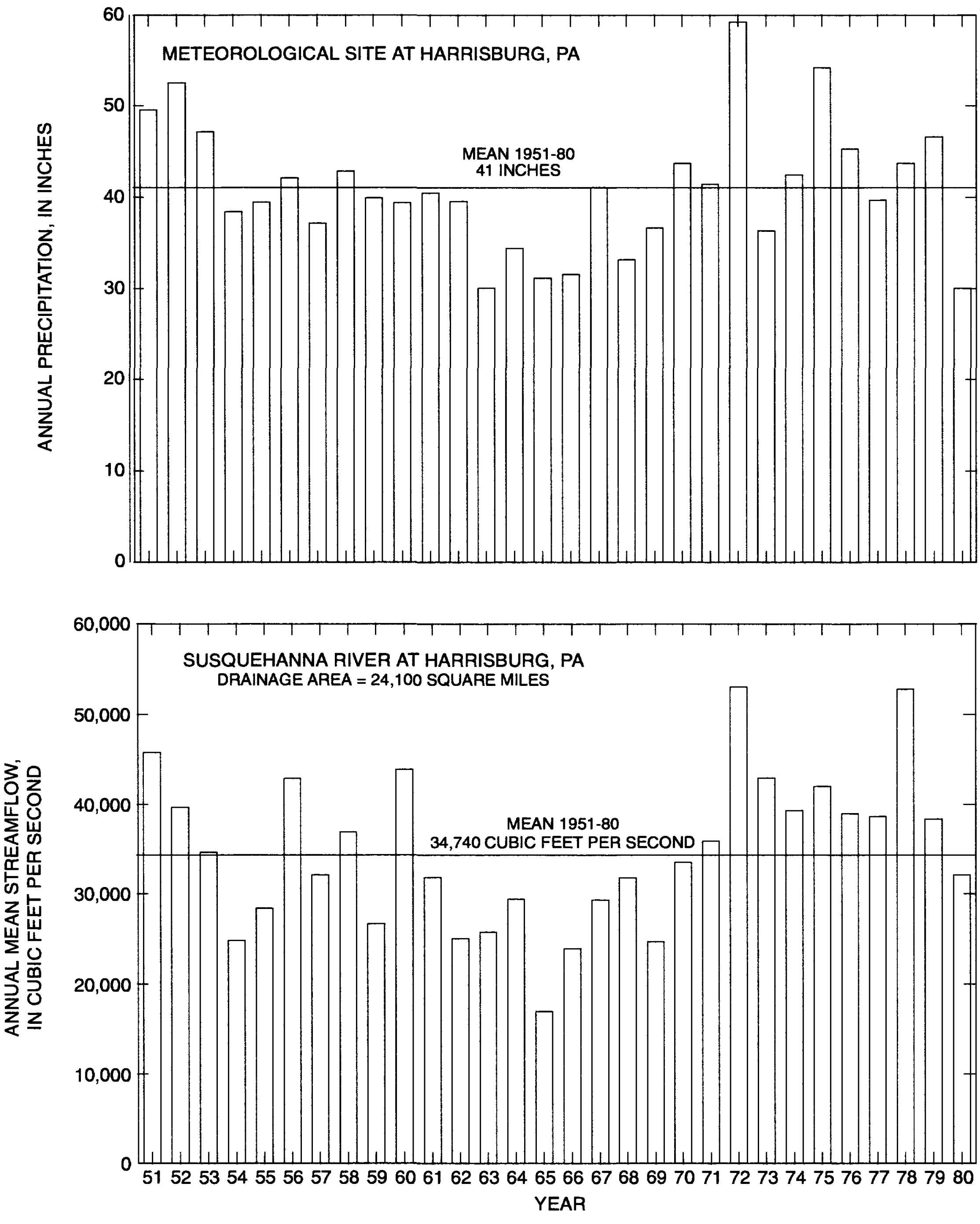



**Figure 3.** Annual precipitation at Harrisburg for 1951-80, and annual mean streamflows at selected sites in the Lower Susquehanna River Basin, by water year.

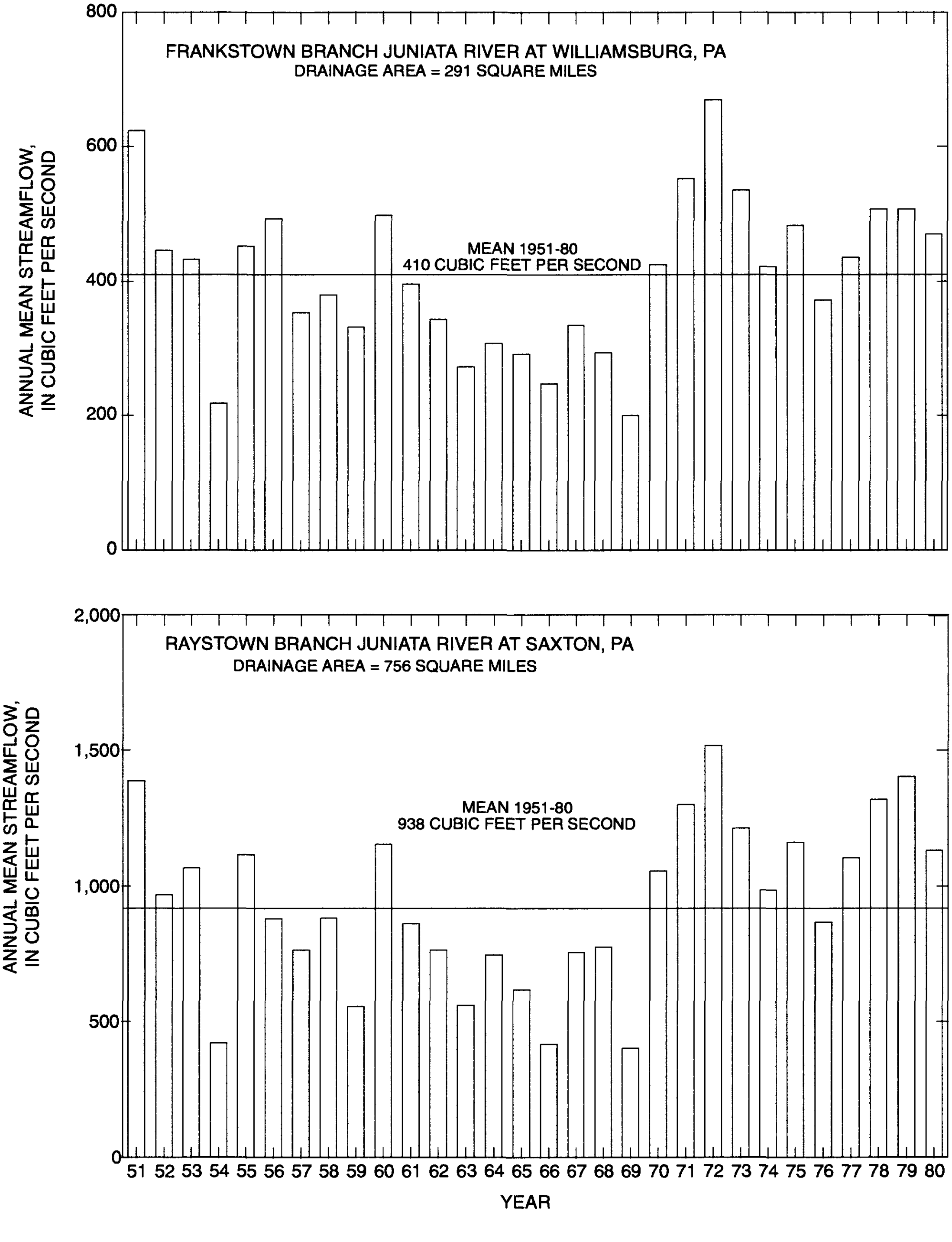
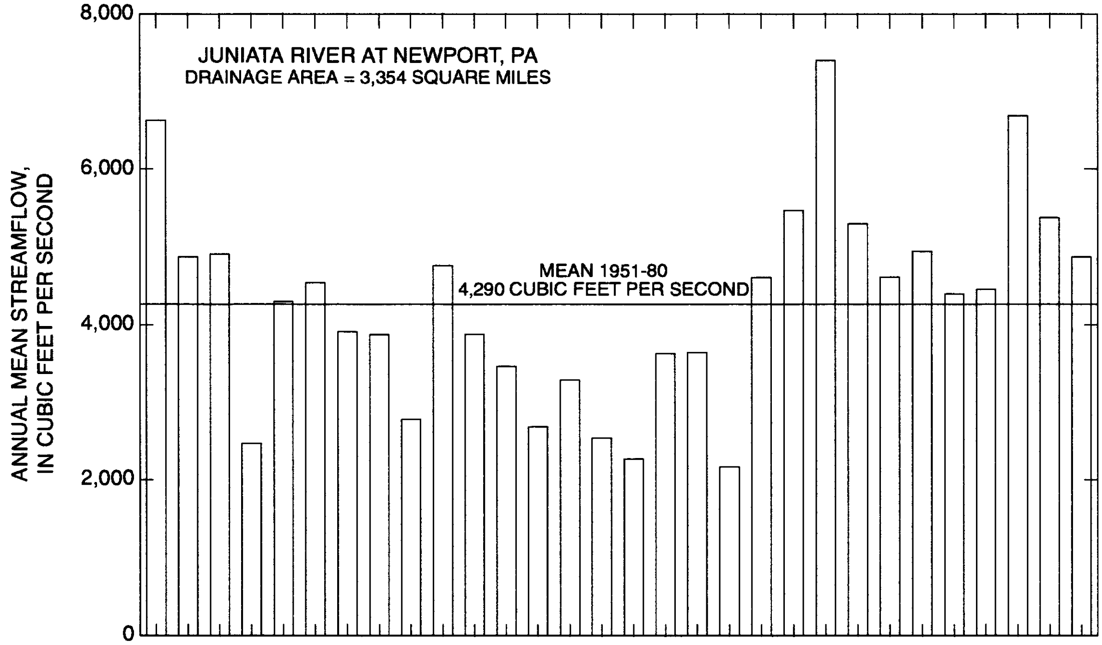



**Figure 3.** Annual precipitation at Harrisburg for 1951-80, and annual mean streamflows at selected sites in the Lower Susquehanna River Basin, by water year—Continued.



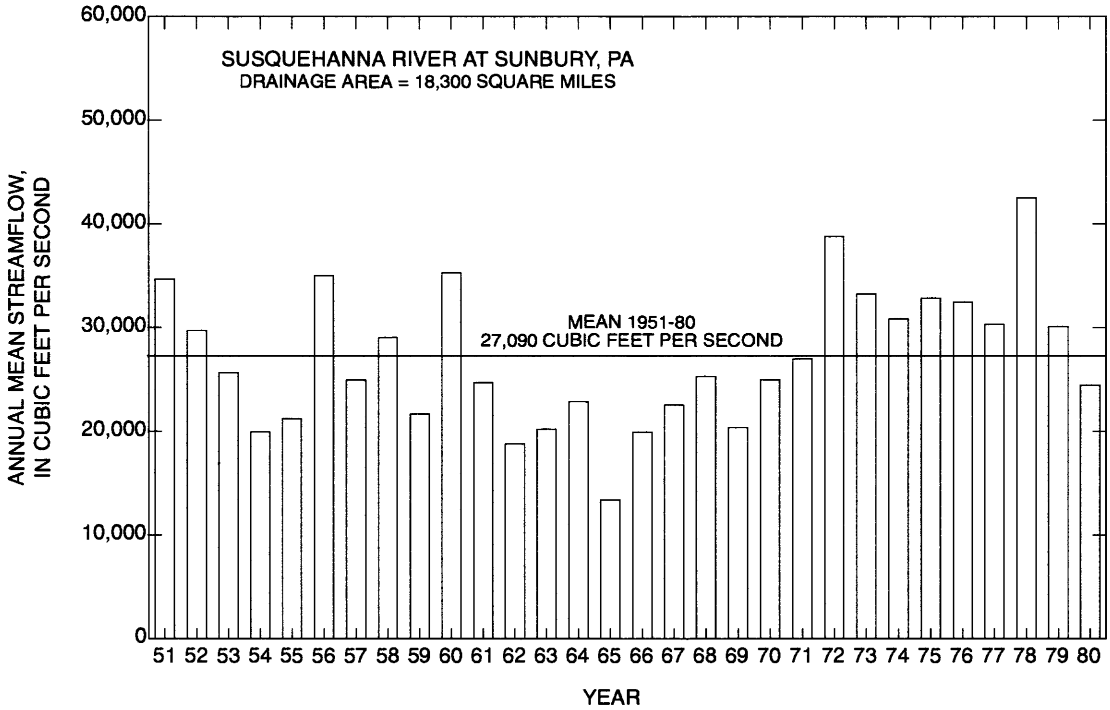




**Figure 3.** Annual precipitation at Harrisburg for 1951-80, and annual mean streamflows at selected sites in the Lower Susquehanna River Basin, by water year—Continued.

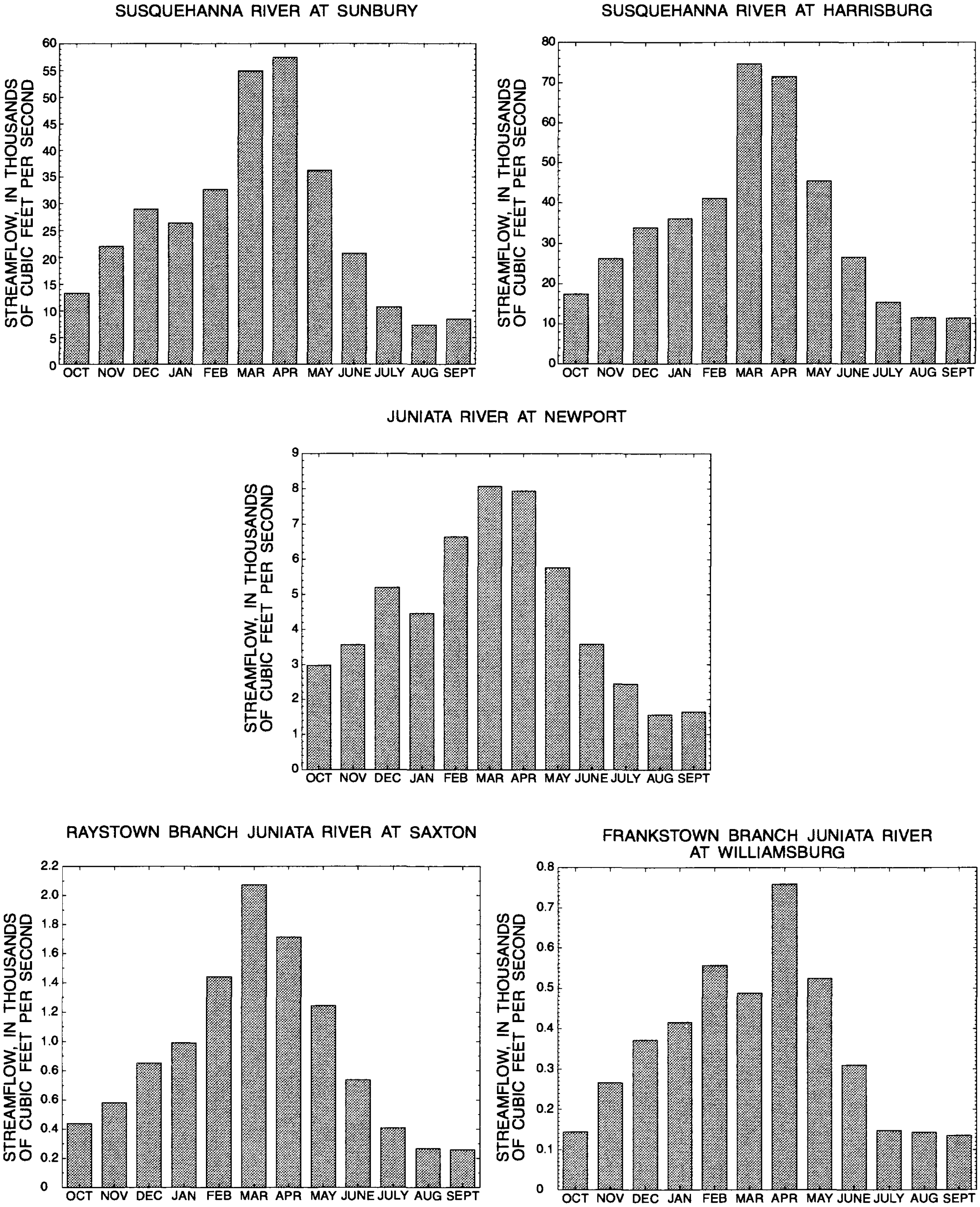



**Figure 4.** Average monthly streamflows at selected streamflow-gaging sites in the Lower Susquehanna River Basin for water years 1951-80.

## DESCRIPTION OF WATER QUALITY IN THE STUDY UNIT

Water quality in the study unit is affected by land use and land-use activities. Coal mining activity and agriculture have the most impact on water quality in the study unit (Risser and Siwiec, 1996). In the following sections, these and other activities and their effects on water quality are discussed. Known areas experiencing water-quality problems also are located and described.

### Effects of Land Use on Water Quality

Sources of water-quality degradation are usually concentrated in areas of intense land use. In the Lower Susquehanna River Basin, the major sources of contamination are mine drainage, agricultural runoff, urban runoff, urban and industrial waste discharges, atmospheric deposition, and septic-system effluent. Locations of degraded streams in the study unit are shown in Risser and Siwiec (1996, plate 3).

In Pennsylvania, abandoned-mine drainage, the single greatest source of surface-water-quality degradation, is responsible for nearly half of the total miles of streams degraded (Pennsylvania Department of Environmental Resources, 1992). Low pH of streams affected by mine drainage and the toxic properties of metals, as well as the smothering effects of iron precipitates, are the major water-quality problems caused by mine drainage. In the Lower Susquehanna River Basin, only the northwestern corner contains coal deposits, but the materials introduced by the mine drainage are transported into the river system and affect downstream water quality. Risser and Siwiec (1996) indicate that 65 percent of the stream miles in the study unit that do not meet their designated water-quality standards are contaminated by mine effluent.

Fifteen percent of the stream miles that do not meet designated water-quality standards are contaminated by agricultural runoff (Risser and Siwiec, 1996). About two-thirds of these streams are in the heavily-farmed area of the southeastern part of the study unit. Water-quality problems associated with agricultural land use are increased nutrient loads and habitat loss caused by siltation.

Two sources of agricultural contamination in runoff are commercial fertilizer and animal manure. Estimates of commercial fertilizer applications of nitrogen and phosphorus during 1945-85, summarized by county, are available from Alexander and Smith (1990). Data from this report were used to estimate fertilizer use for 1975, 1980, and 1985 in counties that are wholly or partly in the Lower Susquehanna River Basin (table 1).

As can be seen in table 1, nitrogen applications increased by nearly 10 percent from 1975 through 1980 but decreased slightly more than 20 percent from 1980 through 1985. Phosphorus applications decreased throughout the period; nearly 7 percent from 1975 through 1980 and about 17 percent from 1980 through 1985. The reasons for the changes between the 5-year periods were not investigated for this report. Lancaster County has the highest rate of commercial fertilizer application in the study unit.

A second data source on nutrient availability is a report produced by Petersen and others (1991). This report does not contain any quantified information on commercial fertilizer applications but does provide amounts of nitrogen and phosphorus available from manure. The amounts are based on 1987 U.S. Census Bureau figures on livestock numbers within an area defined by zip code. Petersen and others (1991) used empirical values for the amount of manure produced per animal type and the amount of nitrogen and phosphorus in the manure. The availability of each nutrient was provided, through an animal loading index, for each major stream basin in the study unit. The Chickies Creek Basin in Lancaster County was identified as having the highest animal-loading index in

**Table 1.** *Commercial fertilizer use in selected counties in the Lower Susquehanna River Basin for 1975, 1980, and 1985*

[Data from *Alexander and Smith, 1990;* counties with less than 5 percent of area in study unit are not included; lb/yr, pound per year]

| County[1] | Percent of county in study unit | Nitrogen (1,000 lb/yr) | | | Phosphorus (1,000 lb/yr) | | |
|---|---|---|---|---|---|---|---|
| | | 1975 | 1980 | 1985 | 1975 | 1980 | 1985 |
| Adams | 52 | 5,244 | 5,495 | 4,288 | 2,249 | 2,012 | 1,509 |
| Bedford | 71 | 2,977 | 3,494 | 3,081 | 1,277 | 1,279 | 1,084 |
| Berks | 11 | 8,175 | 8,468 | 6,735 | 3,506 | 3,101 | 2,369 |
| Blair | 100 | 2,067 | 2,253 | 1,633 | 887 | 825 | 574 |
| Centre | 26 | 2,990 | 3,494 | 2,882 | 1,282 | 1,279 | 1,014 |
| Chester | 12 | 5,739 | 6,053 | 5,247 | 2,461 | 2,216 | 1,846 |
| Cumberland | 100 | 4,471 | 4,634 | 3,675 | 1,918 | 1,697 | 1,293 |
| Dauphin | 100 | 3,010 | 3,478 | 2,580 | 1,291 | 1,273 | 908 |
| Franklin | 21 | 7,171 | 7,746 | 6,148 | 3,076 | 2,836 | 2,163 |
| Fulton | 34 | 1,175 | 1,456 | 1,354 | 504 | 533 | 476 |
| Huntingdon | 100 | 2,046 | 2,536 | 1,706 | 878 | 928 | 600 |
| Juniata | 100 | 1,999 | 1,794 | 1,549 | 857 | 657 | 545 |
| Lancaster | 100 | 14,890 | 15,321 | 12,037 | 6,386 | 5,610 | 4,235 |
| Lebanon | 86 | 3,588 | 4,053 | 3,333 | 1,539 | 1,484 | 1,173 |
| Mifflin | 100 | 2,016 | 2,247 | 1,545 | 865 | 823 | 544 |
| Northumberland | 63 | 3,248 | 3,855 | 2,864 | 1,393 | 1,412 | 1,008 |
| Perry | 100 | 2,454 | 2,682 | 2,039 | 1,052 | 982 | 717 |
| Schuylkill | 42 | 2,625 | 3,457 | 2,218 | 1,126 | 1,266 | 780 |
| Snyder | 100 | 2,237 | 2,446 | 1,780 | 959 | 895 | 626 |
| Union | 23 | 1,933 | 1,986 | 1,934 | 829 | 727 | 681 |
| York | 100 | 9,530 | 9,903 | 7,660 | 4,087 | 3,626 | 2,695 |
| Cecil, Md. | 39 | 4,306 | 5,829 | 4,212 | 1,582 | 1,845 | 1,093 |
| Harford, Md. | 42 | 3,795 | 5,569 | 5,660 | 1,394 | 1,762 | 1,469 |
| STUDY UNIT TOTAL[2] | | 63,784 | 69,755 | 54,559 | 27,155 | 25,311 | 20,933 |

[1]Pennsylvania unless otherwise noted.

[2]Total derived from sum of products of percent area within study unit and annual total.

the Commonwealth. The Conestoga River Basin, which drains most of Lancaster County, had the second-highest animal loading index in the study unit (fig. 1). Nitrogen and phosphorus from manure available for runoff into surface water (in thousands of pounds per year) for the watersheds in the study unit with the largest loads are shown in figure 5.

Urban runoff and municipal and industrial discharges account for another 10 percent of the contaminated stream miles. Runoff and discharges from these sources introduce high concentrations of nutrients, heavy metals, organic contaminants, and other oxygen-consuming materials. An additional 4 percent of the contaminated stream miles are degraded by the introduction of high concentrations of nutrients from onsite wastewater (septic) systems. The degradation of the remaining stream miles that do not meet their designated water-quality standards is accounted for by atmospheric deposition and natural conditions. Low pH of precipitation in Pennsylvania adversely affects poorly buffered headwater streams.

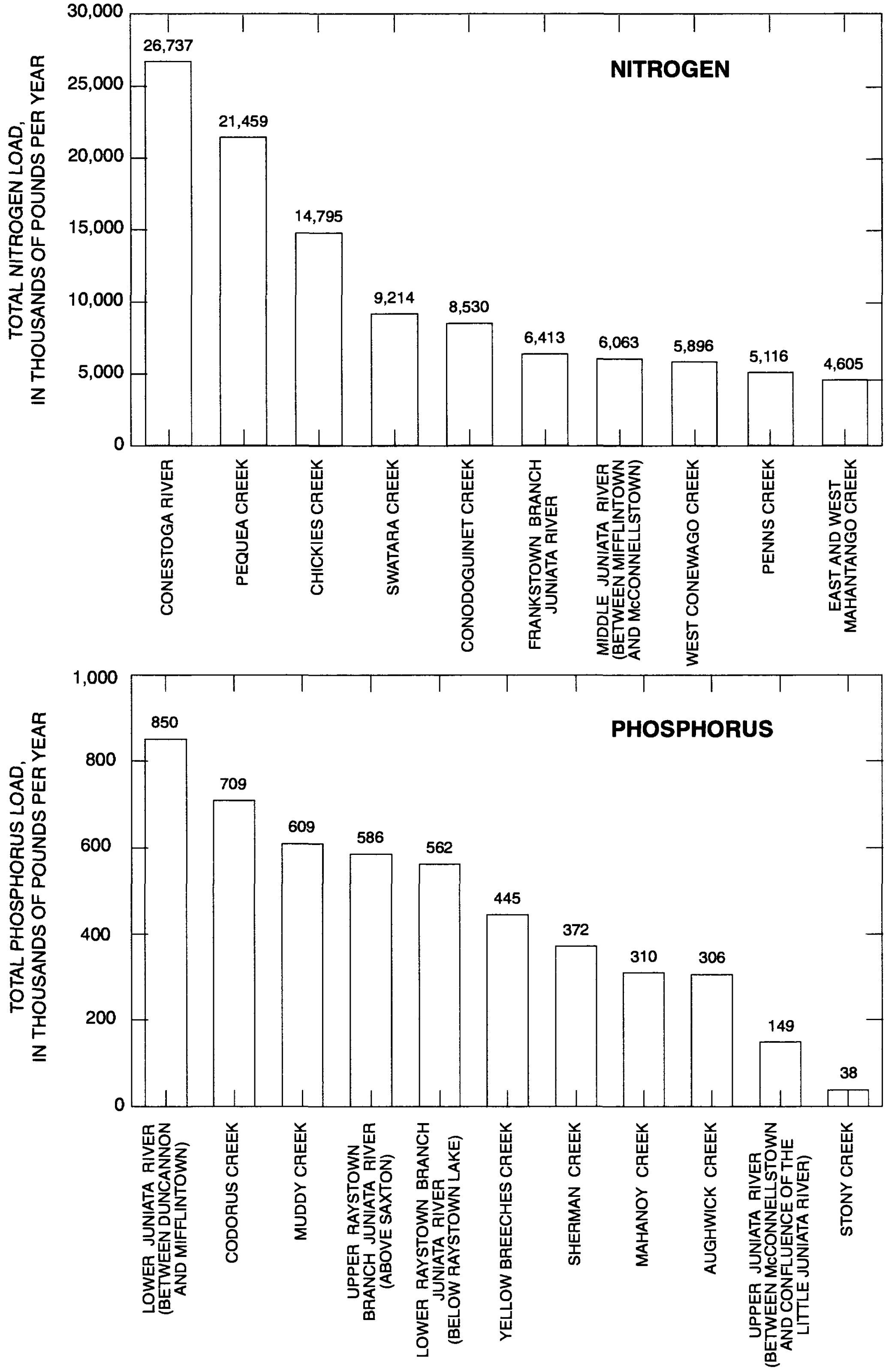



**Figure 5.** Nitrogen and phosphorus loads from manure available for surface runoff in selected watersheds in the Lower Susquehanna River Basin, 1987.

## Location of Known Water-Quality Problems

The chemistry of precipitation on the Lower Susquehanna River Basin has been greatly affected by humans (Turk, 1983). Emissions of sulfur and nitrogen oxides to the atmosphere have caused some of the most acidic precipitation in the Nation. During 1982-88, the spatial distribution of precipitation-weighted multiannual mean pH of precipitation in the basin ranged from 4.08 to 4.20 (Lynch, 1990). Precipitation is believed to contribute from 25 to 40 percent of the nitrogen load to the Chesapeake Bay (Fisher and others, 1988).

As stated in the land-use section, abandoned-mine drainage and agricultural practices are the two major causes of water-quality degradation in Pennsylvania (Risser and Siwiec, 1996; Pennsylvania Department of Environmental Resources, 1992). Streams degraded by agricultural runoff are affected by siltation and elevated nutrient concentrations, primarily forms of nitrogen and phosphorus. The predominantly agricultural area in the southeastern part of the study unit contains most of the stream miles contaminated by agricultural runoff. Most of the streams are in the Conestoga River and Pequea Creek Basins. Small areas in the Raystown Branch Juniata River and the Swatara Creek Basins also are affected by agricultural runoff (fig. 1).

Other nutrient sources are industrial and municipal point sources, onsite wastewater systems, and urban runoff. In the Lower Juniata River Basin, 99 percent of the 944 miles of streams that have been assessed as of 1992 are unimpaired. However, industrial and municipal point sources, mainly in the Kishacoquillas Creek Basin, are responsible for 60 percent of the stream miles that are degraded.

Industrial and municipal point sources and urban runoff are a cause of water-quality degradation in the Upper Juniata River Basin for about 20 percent of the degraded streams, and onsite wastewater systems are the cause for another 20 percent of the streams. Most of these affected reaches are short (less than 10 mi) and are scattered throughout the basin. This subbasin of the study unit has the largest number of stream miles degraded by point sources, urban runoff, and on-site systems.

## DESCRIPTION OF NUTRIENT AND SUSPENDED-SEDIMENT DATA SOURCES AND ANALYTICAL METHODS

### Data-Collection Programs and Objectives

Three major databases were examined to determine their feasibility for use in the analysis of suspended-sediment and nutrient data: the USGS National Water Information System (NWIS), non-USGS water-quality data in the U.S. Environmental Protection Agency (USEPA) STORET system, and a U.S. Department of Energy (DOE) National Uranium Resource Evaluation (NURE) database. In addition, data and conclusions from published reports of various other sources are included herein. The number of sites and nutrient and suspended-sediment samples collected from within the Lower Susquehanna River Basin that were in each of the three databases for water years 1980-89 are listed in table 2. For this report, the term "available" is defined as readily acquired and in an electronic form. "Nutrient" data include all forms of nitrogen and phosphorus detected in water and bottom material, and "well" data include nitrogen and phosphorus detected in ground-water wells.

**Table 2.** *Number of sites and available nutrient analyses for the Lower Susquehanna River Basin in water-quality databases for water years 1980-89*

[NWIS, National Water Information System; STORET, Storage and Retrieval; NURE, National Uranium Resource Evaluation]

| Data-collection source | Water-quality databases | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|
| | NWIS | | STORET | | NURE | | | |
| | Number of analyses | Number of sites | Number of analyses | Number of sites | Number of analyses | Number of sites | Number of analyses | Number of sites |
| Streams | 14,322 | 91 | 6,619 | 401 | 0 | 0 | 20,961 | 502 |
| Springs | 294 | 21 | 290 | 39 | 0 | 0 | 584 | 60 |
| Wells | 2,588 | 849 | 2,256 | 308 | 0 | 0 | 4,844 | 1,157 |
| Bottom material | 56 | 54 | 0 | 0 | 840 | 840 | 896 | 894 |
| Precipitation | 0 | 0 | 1,352 | 3 | 0 | 0 | 1,352 | 3 |
| TOTAL | 17,270 | 1,015 | 10,517 | 751 | 840 | 840 | 28,637 | 2,618 |

Most NWIS samples were collected by the USGS, but some were collected by personnel of the Pennsylvania Department of Environmental Protection (PaDEP)[1] and the Susquehanna River Basin Commission (SRBC). About three-fourths of the samples in the NWIS database were analyzed by the USGS National Water Quality Laboratory; the remaining samples were analyzed by PaDEP laboratories.

The objectives of studies for which the data stored in NWIS were collected fall under three principal categories: (1) long-term monitoring of concentrations or loads at specific sites, (2) reconnaissance to determine water quality in a selected area, or (3) research of hydrologic and water-quality processes in small areas.

[1] Prior to 1995, the Pennsylvania Department of Environmental Protection was known as the Pennsylvania Department of Environmental Resources.

The STORET database is a repository for data from several State and Federal agencies, including the USGS. The most common collectors of data in the study unit, other than the USGS, are the USEPA who maintains the database, the Maryland Department of the Environment (MDE), the PaDEP, and SRBC. Data in the STORET database were collected for various reasons. Generally, the data were collected for the same reasons as those given for the NWIS database; but because several regulatory agencies also use this database, data collected specifically for monitoring of permitted discharges and their effect on quality of receiving waters also are included.

The data for NURE were collected by DOE prime contractors, the DOE itself, DOE-sponsored research and development groups, the USGS, the U.S. Bureau of Mines, and other Federal and state agencies (Heffner, 1979). The primary purpose of data collection for this program was to assess the uranium reserves of the United States and to identify new areas favorable for uranium exploration by industry. Most data were collected in the late 1970's; but because of the wide areal coverage in the study unit, they were included in this analysis. Because the data sites were located to meet density requirements for sampling sites and were not directed towards specific sites, the data provide geographically unbiased background information.

## Data-Selection Methods

The NWIS water-quality database was selected as the primary database for analysis. It contains a sufficient number of analyses and sites to provide a reasonable understanding, with some shortcomings, of the current water quality in the Lower Susquehanna River Basin during the 1980's; the emphasis is on nutrients and sediment. The use of one primary database also eliminates the need to compare results from different laboratory analytical methods. Exceptions to this were use of NURE bottom-material nutrient data to provide another line of evidence of water quality, and use of the three STORET precipitation-quality sites. Data comparable to those in the alternative databases were not available in NWIS. In addition, the time period analyzed was extended to include bottom-material data collected in 1977 throughout the study unit and in 1990 and 1991 from three consecutive reservoirs on the Lower Susquehanna River.

Various programs and objectives produced the data stored in NWIS. The storage of data in this one system created an assemblage of data that were collected at different times, at different frequencies, and for different nutrient species. As a first step in sorting the data into similar groups, the sites were grouped by program, and then the program groups with similar data-collection objectives were assembled into data sets. This sorting method provided a data set that could be compared within itself and, together, the sites could be used to provide insight into the water quality in the study unit.

For example, the nutrient data for streams in the study unit for long-term monitoring generally included a broad suite of nutrients at regular intervals at specific sites over several years. Water-quality reconnaissance consisted of collecting one or two samples at many sites during a short period, generally 2 to 4 weeks. Nutrient data collected to assist in the understanding of hydrologic and water-quality processes are common to programs that provide information to managers so that they can determine ways to control a mechanism that degrades water quality. Data for these process-understanding programs are collected at streams, springs, and wells that generally drain very small areas, such as field plots, and receive recharge from the same areas. The data are collected at regular intervals and during specific hydrologic events, such as high flows or low flows. The constituents of interest are generally only those that are specific to the problem being studied. The three program objectives were used to divide the stream, spring, well, and bottom-material data sets into three discrete groups: Long-term Monitoring Sites, Synoptic Areal Survey Sites, and Project and Research Sites.

## Methods of Analysis

Data that are grouped together with similar data-collection objectives are summarized primarily by bar graphs, boxplots, and line graphs. Previously published analyses and conclusions also are used. An attempt was made not to duplicate the efforts of any previous investigations.

A few concentrations were stored as censored values. Censored values are those that have been qualified by some sort of remark such as "less-than" or "estimated." Censored nutrient concentrations were less than 10 percent of the total number of concentration values available for analysis and were stored as a concentration less than the detection limit. For this reason, and because of the large number of uncensored concentrations available (generally 1,000 or more), the censored concentrations were considered to be insignificant for the statistical analysis and were not used.

The following logic was used for statistically summarizing the data. For data sets or subsets with fewer than 10 observations, only a median was reported. For data sets with 10 to 15 observations, only 25th, 50th (median), and 75th percentiles were reported. For data sets with 16 to 99 observations, the 10th and 90th percentiles were used because they are statistically valid. For data sets with more than 99 observations, the 1st, 25th, 50th, 75th, and 99th percentiles were reported. This logic also was followed for boxplots, with the exception that 1st and 99th percentiles are shown for all data sets consisting of more than 15 observations.

Methods used for hypothesis tests, for trend tests, and for developing boxplots followed those described in Hirsch and others (1991) and Helsel and Hirsch (1992). The statistical significance of differences between medians of data sets or subsets were determined by use of the Kruskal-Wallis test described in Helsel and Hirsch (1992). Locally weighted scatterplot smooth (LOWESS) curves were used to assist in determining relations between variables and to show any possible tendencies. Techniques for this procedure are described in Cleveland (1985) and Helsel and Hirsch (1992). LOWESS curves are a graphical technique and are not the result of a statistical analysis. The curves may indicate a general direction or tendency, but it may not be statistically significant.

Estimates of stream nutrient and suspended-sediment loads not published previously were developed on the basis of procedures described by Cohn and others (1989). Estimates of atmospheric loads not published previously were developed on the basis of procedures described by Sisterson (1990).

## Description of Data-Collection Sites

The grouping of sites as described in the previous section resulted in 10 distinct data sets. Analyses of stream samples were divided into three data sets: springs, wells, and bottom material into two data sets each, and one data set for precipitation analyses (table 3). These data sets are a subset of the databases listed in table 2. All nutrient analyses available in the databases (regardless of the form of nitrogen or phosphorus) and the number of sites where these data were collected are summarized in table 2. Information about only those analyses and sites that could be associated with a collecting and analyzing agency and only for specific forms of nutrients (dissolved nitrite plus nitrate, total phosphorus, and suspended sediment) are summarized in table 3. The analyzing agency shown for each group in table 3 is the agency associated with the nitrogen and phosphorus analyses. Almost all the suspended-sediment analyses were performed in the USGS sediment laboratory in Lemoyne, Pa.

**Table 3.** *Description of data sets, number of sites, and number of selected nutrient analyses in the Lower Susquehanna River Basin, water years 1980-89*

[N, dissolved nitrite plus nitrate; P, total phosphorus; S, suspended sediment
Collecting agency: USGS, U.S. Geological Survey; SRBC, Susquehanna River Basin Commission; PaDEP, Pennsylvania Department of Environmental Protection; U.S. DOE, U.S. Department of Energy; NADP, National Atmospheric Deposition Program; NPS, National Park Service
Analyzing agency: USGS, National Water Quality Laboratories in Doraville, Ga., or Lakewood, Co.; PaDEP, Pennsylvania Department of Environmental Protection Water Quality Laboratory; U.S. DOE, Department of Energy Contract Laboratory; NADP, Illinois State Water Survey Board Laboratory; PSU, Water Quality Laboratory of the Environmental Resources Research Institute, Pennsylvania State University
Collection method: EWI, equal width increment; GRB, grab or hand-dipped; COR, core; ATS, autosampler
Collection frequency: M, monthly; Q, quarterly; S, storms; D, daily; Y, yearly; O, once; I, intermittent; W, weekly; 6M, semi-annually; T, once or twice
Database: NWIS, National Water Information System; NURE, National Uranium Resource Evaluation; STORET, Storage and Retrieval]

| Collecting agency | Analyzing agency | Collection method | Collection frequency | Sampling period | Database | Number of sites | | | Number of analyses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | N | P | S | N | P | S |
| | | | Streams - long-term monitoring sites | | | | | | | | |
| USGS | USGS | EWI | M, Q, S | 1980-89 | NWIS | 7 | 10 | 7 | 682 | 728 | 1,093 |
| USGS | PaDEP | EWI | M, S | 1987-89 | NWIS | 1 | 1 | 1 | 115 | 115 | 86 |
| SRBC | USGS | EWI | M, S | 1984-85 | NWIS | 11 | 11 | 11 | 13 | 248 | 250 |
| SRBC | PaDEP | EWI | M, S | 1985-89 | NWIS | 13 | 13 | 13 | 1,128 | 2,463 | 2,436 |
| PaDEP | PaDEP | EWI | D | 1989 | NWIS | 1 | 1 | 1 | 26 | 26 | 21 |
| | | | Streams - synoptic areal survey sites | | | | | | | | |
| USGS | USGS | GRB, EWI | M, Y, S | 1980-89 | NWIS | 10 | 31 | 17 | 64 | 167 | 324 |
| USGS | PaDEP | GRB, EWI | M | 1985-86 | NWIS | 2 | 2 | 2 | 40 | 40 | 39 |
| PaDEP | PaDEP | GRB | O | 1982 | NWIS | 0 | 1 | 1 | 0 | 3 | 3 |
| | | | Streams - project and research sites | | | | | | | | |
| USGS | USGS | GRB, EWI | M, S | 1981-89 | NWIS | 15 | 18 | 22 | 874 | 1,479 | 4,874 |
| USGS | PaDEP | GRB, EWI | M, S | 1982-89 | NWIS | 14 | 14 | 14 | 1,065 | 3,145 | 2,395 |
| SRBC | USGS | GRB, EWI | M, S | 1985 | NWIS | 0 | 1 | 1 | 0 | 18 | 18 |
| SRBC | PaDEP | GRB | M, S | 1985-86 | NWIS | 1 | 1 | 1 | 43 | 43 | 43 |
| PaDEP | PaDEP | GRB | S | 1982 | NWIS | 0 | 3 | 3 | 0 | 46 | 45 |
| | | | Springs - synoptic areal survey sites | | | | | | | | |
| USGS | PaDEP | GRB | O | 1985 | NWIS | 10 | 0 | 0 | 10 | 0 | 0 |
| | | | Springs - project and research sites | | | | | | | | |
| USGS | USGS | GRB | I | 1987 | NWIS | 2 | 0 | 0 | 4 | 0 | 0 |
| USGS | PaDEP | GRB | W, Q | 1983-87 | NWIS | 4 | 4 | 0 | 269 | 55 | 0 |
| | | | Wells - synoptic areal survey sites | | | | | | | | |
| USGS | USGS | | 6M, Y | 1981-89 | NWIS | 80 | 150 | 0 | 160 | 255 | 0 |
| USGS | PaDEP | | I | 1980-89 | NWIS | 422 | 110 | 0 | 427 | 112 | 0 |
| SRBC | PaDEP | | T | 1980-89 | NWIS | 144 | 0 | 0 | 144 | 0 | 0 |
| PaDEP | PaDEP | | O | 1981 | NWIS | 55 | 0 | 0 | 55 | 0 | 0 |
| | | | Wells - project and research sites | | | | | | | | |
| USGS | USGS | | I, Q | 1982-86 | NWIS | 6 | 4 | 0 | 12 | 10 | 0 |
| USGS | PaDEP | | M | 1981,83-89 | NWIS | 20 | 17 | 0 | 236 | 41 | 0 |
| | | | Bottom material - synoptic areal survey sites | | | | | | | | |
| U.S. DOE | U.S. DOE | GRB | O | 1977 | NURE | 0 | 840 | 0 | 0 | 840 | 0 |

**Table 3.** *Description of data sets, number of sites, and number of selected nutrient analyses in the Lower Susquehanna River Basin, water years 1980-89—Continued*

[N, dissolved nitrite plus nitrate; P, total phosphorus; S, suspended sediment
Collecting agency: USGS, U.S. Geological Survey; SRBC, Susquehanna River Basin Commission; PaDEP, Pennsylvania Department of Environmental Protection; U.S. DOE, U.S. Department of Energy; NADP, National Atmospheric Deposition Program; NPS, National Park Service
Analyzing agency: USGS, National Water Quality Laboratories in Doraville, Ga., or Lakewood, Co.; PaDEP, Pennsylvania Department of Environmental Protection Water Quality Laboratory; U.S. DOE, Department of Energy Contract Laboratory; NADP, Illinois State Water Survey Board Laboratory; PSU, Water Quality Laboratory of the Environmental Resources Research Institute, Pennsylvania State University
Collection method: EWI, equal width increment; GRB, grab or hand-dipped; COR, core; ATS, autosampler
Collection frequency: M, monthly; Q, quarterly; S, storms; D, daily; Y, yearly; O, once; I, intermittent; W, weekly; 6M, semi-annually; T, once or twice
Database: NWIS, National Water Information System; NURE, National Uranium Resource Evaluation; STORET, Storage and Retrieval]

| Collecting agency | Analyzing agency | Collection method | Collection frequency | Sampling period | Database | Number of sites | | | Number of analyses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | N | P | S | N | P | S |
| | | | | Bottom material - project and research sites | | | | | | | |
| USGS | USGS | COR | O | 1990-91 | NWIS | 0 | 53 | 0 | 0 | 53 | 0 |
| USGS | USGS | GRB | T | 1980 | NWIS | 1 | 1 | 0 | 1 | 2 | 0 |
| | | | | Precipitation - long-term monitoring | | | | | | | |
| NADP | NADP | ATS | W | 1980-89 | STORET | 1 | 0 | 0 | 452 | 0 | 0 |
| PaDEP | PSU | ATS | W | 1983-89 | STORET | 1 | 0 | 0 | 377 | 0 | 0 |
| NPS | PSU | ATS | W | 1984-89 | STORET | 1 | 0 | 0 | 327 | 0 | 0 |

## Quality Assurance of Available Data

Most data used in this retrospective analysis were collected and analyzed by the USGS or under USGS supervision. Quality-assurance practices for the collection and analysis of USGS data are documented by Friedman and Erdmann (1982). Recent internal memorandums have described biases in methods used previously to determine concentrations at the USGS National Water Quality Laboratories for total phosphorus, ammonia, nitrite, and nitrite plus nitrate.

Concentrations of total phosphorus in samples analyzed by the USGS from 1973 through 1990 had a negative bias because of the incomplete digestion of suspended sediment during sample preparation. Only samples whose concentrations of suspended sediment exceeded 50 mg/L appear to have been affected. A new sample preparation method was instituted in 1990. Herein, trends are not affected by the bias because the method was constant throughout water years 1980-89; however, loads computed during this period may be lower than the actual loads.

Another recent USGS memorandum described a negative bias in concentrations reported. This situation also was created by the incomplete digestion of samples. The bias was determined for analyses of total ammonia, total nitrite, and total nitrite plus nitrate. Again, trends during water years 1980-89 are not affected because the method was changed in 1992; however, estimates of loads for this period may be low.

PaDEP and SRBC Quality Assurance plans are described in internal documents and can be requested from those agencies. Quality assurance for the data collected in the NURE program by DOE is documented in Appendix D of Heffner (1979). Quality assurance for data collected by the NADP program is documented in National Atmospheric Deposition Program (1984).

## CHARACTERISTICS OF NUTRIENT AND SUSPENDED-SEDIMENT DATA

This section of the report describes the available nutrient and suspended-sediment data. The sites of data collection are shown in relation to their location within the Lower Susquehanna River Basin. In addition, samples are described in terms of when they were collected and of hydrologic conditions during the sampling. Concentrations and loads of nutrients and suspended sediment are described in relation to the physical setting that they represent, and trends, if any, are shown.

The types and number of sites used in the analyses described herein are listed in table 3. When available, data for the following constituents were retrieved for possible analysis (constituents that are underlined were those examined in most detail): (1) dissolved and total ammonia, (2) dissolved and total ammonia plus organic nitrogen, (3) dissolved and total organic nitrogen, (4) dissolved and total nitrite, (5) dissolved and total nitrite plus nitrate, (6) dissolved and total nitrate, (7) dissolved and total nitrogen, (8) dissolved and total phosphorus as orthophosphate, (9) dissolved and total phosphorus, (10) suspended sediment, and (11) suspended sediment, percentage less than 0.062 mm.

Because most nitrogen in streams and ground water is generally in the form of nitrate (Hem, 1992), the primary forms of nitrogen used for data analysis were dissolved nitrite plus nitrate. If dissolved nitrite plus nitrate concentrations were not available for analysis, total nitrite plus nitrate or dissolved nitrate concentrations were substituted. Similarly, because most phosphorus is transported while sorbed to sediments (Hem, 1992), total phosphorus was used as the primary form of phosphorus for this data analysis. In ground water, because of the lack of particulate matter, concentrations of total and dissolved forms of phosphorus are considered equivalent. If total phosphorus concentrations were not available for analysis, dissolved phosphorus or dissolved orthophosphate concentrations were substituted. Hence-forth, the term "nitrate" is used as an equivalent term for "dissolved nitrite plus nitrate," and the term "phosphorus" is used as an equivalent term for "total phosphorus." Any deviation from these initial selections and this nomenclature will be explained in the text or figures. In addition, all years mentioned are water years.

The number of analyses completed during 1980-89 for nitrate (dissolved nitrate as nitrate for wells) and dissolved ammonia from the various sources were compared (fig. 6). Similarly, the number of phosphorus and dissolved orthophosphate analyses were compared (fig. 7). For this comparison, all analyses were counted separately, including multiple analyses in a single day from one site. For ammonia and nitrate (fig. 6), four to five times more analyses were available from stream samples than from the other sample media. For orthophosphate and phosphorus (fig. 7), 10 to 20 times more analyses were available for stream samples than for the other sample media. For all four constituents, the second highest number of analyses were available for ground water.

The number of total and dissolved analyses completed during 1980-89 for the same constituents are given in table 4. Total analyses are derived from unfiltered samples and generally include a digestion of particulate matter before analyses are completed. Dissolved analyses are completed from water samples that were passed through a 0.45-micrometer filter. For the analyses of stream samples, total analyses outnumbered dissolved analyses by about 1.5 to 1 for all the constituents except orthophosphate; more than 80 percent of the orthophosphate analyses were dissolved. For springs and wells, dissolved analyses outnumbered total analyses by about 3 to 1.

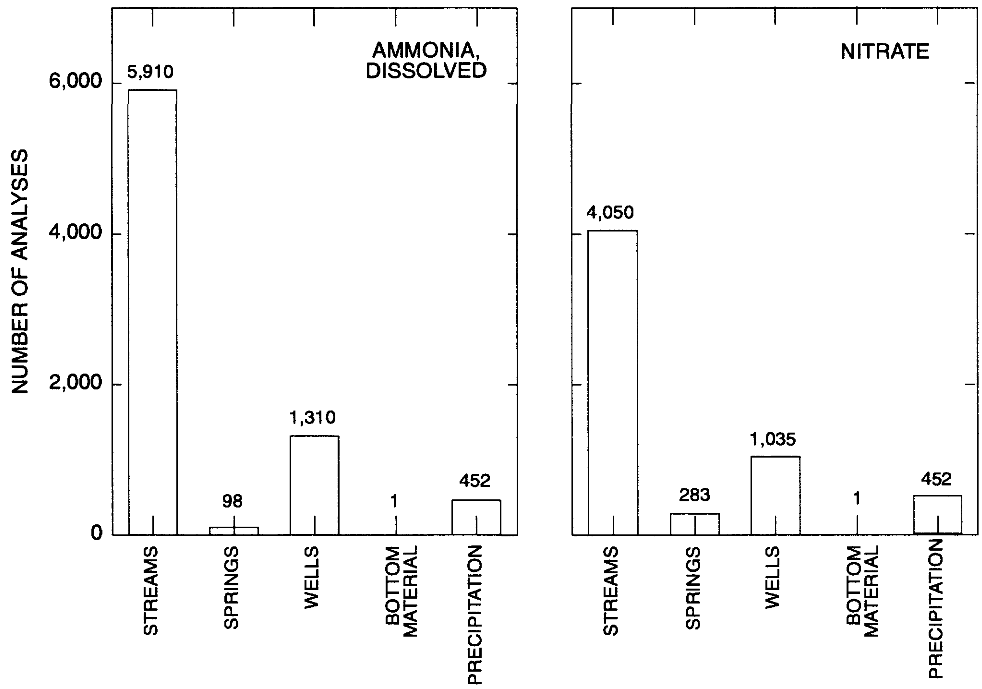



**Figure 6.** Number of analyses for ammonia and nitrate from five selected sample media, water years 1980-89, Lower Susquehanna River Basin.

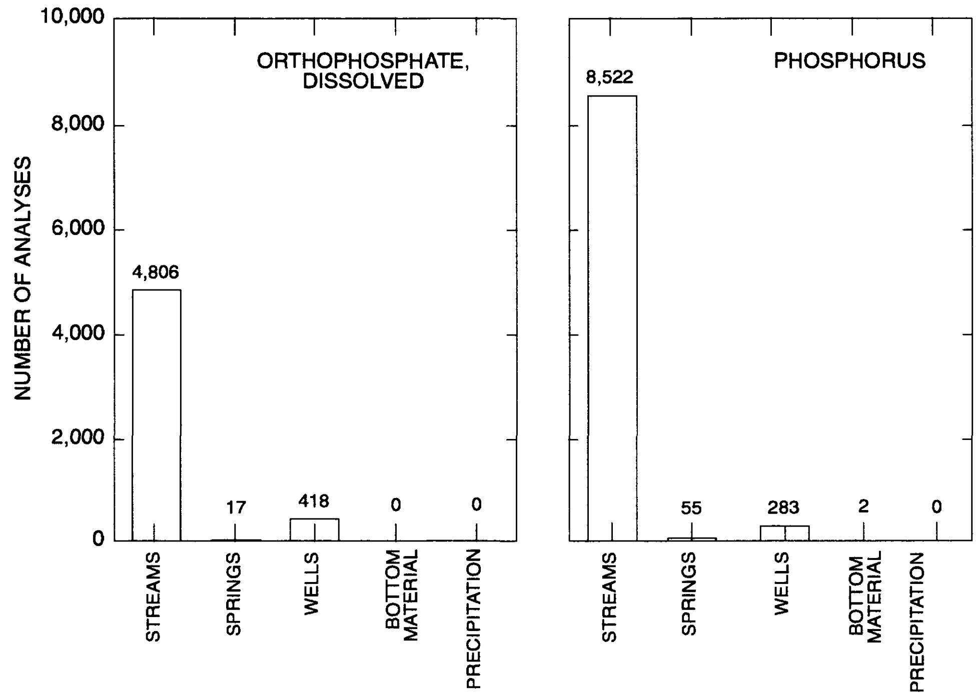



**Figure 7.** Number of analyses for dissolved orthophosphate and total phosphorus from five selected sample media, water years 1980-89, Lower Susquehanna River Basin.

