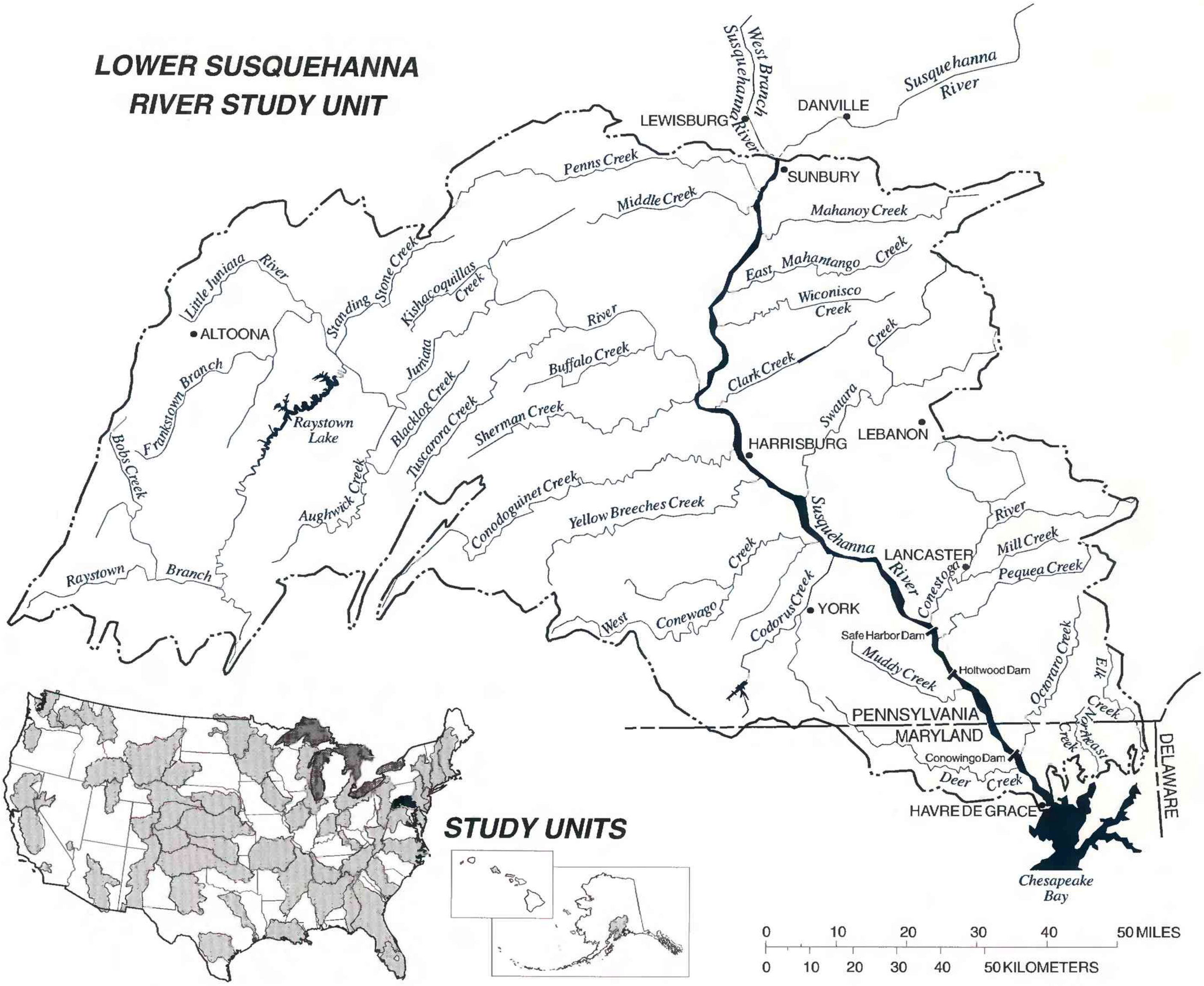
Water-Quality Assessment of the Lower Susquehanna River Basin, Pennsylvania and Maryland: Environmental Setting

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

Water-Resources Investigations Report 94-4245



NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

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Dennis W. Risser and Steven F. Siwiec

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Lemoyne, Pennsylvania
1996

U.S. DEPARTMENT OF THE INTERIOR
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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 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

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

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

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS, 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			
	acre	0.4047	hectare
	square foot (ft^2)	0.09290	square meter
	square mile (mi^2)	2.590	square kilometer
Volume			
	gallon (gal)	3.785	liter
Flow			
	gallon per minute (gal/min)	0.06308	liter per second
	cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer
Mass			
	pound (lb)	0.4545	kilogram
	pound per acre (lb/acre)	1.123	kilogram per hectare
	ton (short, 2,000 pounds)	0.9072	metric ton
Temperature			
	degree Fahrenheit (°F)	°C=5/9 (°F-32)	degree Celsius
Specific capacity			
	gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, called Sea Level of 1929.

Abbreviated water-quality units used in report:

mg/L, milligrams per liter
pCi/L, picoCuries per liter

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

by Dennis W. Risser and Steven F. Siwiec

ABSTRACT

The environmental setting is the framework of natural and human components that influence water quality within the Lower Susquehanna River Basin. Because a principal objective of the National Water-Quality Assessment is to relate water quality to factors that affect its composition, an understanding of the environmental setting is essential for successful completion of the study.

The study unit consists of 9,350 square miles of the Lower Susquehanna River Basin from where the West Branch joins the main stem of the Susquehanna River near Sunbury, Pa., downstream to the Chesapeake Bay at Havre de Grace, Md. The basin lies predominantly in the Ridge and Valley and Piedmont Physiographic Provinces and is underlain by Precambrian to Triassic bedrock. About 98 percent of the biological communities in the basin are situated within the Central Appalachian Ridges and Valleys and Northern Piedmont ecoregions. Precipitation averages about 40 inches per year, and its pH averaged between 4.08 and 4.20 during 1982-88; this precipitation is some of the most acidic in the nation.

The Susquehanna River discharges an average of about 38,300 cubic feet per second of water into Chesapeake Bay. This discharge carries about 45 percent of the freshwater, 40 percent of the sediment, 39 percent of the nitrogen, and 24 percent of the phosphorus to the bay. Before entering Chesapeake Bay, the Susquehanna flows through four major dams; the three nearest the mouth of the river have trapped 259 million tons of sediment, 913,000 tons of nitrogen, and 226,000 tons of phosphorus.

Ground water is present in regolith and fractured bedrock and is encountered at depths ranging from a few feet below land surface in valley settings to as much as 100 feet beneath hills. Ground-water flow paths, controlled mainly by topography and depth of fracturing, are local and generally less than about 300 feet deep. On average, base flow of streams accounts for about 60 percent of total streamflow and sustains streamflow during dry periods. In carbonate-rock terranes, where base flow can exceed 80 percent of streamflow, the ground-water contributions to streams not only sustain streamflow but provide the quality of water needed to create the exceptional value, cold-water fishery habitats for which "limestone streams" in the study area are well known.

The 1.9 million people who inhabit the Lower Susquehanna River Basin affect the basin's water quality by disrupting natural physical characteristics of the basin (soil, vegetation, physiography) and by directly adding contaminants to surface water and land. The greatest effects are in the southeastern part of the basin in and around Harrisburg, Lancaster, and York where about 71 percent of the population resides.

Land use in the basin is about 47 percent agriculture, 47 percent forest, and 4 percent urban. The remaining 2 percent consists of bodies of water and barren land. Some of the most intensive agriculture in Pennsylvania is in the southeastern part of the study unit. Annual applications of nitrogen from manure in some parts of this area are as large as 92 pounds per acre per year. Mining of coal is the greatest cause of severe stream water-quality degradation in the basin. About 300 stream miles have been significantly contaminated by mine drainage. The urban environment provides contaminants from nonpoint source runoff, sewage-treatment facilities, industrial discharges, landfills, and leaking storage tanks. About 600 point-source discharges of wastes to streams (excluding single residences and small flows) are legally permitted by the State in the study unit. Of these, 49 major public-owned sewage-treatment plants discharge about 155 million gallons per day of effluent. Twenty-three major industrial discharges total about 93 million gallons per day, the largest of which are wastewater from food processing, paper making, and steel making. Other activities affecting water quality include surface impoundments, septic systems, land application of sludge, and injection wells.

Five major subdivisions of the major physiographic provinces in the area that contain similar physiographic features and rock types are identified as a framework for water-quality assessment: (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. These subdivisions are useful for making comparisons of water quality between areas of differing environmental setting and also for estimating water-quality conditions where settings are similar but specific water-quality information is lacking.

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 (Leahy and others, 1990)

The principal goal of the NAWQA program is to provide water-quality information that will assist policy makers and managers in their attempts to address water-quality issues at the national, state, and local levels.

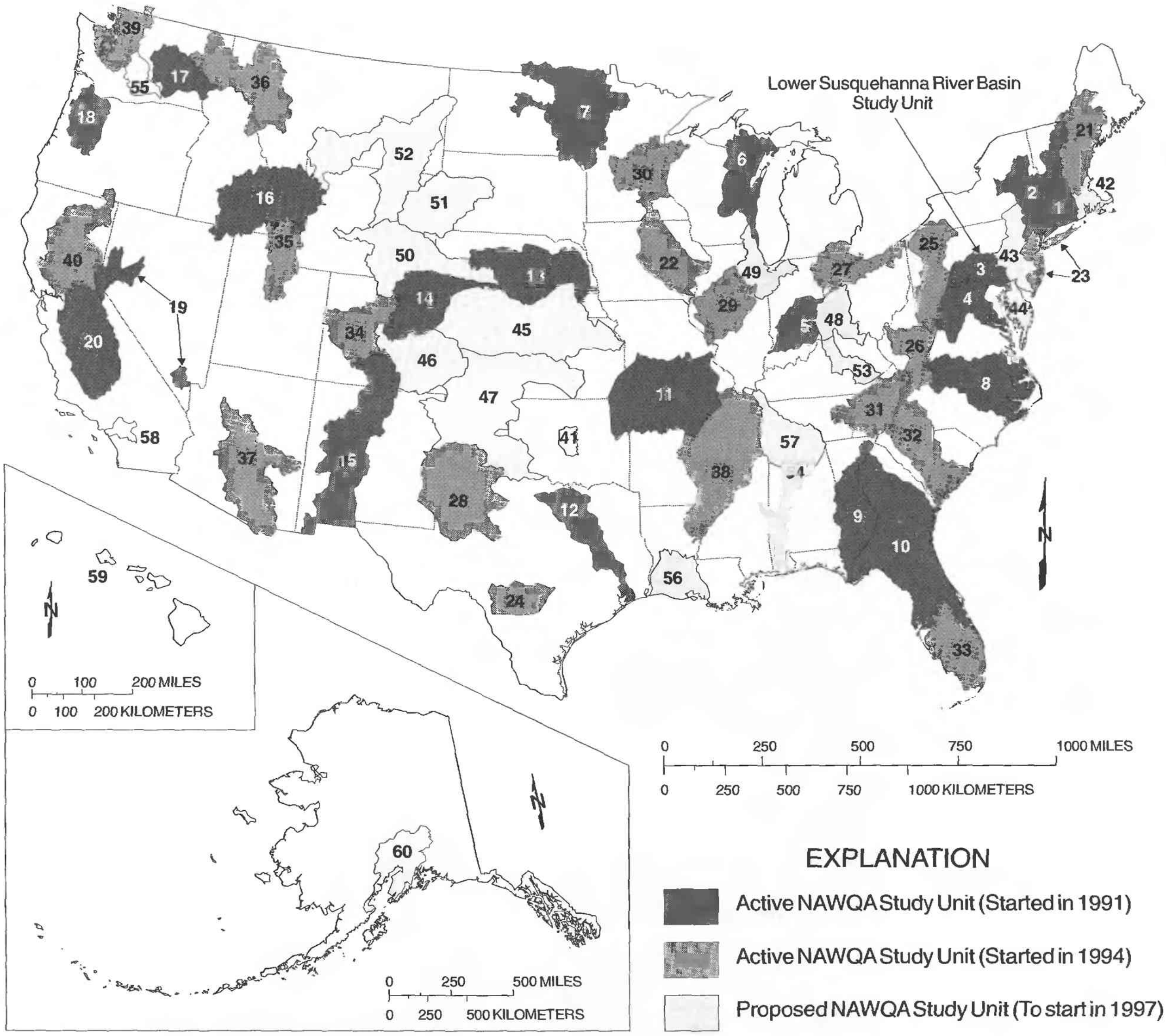
The NAWQA program proposes to assess the water quality in 60 individual study units (fig. 1). The 60 study units are river basins or aquifer systems that range from 1,200 to about 48,000 mi^2 and represent about 60 to 70 percent of the Nation's water use (Engelbrecht and others, 1990). The Lower Susquehanna River Basin study unit, hereinafter termed "the study unit," was among the first 20 study units where the assessment began in 1991.

Purpose and Scope

This report describes the environmental setting of the study unit. The environmental setting is the sum of all natural and human components that affect the quality of surface and ground waters within the basin as shown schematically in figure 2. This description of the environmental setting of the study unit is one of the NAWQA objectives and will contribute to the assessment of water quality nationwide.

The scope of this report is limited to a description of the major components of the environmental setting and some examples of their effects on water quality. A detailed evaluation of the complex interrelations between the environmental setting and water quality are beyond the scope of this report.

The study unit was selected for study (rather than the entire Susquehanna River Basin) so that resources could be focused where land-use activities associated with intensive agriculture and heavily populated areas are most likely to affect water quality.