**Table 4.** *Number of analyses for total and dissolved ammonia, nitrate, orthophosphate, and phosphorus from five selected sample media in the Lower Susquehanna River Basin, water years 1980-89*

| Sample medium | Ammonia | | Ntrate | | Orthophosphate | | Phosphorus | |
|---|---|---|---|---|---|---|---|---|
| | Total | Dissolved | Total | Dissolved | Total | Dissolved | Total | Dissolved |
| Streams | 7,815 | 5,910 | 7,988 | 4,051 | 1,071 | 4,806 | 8,522 | 5,873 |
| Springs | 56 | 98 | 54 | 283 | 0 | 17 | 55 | 95 |
| Wells | 292 | 1,310 | 133 | 1,035 | 0 | 418 | 283 | 729 |
| Bottom material | 1 | 0 | 1 | 0 | 0 | 0 | 2 | 10 |
| Precipitation | 0 | 452 | 0 | 452 | 0 | 0 | 0 | 0 |

## Spatial Distribution of Sampling Sites

Locations of precipitation, stream, well, spring, and bottom-material sites at which nutrient or suspended-sediment data were collected during 1980-89 are shown in figures 8, 9, and 10. Data-collection sites for individual projects and research studies are generally clustered in small areas. These sites are shown on the maps, but because of the scale of figures 8-10, the multiple sites may not be distinguishable. Precipitation sites where nutrient data were collected and stream sites where nutrient and (or) suspended sediment were collected are shown together (fig. 8).

Wells and springs where nutrient data were collected during 1980-89 are shown in figure 9, and bottom-material sites where nutrient data were collected during 1977-90 are shown in figure 10. A dense network of bottom-material sites in the reservoirs on the Lower Susquehanna River is not easily distinguished on this small-scale map. More detailed maps that locate the sites can be found in the 1991 water year Water-Resources Data Report for Pennsylvania published by the USGS (Durlin and Schaffstall, 1992, p. 238, 242, and 250).

Available data seem to be sufficient for determining broad-scale areal variations of nutrients in surface water and ground water. For nutrient data, the well, spring, and bottom-material sites in the Lower Susquehanna River Basin were distributed reasonably well (figs. 9 and 10). Because of the difficulty of determining ground-water flow characteristics, especially in carbonate terrains, the extrapolation of ground-water quality information outside the immediate area of the sampled well is not common.

The spatial distribution and density of stream sites (fig. 8) is uneven. However, unlike well, spring, and bottom-material sites, which are indicative of local conditions, stream sites generally represent the water quality of the area drained by the stream upstream from the sample-collection site. If the characteristics of the stream and the area it drains are understood, then the water-quality data collected at specific points along a stream can be extrapolated beyond those points to larger parts of the stream or to the area that it drains. Because of this, the distribution of stream sites shown in figure 8 is not complete but is considered acceptable for spatial analyses of water quality in the Lower Susquehanna River Basin.

The distribution of stream sites sampled for suspended sediment is not as widespread as that for nutrients. The difference in distributions is largely the result of differences in purpose of data collection. Most nutrient-sampling programs are developed to increase the understanding of nutrient occurrence and are designed to collect a large amount of data over a wide area to determine spatial occurrence of elevated nutrient concentrations with respect to background nutrient concentrations. Programs designed to collect suspended sediment generally are designed to determine the amount of sediment discharged from a watershed or basin; thus, sites are commonly near the

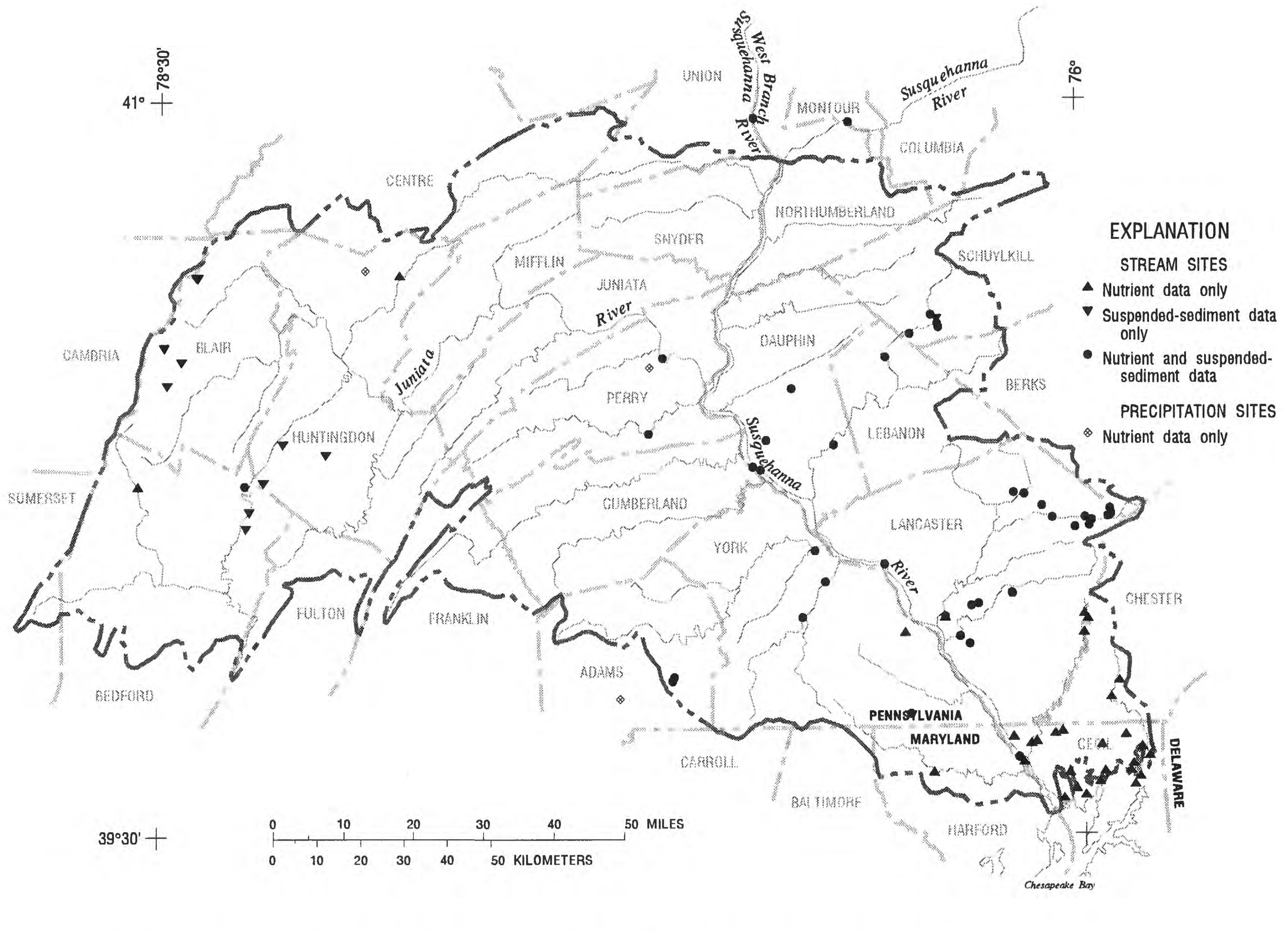



**Figure 8.** Precipitation and stream sites and type of data collected at each site, water years 1980-89, Lower Susquehanna River Basin.

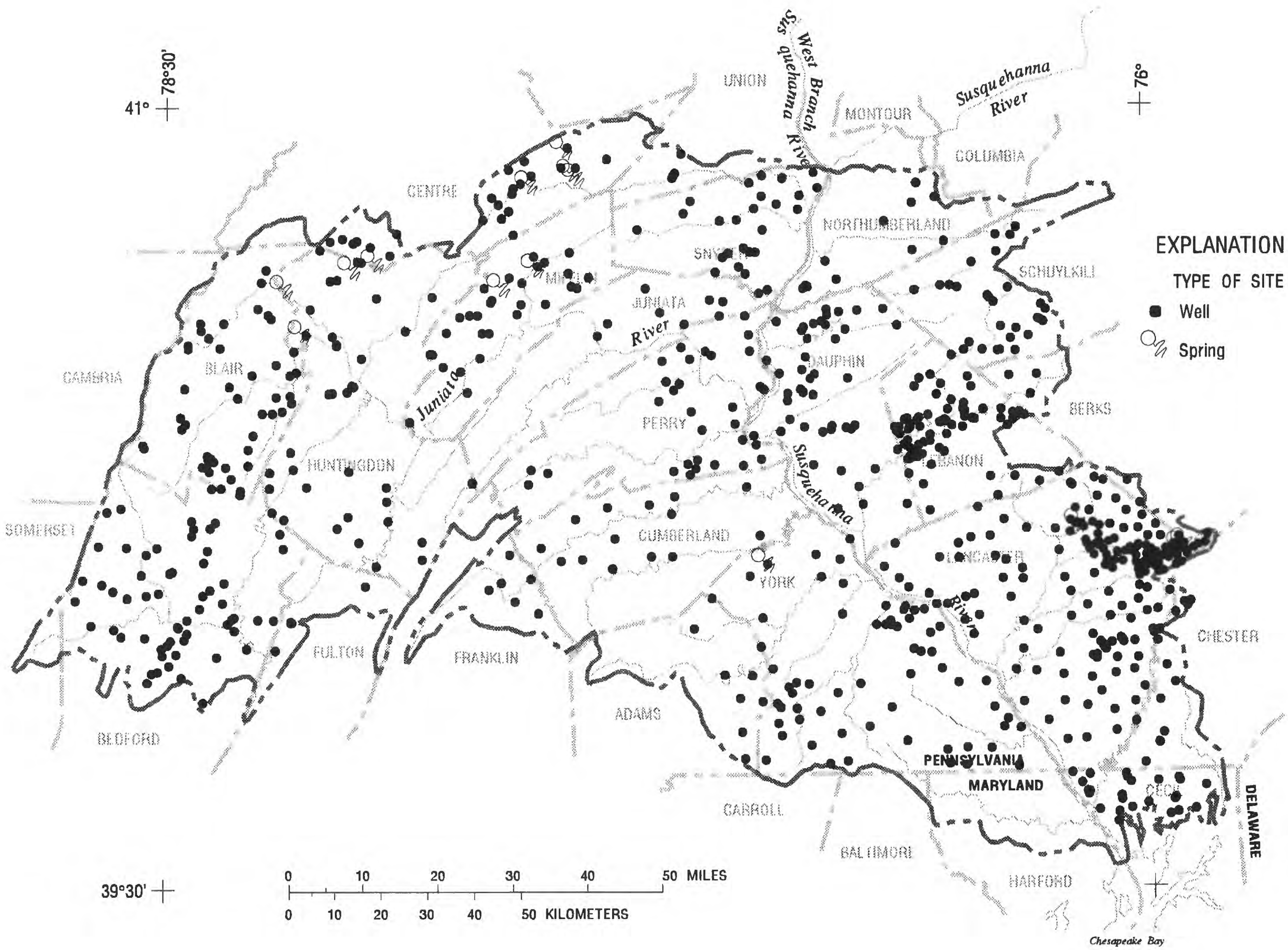



**Figure 9.** Well and spring sites where nutrient data were collected, water years 1980-89, Lower Susquehanna River Basin.


**Figure 10.** Bottom-material sites where nutrient data were collected during water years 1977-90, Lower Susquehanna River Basin.

mouth of a stream and not throughout a watershed (fig. 8). Because most suspended-sediment data-collection sites are near the mouths of streams, they may include the drainage area of a nutrient data-collection site in the upper part of the watershed.

For this report, data-collection sites are classified by use of the physical features of the area drained by a stream or the area surrounding a well. Three characteristics were used: physiographic province, underlying bedrock type, and predominant land use or human activity in the surrounding area or in the drainage area. The most recent land-use data available were collected in the mid-1970's. A land-use and land-cover classification system developed by Anderson and others (1976) was used. This method of site categorization provides an opportunity to determine the characteristic water quality of each of the subunit combinations of physiography, bedrock, and land use. The major hydrogeologic settings in the study unit are described by Risser and Siwiec (1996). These hydrogeologic settings subdivided with land use are the potential subunits within the Lower Susquehanna River Basin. The combination of these factors and the number of sites within each data set that can be categorized by subunit and location of nitrate data-collection sites during 1980-89 provides a matrix of basin characteristics and available data (table 5).

Coverage of the subunits by data-collection sites is sparse, especially for springs and bottom-material sites. The subunits are well covered by wells and sparsely covered by stream sites. In the 1980's, nutrient data were collected at various stream sites and at synoptic areal survey wells. The number of sites shown in table 5 may not agree with those listed under each sampling medium in table 2 as certain sites cannot be classified into one subunit. These sites are generally at or near the mouth of a large tributary or on the Susquehanna River.

Depth is another factor that can be used to describe the spatial distribution for wells. Wells sampled during synoptic surveys usually have a large range of depths because existing domestic-supply wells commonly are used. Domestic wells are generally drilled deeper than observation wells, and sampling these wells increases the potential for deep-well data.

Wells used in research projects are usually drilled specifically for the purpose of monitoring shallow ground water beneath field plots. Depth is less than 100 ft for nearly 75 percent of the ground-water project and research wells. The synoptic areal survey data set for ground water has a different distribution for well depth. Slightly more than 25 percent of the wells sampled were drilled to a depth of less than 100 ft, and slightly more than 75 percent were drilled to a depth of less than 250 ft. The most common depth interval sampled was 50 to 150 ft. About 45 percent of the wells sampled are in this class.

A review of the PaDEP water-well inventory system for all domestic water-supply wells in the study unit revealed that about 20 percent of the wells were drilled to a depth of less than 100 ft, 50 percent between 100 and 200 ft, and 20 percent between 200 and 300 ft. About 10 percent were greater than 300 ft deep (Bruce Lindsey, U.S. Geological Survey, Lemoyne, Pa., oral commun., 1994). Distributions of depth for all inventoried wells and for the wells sampled during synoptic areal surveys are similar. Because the synoptic areal survey wells are well distributed spatially and their depth distribution is similar to all the inventoried wells in the study unit, the water-quality information collected during synoptic areal surveys can be used as a reasonable indicator of areal ground-water quality.

**Table 5.** *Number of sites within each data set that can be categorized by subunit and location of nitrate data-collection site, water years 1980-89, Lower Susquehanna River Basin*

[A, agriculture; F, forest; U, urban]

| Data set | Piedmont Province | | | | | | | | | Great Valley Section[1] | | | Appalachian Mountain Section[2] | | | Ridge and Valley Province | | | Total of all subunits | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Crystalline bedrock | | | Carbonate bedrock | | | Siliciclastic bedrock | | | Carbonate bedrock | | | Carbonate bedrock | | | Siliciclastic bedrock | | | | | |
| | A | F | U | A | F | U | A | F | U | A | F | U | A | F | U | A | F | U | A | F | U |
| **Streams** | | | | | | | | | | | | | | | | | | | | | |
| Long-term monitoring sites | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 5 | 1 | 1 |
| Synoptic areal survey sites | 4 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 5 | 5 | 1 |
| Project and research sites | 2 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 17 | 1 | 0 |
| **Springs** | | | | | | | | | | | | | | | | | | | | | |
| Synoptic areal survey sites | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 |
| Project and research sites | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 |
| **Wells** | | | | | | | | | | | | | | | | | | | | | |
| Synoptic areal survey sites | 61 | 14 | 3 | 83 | 1 | 7 | 34 | 9 | 4 | 11 | 0 | 1 | 76 | 14 | 4 | 209 | 102 | 21 | 474 | 140 | 40 |
| Project and research sites | 0 | 0 | 0 | 17 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 1 | 1 |
| **Bottom-material sites** | | | | | | | | | | | | | | | | | | | | | |
| Synoptic areal survey sites | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Project and research sites | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[1] Great Valley Section of Ridge and Valley Province.

[2] Appalachian Mountain Section of Ridge and Valley Province.

## Temporal Distribution of Samples

The annual, seasonal, and monthly distribution of samples collected during 1980-89 was examined in this analysis. Depending on the data-set type, a good to fair spatial distribution of nutrient sample-collection sites is available for the Lower Susquehanna River Basin. However, sample-collection frequency during 1980-89 from streams, springs, and wells for determinations of nitrate and phosphorus (as orthophosphate for wells) resulted in inequalities in the data sets (table 6). All the available data sets for streams, springs, and wells are included in the table.

**Table 6.** *Number of nitrate and phosphorus analyses for streams, springs, and wells, water years 1980-89, Lower Susquehanna River Basin*

| Year | Nitrate | | | Phosphorus | | |
|---|---|---|---|---|---|---|
| | Streams | Springs | Wells | Streams | Springs | Wells |
| 1980 | 532 | 0 | 178 | 553 | 0 | 0 |
| 1981 | 287 | 0 | 336 | 330 | 0 | 35 |
| 1982 | 34 | 0 | 81 | 129 | 0 | 79 |
| 1983 | 40 | 0 | 132 | 255 | 0 | 136 |
| 1984 | 384 | 41 | 175 | 836 | 43 | 93 |
| 1985 | 293 | 53 | 81 | 773 | 12 | 23 |
| 1986 | 728 | 59 | 22 | 1,027 | 0 | 8 |
| 1987 | 1,132 | 46 | 19 | 1,551 | 0 | 0 |
| 1988 | 342 | 42 | 11 | 1,666 | 0 | 44 |
| 1989 | 279 | 42 | 0 | 1,402 | 0 | 0 |

The number of samples collected annually during 1980-89 was unevenly distributed. Most of the sampling for nutrients in ground water was done in the early 1980's, during areal surveys in 1980-84. A few project and research wells in a small area were sampled frequently in the late 1980's. Most streamwater nutrient samples were collected during 1986-89 for programs with mass-balance and basin-yield objectives. Areal surveys to determine surface-water quality were done in the mid-1980's, but only about 30 samples per year were collected. Most samples from spring research sites were collected in the mid- to late 1980's. Areal surveys on springs produced very few nutrient data for 1980-89.

Except for two seasons, samples collected at long-term monitoring sites and at project and research sites are spread fairly evenly throughout the year (fig. 11). Project and research programs typically are similar in their temporal data-collection objectives but greatly different in spatial scale. For the long-term monitoring programs, the number of samples collected during early spring and late summer were almost double the number collected during the rest of the year. Most samples for areal surveys were collected during October and November (fig. 11). Of the ground-water samples collected during 1980-89 for areal surveys, almost 90 percent were collected during April to September. Summaries of these water-quality data are biased towards growing-season conditions.

Sample distribution per month in each data set can be used as an indication of the applicability of the data to specific questions about temporal variability. Questions concerning month-to-month or season-to-season variations of nutrient concentrations can be answered only by data collected from the long-term monitoring or project and research data sets where data were collected monthly on a routine basis. The two data sets differ in basin scale. Project and research data sets are generally developed for small basins, whereas long-term monitoring sites are generally on large tributaries and the main

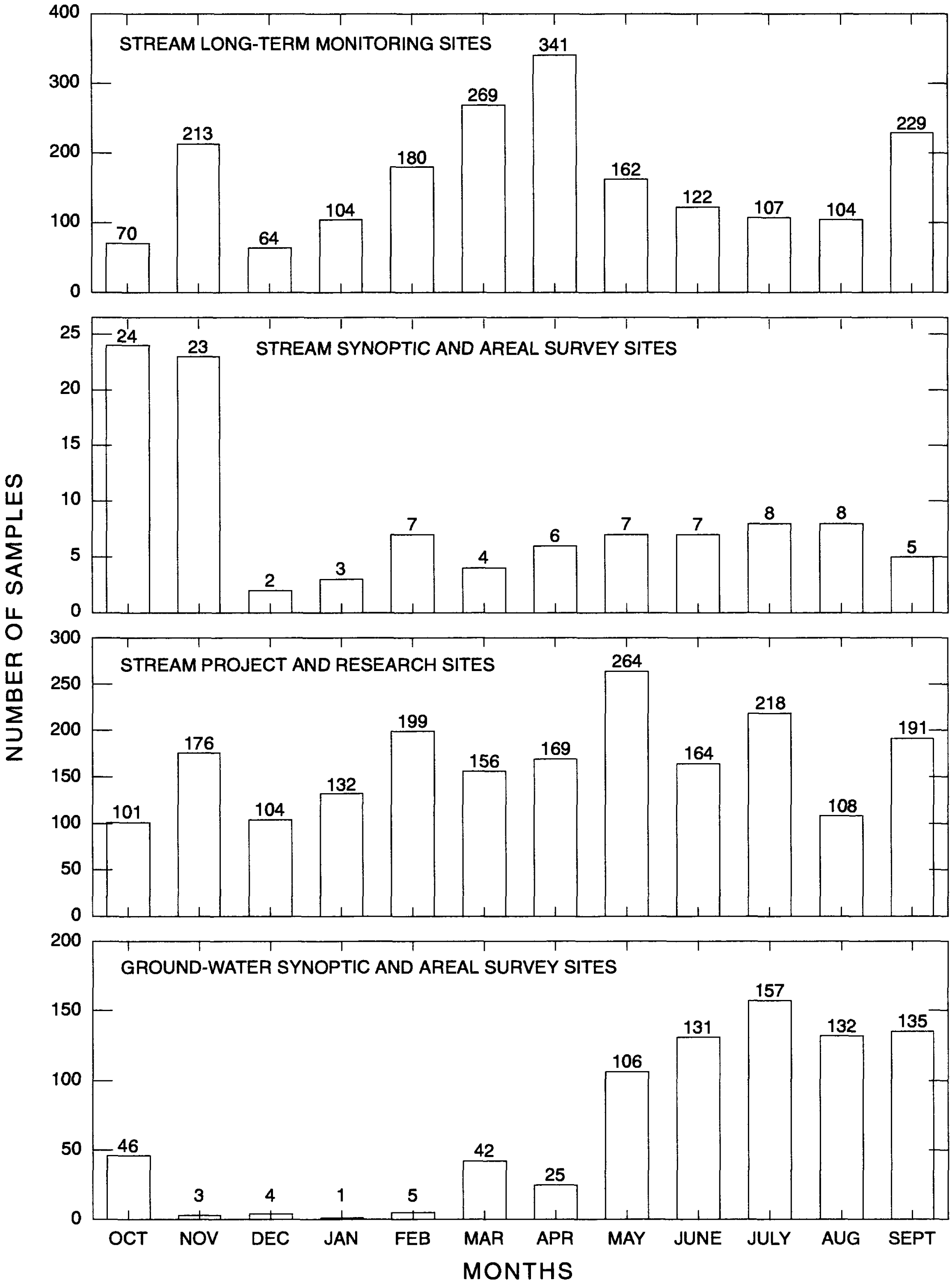



**Figure 11.** Number of samples, by month and data set, analyzed for nitrate concentration, water years 1980-89, Lower Susquehanna River Basin.

stem. Questions concerning the variability of seasons (growing, nongrowing, spring runoff, summer low-flow) between years can be answered by intermittently collected data from the areal survey data sets if the data were collected during like seasons over a period of years.

## Hydrologic Distribution of Samples

For stream samples, the hydrologic distribution of samples collected at a particular site can be described by relating the distribution of sampled flows to the long-term flow distribution. This relation was examined to determine whether the water-quality data associated with the samples accurately represent the water-quality conditions that vary with streamflow. For example, if streamflow at a particular water-quality sampling site exceeded 1,000 $ft^3/s$ about 5 percent of the time during the period that the sampling program was active, then, ideally, about 5 percent of the water-quality data should have been collected when the streamflow at the site exceeded 1,000 $ft^3/s$. An analysis of water-quality data collected predominantly at low flow may be biased positively for dissolved constituents and negatively for constituents normally transported in a suspended phase. Alternatively, samples collected predominantly at high flow may be biased negatively for dissolved constituents and positively for constituents transported primarily in a suspended phase. For the data to be representative, the frequency of the sampled flows must be analogous to the long-term streamflow distribution.

The number of nitrate samples collected at three selected sites within the study unit were grouped to correspond to 10 flow-duration intervals (fig. 12). The flow-duration intervals were developed from the daily mean streamflows recorded during the period of water-quality data collection. The percentiles along the x-axis indicate the percentage of the flows corresponding to the duration of daily mean discharge. The percentage range was divided into ten 10-percent segments between 0 and 100 percent. A value near 100 percent corresponds to a low flow and a value near 0 percent corresponds to a high flow. Ideally, each 10-percent interval should include 10 percent of the samples, and the height of the bar in each segment would be equal to the horizontal line drawn across the graph. Samples for nitrate are indicated on the graphs, but most samples also included analyses for phosphorus and suspended sediment. Similar sample-collection patterns are generally observed for these constituents.

The three sites shown in figure 12 were selected to provide an indication of the flow conditions sampled for programs with different objectives. The objectives of the long-term monitoring site on the Susquehanna River at Harrisburg and the project and research site on Little Conestoga Creek near Churchtown required samples that are biased towards high flows in order to define the transport of materials through the stream system during runoff periods. A high percentage of loads are transported when flows are in the 0- to 25-percentile range (high flows), and sampling is biased towards times of high flow (fig. 12, top and middle). With some exceptions, this pattern of sampling is most common for these two types of programs.

Collecting data over a range of flow conditions is not an objective of synoptic areal surveys. The objectives for these types of studies generally do not include the transport of materials over a period of time, although instantaneous loads computed at each site may be used to estimate a mass balance for a particular constituent. Collecting data during a particular flow condition is generally the main objective. Data from synoptic areal survey sites are generally collected at stable base-flow periods from late spring to late fall. As shown by the data collected at the site on Swatara Creek at Suedberg, Pa. (fig. 12, bottom), the flow distribution of the samples is biased towards low flows. About one-half of the samples were collected at flows that are equaled or exceeded 75 percent of the time. In general, although samples collected from long-term monitoring and

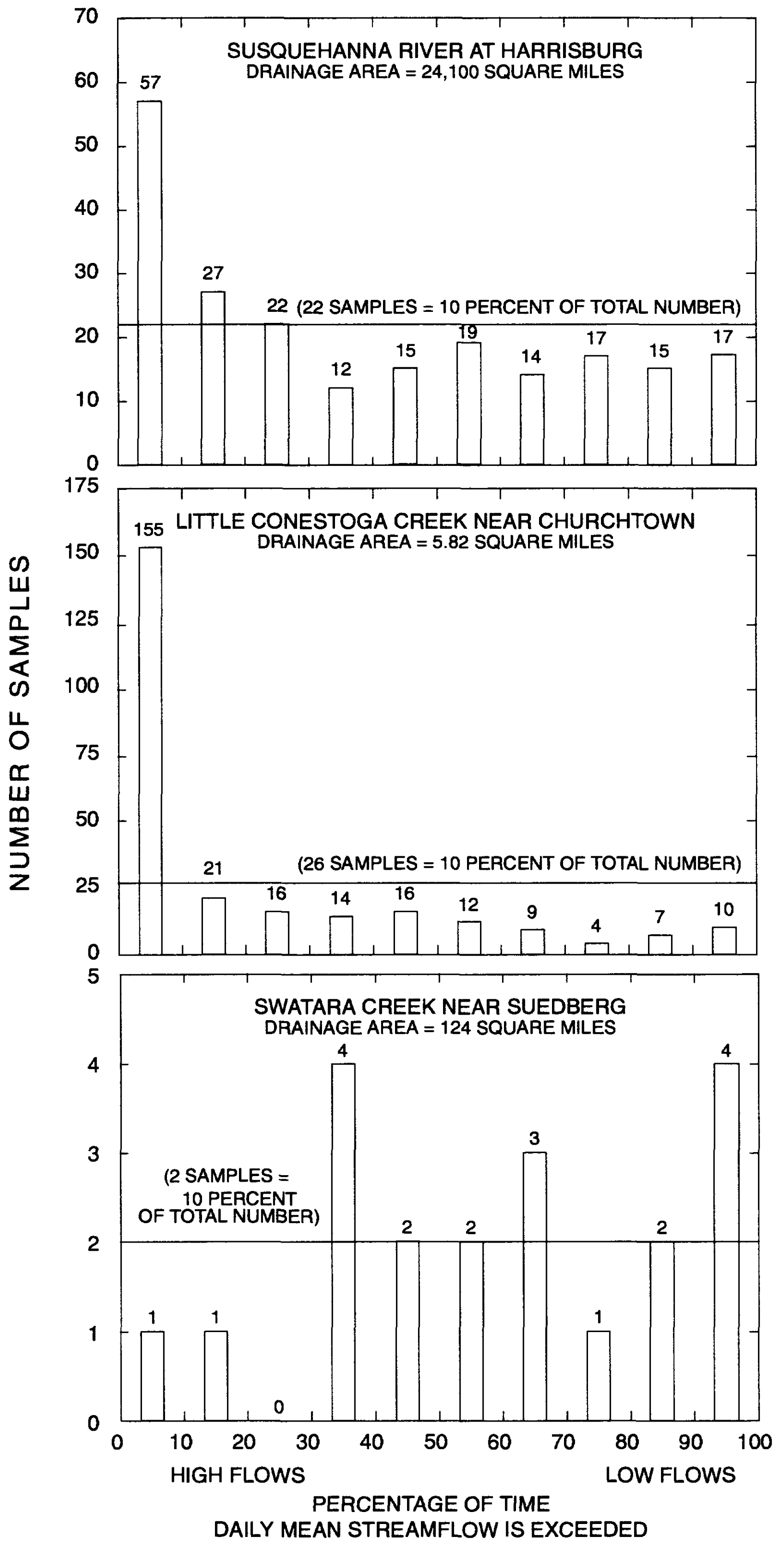



**Figure 12.** Distribution of nitrate samples collected during water years 1980-89 over the range of daily mean streamflows for selected sites in the Lower Susquehanna River Basin.

project and research sites are biased toward high flows, they provide a better coverage of flow conditions; samples collected during synoptic and areal surveys are poorly distributed throughout the range of flow.

The hydrologic distribution of ground-water samples is described by relating the number of samples to well depth (fig. 13). Two data sets are shown in figure 13: project and research sites, and synoptic areal survey sites. The project data set is biased toward shallow wells. About two-thirds of the samples from project wells were collected from wells less than 100 ft deep. Water sampled from shallow (0-100 ft) wells is generally more recent to the system than water sampled from deeper wells. Most projects done during the 1980's were designed to link current land use and agricultural practices to ground-water quality. For this reason, recently introduced water and shallow ground-water systems were targeted.

Samples included in the ground-water synoptic areal survey data set covered a wider range of depths. Only 25 percent of the samples were collected from wells less than 100 ft deep, and slightly more than two-thirds of the samples were from wells less than 200 ft deep. About 10 percent of the wells sampled for synoptic areal surveys were deeper than 300 ft. The change in the sample distribution for synoptic sites is probably because of the reliance on homeowner wells for the samples. Homeowner wells are generally drilled deeper than observation wells to ensure that an acceptable quantity and quality of water are available. The inclusion of samples from deeper wells in the data set allowed comparisons of water quality between shallow and deep wells, and, in turn, comparisons of water with different ages.

## Streamflow and Ground-Water Conditions

The degree to which the ranges of sampled streamflows and ground-water levels match the actual distribution is important in the analysis of water-quality data. In addition, the degree to which the distributions of streamflows and ground-water levels during the period of data collection match the long-term distribution also is important. Even though the period being reviewed for this report is 10 years, significant biases may be introduced by dry or wet periods that can last up to several years.

The departure of the annual mean streamflows for 1980-89 from the long-term mean annual streamflow for two stream sites was determined (fig. 14). The two sites are on large streams with flow records of more than 50 years. They were chosen over sites on smaller streams to dampen the effects of the rapid hydrologic responses that are typical for small watersheds. The departure of the individual years is indicated by the bar, and the long-term mean is indicated by the horizontal line at a value of zero. For the sites on the Juniata River at Newport and on the Susquehanna River at Marietta, the data indicate that annual mean streamflows were less than the long-term mean annual streamflow in 7 of the 10 years. The conclusion is that even if the actual streamflow distribution was matched by that of the sampled streamflows, samples collected during the decade may have a bias towards high dissolved concentrations and low suspended concentrations because the flows were lower than normal.

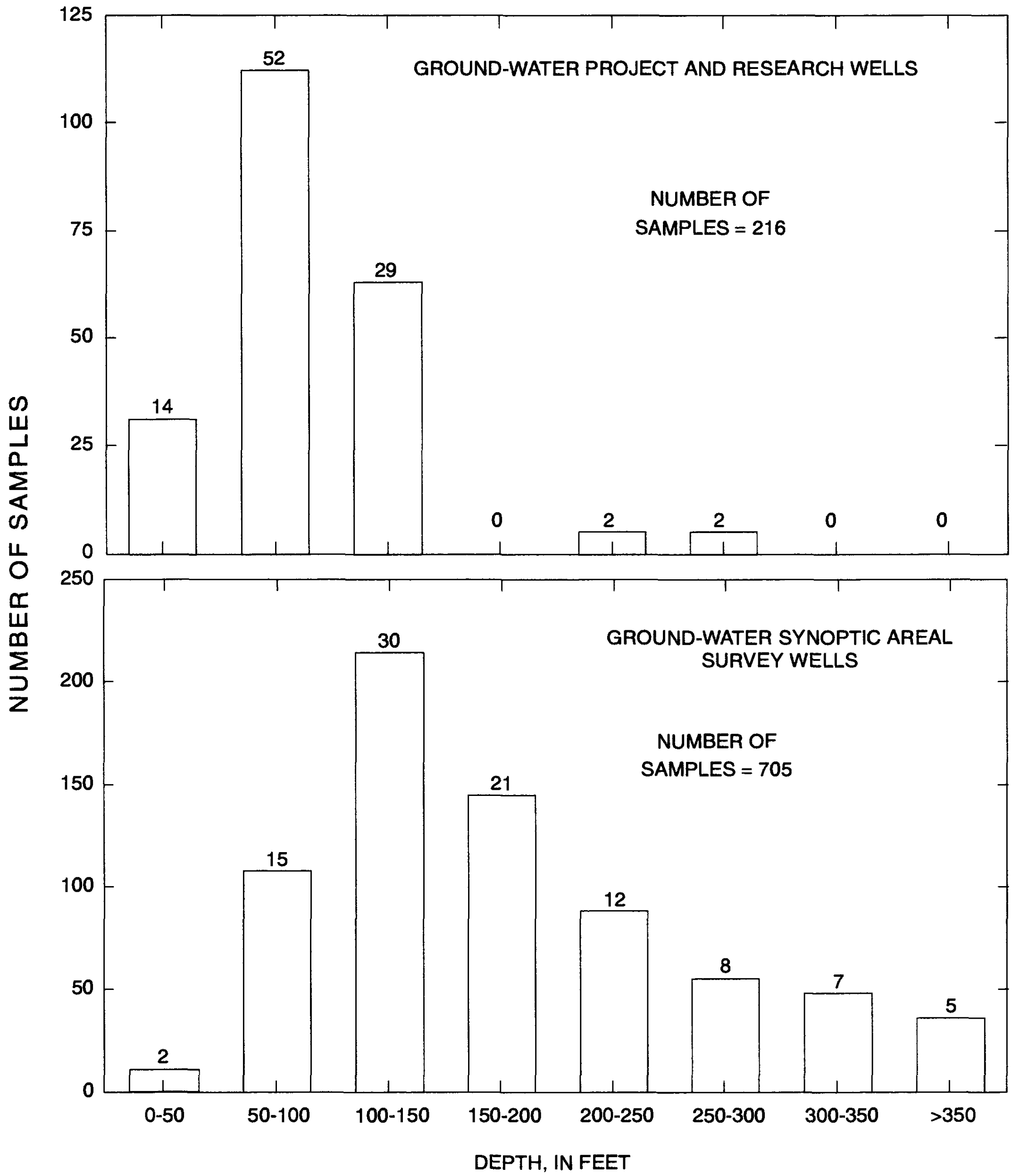



**Figure 13.** Number of ground-water samples collected for nitrate determinations in the Lower Susquehanna River Basin, water years 1980-89, in relation to well depth. [>, greater than]

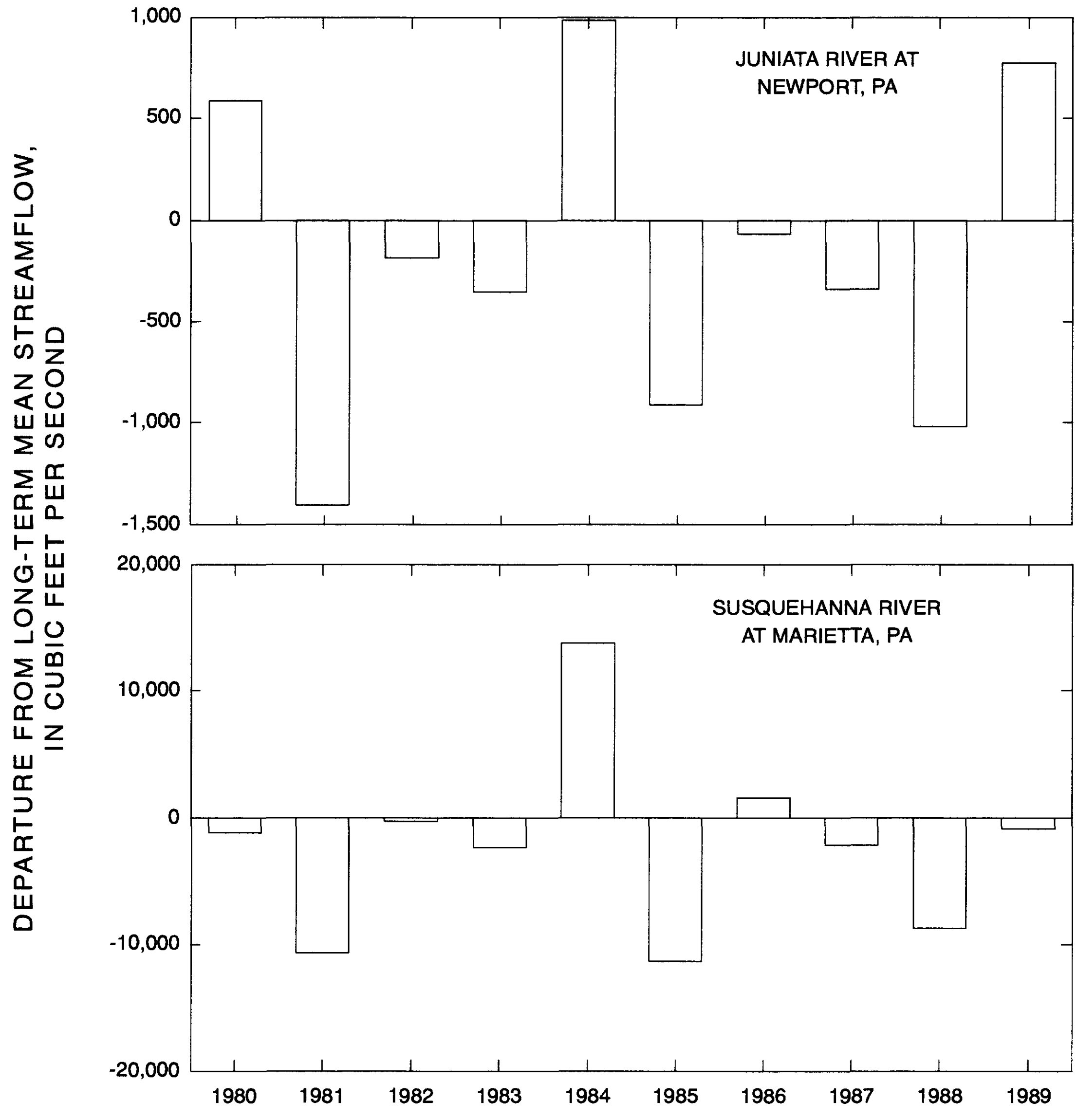



**Figure 14.** Departure of annual mean streamflow for water years 1980-89 from mean annual streamflow for the period of record at two sites in the Lower Susquehanna River Basin.

Three observation wells that represent three rock-type settings were selected to review trends in water levels during the 1980's. The period of record for the long-term water-level records for these wells ranged from 30 to 40 years. The departures for the individual years of the annual mean water level from the long-term mean annual water level were determined (fig. 15). At two of the wells (LN514 and JU351), the mean water levels for 6 of the 10 years were lower than the long-term mean water level. At the remaining well (CU2), mean water levels for 7 of the 10 years were above normal. The conclusions from this review are that basin wide ground-water levels for 1980-89 show no indication toward either dry or wet periods and that water-quality data collected throughout the decade should not be biased by abnormal hydrologic conditions. Data collected in an individual year or during a particular 2- to 3-year period may show a bias because of above- or below-normal recharge to the ground-water system.

An analysis of monthly streamflow and ground-water levels provided more seasonal definition (fig. 16). A general assumption is that the data collected during 1980-89 at these few sites represent the hydrologic conditions of the Lower Susquehanna River Basin. Ground-water levels for all months were near normal. Generally, streamflows were near normal from midsummer through late fall and above normal for late fall through midsummer, except for January, March, and September, when streamflows were below normal.

On the basis of the comparison of hydrologic conditions during 1980-89 and the long-term record, the authors believe that a bias in concentrations may be possible only for streamflow and ground-water samples collected at spring runoff during 1980-89. Mean monthly flows during this season and the decade were abnormally high. Total concentrations may be biased high, and dissolved concentrations may be biased low. This is an important consideration because many of the streamflow samples were collected during spring runoff (high flow).

## Concentrations of Nutrients and Suspended Sediment

### Basinwide Variability

Areal variability of concentrations of nitrate, phosphorus, and suspended sediment are examined in this section. All data sets where nutrient or suspended-sediment data were collected during 1980-89 were included in the analysis. Concentrations of suspended sediment were available for streams only. Locations of sites where these data were collected are shown in figures 8, 9, and 10.

For streams and springs, nitrate and phosphorus data were usually collected at each site. The most common constituent determined in samples from wells was nitrate, and the most common analysis for nitrate was dissolved nitrate as nitrogen. This form of nitrogen was used for the analysis of data collected from wells and springs during synoptic areal surveys. The dominance of nitrate as constituent of choice for analysis is probably because of investigations of potential health risks from high concentrations of nitrate. Phosphorus concentrations in drinking water are generally not a health concern. Bottom-material samples were generally not analyzed for nitrate. Phosphorus is commonly associated with suspended and deposited sediments (Hem, 1992) and is the most common nutrient analysis in bottom material.

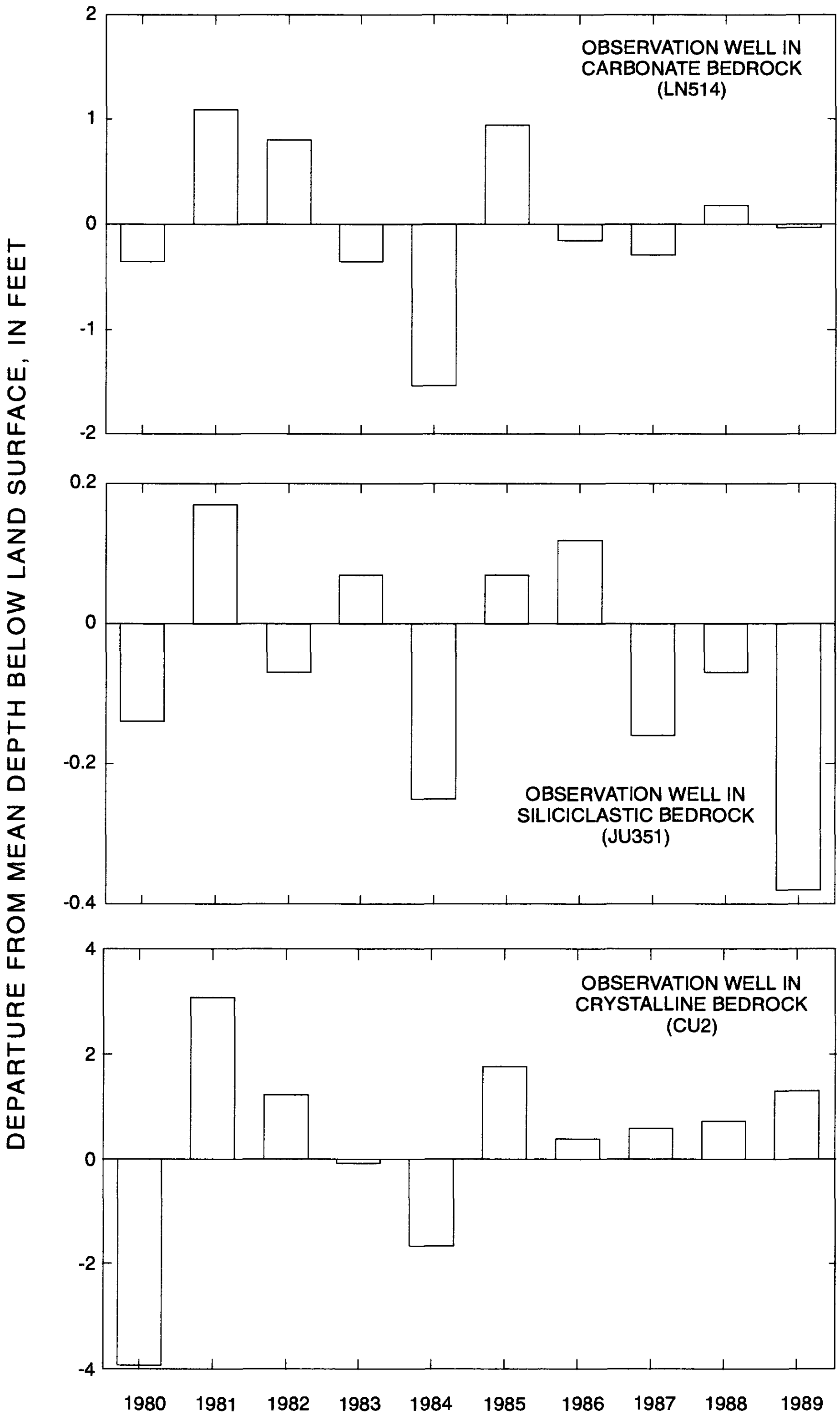



**Figure 15.** Departure of annual mean depth below land surface for water years 1980-89 from mean annual depth below land surface for the period of record at three observation wells in the Lower Susquehanna River Basin.

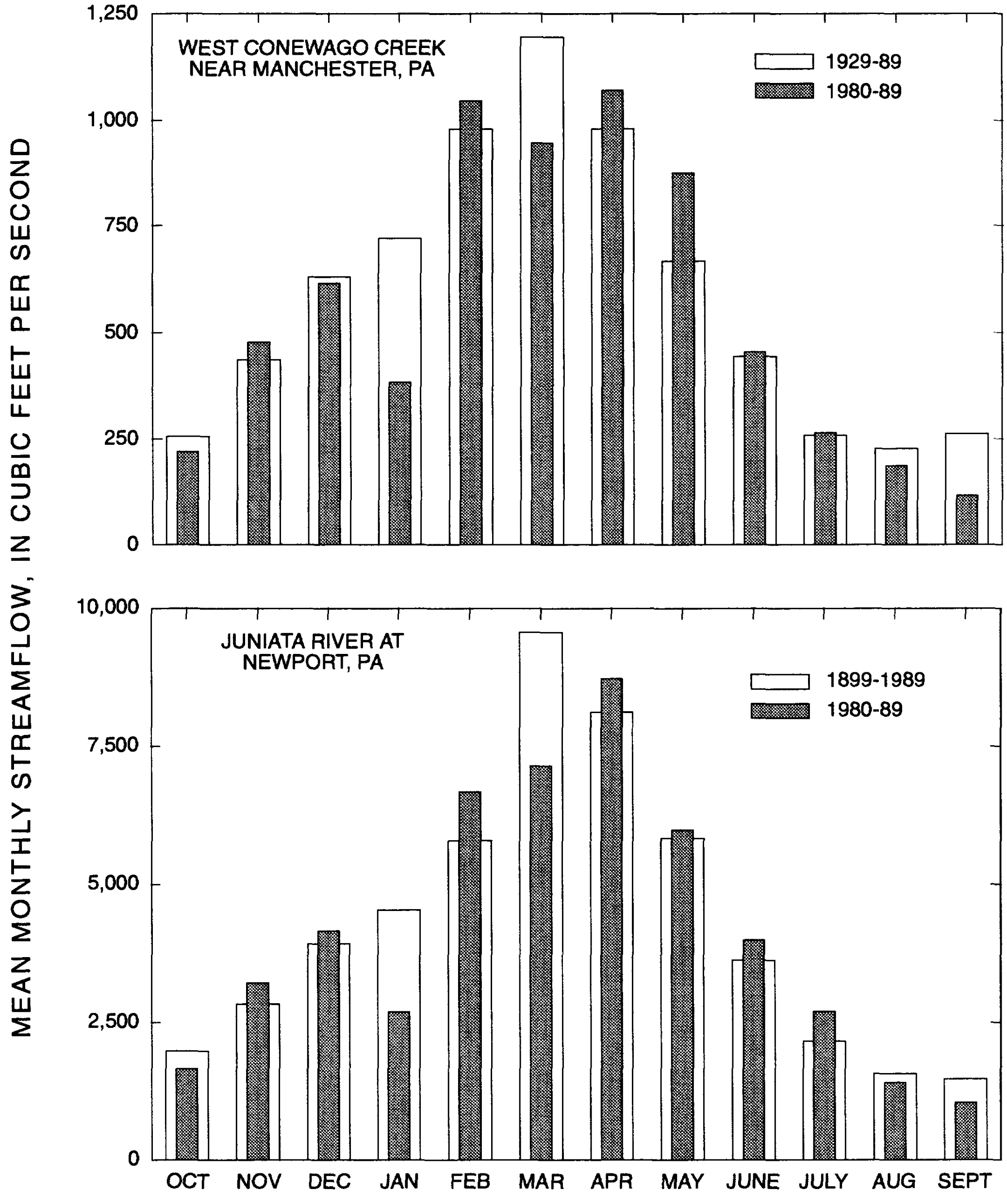



**Figure 16.** Mean monthly streamflow at two selected streams and depth below land surface at two selected observation wells in the Lower Susquehanna River Basin for water years 1980-89 and for the period of record.

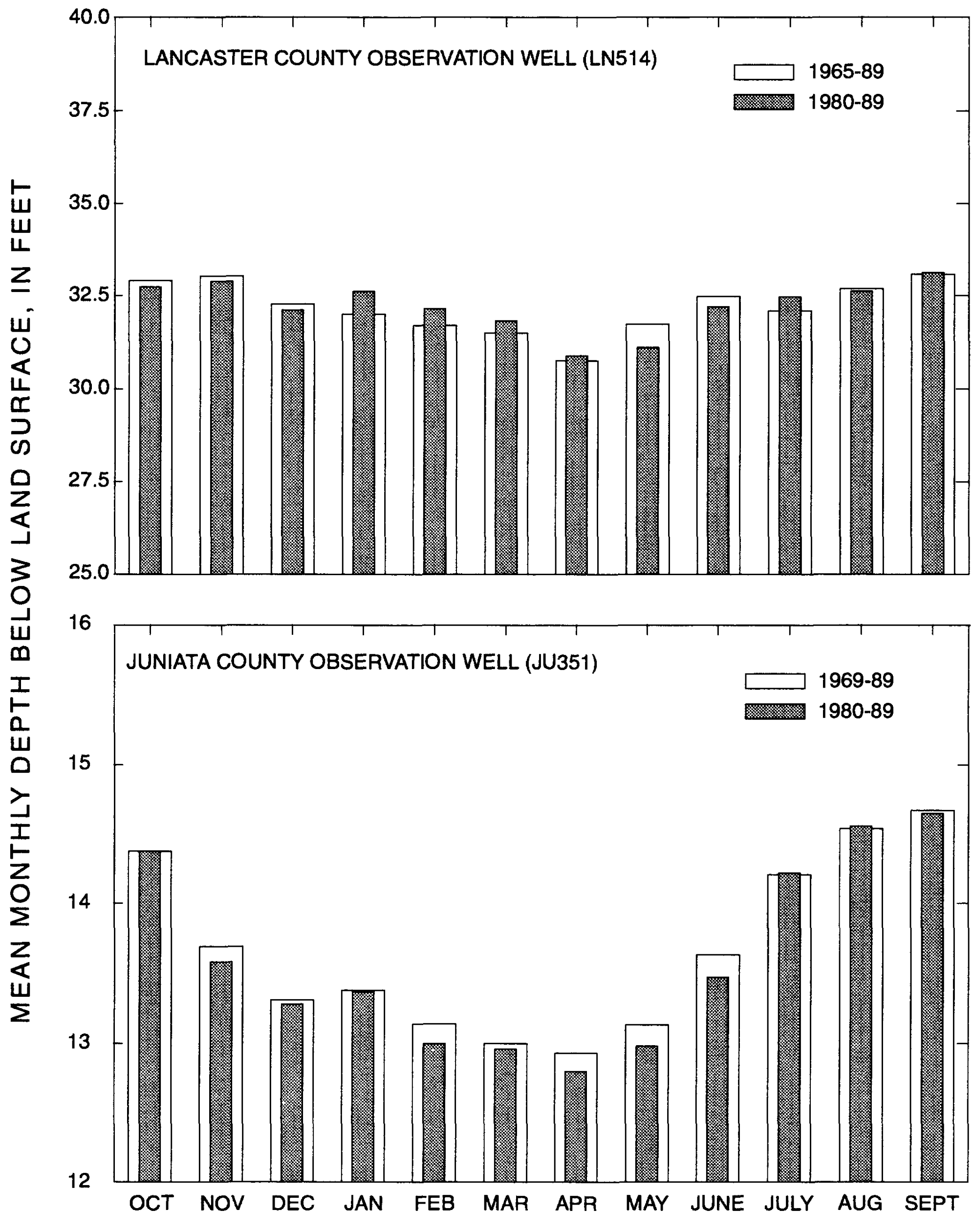



**Figure 16.** Mean monthly streamflow at two selected streams and depth below land surface at two selected observation wells in the Lower Susquehanna River Basin for water years 1980-89 and for the period of record—Continued.

Nitrate data at selected long-term monitoring sites on tributaries and the Susquehanna River, selected project and research sites on small streams, a project and research well, and a project and research spring were compared; summary statistics from this comparison are given in figure 17 and table 7. Nitrate data for the synoptic areal survey data sets for streams, wells, and springs also were compared.

Median nitrate concentrations from long-term monitoring sites on tributaries to the Susquehanna River during 1980-89 appear to fall into three categories. The medians of concentrations measured in the streams draining the three northernmost basins—Juniata River, Sherman Creek, and Paxton Creek—were less than 2 mg/L. Median concentrations from streams that drain the center of the lower part of the study unit—Swatara Creek, West Conewago Creek, and Codorus Creek—were between 2 and 4 mg/L. Median concentrations from the two basins that drain the southeastern part of the study unit, Conestoga River and Pequea Creek, were the highest at 5 mg/L or slightly higher (fig. 17). Concentrations for the second and third groups of sites, especially the third group, also appear to have been more variable than those of the first group. The data from the long-term monitoring sites on tributaries seem to indicate a north-to-south trend of increasing nitrate concentrations.