MAP NO.	STUDY-UNIT NAME	MAP NO.	STUDY-UNIT NAME	MAP NO.	STUDY-UNIT NAME
1.	Connecticut, Housatonic, and Thames River Basins	21.	Northern New England Basins	41.	Central Oklahoma Aquifer (PILOT)
2.	Hudson River Basin	22.	Eastern Iowa Basins	42.	Southeastern New England
3.	Lower Susquehanna River Basin	23.	Long Island-New Jersey Coastal Drainages	43.	Delaware River Basin
4.	Potomac River Basin	24.	South Central Texas	44.	Delmarva Peninsula (PILOT)
5.	White River Basin	25.	Allegheny and Monongahela Basins	45.	Kansas River Basin (PILOT)
6.	Western Lake Michigan Drainage	26.	Kanawha-New River Basin	46.	Upper Arkansas River Basin
7.	Red River of the North	27.	Lake Erie-Lake Saint Claire Drainage	47.	Central High Plains
8.	Albemarle-Pamlico Drainage	28.	Southern High Plains	48.	Great and Little Miami River Basins
9.	Apalachicola-Chattahoochee-Flint River Basin	29.	Southern Illinois	49.	Upper Illinois River Basin (PILOT)
10.	Georgia-Florida Coastal Plain	30.	Upper Mississippi River Basin	50.	North Platte River Basin
11.	Ozark Plateaus	31.	Upper Tennessee River Basin	51.	Cheyenne and Belle Fourche Basins
12.	Trinity River Basin	32.	Santee Basin and Coastal Drainage	52.	Yellowstone Basin
13.	Central Nebraska Basin	33.	Southern Florida	53.	Kentucky River Basin (PILOT)
14.	South Platte River Basin	34.	Upper Colorado Basin	54.	Mobile River and Tributaries
15.	Rio Grande Valley	35.	Great Salt Lake Basins	55.	Yakima River Basin (PILOT)
16.	Upper Snake River Basin	36.	Northern Rockies Intermontane Basins	56.	Chicot-Evangeline
17.	Central Columbia Plateau	37.	Southern Arizona	57.	Lower Tennessee River Basin
18.	Willamette Basin	38.	Mississippi Embayment	58.	Santa Ana Basin
19.	Nevada Basin and Range	39.	Puget Sound Drainages	59.	Oahu
20.	San Joaquin-Tulare Basins	40.	Sacramento Basin	60.	Cook Inlet Basin

Figure 1. Location of study units for the National Water-Quality Assessment (NAWQA) program. (Modified from Leahy and others, 1990, fig. 1.)

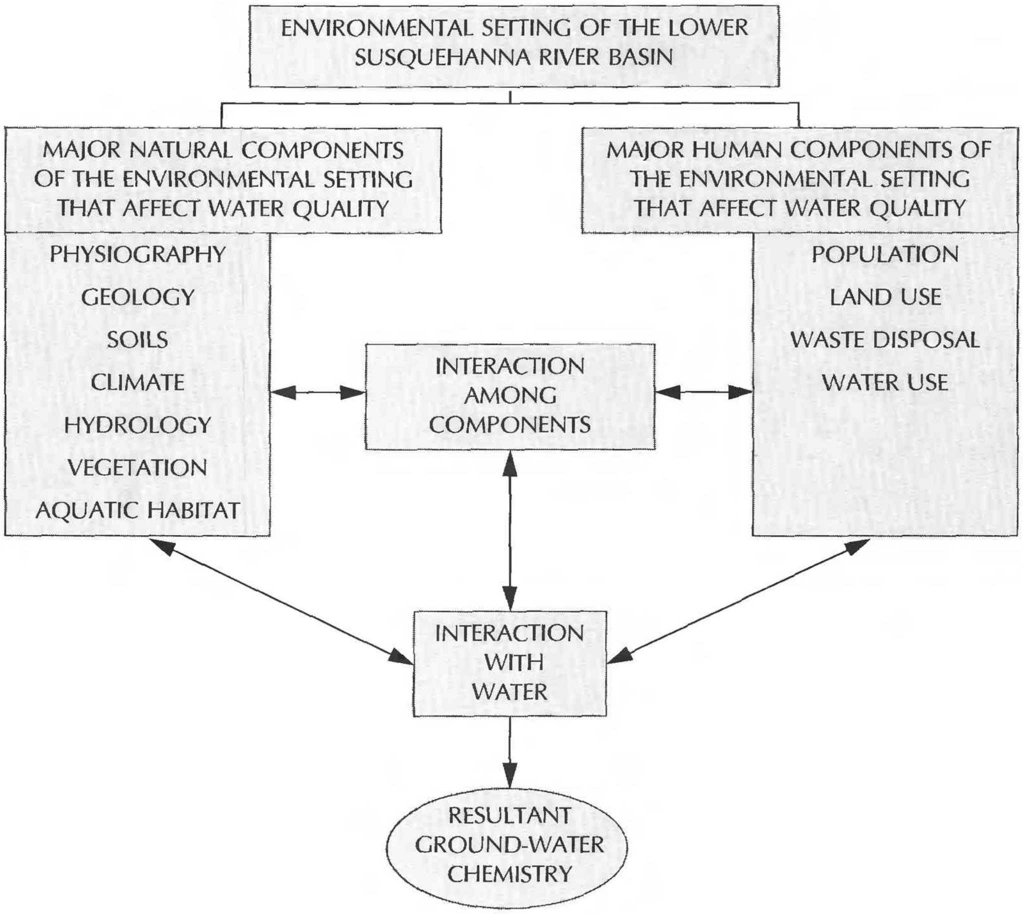


Figure 2. Major natural and human components affecting water quality in the Lower Susquehanna River Basin.

Location 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 River Basin lies within Pennsylvania. From its headwaters in central New York state, the Susquehanna River flows 447 mi to its mouth at the Chesapeake Bay. In terms of total discharge at its mouth, 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 Susquehanna River Basin from where the West Branch and main stem of the Susquehanna River join near Sunbury, Pa., downstream to the Chesapeake Bay at Havre de Grace, Md. (fig. 3). The study unit also includes parts of the Northeast River and Elk River Basins located upstream from the Fall Line. These rivers, which drain directly into Chesapeake Bay, add about 150 mi^2 to the area of the study unit. In this report, the term "Lower Susquehanna River Basin" is meant to include this small area that is drained 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 Potomac River Basin, small basins that drain directly into Chesapeake Bay, and the Fall Line; to the east by the Delaware River Basin; and to the west by the Allegheny River Basin (fig. 3).

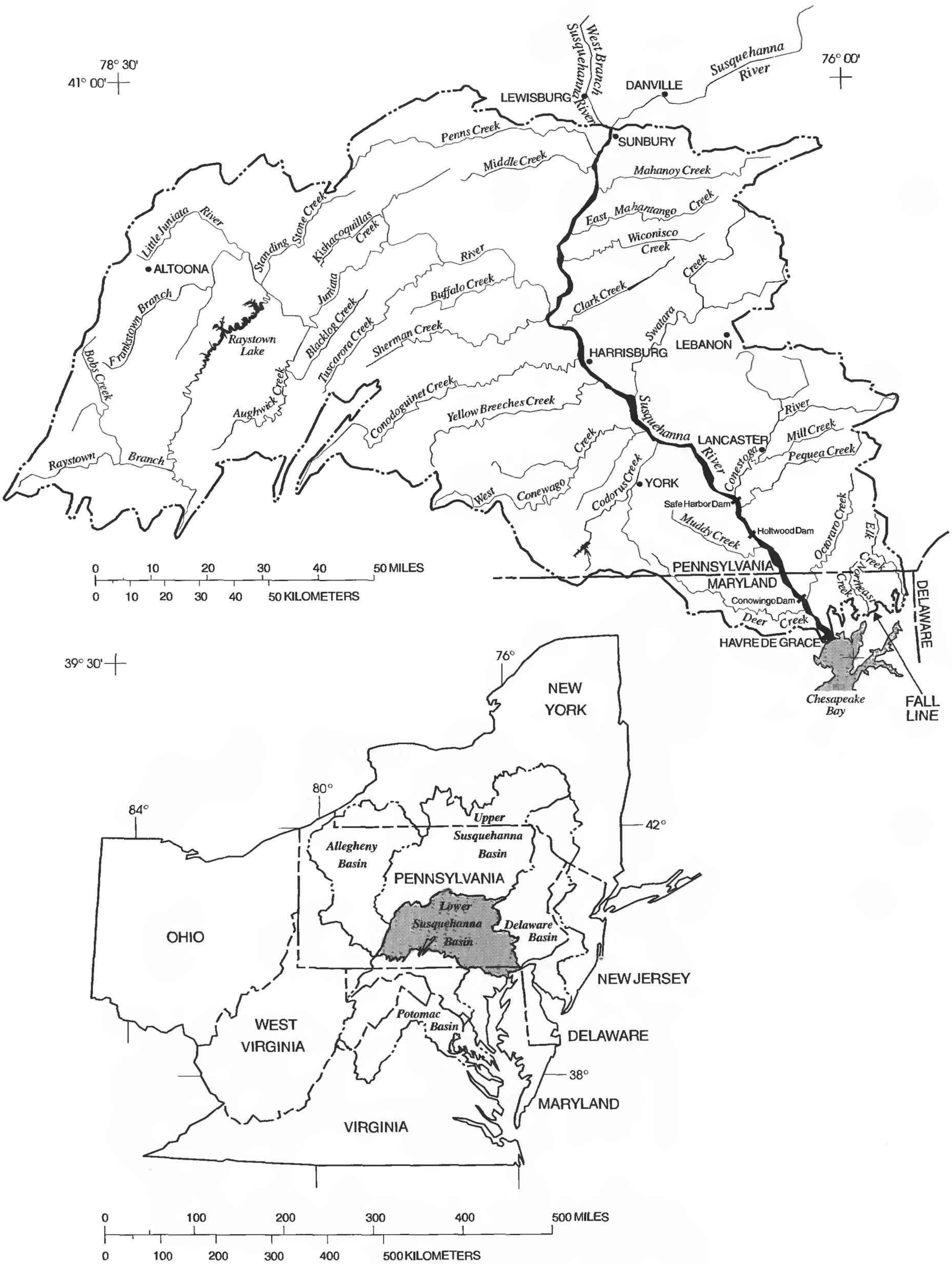


Figure 3. Location of the Lower Susquehanna River Basin.

Water-Quality Problems

Water-quality problems arise when water in a particular stream or ground-water system is found to be unacceptable for a particular use. The problems can be caused by both point and nonpoint sources of contamination. At a NAWQA briefing on May 30, 1991, 60 representatives from water-resources agencies in Pennsylvania and Maryland were asked to identify the major water-quality problems in the study unit. The four water-quality problems they cited most frequently were sedimentation, nutrients, pesticides, and general agricultural wastes.

Clearly, the dominant water-quality issues perceived by representatives of these agencies are mostly nonpoint sources of contamination. The perception of nonpoint-source problems probably predominate today because Federal and State regulations during the past 20 years have focused on reducing point sources of contamination to the Nation's waters.

A stream assessment conducted as part of the Clean Water Act Amendments of 1987 underscores the importance of nonpoint sources of contamination (Frey, 1990; McMorran, 1990). The assessment shows that nonpoint-source contamination from coal mining and agriculture is responsible for the water-quality degradation at 80 percent of streams in the study unit where water quality was degraded to the point that the stream's "designated use" could not be attained (fig. 4). Designated uses are not all water uses in the strictest sense but are categories identified in the Pennsylvania legal code so that water-quality criteria can be assigned to protect a related use or intrinsic value. Designated uses that are protected in Pennsylvania are water supply for fish and other aquatic life; water supply for drinking, industry, livestock, wildlife, and irrigation; boating, fishing, water-contact sports, and aesthetic recreational uses; navigation; and high-quality and exceptional-value waters (Commonwealth of Pennsylvania, 1992, table 1).

Although nonpoint sources of contamination are a major cause of surface-water degradation, localized point sources of contamination are perceived as some of the most serious problems for ground-water resources. For example, five of the major sources of ground-water contamination listed by Frey (1990) are point sources (table 1).

Table 1. *Sources of ground-water contamination in Pennsylvania ranked according to perceived potential hazard, 1990*[1]

Contamination source or activity (Italics indicate pointsource)
1) *Gas Station Underground Storage Tanks*
2) Coal Mining
3) *Surface Impoundments*
4) *Underground Storage Tanks, Excluding Gas Stations*
5) Land Application of Animal Waste
6) *Municipal Waste Landfills*
7) *Chemical Plants*

[1] Frey, 1990.

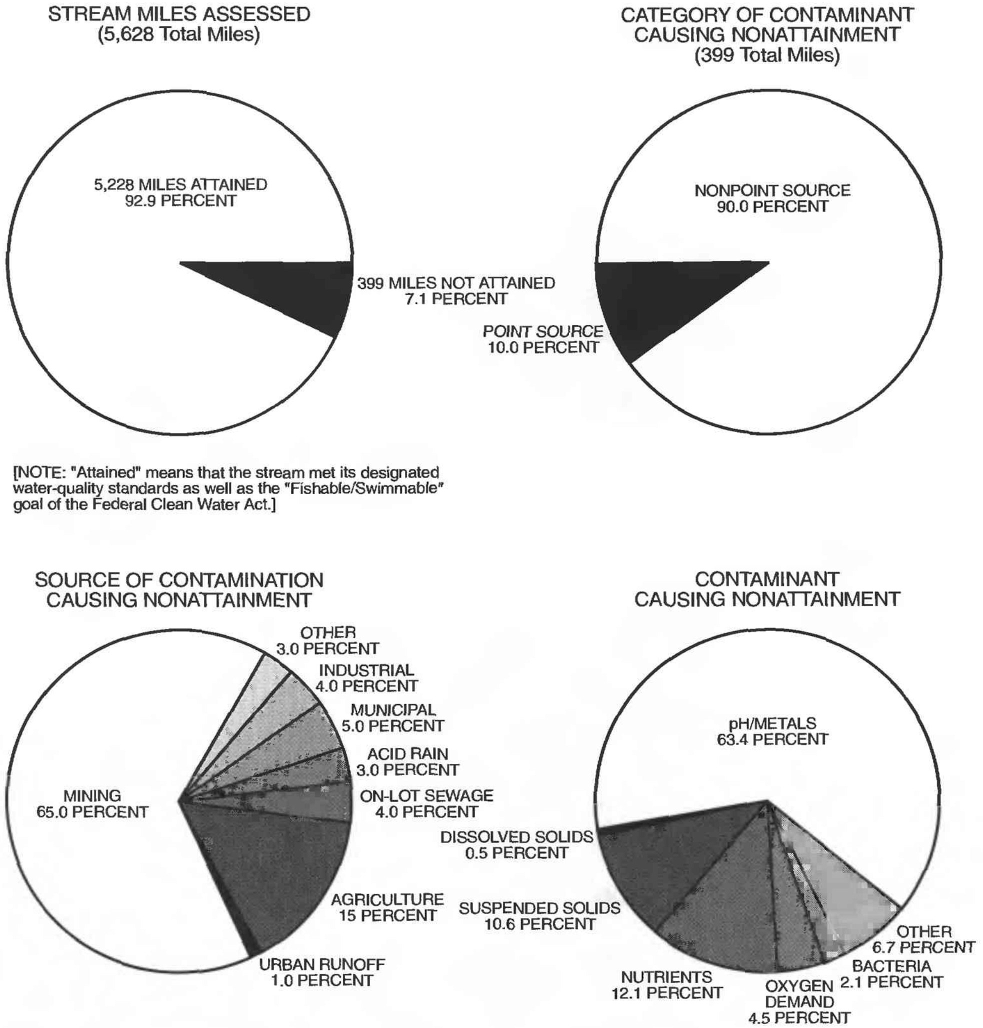


Figure 4. Summary of the 1990 Pennsylvania assessment of streams within the Lower Susquehanna River Basin.
[Data from Frey (1990).]