The only available main-stem nutrient data within the study unit were collected at three sites. The median concentrations of nitrate at the main-stem sites at Harrisburg, Marietta, and Conowingo, presented in downstream order, ranged from 1.1 to 1.2 mg/L (fig. 17). The data collected directly from the mainstem do not fit the marked north-to-south trend in median concentrations indicated by the tributary data.

Data from the four project and research sites on streams draining small basins indicate the range of nitrate concentrations measured in samples collected from headwater streams in the study unit. The streams, in order of smallest to largest drainage basin, are Brush Run, Little Conestoga Creek, Stony Creek, and Swatara Creek (fig. 17). The drainage areas of the four sites range from 0.4 to 167 $mi^2$. The median concentrations of nitrate at each of these sites were similar to those for the larger basins into which they drain (fig. 17, table 7). Brush Run is a tributary to West Conewago Creek, Little Conestoga Creek is a tributary to the Conestoga River, Stony Creek drains directly into the Susquehanna River above Harrisburg, and the site on Swatara Creek is about two-thirds of the way up the Swatara Creek Basin. At Stony Creek and Swatara Creek, the northern sites, median concentrations were 0.08 and 0.7 mg/L, respectively. At Brush Run, in the southwest part of the study unit, median concentration was 2.7 mg/L; and at the Little Conestoga Creek, median concentration was 5.9 mg/L. The pattern of variability seen with the nitrate concentrations from the long-term stream-monitoring sites was duplicated at these sites (fig. 17). Variability in concentration was greater at sites with median concentrations greater than 2 mg/L than at sites with median concentrations less than 2 mg/L.

Nitrate data from samples collected at two project and research sites, a well and a spring, and from the synoptic areal survey data sets for streams, wells, and springs also were analyzed (fig. 17). Choices to represent a well and a spring were limited. At the two sites that were selected, nitrate concentrations were at the upper end of the range expected in the study unit. Median concentrations at well LN1646 and spring SP58, both in northeastern Lancaster County and within the Little Conestoga Creek Basin, were 9.5 and 12 mg/L, respectively. Although these concentrations may be representative of the quality of ground water in their local area, data were collected from these sites as a part of a program specifically designed to investigate water that was already degraded. The data collected from these two sites illustrate the importance of understanding why the data were collected for individual studies before combining the data sets to represent regional water quality.

One of the best uses for synoptic areal survey data is to describe the water quality of a region. The median concentrations of the synoptic areal survey stream, well, and spring data sets (1.6, 2.4, and 3.3 mg/L, respectively) (fig. 17) were similar to those found at the selected surface-water sites.

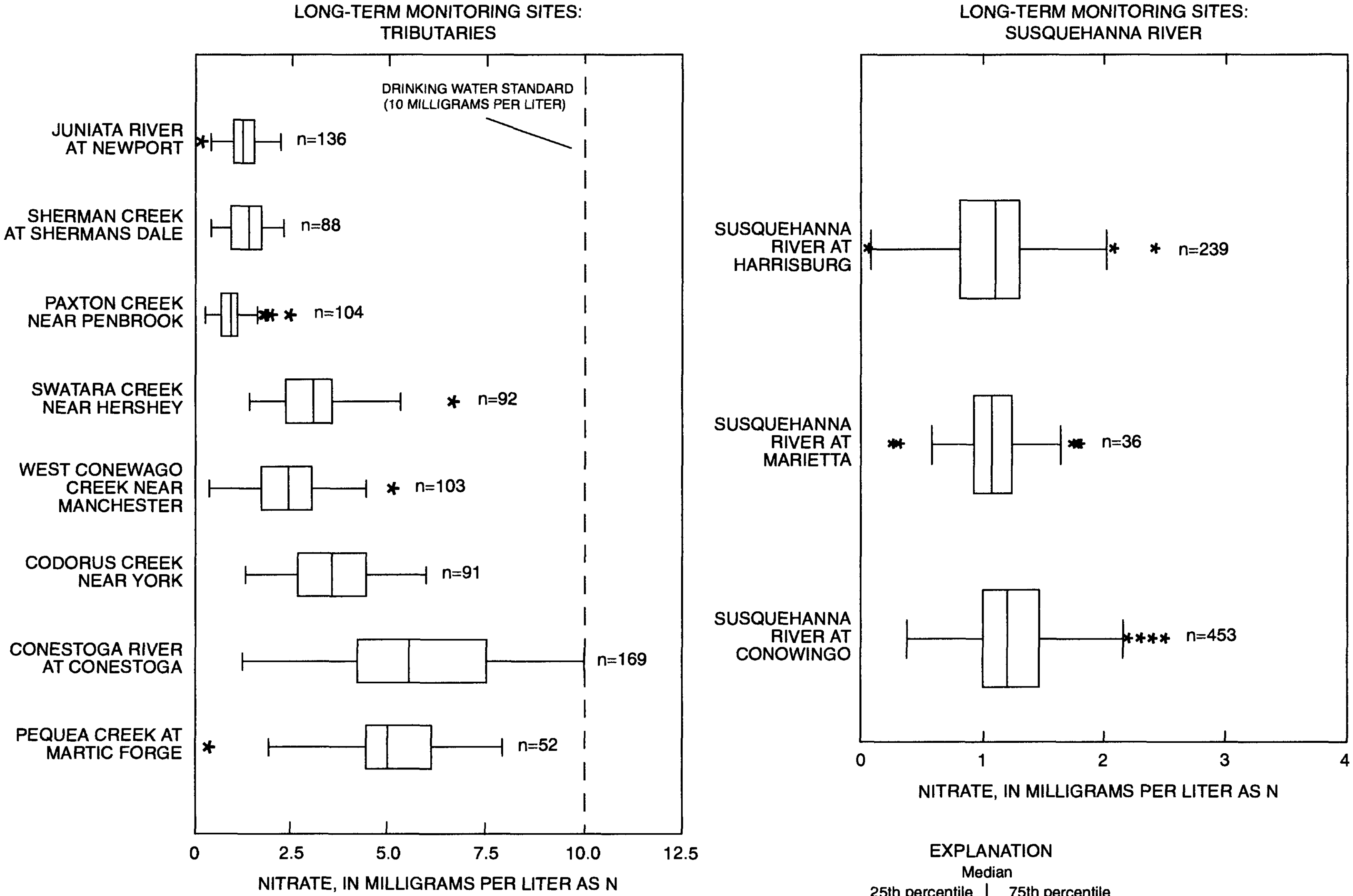
In summary, median concentrations of nitrate in streams and ground water in most areas were less than 4 mg/L except in the southeastern part of the basin where median concentrations of 10 mg/L were not uncommon.

Data collected during 1980-89 were used to determine areal distribution of median nitrate concentrations in the Lower Susquehanna River Basin (fig. 18). Magnitude of the median nitrate concentration computed for each site is expressed by the size of the symbol at the sampling location. The identification number next to each site-locator symbol is referenced to table 7. The sites are the same long-term monitoring and project and research sites on streams, the project and research well, and the project and research spring presented in figure 17. The pattern of increasing nitrate concentrations from north to south (downstream) is evident.

Phosphorus data (fig. 19) were analyzed for the same sites as were the nitrate data. Summary statistics for phosphorus concentrations at each of the sites and site groups are listed in table 7. Orthophosphate (as phosphorus) instead of total phosphorus was used for the analysis of concentrations measured in wells and springs during synoptic areal surveys. Total phosphorus data were generally not available in well and spring synoptic areal survey data sets. Dissolved orthophosphate was a more common constituent for these data sets. The ranking described earlier for median nitrate concentrations at long-term monitoring sites established on tributaries to the Susquehanna River during 1980-89 was duplicated, with one exception, by median concentrations of phosphorus (fig. 19). Concentrations generally increased from north to south in the study unit. The exception was the median concentration at the site on West Conewago Creek, which drains an area west of the Susquehanna River in the south-central part of the basin. For nitrate concentrations, this site ranked near the middle of the group of eight tributaries; for phosphorus concentrations, it had the next-to-highest median concentration. Sherman Creek and the Juniata River had median concentrations of phosphorus less than 0.1 mg/L. At the next downstream sites—Paxton Creek, Swatara Creek, West Conewago Creek, Codorus Creek, and Pequea Creek—median concentrations ranged from 0.1 mg/L to 0.25 mg/L. At only one tributary—the Conestoga River, with a median concentration of 0.6 mg/L—was median concentration greater than 0.25 mg/L.

For the sites on the Susquehanna River, median phosphorus concentrations increased downstream from Harrisburg to Marietta until the water passed through the three consecutive reservoirs above the site at Conowingo (fig. 19, second graph). The median concentration at Conowingo was less than the median at Marietta and Harrisburg. Ott and others (1991) indicated that the reservoir system on the river is a trap for sediment and phosphorus.

Median concentrations of phosphorus from the four project and research sites on streams (fig. 19, third graph) bracketed the concentrations measured in the Susquehanna River tributaries. Median concentrations at the two northern sites, Stony Creek and Swatara Creek, were less than 0.05 mg/L. Median concentrations at the two southern sites, Brush Run and Little Conestoga Creek, were 0.98 and 1.9 mg/L, respectively. Brush Run is a small tributary of West Conewago Creek, the Susquehanna River tributary with



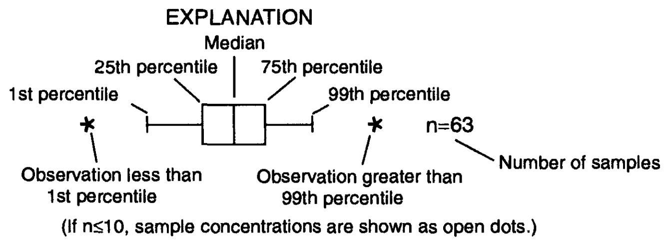



**Figure 17.** Nitrate concentrations at selected sites in the Lower Susquehanna River Basin, water years 1980-89. [For ground-water synoptic areal survey sites, constituent used is dissolved nitrate.]

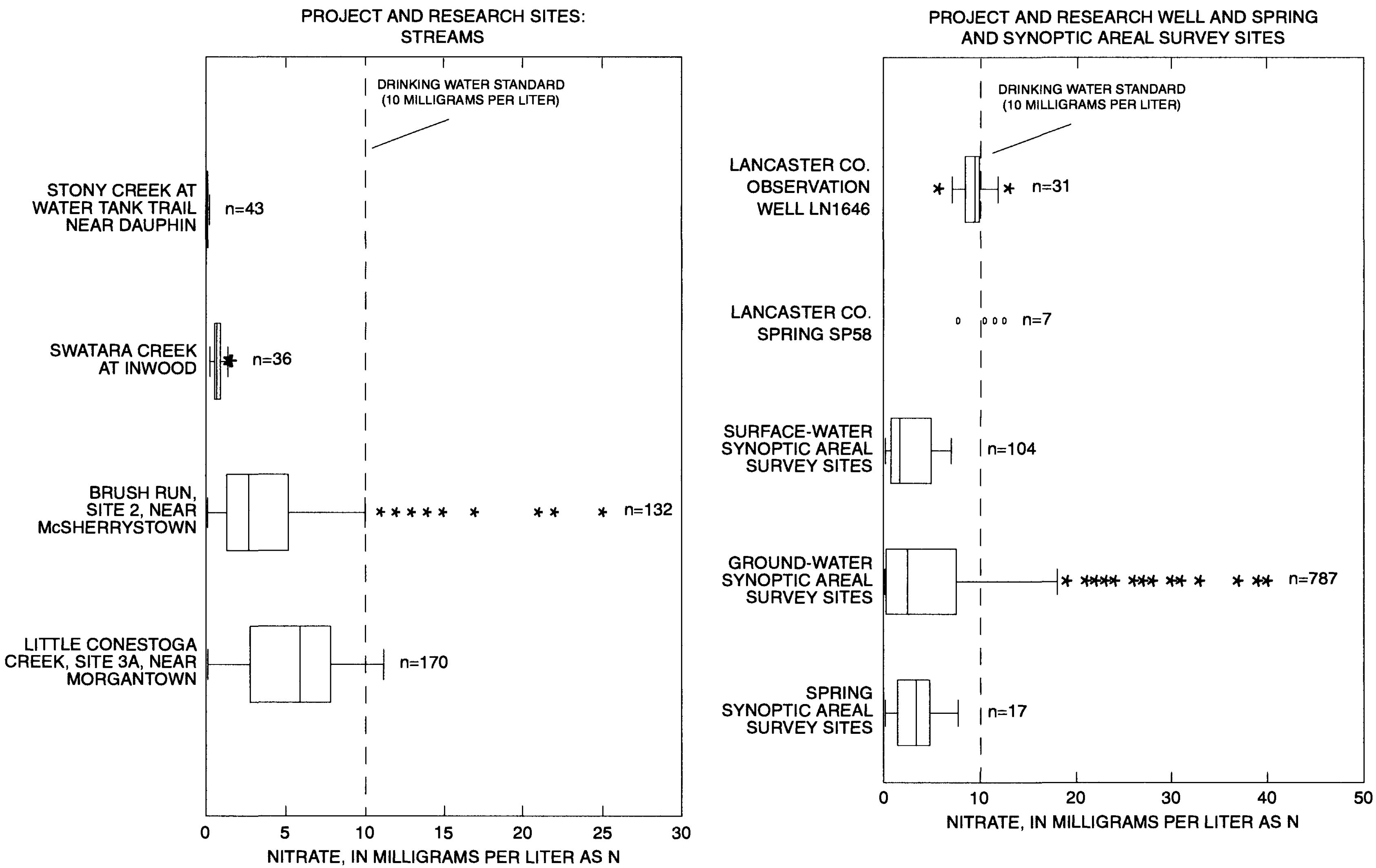



**Figure 17.** Nitrate concentrations at selected sites in the Lower Susquehanna River Basin, water years 1980-89—Continued.

**Table 7.** *Statistical summary of nitrate, phosphorus, and suspended-sediment data collected during water years 1980-91 at individual sites or groups of sites in the Lower Susquehanna River Basin*

[Nitrate and phosphorus constituents for the synoptic areal survey sites at wells and springs are dissolved nitrate as nitrogen and dissolved orthophosphate as phosphorus; units for the reservoir-site concentrations are given in milligrams per kilogram of dry material; n, number of samples; P1, 1st percentile; P25, 25th percentile; P75, 75th percentile; P99, 99th percentile; <, less than; >, greater than; --, too few samples to compute a reliable statistic; N/A, not applicable]

| Site or data-set name[1] | Site number | Map ID number (fig. 18) | Nitrate concentration, in milligrams per liter as nitrogen | | | | | | Phosphorus concentration, in milligrams per liter as phosphorus | | | | | | Suspended-sediment concentration, in milligrams per liter | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | n | P1 | P25 | Median | P75 | P99 | n | P1 | P25 | Median | P75 | P99 | n | P1 | P25 | Median | P75 | P99 |
| Long-term monitoring at tributary sites | | | | | | | | | | | | | | | | | | | | |
| Juniata River at Newport | 01567000 | 1 | 136 | 0.2 | 1.0 | 1.2 | 1.5 | 2.1 | 233 | 0.01 | 0.06 | 0.08 | 0.12 | 0.40 | 271 | 1 | 10 | 34 | 75 | 506 |
| Sherman Creek at Shermans Dale | 01568000 | 2 | 88 | <.8 | .9 | 1.4 | 1.7 | >1.9 | 196 | .01 | .04 | .07 | .13 | .60 | 195 | 1 | 8 | 24 | 81 | 1,230 |
| Paxton Creek near Penbrook | 01571000 | 3 | 104 | .3 | .7 | .9 | 1.1 | 2.4 | 220 | .01 | .06 | .14 | .25 | .82 | 214 | 1 | 22 | 142 | 498 | 8,780 |
| Swatara Creek near Hershey | 01573560 | 4 | 92 | <1.9 | 2.3 | 3.0 | 3.5 | >4.2 | 209 | .02 | .07 | .10 | .18 | .90 | 209 | 2 | 14 | 37 | 201 | 715 |
| W. Conewago Creek near Manchester | 01574000 | 5 | 103 | .4 | 1.7 | 2.4 | 3.0 | 5.0 | 234 | .05 | .15 | .25 | .36 | 1.4 | 234 | 1 | 21 | 64 | 189 | 1,080 |
| Codorus Creek near York | 01575500 | 6 | 91 | <1.9 | 2.6 | 3.5 | 4.4 | >4.8 | 193 | .05 | .09 | .15 | .25 | 1.6 | 192 | 4 | 17 | 40 | 207 | 3,140 |
| Conestoga River at Conestoga | 01576754 | 7 | 169 | 1.3 | 4.2 | 5.5 | 7.5 | 9.9 | 464 | .15 | .41 | .60 | .91 | 4.4 | 462 | 5 | 90 | 278 | 732 | 3,720 |
| Pequea Creek at Martic Forge | 01576787 | 8 | 52 | <3.3 | 4.4 | 5.0 | 6.1 | >7.1 | 53 | <.05 | .12 | .21 | .47 | >.86 | 63 | <14 | 34 | 82 | 329 | >817 |
| Long-term monitoring at Susquehanna River sites | | | | | | | | | | | | | | | | | | | | |
| Susquehanna River at Harrisburg | 01570500 | 9 | 239 | .1 | .8 | 1.1 | 1.3 | 2.1 | 374 | .01 | .05 | .07 | .14 | .41 | 547 | 1 | 17 | 69 | 178 | 476 |
| Susquehanna River at Marietta | 01576000 | 10 | 36 | <.7 | .9 | 1.1 | 1.2 | >1.7 | 127 | .02 | .06 | .10 | .14 | .49 | 126 | 4 | 24 | 54 | 108 | 363 |
| Susquehanna River at Conowingo, Md. | 01578310 | 11 | 453 | .5 | 1.0 | 1.2 | 1.5 | 2.4 | 455 | .01 | .04 | .06 | .08 | .34 | 485 | 2 | 10 | 18 | 40 | 284 |
| Project and research sites | | | | | | | | | | | | | | | | | | | | |
| Stony Cr. at Water Tank Trail near Dauphin | 01568750 | 12 | 43 | <.02 | .04 | .08 | .1 | >.2 | 61 | <.01 | .02 | .03 | .05 | >.09 | 62 | <2 | 3 | 7 | 27 | >74 |
| Swatara Creek at Inwood | 01572200 | 13 | 36 | <.5 | .6 | .7 | .9 | >1.3 | 73 | <.02 | .03 | .04 | .07 | >.17 | 75 | <2 | 4 | 10 | 21 | >135 |
| Brush Run, Site 2, near McSherrystown | 01573810 | 14 | 132 | .1 | 1.3 | 2.7 | 5.2 | 24 | 435 | .06 | .64 | .98 | 1.8 | 13 | 822 | 6 | 42 | 101 | 265 | 3,440 |
| L. Conestoga Cr., Site 3A, at Morgantown | 0157608335 | 15 | 170 | .6 | 2.8 | 5.9 | 7.8 | 11 | 554 | .11 | .76 | 1.9 | 3.1 | 11 | 773 | 6 | 72 | 431 | 1,260 | 9,970 |
| Observation well, Lancaster Co. LN1646 | 400744075584701 | 16 | 31 | <7.3 | 8.5 | 9.5 | 10 | >11 | 40 | <.01 | .03 | .04 | .07 | >.10 | 0 | -- | -- | -- | -- | -- |
| Spring, Lancaster Co. SP58 | 400744075583901 | 17 | 7 | -- | -- | 12 | -- | -- | 40 | <.02 | .03 | .04 | .06 | >.07 | 0 | -- | -- | -- | -- | -- |

**Table 7.** *Statistical summary of nitrate, phosphorus, and suspended-sediment data collected during water years 1980-91 at individual sites or groups of sites in the Lower Susquehanna River Basin—Continued*

[Nitrate and phosphorus constituents for the synoptic areal survey sites at wells and springs are dissolved nitrate as nitrogen and dissolved orthophosphate as phosphorus; units for the reservoir-site concentrations are given in milligrams per kilogram of dry material; n, number of samples; P1, 1st percentile; P25, 25th percentile; P75, 75th percentile; P99, 99th percentile; <, less than; >, greater than; --, too few samples to compute a reliable statistic; N/A, not applicable]

| Site or data-set name[1] | Site number | Map ID number (fig. 18) | Nitrate concentration, in milligrams per liter as nitrogen | | | | | | Phosphorus concentration, in milligrams per liter as phosphorus | | | | | | Suspended-sediment concentration, in milligrams per liter | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | n | P1 | P25 | Median | P75 | P99 | n | P1 | P25 | Median | P75 | P99 | n | P1 | P25 | Median | P75 | P99 |
| Synoptic areal survey site groups | | | | | | | | | | | | | | | | | | | | |
| *Streams* - Synoptic Areal Survey Sites | N/A | N/A | 104 | 0.1 | 0.7 | 1.6 | 4.9 | 7.0 | 211 | 0.01 | 0.04 | 0.10 | 0.22 | 4.5 | 366 | 1 | 5 | 14 | 59 | 1,090 |
| *Wells* - Synoptic Areal Survey Sites | N/A | N/A | 787 | .01 | .10 | 2.4 | 7.5 | 31 | 367 | <.01 | .01 | .01 | .02 | .14 | 0 | -- | -- | -- | -- | -- |
| *Springs* - Synoptic Areal Survey Sites | N/A | N/A | 17 | <.4 | 1.4 | 3.3 | 4.7 | >7.6 | 15 | -- | <.01 | <.01 | .01 | -- | 0 | -- | -- | -- | -- | -- |
| Bottom-material site groups | | | | | | | | | | | | | | | | | | | | |
| Lower Susquehanna River Reservoirs | N/A | N/A | 0 | -- | -- | -- | -- | -- | 54 | <385 | 520 | 855 | 1,100 | >1,250 | 0 | -- | -- | -- | -- | -- |
| NURE Program - Lower Susq. River Basin | N/A | N/A | 0 | -- | -- | -- | -- | -- | 840 | 200 | 400 | 500 | 700 | 1,400 | 0 | -- | -- | -- | -- | -- |

[1] Sites are in Pennsylvania unless otherwise noted.

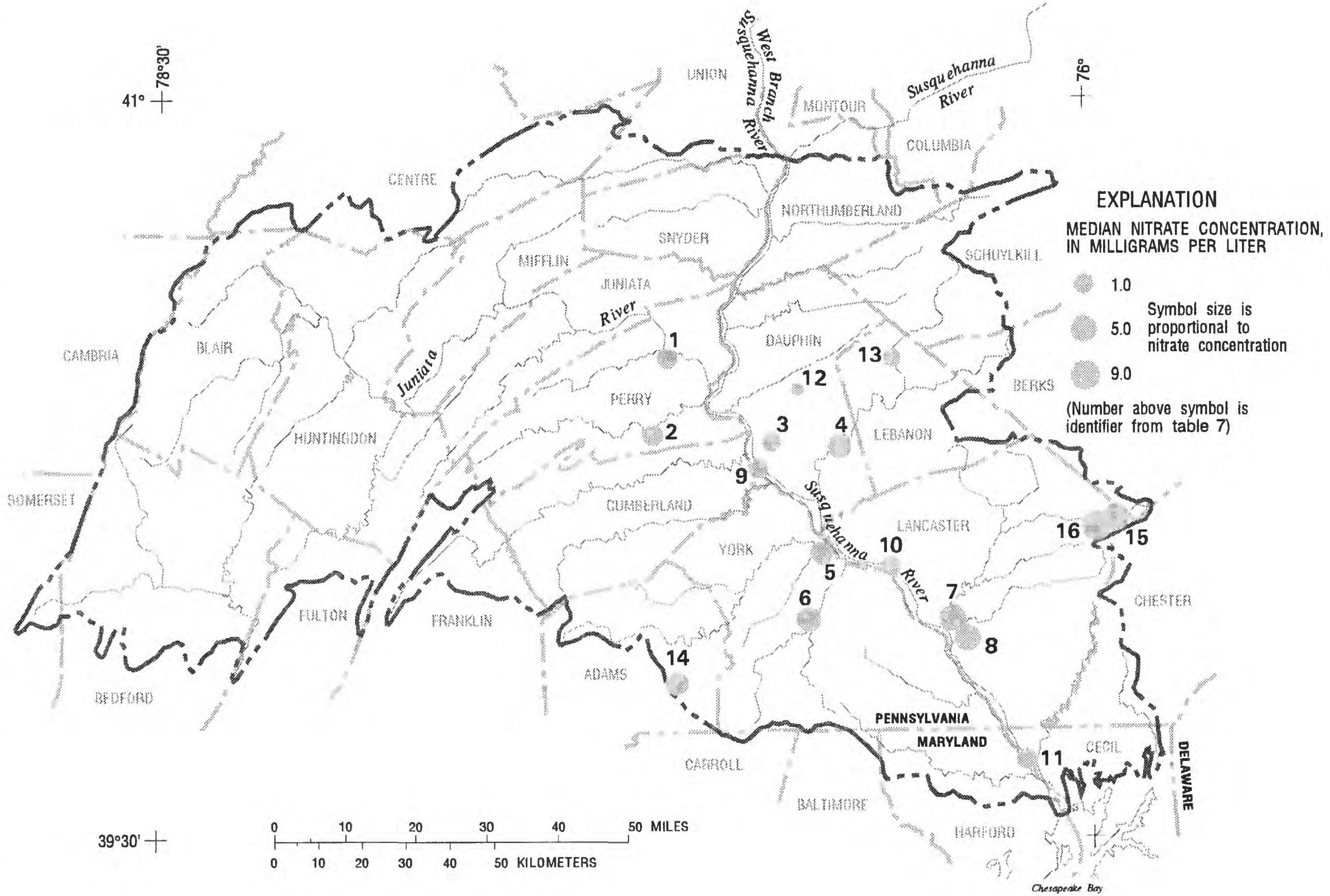
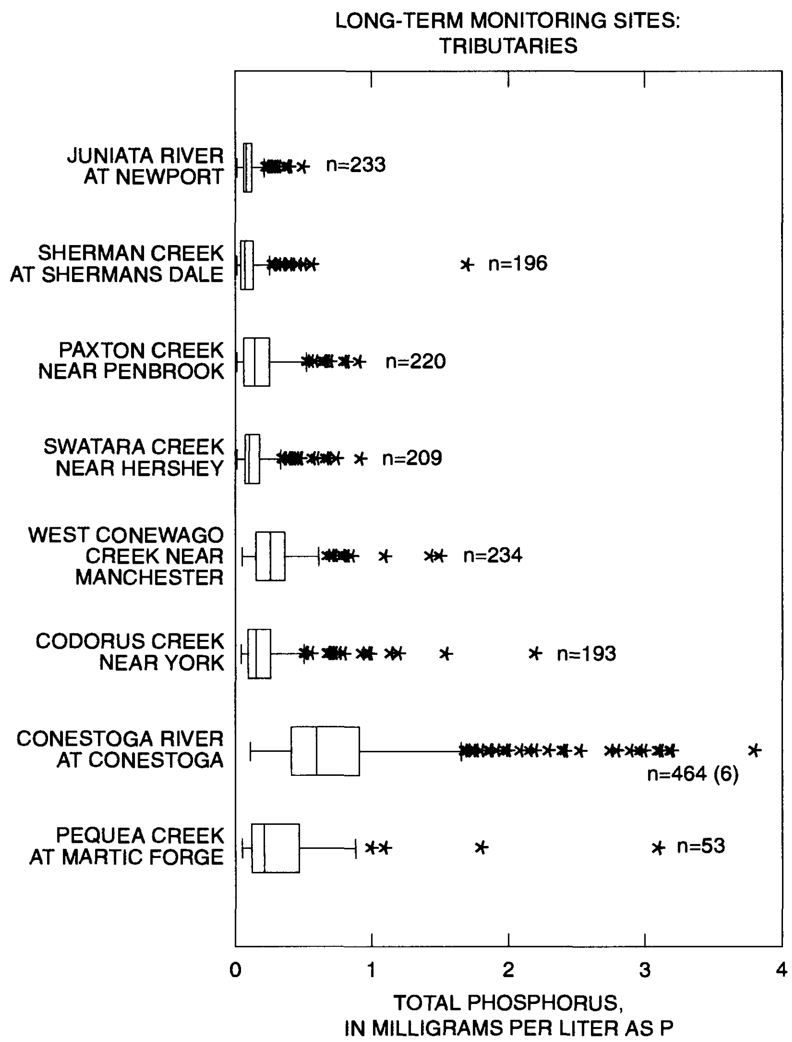
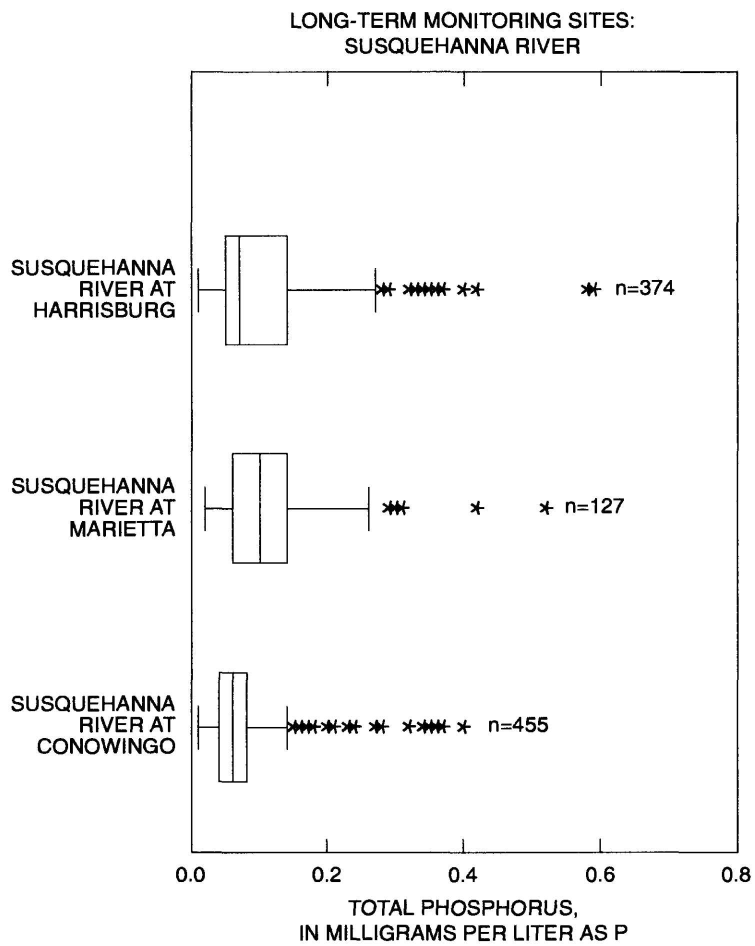



**Figure 18.** Areal distribution of median nitrate concentrations from data collected during water years 1980-89 at long-term monitoring and project and research sites on streams, a project and research well, and a project and research spring in the Lower Susquehanna River Basin.




EXPLANATION

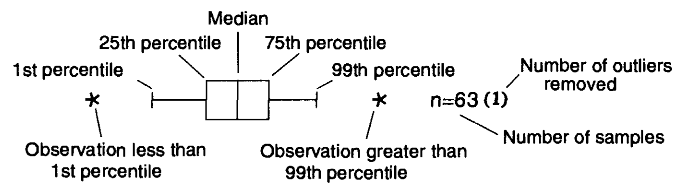



**Figure 19.** Phosphorus concentrations at selected sites in the Lower Susquehanna River Basin, water years 1980-89.

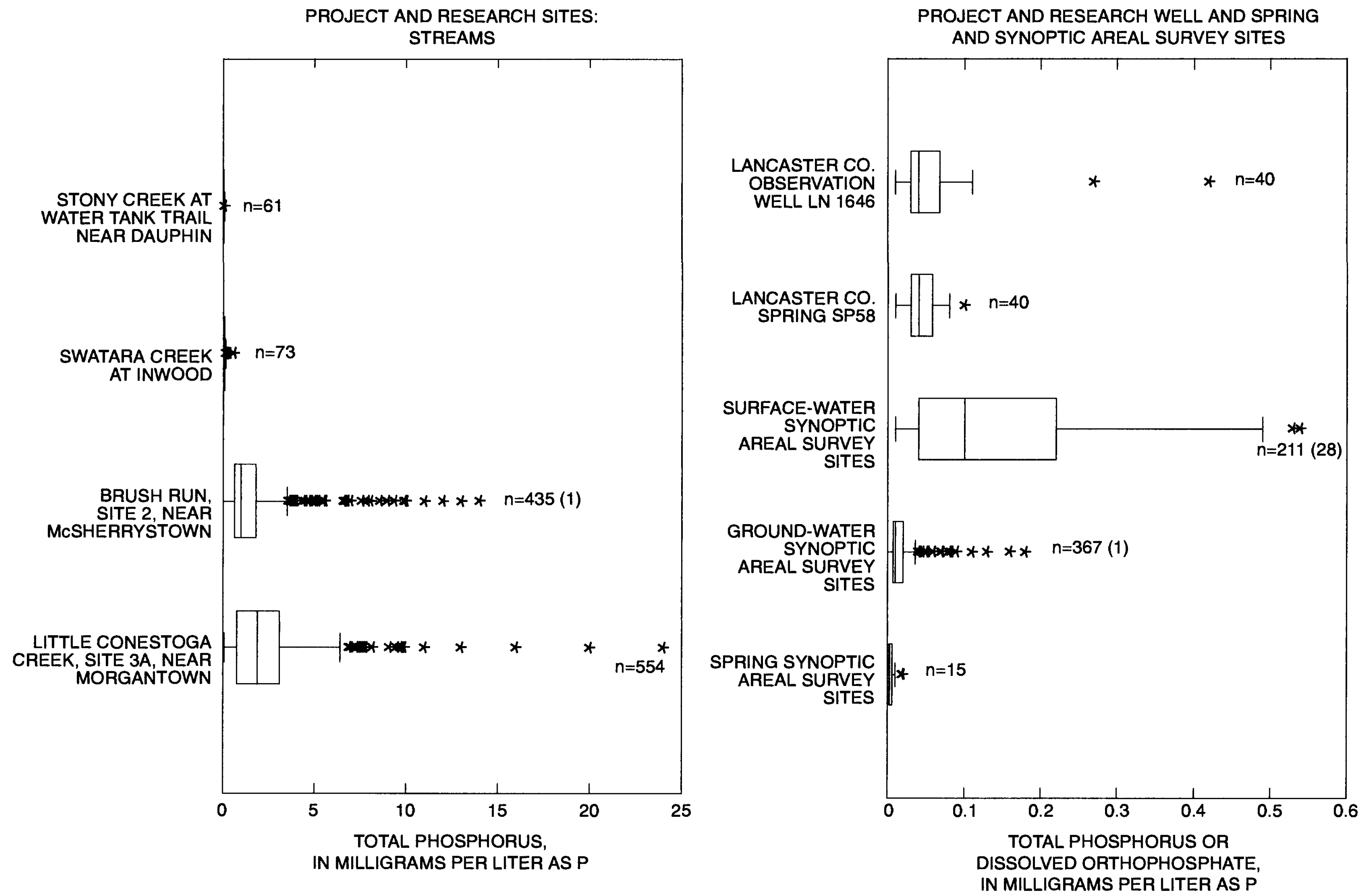



**Figure 19.** Phosphorus concentrations at selected sites in the Lower Susquehanna River Basin, water years 1980-89—Continued.

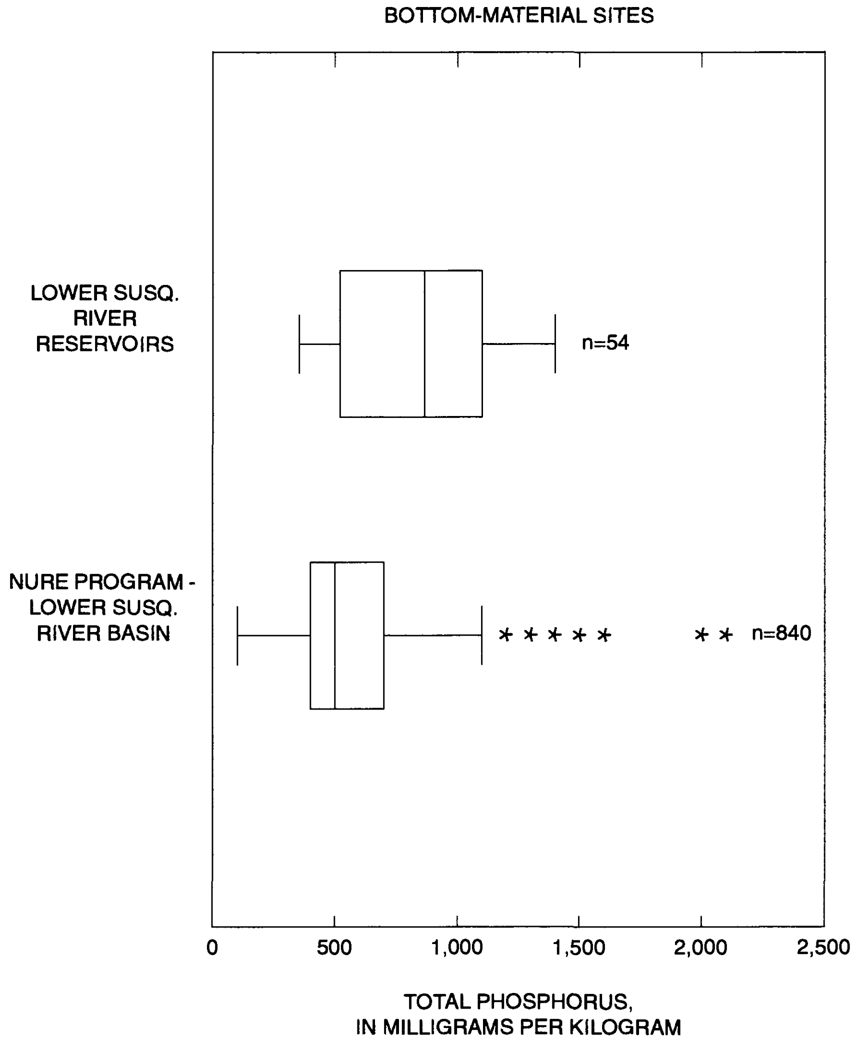



**Figure 19.** Phosphorus concentrations at selected sites in the Lower Susquehanna River Basin, water years 1980-89—Continued.

the next-to-highest median phosphorus concentration of the tributaries. The project and research site with the highest median phosphorus concentration is on a small tributary to the Conestoga River, the Susquehanna River tributary that had the highest median concentration of phosphorus of the major tributaries.

Median concentrations of phosphorus at the project and research well and spring were less than 0.05 mg/L (fig. 19, fourth graph)—a concentration lower than those generally measured in streams in the same locale. Phosphorus in streams is normally associated with suspended sediment. The general absence of suspended sediment in wells and springs may explain the difference in median concentrations between surface and ground water. In the synoptic areal survey data sets for water wells and springs alike, median concentrations were less than or equal to 0.01 mg/L (fig. 19, fourth graph).

Locations of the bottom-material sampling sites are shown in figure 10. The first data set displayed in figure 19 (fifth graph) consists of cores collected in 1990 and 1991 from the Lower Susquehanna River reservoirs. The median concentration of these samples for total available phosphorus was 855 mg/kg of dry material. The second bottom-material data set was collected in 1977 by the NURE Program at 840 stream sites throughout the basin. The median concentration for this data set was 500 mg/kg of dry weight.

Suspended-sediment concentrations for samples collected at the long-term monitoring and the project and research stream sites are compared (fig. 20), and statistical summaries of the concentrations are given in (table 7). The distribution pattern shown previously for concentrations of nitrate and phosphorus from tributaries to the Susquehanna River is highly similar to the pattern of suspended-sediment concentrations (fig. 20). One exception is the site on Paxton Creek, near the center of the study unit, with the second highest median concentration (142 mg/L). Among the northernmost large tributaries (Juniata River, Sherman Creek, and Swatara Creek), median concentrations ranged from 24 to 37 mg/L. At West Conewago Creek and Codorus Creek, in the middle of the study unit, median concentrations were 64 and 40 mg/L, respectively. At the two tributaries in the southeasternmost part of the study unit, Conestoga River and Pequea Creek, some of the highest median concentrations were found (278 and 82 mg/L, respectively).

Concentrations of suspended sediment in the Susquehanna River main stem decreased with distance downstream (fig. 20, second graph). This is the opposite of the general tributary and main-stem patterns for concentrations of nitrate and phosphorus upstream from the reservoirs. Because of the reservoirs, a dramatic decrease in suspended-sediment content was measured at Conowingo, Md., near the mouth of the Susquehanna River.

Distribution patterns for suspended sediment at the project and research sites were similar to those for nitrate and phosphorus. Median concentrations of suspended sediment at the two northern sites (Stony Creek and Swatara Creek) were the lowest of all the sites investigated; 7 and 10 mg/L, respectively. Median concentrations at the two sites in the southern and the southeastern parts of the study unit (Brush Run and Little Conestoga Creek) were higher than all but two of the major tributaries. The median concentrations at these two sites were 101 and 431 mg/L, respectively. The median concentration of suspended sediment at Little Conestoga Creek was the highest of all the streams.

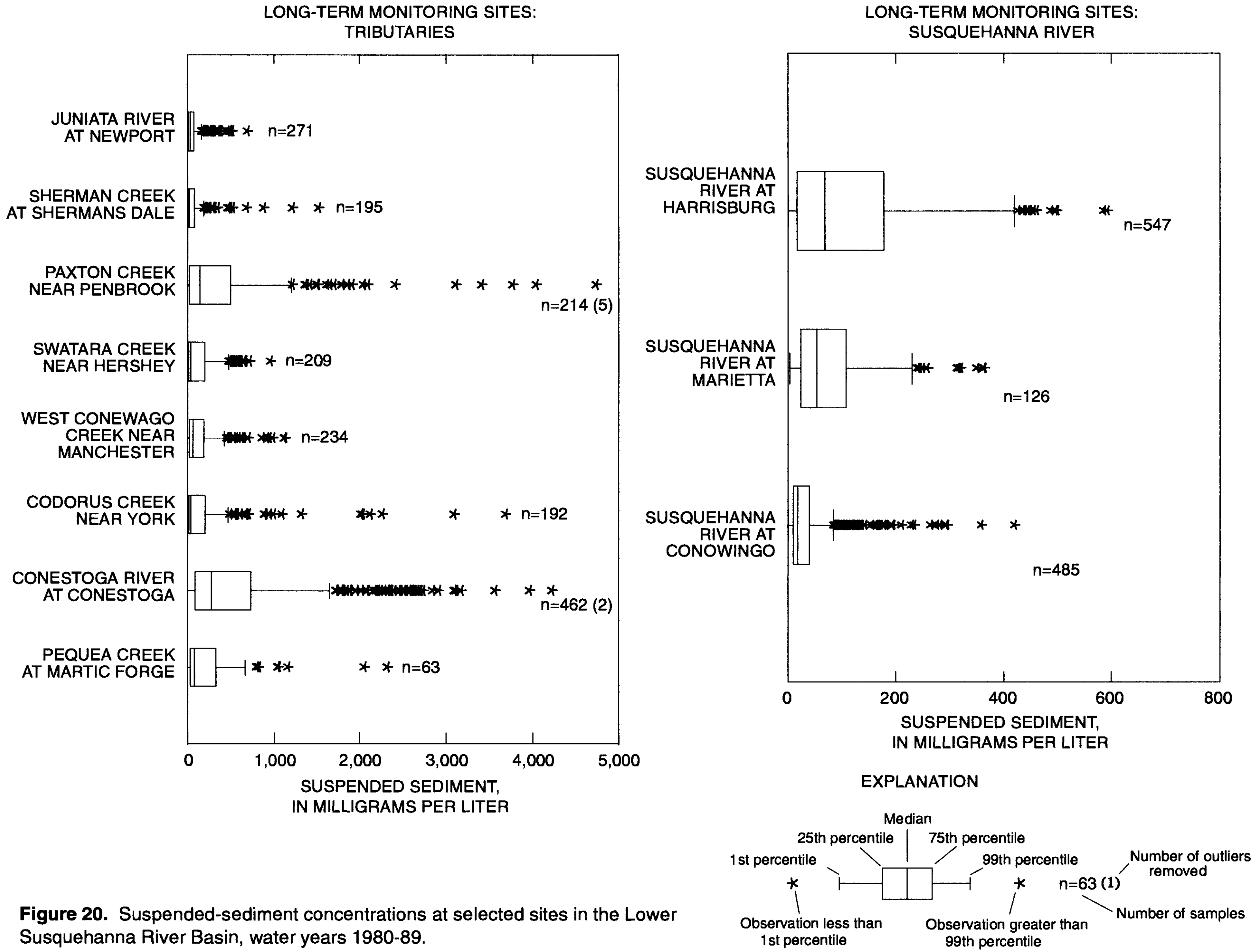



**Figure 20.** Suspended-sediment concentrations at selected sites in the Lower Susquehanna River Basin, water years 1980-89.

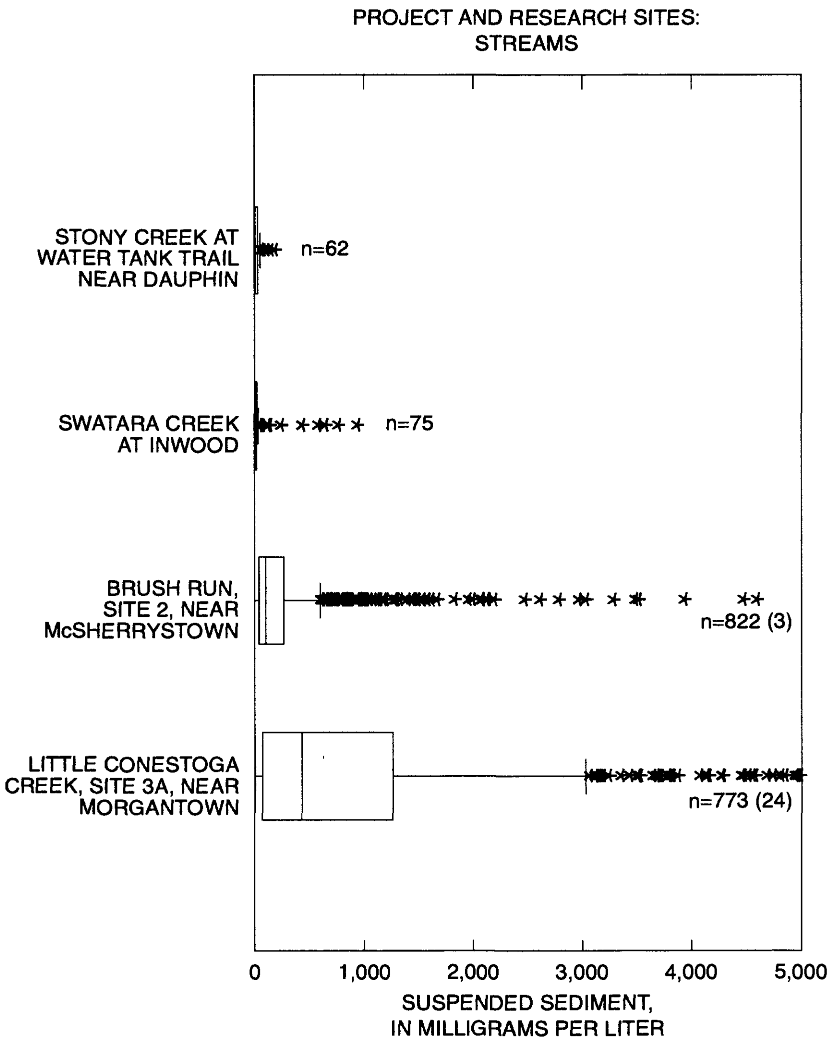



**Figure 20.** Suspended-sediment concentrations at selected sites in the Lower Susquehanna River Basin, water years 1980-89—Continued.

## Relation of Concentrations of Nutrients and Suspended Sediment to Streamflow

Nutrient and suspended-sediment data collected at stream sites during 1980-89 can be used to define relations of concentration to streamflow; and, where data are few or unavailable, they can be used to show where a scarcity of data affects efforts to describe these relations. The relations between streamflow and concentrations of nitrate, phosphorus, and suspended sediment for four long-term monitoring sites on streams are shown in figures 21-25. The sites were selected to present the relation between constituent concentrations and streamflow at sites that differ in drainage-basin size and other basin characteristics. The drainage areas of the sites range from 11 $mi^2$ at the Paxton Creek site to nearly 26,000 $mi^2$ at the Susquehanna River site. The Paxton Creek site drains a mixed urban and residential area. Water quality at the Conestoga River site is mainly the result of agricultural practices, but it also has been influenced by urban and point sources of contamination. The Juniata River, the largest tributary in the Lower Susquehanna River Basin, drains an area of mixed land use and lithology. The site on the

Susquehanna River at Marietta reflects the cumulative water quality of the basin before the river enters the reservoirs. The only major tributary not included in the flow passing the Marietta site is the Conestoga River.

Locally weighted scatterplot smoothed (LOWESS) curves are used in figures 21-25 to emphasize the relation between concentration and streamflow. These are not statistics-based regression lines, so they may be used whether the relation is linear or nonlinear. The curves are developed by including a defined number of points along the x-axis and determining an average y-value for that group of points. The "window" moves progressively along the x-axis, one point at a time, and the average y-value is used to determine the points along the LOWESS curve. The curve is provided as a visual indicator of a general direction or tendency for the relation. A statistically derived equation relating the two variables is not a product of the LOWESS curve development process.

The four LOWESS curves developed for streamflow and nitrate concentrations indicate three types of relations (fig. 21). The data collected from the Juniata River and Susquehanna River (the sites with the two largest drainage areas) describe a relation in which the nitrate concentration rises until the streamflow reaches a value that was exceeded 25 to 30 percent of the time during 1980-89. At this flow, a dilution effect appears to begin. This type of streamflow-concentration relation implies that a limited source of readily available nitrate is mobilized with the initial energy provided by rainfall and is transported quickly to the stream. The release of nitrate appears to increase with time, which increases the nitrate concentration in the stream, until the nitrate supply apparently becomes exhausted or nearly exhausted at a certain point after runoff begins.

Nitrate data collected from the site on the Conestoga River indicate that dilution is a major factor throughout the range of sampled streamflows (fig. 21). This relation indicates that a source of nitrate provides a relatively constant concentration to the system. Apparently, the concentration of the supplied material is not dependent on streamflow or other hydrologic conditions. Two possible sources of this type are ground-water and spring discharges into the channel and treated wastewater discharges.

The final type of relation identified is a combination of the two previously described relations (Paxton Creek nitrate data, fig. 21). The small drainage area of the basin (11 $mi^2$) also could affect this mixture of relation types. The LOWESS curve indicates an initial dilution of nitrate concentration followed by an increase in nitrate concentration at higher streamflows. The change from dilution to increased concentration is at a flow that was exceeded about 50 percent of the time during 1985-88. A dilution effect appears again at streamflows that were exceeded only 1 to 5 percent of the time. These streamflows would be produced during extreme storms. The system indicated by this curve may consist of multiple source types: one or more near the site and one or more at distance. The nearby source provides constant input of nitrate to the stream, which is then diluted to lower and lower concentrations by the increasing streamflow. Later, the more distant source provides additional nitrate to the stream, and concentrations begin to rise. Nitrate concentrations in the stream continue to rise until the delivery rate from the upstream source becomes constant or decreases, and the concentrations are then reduced.

In hydrologic systems, most phosphorus is generally transported while adsorbed to suspended material during runoff and is related to the concentration of suspended sediment. When the stream is at base flow, concentrations of phosphorus are low and most of the phosphorus is dissolved.

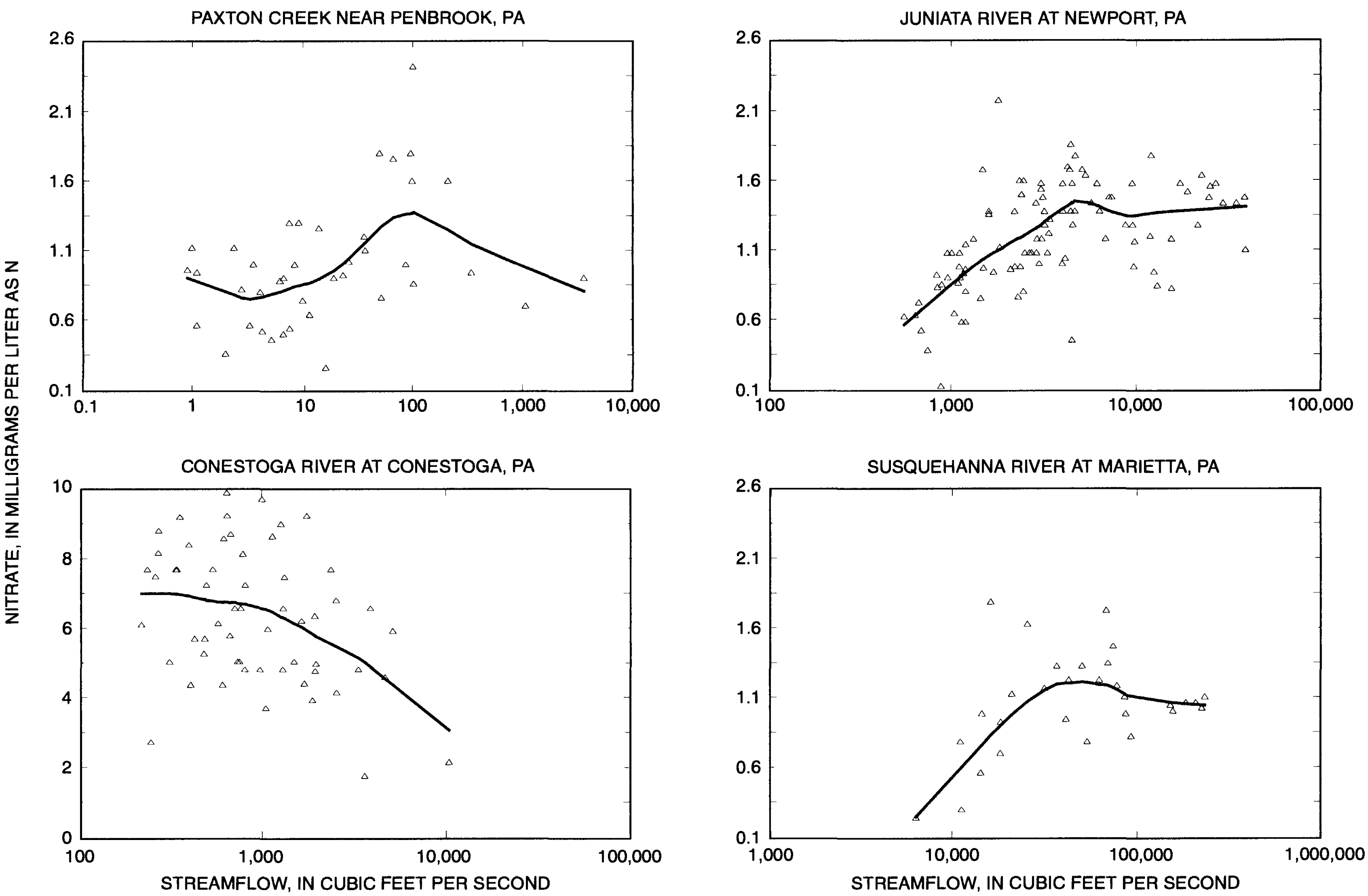



**Figure 21.** The relation of streamflow to concentration of nitrate at four selected sites in the Lower Susquehanna River Basin for various periods during water years 1980-89.