In addition to the general water-quality problems caused by mining, agricultural, and urban land uses, several other specific water-quality issues have received attention in the study unit:

Chesapeake Bay—Degradation of this estuary has been linked to elevated loads of nutrients, sediments, and toxic compounds. Reducing the loads contributed from the Susquehanna River Basin has become the focus of several research and management programs in the study unit (Frey, 1990, p. 95).

Atmospheric Deposition—The study unit receives some of the most acidic precipitation in the nation (Turk, 1983). The effects of the acidic deposition and the accompanying loads of nutrients and trace metals are a major water-quality issue.

Karstic Aquifer Systems—Carbonate rocks underlie 17 percent of the study unit; much of which is characterized by closed depressions, sinkholes, and other karst features. The extent of ground-water contamination in these and other highly fractured rocks is a major ground-water-quality issue.

Radon in Ground Water—The U.S. Environmental Protection Agency (USEPA) recently proposed a maximum contaminant level of 300 pCi/L for radon in public water supplies (U.S. Environmental Protection Agency, 1991b). A preliminary assessment of domestic-supply wells indicates that about 80 percent of wells are likely to withdraw water exceeding the proposed limit (U.S. Geological Survey, Lemoyne Pa., unpublished data, 1991).

Bacterial Contamination—Since 1979, seven outbreaks of giardiasis have affected about 300,000 people in Pennsylvania. The disease is transmitted by ingesting cysts of the protozoan *Giardia lamblia,* which is carried in the feces of animals and humans. Monitoring of public surface-water systems for the *Giardia* cysts that began in 1985 has detected the protozoan in about 24 percent of unfiltered public water systems statewide (Frey, 1990). In addition, bacterial contamination of shallow ground water from on-lot septic systems and animal wastes also is an important ground-water issue.

Previous Investigations

Hundreds of previous studies have been conducted that contain information on the physical, cultural, or hydrologic characteristics within the study unit. The principal investigators or funding sources for most of these studies are bureaus within the Pennsylvania Department of Environmental Resources (PaDER), the USEPA, the Susquehanna River Basin Commission, the U.S. Department of Agriculture, the Army Corps of Engineers, the USGS, the National Academy of Science, and various colleges within the Pennsylvania State University. Dozens of these studies are cited in the *Selected References* section at the end of this report (for example, Taylor and Werkheiser, 1984; Reed, 1980; Pionke and Urban, 1985).

Two comprehensive studies of the environmental setting of the study unit have been conducted: In 1970, an interagency group called the Susquehanna River Basin Study Coordinating Committee published a detailed summary of the resources within the entire Susquehanna River Basin. The Susquehanna River Basin Study Coordinating Committee report includes separate appendixes on economics and geography, hydrology, flood control, water supply and quality, recreation, power, mineral resources, and land treatment and management (Susquehanna River Basin Study Coordinating Committee, 1970). The State Water Plan for Pennsylvania also contains a comprehensive discussion of the environmental setting of stream basins within the state. Four reports from the State Water Plan (subbasins 6, 7, 11, and 12) describe the Lower Susquehanna River Basin (Pennsylvania Department of Environmental Resources, 1979; 1980; 1980a; 1980b).

NATURAL COMPONENTS OF THE ENVIRONMENTAL SETTING

The natural components of the environmental setting of the study unit include physiography, geology, soil, climate, hydrology, vegetation, and aquatic habitat. These characteristics are the major natural factors that control the movement and chemical quality of water in the basin (fig. 2). They exert this control primarily by affecting the water budget, sediment availability, minerals available for dissolution, and chemical reactions that are likely to occur. The natural components of the study unit are described in the following sections.

Physiography

The study unit can be divided into physiographic provinces, each of which has distinctive characteristics that are derived from its particular geologic framework. This framework, in turn, gives rise to distinctive landforms that result in particular vegetation, soil, water, and climate (Hunt, 1967, p. 3). The landforms affect water quality in the study unit to a great extent by controlling the distribution of precipitation and the physical pathway that surface runoff and ground water must follow on its way to the Susquehanna River. The basin relief, hillslope morphology, and stream-drainage pattern dictate the residence time of runoff with soil, rocks, and vegetative cover—all factors that affect the sediment and natural chemical composition of surface and ground waters in the basin.

The study unit contains parts of five physiographic provinces: the Appalachian Plateaus, Ridge and Valley, Blue Ridge, New England, and Piedmont (Berg and others, 1989), but the basin lies predominantly within the Ridge and Valley and Piedmont Physiographic Provinces. The shaded relief map (fig. 5) shows the regional setting of the study unit in relation to physiographic provinces and the distinct differences in topography.

The Allegheny Mountain Section of the Appalachian Plateaus Physiographic Province lies along the western margin of the study unit and accounts for about 2 percent of the total basin area (map 1). The section is a dissected mountainous, upland plateau characterized by wide ridges, broad valleys, and local relief of 600 to 1,000 ft. A major escarpment called the Allegheny Front separates the Appalachian Plateaus Physiographic Province from the Ridge and Valley Physiographic Province to the east. An outlier of this escarpment, Blue Knob, is the highest point in the study unit and rises to 3,136 ft above sea level. Streams within the Appalachian Plateaus are headwater reaches of the Juniata River, a tributary to the Susquehanna River.

The Ridge and Valley Physiographic Province is situated to the east of the Allegheny Front and covers 68 percent of the study unit. The province is divided into two parts: the Appalachian Mountain Section and the Great Valley Section. The Appalachian Mountain Section accounts for 86 percent of the Ridge and Valley Physiographic Province in the study unit and is characterized by long, narrow ridges and valleys that trend southwest to northeast. These features were created by the action of differential erosion on shale, carbonate rocks, and sandstone that had been deformed into tight, plunging folds (fig. 5). Local relief created by these eroded folds is high, commonly exceeding 1,000 ft. In valleys where the bedrock floor consists of limestone, rich agricultural soil has been formed in addition to karstic features such as sinkholes and large springs. West of the Susquehanna River, the Appalachian Mountain Section is drained primarily by the Juniata River, which crosses the fabric of the ridge-and-valley structure in a trellised pattern that is linked across ridges by a series of water gaps.

The Great Valley Section is situated within the eastern margin of the Ridge and Valley Physiographic Province and covers about 10 percent of the study unit in Franklin, Cumberland, Dauphin, Lebanon, and Berks Counties. The area is a broad 10-15 mi wide

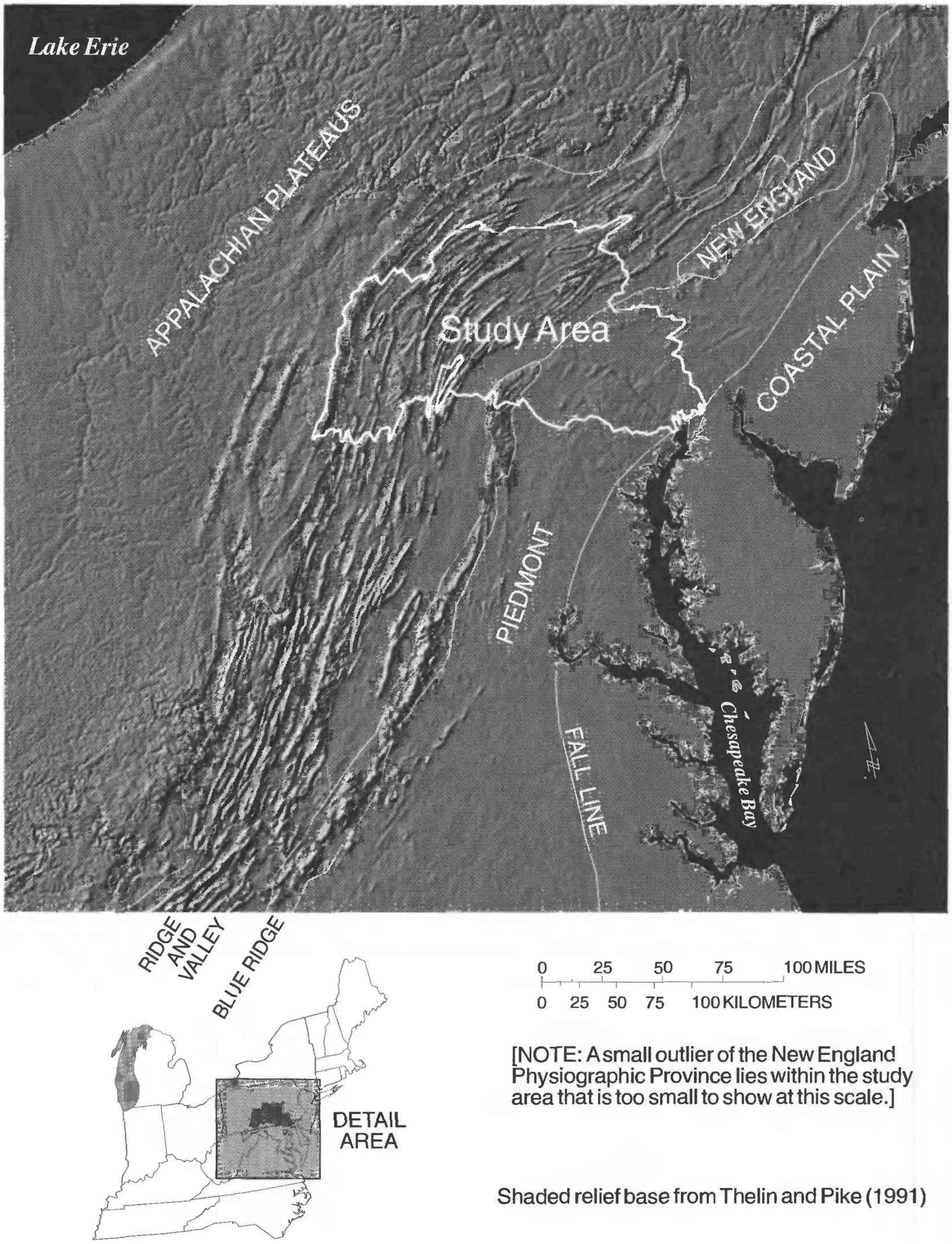


Figure 5. Shaded relief and relation of the Lower Susquehanna River Basin to physiographic provinces in the eastern United States.

valley eroded into a complex assemblage of thrusted and folded shale, siltstone, and carbonate rock that extends across the study unit from southwest to northeast. Shale and siltstone predominate beneath the northern part of the Great Valley, whereas carbonate rocks lie beneath the southern part. Dissolution of the carbonate rocks has created rich soil for agriculture and formed the karst topography, large springs, and "limestone streams" for which the area is well known.

South Mountain, in the Blue Ridge Physiographic Province, covers slightly less than 2 percent of the study unit in Cumberland, Franklin, Adams, and York Counties. South Mountain is a mountainous region where elevations range from about 450 to 2,100 ft. Resistant quartzite and metavolcanic rocks underlie most of the section. These rocks have been sculpted by a dendritic stream network and extensive mass wasting. The mass wasting has formed deposits of colluvium several hundred feet thick along the margins of the mountain (Becher and Root, 1981). Streams that drain South Mountain are the headwater tributaries of Conodoguinet, Yellow Breeches, and Conewago Creeks.

The Reading Prong Section of the New England Physiographic Province lies within the study unit at the intersections of Lebanon, Lancaster, and Berks Counties where an outlier of resistant gneiss forms a circular hill with about 500 ft of relief. Only about 6 mi^2 of the Reading Prong lies within the study unit.

The Piedmont Physiographic Province, which covers 29 percent of the study unit, is situated to the east and south of South Mountain and the Great Valley. The province is characterized by low, rolling hills and broad valleys and is divided into three distinct sections: the Gettysburg-Newark Lowland, Piedmont Lowland, and Piedmont Upland. The Gettysburg-Newark Lowland forms the western part of the Piedmont Physiographic Province. The term "lowland" is a misnomer because throughout most of the study unit this section is characterized by rolling hills, highlands, and isolated knobs. The topography was formed by erosion of rocks of Triassic age composed of soft shale and sandstone interbedded with resistant conglomerate and diabase intrusives.

The Piedmont Lowland Section of the Piedmont Physiographic Province is situated between the Gettysburg-Newark Lowland and Piedmont Upland Sections, mostly in York and Lancaster Counties. The topography is a lowland setting characterized by broad valleys and low hills. Altitudes generally range from 200 to 600 ft. The lowland setting was created by erosion of carbonate rocks and phyllitic shales. The carbonate rocks underlie about 90 percent of the Piedmont Lowland and are mantled by residual soil that supports the most intensive agricultural activity in Pennsylvania (U.S. Department of Commerce, 1990).

The Piedmont Upland Section of the Piedmont Physiographic Province is located in the southeastern part of the study unit. The region is underlain by metamorphic rocks—mostly schist, gneiss, and quartzite—that have been sculpted by streams into a rolling upland with broad hills and some steep-sided valleys. The upland areas, which generally range from 500 to 800 ft in altitude, are mantled by saprolite that has weathered from the underlying bedrock. Major streams that drain the area include Muddy, Deer, and Octoraro Creeks.