The relation of phosphorus and streamflow for the same four long-term monitoring sites was developed (fig. 22). Unlike the relations shown for nitrate, transport characteristics of phosphorus were similar at the four sites. An initial dilution effect of the dissolved phosphorus followed by the introduction of material adsorbed to suspended material from an overland runoff source is the pattern that can be concluded from the LOWESS curves. In the three largest basins, concentrations of phosphorus increase markedly at a streamflow slightly above a flow exceeded 50 percent of the time during 1980-89. The data from the Paxton Creek Basin indicates two changes in the slope of the curve. This pattern indicates two sources of material—one more distant from the sampling site than the other. The initial dilution effect seen at all the sites is probably the result of a timing difference between the introduction of runoff to the stream from the area just above the sampling site and the transport of materials from erodible areas within the basin. This effect also may be related to an initial dilution of dissolved material and the introduction of greater amounts of suspended material as streamflow increases, or it may be related to the release of phosphorus from algae during low flow in the fall.

The relation of streamflow and the concentration of suspended sediment also was analyzed at the same four sites (fig. 23). Transport processes of suspended sediment and phosphorus are usually closely related in hydrologic systems. At these four sites, patterns similar to those for phosphorus are shown by the LOWESS curves; thus, similar transport mechanisms are likely.

The relation of concentrations of nitrate to streamflow can be discussed in terms of low-flow and high-flow periods. Arbitrary definitions of low flow and high flow were established for this report: low flow is a streamflow that was exceeded more than 75 percent of the days during 1980-89, whereas high flows are flows that were exceeded less than 25 percent of the days during the same period. Owing to the extremity of these criteria for low and high flows, they most likely represent typical base flow conditions for the fall and typical high base flow and stormflow for the spring. Boxplots and summary statistics for concentrations of nitrate during low-flow and high-flow periods are given in figure 24 and table 8. The concentrations displayed in the figure and table for low and high flows may be affected by the potential seasonality of the flow criteria. The six streams presented in the figure and table include the four sites used in the discussions of the relation of streamflow and concentration and two additional project and research sites, on Brush Run and Little Conestoga Creek. These two additional streams drain small basins (0.4 and 1.4 $mi^2$, respectively) and are included for comparison with the larger basin streams.

The boxplots and the summary statistics support the conclusions made in the previous paragraphs on the relation between nitrate concentration and streamflow. A comparison of the median values for low flow and high flow at each of the sites shows the same pattern suggested by the LOWESS curves (fig. 21). Boxplots also indicate variability around the median concentration. Variability in nitrate concentration in the Juniata River appears to be constant regardless of the type of flow. Insufficient data are available to make this analysis for the Paxton Creek, Conestoga River, and Susquehanna River at Marietta sites.

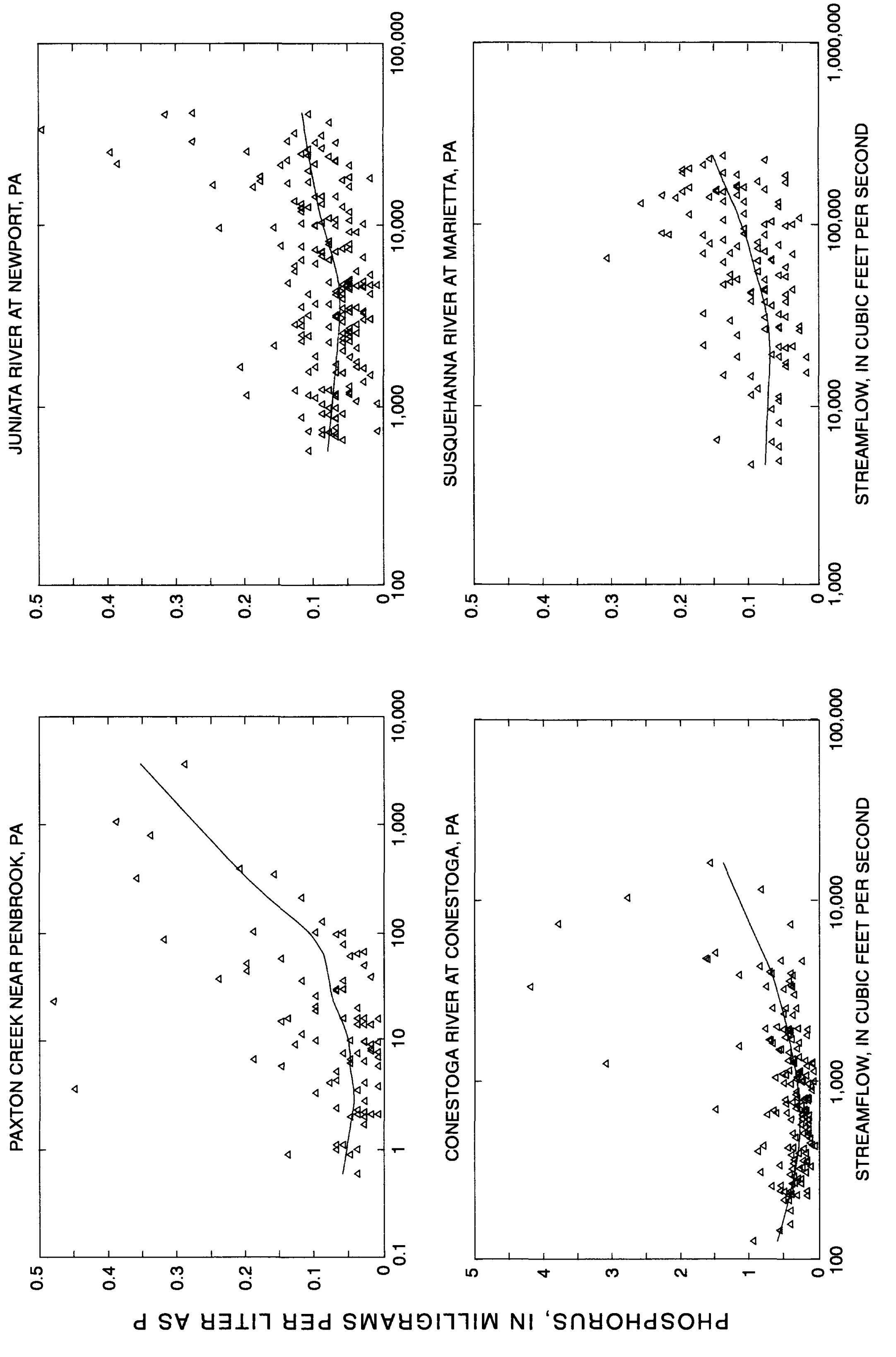



**Figure 22.** The relation of streamflow to concentration of phosphorus at four selected sites in the Lower Susquehanna River Basin for various periods during water years 1980-89.

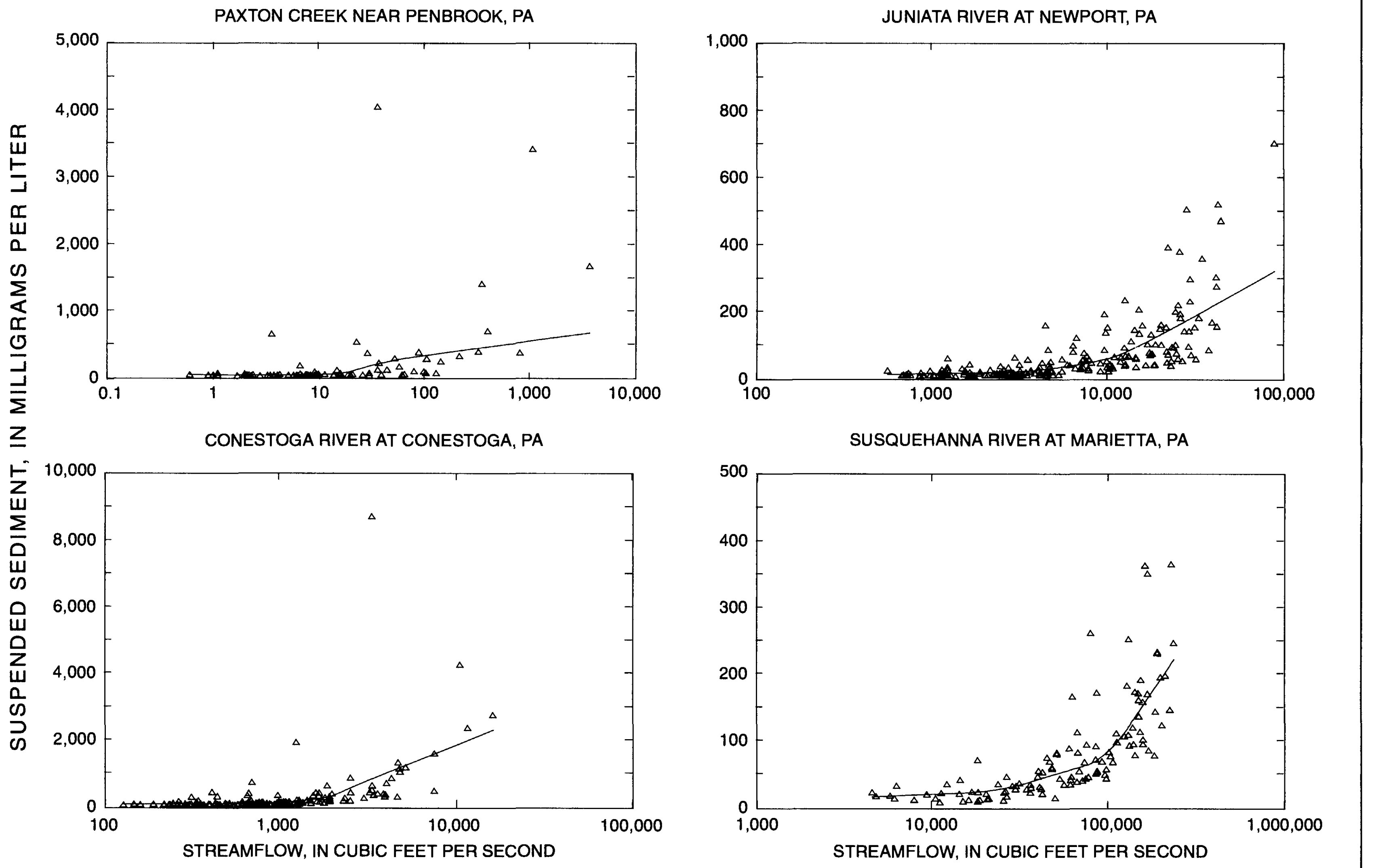



**Figure 23.** The relation of streamflow to concentration of suspended sediment at four selected sites in the Lower Susquehanna River Basin for various periods during water years 1980-89.

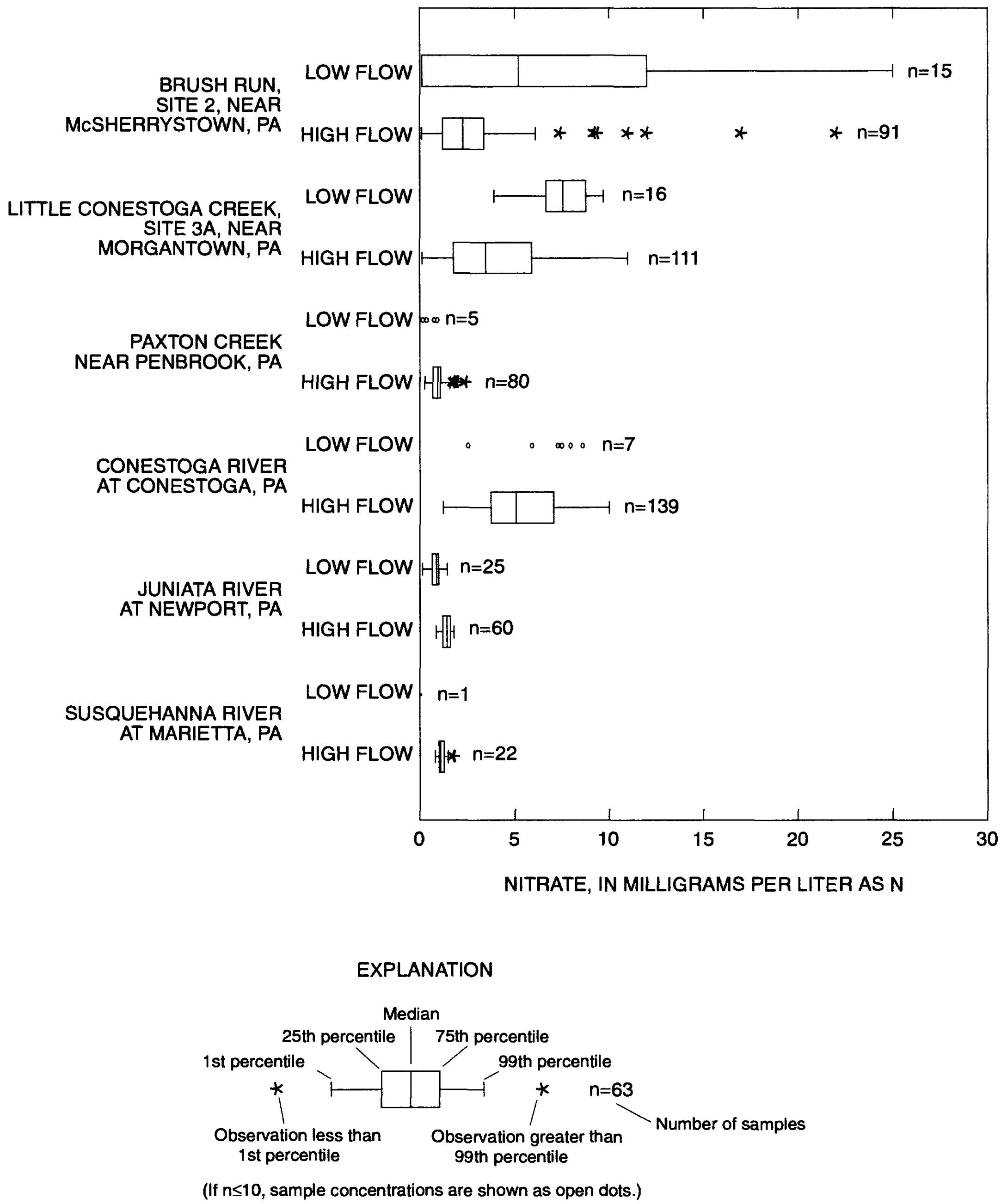



**Figure 24.** Concentrations of nitrate at six selected streams in the Lower Susquehanna River Basin for low flow and high flow and various periods during water years 1980-89.

**Table 8.** *Statistical summary of concentrations of nitrate in selected streams in the Lower Susquehanna River Basin at low flow and high flow for various periods during water years 1980-89*

[$ft^3/s$, cubic foot per second; n, number of samples; P1, 1st percentile; P25, 25th percentile; P75, 75th percentile; P99, 99th percentile; <, less than; >, greater than; --, too few samples to compute a reliable statistic]

| Site name | Type of Flow | Flow criterion ($ft^3/s$) | Nitrate concentration, in milligrams per liter as nitrogen | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | n | P1 | P25 | Median | P75 | P99 |
| Brush Run, site 2, near McSherrystown, Pa. | Low | <0.02 | 15 | -- | 0.10 | 5.2 | 12.0 | -- |
| | High | >.3 | 91 | <0.84 | 1.2 | 2.3 | 3.4 | >7.1 |
| Little Conestoga Creek, site 3A, at Morgantown, Pa. | Low | <.3 | 16 | <4.4 | 6.6 | 7.6 | 8.8 | >9.6 |
| | High | >1.1 | 111 | .20 | 1.8 | 3.5 | 5.9 | 11.0 |
| Paxton Creek near Penbrook, Pa. | Low | <2.3 | 5 | -- | -- | .94 | -- | -- |
| | High | >13 | 80 | <.60 | .69 | .94 | 1.1 | >1.6 |
| Conestoga River at Conestoga, Pa. | Low | <290 | 7 | -- | -- | 7.5 | -- | -- |
| | High | >690 | 139 | 1.2 | 3.7 | 5.1 | 7.1 | 9.9 |
| Juniata River at Newport, Pa. | Low | <1,220 | 25 | <.48 | .64 | .87 | .99 | >1.1 |
| | High | >4,640 | 60 | <.94 | 1.2 | 1.4 | 1.6 | >1.7 |
| Susquehanna River at Marietta, Pa. | Low | <10,500 | 1 | -- | -- | .26 | -- | -- |
| | High | >41,700 | 22 | <.86 | 1.0 | 1.1 | 1.3 | >1.7 |

Because of the inability of small streams to dilute even moderate inputs of constituents, small streams with low flows generally have the highest variability of instream constituent concentrations. The concentrations of nitrate measured at Brush Run, the smallest stream, were the most variable among all the sites at low flow and high flow concentrations, and concentrations at low flow were more variable than concentrations at high flow. At the remaining stream, Little Conestoga Creek, median low-flow concentration was highest, and concentration of nitrate in samples collected during high-flow periods also showed high variability.

### Relation of Concentrations of Nutrients to Well Characteristics

Concentrations of dissolved nitrate as nitrogen and dissolved orthophosphate as phosphorus were related to the occurrence of ground water in shallow and deep aquifers by use of depth of the open interval as a surrogate for the aquifer depth. The two chemical constituents used here are different from the two constituents used for previous discussions but, for this data set, more samples were available for these two constituents than for dissolved nitrite plus nitrate as nitrogen and total phosphorus. Dissolved nitrate as nitrogen is for all practical purposes the same as dissolved nitrite plus nitrate as nitrogen because natural water generally contains very little nitrite. Orthophosphate concentrations are generally similar to phosphorus concentrations in ground water; and because concentrations from the groups of wells are compared only to each other, the increased number of samples justifies substitution of orthophosphate for phosphorus here. The assumptions made in this analysis are that (1) depth of the well is related to the depth at which the water in the well is produced, (2) water from the shallow wells represents water most recently recharged through the soil and is presumably younger than the water from deeper wells, and (3) shallow and deep waters do not mix in deep wells. Nutrient-concentration data for wells that were sampled during synoptic areal surveys were selected for analysis because of the large range of well depths; 618 wells met these criteria.

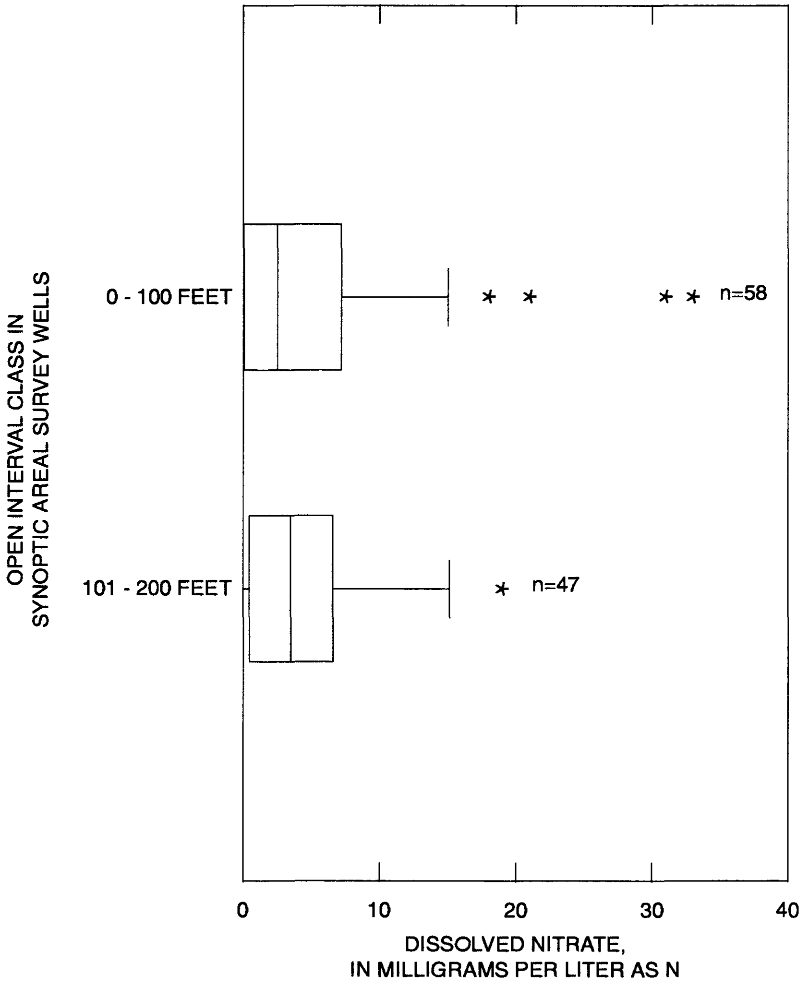
The depth below the land surface of the open interval midpoint was determined by computing the average of the depths of the bottom of the casing and the well. The depth of the midpoint of the open interval was used to classify the well into three classes: 0 to 100, 101 to 200, and greater than 200 ft. An insufficient number of wells with depths greater than 200 ft and with nutrient data were available for analysis. In addition, only wells with open intervals less than or equal to 50 ft were selected for analysis. Under these restrictions, 105 samples with dissolved nitrate as nitrogen concentrations and 52 samples with dissolved orthophosphate as phosphorus concentrations were available for analysis. The number of samples available and the geographic distribution of the wells also was marginally suitable.

Comparisons of median concentrations of nitrate and the variability of the concentrations for the 0- to 100-ft and 101- to 200-ft classes show little difference in wells with open-interval midpoints less than 200 ft below the land surface (fig. 25). The median concentrations for the two synoptic areal survey data sets were 2.5 and 3.5 mg/L for the 0- to 100-ft and 101- to 200-ft classes, respectively. The range of concentrations was greater for wells with open-interval midpoints less than 100 ft deep; however, the concentration outliers for this class were all collected from one well.

Similarly, orthophosphate data for wells were separated into two classes on the basis of depth of the open-interval midpoint. Median concentrations for the wells in the 0- to 100-ft class and the 101- to 200-ft class were 0.01 and 0.015 mg/L, respectively (fig. 26). Although the medians were similar, the variability of the concentrations of the two classes of wells is visibly different. The maximum concentration of the 20 samples in the 0- to 100-ft class is 0.04 mg/L. In the 101- to 200 ft class, the maximum concentration is 0.11 mg/L, and 12 of the 32 concentrations exceed 0.04 mg/L.

### Relation of Concentrations of Nutrients and Suspended Sediment to Physiography, Geology, and Land Use

Concentrations of nutrients and suspended sediment in streams and wells are commonly affected by environmental factors. Bedrock underlies a drainage basin and, in places, forms an aquifer. Structure and mineralogy of bedrock determine the rate of ground-



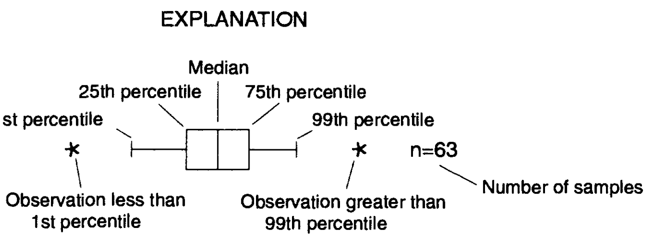




**Figure 25.** Relation of depth of open interval to concentration of dissolved nitrate as nitrogen at wells sampled during synoptic areal surveys, Lower Susquehanna River Basin, water years 1980-89.

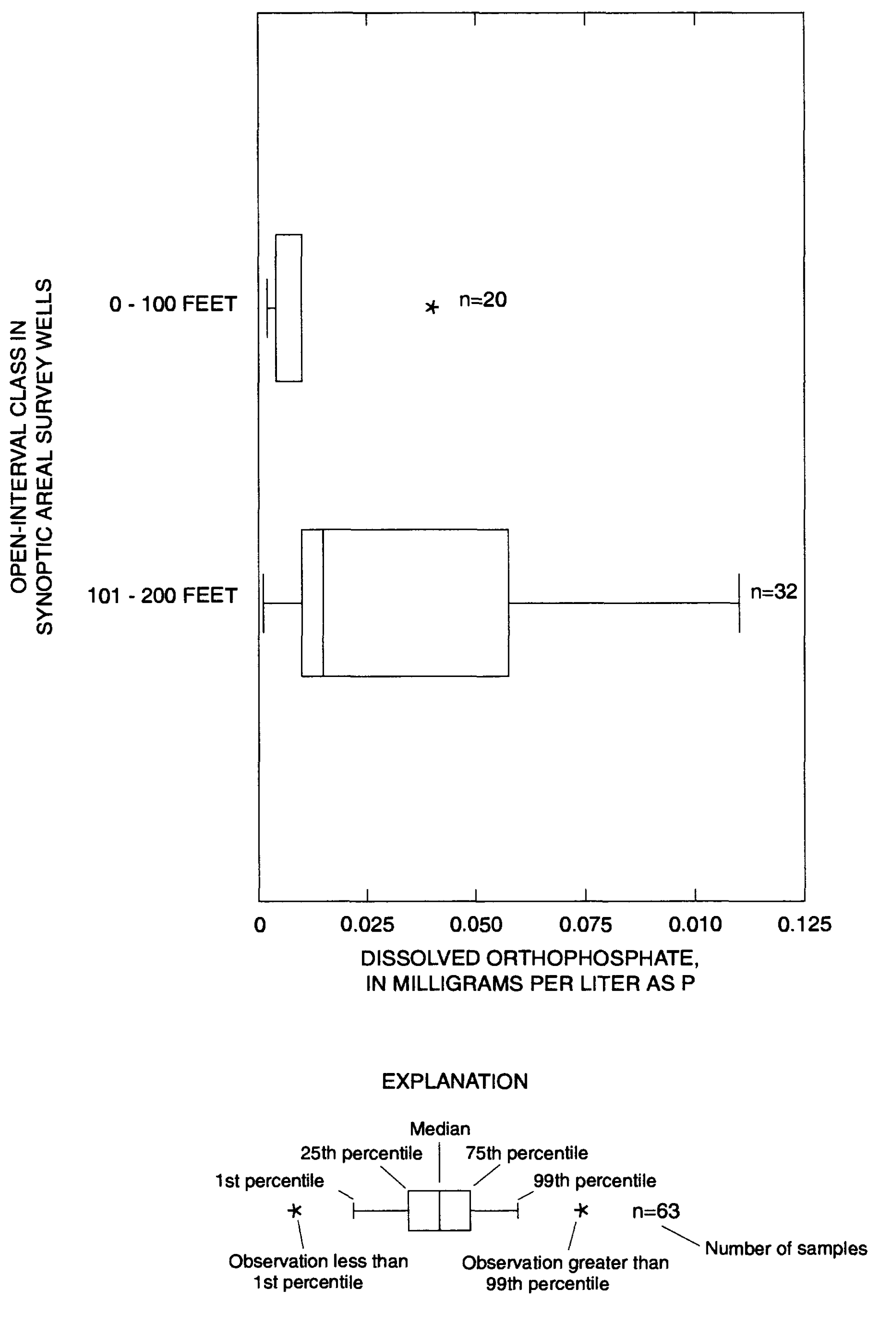



**Figure 26.** Relation of depth of open interval to concentration of dissolved orthophosphate as phosphorus at wells sampled during synoptic areal surveys, Lower Susquehanna River Basin, water years 1980-89.

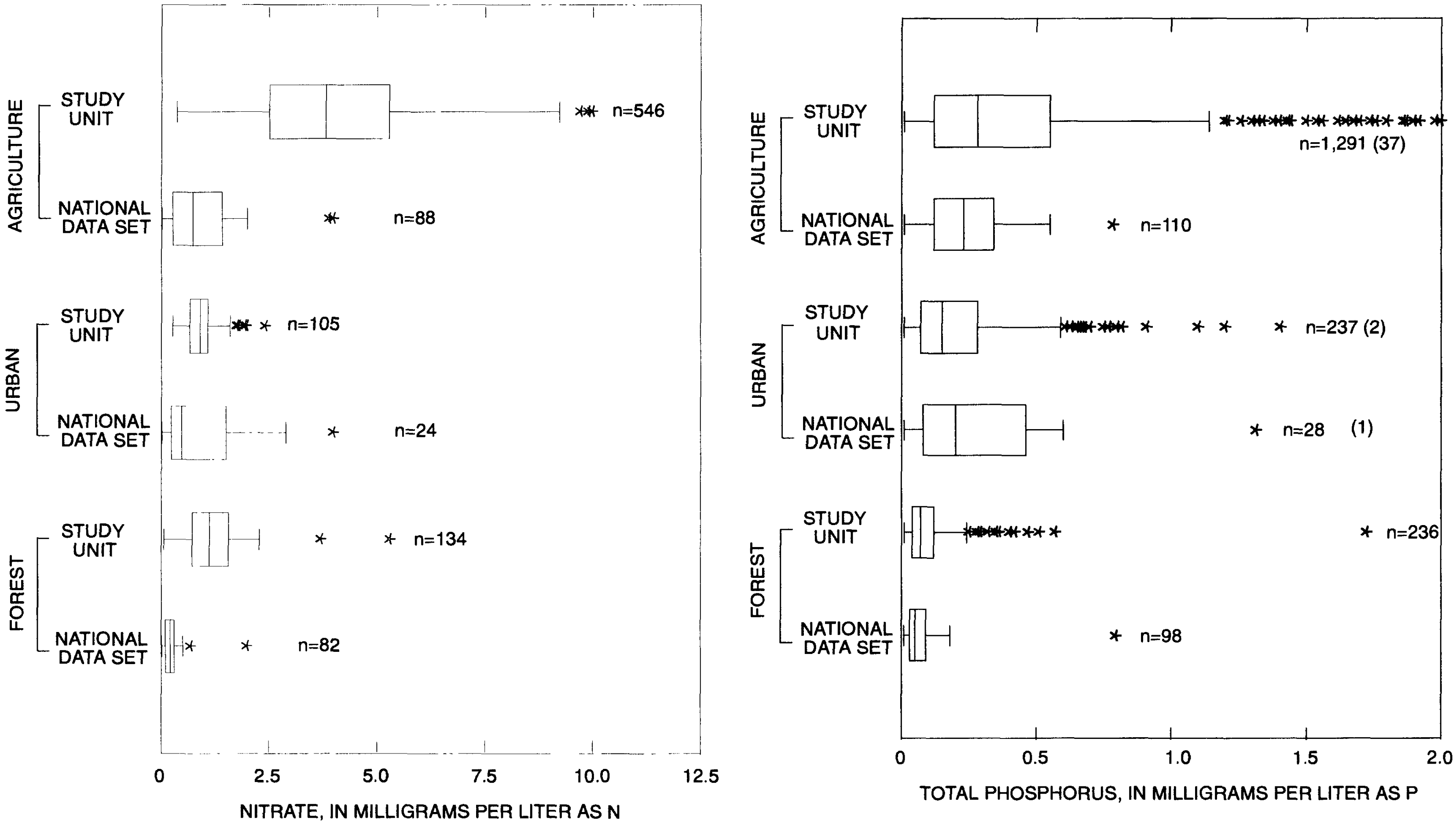
water flow through it and the natural or background chemistry of the ground water. The chemistry of ground water has a significant influence on base-flow streamwater chemistry.

For this study, the rock formations underlying the Lower Susquehanna River Basin were grouped into three general types of bedrock: siliciclastic, crystalline, and carbonate. The three dominant land uses in the study unit are forest, urban, and agriculture. The dominant land use within the long-term monitoring stream basins was determined by Ott and others (1991). The dominant land use of basins upstream from synoptic areal survey sites was determined by use of an overlay of basin location and available land-use/land-cover information. Where a land use did not occupy greater than 50 percent of the basin, the dominant land use immediately upstream from the sampling site was used to designate the basin's dominant land use. The term "land use" is used to describe both the treatment of the land surface and the human activity associated with the treatment. For example, in agricultural areas the type of crop grown on the land and the cultivating, planting, and fertilizing associated with the production of the crop that may affect concentrations of nutrients and suspended sediment are all included in the environmental factor termed "agricultural land use." Characteristics of the rock-type and land-use groups in the Lower Susquehanna River Basin are described in more detail in earlier sections of this report and by Risser and Siwiec (1996).

The relation of concentrations of nitrate, phosphorus, and suspended sediment in streams to land use was evaluated (fig. 27). The data subset selected for this discussion included long-term monitoring tributaries to the Susquehanna River and synoptic areal survey sites on streams. No main-stem sites were included because of the difficulty in assigning a dominant land use to the area drained by the stream. No project and research sites on streams were included because of the small area drained by the stream and the magnified effects of land use on these small basins. As a point of reference, boxplots describing the distribution of concentrations of nutrients and suspended sediment throughout the Nation also are shown. Sites for the national data set were randomly selected from a subset of a 1,400-site database that met land-use selection criteria described by Smith and others (1992). These same criteria were used to classify stream basins in the study unit.

Within the study unit, as well as nationally, streams that drain areas dominated by agriculture are characterized by elevated concentrations of nutrients and suspended sediment with respect to those found in areas of other land-use types. The greatest difference among the land uses is in nitrate concentration. Concentrations of nitrate in streams draining agricultural areas are much higher than those in urban or forested areas. Relatively little difference in nitrogen concentration is evident between urban and forested settings, except for the median from the national forested data set, which is the lowest for all the groups. Streams draining forested areas have the lowest median concentrations of phosphorus and suspended sediment. Of the constituent data examined, concentrations of suspended sediment are least variable among the land-use settings.

Data to test the statistical significance of differences between the medians of the Lower Susquehanna River Basin and national data sets were not available. However, a nonstatistical approach of visually comparing the medians of similar data subsets in figure 27 indicates that median concentrations in the study unit, for most of the constituents within each land-use setting, were higher than the medians computed for the national data set. Exceptions were suspended-sediment concentrations in agricultural and forested settings and phosphorus concentrations in urban settings. No immediate explanation is available for the results of this comparison, except that streams located in



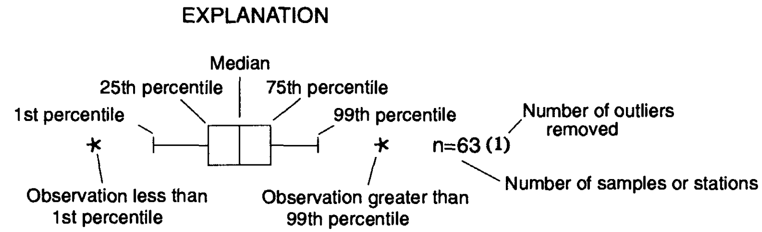




**Figure 27.** Concentrations of nitrate, phosphorus, and suspended sediment in streams draining selected land uses in the Lower Susquehanna River Basin and nationally, water years 1980-89. (Except those given for the national data sets, values for "n" are number of samples. The "n" values for the national data set are number of stations with 8-10 years of data—number of samples is unknown.)

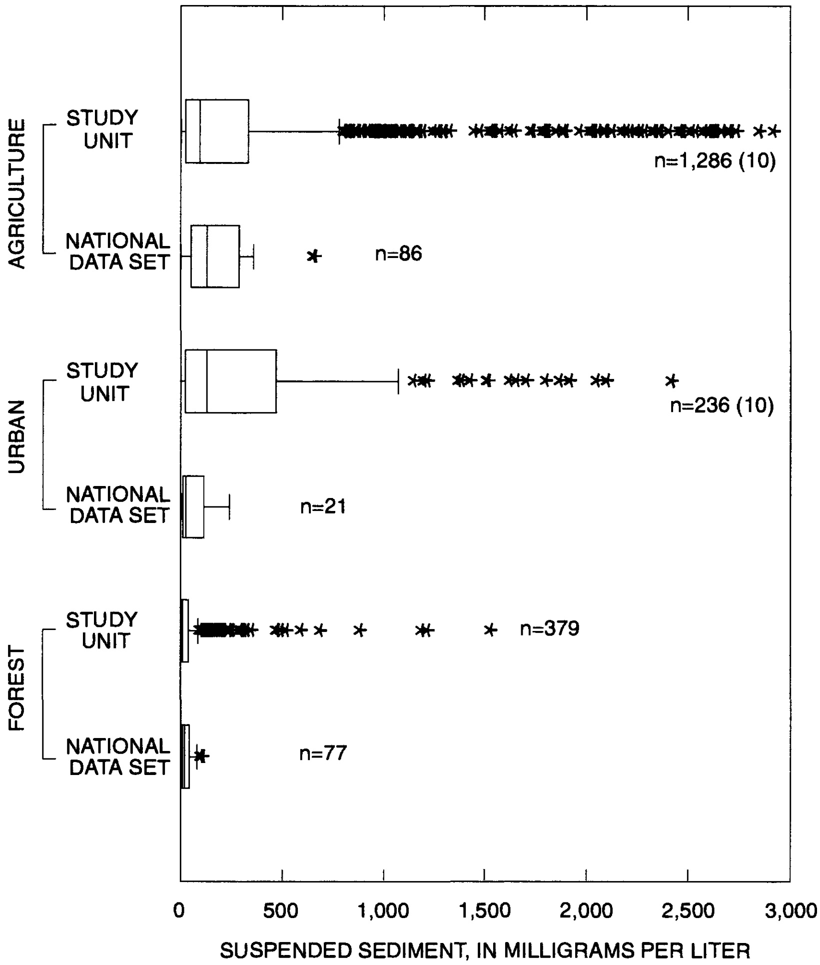



**Figure 27.** Concentrations of nitrate, phosphorus, and suspended sediment in streams draining selected land uses in the Lower Susquehanna River Basin and nationally, water years 1980-89. (Except those given for the national data sets, values for "n" are number of samples. The "n" values for the national data set are number of stations with 8-10 years of data—number of samples is unknown.)—Continued.

forested settings in the study unit were generally pristine and were sampled to define reference or background conditions. Forested-setting streams included in the national data set may include areas of active logging, which generally increase the erodibility of soils and the availability of suspended sediment for transport.

Incorporating physiographic province and bedrock type into the analysis allows for a further level of analysis of the land uses and their relation to concentrations of nutrients and suspended sediment. Given 3 land-use settings, 2 physiographic provinces, and 3 bedrock types within the study unit, a total of 18 bedrock/land-use subunits are potentially available. Only 11 of these subunits exist in the Lower Susquehanna River Basin.

Concentrations of nitrate for the 11 subunits in the Lower Susquehanna River Basin were assembled (fig. 28). Synoptic areal survey data sets for wells (GW) and streams (SW) and data from large tributaries (TRIB) to the Susquehanna River that drain relatively homogeneous areas of bedrock type and land use were included. The concentrations in the GW data set include determinations of dissolved nitrate as nitrogen without nitrite. Determinations of dissolved nitrate alone can generally be considered equivalent to determinations of dissolved nitrite plus nitrate. For each of the subunits, nitrate concentrations in ground water appear to be more variable than those in surface water. This may be a result of the relatively large number of samples from wells available for analysis in comparison with the number of samples available for streams.

Median concentrations of nitrate from all the data sets in all the subunits are less than the Pennsylvania drinking-water standard of 10 mg/L (Commonwealth of Pennsylvania, 1994). For data collected from wells in the Piedmont Physiographic Province in carbonate rock settings, however, 25 percent of the nitrate concentrations exceed the standard; in the Piedmont crystalline agricultural subunit, 10 percent of the concentrations exceed the standard. In the Ridge and Valley carbonate agricultural subunit, 10 percent of the concentrations exceed the Pennsylvania drinking-water standard. The data are depicted in figure 29 and also summarized in table 9.

Median concentrations of nitrate were generally lowest in the siliciclastic bedrock subunits of the Ridge and Valley Physiographic Province and highest in carbonate bedrock subunits of the Piedmont Physiographic Province (table 9 and fig. 29). In addition, median concentrations in water samples collected from areas dominated by agricultural land use were generally higher than those in areas of forested land use. The highest median concentration of nitrate was measured in wells in the carbonate bedrock agricultural subunit of the Piedmont Physiographic Province. The lowest median concentration was in the siliciclastic bedrock forested subunit of the Ridge and Valley Physiographic Province. The median concentrations of nitrite plus nitrate (nitrate only for wells) of different subunits within the Lower Susquehanna River Basin, from data sets where 30 or more samples were available for analysis, are shown in figure 29. Comparisons are made among provinces, bedrock types, and land uses. Median concentrations for the "Piedmont" and "Carbonate" strata are consistently at the top of each group, and median concentrations for the "Ridge and Valley" strata dominate the bottom of each group, an indication that median nitrate concentrations were generally higher in Piedmont Physiographic Province and carbonate bedrock subunits.

Although the data subsets had different medians, the differences between the medians may not be statistically significant because of the variability of the number of samples between data subsets and the variability of concentrations within each data subset. Comparisons of the data from the different subunits, by use of the Kruskal-Wallis test (Helsel and Hirsch, 1992, p. 159-163), indicate significant differences between several of the data subsets. Significant differences in median concentrations for sites with sufficient data for testing are listed in table 10, and comparisons that were not statistically significant and data sets with insufficient data for testing are listed in table 11. The confidence level used to determine statistical significance was 95 percent ($p = 0.05$). All differences shown in table 10 exceeded that confidence level limit and are at a level of 97 percent or greater ($p \leq 0.03$). The median concentrations of nitrate for each subunit in table 10 were determined from combined surface-water and ground-water data sets, unless otherwise noted.

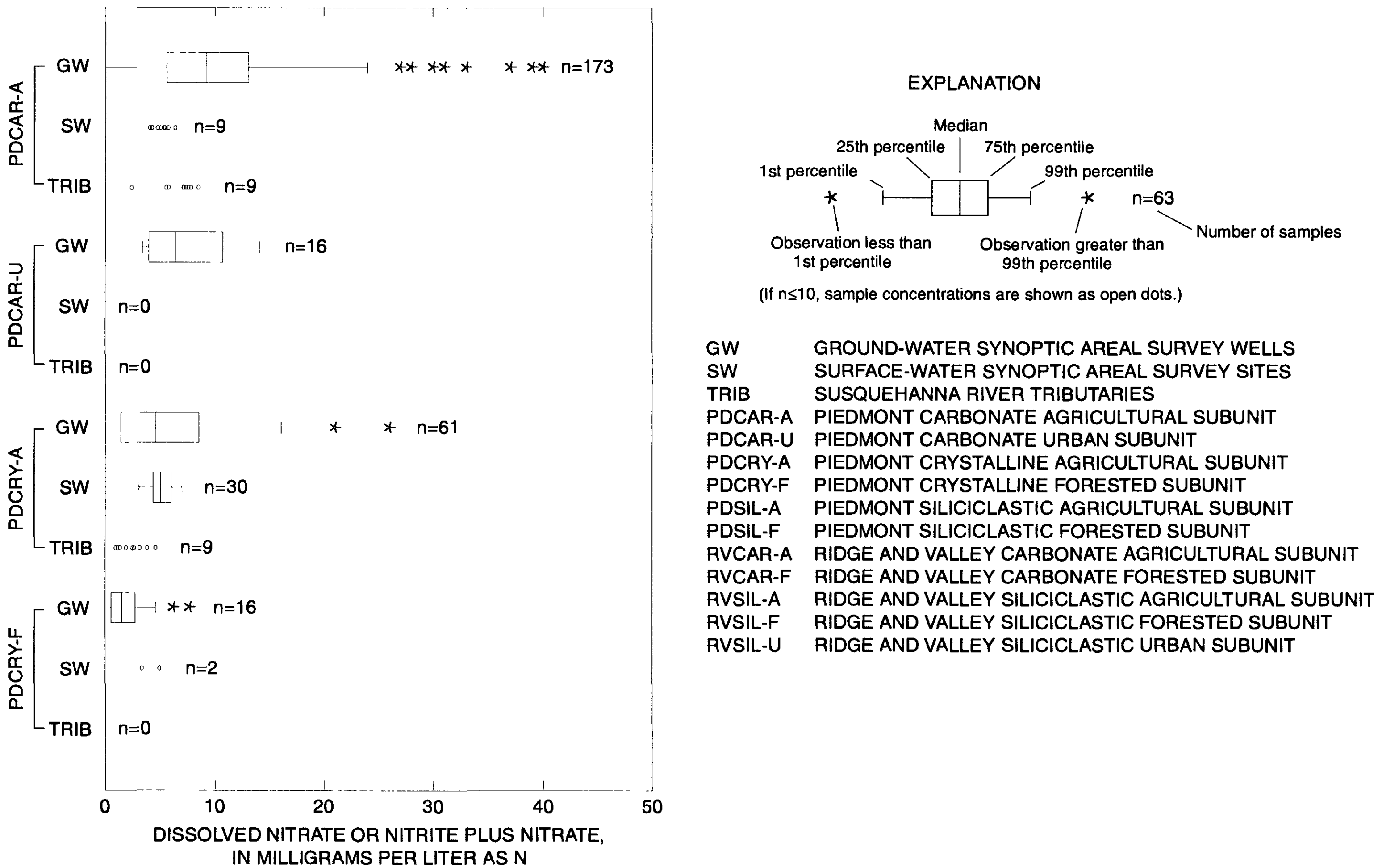



**Figure 28.** Concentrations of nitrite plus nitrate in streamwater and concentrations of nitrate in well water for selected subunits in the Lower Susquehanna River Basin, water years 1980-89.

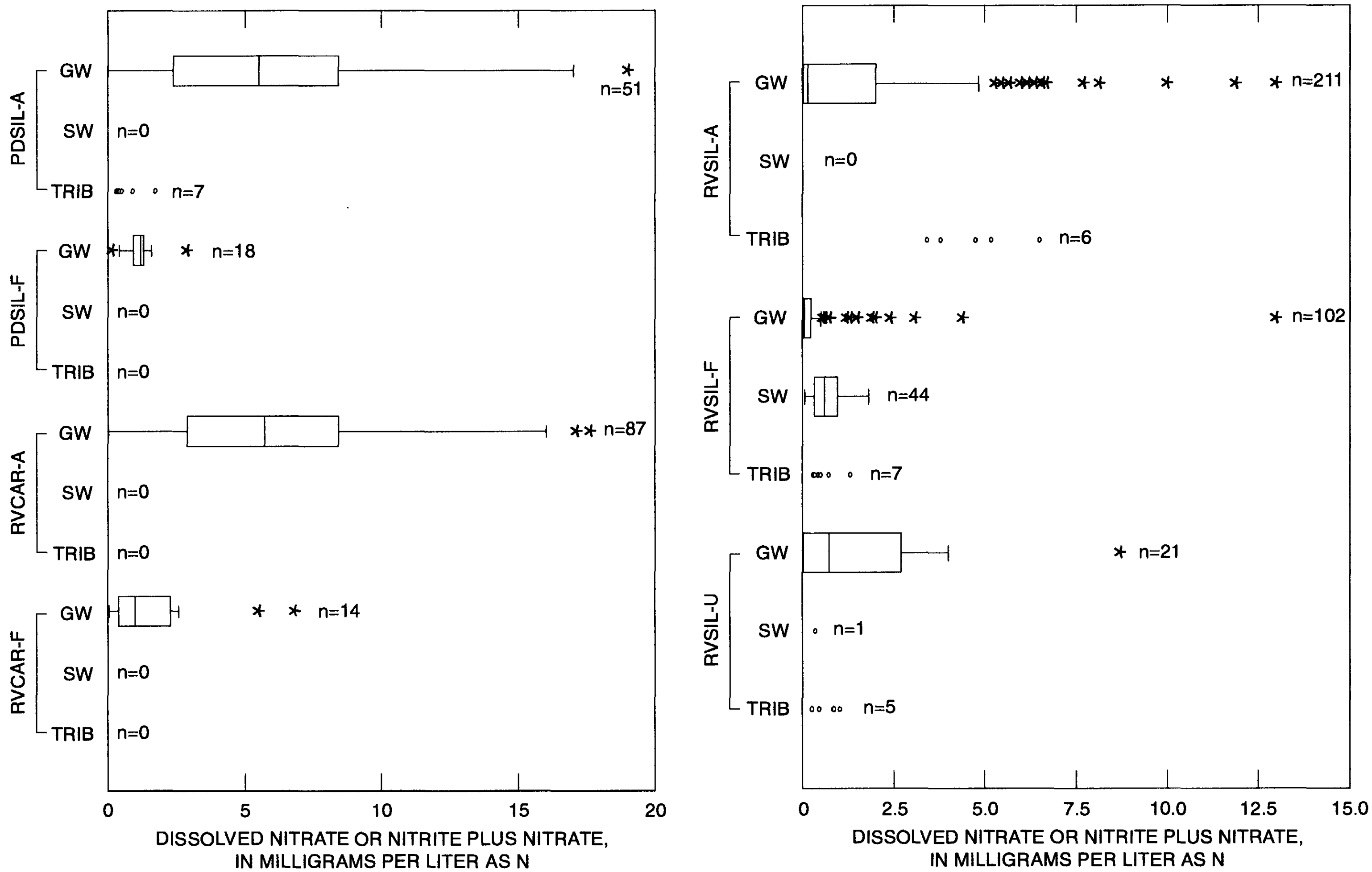



**Figure 28.** Concentrations of nitrite plus nitrate in streamwater and concentrations of nitrate in well water for selected subunits in the Lower Susquehanna River Basin, water years 1980-89—Continued.

**Table 9.** *Statistical summary of concentrations of dissolved nitrite plus nitrate in streamwater and concentrations of dissolved nitrate in well water from selected subunits in the Lower Susquehanna River Basin, water years 1980-89*

[Ground water, synoptic areal survey wells; Surface water, synoptic areal survey streams; Tributaries; large tributaries to the Susquehanna River; n, number of samples; P1, 1st percentile; P25, 25th percentile; P75, 75th percentile; P99, 99th percentile; <, less than; >, greater than; --, too few samples to compute a reliable statistic]

| Province | Bedrock type | Land use | Site type | Nitrate concentration, in milligrams per liter as N | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | n | P1 | P25 | Median | P75 | P99 |
| Piedmont | Carbonate | Agriculture | Ground water | 173 | 0.02 | 5.6 | 9.2 | 13 | 40 |
| | | | Surface water | 9 | -- | -- | 5.7 | -- | -- |
| | | | Tributaries | 9 | -- | -- | 7.5 | -- | -- |
| | | Urban | Ground water | 16 | <3.4 | 4.0 | 6.4 | 11 | >13 |
| | | | Surface water | 0 | No data available | | | | |
| | | | Tributaries | 0 | No data available | | | | |
| | Crystalline | Agriculture | Ground water | 61 | <.40 | 1.4 | 4.6 | 8.5 | >13 |
| | | | Surface water | 30 | <3.8 | 4.4 | 5.1 | 6.0 | >6.9 |
| | | | Tributaries | 9 | -- | -- | 2.9 | -- | -- |
| | | Forest | Ground water | 16 | <.02 | .50 | 1.6 | 2.8 | >6.6 |
| | | | Surface water | 2 | -- | -- | 4.5 | -- | -- |
| | | | Tributaries | 0 | No data available | | | | |
| | Siliciclastic | Agriculture | Ground water | 51 | <.60 | 2.4 | 5.5 | 8.4 | >9.8 |
| | | | Surface water | 0 | No data available | | | | |
| | | | Tributaries | 7 | -- | -- | .60 | -- | -- |
| | | Forest | Ground water | 18 | <.40 | .90 | 1.2 | 1.3 | >1.7 |
| | | | Surface water | 0 | No data available | | | | |
| | | | Tributaries | 0 | No data available | | | | |
| Ridge and Valley | Carbonate | Agriculture | Ground water | 87 | >.60 | 2.9 | 5.7 | 8.4 | >13 |
| | | | Surface water | 0 | No data available | | | | |
| | | | Tributaries | 0 | No data available | | | | |
| | | Forest | Ground water | 14 | -- | .40 | 1.0 | 2.3 | -- |
| | | | Surface water | 0 | No data available | | | | |
| | | | Tributaries | 0 | No data available | | | | |
| | Siliciclastic | Agriculture | Ground water | 211 | .01 | .02 | .15 | 2.0 | 12 |
| | | | Surface water | 0 | No data available | | | | |
| | | | Tributaries | 6 | -- | -- | 5.1 | -- | -- |
| | | Forest | Ground water | 102 | .01 | .02 | .04 | .20 | 13 |
| | | | Surface water | 44 | <.10 | .30 | .60 | 1.0 | >1.4 |
| | | | Tributaries | 7 | -- | -- | .50 | -- | -- |
| | | Urban | Ground water | 21 | <.02 | .02 | .70 | 2.7 | >3.9 |
| | | | Surface water | 1 | -- | -- | .40 | -- | -- |
| | | | Tributaries | 5 | -- | -- | .90 | -- | -- |

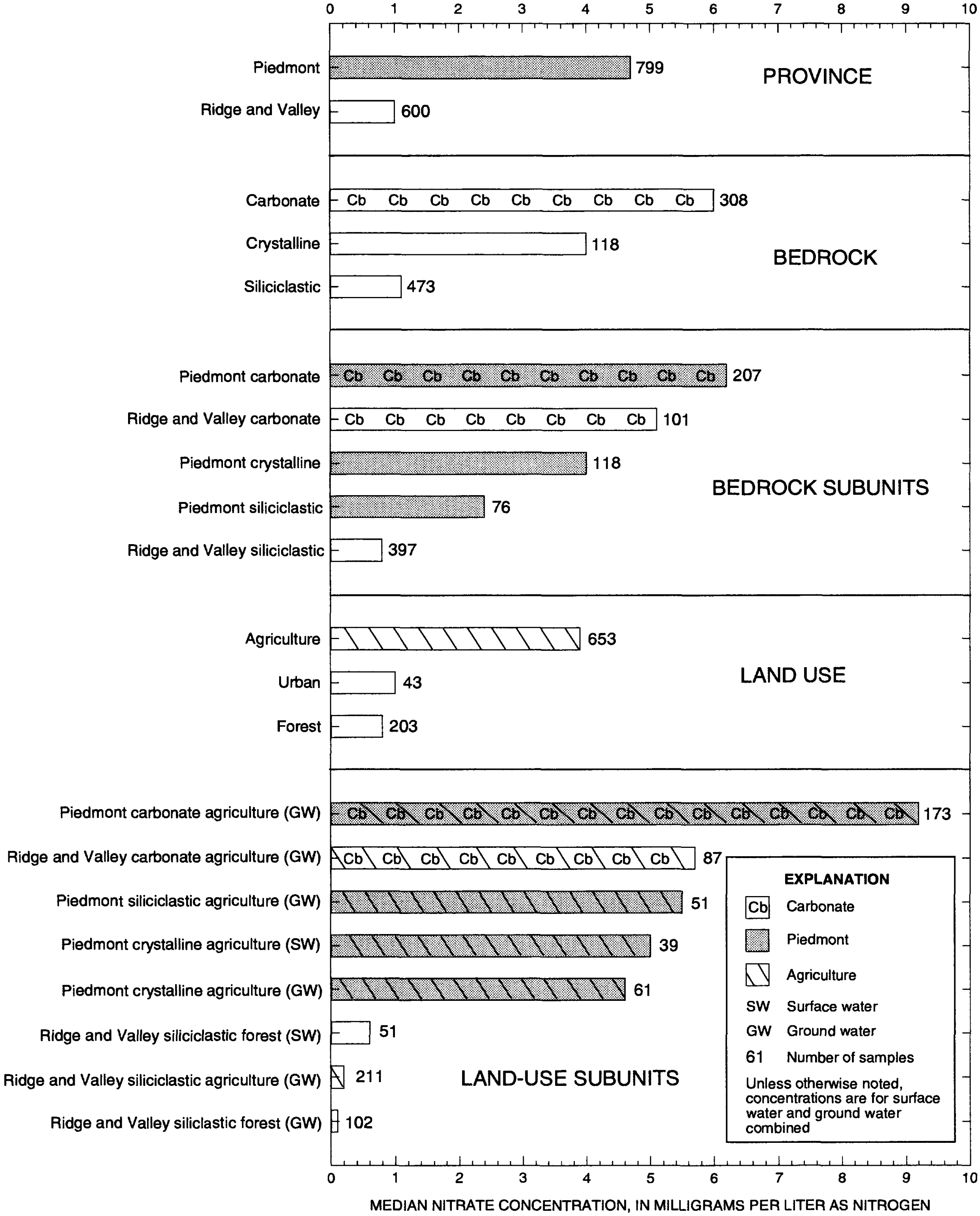



**Figure 29.** Median concentrations of nitrite plus nitrate (nitrate only for ground water), by subunit, in the Lower Susquehanna River Basin for samples collected during water years 1980-89.

**Table 10.** *Statistically significant differences in median concentrations of nitrate between subunits based on province, bedrock, and land-use type in the Lower Susquehanna River Basin for samples collected during water years 1980-89*

[All subunit A and B comparisons are made with combined surface-water and ground-water concentrations unless otherwise noted; confidence level for all tests shown in the table was 97 percent or greater; mg/L, milligram per liter; Pied., Piedmont Physiographic Province; R&V, Ridge and Valley Physiographic Province; GW, ground water; SW, surface water]

| Subunit A | Number of samples | Median concentration (mg/L) | Subunit B | Number of samples | Median concentration (mg/L) | Difference, in mg/L |
|---|---|---|---|---|---|---|
| | | | Comparisons by province | | | |
| Piedmont | 799 | 4.7 | Ridge and Valley | 769 | 1.0 | 3.7 |
| | | | Comparisons by type of bedrock | | | |
| Carbonate | 767 | 6.0 | Crystalline | 203 | 4.0 | 2.0 |
| Crystalline | 203 | 4.0 | Siliciclastic | 846 | 1.1 | 2.9 |
| Carbonate | 767 | 6.0 | Siliciclastic | 846 | 1.1 | 4.9 |
| | | | Comparisons by type of land use | | | |
| Agriculture | 1,129 | 3.9 | Forest | 285 | .8 | 3.1 |
| Agriculture | 1,129 | 3.9 | Urban | 154 | 1.0 | 2.9 |
| Urban | 154 | 1.0 | Forest | 285 | .8 | .2 |
| | | | Comparisons by province and type of bedrock | | | |
| Piedmont carbonate | 420 | 6.2 | Piedmont crystalline | 203 | 4.0 | 2.2 |
| Piedmont crystalline | 203 | 4.0 | Piedmont siliciclastic | 176 | 2.4 | 1.6 |
| Piedmont carbonate | 420 | 6.2 | Ridge and Valley carbonate | 106 | 5.1 | 1.1 |
| Ridge and Valley carbonate | 106 | 5.1 | Piedmont crystalline | 203 | 4.0 | 1.1 |
| Piedmont crystalline | 203 | 4.0 | Ridge and Valley siliciclastic | 663 | .8 | 3.2 |
| Piedmont siliciclastic | 176 | 2.4 | Ridge and Valley siliciclastic | 663 | .8 | 1.6 |
| | | | Comparisons by province, type of bedrock, and type of land use | | | |
| Pied. carbonate agriculture - GW | 173 | 9.2 | R&V carbonate agriculture - GW | 87 | 5.7 | 3.5 |
| Pied. carbonate agriculture - GW | 173 | 9.2 | R&V siliciclastic agriculture - GW | 211 | .2 | 9.0 |
| Pied. carbonate agriculture - GW | 173 | 9.2 | Pied. crystalline agriculture - GW | 61 | 4.6 | 4.6 |
| Pied. carbonate agriculture - GW | 173 | 9.2 | Pied. siliciclastic agriculture - GW | 51 | 5.5 | 3.7 |
| Pied. siliciclastic agriculture - GW | 51 | 5.5 | R&V siliciclastic agriculture - GW | 211 | .2 | 5.3 |
| Pied. crystalline agriculture - GW | 61 | 4.6 | R&V siliciclastic agriculture - GW | 211 | .2 | 4.4 |
| R&V carbonate agriculture - GW | 87 | 5.7 | R&V siliciclastic agriculture - GW | 211 | .2 | 5.5 |
| R&V siliciclastic forest - SW | 44 | .6 | R&V siliciclastic forest - GW | 102 | .1 | .5 |
| Pied. crystalline agriculture - SW | 30 | 5.0 | R&V siliciclastic forest - SW | 44 | .6 | 4.4 |

**Table 11.** *Comparisons of median concentrations of nitrate between subunits in the Lower Susquehanna River Basin from samples collected during 1980-89 that were not statistically significant or lacked sufficient data for testing*

[All subunit A and B comparisons are made with combined surface-water and ground-water concentrations unless otherwise noted; All comparisons that failed the test had a confidence level of 95 percent or less; less than 30 samples was considered to be insufficient data; Pied., Piedmont Physiographic Province; R&V, Ridge and Valley Physiographic Province; GW, synoptic areal survey ground-water well samples; SW, synoptic areal survey stream samples]

| Subunit A | Number of samples | Subunit B | Number of samples |
|---|---|---|---|
| Comparisons that were not statistically significant | | | |
| Ground water - all synoptic areal survey samples | 783 | Surface water - all synoptic areal survey samples | 104 |
| Ground water - all synoptic areal survey samples | 783 | Surface water - long-term monitoring tributaries | 1,237 |
| Surface water - all synoptic areal survey samples | 104 | Surface water - long-term monitoring tributaries | 1,237 |
| Pied. Crystalline Agriculture - SW | 30 | Pied. Crystalline Agriculture - GW | 61 |
| Pied. Siliciclastic Agriculture - GW | 51 | R&V Carbonate Agriculture - GW | 87 |
| Pied. Crystalline Agriculture - GW | 61 | R&V Carbonate Agriculture - GW | 87 |
| Pied. Crystalline Agriculture - GW | 61 | Pied. Siliciclastic Agriculture - GW | 51 |

Synoptic areal survey sample data sets with insufficient data (number of samples < 30)

| Surface-water data sets | Ground-water data sets |
|---|---|
| Pied. Carbonate Agriculture | Pied. Carbonate Forest |
| Pied. Carbonate Forest | Pied. Carbonate Urban |
| Pied. Carbonate Urban | Pied. Crystalline Forest |
| Pied. Crystalline Forest | Pied. Crystalline Urban |
| Pied. Crystalline Urban | Pied. Siliciclastic Forest |
| Pied. Siliciclastic Agriculture | Pied. Siliciclastic Urban |
| Pied. Siliciclastic Forest | R&V Carbonate Forest |
| Pied. Siliciclastic Urban | R&V Carbonate Urban |
| R&V Carbonate Agriculture | R&V Siliciclastic Urban |
| R&V Carbonate Forest | |
| R&V Carbonate Urban | |
| R&V Siliciclastic Agriculture | |
| R&V Siliciclastic Urban | |

Concentrations of suspended sediment categorized by subunit, type of site, and streamflow condition are shown as boxplots in figure 30 and are summarized in table 12. The concentrations represent three types of stream sites that drain six subunits during low flow and high flow. The conditions associated with the site types are synoptic areal survey streams during low flow, large tributaries to the Susquehanna River during low flow, and the same tributaries during high flow. As with previous low-flow and high-flow categorizations, low flow is defined as the flow that was exceeded more than 75 percent of the time, and high flow as the flow that was exceeded less than 25 percent of the time during 1980-89. The flows included in these two categories, because of the extremity of the criteria, may include some seasonal variability.

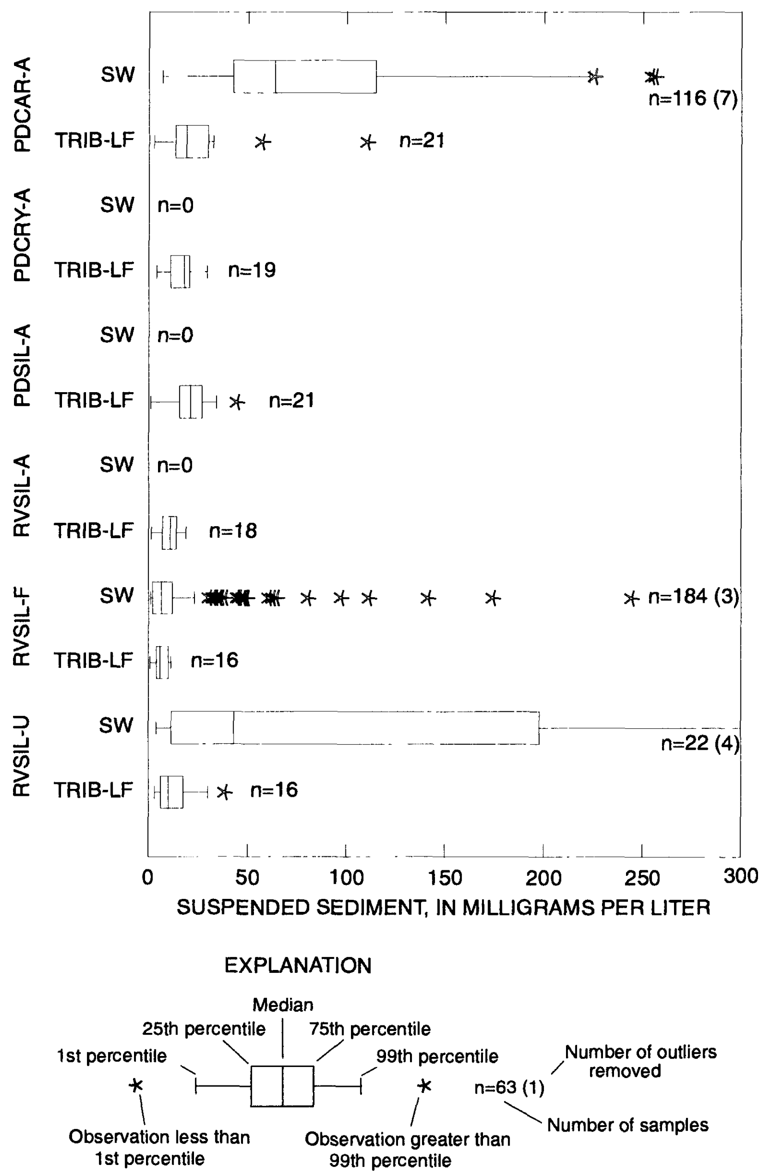
During low and high flows, samples collected in the siliciclastic bedrock forested subunit of the Ridge and Valley Physiographic Province had the lowest median concentrations of suspended sediment (table 12), and samples collected in the carbonate bedrock agricultural subunit of the Piedmont Physiographic Province had the highest median concentrations. In general, samples collected from all land uses underlain by siliciclastic bedrock in the Ridge and Valley Physiographic Province had lower median concentrations than areas underlain by carbonate bedrock in the Piedmont Province. In addition, data collected during synoptic surveys of streams had greater variability than those collected at tributary sites during low flow and at a regular frequency. This difference in variability is probably affected more by a variation in or inconsistency of the land use of the settings sampled for the synoptic surveys rather than the natural variability of the water-quality data.

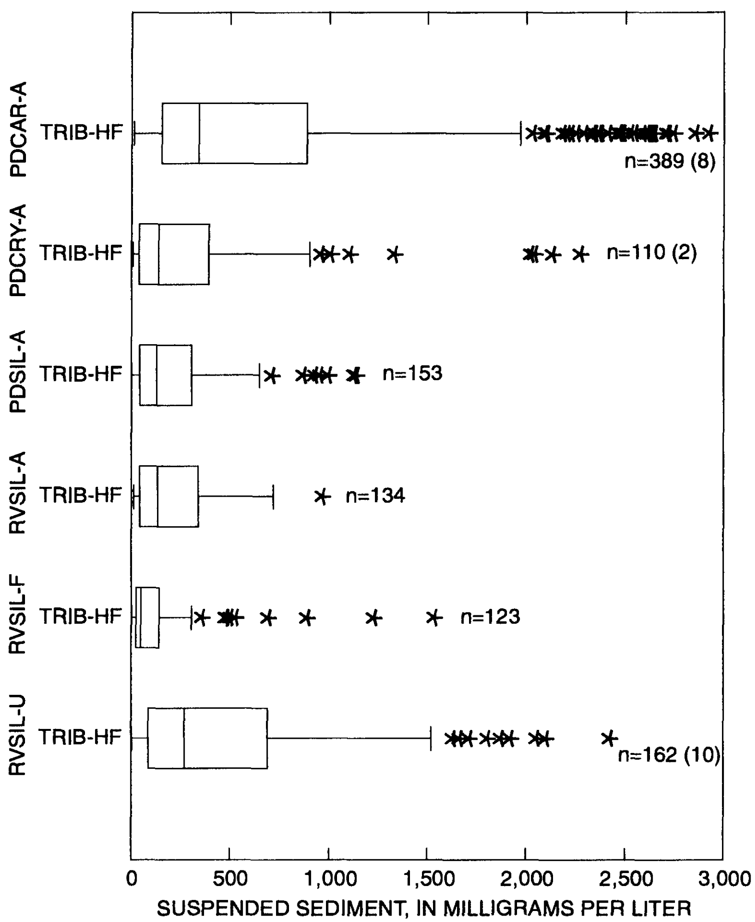
Median concentrations of suspended sediment among the synoptic areal survey sites ranged from 6 mg/L at siliciclastic bedrock forested sites in the Ridge and Valley Physiographic Province to 64 mg/L at carbonate bedrock agricultural sites in the Piedmont Physiographic Province (table 12). During low flow, median concentrations from tributaries ranged from 6 to 21 mg/L; during high flow, the range was 49 to 342 mg/L. The median concentration for all samples was 46 mg/L. The median concentrations of suspended sediment from synoptic areal surveys were most similar to those from tributaries at low flow.

### Relation of Concentrations of Nutrients and Suspended Sediment to Percentage of Drainage Area in Agriculture and Agricultural Practices

Three other factors that may relate to nutrient concentrations in streams are percentage of drainage area that is used for agriculture, volume of manure produced (and assumed to be applied) within the drainage area, and amount of commercial fertilizer applied to the area drained by the stream. Ott and others (1991) reported percentage of agricultural land and animal-manure production for 1985 within the drainage areas of each of the major tributaries in the Lower Susquehanna River Basin. The manure-production data are based on the number and type of animals within each basin to account for variability by type of animal. Manure-production data should be used as an indicator of agricultural activity only, not an accurate predictor of nitrogen and phosphorus concentrations likely in an agricultural basin.

Similarly, the preceding constraints should be applied to predictions of nutrient concentrations based on the commercial-fertilizer data. The commercial-fertilizer application data for each basin were developed from county-level data, and the variability of nitrogen and phosphorus content were not considered (U.S. Environmental Protection Agency, 1990). These data and median concentrations of nitrate, phosphorus, and




ABBREVIATIONS

| | |
|---|---|
| SW | SURFACE-WATER SYNOPTIC AREAL SURVEY SITES |
| TRIB-LF | SUSQUEHANNA RIVER TRIBUTARIES, LOW FLOW |
| TRIB-HF | SUSQUEHANNA RIVER TRIBUTARIES, HIGH FLOW |
| PDCAR-A | PIEDMONT CARBONATE AGRICULTURAL SUBUNIT |
| PDCRY-A | PIEDMONT CRYSTALLINE AGRICULTURAL SUBUNIT |
| PDSIL-A | PIEDMONT SILICICLASTIC AGRICULTURAL SUBUNIT |
| RVSIL-A | RIDGE AND VALLEY SILICICLASTIC AGRICULTURAL SUBUNIT |
| RVSIL-F | RIDGE AND VALLEY SILICICLASTIC FORESTED SUBUNIT |
| RVSIL-U | RIDGE AND VALLEY SILICICLASTIC URBAN SUBUNIT |

**Figure 30.** Concentrations of suspended sediment in streams for selected subunits in the Lower Susquehanna River Basin from samples collected during water years 1980-89.

**Table 12.** *Statistical summary of concentrations of suspended sediment in streams for selected subunits in the Lower Susquehanna River Basin from samples collected during water years 1980-89*

[n, number of samples; P1, 1st percentile; P25, 25th percentile; P75, 75th percentile; P99, 99th percentile; SW, surface water; >, greater than; <, less than]

| Physiographic Province | Bedrock type | Land use | Site type | Suspended-sediment concentration, in milligrams per liter | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | n | P1 | P25 | Median | P75 | P99 |
| Piedmont | Carbonate | Agriculture | SW synoptic | 116 | 8 | 42 | 64 | 115 | 1,260 |
| | | | Tributaries (low flow) | 21 | <4 | 14 | 19 | 30 | >99 |
| | | | Tributaries (high flow) | 389 | 16 | 153 | 342 | 886 | 4,000 |
| | Crystalline | Agriculture | SW synoptic | 0 | No data available | | | | |
| | | | Tributaries (low flow) | 19 | <7 | 11 | 18 | 21 | >28 |
| | | | Tributaries (high flow) | 110 | 9 | 40 | 138 | 394 | 3,620 |
| | Siliciclastic | Agriculture | SW synoptic | 0 | No data available | | | | |
| | | | Tributaries (low flow) | 21 | <5 | 16 | 21 | 27 | >34 |
| | | | Tributaries (high flow) | 153 | 3 | 42 | 128 | 306 | 1,130 |
| Ridge and Valley | Siliciclastic | Agriculture | SW synoptic | 0 | No data available | | | | |
| | | | Tributaries (low flow) | 18 | <2 | 7 | 11 | 14 | >16 |
| | | | Tributaries (high flow) | 134 | 12 | 42 | 134 | 339 | 878 |
| | | Forest | SW synoptic | 184 | 1 | 2 | 6 | 12 | 683 |
| | | | Tributaries (low flow) | 16 | <1 | 4 | 6 | 10 | >11 |
| | | | Tributaries (high flow) | 123 | 1 | 24 | 49 | 142 | 1,460 |
| | | Urban | SW synoptic | 22 | <9 | 12 | 43 | 198 | >697 |
| | | | Tributaries (low flow) | 16 | <4 | 6 | 10 | 18 | >38 |
| | | | Tributaries (high flow) | 162 | 4 | 86 | 270 | 692 | 10,600 |

suspended sediment for 1980-89 from eight selected tributaries are summarized in table 13. The concentrations were determined from the analysis of samples collected from six tributaries that drain areas larger than 200 $mi^2$ and two tributaries that drain areas less than 25 $mi^2$ (Paxton Creek and Stony Creek). Each of the tributaries flows directly into the Lower Susquehanna River.

The streams in table 13 are shown in order by increasing agricultural area in their drainage basins. A positive, but poorly defined, correlation exists between concentrations of nitrate, phosphorus, and suspended sediment and the three agricultural-activity indicators—percentage of the drainage area that is used for agricultural practices, amount of animal manure produced, and amount of commercial fertilizer applied. The best definition of the relation is provided by the factor percentage of agricultural area in the basin and median nitrate concentration—a result also found by Koerkle and others (1996). Among the streams, patterns of animal-manure production and commercial-fertilizer applications generally followed the pattern of agricultural area in the basin. The amount of manure produced and commercial fertilizer applied in a basin also provide a reasonable indication of the nitrate concentration in the stream draining the basin. The relation is weaker for the concentrations that might be expected for phosphorus and suspended sediment, but it still provides a reasonable indication of what level of concentration might be expected based on the agricultural activity in the basin (table 13). The median concentrations for Paxton and Codorus Creeks were somewhat anomalous. Their variation from the concentration patterns of the other streams may be related to higher percentages of urban land use in the other basins.

### Relation of Concentrations of Nutrients and Suspended Sediment to Time of Year

In previous sections of this report, "Temporal Distribution of Samples," the number of samples collected each month of the year were reported (fig. 11) and ways in which objectives of a sampling program may determine the annual distribution of samples was discussed. The objectives of the programs active during 1980-89 (and their resultant sampling strategies) also determined the availability of data to describe monthly and seasonal variations in concentrations of nutrients. This section presents the variability of nutrient concentrations in relation to month of the year and to growing season. The growing season, for the purposes of this report, is defined as the period from April through September, and the remainder of the year (October through March) is considered the nongrowing season.

The highest monthly median nitrate concentration occurred during December, January, or February, as indicated by stream data collected from major tributaries to the Lower Susquehanna River and at project and research sites and also well data collected during synoptic areal surveys (concentrations reported do not include nitrite) and at project and research sites. (fig. 31). Whether the high median concentrations during the winter months were a natural condition or an artifact of the sampling program was not determined, although Koerkle and others (1996) report a similar pattern for nitrate concentrations in small streams in agricultural areas over a 5-year period. This pattern was not evident in data sets for stream synoptic areal surveys and precipitation. The highest median concentration at stream synoptic areal survey sites occurred in October. This high concentration may be an artifact of the number of samples collected during the month in comparison to other months of the year. A larger number of samples during the fall may have defined the natural range of concentrations better than the data sets available for other months. The median nitrate concentration in precipitation was highest in May.

**Table 13.** *Drainage area, agricultural land use, animal manure production, average annual commercial fertilizer application, and median concentrations of nitrate, phosphorus, and suspended sediment for selected tributaries in the Lower Susquehanna River Basin, water years 1980-89*

[Sites are listed in order by increasing percentage of agricultural land in basin; mi$^2$, square mile; (ton/acre)/yr, ton per acre per year; (lb/acre)/yr, pound per acre per year; mg/L, milligram per liter; <, less than; --, no data are available]

| Stream basin | Drainage area (mi$^2$) | Agricultural land in basin[1] (percent) | Animal manure production[2] [(ton/acre)/yr] | Commercial fertilizer application[3] [(lb/acre)/yr] | Median nitrate concentration (mg/L) | Median phosphorus concentration (mg/L) | Median suspended-sediment concentration (mg/L) |
|---|---|---|---|---|---|---|---|
| Stony Creek | 21.9 | < 1.0 | < 0.1 | -- | 0.08 | 0.03 | 7 |
| Sherman Creek | 200 | 24.4 | .76 | 6.37 | 1.38 | .07 | 24 |
| Juniata River | 3,354 | 25.2 | .81 | 5.17 | 1.22 | .08 | 34 |
| Paxton Creek | 11.2 | 39.8 | .001 | -- | .91 | .14 | 142 |
| Codorus Creek | 267 | 44.9 | 1.10 | 11.47 | 3.08 | .30 | 189 |
| Swatara Creek | 483 | 45.6 | 1.77 | 11.26 | 3.04 | .10 | 37 |
| West Conewago Creek | 510 | 57.1 | 1.44 | 11.76 | 2.40 | .26 | 64 |
| Conestoga River | 470 | 62.7 | 5.24 | 22.14 | 5.50 | .60 | 278 |

[1] Based on 1985 data (Ott and others, 1991).
[2] Based on 1985 data (Ott and others, 1991).
[3] Average annual commercial fertilizer application rates (U.S. Environmental Protection Agency, 1990).

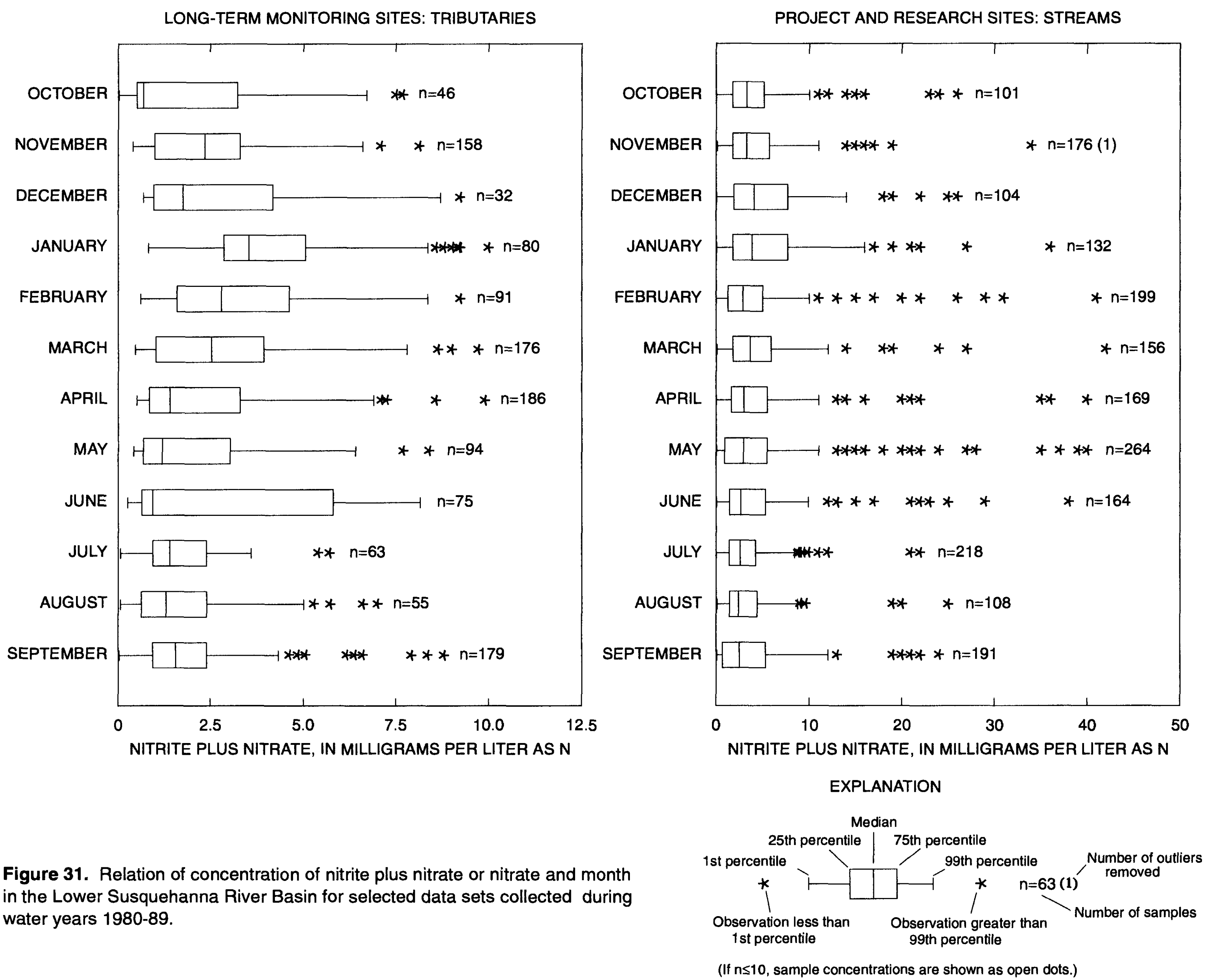



**Figure 31.** Relation of concentration of nitrite plus nitrate or nitrate and month in the Lower Susquehanna River Basin for selected data sets collected during water years 1980-89.

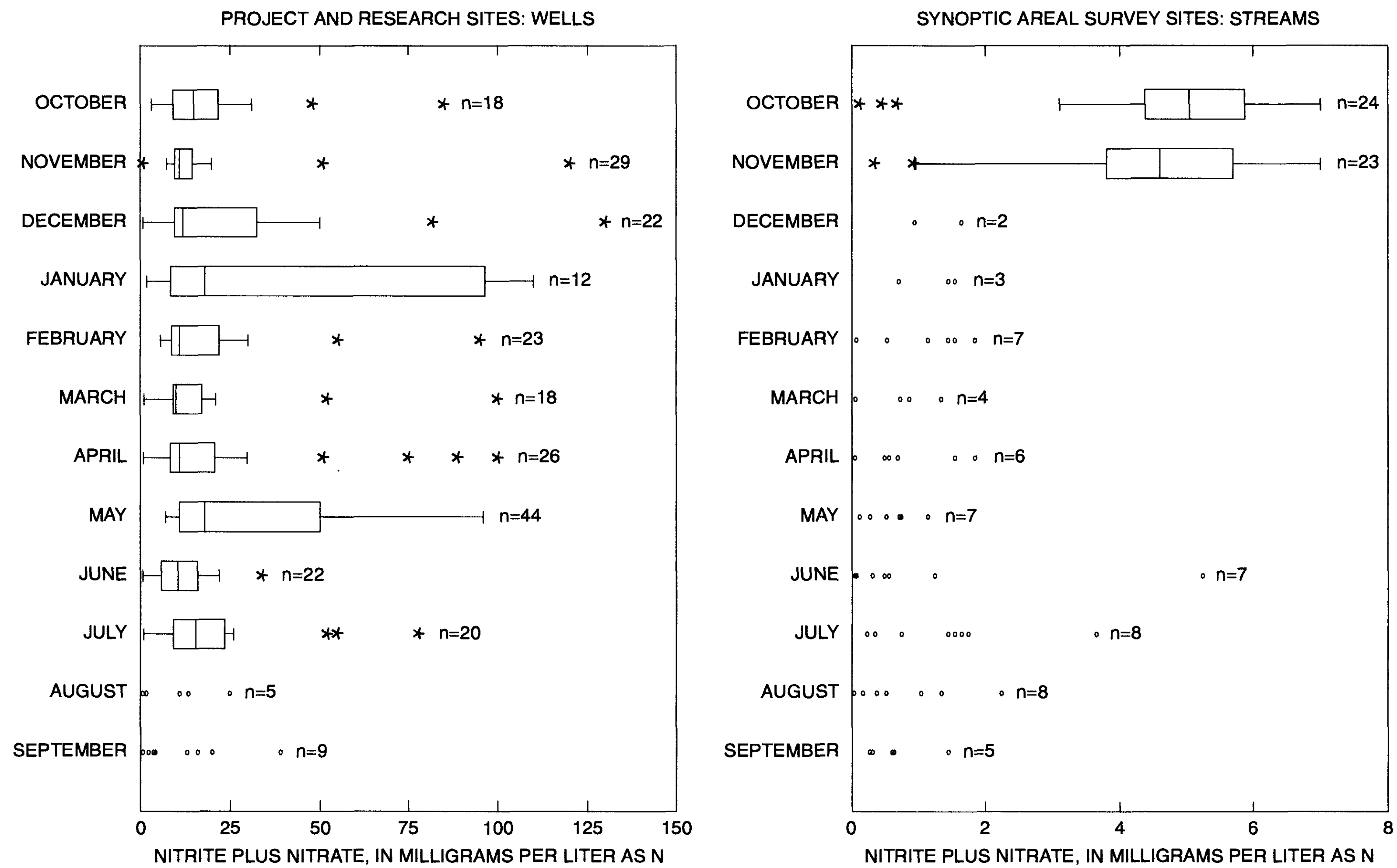



**Figure 31.** Relation of concentration of nitrite plus nitrate or nitrate and month in the Lower Susquehanna River Basin for selected data sets collected during water years 1980-89—Continued.

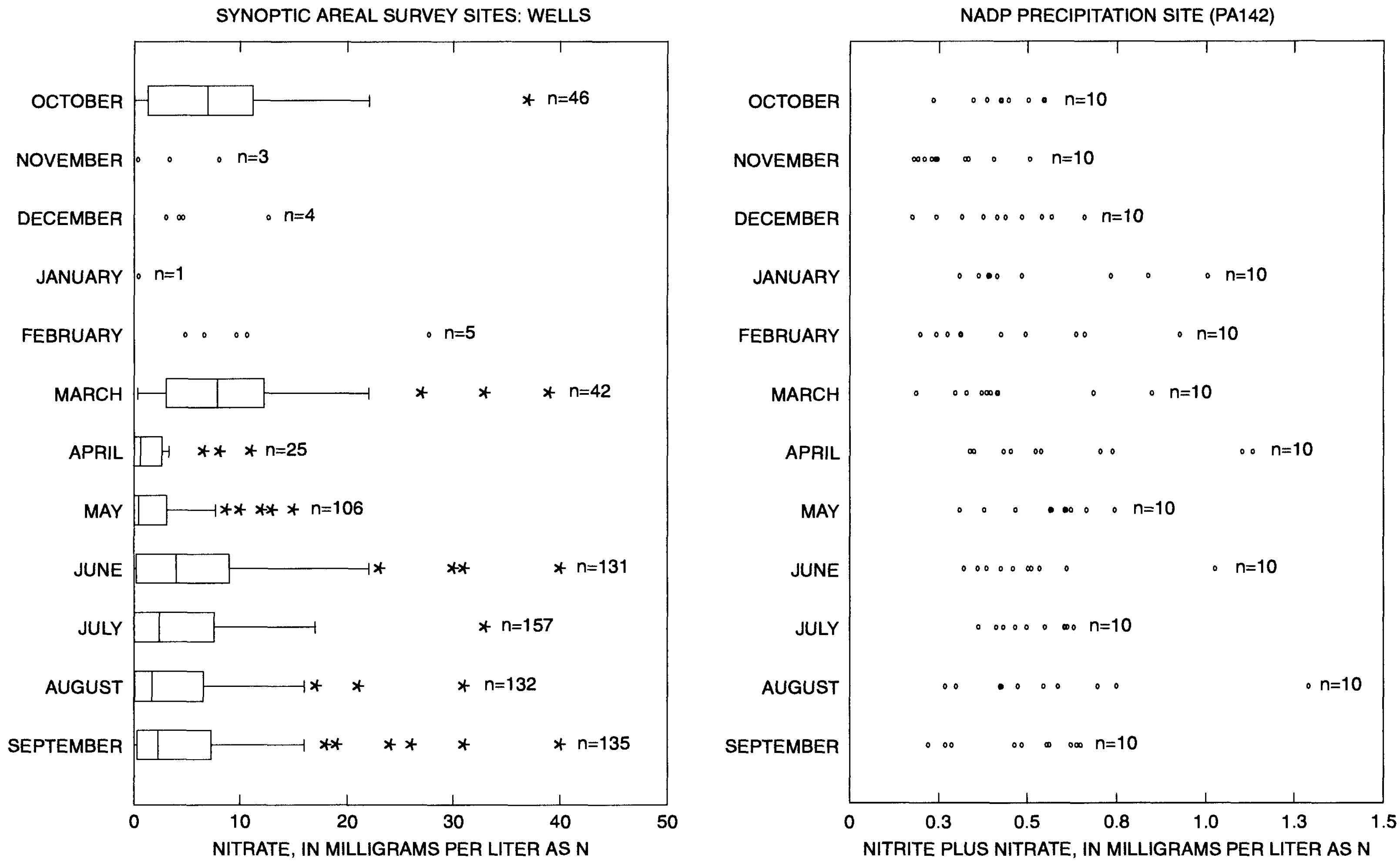



**Figure 31.** Relation of concentration of nitrite plus nitrate or nitrate and month in the Lower Susquehanna River Basin for selected data sets collected during water years 1980-89—Continued.

Also similar to the results found by Koerkle and others (1996), the median concentrations of nitrate generally were lowest during June and July. Exceptions to this pattern were identified in the synoptic areal survey well data set (the lowest median concentration was in early spring) and the precipitation data set (lowest monthly median concentration for precipitation was in November).

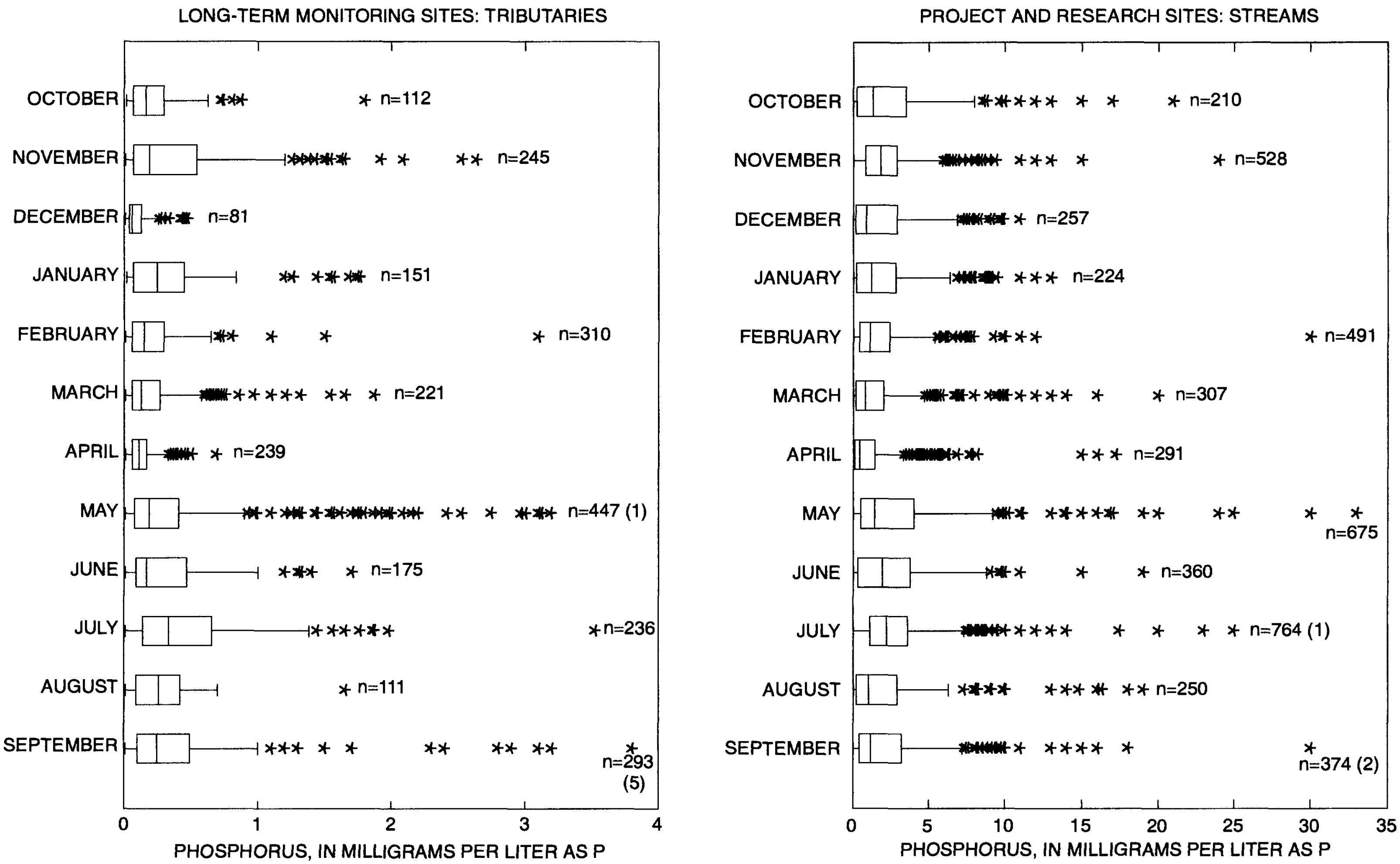
The monthly medians of concentrations of phosphorus, from four data sets collected during the same period, are shown in figure 32. Unlike concentrations of nitrate, concentrations of phosphorus in streams were highest during May, June, and July, and generally were lowest in March and April. These results are similar to those found by Koerkle and others (1996) for small agricultural stream basins in south-central Pennsylvania. This pattern reflects a transport mechanism dominated by spring runoff. For the fourth data set, ground-water data collected for a research project, the median phosphorus concentration was highest in April.

The same data sets were used to compare nitrate and phosphorus concentrations in the growing and nongrowing seasons. With the exception for precipitation samples and samples collected from wells at project and research sites, the median concentrations of nitrate were highest in the nongrowing season (fig. 33). For all site types, the highest median concentrations of nitrate for both the growing and nongrowing seasons were in project and research wells: concentrations were almost double those in streams and more than 20 times those measured in precipitation. This finding may be due to the abundance of ground-water data in the project and research well data set from aquifers where water quality was impaired by agricultural activities.

Nitrate concentrations ranged from 0 to 1.5 mg/L for precipitation samples and from 0 to 150 mg/L for wells sampled for projects and research. For the samples collected from streams during synoptic areal surveys, the median and range of the concentrations of phosphorus may have a significant bias because of the apparent emphasis on sampling during the nongrowing season.

The relation between seasons and concentrations of phosphorus among the different types of studies seems inconsistent (fig. 34). The lack of consistency among data sets may be related to study designs focused on areas affected by agriculture. Median concentrations of phosphorus from long-term monitoring sites on tributaries and streams sampled for projects and research were higher during the growing season than during the nongrowing season. Median concentrations of phosphorus from streams sampled during synoptic areal surveys and from wells at project and research sites had lower median concentrations during the growing season than during the nongrowing season. The agreement of these two data sets is not surprising because the flow in streams sampled during synoptic areal surveys is generally dominated by ground-water discharge. Median and ranges of the concentrations of phosphorus from streams sampled during synoptic areal surveys may be significantly biased because of the emphasis on sampling during the nongrowing season. The higher median concentrations of phosphorus during the nongrowing season in samples collected from project and research ground-water wells may reflect the influence of recharge periods on the concentration of nutrients in ground water. Data in two data sets—precipitation and wells sampled during synoptic areal surveys—were insufficient for testing and discussion.

Median concentrations of phosphorus were highest for project and research sites on streams and lowest for wells sampled for projects and research. The range of concentrations of phosphorus measured among the four data sets indicates the differences in variability among the data sets. The upper limit on scales to accommodate the concentrations displayed in figure 34 ranged from 0.4 mg/L to 25 mg/L as P. Concentrations for both seasons within each data set are fairly equally distributed.



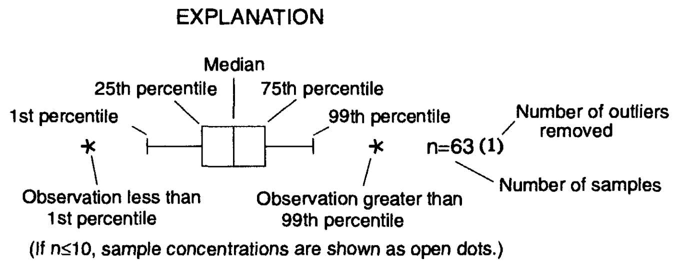




**Figure 32.** Relation of concentration of phosphorus and month in the Lower Susquehanna River Basin for selected data sets collected during water years 1980-89.

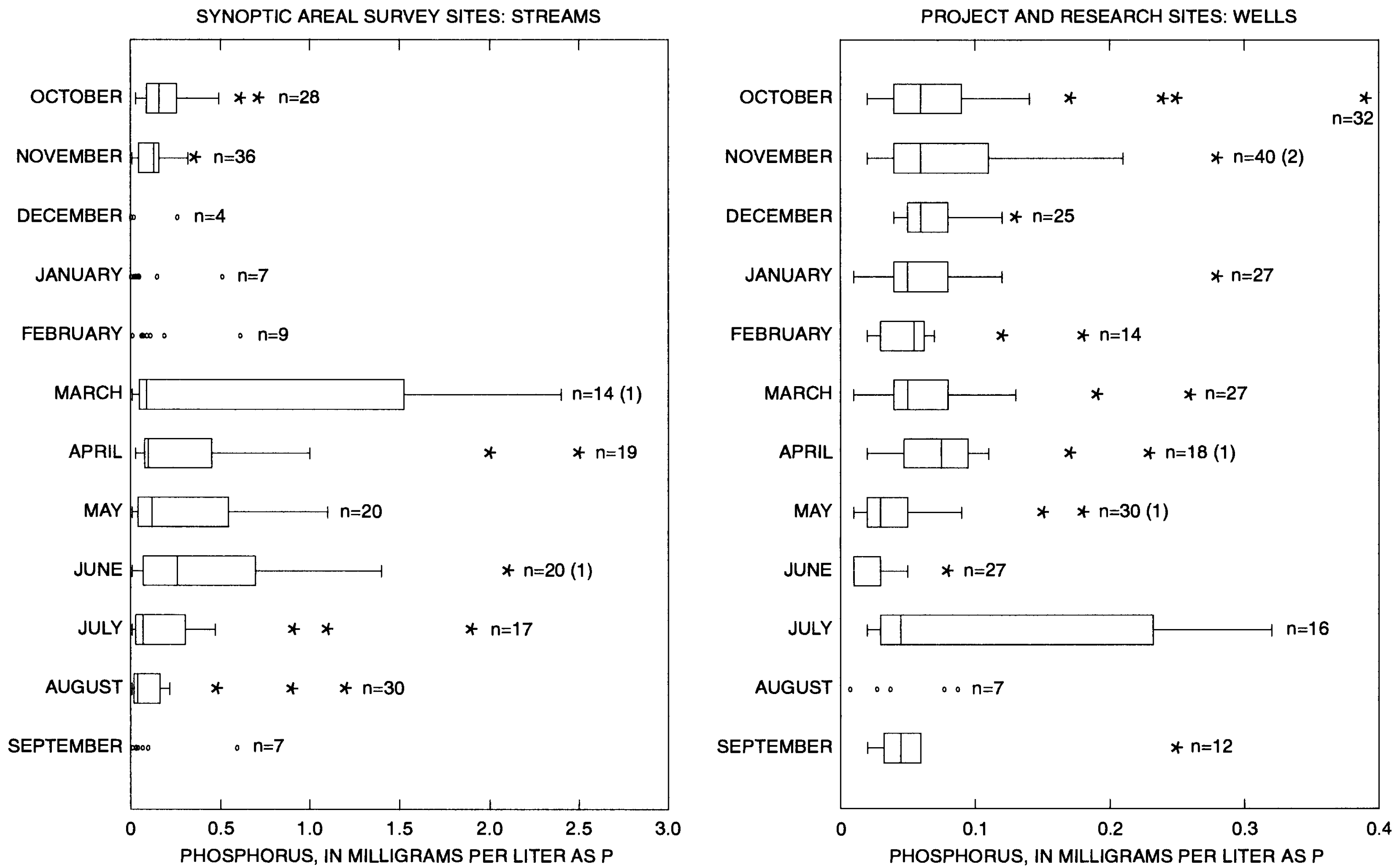



**Figure 32.** Relation of concentration of phosphorus and month in the Lower Susquehanna River Basin for selected data sets collected during water years 1980-89—Continued.

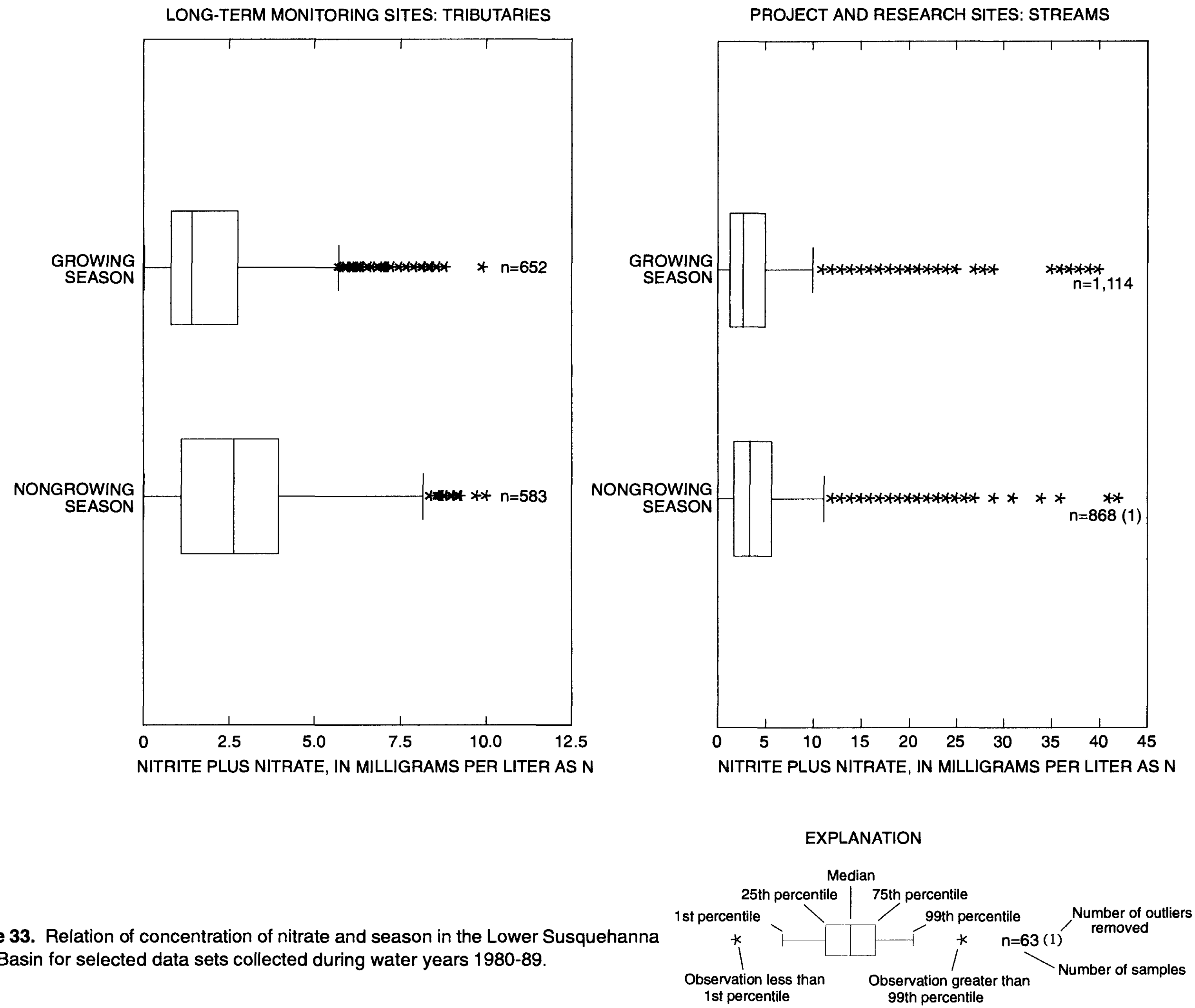



**Figure 33.** Relation of concentration of nitrate and season in the Lower Susquehanna River Basin for selected data sets collected during water years 1980-89.

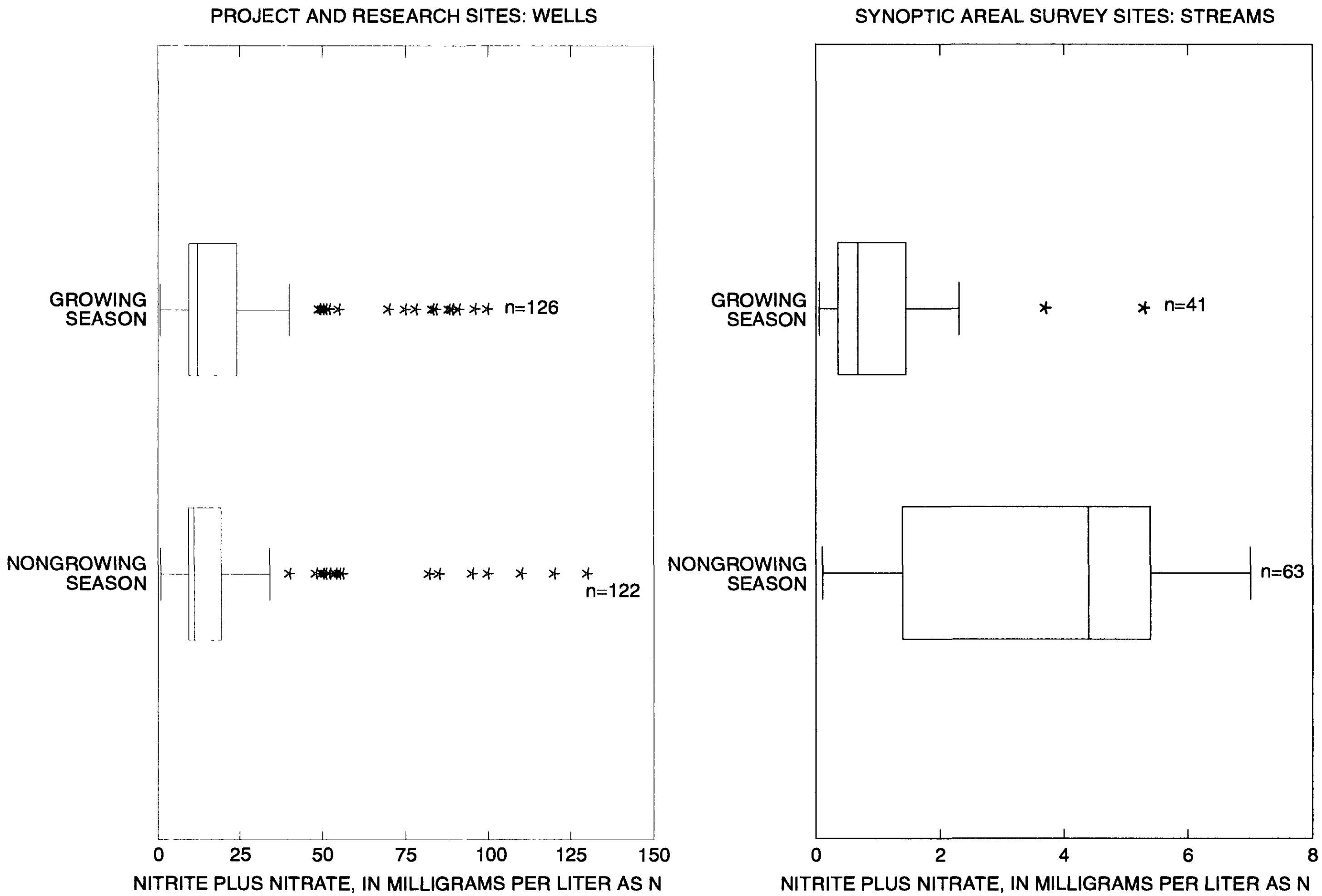



**Figure 33.** Relation of concentration of nitrate and season in the Lower Susquehanna River Basin for selected data sets collected during water years 1980-89—Continued.