The Piedmont Physiographic Province is bounded to the southeast by the Fall Line, which is a narrow zone of rapids and waterfalls between the Piedmont and Coastal Plain Physiographic Provinces. The Susquehanna River discharges from the study unit into Chesapeake Bay at the Fall Line near Havre de Grace, Md.

Geology and Soil

The geology in the study unit exerts a primary influence on the major-ion, trace element, and radiochemical concentrations of surface and ground waters. Components of the rocks are released to water and overlying soil by the processes of physical and chemical weathering. Physical weathering is the disintegration of rock into smaller particles without major chemical alteration. The widespread presence of colluvium and boulder fields on mountain flanks in the Ridge and Valley and Blue Ridge Physiographic Provinces attests to the activity of the physical-weathering processes (Ciolkosz and others, 1980).

Chemical weathering of the bedrock releases ions when acidic infiltrating water dissolves minerals from the rocks. The acidic water is produced either naturally by respiration of plants and bacterial metabolism or by air pollution. Features in the study unit resulting from chemical erosion include karst terranes in areas underlain by carbonate rocks and thick saprolite formed on crystalline rocks in the Piedmont.

Three reactions summarize the principal chemical-weathering pathways by which major ions and trace elements are released from rocks to waters in the study unit.

Carbonate Weathering:
Acidic Water + Calcite and Dolomite = Calcium + Magnesium + Bicarbonate

Silicate Weathering:
Acidic Water + Silicate Minerals = Sodium + Calcium + Magnesium + Potassium+ Bicarbonate + Silica

Sulfide Weathering:
Water + Oxygen + Pyrite = Sulfate + Acid + Iron

Bedrock

Rocks in the study unit range in age from Precambrian to Triassic and are structurally complex and lithologically diverse. The structural complexity across physiographic provinces (fig. 6) is the result of several periods of uplift and collision of continental plates—the most recent in Permian time. The most intensely deformed rocks and complex structures are in the Piedmont, nearest the edge of the deforming plate. Rocks in the Ridge and Valley Physiographic Province are folded and faulted but not greatly metamorphosed because they were further from the source of the deformation. After the most intense deformation, tensional forces opened large grabens throughout the Gettysburg/Newark Lowland during the Triassic period. These Triassic basins were filled with sand and mud from the adjacent uplands and intruded by volcanic diabase.

The study unit contains a wide diversity of rock types, as exemplified by the 156 geologic formations mapped by Berg and others (1980). The generalized sequence of rock types consists of basal crystalline rocks overlain by carbonate rocks of Cambrian and Ordovician age, siliciclastic rocks of Ordovician and Silurian age, more carbonate rocks of Silurian and Devonian age, siliciclastic rocks of Devonian through Pennsylvanian age, and siliciclastic rocks with diabase intrusions of Triassic age (fig. 7).

The number and complexity of rock types were organized into a basinwide geologic framework by grouping formations in the study unit according to major physiographic province and generalized rock type (fig. 8). These groupings identify areas among which the major ionic composition of ground water is expected to differ. Rock types are mapped in plate 1 according to this scheme.

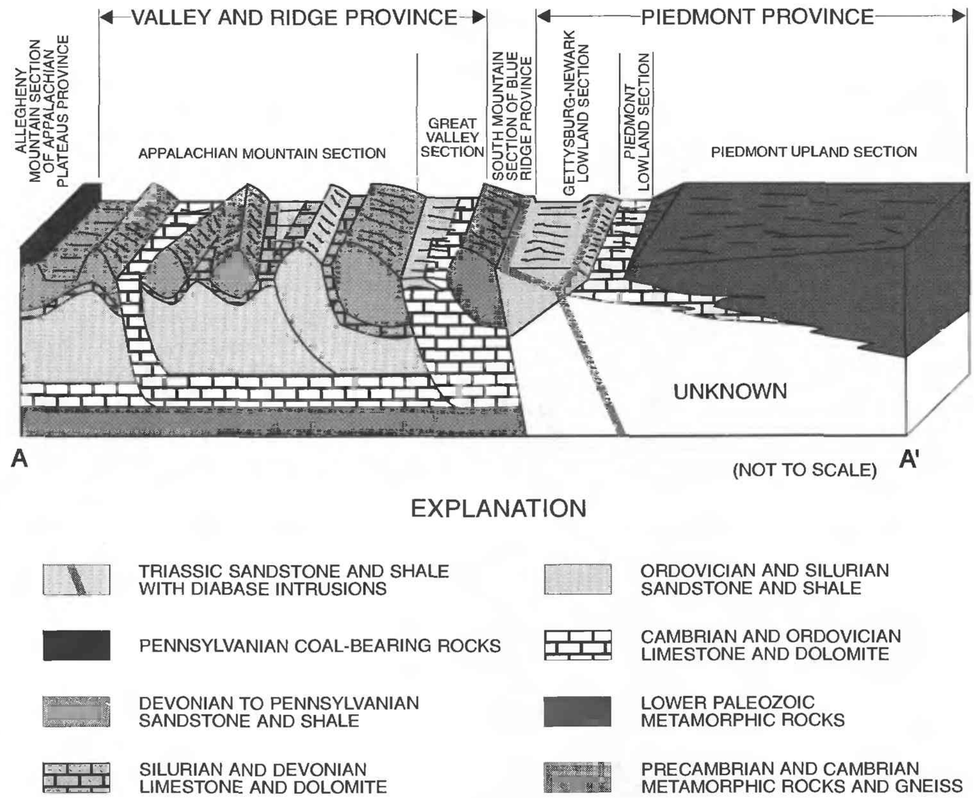


Figure 6. Generalized geologic structure across physiographic sections.

Crystalline rocks

The oldest rocks in the study unit are crystalline rocks that crop out in the Piedmont Upland, South Mountain, and Reading Prong Sections (pl. 1). These rocks are Precambrian, Cambrian, and Ordovician-aged metamorphic and igneous crystalline rocks consisting primarily of schist, gneiss, gabbro, phyllite, metavolcanic rocks, and quartzite; slate and serpentinite are less common. Structurally, these crystalline rocks have been subjected to several episodes of deformation and are the most intensely recrystallized rocks in the study unit.

Some of the youngest rocks are also crystalline—diabase sills and dikes of Triassic age. These rocks were intruded into sandstones and shales of the Gettysburg-Newark Lowland Section (pl. 1).

Silicate weathering has a major effect on the ground-water chemistry in crystalline rocks because the rocks contain very few carbonate minerals. Silicate weathering in the absence of carbonate minerals results in ground waters that contain few dissolved solids and are corrosive. Median hardness of 59 ground-water samples from wells completed in crystalline rocks (Taylor and Werkheiser, (1984) is only 47 mg/L (fig. 9). The median pH of 6.0 for these same samples is the lowest among the three major rock-type categories.

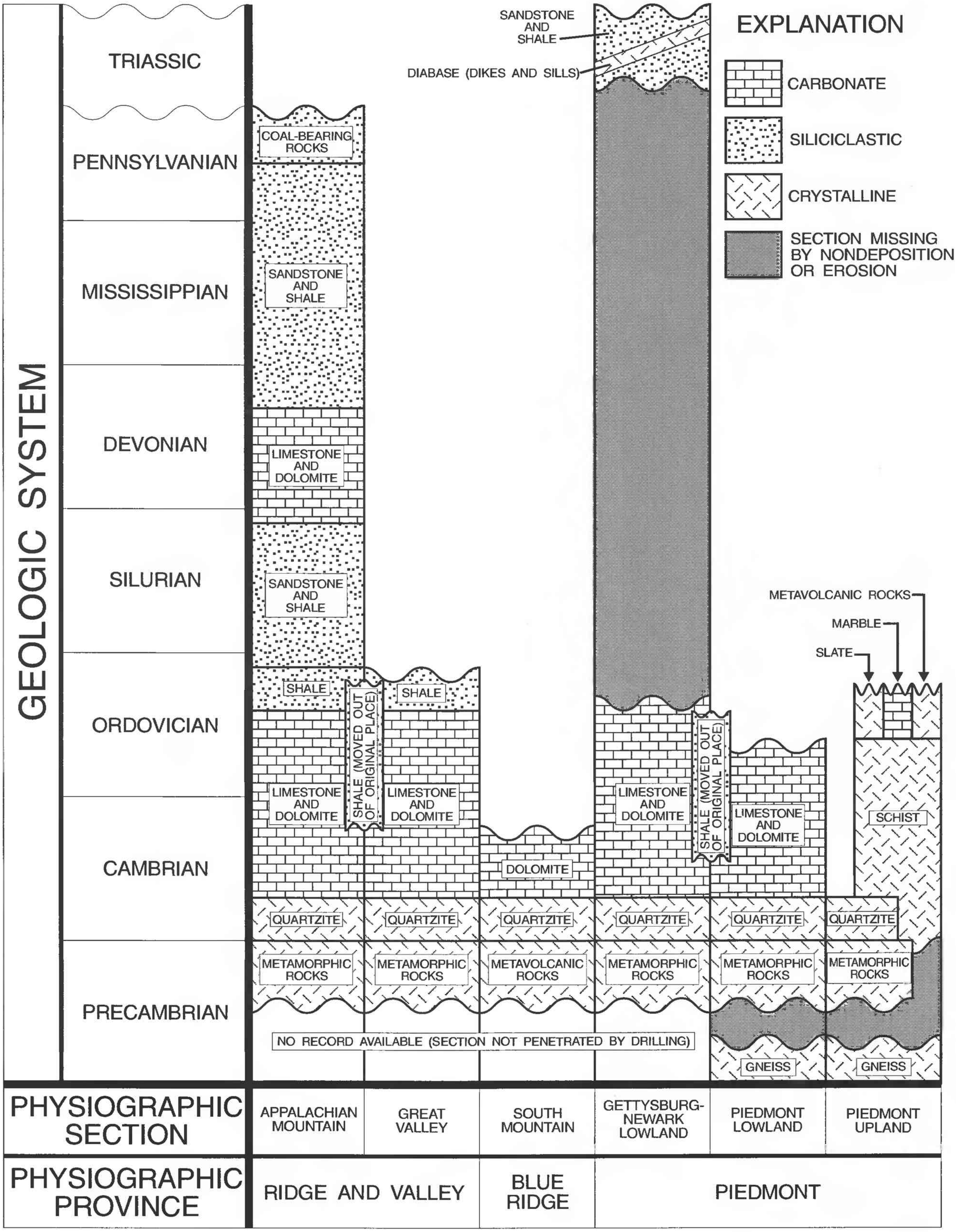


Figure 7. Correlation chart of rock types in the Lower Susquehanna River Basin.

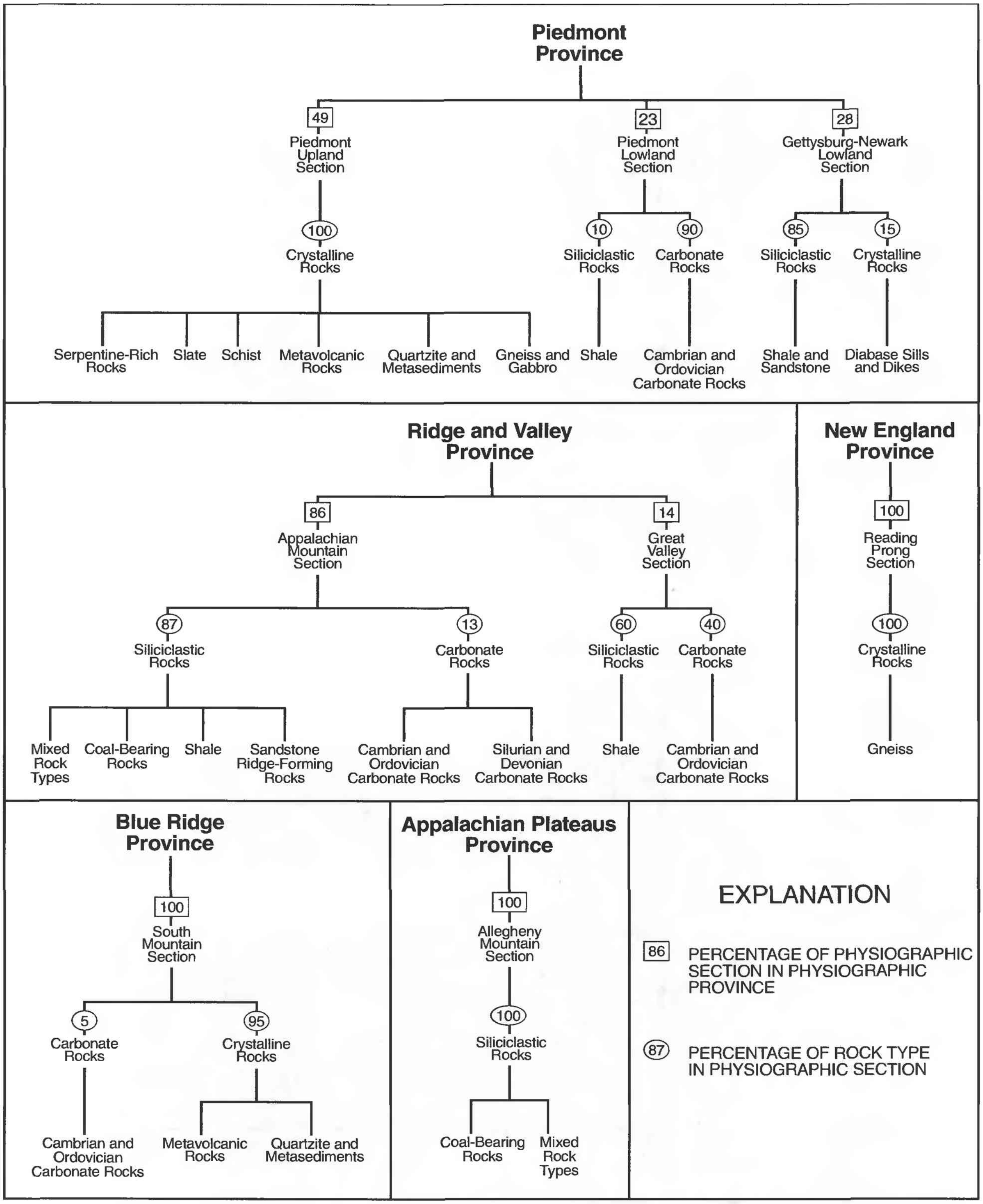


Figure 8. Geologic framework of the Lower Susquehanna River Basin based on physiographic provinces and generalized rock types.