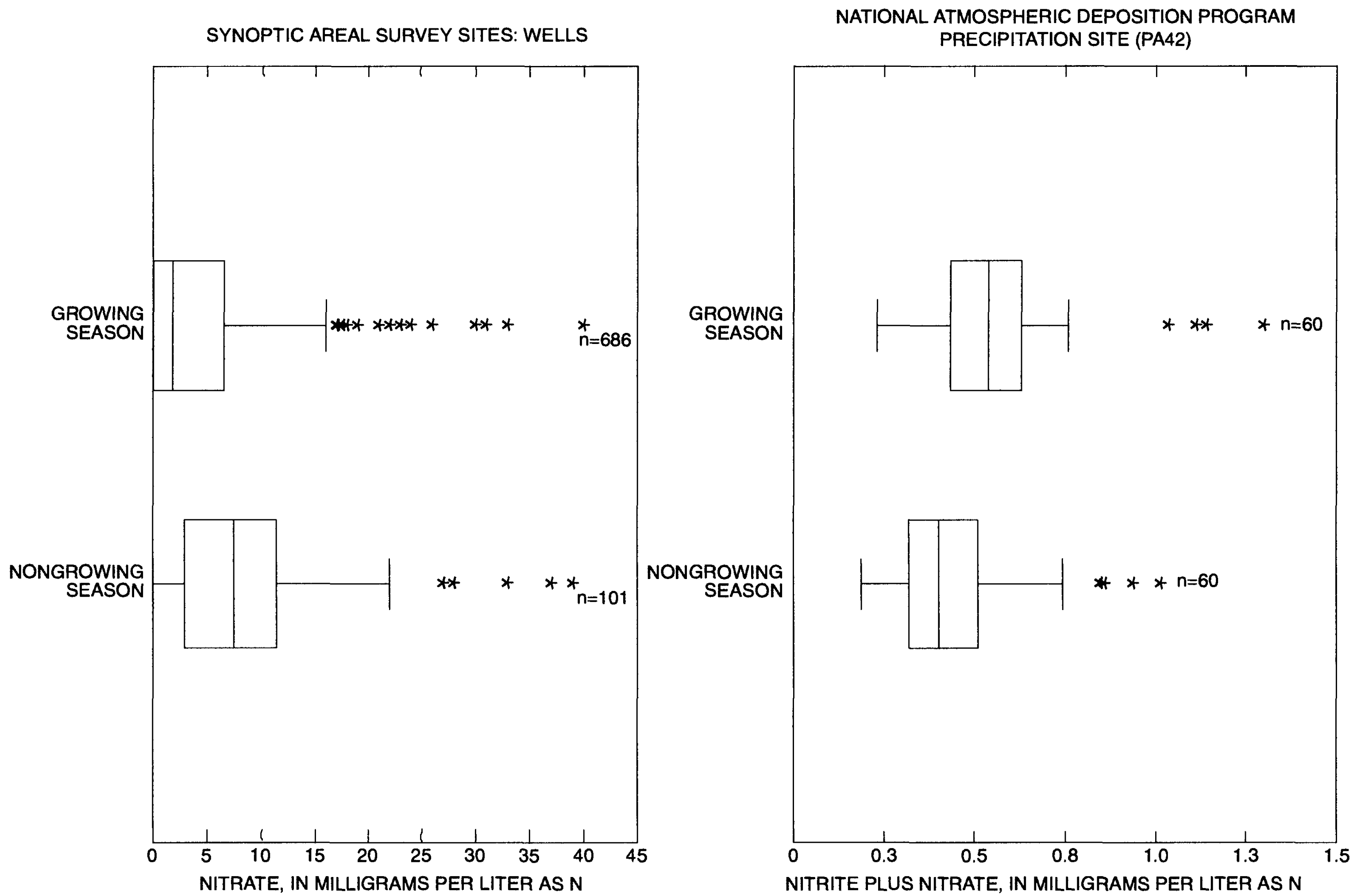
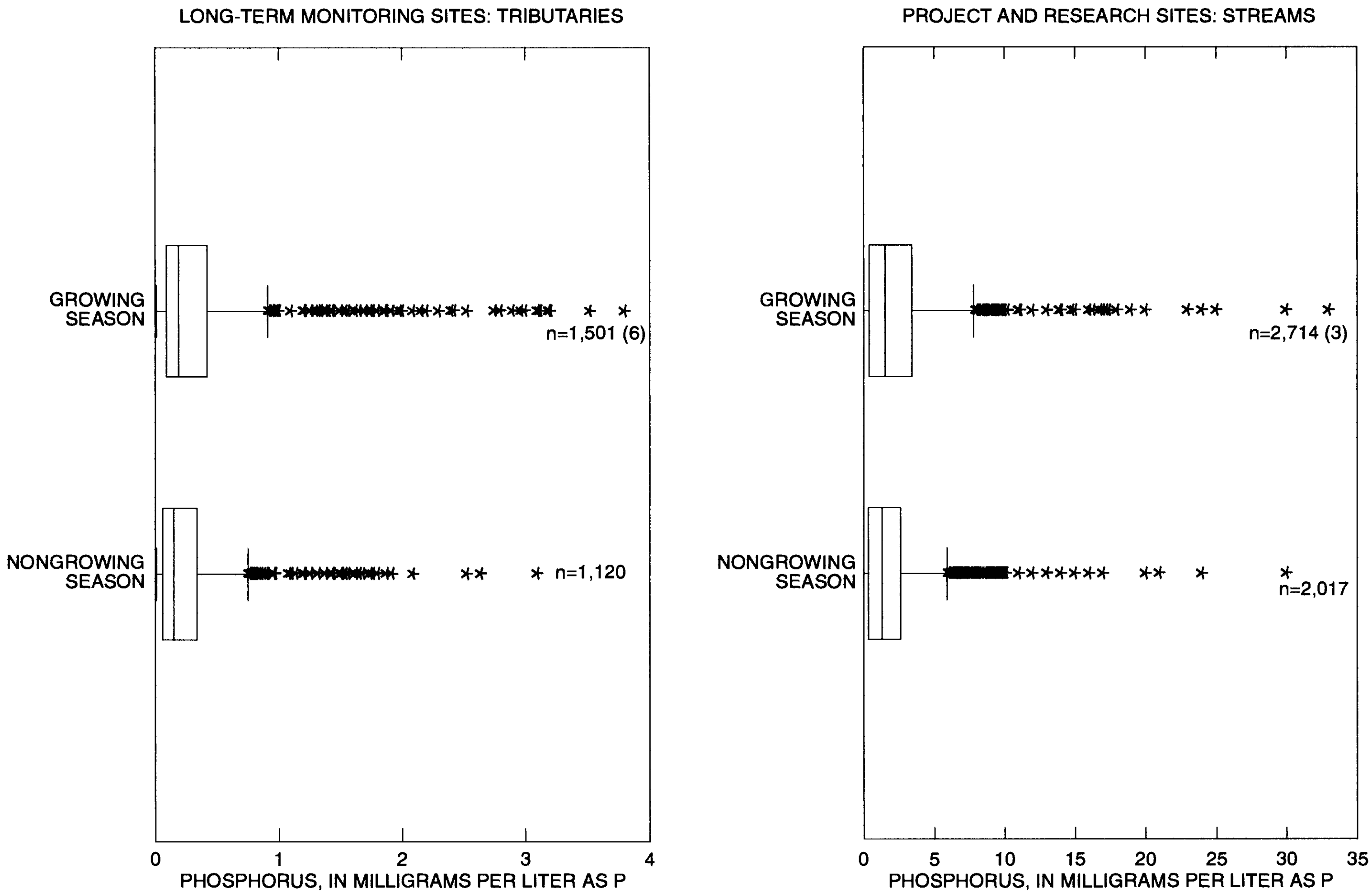



**Figure 33.** Relation of concentration of nitrate and season in the Lower Susquehanna River Basin for selected data sets collected during water years 1980-89—Continued.



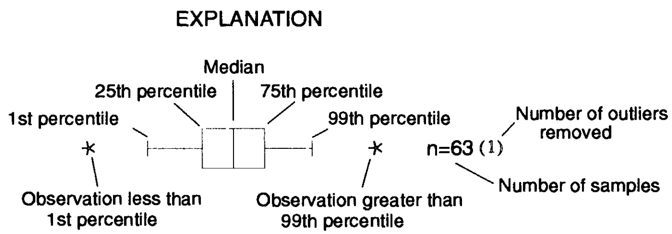




**Figure 34.** Relation of concentration of phosphorus and season in the Lower Susquehanna River Basin for selected data sets collected during water years 1980-89.

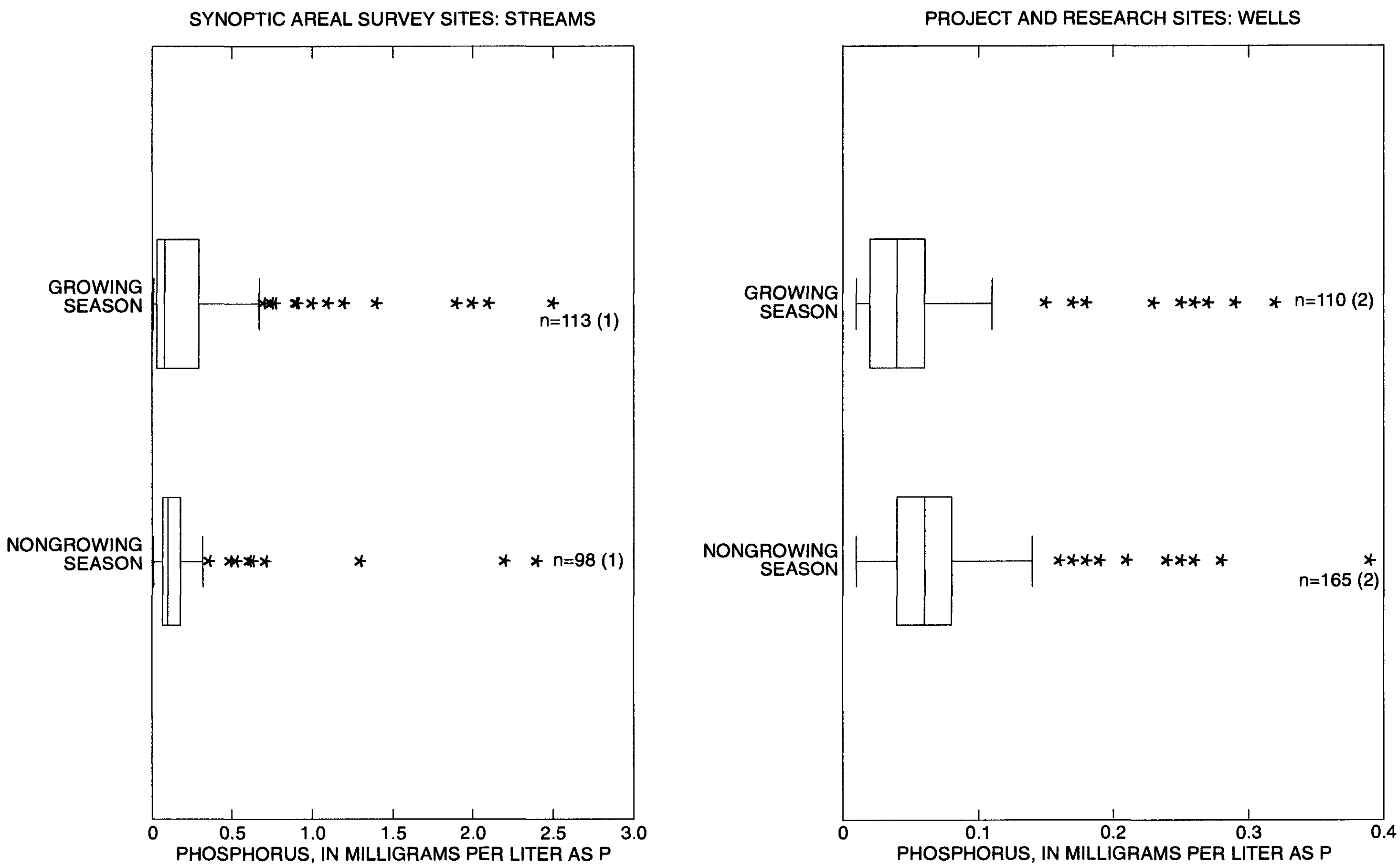



**Figure 34.** Relation of concentration of phosphorus and season in the Lower Susquehanna River Basin for selected data sets collected during water years 1980-89—Continued.

The Kruskal-Wallis test (Helsel and Hirsch, 1992, pp. 159-163) was applied to each of the data sets to determine whether the difference between the median concentrations of the growing and nongrowing seasons was statistically significant. Of the 10 tests, 8 of the median differences were significant at a $p \leq 0.05$ (table 14). Thus, significantly different phosphorus concentrations are likely in most waters between growing and nongrowing seasons. The two differences that were not significant at this level were (1) concentrations of nitrate at wells sampled for projects and research and (2) concentrations of phosphorus in samples collected from streams for synoptic areal surveys. The lack of significant difference for these two data sets may be related more to study design than to environmental factors.

**Table 14.** *Median concentrations of nitrate and phosphorus in relation to growing season in the Lower Susquehanna River Basin for selected data sets collected during water years 1980-89*

[Nitrate concentrations for synoptic survey wells are dissolved nitrate as nitrogen; differences between side-by-side cells are statistically significant, as determined by the Kruskal-Wallis test, at a confidence level of 95 percent, except where shaded; mg/L, milligrams per liter; --, insufficient data available]

| Data set | Median nitrate concentration (mg/L) | | Median phosphorus concentration (mg/L) | |
|---|---|---|---|---|
| | Growing season | Nongrowing season | Growing season | Nongrowing season |
| Streams - long-term monitoring tributary sites | 1.4 | 2.6 | 0.19 | 0.15 |
| Streams - synoptic areal survey sites | .7 | 4.4 | .08 | .10 |
| Streams - project and research sites | 2.7 | 3.4 | 1.5 | 1.3 |
| Wells - synoptic areal survey sites | 1.8 | 7.5 | -- | -- |
| Wells - project and research sites | 12.0 | 11.0 | .04 | .06 |
| Precipitation - (Leading Ridge site - PA42) | .5 | .4 | -- | -- |

## Long-Term Trends

Long-term trends or patterns in available data were determined for 1975-89. A minimum of 5 years of data and at least quarterly samples were the criteria used to screen the environmental data sets used for this initial nonstatistical analysis. These restrictions eliminated all ground-water and spring-water samples available for this period. The data remaining were nutrient and suspended-sediment determinations for surface-water samples and nitrate determinations for precipitation samples.

Patterns for concentrations of nutrients and suspended sediment in samples from streams with long-term monitoring sites were determined by plotting time series of streamflow-adjusted data. This adjustment procedure was designed to eliminate the effects of short-term variability in streamflow when testing for trends in water quality. Concentrations were adjusted for streamflow by developing a relation between concentration and streamflow at the time of sample collection to determine the expected concentration for a given streamflow. The method used for this procedure is explained in Lanfear and Alexander (1990, p. 7). Patterns for precipitation data were evaluated by use of unadjusted data.

LOWESS curves, as described by Helsel and Hirsch (1992), were used to indicate patterns of tendency in streamflow-adjusted concentrations of nitrate at selected stream sites and in unadjusted concentrations at the NAPD precipitation site for 1975-89 (fig. 35). In addition, tendencies in commercial fertilizer use (sales) and manure production for Lancaster County, a predominantly agricultural county, are shown. (See fig. 2 for county location.) The lines indicating patterns over time in figures 35-37 are not generated by statistically rigorous techniques and should not be interpreted as an indication of statistically significant trends. The lines are used only to display simultaneous changes in concentrations, or loads in the case of nitrogen inputs, among a group of sites. Before 1980, most water-quality samples were analyzed for total nitrate only, from unfiltered samples. Few analyses of filtered samples (dissolved nitrate) were available for 1975-80.

Five of the six sites with the largest drainage areas (Susquehanna River sites at Danville, Harrisburg, and Conowingo, and the West Branch Susquehanna River and Juniata River near their mouths) show a slight tendency of increasing nitrate concentrations during 1980-85 and then unchanging or slightly decreasing concentrations during 1985-89 (fig. 35). Data at the sixth site, the Susquehanna River at Marietta, were insufficient to determine any tendencies in nitrate concentration. During 1986, a water-quality sampling program began that increased the data-collection frequency. The increased frequency of data collection may have had some effect on the trends shown in figure 35.

The other surface-water-quality sites shown on figure 35 are on tributaries to the Susquehanna River. Their drainage basins range from 10 to about 500 $mi^2$. Most of the data were collected from these streams during 1986-88. The figure labeled "Synoptic Areal Survey Streams" includes synoptic survey samples collected from multiple streams during 1975-89. The drainage basins of these sites range in size from 1.0 to nearly 1,000 $mi^2$, but most are less than 200 $mi^2$. An analysis for a pattern of tendency of these data is not valid; but because of the areal coverage of this data set, it is being used here to provide a general indication of nitrate concentrations in all streams within the basin during 1980-89. Additional long-term data would be needed to estimate tendencies at these sites.

Three non-surface-water data sets—commercial fertilizer use, manure production, and precipitation—also were available for an analysis of patterns of tendency. Fertilizer-use data were developed for 1975-85 from statewide use estimates that were disaggregated

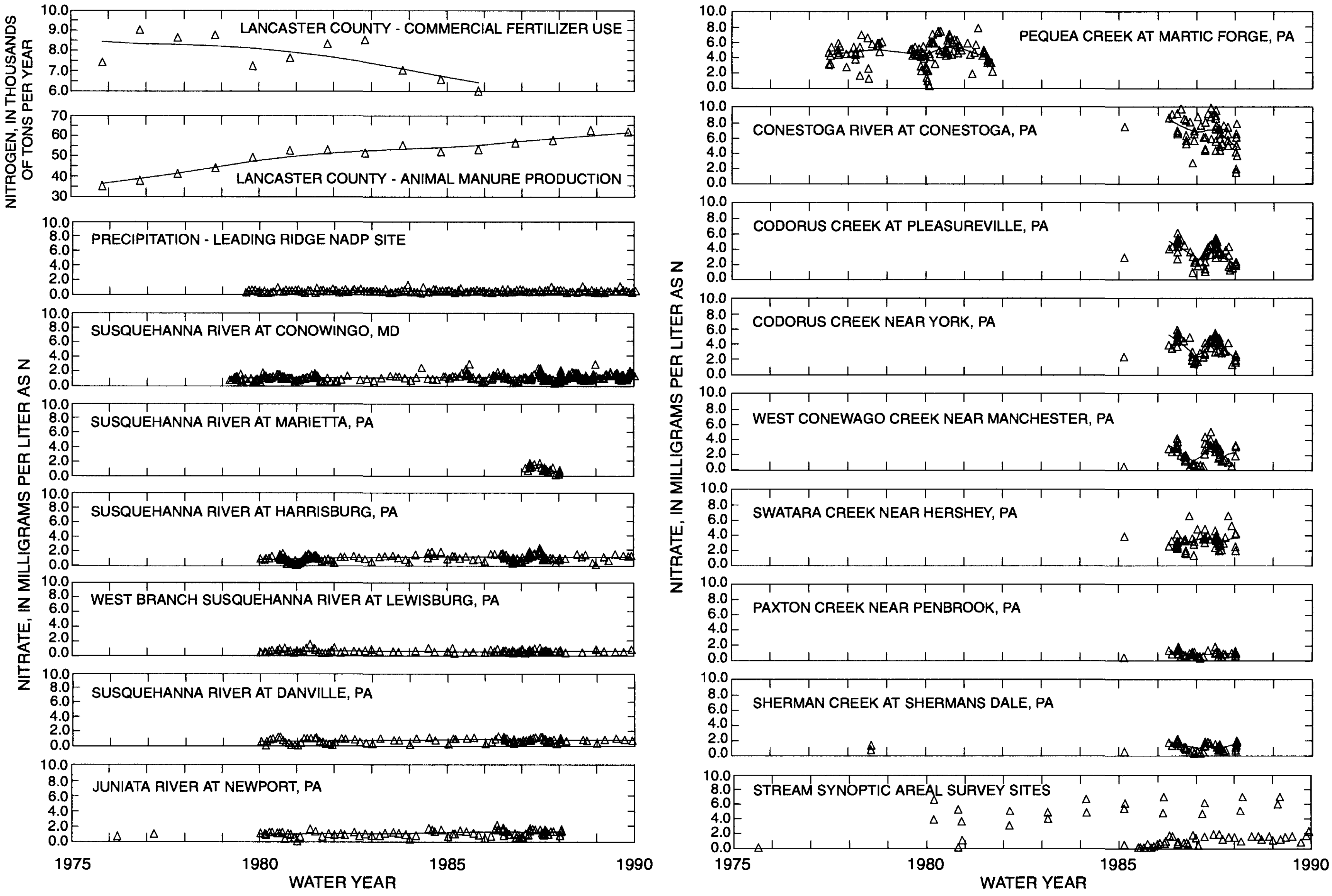



**Figure 35.** Patterns in commercial fertilizer use and manure production for a selected agriculturally dominated county and in nitrate concentrations at selected stream-quality and precipitation sites in the Lower Susquehanna River Basin, water years 1975-89.

to a county-based amount in proportion to the amount of fertilized acreage in each county (Alexander and Smith, 1990). The data for Lancaster County indicate a tendency for a decreasing load for the period. The nutrient load of manure was calculated from county-based estimates of animal units (1000 lb of animal weight) and Soil Conservation Service guidelines for nitrogen and phosphorus content of manure from different animal types (R.B. Alexander, U.S. Geological Survey, Reston, Va., written commun., October 1992). These data, for the same county, indicate a tendency for an increasing load. Precipitation data collected during 1979-89 indicate no tendencies for the period.

A comparison of the tendencies associated with these three potential inputs of nitrogen to surface water (precipitation, fertilizer, and manure) with the data collected from surface-water sites indicates a possible correlation of nutrient concentrations in streams to the amount of manure applied to the land surface. The amount of nitrogen introduced by fertilizer is generally one-fifth to one-eighth of that introduced by manure applications and, in this general analysis, its decreasing load appears to have had little effect on concentrations of nitrogen in streams. The pattern of increasing load of manure amounts applied during 1975-90 seems to coincide with upward trends of nitrogen concentrations in the larger streams.

Stricter requirements were applied to these data sets before statistical trend tests were applied. The following criteria developed by Lanfear and Alexander (1990) were used: minimum record length of 8 years, sampling frequency at least quarterly, collection of at least half of the samples in the first and last third of the time period, and availability of streamflow data with each sample so that nitrate concentrations can be adjusted based on streamflow. Because of these criteria and the scarcity of data for 1975-80, trend analyses could only be done on data collected during 1980-89 at five surface-water sites and at the precipitation site. At a confidence level of 95 percent ($p \leq 0.05$), no statistically significant trends were detected in concentrations of nitrate at the precipitation site or in streamflow-adjusted concentrations at four stream sites; Susquehanna River sites at Danville, Harrisburg and Conowingo, and the West Branch Susquehanna River site at Lewisburg. A significant upward trend of 0.06 mg/L per year was detected in data from the Juniata River at Newport.

Smith and others (1992) also analyzed streamflow-adjusted concentrations of nitrate from the Susquehanna River at Conowingo for 1980-89 using the same test, and they detected a statistically significant upward trend. The reason for the contradiction between the results of the two trend tests on the data from the Conowingo site is unknown, but it is probably related to data-selection techniques.

LOWESS curves also were developed from phosphorus concentrations in samples collected at selected stream sites and phosphorus contributions from commercial fertilizer and manure (fig. 36). Sufficient data for an analysis for patterns of tendency through the whole 1975-89 period were available at the large-river sites. The phosphorus concentrations in the "Synoptic Areal Survey Streams" data set were fairly well distributed throughout the period; but because of the multiple-site sampling strategy, an analysis for patterns of tendency is not valid. Most of the data collection at the other sites was completed during 1985-89, too short a period for analysis.

Sufficient data were available for analysis at the Susquehanna River sites at Danville, Harrisburg, and Conowingo, at the West Branch Susquehanna River site at Lewisburg, and at the Juniata River site at Newport. The LOWESS curves in figure 36 do not indicate any patterns of tendency in phosphorus concentrations.

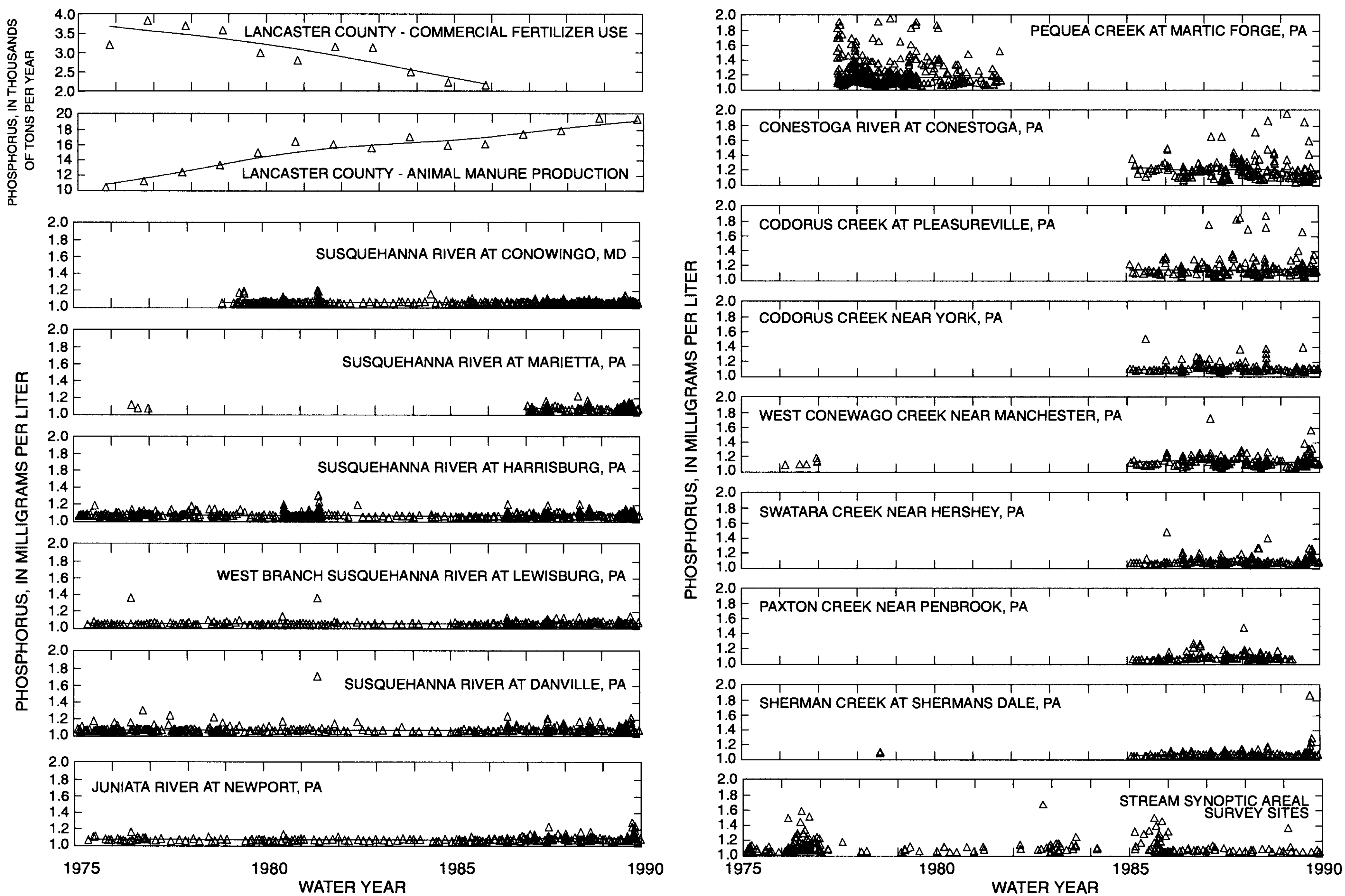



**Figure 36.** Patterns in commercial fertilizer use and manure production for a selected agriculturally dominated county and in phosphorus concentrations at selected stream-quality sites in the Lower Susquehanna River Basin, water years 1975-89.

Because annual amounts of phosphorus content from fertilizer and manure were based on the amount of fertilizer used and manure produced, patterns for potential phosphorus contributions were similar to those described for nitrogen. Phosphorus from fertilizer showed a tendency toward a decreasing load during 1975-85. Manure-produced phosphorus tended to gradually increase during 1975-90 in Lancaster County, an agriculturally dominated county. Patterns in concentrations of phosphorus in streams appear to have been unrelated to patterns in potential contributions from commercial fertilizer and manure.

Statistical trend tests were applied to the phosphorus concentrations collected at five stream sites during 1980-89. No data were available to apply similar tests to concentrations of nutrients in ground water. At a confidence level of 95 percent ($p \leq 0.05$), no statistically significant trends were detected in streamflow-adjusted phosphorus concentrations from samples collected at the Susquehanna River sites at Danville and Harrisburg. Statistically significant upward trends were detected at the West Branch Susquehanna River site at Lewisburg (0.002 mg/L per year) and at the Juniata River site at Newport (0.003 mg/L per year). A statistically significant downward trend was detected at the Susquehanna River site at Conowingo (<0.001 mg/L per year).

Smith and others (1992) detected no trend at the Conowingo site for 1982-89. The contradiction between the results of the two trend tests on the data from the Conowingo site is probably due to rounding of the results, but it also may be related to an analysis of different time periods. A trend of <0.001 mg/L per year is very small and, for all practical purposes, could be considered equivalent to zero. In addition, for comparison of the tests to be valid, the time periods used must be identical (Helsel, 1992, p.97), and they are not.

Patterns of tendency in concentrations of suspended sediment were reviewed by use of LOWESS curves (fig. 37). Statistical trend tests on concentrations of suspended sediment collected at the sites with sufficient data during 1980-89 indicated no statistically significant trend at four of the sites; the Susquehanna River sites at Danville and Harrisburg, the West Branch Susquehanna River site at Lewisburg, and the Juniata River site at Newport. A statistically significant downward trend of <1 mg/L per year was detected, at the 95-percent confidence level, at the Susquehanna River site at Conowingo. The trend detected at the Conowingo site agrees with the results of Smith and others (1992).

The 1980-89 trends detected in concentrations of nitrate, phosphorus, and suspended sediment collected at selected surface-water and precipitation sites are summarized in table 15. A confidence level of 95 percent was used to determine statistical significance.

Trends determined at the five large-river sites can be used only as a general indication of the changing quality of the streams in the Lower Susquehanna River Basin. Data were insufficient to correlate land use or human-activity changes with changes in water quality in small tributary basins. Long-term precipitation data available from one site in the study unit could be used to determine trends in concentrations of total nitrogen in precipitation, but the conclusions would not be applicable basinwide. Data collected at synoptic sites are sufficient to determine areal patterns within the Lower Susquehanna River Basin but should not be used to indicate a temporal pattern at any particular area within the study unit. Changes in land use and the human activities associated with the land use are probably major causes of changes in surface- and ground-water quality; but, in order to determine the causes of detected trends, additional water-quality data would be needed to define water-quality characteristics of small, homogeneous drainage basins and aquifers (in terms of bedrock and land use) and additional causal-factor data also would be needed.

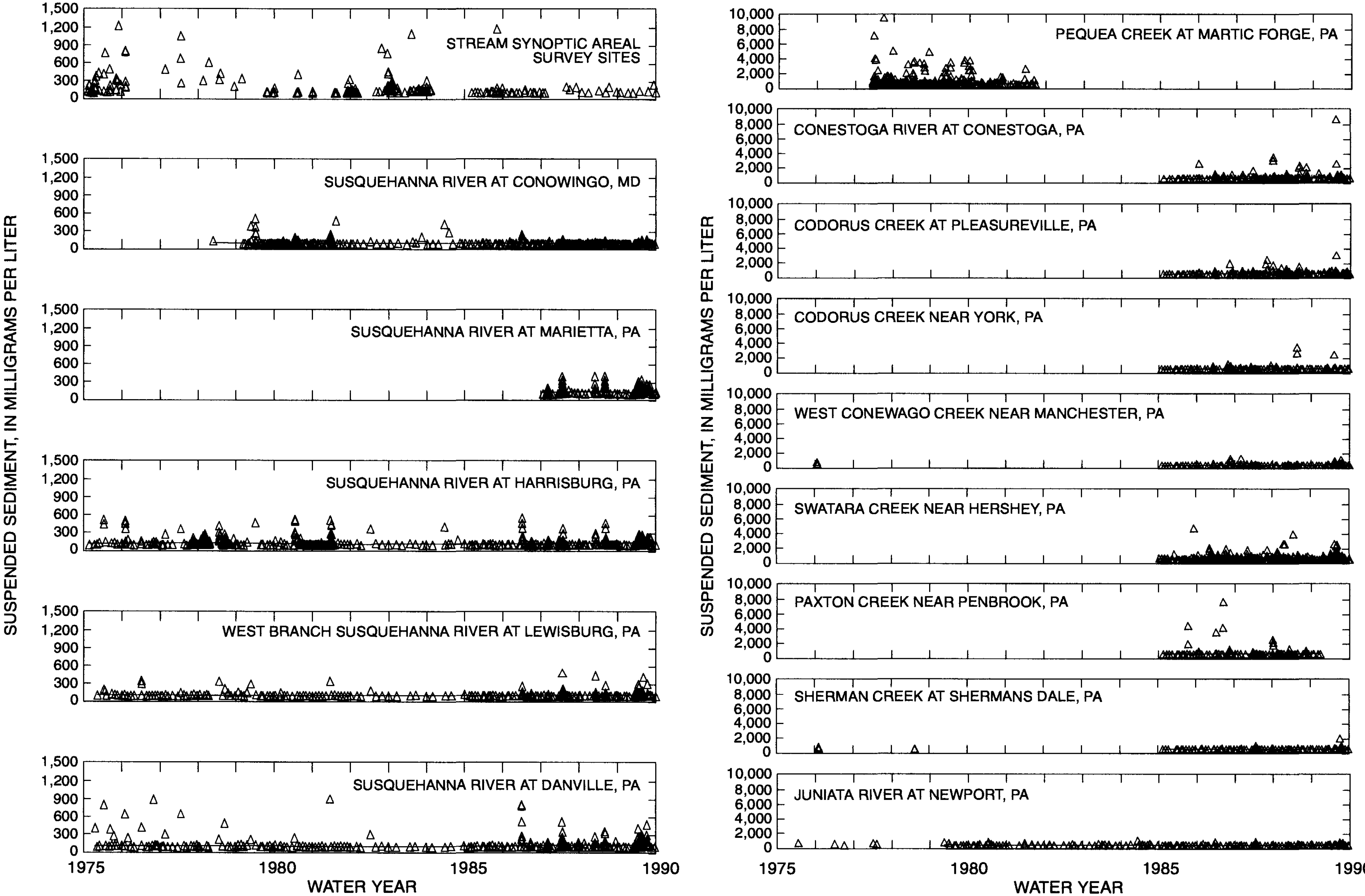



**Figure 37.** Patterns in concentrations of suspended sediment at selected stream-quality sites in the Lower Susquehanna River Basin, water years 1975-89.

**Table 15.** *Summary of trends detected in concentrations of nitrate, phosphorus, and suspended sediment from samples collected during water years 1980-89 at selected surface-water and precipitation sites in the Lower Susquehanna River Basin*

[A confidence level of 95 percent ($p \leq 0.05$) was used to determine statistical significance; (mg/L)/yr, milligram per liter per year; --, not determined; <, less than; >, greater than; N/A, not applicable]

| Site | Nitrate | | | Phosphorus | | | Suspended sediment | | |
|---|---|---|---|---|---|---|---|---|---|
| | Trend detected | Slope [(mg/L)/yr] | *p* value | Trend detected | Slope [(mg/L)/yr] | *p* value | Trend detected | Slope [(mg/L)/yr] | *p* value |
| Danville | None | -- | >0.05 | None | -- | >0.05 | None | -- | >0.05 |
| Lewisburg | None | -- | >0.05 | Upward | 0.002 | <0.01 | None | -- | >0.05 |
| Newport | Upward | 0.06 | <0.01 | Upward | .004 | <0.01 | None | -- | >0.05 |
| Harrisburg | None | -- | >0.05 | None | -- | >0.05 | None | -- | >0.05 |
| Conowingo | None | -- | >0.05 | Downward | -.001 | 0.04 | Downward | -0.60 | <0.01 |
| Synoptic | No test | N/A | N/A | None | -- | >0.05 | Downward | -.05 | <0.01 |
| Precipitation | None | -- | >0.05 | No test | N/A | N/A | No test | N/A | N/A |

## Loads of Nutrients and Suspended Sediment

Nutrient and suspended-sediment data for computations of loads are potentially available from four types of sites: long-term monitoring sites, synoptic areal survey sites, project and research sites on streams, and long-term precipitation monitoring sites. In addition, loading information from a point-source inventory developed by the USEPA Chesapeake Bay Program will provide data on other stream load inputs. The following three criteria were applied to the data set from each stream site: (1) a minimum of 40 observations during a period of relatively similar hydrologic conditions, (2) a minimum of 4 observations during each calendar season, and (3) a minimum of 10 percent of the total number of observations collected during streamflows that equaled or exceeded the upper 10th percentile of flow for the period of interest. Data collected from precipitation sites and inventoried from point-source data sets need only meet the criterion of a minimum of 40 observations. After application of these criteria, data for 23 stream sites, 3 precipitation sites, and 72 point sources were available for computations of annual load for all or some of the selected constituents (table 16).

General information about the "major" municipal and industrial point sources in the Lower Susquehanna River Basin, grouped by drainage basin, is listed in table 17. The number of sources given for each subbasin are those that discharge to the stream above the location of the stream-monitoring site. Additional point sources may discharge to the stream between the monitoring site and the stream mouth. Herein, "major" is defined as a point source determined by the Chesapeake Bay Foundation (U.S. Environmental Protection Agency, 1988) to be a "major" point source. The designation is based primarily on the magnitude of the load but also includes smaller discharges that may substantially affect streamwater quality. The table also includes ratios of the total known point-source discharge to the long-term average monthly streamflow at sites near the mouth of the selected streams. March and September streamflows were selected as representative of typical high and low base-flow periods observed during the year. These ratios are indicative of the influence the combined point-source discharges may have on the water quality of the stream. The two streams with the highest ratios of point-source discharge to streamflow were Codorus Creek and the Conestoga River.

**Table 16.** *Stream and precipitation sites in the Lower Susquehanna River Basin that meet qualifying criteria for computation of annual nutrient and suspended-sediment load*

[$mi^2$, square mile; LT, long-term monitoring; PR, project and research; N/A, not applicable; <, less than; --, no data]

| Site | Data set | Drainage area ($mi^2$) | Period of data collection | Nitrate | | Phosphorus | | Suspended sediment | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Number of obser-vations | Number of obser-vations above the 10th percentile | Number of obser-vations | Number of obser-vations above the 10th percentile | Number of obser-vations | Number of observations above the 10th percentile |
| Tributary sites | | | | | | | | | |
| Brush Run near McSherrystown | PR | 0.38 | 1986-89 | 128 | 65 | 428 | 270 | 805 | 579 |
| Bald Eagle Creek near Fawn Grove | PR | .43 | 1986-89 | 88 | 40 | 254 | 180 | 414 | 287 |
| Pequea Creek tributary No. 1 at Strasburg | PR | .56 | 1980-81 | <40 | -- | <40 | -- | 100 | 72 |
| Pequea Creek tributary No. 2 at Strasburg | PR | .59 | 1980-81 | <40 | -- | <40 | -- | 100 | 75 |
| Little Conestoga Creek, site 3A, near Morgantown | PR | 1.42 | 1985-89 | 169 | 97 | 553 | 443 | 734 | 582 |
| Little Conestoga Creek near Churchtown | PR | 5.82 | 1983-89 | 264 | 155 | 963 | 733 | 995 | 759 |
| Paxton Creek near Penbrook | LT | 11.2 | 1985-88 | 104 | 65 | 220 | 139 | 214 | 131 |
| Stony Creek near Dauphin | PR | 21.9 | 1985-86 | [1] 43 | 25 | 61 | 30 | 61 | 30 |
| Little Swatara Cr. at Pine Grove | PR | 34.3 | 1982-84 | <40 | -- | 59 | 14 | [2] 244 | 21 |
| Conestoga River near Terre Hill | PR | 49.2 | 1982-83 | <40 | -- | <40 | -- | 68 | 27 |
| Swatara Creek at Pine Grove | PR | 72.6 | 1982-84 | <40 | -- | 59 | 15 | 197 | 21 |
| Sherman Creek at Shermans Dale | LT | 200 | 1985-89 | 88 | 33 | 196 | 84 | 195 | 84 |
| Codorus Creek near York | LT | 222 | 1985-89 | 91 | 38 | 193 | 77 | 192 | 78 |
| Codorus Creek at Pleasureville | LT | 267 | 1985-89 | 159 | 112 | 403 | 289 | 401 | 287 |
| Conestoga River at Conestoga | LT | 470 | 1985-89 | 169 | 119 | 464 | 327 | 462 | 328 |
| Swatara Creek near Hershey | LT | 483 | 1985-89 | 92 | 39 | 209 | 80 | 209 | 80 |
| West Conewago Creek near Manchester | LT | 510 | 1985-89 | 103 | 52 | 234 | 101 | 234 | 101 |
| Juniata River at Newport | LT | 3,354 | 1980-89 | 136 | 39 | 233 | 81 | 268 | 101 |
| West Branch Susquehanna River and Susquehanna River sites | | | | | | | | | |
| West Br. Susquehanna River at Lewisburg | LT | 6,847 | 1985-89 | 117 | 21 | 205 | 55 | 217 | 54 |
| Susquehanna River at Danville | LT | 11,220 | 1985-89 | 124 | 31 | 211 | 64 | 206 | 63 |
| Susquehanna River at Harrisburg | LT | 24,100 | 1980-81<br>1985-89 | 215 | 57 | 314 | 101 | 307 | 99 |
| Susquehanna River at Marietta | LT | 25,990 | 1987-89 | <40 | -- | 127 | 56 | 126 | 56 |
| Susquehanna River at Conowingo | LT | 27,100 | 1980-81<br>1985-89 | 453 | 192 | 455 | 191 | 482 | 234 |
| Precipitation sites | | | | | | | | | |
| Leading Ridge | N/A | N/A | 1980-89 | 452 | N/A | 0 | N/A | 0 | N/A |
| Little Buffalo | N/A | N/A | 1983-89 | 377 | N/A | 0 | N/A | 0 | N/A |
| Gettysburg | N/A | N/A | 1984-89 | 327 | N/A | 0 | N/A | 0 | N/A |

[1] This data set was eliminated because it did not meet the seasonality criterion.

[2] This data set was eliminated because it did not meet the upper 10th percentile of flow criterion.

**Table 17.** *General information about major point sources in the Lower Susquehanna River Basin, grouped by drainage basin*

[(Mgal/d)/yr, million gallons per day per year]

| Drainage basin | Number of known point sources | Number of municipal point sources | Number of industrial point sources | Total discharge of all point sources [(Mgal/d)/yr] | Average discharge of all point source [(Mgal/d)/yr] | Ratio of total point-source discharge to average March streamflow (percent) | Ratio of total point-source discharge to average September streamflow (percent) |
|---|---|---|---|---|---|---|---|
| Juniata River | 13 | 8 | 5 | 25.4 | 1.96 | 0.49 | 2.4 |
| Sherman Creek | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Swatara Creek | 3 | 2 | 1 | 6.81 | 2.27 | .86 | 3.1 |
| West Conewago Creek | 2 | 2 | 0 | 4.63 | 2.31 | .61 | 2.8 |
| Codorus Creek | 6 | 4 | 2 | 39.4 | 6.57 | 5.1 | 12.0 |
| Susquehanna R. above Reservoirs | 59 | 40 | 19 | 210 | 3.57 | .43 | 2.6 |
| Conestoga River | 6 | 5 | 1 | 25.9 | 4.31 | 5.6 | 9.2 |
| Susquehanna R. below Reservoirs | 72 | 49 | 23 | 246 | 3.42 | .53 | 2.3 |

### Basinwide Variability

Annual loads of nitrate, phosphorus, and suspended sediment for 1980-89 for sites that met the data-evaluation criteria described in the previous section and are listed in tables 18-20. The loads are either from USGS studies where loads were computed and published, or from unpublished load computations from other sources. Sites for which sufficient data are available for load computations seem to have been established specifically for that purpose. In addition to the loads, the ratios of the 1980-89 annual mean streamflows at the Susquehanna River at Harrisburg to the long-term mean streamflow, based on 100 years of record, are given in the tables. The ratios were included to give some indication of the "normality" of the individual years, as far as precipitation and streamflow are concerned.

Published loads of dissolved or total nitrate for the period 1980-89 are summarized in table 18. Langland and Fishel (1995) did not publish nitrate loads. For those sites (reference B, table 18), published total nitrogen loads and ratios of concentrations of nitrate and total nitrogen were used to estimate nitrate loads. Errors of prediction for all published loads, if available, are given in the individual references.

The areal variability of stream nitrate loads does not seem to be related to location in the study unit; rather, variability appears to be more related to size of drainage area and the magnitude of streamflow. Exceptions to this tendency are Little Conestoga Creek, site 5 (table 18, Map ID no. 4) and the Conestoga River (table 18, Map ID no. 9), two highly intensive agricultural basins underlain by carbonate rock. The high loads at these sites may be a result of local agricultural practices. At West Conewago Creek (table 18, Map ID no. 11), which drains a mixed agricultural and forested basin underlain by siliciclastic rock, loads also were higher than expected. Lynch (1990) suggests that variability in loads from precipitation are more dependent on precipitation amounts than on concentration. A graphical display of the basinwide variability of the annual nitrate loads at several sites within the basin for 1987 is shown in figure 38. Data from 1987 were selected for this figure because it was the most complete data set for the selected sites and indicated a mid-study load estimate.

**Table 18.** *Annual loads of total or dissolved nitrate at selected stream sites and deposition at selected precipitation sites in the Lower Susquehanna River Basin, water years 1980-89*

[Map ID no., use this number to locate site on figure 38; mi², square miles; Diss., dissolved; --, no data; N/A, not applicable; data from Ott and others (1991) are calendar-year loads; A, Langland and Fishel (1996); B, Langland and Fishel (1995); C, Koerkle and others (1996); D, Ott and others (1991); E, Gwen Scott, NADP/NTN Coordination Office, written commun., (1992); F, J. Lynch, Pennsylvania State University, written commun., (1993)]

| Site | Drainage area (mi²) | Location | Map ID no. (fig. 1) | Data type | Reference for data source | Load, in thousands of pounds 1980 (0.94)[1] | 1981 (0.68) | 1982 (0.97) | 1983 (0.89) | 1984 (1.31) | 1985 (0.67) | 1986 (1.01) | 1987 (0.91) | 1988 (0.74) | 1989 (0.94) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tributary Sites | | | | | | | | | | | | | | | |
| Brush Run, Site 2 | 0.38 | near McSherrystown, Pa. | 1 | Diss. | A | -- | -- | -- | -- | -- | -- | 1.2 | 2.4 | 2.3 | 4.0 |
| Bald Eagle Creek | .43 | near Fawn Grove, Pa. | 2 | Diss. | B | -- | -- | -- | -- | -- | -- | 3.1 | 3.1 | 6.1 | 4.2 |
| Little Conestoga Creek, Site 3A | 1.42 | near Morgantown, Pa. | 3 | Total | C | -- | -- | -- | -- | -- | 6.3 | 15.7 | 12.3 | 15.2 | 16.9 |
| Little Conestoga Creek, Site 5 | 5.82 | near Churchtown, Pa. | 4 | Total | C | -- | -- | -- | -- | -- | 32.6 | 68.0 | 91.5 | 98.6 | 115 |
| Paxton Creek | 11.2 | near Penbrook, Pa. | 5 | Total | D | -- | -- | -- | -- | -- | 14.0 | 27.7 | 30.2 | 31.3 | -- |
| Sherman Creek | 200 | at Shermans Dale, Pa. | 6 | Total | D | -- | -- | -- | -- | -- | 602 | 649 | 635 | 500 | 1,040 |
| Codorus Creek | 222 | near York, Pa. | 7 | Total | D | -- | -- | -- | -- | -- | 1,120 | 1,230 | 1,160 | 1,180 | 1,350 |
| Codorus Creek | 267 | at Pleasureville, Pa. | 8 | Total | D | -- | -- | -- | -- | -- | 1,650 | 1,670 | 1,630 | 1,590 | 1,750 |
| Conestoga River | 470 | at Conestoga, Pa. | 9 | Total | D | -- | -- | -- | -- | -- | 6,250 | 8,750 | 7,680 | 8,260 | 10,600 |
| Swatara Creek | 483 | near Hershey, Pa. | 10 | Total | D | -- | -- | -- | -- | -- | 2,670 | 4,530 | 4,190 | 3,620 | 4,970 |
| West Conewago Creek | 510 | near Manchester, Pa. | 11 | Total | D | -- | -- | -- | -- | -- | 1,450 | 2,510 | 2,670 | 2,150 | 3,300 |
| Juniata River | 3,354 | at Newport, Pa. | 12 | Total | D | -- | -- | -- | -- | -- | 12,900 | 11,300 | 9,010 | 7,680 | 14,000 |
| Susquehanna River sites | | | | | | | | | | | | | | | |
| West Branch Susquehanna River | 6,847 | at Lewisburg, Pa. | 13 | Total | D | -- | -- | -- | -- | -- | 15,200 | 16,900 | 12,400 | 10,400 | 14,400 |
| Susquehanna River | 11,220 | at Danville, Pa. | 14 | Total | D | -- | -- | -- | -- | -- | 21,100 | 30,200 | 21,700 | 18,100 | 24,600 |
| Susquehanna River | 24,100 | at Harrisburg, Pa. | 15 | Total | D[2] | -- | 25,200 | -- | -- | -- | 49,600 | 65,400 | 50,500 | 43,300 | 64,000 |
| Susquehanna River | 27,100 | at Conowingo, Md. | 17 | Total | D[3] | 65,000 | 72,000 | -- | -- | -- | 77,800 | 99,900 | 80,000 | 72,000 | 113,000 |
| Precipitation sites (wet deposition, in thousands of pounds per square mile) | | | | | | | | | | | | | | | |
| Leading Ridge | N/A | at Masseyburg, Huntingdon County, Pa. | N/A | Diss. | E | 2.62 | 2.39 | 3.01 | 2.24 | 3.45 | 2.38 | 3.05 | 3.31 | 2.48 | 3.02 |
| Little Buffalo | N/A | at Little Buffalo State Park, Perry County, Pa. | N/A | Diss. | F | -- | -- | -- | 2.80 | 4.05 | 2.77 | 3.39 | 2.89 | 2.48 | 2.90 |
| Gettysburg | N/A | at Gettysburg Battlefield National Park, Adams County, Pa. | N/A | Diss. | F | -- | -- | -- | -- | 3.83 | 2.43 | 2.68 | 2.99 | 2.23 | 2.56 |

[1] Values shown in parentheses under each year are ratios of annual mean to long-term (100-year) mean streamflow at the site on the Susquehanna River at Harrisburg, Pa.
[2] Data for 1981 are from Fishel (1984). Loads are for a year of data collection from April 1980 through March 1981.
[3] Data for 1980-81 are from L. Zynjuk (U.S. Geological Survey, written commun., 1993).

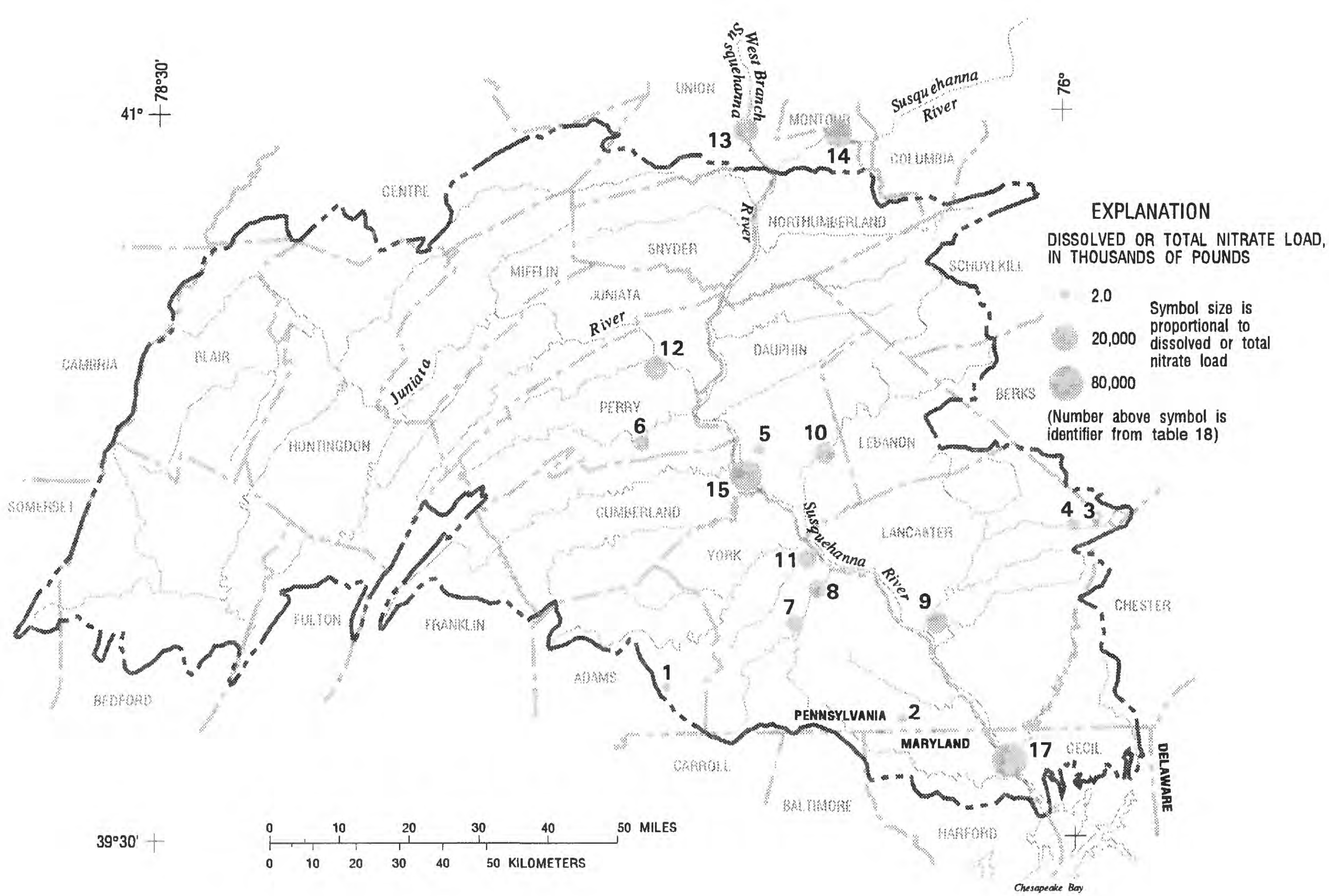



**Figure 38.** Stream sites in the Lower Susquehanna River Basin where sufficient data were available for computation of dissolved or total nitrate load and the relative magnitude of the loads at each site for water year 1987. (Site numbers refer to table 18.)

Published loads of phosphorus for 1980-89 are summarized in table 19. The negative bias in phosphorus concentrations for samples measured at the USGS National Water Quality Laboratories, which was noted previously in this report, does not affect most of the loads determined by these studies because most of the chemical analyses for these studies were done by the PaDEP Water Quality Laboratory.

Similar to nitrate, the factors that seem to influence the basinwide variability of phosphorus loads are hydrologic conditions and drainage area. The stream sites are sorted and listed in order of increasing drainage area in table 19. Streams where loads were high or low, relative to their drainage area are the highly agricultural Little Conestoga Creek and Conestoga River with higher than expected loads, and Bald Eagle Creek and the Susquehanna River at Conowingo with lower than expected loads. The site at Conowingo is a main-stem site immediately downstream from three consecutive reservoirs. Ott and others (1991, p. 155) indicate that about 40 percent of the phosphorus transported to the reservoirs is trapped.

Published loads of suspended sediment for the period 1980-89 are summarized in table 20. Suspended-sediment loads computed for 1983 at the Conestoga River site at Terre Hill and computed for 1981 at the Susquehanna River at Harrisburg by Fishel (1984) are for a year of data collection beginning in April and ending in March.

The areal variability of suspended-sediment loads also does not seem to be related to location within the Lower Susquehanna River Basin (fig. 39); again, the variability of the annual loads of suspended sediment in the basin for 1987 appears to be more related to size of drainage area and the magnitude of streamflow. In table 20, where the sites are ordered by drainage area, a pattern of increasing load with increasing drainage area is evident. Sites that do not fit into this general pattern are probably affected by some factor other than basin size or streamflow. The two most obvious anomalies are the Conestoga River, the highly intensive agricultural basin, with a higher than expected load and the main-stem site below the three reservoirs, with a lower than expected load. Ott and others (1991) state that about 70 percent of the suspended sediment transported to the reservoirs is trapped.

### Relation of Loads and Yields of Nutrients and Suspended Sediment to Streamflow

Because streamflow is a component of the equation to compute loads, if sufficient concentration data are collected, the relation between loads and streamflow is generally well defined. Once defined for a stream, this relation is commonly used to predict loads on the basis of recorded streamflows. These relations were available from published reports for several nutrient constituents and suspended sediment for the sites listed in tables 18-21. An example of the relation between annual total nitrogen, total phosphorus, and suspended-sediment yields and the ratio of annual mean streamflow to long-term average streamflow is shown in figure 40. The observed error range is ± one standard deviation and is obtained by averaging the prediction errors, in percentage, for the 5-year period and applying it to the regression line.

Annual yields are annual loads per unit drainage area above the site, generally shown as tons per square mile per year or pounds per acre per year. The use of a yield, as opposed to a load, normalizes the load being discharged by a stream drainage area and provides a value that could be interpreted as the "productivity" of that area. The higher the yield, the more of the materials of interest are likely available for introduction to ground- and surface-water systems.

**Table 19.** *Annual loads of total phosphorus at selected stream sites in the Lower Susquehanna River Basin, water years 1980-89*

[$mi^2$, square miles; --, no data; data from Ott and others (1991) are calendar-year loads; A, Langland and Fishel (1996); B, Langland and Fishel (1995); C, Koerkle and others (1996); D, Ott and others (1991); E, Fishel and others (1988)]

| Stream | Drainage area ($mi^2$) | Location | Data source | Load, in thousands of pounds: 1980 (0.94)[1] | 1981 (0.68) | 1982 (0.97) | 1983 (0.89) | 1984 (1.31) | 1985 (0.67) | 1986 (1.01) | 1987 (0.91) | 1988 (0.74) | 1989 (0.94) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Tributary sites | | | | | | | | | | |
| Brush Run, Site 2 | 0.38 | near McSherrystown, Pa. | A | -- | -- | -- | -- | -- | -- | 0.54 | 1.01 | 0.95 | 1.21 |
| Bald Eagle Creek | .43 | near Fawn Grove, Pa. | B | -- | -- | -- | -- | -- | -- | .16 | .14 | .70 | .26 |
| Little Conestoga Cr., Site 3A | 1.42 | near Morgantown, Pa. | C | -- | -- | -- | -- | -- | 1.30 | 1.44 | 2.48 | 2.77 | 2.09 |
| Little Conestoga Creek, Site 5 | 5.82 | near Churchtown, Pa. | C | -- | -- | -- | -- | -- | 9.72 | 6.66 | 15.1 | 18.8 | 17.6 |
| Paxton Creek | 11.2 | near Penbrook, Pa. | D | -- | -- | -- | -- | -- | 1.19 | 5.05 | 7.40 | 3.26 | -- |
| Stony Creek | 21.9 | at Water Tank Trail near Dauphin, Pa. | D | -- | -- | -- | -- | -- | .89 | 3.04 | -- | -- | -- |
| Lower Little Swatara Creek | 34.3 | at Pine Grove, Pa. | E | -- | -- | -- | 9.04 | -- | -- | -- | -- | -- | -- |
| Swatara Creek | 72.6 | above Highway Bridge 895 at Pine Grove, Pa. | E | -- | -- | -- | 17.0 | -- | -- | -- | -- | -- | -- |
| Sherman Creek | 200 | at Shermans Dale, Pa. | D | -- | -- | -- | -- | -- | 40.3 | 49.3 | 44.1 | 30.7 | 102 |
| Codorus Creek | 222 | near York, Pa. | D | -- | -- | -- | -- | -- | 68.3 | 60.6 | 59.3 | 55.9 | 53.7 |
| Codorus Creek | 267 | at Pleasureville, Pa. | D | -- | -- | -- | -- | -- | 134 | 152 | 171 | 166 | 161 |
| Conestoga River | 470 | at Conestoga, Pa. | D | -- | -- | -- | -- | -- | 461 | 869 | 764 | 776 | 777 |
| Swatara Creek | 483 | near Hershey, Pa. | D | -- | -- | -- | -- | -- | 104 | 229 | 206 | 144 | 252 |
| West Conewago Creek | 510 | near Manchester, Pa. | D | -- | -- | -- | -- | -- | 257 | 339 | 341 | 151 | 376 |
| Juniata River | 3,354 | at Newport, Pa. | D | -- | -- | -- | -- | -- | 719 | 800 | 734 | 608 | 1,110 |
| | | | Susquehanna River sites | | | | | | | | | | |
| West Branch Susquehanna River | 6,847 | at Lewisburg, Pa. | D | -- | -- | -- | -- | -- | 892 | 1,450 | 1,260 | 1,010 | 1,420 |
| Susquehanna River | 11,220 | at Danville, Pa. | D | -- | -- | -- | -- | -- | 2,160 | 4,360 | 3,140 | 2,270 | 3,320 |
| Susquehanna River | 24,100 | at Harrisburg, Pa. | D[2] | -- | 5,860 | -- | -- | -- | 3,540 | 7,320 | 5,540 | 4,000 | 5,460 |
| Susquehanna River | 25,990 | at Marietta, Pa. | D | -- | -- | -- | -- | -- | -- | -- | 6,650 | 5,060 | 8,020 |
| Susquehanna River | 27,100 | at Conowingo, Md. | D[3] | 4,650 | 4,780 | -- | -- | -- | 3,600 | 5,620 | 4,010 | 3,200 | 5,550 |

[1] Value shown in parentheses under each year are ratios of annual mean to long-term (100-year) mean streamflow at the site on the Susquehanna River at Harrisburg, Pa.
[2] Data for 1981 are from Fishel (1984).
[3] Data for 1980-81 are from L. Zynjuk (U.S. Geological Survey, written commun., 1993).

**Table 20.** *Annual loads of suspended sediment at selected stream sites in the Lower Susquehanna River Basin, water years 1980-89*

[Map ID no., use this number to locate site on figure 39; N/A, not applicable; --, no data; data from Ott and others (1991) are calendar-year loads; A, Langland and Fishel (1996); B, Langland and Fishel (1995); C, Koerkle and others (1996); D, Ott and others (1991); E, Buchanan (1983), and Buchanan and others (1984); F, Loper and others (1985)]

| Site | Drainage area ($mi^2$) | Location | Map ID no. (fig. 39) | Data source | Load, in thousands of pounds 1980 (0.94)[1] | 1981 (0.68) | 1982 (0.97) | 1983 (0.89) | 1984 (1.31) | 1985 (0.67) | 1986 (1.01) | 1987 (0.91) | 1988 (0.74) | 1989 (0.94) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Tributary sites | | | | | | | | | |
| Brush Run, Site 2 | 0.38 | near McSherrystown, Pa. | 1 | A | -- | -- | -- | -- | -- | -- | 94.8 | 121 | 92.6 | 257 |
| Bald Eagle Creek | .43 | near Fawn Grove, Pa. | 2 | B | -- | -- | -- | -- | -- | -- | 50 | 215 | 265 | 355 |
| Little Conestoga Creek, Site 3A | 1.42 | near Morgantown, Pa. | 3 | C | -- | -- | -- | -- | -- | 532 | 430 | 1,680 | 1,720 | 863 |
| Little Conestoga Creek, Site 5 | 5.82 | near Churchtown, Pa. | 4 | C | -- | -- | -- | 5,010 | -- | 7,650 | 3,140 | 10,000 | 15,300 | 15,200 |
| Paxton Creek | 11.2 | near Penbrook, Pa. | 5 | D | -- | -- | -- | -- | -- | 3,830 | 15,900 | 24,000 | 10,300 | -- |
| Stony Creek | 21.9 | at Water Tank Trail near Dauphin, Pa. | N/A | D | -- | -- | -- | -- | -- | 424 | 1,430 | -- | -- | -- |
| Conestoga River | 49.2 | near Terre Hill, Pa. | N/A | E | -- | -- | -- | 54,500 | -- | -- | -- | -- | -- | -- |
| Swatara Creek | 72.6 | above Highway Bridge 895 at Pine Grove, Pa. | N/A | E, F | -- | -- | 22,700 | 31,600 | 52,400 | -- | -- | -- | -- | -- |
| Sherman Creek | 200 | at Shermans Dale, Pa. | 6 | D | -- | -- | -- | -- | -- | 21,400 | 32,400 | 28,000 | 16,600 | 114,000 |
| Codorus Creek | 222 | near York, Pa. | 7 | D | -- | -- | -- | -- | -- | 70,600 | 34,700 | 29,900 | 42,600 | 47,300 |
| Codorus Creek | 267 | at Pleasureville, Pa. | 8 | D | -- | -- | -- | -- | -- | 58,600 | 69,800 | 92,100 | 109,000 | 101,000 |
| Conestoga River | 470 | at Conestoga, Pa. | 9 | D | -- | -- | -- | -- | -- | 145,000 | 366,000 | 399,000 | 503,000 | 467,000 |
| Swatara Creek | 483 | near Hershey, Pa. | 10 | D | -- | -- | -- | -- | -- | 61,400 | 241,000 | 273,000 | 173,000 | 337,000 |
| West Conewago Creek | 510 | near Manchester, Pa. | 11 | D | -- | -- | -- | -- | -- | 155,000 | 260,000 | 477,000 | 78,500 | 431,000 |
| Juniata River | 3,354 | at Newport, Pa. | 12 | D[2] | 465,000 | 292,000 | 342,000 | 332,000 | 841,000 | 336,000 | 351,000 | 325,000 | 288,000 | 806,000 |
| | | | | | Susquehanna River sites | | | | | | | | | |
| West Branch Susquehanna River | 6,847 | at Lewisburg, Pa. | 13 | D | -- | -- | -- | -- | -- | 545,000 | 954,000 | 444,000 | 497,000 | 1,040,000 |
| Susquehanna River | 11,220 | at Danville, Pa. | 14 | D | -- | -- | -- | -- | -- | 1,130,000 | 3,660,000 | 1,680,000 | 942,000 | 2,710,000 |
| Susquehanna River | 24,100 | at Harrisburg, Pa. | 15 | D[3] | -- | 4,600,000 | -- | -- | -- | 2,040,000 | 5,690,000 | 2,950,000 | 2,050,000 | 4,090,000 |
| Susquehanna River | 25,990 | at Marietta, Pa. | 16 | D | -- | -- | -- | -- | -- | -- | -- | 3,340,000 | 3,070,000 | 7,360,000 |
| Susquehanna River | 27,100 | at Conowingo, Md. | 17 | D[4] | 1,990,000 | 2,100,000 | -- | -- | -- | 958,000 | 2,060,000 | 1,130,000 | 856,000 | 1,980,000 |

[1] Values shown in parentheses each year are ratios of annual mean to long-term (100-year) mean streamflow at the site on the Susquehanna River at Harrisburg, Pa.

[2] Data for 1980-84 are from the USGS Water-Data reports for water years 1981-85: USGS, 1982b; Buchanan, 1983; Buchanan and others, 1984; Loper and others, 1985; Loper and others, 1986.

[3] Data for 1981 are from Fishel (1984).

[4] Data for 1980-81 are from L. Zynjuk (U.S. Geological Survey, written commun., 1993).

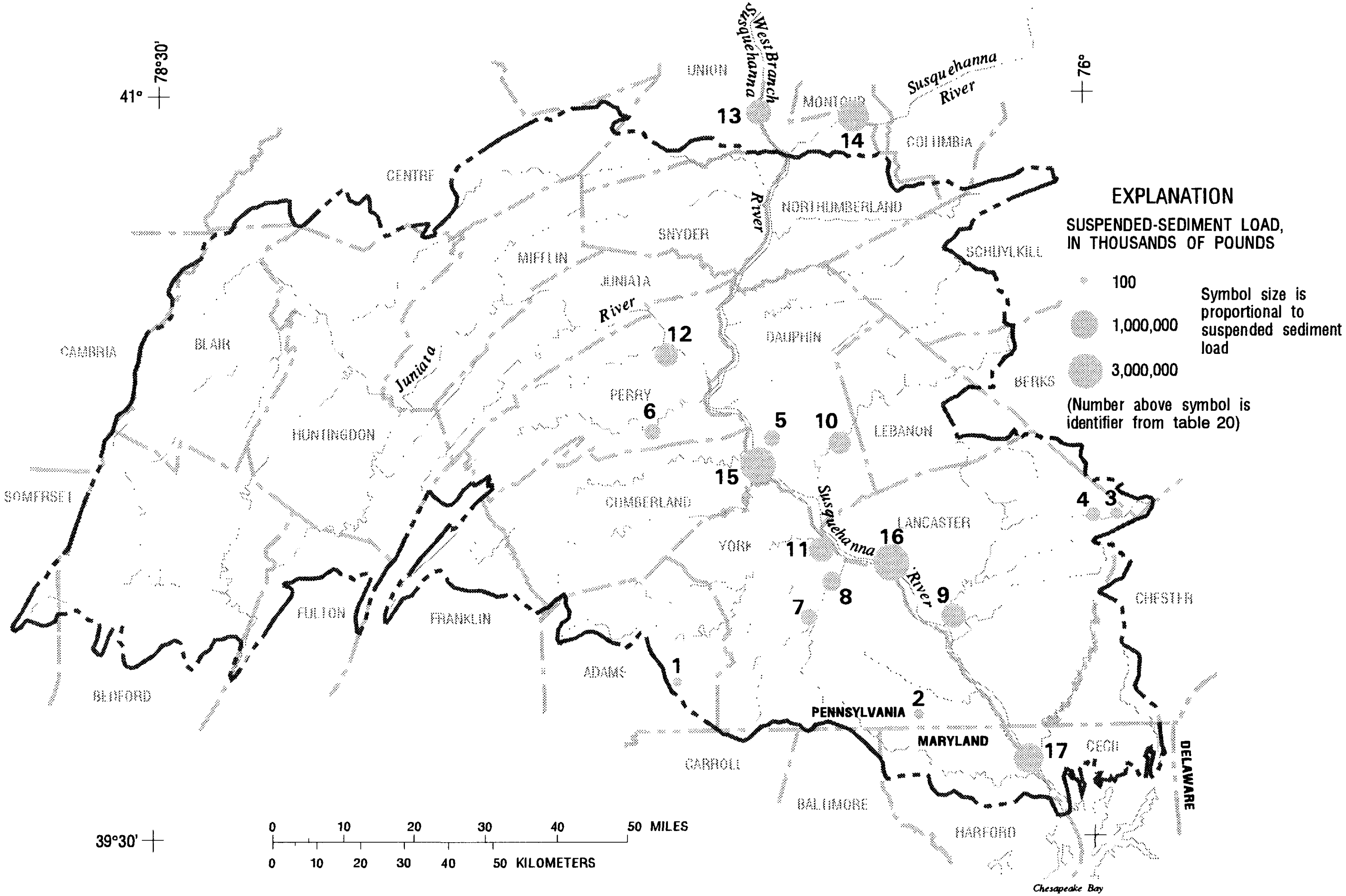



**Figure 39.** Stream sites in the Lower Susquehanna River Basin where sufficient data were available for computation of suspended-sediment load and the relative magnitude of the loads for water year 1987. (Site numbers refer to table 20.)

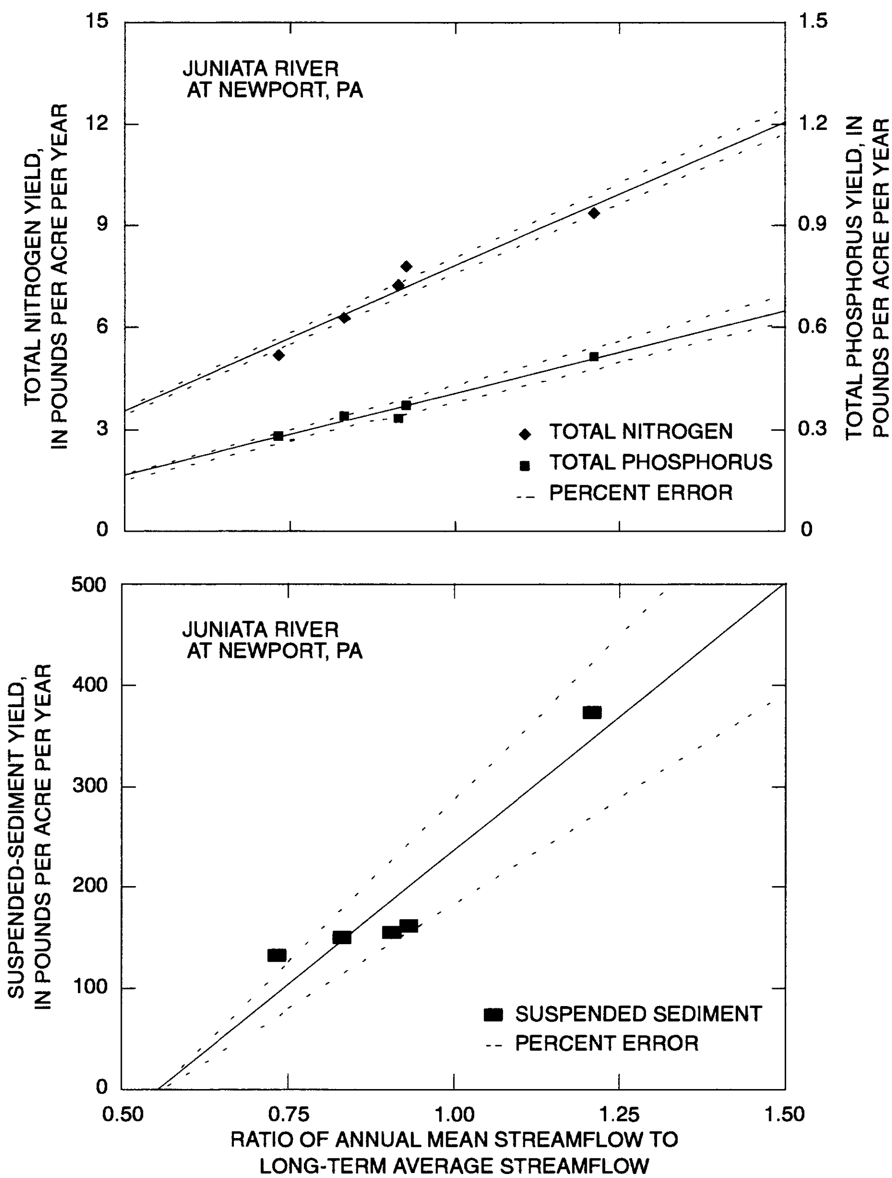



**Figure 40.** Relation of total nitrogen, total phosphorus, and suspended-sediment yield and the ratio of annual mean streamflow to long-term average streamflow at three sites in the Lower Susquehanna River Basin, water years 1980-89 (modified from Ott and others, 1991; percent error lines represent ± one standard deviation, as determined by Ott and others, 1991).

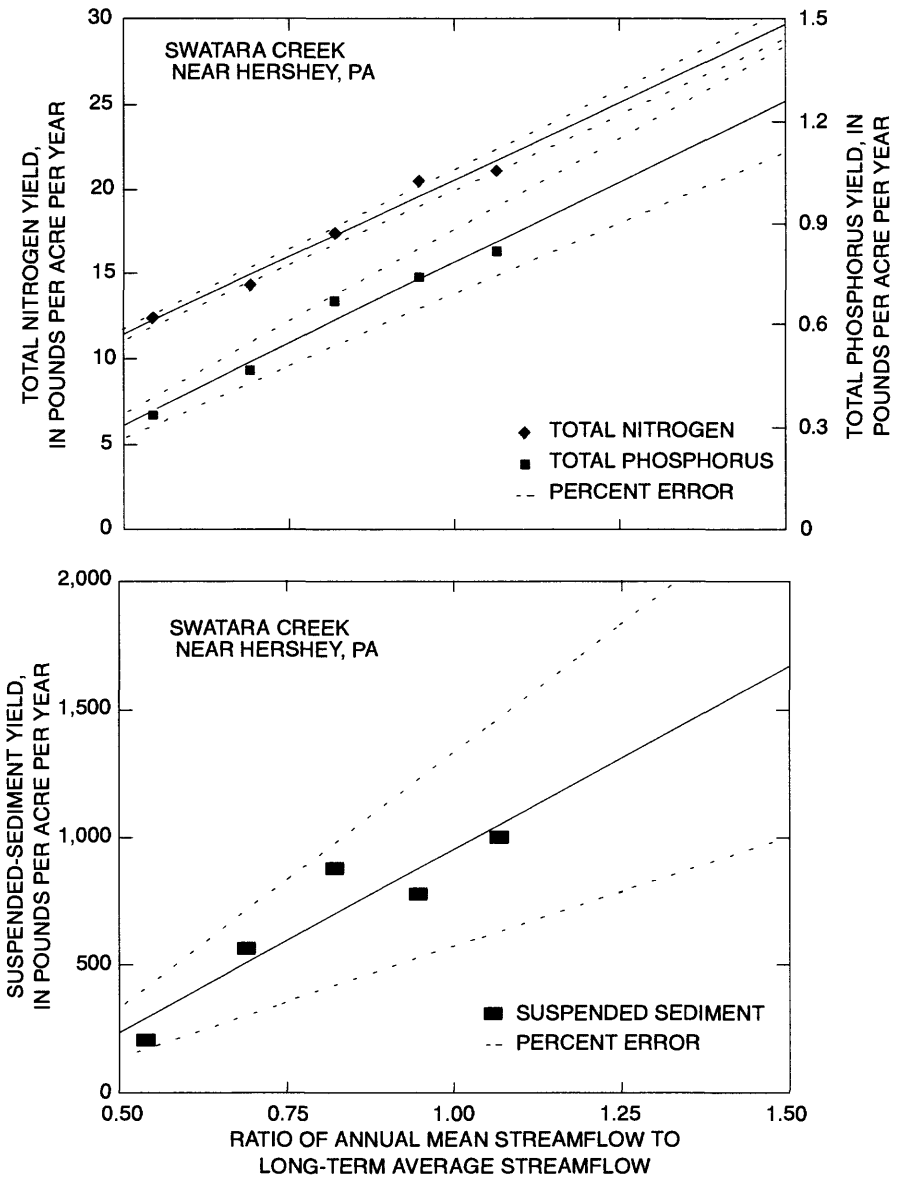



**Figure 40.** Relation of total nitrogen, total phosphorus, and suspended-sediment yield and the ratio of annual mean streamflow to long-term average streamflow at three sites in the Lower Susquehanna River Basin, water years 1980-89 (modified from Ott and others, 1991; percent error lines represent ± one standard deviation, as determined by Ott and others, 1991)—Continued.

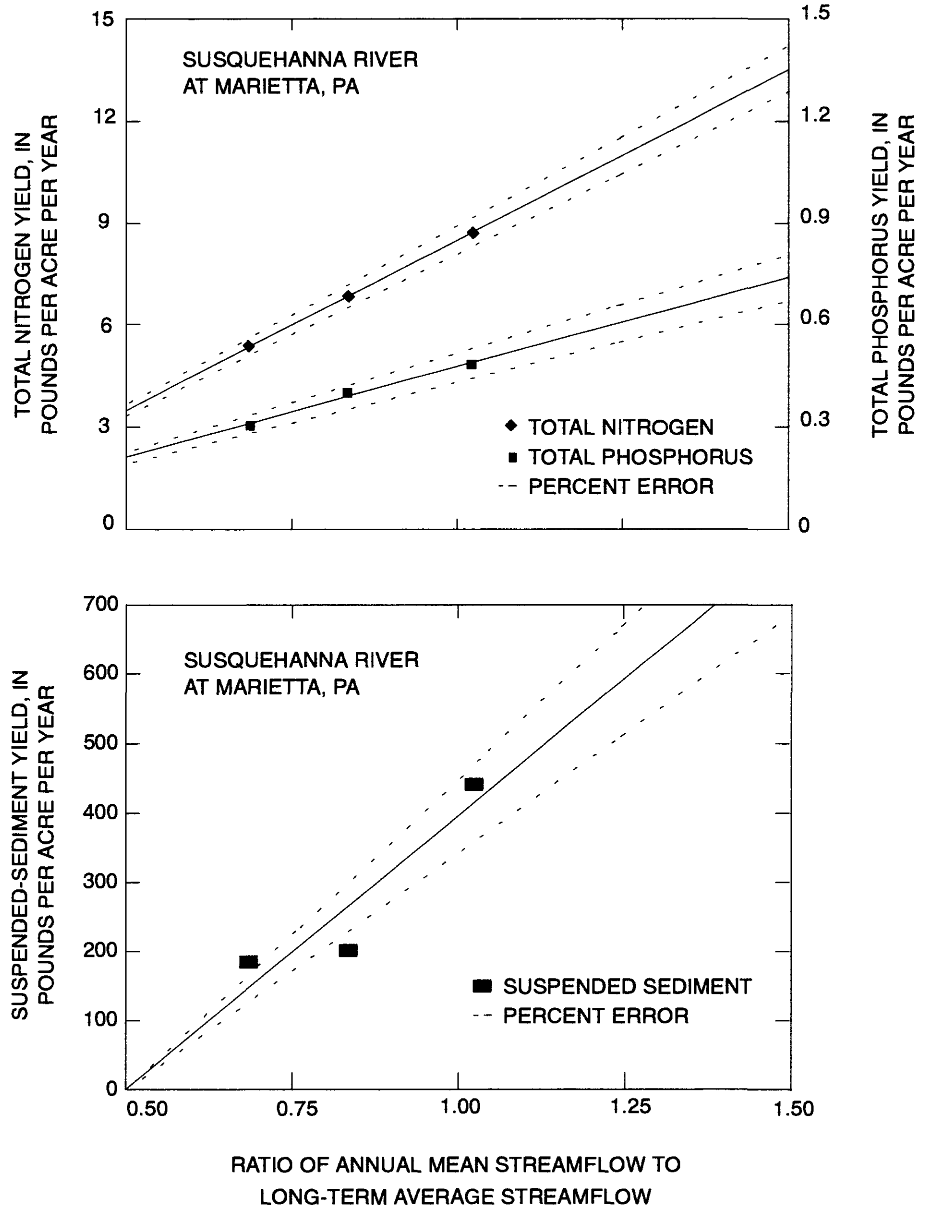



**Figure 40.** Relation of total nitrogen, total phosphorus, and suspended-sediment yield and the ratio of annual mean streamflow to long-term average streamflow at three sites in the Lower Susquehanna River Basin, water years 1980-89 (modified from Ott and others, 1991; percent error lines represent ± one standard deviation, as determined by Ott and others, 1991)—Continued.

The relations of yield and streamflow for a moderately large tributary (Swatara Creek near Hershey, Pa., drainage area = 483 $mi^2$), a large tributary (Juniata River at Newport, Pa., drainage area = 3,354 $mi^2$), and the largest main-stem site above the reservoirs (Susquehanna River at Marietta, Pa., drainage area = 25,990 $mi^2$) are shown in figure 40. In comparisons of streams, an inverse relation between drainage area and yield is typical if streamflow is the dominant cause of variability and other environmental conditions are not affecting the relation. This relation is generally supported by the data shown for Swatara Creek and the Susquehanna River at Marietta. Suspended-sediment yields of the Juniata River Basin above Newport were abnormally low because of a large reservoir on the Raystown Branch of the Juniata River. The change in annual loads of suspended sediment after the construction of the reservoir in 1972 is documented by the double-mass accumulation curve of annual suspended-sediment load and annual streamflow presented in the USGS Water-Data Report for Pennsylvania (1980, p. 190). The double-mass curve shows a marked decrease in annual sediment loads after 1972. The expected annual suspended-sediment yields of the three sites for an annual streamflow equal to the long-term streamflow (x-axis value = 1) are about 950 lb/acre for Swatara Creek, about 240 lb/acre for the Juniata River, and about 400 lb/acre for the Susquehanna River at Marietta (Ott and others, 1991, p. 141).

The major differences between the yield/streamflow relations of these three streams are the magnitude of the yields and the rate of change in yield with a change in annual streamflow. The slope (rate of change) of the line relating annual yield to annual streamflow indicates the responsiveness of the system to changes in streamflow. The slope of the line relating yield of suspended sediment to streamflow can be used to predict the change in the annual yield for a given ratio of a particular year's mean streamflow and the long-term mean. For example, in a year when the annual mean streamflow was 25 percent higher than the long-term mean (an x-axis value of 1.25), the expected annual yield of suspended sediment of Swatara Creek would be about 350 lb/acre higher (an increase from 950 to 1,300 lb/acre). For the same ratio of annual streamflow to long-term mean streamflow, the expected yield of suspended sediment of the Juniata River would be about 135 lb/acre higher (an increase from 240 to 375 lb/acre); and at Marietta, the expected yield would be about 200 lb/acre (an increase from 400 to 600 lb/acre).

In most hydrologic systems, water carried in streams is considered to consist of two fractions: a base-flow component made up of ground water that discharges into the channel and a direct-runoff component that enters the channel during rainstorms or snowmelt. Loads carried by streams can be separated in a similar manner. The base-flow components for average annual loads of nitrate and phosphorus at selected sites within the Lower Susquehanna River Basin are shown in figure 41. Data are from Fishel (1988), Ott and others (1991), Langland and Fishel (1993), and Koerkle and others (1996).

Differences in the magnitude of the loads carried by the streams can be compared by reporting the base-flow component as a percentage of the total load. Figure 41 shows (1) the relative differences between the ratios of base flow to stormflow for nitrate and phosphorus loads between sites and (2) the relative differences between nitrate and phosphorus loads. For these data, basin size and the magnitude of the nitrate and phosphorus loads carried by base flow are apparently unrelated (fig. 41).

The ranges of the average annual loads carried in base flow were 45 to 76 percent for nitrate and 20 to 33 percent for phosphorus. This difference in the base-flow components between the two constituents indicates two different transport mechanisms.

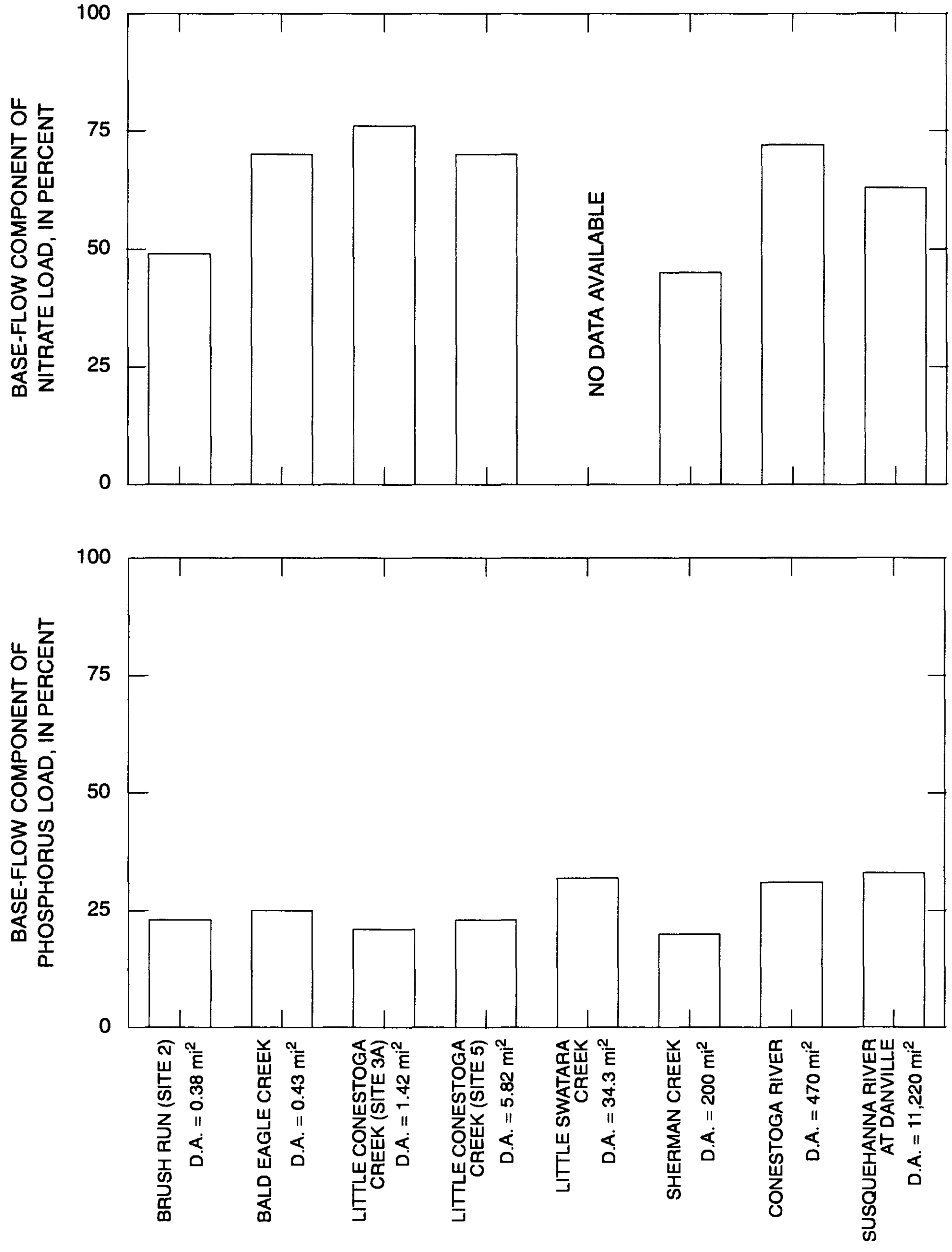



**Figure 41.** Percentage of total nitrate and phosphorus load transported by base flow in water year 1987 at selected stream sites within the Lower Susquehanna River Basin, in order of increasing drainage area (D.A., drainage area; $mi^2$, square miles).

Most of the nitrate load seems to be introduced by ground-water discharge to the stream channel. Most of the phosphorus load seems to be transported during stormflow; thus, the dominant transport mechanism for phosphorus is probably overland runoff.

### Relation of Loads and Yields of Nutrients and Suspended Sediment to Drainage Area, Physiography, Geology, and Land Use

Several subunits have been delineated in the Lower Susquehanna River Basin for use in describing the water quality in the study unit. They are described earlier in this report and in detail by Risser and Siwiec (1996). In general, the dominant land use of an area within the basin is closely related to underlying rock type. For example, areas underlain by carbonate rocks are being farmed and areas underlain by siliciclastic rocks are forested. Land use in areas underlain by crystalline rocks is mixed, but agriculture is slightly dominant.

Agricultural factors that seem to affect loads of nutrients and suspended sediment are manure production and the amount of agriculture in a basin. Although each of these factors may be equally influential, only one—the percentage of area in agriculture—will be used to relate yields of nutrients and suspended sediment to physical setting.

The relation of percentage of agriculture in the area drained by the selected stream to the yields of nitrate, phosphorus, and suspended sediment is shown in figure 42. Yields are those reported by the authors of the various reports as representative of the area or areas studied. Data are from Ott and others (1991), Langland and Fishel (1993), and Koerkle and others (1996). The data from Langland and Koerkle are from studies of the effect of best-management practices on water quality in agricultural areas. Major changes in water quality over a short period of time caused by the implementation of best-management agricultural practices (BMP's) were observed by Langland and Fishel (1993), and Koerkle and others (1996). Because the water-quality data collected before and after BMP's are so different, the data collected for the Langland and Koerkle studies during pre- and post-implementation phases were treated as separate data sets. The regression lines, developed by use of techniques described by Helsel and Hirsch (1992, p. 222-224), are provided only as an indicator of the general trend of the relations and not as the result of a rigorous statistical test.

Yields of nitrate, phosphorus, and suspended sediment seem to increase with increasing percentage of drainage area in agriculture, although the relation also may be affected by basin size. Large basins, because of their reduced channel slope, tend to trap more sediment than smaller basins. If the basins with the large percentage of agricultural land use are also the small basins (which is common), basin size and percentage of agricultural land may interact in such a way to obscure the relation.

A comparison of the slope of the least-squares regression lines and a line with a slope of zero in figure 42 indicates that, based on strict magnitude of yield change, yields of suspended sediment are most influenced by changes in the amount of agricultural land use. On the basis of percentage increases, however, phosphorus loads are influenced more than loads of nitrate and suspended sediment by changes in the amount of agricultural land use and (or) basin size. The estimate of change in the annual phosphorus yield for a 10-percent change of agricultural land from 30 to 40 percent is about 32 percent (210 lb/acre). A 10-percent increase in agricultural land from 30 to 40 percent produces nearly a 12-percent estimated change in suspended-sediment yield (65,000 lb/acre). Nitrate yields are the least affected by a change in agricultural area; a 10-percent increase in agricultural land from 30 to 40 percent produces only a 5-percent estimated change in nitrate yield (500 lb/acre).

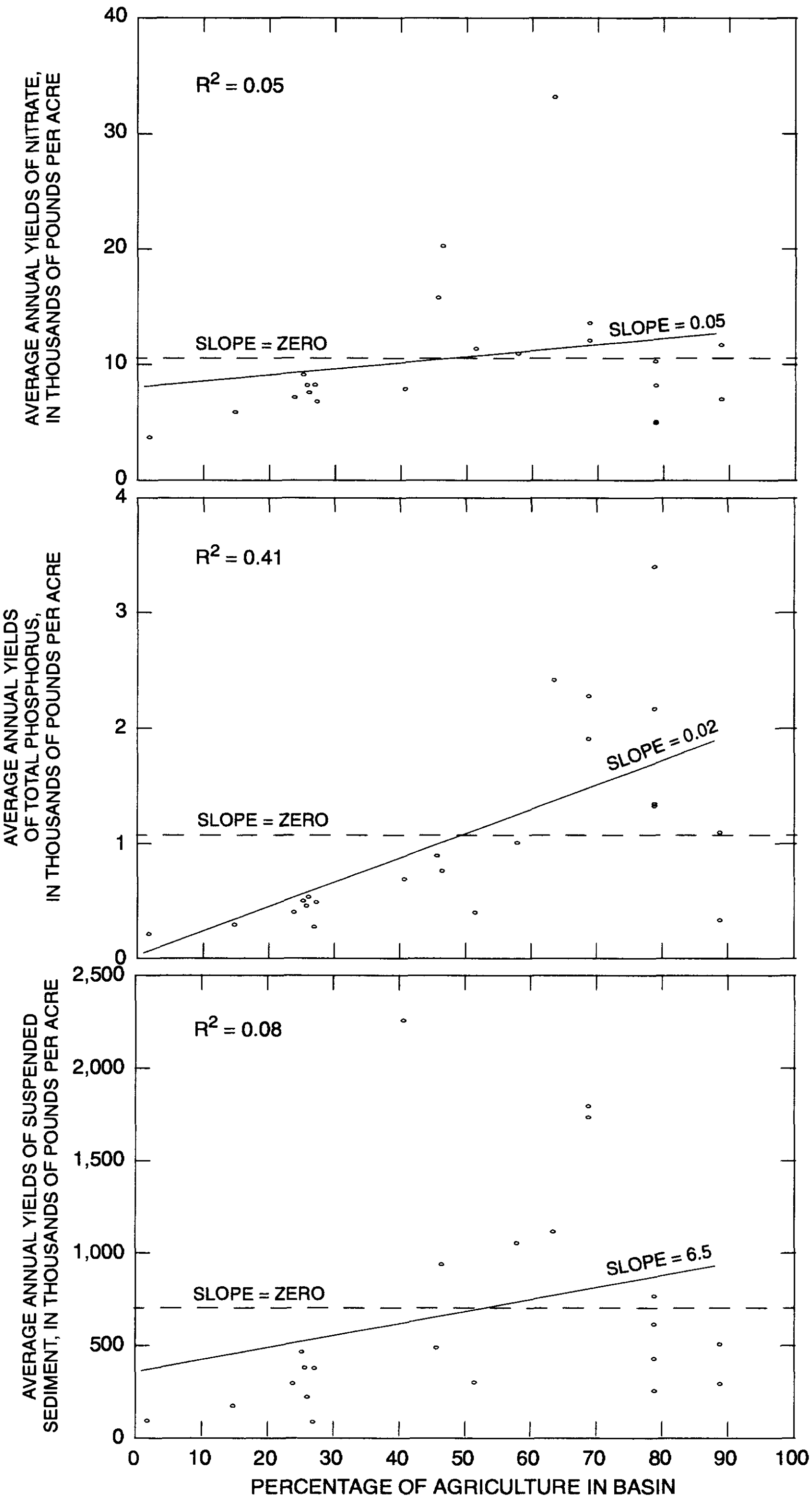



**Figure 42.** Relation of percentage of agriculture in the area drained by the selected streams in the Lower Susquehanna River Basin to the average annual yields of nitrate, phosphorus, and suspended sediment during water years 1980-89.

Differences in base-flow/stormflow ratios for loads of nutrients also may be related to the physical setting of the area drained by a stream. Underlying rock type and land use seem to affect the base-flow/stormflow ratio of nitrate loads. Base-flow loads of nitrate and phosphorus from seven streams are shown in figure 43 in order by increasing percentage of drainage area in agriculture. Drainage basins of three of the four sites where 70 percent or greater of the total load of nitrate is carried by low flows are carbonate-bedrock-dominated systems with extensive agriculture land use. The basin of the fourth site (Bald Eagle Creek) is underlain by crystalline rock but has extensive agriculture land use. The areas drained by the three remaining sites are underlain by noncarbonate or mixed rock types and have mixed land use. In the Lower Susquehanna River Basin, base flow is a larger component of the total flow in carbonate systems than in noncarbonate systems (Risser and Siwiec, 1996). Ground-water discharge to stream channels seems to be the dominant mechanism of transport for nitrate in agricultural areas underlain by carbonate rock. Grouping the streams by percentage of area in agriculture does not appear to define any relation between this factor and loads of phosphorus (fig. 43).

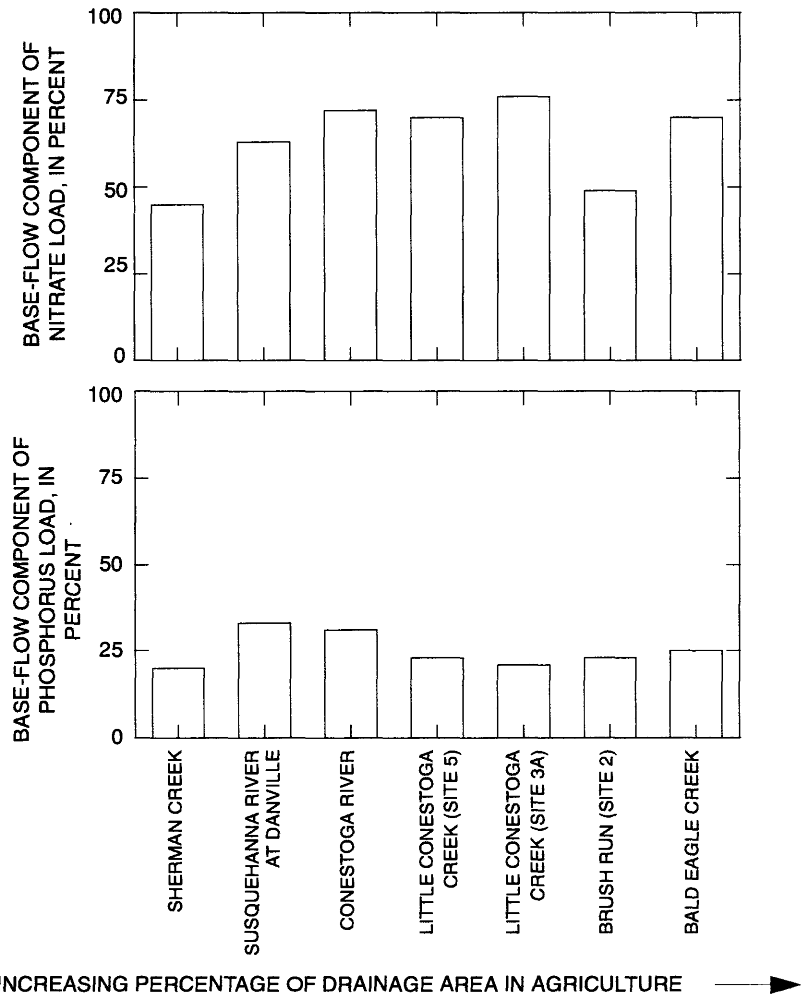



**Figure 43.** Percentage of total nitrate and phosphorus load transported by base flow in water year 1987 at selected stream sites in the Lower Susquehanna River Basin, in order by increasing percentage of drainage area in agriculture.

## Seasonal Varability in Loads of Nutrients and Suspended Sediment

Four representative streams ranging in drainage area from 0.4 to 24,100 $mi^2$ have been selected to show monthly and seasonal load patterns, as well as similarities or differences that may be related to basin size (fig. 44). A precipitation site is included in the figure to show monthly and seasonal variations that may influence the load patterns. Water years 1986 and 1987 were selected because they represent a common period of data collection among the sites.

Seasonal patterns in nitrate and total phosphorus loads for the four streams—Bald Eagle Creek, Sherman Creek, Juniata River, and Susquehanna River at Harrisburg—seem to have been similar regardless of basin size (fig. 44). An annual cycle of the largest loads in February and March and the smallest loads in August or September is evident. In relation to the growing season (generally April to September), the peak loads were immediately before the growing season and the smallest loads were in the middle of the growing season. The seasonal patterns of loads of nutrients in streams closely resemble common seasonal patterns for streamflow.

Precipitation provides a large part of the nutrient load to forested areas. The annual-cycle pattern for precipitation data is similar to that for the nutrients (fig. 44), except that they seem to be offset from the stream cycles by 3 to 6 months. The peak monthly load of nitrogen in wet deposition in rural areas during the 2-year period was in May, at the beginning of the growing season, and the lowest loads were in February, immediately before the beginning of the growing season, when the largest loads were transported by streams. An explanation for the temporal offset between loads in streams and precipitation is beyond the scope of this report.

## Long-Term Trends in Loads of Nutrients and Suspended Sediment

Long-term, statistically based trends in loads of nutrients and suspended sediment, basinwide, were not determined because of insufficient data. Most data sets failed to meet the requirement of a minimum of 8 years of nearly continuous data. At only two sites were data sets of sufficient length to test for changes over time—analyses for nitrate in precipitation at the Leading Ridge site, and analyses for suspended sediment in samples from the Juniata River at Newport.

For nitrate in precipitation, Lynch (1990) analyzed the data collected at the Leading Ridge precipitation site during 1982-88. An upward trend in precipitation-weighted estimates of monthly nitrate concentration was identified; however, the trend was not statistically significant.

The addition of a large reservoir to the upper Juniata River system in 1972 greatly affected the hydrology and water quality of the Juniata River at Newport. Since the installation of the reservoir, streamflow records are affected by storage in the reservoir and long-term water-quality monitoring by the USGS has been discontinued at the Newport site.

Tendencies for change over time, indicated with LOWESS curves, for loads of suspended sediment in the Juniata River and streamflow for 1975-89 are shown in figure 45. Although the figure does not represent a rigorous statistical test of the data, a comparison of the lines of tendency for streamflow and loads of suspended sediment are indicative of the change in the loads during the period and the influence that changes in streamflow over time may have on the change in loads over the same time period. The scatter of the data points in the figure indicate that loads and streamflow vary

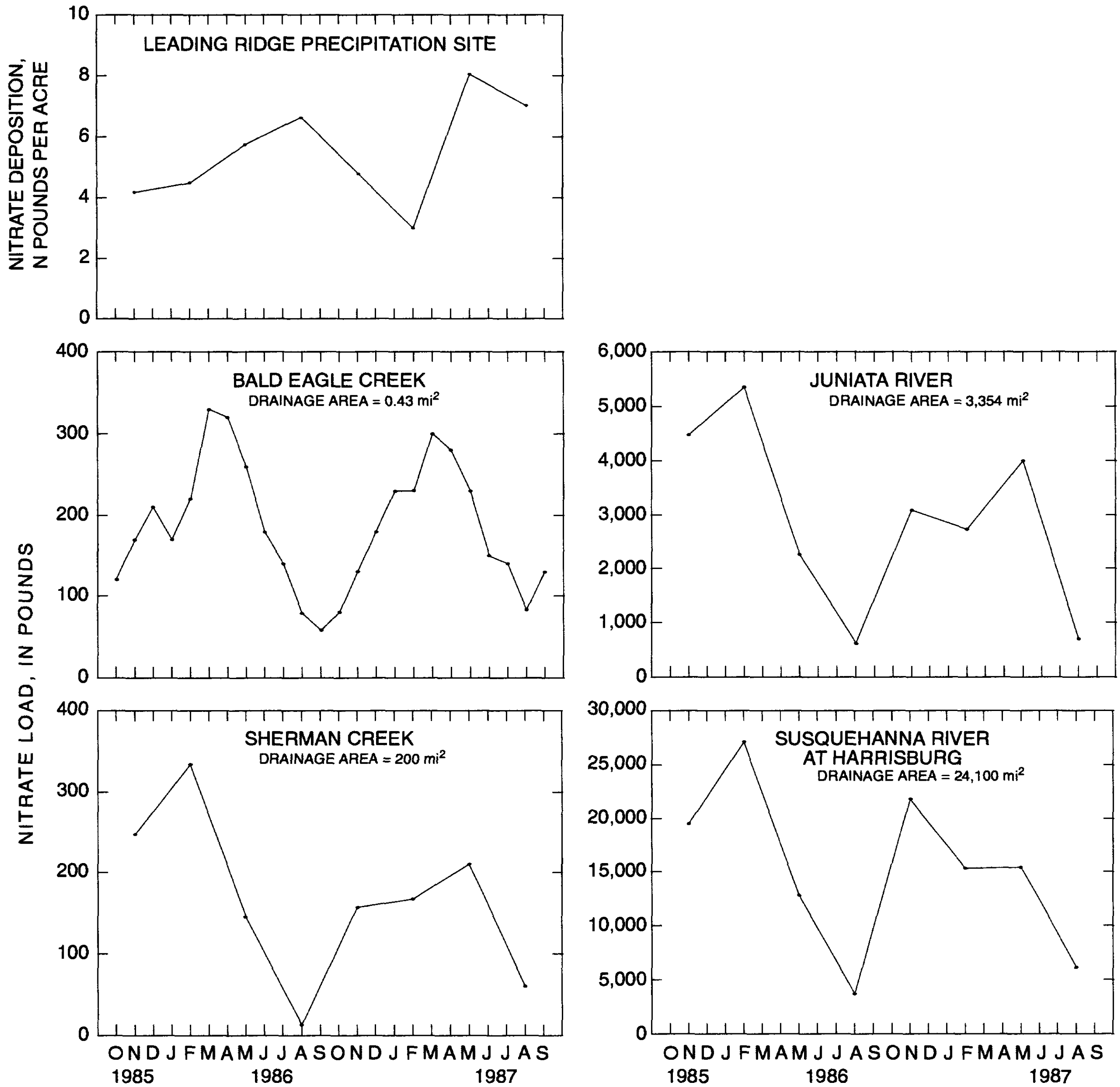



**Figure 44.** Monthly or seasonal patterns of loads of nitrate in precipitation and loads of nitrate and phosphorus in selected streams in the Lower Susquehanna River Basin, water years 1986-87 (mi$^2$, square miles).