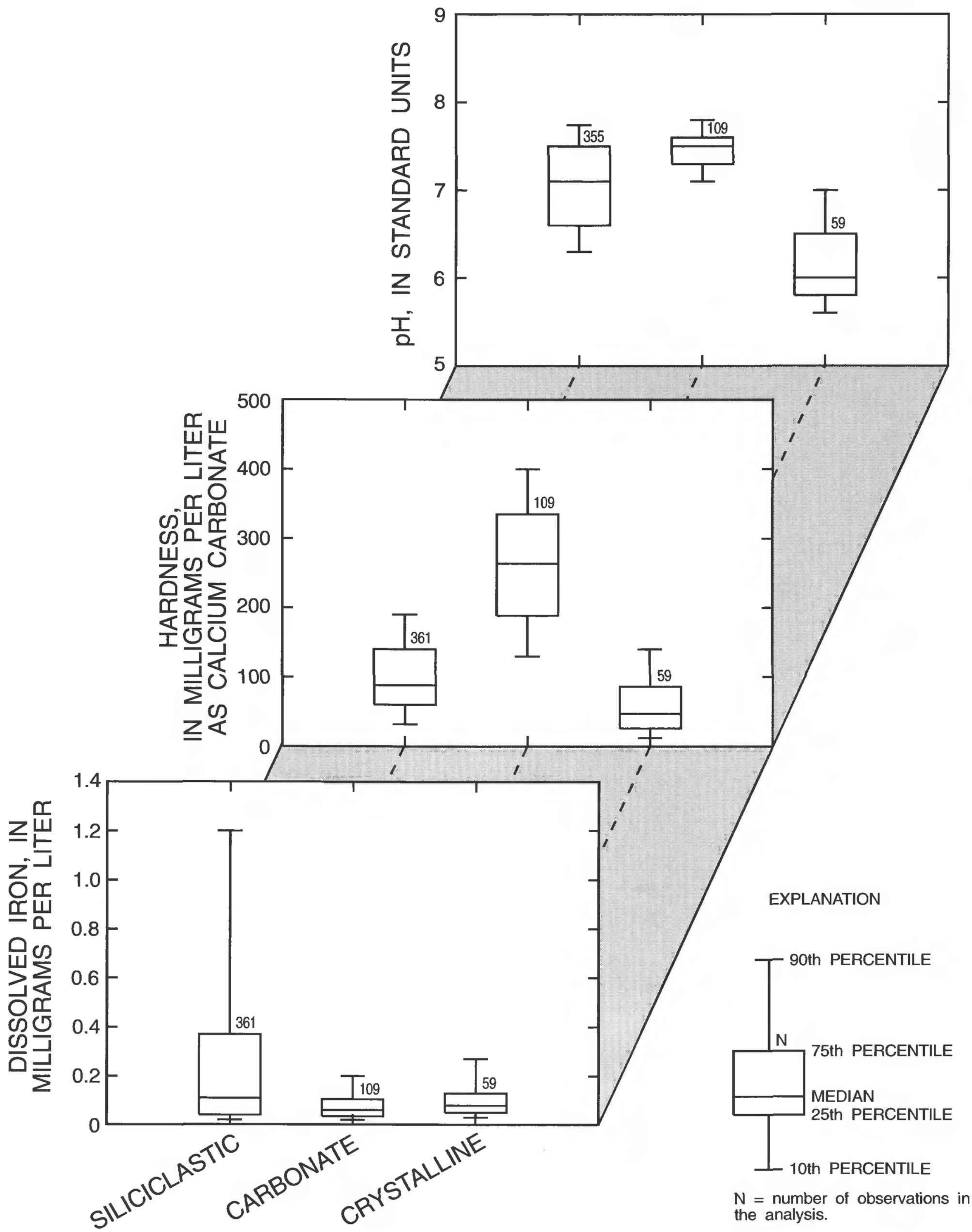


Figure 9. Selected chemical properties in ground water from three types of rocks in the Lower Susquehanna River Basin.

Carbonate rocks

Most of the carbonate rocks in the study unit were deposited either during the Cambrian and Ordovician periods or the Silurian and Devonian periods (fig. 7). In the Piedmont Lowland, Great Valley, and South Mountain Sections, the carbonate rocks that crop out are of Cambrian and Ordovician age (pl. 1). These rocks consist mostly of fairly thick-bedded limestone and dolomite with only minor amounts of marble and interbedded shale. Multiple periods of mountain building have deformed these rocks into complexly folded and thrusted structures.

The Appalachian Mountain Section includes carbonate rocks of Cambrian to Ordovician and Silurian to Devonian age. These rocks have undergone deformation into tight, plunging folds but are less deformed than the carbonate rocks of the Piedmont and Great Valley. The Cambrian to Ordovician carbonate rocks crop out intermittently across a wide band along the western margin of the Appalachian Mountain Section (pl. 1). The Silurian and Devonian carbonate rocks are interbedded with siliciclastic shales and sandstones to a greater degree than the Cambrian and Ordovician carbonate rocks. These interbedded carbonates interfinger throughout the Appalachian Mountain Section in thin ribbons less than 1 mi wide.

Weathering of carbonate rocks provides solutes that increase the dissolved-solids concentrations, acid-neutralizing capacity, hardness, and pH of ground water. The median hardness of 264 mg/L for 361 ground-water samples from carbonate rocks is three times the median for hardness for ground water from siliciclastic rocks and six times the median for crystalline rocks. Ground water from these rocks are all mapped as "hard" (greater than 100 mg/L) in map 2. The median pH of 7.5 for carbonate rocks also is the greatest among the three major rock-type categories (fig. 9).

Siliciclastic rocks

Siliciclastic rocks consist of sandstone, shale, siltstone, and conglomerate. These rocks are widely distributed throughout the Piedmont Lowland, Great Valley, Appalachian Mountain, Allegheny Mountain, and Gettysburg-Newark Lowland Sections (pl. 1). The oldest siliciclastic rocks are shales of Cambrian and Ordovician age that crop out in the Piedmont Lowland and Great Valley. The shale, like other rocks in these areas, has been extensively deformed.

Siliciclastic rocks of Ordovician through Pennsylvanian age crop out in the Appalachian Mountain and Allegheny Mountain Sections (pl. 1). The mountainous topography of the Appalachian Mountain Section is largely the result of differential erosion between folded quartz-rich sandstone forming the ridges and more erodible shale and soluble limestone in the valleys. Some siliciclastic rocks of Pennsylvanian and Mississippian age contain coal. Bituminous coal is present in the Broad Top Mountain area and along the Allegheny Front; whereas east of the Susquehanna, the coal has been metamorphosed to anthracite.

The youngest siliciclastic rocks found in the study unit are the red shale, siltstone, sandstone, and conglomerate in the Gettysburg-Newark Lowland. These rocks were formed from stream sediments that filled a down-faulted block structure during the Triassic period.

The major-ion chemistry of ground waters in these rocks is quite variable because of the presence or absence of carbonate cement. The large range in pH and hardness is shown in figure 9. Values of pH less than 7 and hardness less than 50 mg/L as calcium carbonate are typical of waters in orthoquartzite sandstone and conglomerate lacking carbonate cement. The headwaters of streams that form in these rocks are vulnerable to the effects of acid precipitation. Values of pH greater than 7 and hardness greater than 100 mg/L as calcium carbonate are characteristic of siliciclastic rocks deposited in a marine environment where carbonate minerals are present. Dissolved iron results from sulfide weathering of pyrite that is widely disseminated in noncarbonate siliciclastic rocks. Sulfide weathering commonly dominates in areas of coal-bearing rocks, resulting in surface and ground waters with pH less than 5 and elevated concentrations of dissolved metals such as iron (fig. 9).

Regolith

Regolith is the unconsolidated geologic material including soil that overlies the bedrock. On the basis of about 14,000 driller's logs in the study unit, regolith thickness ranges from 10 to 90 ft at 80 percent of all wells. Because these deposits can store several times more water than the fractured rocks that they mantle, they play an important role in the storage, movement, and quality of surface and ground water. However, the regolith is usually saturated discontinuously throughout only about half of its areal extent and does not usually yield large quantities of water directly to wells, consequently it is not considered by itself a major aquifer in the study unit.

Unconsolidated Sediments and Residuum

Unconsolidated sediments mantle most of the study unit. They primarily include glacial deposits and alluvium, colluvium, and residuum. Glacial ice and meltwater deposited till and stratified drift in the north-central part of the basin during the Illinoian glaciation (Leverett, 1957). The clayey, gray till is on less than 10 percent of the glaciated area. Stratified drift is exposed along the Susquehanna River valley within the glaciated region (pl. 1). Beyond the glaciated boundary, alluvium is in terraces cut along the narrow Juniata and Susquehanna River valleys when the riverbed was near the level of the terrace. Alluvium is present along most streams of any size.

Colluvium is the unconsolidated material usually found at the sides and base of a hillslope through the process of mass wasting. The major accumulations of colluvium are found in the mountainous Ridge and Valley and Blue Ridge Physiographic Provinces. In the Ridge and Valley Physiographic Province, colluvium covers about 30 percent of the land surface along the lower one-half to three fourths of mountain slopes (Ciolkosz and others, 1980). In the Blue Ridge Physiographic Province, colluvium may be as much as 450 ft thick along the western flanks of South Mountain (Becher and Root, 1981). In this area, the colluvium is an important aquifer that steadily releases water to the underlying carbonate bedrock aquifer that discharges to Yellow Breeches Creek.

Residuum is unconsolidated material that has formed in place from the weathering of the underlying bedrock. Residuum thickness varies widely but probably is greatest above the crystalline and carbonate rocks within the Piedmont and Great Valley. In the Appalachian Mountains Section of the Ridge and Valley Physiographic Province, residuum covers about 70 percent of the land surface and is thickest on ridge tops and valley floors (Ciolkosz and others, 1980, p. 33).

Soil

Soil mantles the bedrock and unconsolidated deposits throughout most of the study unit. Soil affects surface-water and ground-water chemistry by influencing (1) physical processes such as runoff, sedimentation, and infiltration, and (2) the availability of organic material, clay, microbiota, and gases that affect the chemical processes of dissolution, precipitation, adsorption, and oxidation-reduction.

The soil in the study unit can be categorized into five major groups according to the parent material from which the soil was formed: carbonate rocks, siliciclastic rocks, crystalline rocks, glacial till, and alluvium (U.S. Department of Agriculture, 1972). With the exception of soil derived from alluvium, the location of soil groups can be deduced from the rock types shown in plate 1. Discontinuous areas of alluvial soil are found adjacent to the Susquehanna River and along the Juniata River in Mifflin and Juniata Counties (U.S. Department of Agriculture, 1972).

Soil in the basin also can be divided into hydrologic groups (map 3) on the basis of its infiltration capacity, which is a function not only of parent material but also of slope, thickness, land use, and land cover (Susquehanna River Basin Study Coordinating Committee, 1970). Soil weathered from carbonate parent materials generally is reported to have "excellent" infiltration capacities. The rapid infiltration of precipitation to underlying solution-enlarged fractures in carbonate-rock terranes makes the shallow ground water in these areas especially susceptible to contamination. Soil developed in siliciclastic parent materials has "good" infiltration capacities if they were weathered from sandy sediments, and "poor" infiltration capacities if weathered from clay-rich shale or glacial till. The poor infiltration capacity of clayey soil causes streams flowing through this soil to rise rapidly after storms and dry up quickly during droughts. Soil formed from crystalline parent material has "good" infiltration capacities; although this soil is clayey, its thick profiles and generally low slopes promote infiltration. Soil adjacent to the major rivers has "very poor" infiltration capacities because it is clayey and often saturated.

Mineral Resources

Naturally occurring mineral deposits can affect the chemistry of surface and ground waters. The greatest effects on water quality are the acid production and sedimentation resulting from the mining of coal and metallic minerals. Nonfuel minerals such as limestone, sandstone, and clay are important economic resources in the study unit, but their effect on water quality is minor compared to that of coal and metallic minerals.

Coal is the most important economic mineral resource in the study area and has been mined since the early 1800's. The coal in the study unit is found principally in Pennsylvanian-aged rocks of the Anthracite, Broad Top, and Main Bituminous fields (pl. 3).

The major metallic mineral deposits and mines in the study area, as summarized by Rose (1970), are shown on plate 1. The metals may be widely disseminated around these locations. All of the mines were worked in the past and are now inactive. The mineral occurrences in plate 1 are grouped according to the age and type of rocks that host the mineral deposits.

Only the magnetite-type deposits of iron are shown on plate 1. Deposits of other minable types of iron (limonite, hematite) are generally small. Limonite "bog iron" is widely scattered throughout the basin except in the Piedmont Upland Section. Hematite is found primarily in sandstone of the Clinton Group of Silurian age.

In addition to the scattered deposits of uranium shown in plate 1, uranium, as well as thorium and radium, is disseminated throughout rocks, providing a source of radiochemicals in water. In sedimentary rocks, concentrations typically are least in carbonate rocks, intermediate in sandstone, and greatest in shale. In igneous rocks, granitic rocks typically contain the most uranium, thorium, and radium. The crystalline rocks of the Piedmont Physiographic Province are a probable source for levels as great as 32,000 pCi/L of radon-222 and 41 pCi/L of radium-226 (Senior and Vogel, 1995).

Climate

The climate of the study unit affects water chemistry through the basin's water budget and precipitation chemistry. The quantity of water added by precipitation and the amount removed by evapotranspiration are major controls on the water available for streamflow and ground water. The temperature and humidity of the basin affect rates of weathering of rocks and soil. In addition, the chemical composition of precipitation that falls on the study unit is the initial chemical signature of the basin's water.

The climate of the study unit is controlled by a prevailing westerly air circulation and the proximity of the basin to the Atlantic Ocean. The westerly winds bring air masses from the central United States and Canada, which give the Appalachian Plateau and Ridge and Valley Physiographic Provinces a humid continental climate characterized by large seasonal temperature variations. A more coastal-type climate exists in the Piedmont Physiographic Province in the southeastern part of the basin where the secondary circulation of warm, moist air from the Atlantic Ocean moderates temperatures and provides precipitation amounts that are somewhat greater than in other parts of the basin (U.S. Geological Survey, 1991).

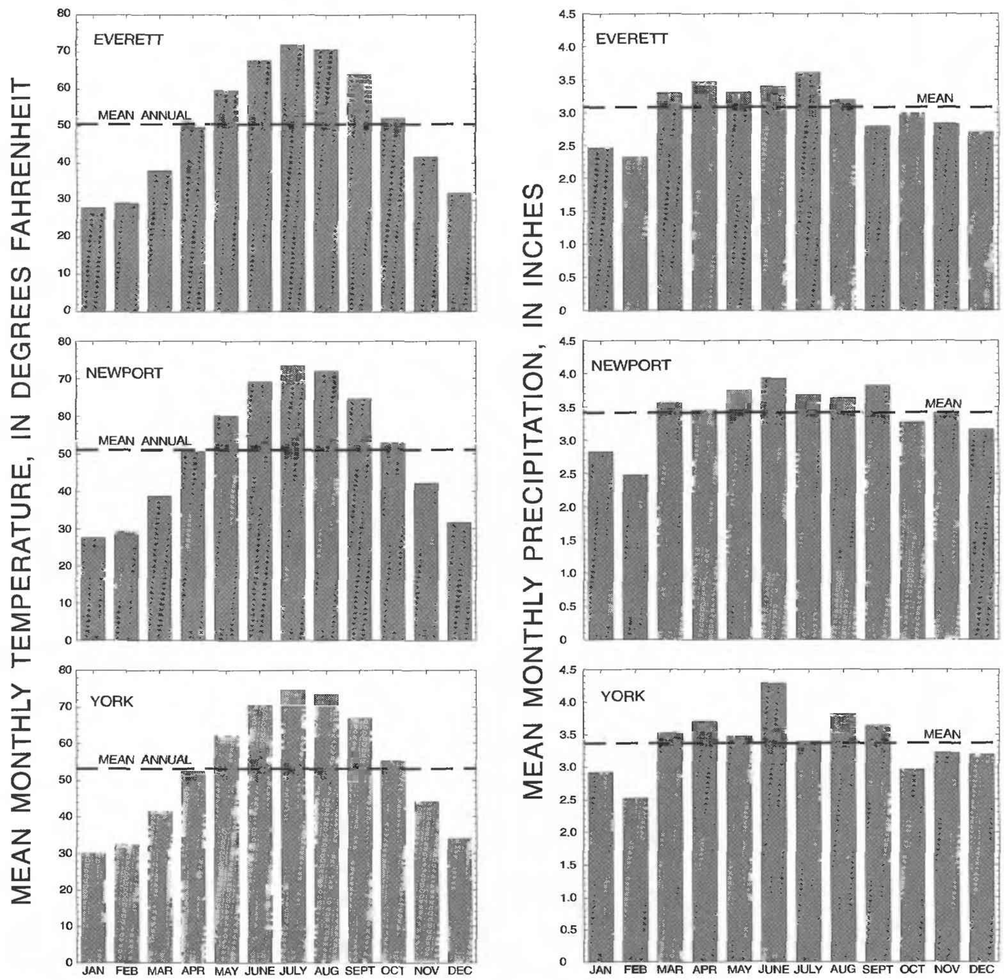
Precipitation

Mean annual precipitation ranged from about 38 to 48 in. and averaged about 40 in. throughout the study unit during 1951-80 (map 4). Precipitation is generally less in the center of the basin than near its western edge because storms that track across the basin with the prevailing westerly winds lose moisture over the Allegheny Mountains before reaching the study unit. This "rain-out" creates a rain shadow throughout the west-central part of the basin. The eastern and southeastern parts of the basin receive additional precipitation when moist Atlantic coastal air is forced inland, and when occasional major tropical storms or hurricanes move northward along the coast.

Precipitation is distributed fairly evenly throughout the year. Mean monthly precipitation typically is 3 to 4 in. (fig. 10). About 45 percent of the annual precipitation is contributed by storms from May through September during the growing season. Most of the remaining 55 percent occurs when vegetation is dormant and, therefore, is available to recharge ground water. Winter precipitation typically includes from about 20 in. of snow near the Maryland border to about 50 in. in the mountains near Altoona (Susquehanna River Basin Study Coordinating Committee, 1970).

Long-term precipitation records show several wet and dry periods since the late 1890's (fig. 11). Precipitation recorded at Lancaster and Harrisburg indicate that most of 1900 through 1930 and the 1960's generally were drier than average and 1931-60 was wetter than average. However, wet and dry periods are not necessarily coincident throughout the basin, as indicated by the precipitation recorded at Selinsgrove. Basinwide, droughts of greatest severity were in 1930-34, 1939-42, 1953-55, and 1961-67.

Tropical storms and hurricanes, which move northward along the Atlantic coast from June through October, periodically affect the study unit. The most extreme example was Hurricane Agnes in June 1972, which produced as much as 18 in. of rain in 5 days and caused the most extensive flooding ever recorded in central Pennsylvania (Miller, 1974). Although hurricanes are infrequent events, their effects on sedimentation and aquatic habitat can be more significant than years of normal conditions.



[NOTE: Locations of weather stations are shown on map 4.]

Figure 10. Mean monthly temperature and precipitation at selected weather stations in the Lower Susquehanna River Basin, 1951-80.

Temperature

Mean annual air temperature ranged from 46 to 55°F in the study unit during 1951-80 (map 5). The warmest areas are in Maryland, which are the farthest south and nearest to sea level in elevation. Mountainous areas of Northumberland, Schuylkill, Centre, and Blair Counties in the northeastern and northwestern parts of the basin are the coldest.

Air temperatures vary widely throughout the year (fig. 10). Mean monthly temperatures range from the high 20's (°F) in January (the coldest month) to the mid 70's in July (the hottest month). The growing season extends from May through September throughout the basin and ranges from about 160 days in the northern areas to 200 days in the south (Susquehanna River Basin Coordinating Committee, 1970). Caution is needed when evaluating the significance of average temperatures and lengths of growing season, especially in the Ridge and Valley Physiographic Province, because the drainage of cool air from ridges into valleys causes large local temperature variations.

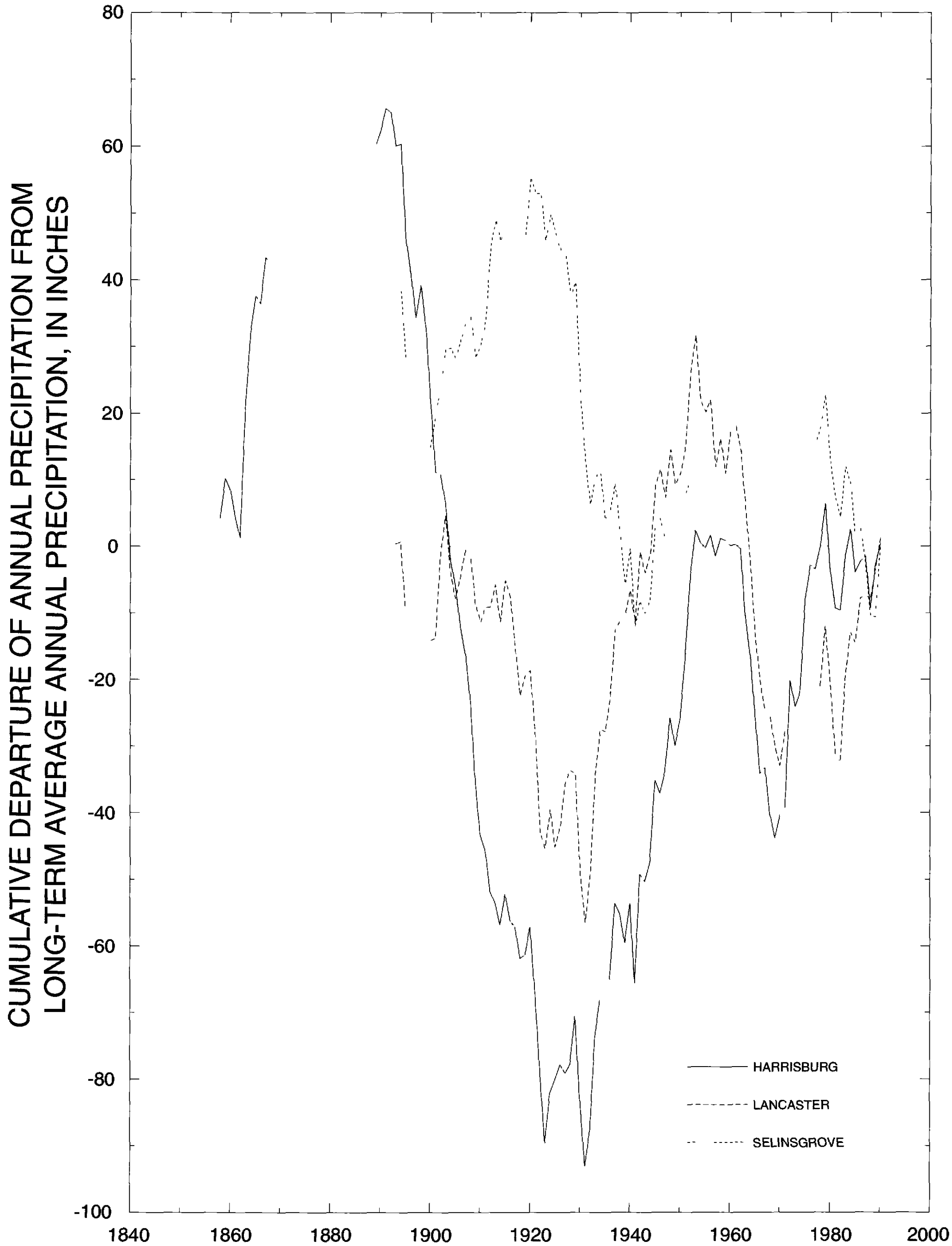


Figure 11. Cumulative departure of annual precipitation from long-term average precipitation at Harrisburg, Selinsgrove, and Lancaster.

Ground water at depths greater than about 50 ft below land surface is maintained at a nearly constant temperature, approximately equal to the mean annual air temperature. According to Eckstein and others (1982), the temperature of ground water at 100 ft below land surface ranges from 51 to 55°F in the study unit. The nearly constant year-around temperatures (52 to 55°F) of many springs in the Great Valley is a reflection of their ground-water source. The high-quality, cold-water fishery habitat of many spring-fed "limestone streams" is because of the large inflow of constant-temperature ground water.

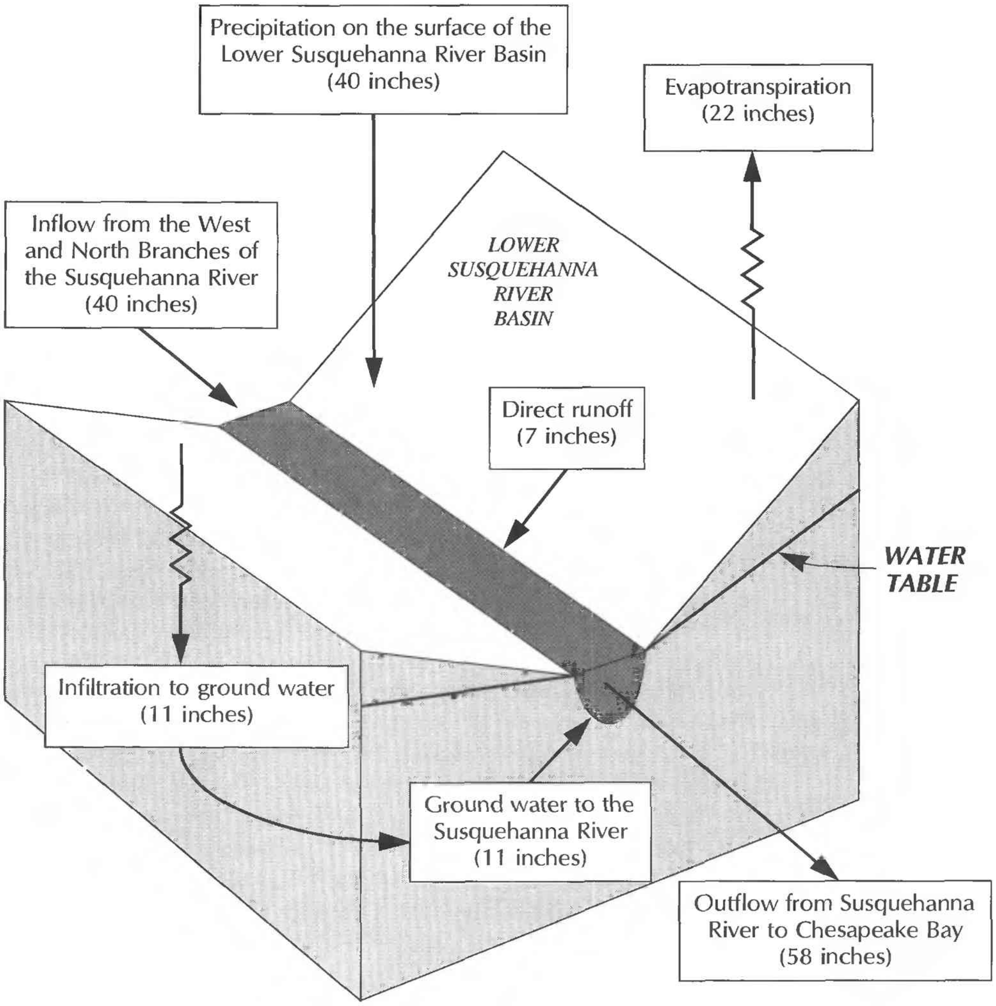
Evapotranspiration

Evapotranspiration is the loss of water by evaporation from the earth's surface and transpiration by plants. Potential evapotranspiration (loss that would occur if sufficient water were available to evaporate or transpire) ranges from about 26 to 29 in/yr (map 6). Because water is not always available, potential evapotranspiration overestimates the actual evapotranspiration. Estimates that better represent the actual evapotranspiration can be computed by assuming that evapotranspiration equals the difference between precipitation and runoff measured at streamflow-gaging stations (also termed water loss). In the study unit, where consumptive withdrawals of water are minor, this assumption is reasonable. Water loss ranges from 16 to 28 in. (map 6).