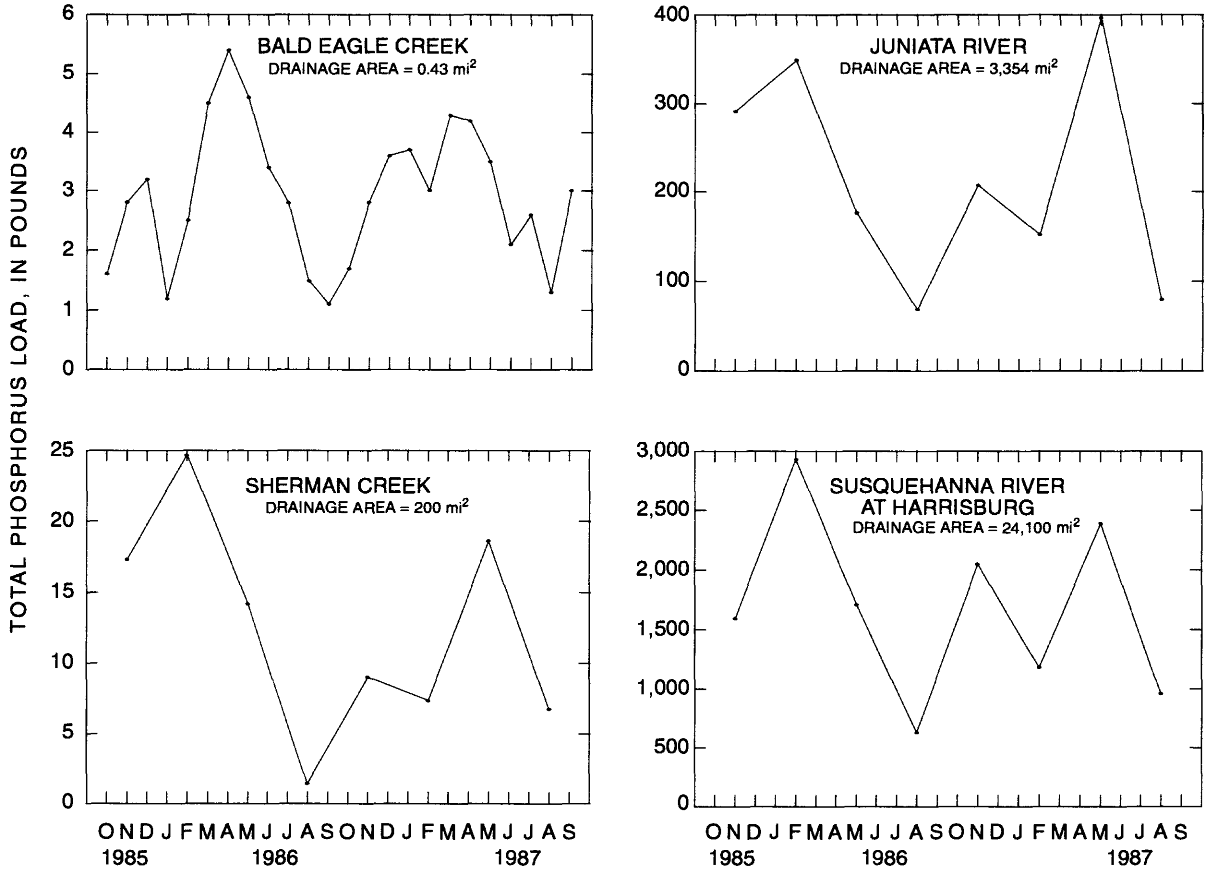



**Figure 44.** Monthly or seasonal patterns of loads of nitrate in precipitation and loads of nitrate and phosphorus in selected streams in the Lower Susquehanna River Basin, water years 1986-87—Continued.

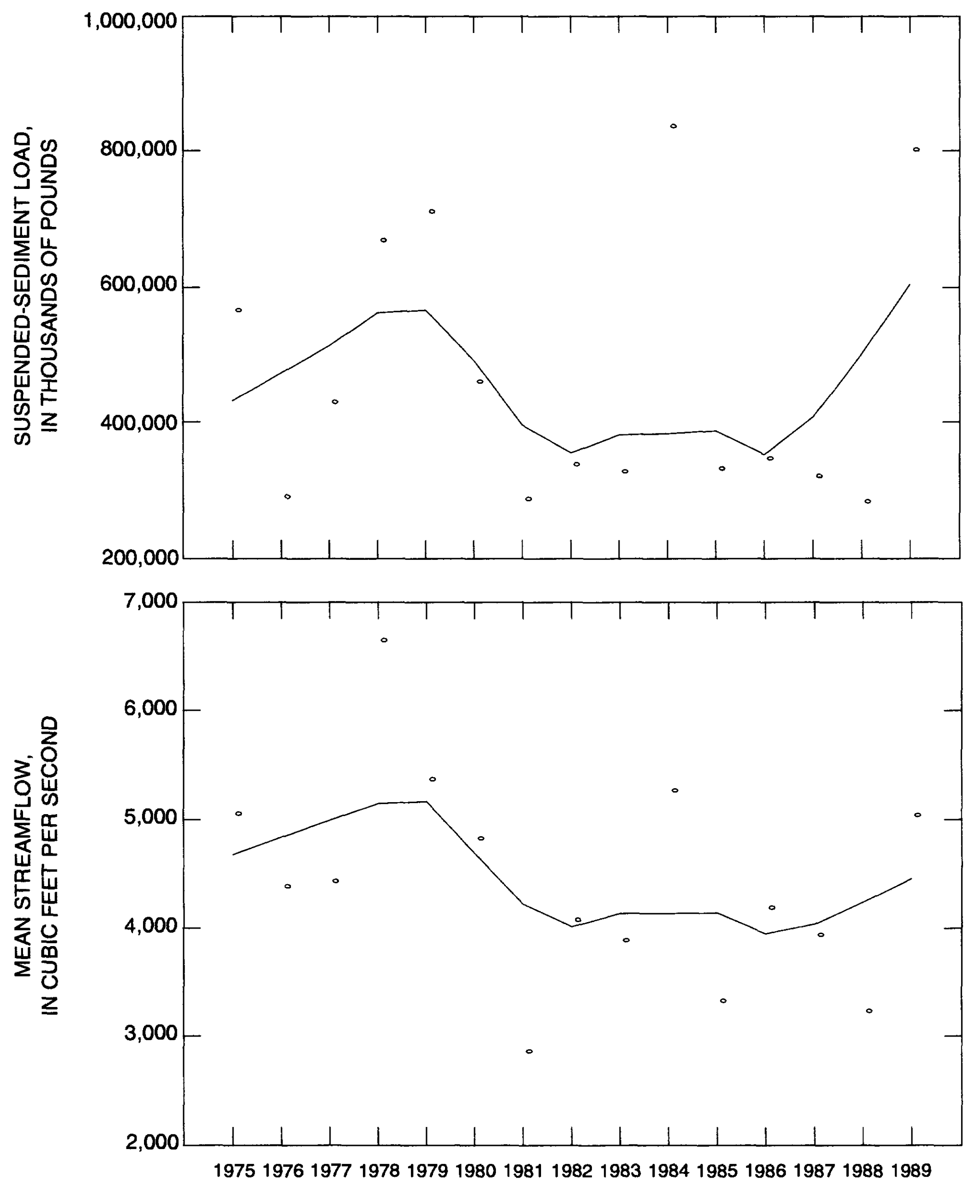



**Figure 45.** Tendencies for change in annual streamflow and suspended-sediment loads of the Juniata River at Newport, Pa., water years 1975-89.

considerably from year to year. The LOWESS curves do not indicate any well-defined tendency, but they do indicate a direct relation between streamflow and the discharge of suspended sediment.

Additionally, loads of water-quality constituents collected before 1975 can be used to evaluate trends. The loads determined by Williams and Reed (1972) and by Ott and others (1991) for six sites used in both studies are summarized in table 21. Williams and Reed summarized available suspended-sediment data from the late 1940's through 1967 and determined loads and yields from streams and areas within the Susquehanna River Basin. Most of the data were collected during 1962-67. Ott and others determined loads from data collected during 1985-89. The table lists the differences between the estimates, in percent, and thus indicates possible trends. Margins of error are not stated in either report, so confidence intervals around the estimates are not available to determine the statistical significance of the differences. The extreme difference between the estimates for Sherman Creek is partially explained by an excessive amount of rainfall received near this site in 1989, during the study by Ott and others (1991). A total of 54.5 in. of rain, 12.5 in. above the normal annual total, was recorded. The average annual streamflow of Sherman Creek was 30 percent above normal in 1989.

**Table 21.** *Historical and current average annual loads of suspended sediment at selected stream sites in the Lower Susquehanna River Basin*

| Stream | Estimated average annual load of suspended sediment, in thousands of pounds per year | | Percent difference in estimates |
|---|---|---|---|
| | From Williams and Reed (1972)[1] | From Ott and others (1991)[2] | |
| Susquehanna River at Danville, Pa. | 3,000,000 | 2,818,000 | –6 |
| West Branch Susquehanna River at Lewisburg, Pa. | 1,000,000 | 828,000 | –17 |
| Juniata River at Newport, Pa. | 528,000 | 509,000 | –4 |
| Sherman Creek at Shermans Dale, Pa. | 34,000 | 61,400 | +80 |
| Susquehanna River at Harrisburg, Pa. | 5,200,000 | 4,800,000 | –8 |
| West Conewago Creek at Manchester, Pa. | 220,000 | 348,000 | +58 |

[1] Data collected during water years 1962-67.
[2] Data collected during water years 1985-89.

## Loads of Nutrients from Atmospheric Deposition

Loads of nutrients from atmospheric deposition are a significant source to the Lower Susquehanna River Basin. Precipitation-weighted nitrate and ammonium concentration data at three sites were available for analysis. Both species of nitrogen were used in the atmospheric deposition computations in an attempt to estimate the load of total nitrogen. Phosphorus data were not available. Annual nitrate loads for the three sites are listed in table 18. Lynch (1990, p. 56) states that "very little variation (in nitrate concentrations) occurs across Pennsylvania." For this reason, average annual ammonium and nitrate concentrations for the Lower Susquehanna River Basin, based on isolines developed by Lynch, were used to compute an average annual load of nitrogen from wet deposition in rural areas.

Areal variations in nitrogen load from rural wet deposition were determined by use of precipitation data from three sites in the basin or near the divide: Leading Ridge, Gettysburg National Park, and Little Buffalo State Park. Because of the tendency of major storms to enter the basin from the west and southwest, and the relatively equal spacing of the sites from north to south, the precipitation measured at the sites was used to estimate precipitation amounts in the upper, middle, and lower sections of the study unit. Mean annual precipitation at these three sites for 1985-90 was used to compute the average annual nitrogen load for the study unit.

Average annual load of nitrate from dry deposition and wet deposition in urban areas and areas of high elevation (greater than 2,000 ft) were estimated by use of methods described by Sisterson (1990). Methods for estimating the dry deposition of ammonium were not available. With Sisterson's methods, ratios of wet to dry deposition from previous studies were used to estimate dry nitrate deposition. In addition, estimates were made for wet and dry deposition in urban areas and for droplet deposition in areas at elevations above 2,000 ft. Extent of urban areas in the study unit was estimated from digital geographic data layers of land use from 1975 (U.S. Geological Survey, 1986). Extent of areas above 2,000 ft was estimated from 1:100,000 topographic maps.

Estimates of wet ammonium and nitrate deposition and dry nitrate deposition in the Lower Susquehanna River Basin are listed in table 22. The estimate of wet ammonium deposition for 1985-90 is 11.5 million pounds. The estimate of nitrate deposition (wet and dry combined) is 87.2 million pounds, and the estimate of annual load of total nitrogen is 98.8 million pounds. In perspective, this amount is nearly equivalent to the estimated annual load of total nitrogen that passes by Harrisburg in the Susquehanna River (Ott and others, 1991, p. 139).

### Point-Source Loads of Nutrients to Streams

The Chesapeake Bay Program (U.S. Environmental Protection Agency, 1988) has identified and collected information on nearly 6,000 point-source dischargers in the Chesapeake Bay drainage. In the Lower Susquehanna River Basin, 252 point-source discharges have been identified. Of these, 49 municipal and 23 industrial discharges have been designated as major discharges. Selected information on locations of major point-source discharges within major subbasins and on general flow characteristics is given in table 17. Risser and Siwiec (1996) provide additional information on locations and flow characteristics.

The major discharges and associated chemical data were used to compute point-source loads of nutrients to streams. These "end-of-pipe" point-source loads do not reflect any changes in the quality of the discharges that may occur in the receiving waters because of natural physical or chemical processes.

Flow data and concentrations of total nitrogen and total phosphorus for each of the discharges were from PaDEP or USEPA Permit Compliance System (PCS) databases. The PaDEP database was considered to be the more reliable of the two and was used as a primary source. Mean effluent discharge and constituent concentrations for 1990 were used. Data from this year are the considered the best available and the most applicable to the 1980-89 study period. Flow data were available for all 72 major discharges. If no concentration data were available, concentrations were estimated on the basis of the Standard Industrial Codes, as suggested by Lugbill (1990).

The major point-source discharges of nitrogen and phosphorus are summarized by subbasin within the Lower Susquehanna River Basin in table 23. The loads given for each tributary subbasin include only those discharged upstream from the stream-monitoring site. Other point sources may discharge between the monitoring site and the mouth of the stream and contribute to the load in the Susquehanna River. The loads from point sources downstream from the tributary-monitoring sites are included in the Susquehanna

**Table 22.** *Estimates of annual ammonium, nitrate, and total nitrogen atmospheric deposition in the Lower Susquehanna River Basin, based on data from water years 1985-90*

[$mi^2$, square miles; $NH_4$ - N, ammonium as nitrogen; $NO_3$ - N, nitrate as nitrogen; Basin, Lower Susquehanna River Basin; --, no data; mg/L, milligrams per liter]

| Physiographic province or region of physiographic province | Area ($mi^2$) | Mean annual precipitation (inches)[1] | Rural wet $NH_4$ – N (thousand pounds/$mi^2$)[2] | Rural wet $NH_4$ – N (thousand pounds)[2] | Rural wet $NO_3$ – N (thousand pounds/$mi^2$)[3] | Rural wet $NO_3$ – N (thousand pounds)[3] | Rural dry $NO_3$ – N (thousand pounds/$mi^2$)[4] | Rural dry $NO_3$ – N (thousand pounds)[4] | Droplet $NO_3$ – N (thousand pounds)[5] | Urban wet $NO_3$ – N (thousand pounds)[6] | Urban dry $NO_3$ – N (thousand pounds)[7] | Total N deposition (thousand pounds)[8] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Upper Ridge and Valley | 2,590 | 41.6 | 1.33 | 3,440 | 2.90 | 7,510 | 2.46 | 6,370 | 23,200 | 180 | 430 | 41,130 |
| Lower Ridge and Valley | 3,290 | 35.7 | 1.14 | 3,750 | 2.49 | 8,190 | 2.12 | 6,970 | 13,200 | 270 | 650 | 33,030 |
| Piedmont | 3,450 | 39.4 | 1.27 | 4,350 | 2.75 | 9,490 | 2.34 | 8,070 | 9.0 | 790 | 1,920 | 24,630 |
| Basin mean | -- | 38.9 | 1.24 | -- | 2.71 | -- | 2.31 | -- | -- | -- | -- | -- |
| Basin total | 9,330 | -- | -- | 11,540 | -- | 25,190 | -- | 21,410 | 36,400 | 1,240 | 3,000 | 98,790 |

[1] Mean annual precipitation is based on 1985-90 average.

[2] Rural wet $NH_4$ – N deposition is based on an average concentration of 0.22 mg/L, per National Atmospheric Deposition Program (1984) and Lynch (1990).

[3] Rural wet $NO_3$ – N deposition is based on an average concentration of 0.48 mg/L, per National Atmospheric Deposition Program (1984) and Lynch (1990).

[4] Rural dry $NO_3$ – N deposition is based on 0.85 dry/wet ratio for Pennsylvania developed by Sisterson (1990).

[5] Droplet $NO_3$ – N deposition is based on 3.0 droplet/(wet + dry) national ratio for area above 2,000 feet (610 meters) developed by Sisterson (1990). Area in Basin with elevation greater than 2,000 feet estimated from 1:100,000-scale USGS topographic maps.

[6] Urban wet $NO_3$ – N deposition is based on 1.75 urban wet /rural wet ratio developed by Sisterson (1990) for urban areas. Urban area in Basin determined from 1975 GIRAS data categories of residential, industrial and commercial complexes, and other urban/built-up land.

[7] Urban dry $NO_3$ – N deposition is based on 5.0 urban dry /rural dry ratio developed by Sisterson (1990) for urban areas. Urban area in Basin determined from 1975 GIRAS data categories of residential, industrial and commercial complexes, and other urban/built-up land.

[8] Total N deposition = (rural wet $NH_4$ × area) + (rural wet $NO_3$ × area) + (rural dry $NO_3$ × area) + droplet $NO_3$ + urban wet $NO_3$ + urban dry $NO_3$.

**Table 23.** *Estimates of loads of nitrogen and phosphorus from major municipal and industrial discharges in the Lower Susquehanna River Basin, water year 1990*

| Subbasin | Nitrogen load, in thousands of pounds | | Phosphorus load, in thousands of pounds | | Total nitrogen load, in thousands of pounds | Total phosphorus load, in thousands of pounds |
|---|---|---|---|---|---|---|
| | Municipal | Industrial | Municipal | Industrial | | |
| Juniata River above Newport | 1,060 | 70 | 116 | 14 | 1,130 | 130 |
| Sherman Creek above Shermans Dale | 0 | 0 | 0 | 0 | 0 | 0 |
| Swatara Creek above Hershey | 340 | 3 | 18 | 0 | 343 | 18 |
| West Conewago Creek above Manchester | 250 | 0 | 28 | 0 | 250 | 28 |
| Codorus Creek above Pleasureville | 1,390 | 60 | 40 | 7 | 1,450 | 47 |
| Susquehanna River above reservoirs | 6,550 | 4,190 | 447 | 3,450 | 10,740 | 3,900 |
| Conestoga River above Conestoga | 1,340 | 30 | 88 | 4 | 1,370 | 92 |
| Susquehanna River below reservoirs (basin outflow) | 8,430 | 4,220 | 562 | 3,450 | 12,650 | 4,010 |

River subbasin loads. Loads indicated for the Susquehanna River include all discharges that enter the river system upstream from that site.

### Nonpoint-Source Loads of Nutrients to Streams

Ancillary data were used to provide estimates of the 1990 nutrient loads to streams from nonpoint sources. The major nonpoint sources identified in the Lower Susquehanna River Basin with data available to this study are commercial-fertilizer applications, animal-manure production, and private septic-system discharges. Loads for each of the nonpoint sources were initially developed from county-level data and then re-distributed spatially to conform to subbasin boundaries.

Loads of commercial fertilizer were estimated from data provided by the USEPA (1990). Data on animal-manure production were provided by R.B. Alexander (U.S. Geological Survey, Reston, Va., written commun., 1992). Manure-production data for the sites on the West Branch Susquehanna River and the Susquehanna River above the study unit, which combine to provide the inflow to the Lower Susquehanna River Basin, are from Ott and others (1991, p. 24). Loads from private septic systems were determined from 1980 Bureau of Census data (U.S. Dept. of Commerce, Pa. State Data Center, written commun., 1991), estimates of residential sewage flow (Commonwealth of Pennsylvania, 1987), and estimates of nutrient concentration in sewage outflow (Pa. Dept. of Environmental Resources, Bureau of Water Quality Management, written commun., 1992). The accuracy of these data is limited by the assumptions made in computing the loading estimates. The assumption of uniformity within a geographic unit probably accounts for most of the error in the estimates.

The estimates of 1990 nutrient loads from atmospheric deposition and the nonpoint-source nutrient load estimates for 1990 for commercial fertilizer, animal manure, and private septic systems are given in table 24. Basin inflow was computed by combining the estimated contributions of the West Branch Susquehanna and Susquehanna River Basins above their confluence. Because of a scarcity of data, the total of nonpoint sources for the basin inflow includes only animal-manure production and is only a partial estimate. Basin outflow loads represent the outflow from the Susquehanna River Basin.

### Mass Balance of Nutrient Loads

The mass balance of nutrient loads within the Lower Susquehanna River Basin was estimated by combining the estimated stream loads, atmospheric-deposition loads, and point- and nonpoint-source loads discussed previously. The atmospheric-deposition load for the entire basin was divided into subbasin components by areal weighting.

The cumulative total of annual source input and average annual stream loads of nitrogen and phosphorus in the Lower Susquehanna River Basin are plotted in figure 46. The magnitudes of the nitrogen and phosphorus loads are noticeably different. Throughout the river system, nitrogen-source input loads were about five times the phosphorus-source input loads. Estimates of phosphorus loads from atmospheric deposition were not available; their exclusion from this summary probably accounts for some of the difference between nitrogen-source and phosphorus-source input loads. The average annual loads of nitrogen in tributaries and in the main stem upstream from the reservoirs were about 15 to 20 times the phosphorus loads. Evidently, more nitrogen reaches the streams than phosphorus.

**Table 24.** *Estimates of the nonpoint-source loads of nutrients in the Lower Susquehanna River Basin, water year 1990*

[N, nitrogen; P, phosphorus; --, no data]

| Subbasin | Atmospheric-deposition load, in thousands of pounds | | Commercial-fertilizer application load, in thousands of pounds | | Animal-manure load, in thousands of pounds | | Septic-system load, in thousands of pounds | | Total nonpoint-sources load, in thousands of pounds | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | N | P | N | P | N | P | N | P |
| Susquehanna River (basin inflow) | -- | -- | -- | -- | 86,800 | 18,100 | -- | -- | [1] 86,800 | [1] 18,100 |
| Juniata River above Newport | 46,400 | -- | 11,100 | 3,500 | 23,400 | 5,190 | 906 | 340 | 81,800 | 9,030 |
| Sherman Creek above Shermans Dale | 2,010 | -- | 815 | 256 | 1,480 | 386 | 60 | 23 | 4,360 | 665 |
| Swatara Creek above Hershey | 3,940 | -- | 3,480 | 1,090 | 9,480 | 2,800 | 317 | 119 | 17,200 | 4,010 |
| West Conewago Creek above Manchester | 3,650 | -- | 3,840 | 1,200 | 6,190 | 1,980 | 344 | 129 | 14,000 | 3,310 |
| Codorus Creek above Pleasureville | 1,910 | -- | 1,960 | 614 | 2,860 | 924 | 238 | 89 | 6,970 | 1,630 |
| Susquehanna River above Reservoirs | 86,100 | -- | 37,000 | 11,600 | 161,600 | 38,200 | 3,160 | 1,190 | 288,000 | 51,000 |
| Conestoga River above Conestoga | 3,360 | -- | 6,660 | 2,090 | 29,100 | 9,290 | 317 | 142 | 39,400 | 11,500 |
| Susquehanna River below Reservoirs (basin outflow) | 98,800 | -- | 52,400 | 16,400 | 222,000 | 57,500 | 4,180 | 1,570 | 377,000 | 75,500 |

[1] The total of nonpoint sources for basin inflow is only a partial estimate, as loads from three of the four known sources are not available.

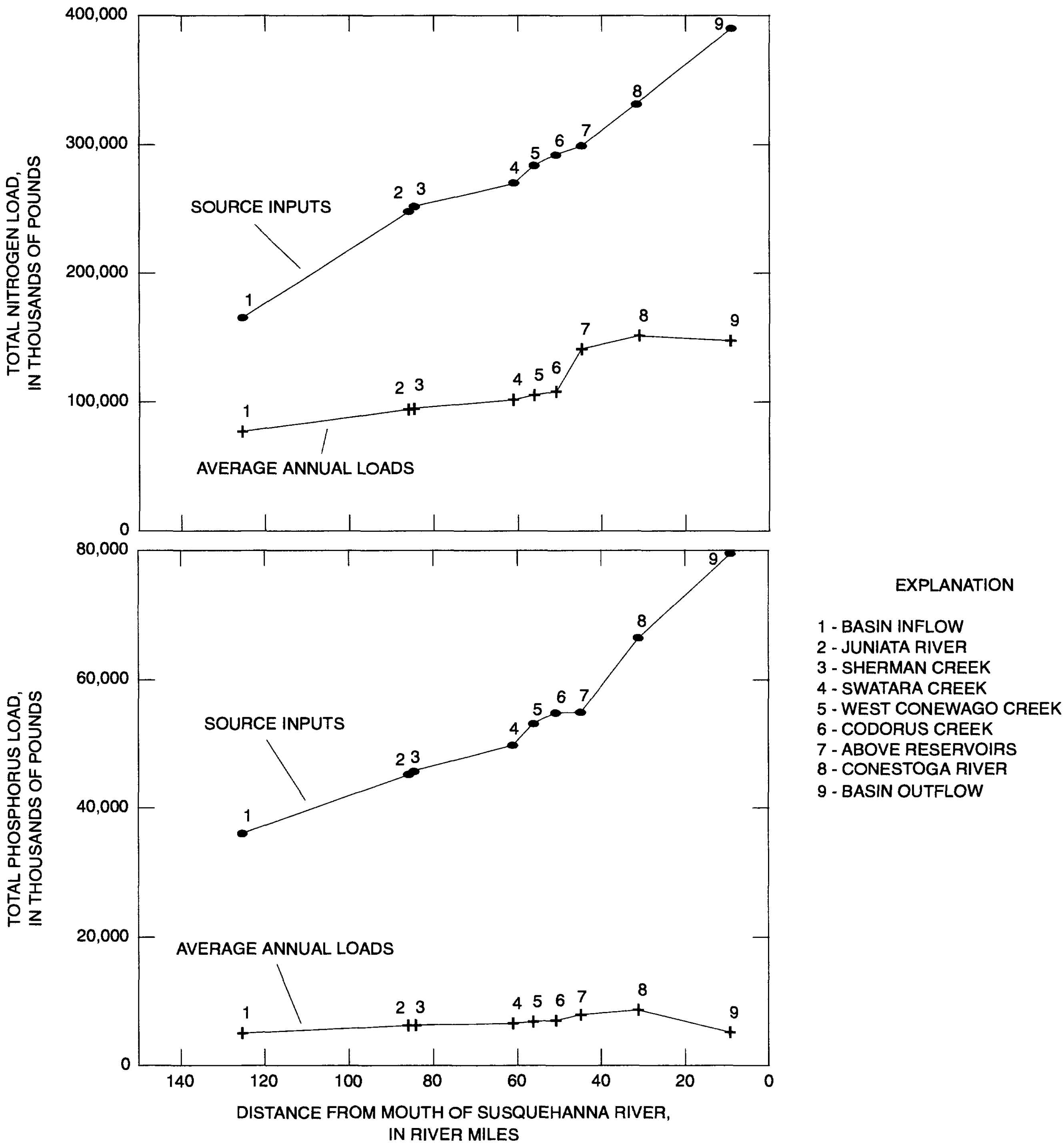



**Figure 46.** Cumulative estimates of annual nutrient source inputs and average loads of total nitrogen and phosphorus discharged by selected tributaries to the Lower Susquehanna River. (Average annual loads are from Ott and others, 1991.)

The difference between the lines indicating the inputs and the measured instream loads is probably the result of the loss of the nutrients to "sinks" within the basin. Harvested crops, removal of sludge from sewage-treatment plants, soil storage, and atmospheric releases are examples of nutrient sinks. Inaccuracy of the input estimates also may be a factor in the difference between the loads.

Source inputs for nitrogen and phosphorus gradually increase throughout the river system. A marked increase in inputs per river mile is evident downstream from river mile 45 (near Marietta, Pa.) for both constituents. Average annual stream loads continue to accumulate in the main stem, and the sums of the tributary loads balance fairly well with measured loads in the main stem upstream from the reservoirs. A decrease in loads, slight for nitrogen and substantial for phosphorus, is noted at the Susquehanna River site downstream from the reservoirs.

The specific loads for each of the source input components for total nitrogen and total phosphorus and, for comparison, the average annual loads determined by Ott and others (1991), are listed in table 25. Because of the lack of available data at the basin inflow site, the total source input was estimated. The estimated source input for the inflow to the basin is based on the assumption that the ratio of instream to source-input loads in the main stem for nitrogen and phosphorus would be relatively constant. The instream to source-input load ratios of nitrogen and phosphorus at the Susquehanna River site upstream from the reservoirs were applied to the instream loads measured at the inflow site to determine the total estimated source-input loads for the inflow.

Percentage of the source inputs of nitrogen measured in the streams ranged from 20 percent for a large tributary to 47 percent at the Susquehanna River site upstream from the reservoirs. Average tributary recovery was about 28 percent. For phosphorus, the ratios of measured stream load to source-input load were much lower than those for nitrogen. The percentages ranged from 6 percent at two medium-sized tributaries to 14 percent at the Susquehanna River site upstream from the reservoirs. The percentage at the site on the Juniata River, a large tributary, was similar to that at the Susquehanna River site upstream from the reservoirs—13 percent at the tributary and 14 percent above the reservoirs. Average percentage of source input measured in the tributaries was 9 percent. Percentages of source inputs of nitrogen and phosphorus measured in the streams of the Lower Susquehanna River Basin are close to those determined in a national study by Puckett (1995). For the northeastern United States, he found that the median of loads measured in streams accounted for 24 percent of the annual nitrogen loading and 7 percent of the annual phosphorus loading to watersheds.

The dominant source input of nitrogen in the Lower Susquehanna River Basin is from either atmospheric deposition or a nonpoint-source input load, generally animal manure (fig. 47). Atmospheric deposition is the largest contributor of nitrogen to the streams draining the upper half of the basin. These subbasins have a high percentage of forest cover. The dominant source of nitrogen in the streams in the lower part of the study unit (where agriculture is the dominant land use) was animal manure. Combined, the percentage of the total source input loads in each subbasin from atmospheric deposition and animal manure ranged from 57 to 84 percent. The contribution from point sources ranged from near 0 to about 17 percent.

Atmospheric deposition data for phosphorus were not available for this study. Of the available source input data for phosphorus, animal manure was dominant in all cases. The ratio of manure input to total source input ranged from 55 to 80 percent. The next largest contributor of phosphorus was commercial fertilizer. The ratio of manure to fertilizer ranged from 4.4:1 to 1.5:1. For phosphorus, the point-source load ranged from near 0 to about 7 percent of the total source load.

**Table 25.** *Estimated nutrient source inputs and measured outflow of total nitrogen and phosphorus in streamflow by major subbasins in the Lower Susquehanna River Basin*

[E, estimate; <, less than; --, no data]

| Subbasin | Inputs, in thousands of pounds per year | | | | | | | Outflow, in thousands of pounds per year | |
|---|---|---|---|---|---|---|---|---|---|
| | Point sources | | Nonpoint sources | | | | Total of sources | Average annual load[1] | Percent of source measured in stream |
| | Municipal discharge to stream | Industrial discharge to stream | Atmospheric deposition | Commercial fertilizer | Animal manure | Septic systems | | | |
| | | | | Loads of total nitrogen | | | | | |
| Susquehanna River (Basin inflow) | -- | -- | -- | -- | 86,800 | -- | [2]165,000 E | 77,300 | [2]47 E |
| Juniata River above Newport | 1,060 | 70 | 46,400 | 11,100 | 23,400 | 906 | 82,900 | 16,800 | 20 |
| Sherman Creek above Shermans Dale | <1 | <1 | 2,010 | 815 | 1,480 | 60 | 4,370 | 1,200 | 27 |
| Swatara Creek above Hershey | 340 | 3 | 3,940 | 3,480 | 9,480 | 317 | 17,500 | 6,340 | 36 |
| W. Conewago Creek above Manchester | 250 | <1 | 3,650 | 3,840 | 6,190 | 344 | 14,200 | 3,650 | 26 |
| Codorus Creek above Pleasureville | 1,390 | 60 | 1,910 | 1,960 | 2,860 | 238 | 8,400 | 2,730 | 32 |
| Susquehanna River above Reservoirs | 6,550 | 4,190 | 86,100 | 37,000 | 161,600 | 3,160 | 299,000 | 141,000 | 47 |
| Conestoga River above Conestoga | 1,340 | 30 | 3,360 | 6,660 | 29,100 | 317 | 40,800 | 10,100 | 25 |
| Susquehanna River below Reservoirs (Basin outflow) | 8,430 | 4,220 | 98,800 | 52,400 | 222,000 | 4,180 | 390,000 | 147,000 | 38 |
| | | | | Loads of total phosphorus | | | | | |
| Susquehanna River (Basin Inflow) | -- | -- | -- | -- | 18,100 | -- | [2]36,000 E | 5,040 | [2]14 E |
| Juniata River above Newport | 116 | 14 | -- | 3,500 | 5,190 | 340 | 9,160 | 1,190 | 13 |
| Sherman Creek above Shermans Dale | <1 | <1 | -- | 256 | 386 | 23 | 665 | 66 | 10 |
| Swatara Creek above Hershey | 18 | <1 | -- | 1,090 | 2,800 | 119 | 4,030 | 242 | 6 |
| W. Conewago Creek above Manchester | 28 | <1 | -- | 1,200 | 1,980 | 129 | 3,340 | 335 | 10 |
| Codorus Creek above Pleasureville | 40 | 7 | -- | 614 | 924 | 89 | 1,670 | 157 | 9 |
| Susquehanna River above Reservoirs | 447 | 3,450 | -- | 11,600 | 38,200 | 1,190 | 54,900 | 7,920 | 14 |
| Conestoga River above Conestoga | 88 | 4 | -- | 2,090 | 9,290 | 142 | 11,600 | 734 | 6 |
| Susquehanna River below Reservoirs (Basin outflow) | 562 | 3,450 | -- | 16,400 | 57,500 | 1,570 | 79,500 | 5,130 | 6 |

[1] Load as determined by Ott and others (1991).

[2] Estimate determined by applying percentage of source measured in Susquehanna River upstream from reservoirs to the average annual inflow load.

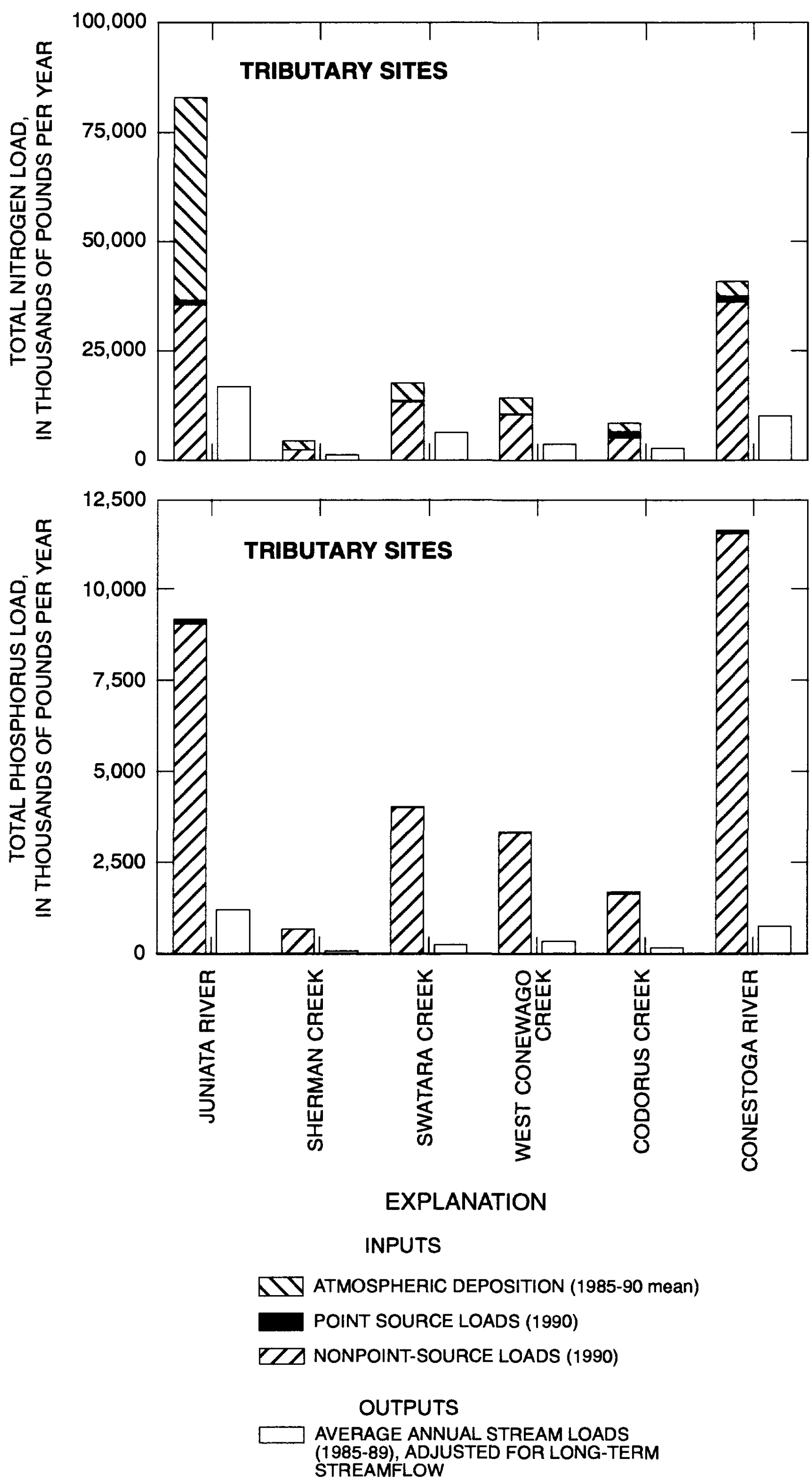



**Figure 47.** Source input loads, by component, and average annual loads of total nitrogen and phosphorus in selected subbasins in the Lower Susquehanna River Basin.

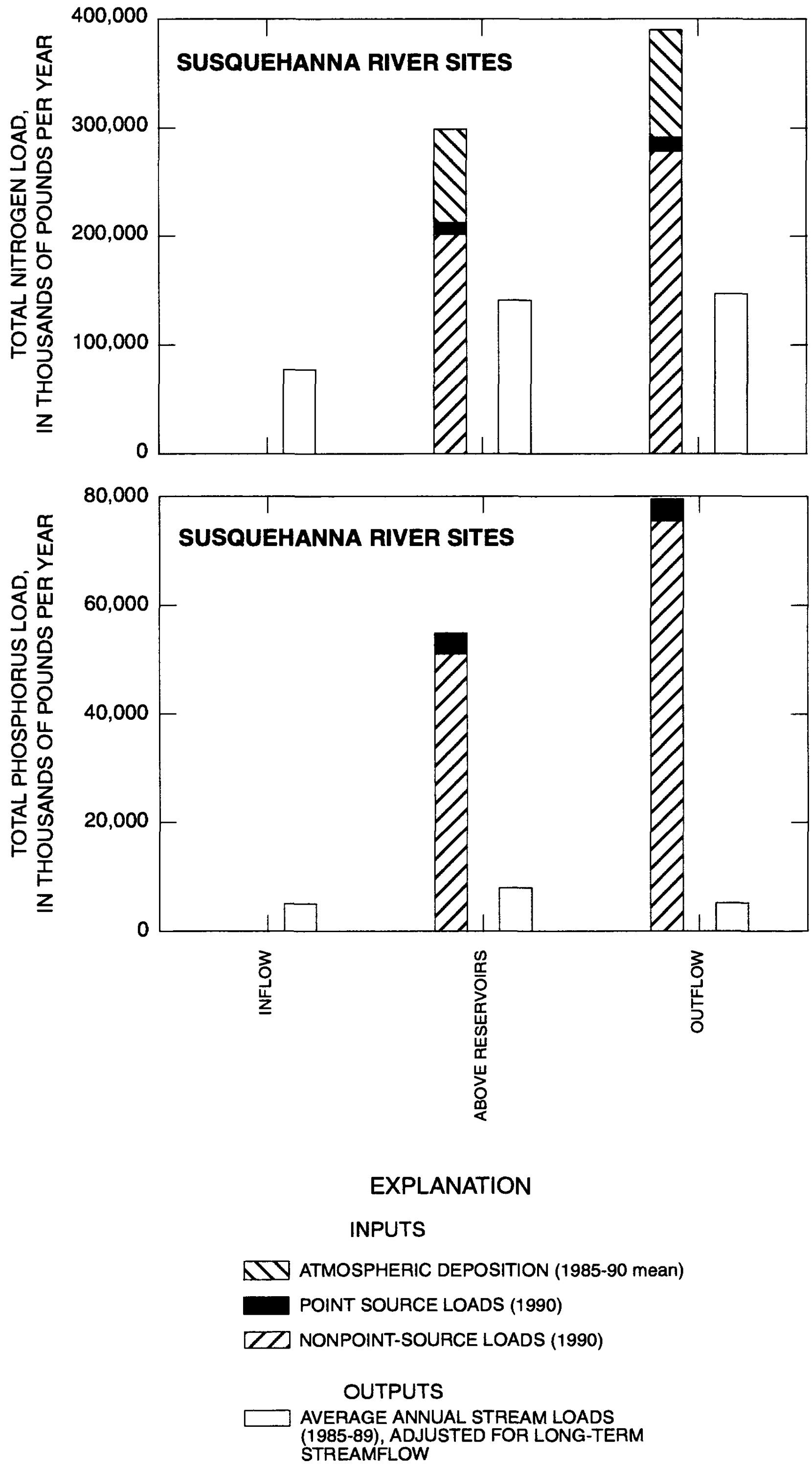



**Figure 47.** Source input loads, by component, and average annual loads of total nitrogen and phosphorus in selected subbasins in the Lower Susquehanna River Basin—Continued.

# LIMITATIONS OF AVAILABLE NUTRIENT AND SUSPENDED-SEDIMENT DATA

During the analysis of concentrations and loads of nutrients and suspended sediment for this report, several deficiencies of the data limited interpretations and characterization of water quality in the Lower Susquehanna River Basin. This section attempts to categorize and summarize those limitations.

## Limitations Due to Sources of Data

Three electronic databases contained water-quality data that were pertinent and available to this study. Each had limitations related to the description of the type of data collected, the methods used, and the objectives of the specific studies for which the data were collected. These attributes were necessary for determining comparability of the water-quality data.

Most of the data were referenced to the program under which the data were collected, but extensive research into written reports was required to determine field and laboratory methods of analysis and the specific objectives of the data-collection programs. Even though extensive analyses were available, the data in the STORET database were not used. These data and the methods used to collect them were unfamiliar to the authors, and the research required to assimilate these data into the study would have been time consuming.

Because of the adequacy of the NWIS water-quality data to meet the objectives of this report and the extent and volume of data available for analysis, this database was selected as the primary source of nutrient and suspended-sediment data. Data from the remaining two databases were used sparingly to complete essential interpretations that could not be made by use of water-quality data exclusively from the USGS NWIS database.

## Limitations Due to Characteristics of Data

The nutrient analyses available for streams were about 10 times more numerous than those for water wells, springs, atmospheric deposition, or bottom material. Nutrient data from springs and bottom material were the least abundant. This disparity in numbers limited the comparisons of water quality of the different sampling sources and limited the interpretations of the data sets with the fewest data.

For wells, data from synoptic studies were most abundant. Although these synoptic-data provided a reasonable areal coverage, generally only one nutrient analysis was available for each well. This limited the confidence of the estimates for this data set. Synoptic areal surveys of wells also covered a large range of depths. Twenty-five percent of the sampled wells were less than 100 ft deep, and about 50 percent were 100 to 250 ft deep. In contrast, wells for which multiple analyses were available were generally shallow; 75 percent of these wells were 100 ft deep or shallower. In addition, few data were available to determine the open interval of the wells. This limited interpretations relating to well depth and nutrient concentrations in well water. An assumption was made on the basis of reported elevations for bottom of casing and the drilled depth of the well; but in carbonate systems where fractures are present, this assumption may be invalid.

The filtering of water from stream samples was not a common practice for the data collected during 1980-89. Determinations of total concentrations (dissolved and suspended phases combined) were prevalent. The amount of data available for interpretation was reduced significantly when only the dissolved phase was considered.

The spatial distribution of nutrient samples from streams collected under the same hydrologic conditions was relatively sparse. The spatial distribution of suspended-sediment data was limited, generally, to the mouths of major tributaries and small streams in the lower part of the study unit. Data for only a few of the hydrogeologic subunits delineated in the study unit were adequate for interpretation. Characterization of streamwater quality was limited to only a few of the subunits, and comparisons of water quality between subunits also were limited.

The number of samples collected from year to year was distributed unevenly. Most of the sampling for nutrients in ground water was completed during 1980-82 as a result of areal surveys. A few wells in a small area were sampled frequently in the late 1980's to determine their water quality during changing environmental conditions. Most streamwater samples analyzed for nutrients were collected during 1986-89 for programs with mass-balance and basin-yield objectives. Areal surveys to determine quality of surface waters were completed in the mid-1980's, but only about 30 samples per year were collected for this purpose. Most samples from springs were collected in the mid- to late 1980's from research sites. Few data are available from areal surveys on springs during 1980-89. Precipitation-quality data were relatively continuous throughout most of the study period; however, no phosphorus data were available. Bottom-material samples were available for only one season. The unavailability of fairly continuous nutrient data throughout 1980-89 compromised the authors' ability to analyze trends in streamwater quality. The analysis of water-quality trends for wells and springs, where continuous nutrient data were rarely collected, was not possible.

Water-quality data collected at a monthly frequency were generally available at long-term monitoring and project and research sites, but data collected for synoptic surveys were generally limited to the late spring and late summer or early fall. This limited the ability to define temporal relations and trends in the study unit. Interpretations of this type were limited to major tributaries, the main stem, and some project and research wells and stream sites in small areas of study. No data were available for basinwide temporal trend tests.

With regard to hydrologic factors, interpretations of nutrient data for streams were limited by the range of streamflows sampled. Sites where data were collected to determine loads were generally sampled over a wide range of streamflows. Sites that were operated to determine temporal trends generally lacked sufficient high-flow data to determine more than individual storm loads. The lack of concentration data for high streamflows inhibited interpretations of water quality, except for base-flow periods. Thus, analysis was limited to the effects of ground-water infiltration and minor hydrologic events on streamwater quality. Interpretations about the effects of direct runoff and ground-water/surface-water relations were compromised by the lack of data collected during stormflows.

Several ancillary data sets were used to determine estimates of concentrations and loads for point and nonpoint sources and to relate water quality to environmental factors. Most of the ancillary data sets were based on countywide population or land-use data. Some of the data sets were available as digital data layers. The estimates were generally developed by applying a general assumption or distributing statewide estimates to the county level. Interpretations of water quality and its relation to the ancillary data were compromised by having to redistribute county-level estimates to the stream-basin level. In addition, the data were collected in various years during 1975-90. Some of the data used by this study to define conditions in 1990 were known to be several years old and not completely accurate but were the best available. Characterization of water quality in relation to environmental factors was compromised by the lack of accurate and timely ancillary data.

In summary, the following interpretations could not be made or were limited by the unavailability of data or the characteristics of the available data.

1. General comparisons of nutrient data from streams, ground water, springs, and bottom material.
2. Characterization of water quality based on dissolved nutrients.
3. Characterization of concentrations of nutrients during high flows, except at sites on major tributaries and on the main stem.
4. Characterization of the relation between well depth and concentrations of nutrients.
5. Characterization of areal and temporal variations in concentrations of nutrients in samples collected from springs and from stream and lake bottoms.
6. Characterization of areal variability in concentrations and loads of nutrients and suspended sediment in streams in the western and northern parts of the Lower Susquehanna River Basin.
7. Characterization of concentrations of nutrients and suspended sediment from small basins only slightly affected by agricultural practices.
8. Characterization of concentrations and loads of nutrients and suspended sediment with respect to physiographic province, lithology, and land use.
9. Determination of seasonal patterns of concentrations of nutrients at sites other than precipitation and long-term stream-monitoring sites and concentrations of suspended sediment at sites other than long-term stream-monitoring sites.
10. Determination of seasonal patterns of loads of nutrients and suspended sediment at stream sites in the western half of the study unit.
11. Determination of trends in concentrations of nutrients at all types of sites and in loads of nutrients in streams.
12. Analysis of the effects of direct runoff and ground-water infiltration on concentrations and loads of nutrients in streams.
13. Determination of atmospheric deposition of phosphorus.
14. Determination of a mass balance for loads of nutrients.

# SUMMARY

Nutrient and suspended-sediment data collected from 1975 through 1990 in the Lower Susquehanna River Basin was reviewed. This report describes the spatial and temporal characteristics of available nutrient and suspended-sediment data, as well as spatial and temporal patterns of concentrations and loads. Total and dissolved forms of nitrogen and phosphorus from precipitation, ground water, surface water, and springs, and bottom material from streams and reservoirs are discussed. The USGS National Water Information System was the primary database used. Supplemental information was taken from USEPA Storage and Retrieval.

Atmospheric deposition is the source of 25 to 40 percent of the annual nitrogen load to the Chesapeake Bay. It is the dominant source of nitrogen for the mostly forested basins draining the upper half of the study unit. The estimate of total annual nitrogen load to the study unit from precipitation is 98.8 million pounds. Peak loads generally occur during late spring. Variability in loads from precipitation depends more on precipitation amount than on concentration. At the Leading Ridge precipitation-monitoring site, the median monthly nitrate concentration is generally highest (0.6 mg/L) in May and lowest (0.25 mg/L) in November. A positive trend in precipitation-weighted estimates of monthly nitrate concentration was detected at the site, but it was not statistically significant. No data on phosphorus in precipitation were available.

Concentrations of nutrients in samples from wells varied with season and with well depth. Median nutrient concentrations in wells and springs generally were highest during the winter and lowest during the spring. Median concentrations of both nitrate and orthophosphate in deep wells were higher than those in shallow wells; median concentrations of nitrate were 2.5 and 3.5 mg/L for wells drawing water at depths of 0 to 100 ft and 101 to 200 ft, respectively. The median concentration of nitrate in springs also was relatively low—3.3 mg/L. For dissolved orthophosphate, the median concentration for all wells was 0.01 mg/L. The maximum concentration of dissolved orthophosphate of the samples collected from wells drawing water at depths of 0 to 100 ft was 0.04 mg/L and for wells drawing water at depths of 101 to 200 ft was 0.11 mg/L.

Differences in concentrations of nutrients in water from wells can be related to hydrogeologic setting. The lowest median concentrations for nitrate in water from wells were generally found in siliciclastic-bedrock forested settings of the Ridge and Valley Province and the highest were found in carbonate-bedrock agricultural settings of the Piedmont Physiographic Province. Although median nitrate concentrations of all the data sets in all of the subunits were less than the Pennsylvania drinking-water standard of 10 mg/L, 25 percent of the measurements from wells in the Piedmont Physiographic Province in carbonate-rock setting exceeded the Pennsylvania drinking-water standard.

Concentrations of nutrients and suspended sediment in streams vary temporally and spatially. Median nitrate concentrations in streams were highest during the winter and concentrations of nitrate and phosphorus generally were lowest during the spring. Phosphorus concentrations were highest during late spring and early summer. A general north-to-south pattern of increasing median nitrate concentrations, from 2 to 5 mg/L, was detected in samples collected in study unit streams. In the main stem, concentrations of suspended sediment decrease with distance downstream. Median concentrations of phosphorus and suspended sediment downstream from the main-stem reservoirs were lower than the upstream main-stem sites.

Nitrate concentrations in streams tended to increase slightly from 1980 through 1985 and then decrease slightly from 1985 through 1989. A pattern of increasing animal-manure production seems to coincide with a pattern of increasing nitrogen concentrations in some of the large streams.

In streams that drain areas dominated by agriculture, concentrations of nutrients and suspended sediment tend to be elevated with respect to those found in areas of other land-use types. Concentrations of nutrients in streams and the amount of commercial fertilizer and animal manure applied to the area drained by the streams seem to be related. Median nutrient and suspended-sediment concentrations within each land-use setting in the Lower Susquehanna River Basin generally are higher than nationwide medians.

On the average, the Susquehanna River discharges 141,000 lb of nitrogen and 7,920 lb of phosphorus to the Lower Susquehanna River reservoir system each year. About 98 percent of the nitrogen and 60 percent of the phosphorus passes through the reservoir system and is discharged to Chesapeake Bay. Phosphorus concentrations in bottom material of streams and reservoirs reflect the capture of phosphorus in the reservoir system. The median dry-weight concentrations of total available phosphorus are 500 and 855 mg/kg for streams and the reservoir system in the study unit, respectively. The areal variability of nitrate, phosphorus, and suspended-sediment loads within the study unit are more related to hydrologic conditions and basin size than to location.

The percentage of the average annual nitrate load carried in base flow ranged from 45 to 76 percent. Two types of nitrogen sources affect nitrate transport: (1) a source of nitrate that is available for direct runoff and is dependent on streamflow, and (2) a source of nitrate that provides a fairly constant supply to the system and is not dependent on streamflow. Animal manure is the dominant source of nitrogen for the streams in the lower agricultural part of the basin. No relation was found between basin size and the percentage of the nitrate load carried during base flow.

The average annual phosphorus load carried in base flow ranged from 20 to 33 percent. Most of the phosphorus load is transported in a suspended phase during runoff and is closely related to the amount of transported suspended sediment. Of the nutrient sources reviewed, animal manure was the dominant source of phosphorus in the study unit.

Average annual yields of nutrients and suspended sediment from tributary basins are directly related to percentage of drainage area in agriculture and inversely to drainage area. For example, measured annual yields of suspended sediment were about 950 lb/acre for a moderately sized tributary and about 400 lb/acre at a large main-stem site. Yields of phosphorus were affected most by changes in the amount of agricultural land use. The least affected yields are those associated with nitrate.

Nonpoint and point sources of nutrients were estimated. Slightly more than 220 million pounds of nitrogen from manure were estimated to have been produced in the Lower Susquehanna River Basin in 1990. Phosphorus loads from manure were slightly more than 57 million pounds. Commercial-fertilizer applications were estimated to be about 52 million pounds of nitrogen and 16 million pounds of phosphorus. Estimates of municipal and industrial loads of nitrogen were 12.6 million pounds. Phosphorus loads were estimated to be 4 million pounds for municipal and industrial discharges. Nitrogen and phosphorus loads from private septic systems were estimated to be 4 million and 1.5 million pounds, respectively. Nonpoint and point sources combined, including atmospheric deposition, provide a potential annual load of 390 million pounds of nitrogen and 79.5 million pounds of phosphorus.

Estimated cumulative loads for nonpoint and point sources show a gradual increase for nitrogen and phosphorus through the river system and a marked increase in inputs immediately above and throughout the reservoir system. The range of percentages of the estimated nonpoint and point sources that were measured in the stream was 20 to 47 percent for nitrogen and 6 to 14 percent for phosphorus.

Comparisons of water quality between the various sampling media and interpretations of the data sets were limited either by the lack of data or by a large disparity in numbers of samples between data sets. The amount of data available for interpretation was reduced significantly when only the dissolved phase was considered. Most interpretive limitations were the result of the lack of certain types of water-quality and ancillary data or the use of outdated ancillary data.

In addition, interpretations of nutrient data from streams were limited by the range of streamflows sampled, sparse areal distribution of nutrient samples collected during similar stream hydrologic conditions, and unavailability of sites where long-term nutrient data had been collected on a fixed interval.

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