Hydrology

The most general conceptualization of the hydrologic framework of the study unit is illustrated by the basinwide water budget (fig. 12). The water volumes were computed from streamflow and precipitation records for 1951-80 and are expressed as inches of water spread evenly over the basin surface. The budget shows that water is added in approximately equal amounts by precipitation on the basin's surface and by streamflow of the Susquehanna River where it enters the study unit at Sunbury. The water quality of the Susquehanna River in the study unit, therefore, is greatly affected by the large volume of water contributed from the watershed upstream from Sunbury. About 22 in. of the 40 in. of precipitation that falls on the basin annually is lost through evapotranspiration. This process concentrates to some extent the solutes dissolved in the precipitation. About 7 in. of the 18 in. of precipitation that is not returned to the atmosphere through evapotranspiration becomes direct runoff to a stream and the remaining 11 in. infiltrates to the ground-water system.

Concentrations of solutes and sediments in streams depend in large part on whether runoff enters the stream predominantly as direct runoff or as ground-water discharge. For example, the water quality of streamflow during storms is dominated by the chemical composition of overland flow; the stream quality during low-flow periods is mainly a function of the ground-water chemistry.



WATER BUDGETS: (Based on streamflow and precipitation measurements, 1951-80)

OUTFLOW (58 inches) = PRECIPITATION (40 inches) + INFLOW (40 inches) − EVAPOTRANSPIRATION (22 inches)

PRECIPITATION (40 inches) = DIRECT RUNOFF (7 inches) + INFILTRATION (11 inches) + EVAPOTRANSPIRATION (22 inches)

Figure 12. Schematic diagram of water budgets for 1951-80, expressed as inches of water on the Lower Susquehanna River Basin surface area.

The Susquehanna River drains all but about 150 mi^2 of the 9,200 mi^2 study unit. The river enters the study unit near Sunbury where the West Branch joins the main stem (pl. 2). Streamflow from the West Branch is measured at a streamflow-gaging station at Lewisburg (pl. 2). Streamflow from the main stem of the Susquehanna River (sometimes referred to as the North Branch) is measured at Danville. From 1951 to 1980, the West and North branches contributed about 28 and 40 percent of the streamflow, respectively, that eventually entered Chesapeake Bay. Downstream from where the branches join, the daily streamflow of the Susquehanna River during 1951-80 averaged about 27,000 ft^3/s at Sunbury; however, variations during 1937-91 were extreme and ranged from 964 to 620,000 ft^3/s.

Thirty-one major tributary streams with drainage basins greater than 100 mi^2 contribute water to the Susquehanna River (fig. 13 and pl. 2). The Juniata River, largest tributary to the Susquehanna, enters about 20 mi upstream from Harrisburg. The Juniata's 3,400 mi^2 watershed accounts for nearly 40 percent of the study unit land area and provides about 11 percent of the Susquehanna's flow to Chesapeake Bay. The Susquehanna River is so wide and shallow that even the addition of water from large tributaries such as the West and North branches of the Susquehanna and the Juniata River do not mix for tens of miles downstream. In fact, the sediment and major-ion chemistry of water from these tributaries can be distinguished at Harrisburg (Anderson, 1963).

Between Harrisburg and the Chesapeake Bay, the Susquehanna River flows through four major dams (York Haven, Safe Harbor, Holtwood, and Conowingo) and their accompanying reservoirs. The three dams nearest the river's mouth create nearly a continuous 30-mi stretch of flat water (fig. 14) that has dramatically changed the aquatic habitat and restricted migration of anadromous fishes. Downstream from Conowingo Dam, the Susquehanna River discharges about 38,300 ft^3/s to the tidewaters of Chesapeake Bay, or about half the bay's total freshwater. Estimates of streamflow, sediment, and nutrient loads contributed to Chesapeake Bay are summarized in table 2

Table 2. *Estimated loads from the Susquehanna River to the Chesapeake Bay in Maryland*

[ft^3/s, cubic foot per second; ton/yr, ton per year]

Constituent	Discharge or load	Percentage of total discharge or load to bay from all sources
Streamflow	[1]38,300 ft^3/s	[2]45 (of freshwater)
Sediment	[3]900,000ton/yr	[4]40
Nitrogen	[5]69,000ton/yr	[5]39
Phosphorus	3,300ton/yr	[5]24

[1] Streamflow of Susquehanna River near Conowingo, Md., adjusted to 58 years of flow at Marietta, Pa.
[2] From Horton and Eichbaum (1991, p. 55).
[3] Lloyd Reed, U.S. Geological Survey, written commun., 1992.
[4] From U.S. Environmental Protection Agency (1982, p. iii).
[5] From U.S. Environmental Protection Agency, average loads for 1984-87 (1992).

Annual streamflow

Precipitation not returned to the atmosphere through evapotranspiration eventually finds its way to streams, either as overland runoff across the land surface, interflow through the soil and unsaturated zone, or from ground-water flow. Streamflow (also called runoff)

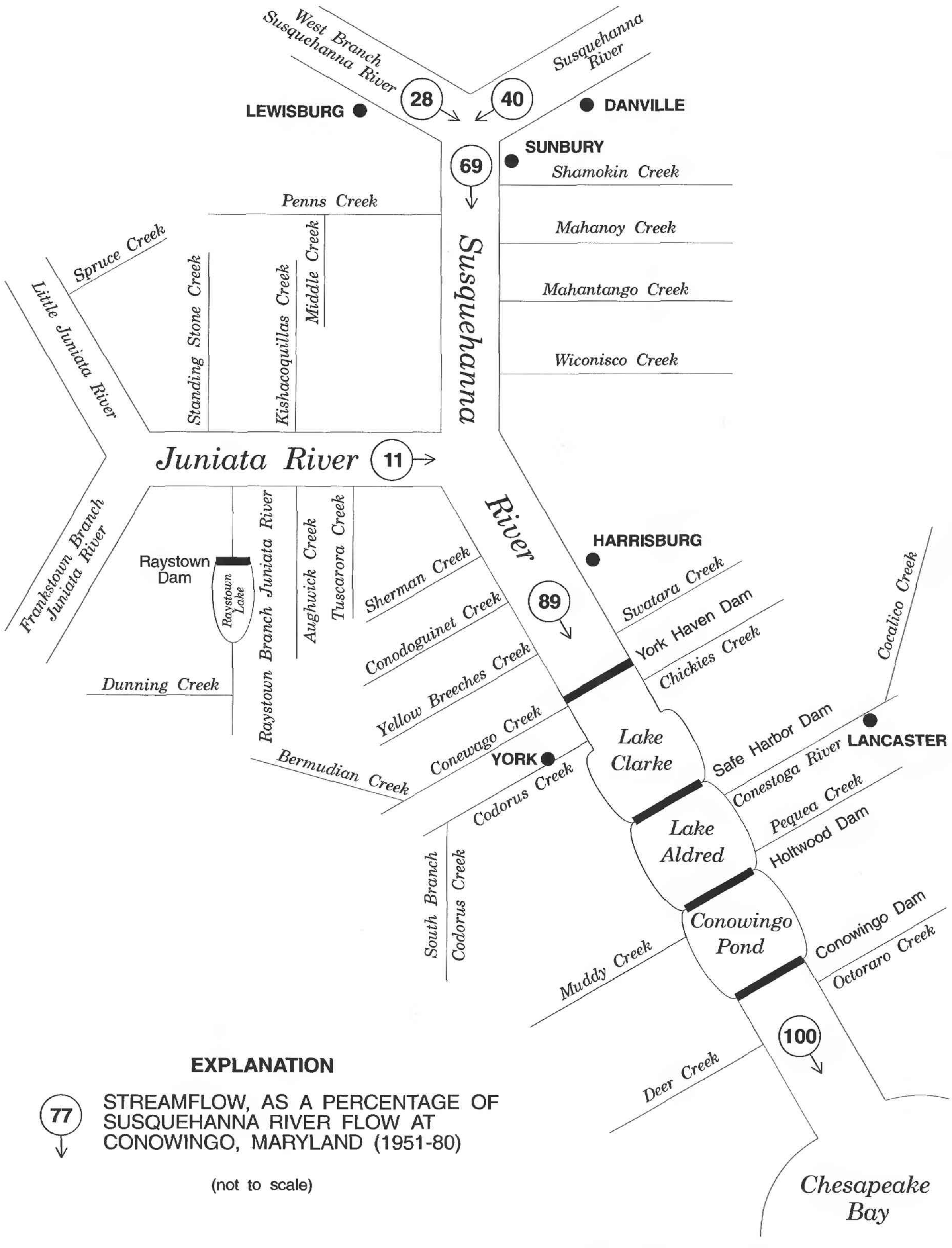


Figure 13. Schematic diagram showing tributaries to the Susquehanna River with basins greater than 100 square miles.

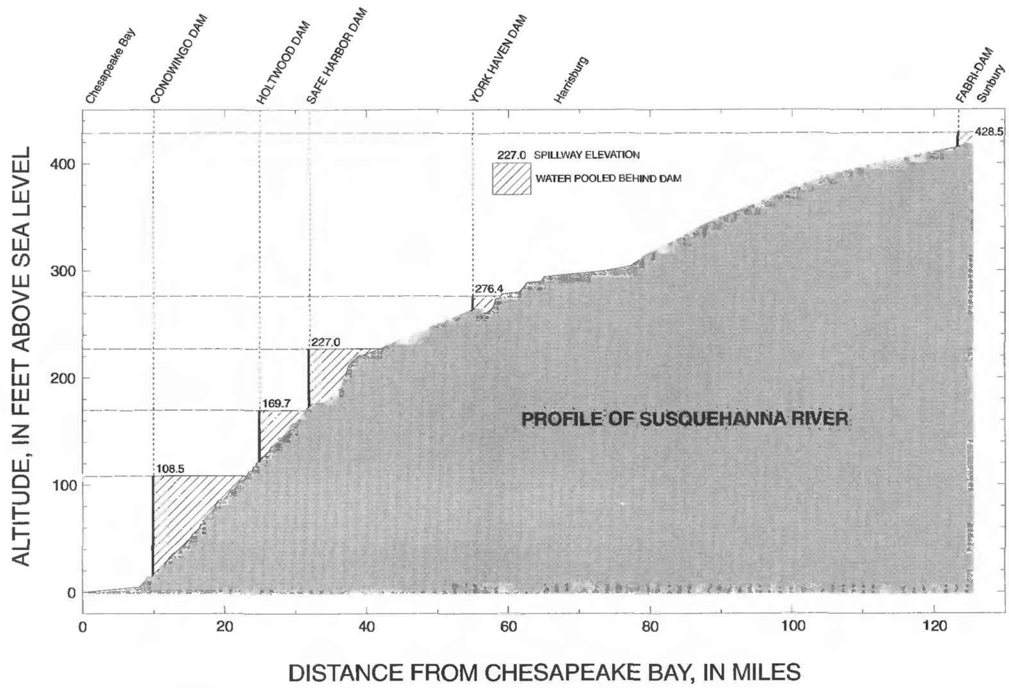


Figure 14. Profile of the Susquehanna River bed from Sunbury to Chesapeake Bay.

expressed as inches of water spread evenly over its entire watershed, averaged about 18 in/yr [1.3 $(ft^3/s)/mi^2$] throughout most of the study unit during 1951-80. Mean annual runoff varied areally between 14 and 26 in. [1.1 to 1.9 $(ft^3/s)/mi^2$] and was greatest in the highlands along the Allegheny Front and in Schuylkill County, where precipitation was greatest and evaporation was least (map 7). Most watersheds produce 16 to 20 in. of runoff per year [1.2 to 1.4 $(ft^3/s)/mi^2$] (table 3).

Overland runoff in a humid, vegetated basin such as the study unit, is relatively minor except where the natural vegetation has been disrupted—such as cultivated fields and impervious urban surfaces (Freeze and Cherry, 1979, p. 219). Nevertheless, overland runoff is the principal mechanism for delivering sediment and many contaminants from the land surface to streams. Interflow can provide a primary source of streamflow, especially where basins have steep slopes mantled by permeable soil such as those in the Ridge and Valley and Blue Ridge Physiographic Provinces. The concentration of dissolved minerals in interflow is small because it moves rapidly and follows a relatively short path to the nearest stream. The long flow paths and slow traveltime compared to overland flow and interflow allow ground water to dissolve larger quantities of minerals from rocks and soil, usually making it the principal source of major ions found in stream water.

Separating the streamflow into overland runoff, interflow, and ground-water flow is possible only in small watersheds that have been intensively instrumented. Hydrograph records, however, can be separated into a rapid "direct runoff," which represents overland flow, interflow, and some unknown amount of ground-water flow; and "base flow," which is some fraction of ground-water flow that discharges to the stream. Base flow commonly is used as an estimate of the ground-water contribution to streams, but it most likely underestimates this source of water because hydrograph-separation techniques tend to underestimate the quantity of ground water contributed during storms.

Table 3. *Streamflow characteristics at selected stream-gaging stations in the Lower Susquehanna River Basin, Pennsylvania and Maryland*

[All streamflow characteristics are cubic foot per second per square mile]

Physiographic section[1] and station name	Drainage area (square miles)	Average runoff[2]	$Q_{7\text{-}10}$[3]	Average annual flood[4]
Appalachian Mountain Section:				
East Mahantango Creek near Dalmatia	162	1.38	0.032	64
Penns Creek at Penns Creek	301	1.45	.117	39
Sherman Creek at Shermans Dale	200	1.43	.070	85
Aughwick Creek near Three Springs	205	1.19	.017	69
Great Valley Section:				
Conodoguinet Creek near Hogestown	470	1.24	.160	29
Yellow Breeches Creek near Camp Hill	216	1.34	.389	26
Gettysburg/Newark Lowland:				
West Conewago Creek near Manchester	510	1.15	.016	55
Piedmont Lowland:				
Conestoga River at Lancaster	324	1.25	.102	49
Piedmont Upland:				
Deer Creek at Rocks, Maryland	124	1.31	[5].210	58
Muddy Creek at Castle Fin	133	1.17	.226	75

[1] From Berg and others (1989).
[2] For period of record.
[3] From Page and Shaw (1977).
[4] From Flippo (1977).
[5] From Carpenter (1983).

Streamflow variations

The concentration of naturally occurring dissolved minerals, sediment, and contaminants in stream water varies greatly depending on the magnitude of streamflow. This variability is caused by the changes in sources of water contributing to the stream during a storm (overland runoff, interflow, and ground water) and the in-stream effects of dilution and washoff (Hirsch and others, 1991). Most major ions are added to the Susquehanna River at a relatively constant rate during base-flow conditions, but when the streamflow is large, the chemical constituents in the base flow are diluted by large quantities of overland runoff and interflow. Dilution also decreases the concentration of contaminants from point-source discharges of wastes added directly to the stream. The increased contribution of overland runoff during storms, however, can cause sediment concentrations in streams to increase. In addition, during storms the physical washoff of chemical constituents and particulate matter from streambed sediments often increases the concentrations of sediment as well as trace elements and nutrients attached to the sediment. In streambeds affected by coal-mine discharge, storm flows will wash deposits of iron hydroxides from the streambed during the early stages of the storm (thereby increasing the concentrations of iron), and dilute the concentrations later during the same storm after the deposits have been washed away.

Approximately 60 percent of annual streamflow occurs from February through May (fig. 15). Streamflow is greatest during March and April because of snowmelt and the small amount of water lost through evapotranspiration, and least during the hot growing-season months of July, August, and September because of the large losses of precipitation through evapotranspiration. Streamflow is almost entirely sustained by contributions from base flow during dry months; even during wet periods, ground water is the major component of streamflow (DeWalle, 1990). Base flow estimated at 24 streamflow-gaging stations ranges from 55 to 88 percent of annual streamflow and averages about 60 percent.

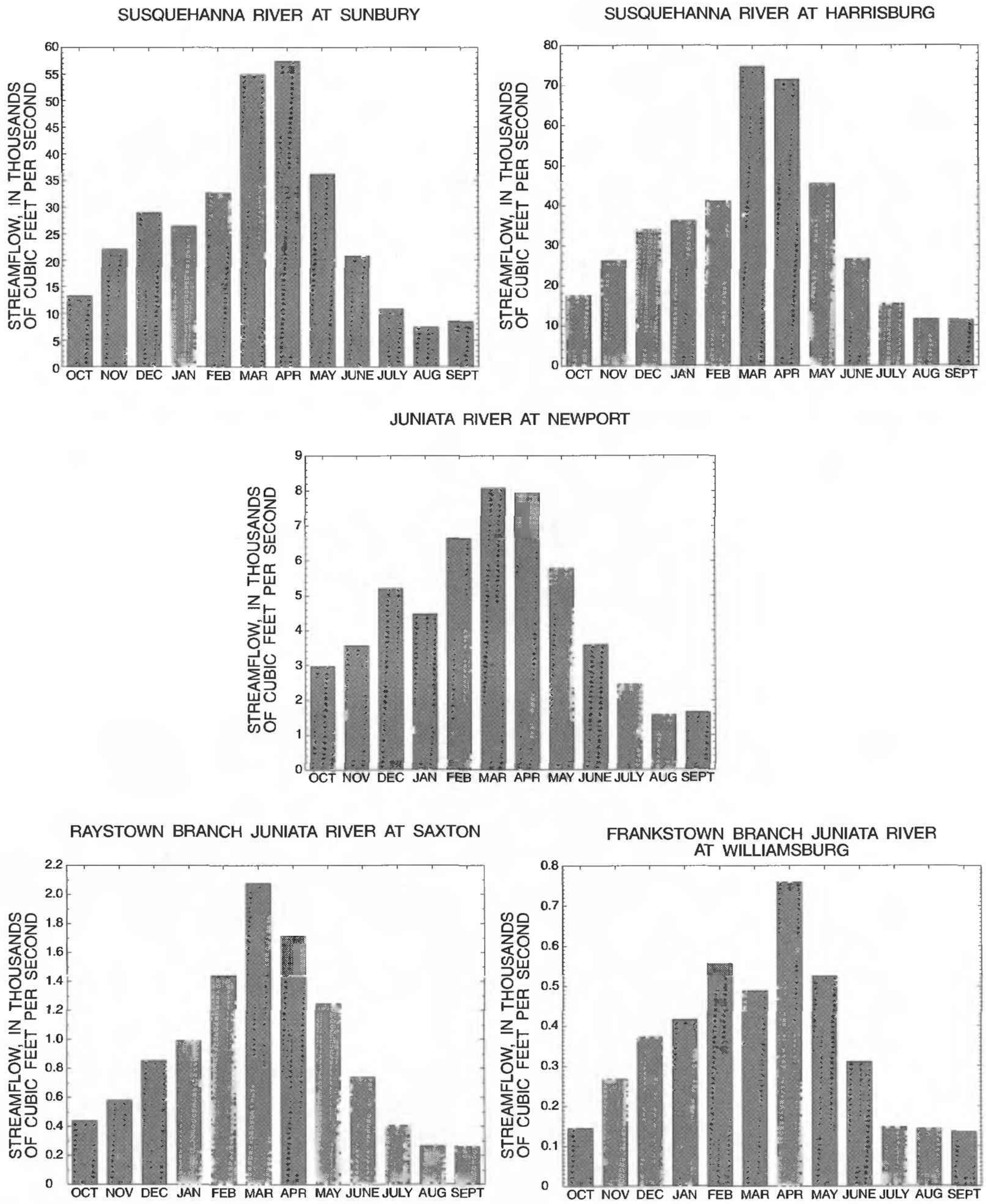


Figure 15. Monthly streamflow at selected gaging stations in the Lower Susquehanna River Basin, 1951-80.

The variability of base-flow contributions among basins is caused by differences in the physical properties in the basin. Physical properties that enhance rapid infiltration of precipitation to depths beyond the reach of root systems will increase the ground-water contributions to streams. The most significant factors that facilitate infiltration are carbonate bedrock and thick, permeable regolith. In carbonate-rock terranes such as parts of the Great Valley Section of the Ridge and Valley Physiographic Province, nearly all precipitation that is not returned to the atmosphere through evapotranspiration infiltrates to the ground-water system. Thick regolith, even on steep-sided mountain slopes of the Appalachian Mountains, also promotes infiltration and stores large quantities of water, which are later released to streams as base flow.

The type of bedrock in a basin affects base-flow contributions to streams as shown by streamflow-duration curves (fig. 16). The smaller the contribution of base flow to the stream, the steeper the slope of the duration curve. Streamflow in West Conewago and Aughwick Creeks contains a small base-flow component because the basins are underlain by shaley rocks that are not mantled by thick saturated regolith. Stony Creek near Dauphin is underlain by similar rock types but the rocks are mantled by a thick, bouldery colluvium that stores and slowly releases water to the stream. The influence of the thick, saprolite soil that mantles crystalline rocks of the Piedmont Upland is illustrated by the duration curve for Muddy Creek. Most of the base flow to streams in this physiographic section is contributed from storage within the regolith. Yellow Breeches Creek is an example of a stream dominated by base flow. This basin is underlain by carbonate rocks and noncarbonate rocks that are mantled by as much as several hundred feet of colluvium. The ground water stored in the carbonate rocks and thick colluvium combine to provide the steady base flow to Yellow Breeches Creek.

Floods.—Floods have a great effect on the water quality of streams. During floods, the processes of dilution and washoff are most extreme, which greatly affects sediment loads, concentrations of dissolved ions and contaminants, and aquatic habitat. Flood-flow characteristics vary widely throughout the study unit. The average annual flood discharge at 10 streamflow-gaging stations ranges from 26 to 85 $(ft/s)/mi^2$ (table 3). Flood discharge is greatest in the Appalachian Mountain Section of the study unit, where steep mountain slopes promote rapid direct runoff to streams. Exceptions to this generalization can be found where basins are underlain by carbonate rocks; for example, the small flood discharge of Penns Creek is moderated by the influence of carbonate rock within its basin. The large percentage of carbonate rock allows precipitation to infiltrate to the ground-water system rather than contribute to direct runoff. The lowest flood flows occur in the Great Valley Section because 40 percent of this section is underlain by carbonate rocks. The Piedmont Lowland Section also is underlain predominantly by carbonate rocks but the intensive agriculture in the area and lesser development of karst topography probably causes greater flood flows than in the Great Valley.

Major floods occurred in the study unit in 1889, 1894, 1936, 1972, and 1975. The greatest recorded flooding in the Susquehanna River was the result of precipitation from Hurricane Agnes during June 20-25, 1972. During 10 days of flooding, about 34 million tons of sediment were discharged to Chesapeake Bay by the Susquehanna River (Schubel, 1975). This sediment load dwarfs the average load of 0.9 million tons of sediment discharged annually by the Susquehanna River. The tremendous influx of sediment and freshwater to Chesapeake Bay during Hurricane Agnes had an adverse effect on some clams, oysters, and aquatic vegetation (U.S. Army Corps of Engineers, 1975). In addition to freshwater and sediment, about 3 million pounds of phosphate and 5 million pounds of nitrate were transported to the Bay and to reservoirs on the Susquehanna River during the Agnes flood (U.S. Army Corps of Engineers, 1975).

Droughts.—Streamflows during times of low flow and drought also vary widely (table 3). The continuous 7-day streamflows with a recurrence interval of 10 years ($Q_{7\text{-}10}$) are lowest in basins underlain by shale thinly mantled by regolith, where direct runoff is

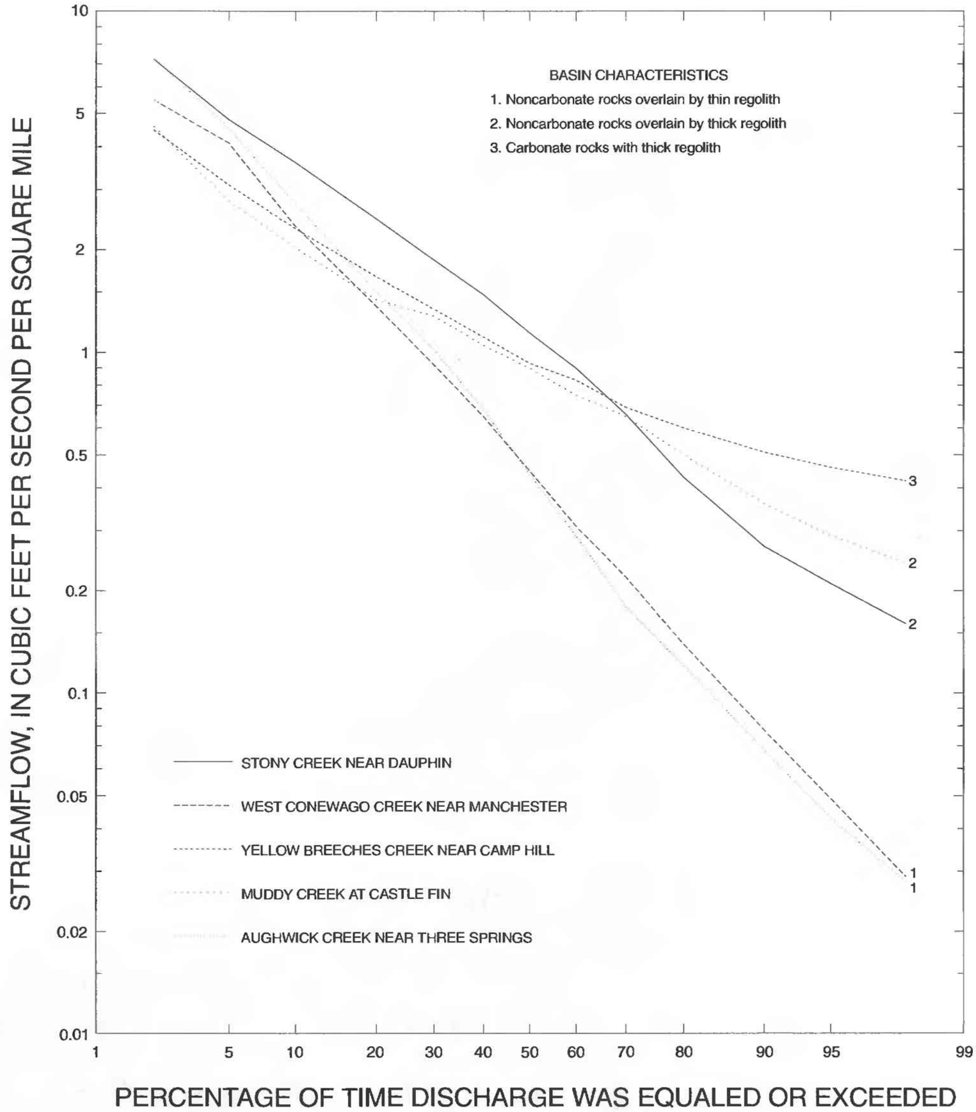


Figure 16. Flow duration curves for selected streamflow-gaging stations in the Lower Susquehanna River Basin for period of record to 1972.

promoted at the expense of infiltration. All basins in the Gettysburg/Newark Lowland and in valleys underlain by shale in the Appalachian Mountain Section fall into this category. Q_{7-10} less than 0.02 $(ft^3/s)/mi^2$ such as in West Conewago and Aughwick Creeks are typical for streams in basins underlain by thinly mantled shale. The streams that sustain the greatest flow during drought are those situated in basins that allow maximum infiltration of precipitation to the ground-water system. These basins either are underlain by a large percentage of carbonate rock (such as Penns Creek, Conodoguinet Creek, and Conestoga River) or a thick mantle of permeable regolith (such as Muddy Creek). In the Yellow Breeches Creek Basin, the large percentage of carbonate rock and several hundred feet of saturated regolith combine to maintain an extremely constant flow and large Q_{7-10} [0.389 $(ft^3/s)/mi^2$] during periods of drought.

Major droughts occurred in the study unit during 1930-34, 1939-42, 1953-55, 1961-67 (U.S. Geological Survey, 1991). The longest period of drought was during the 1960's. During drought periods, the water table declines and base flow is derived from deeper ground-water flow paths than during wetter periods. Ground water that has traveled a longer, slower deep path provides greater concentrations of dissolved solids than does shallow ground water, because of its greater contact time with bedrock. The greatest water-quality problem during drought, however, is that the diminished streamflow volume does not dilute wastewater loads to the same extent as during periods of average flow. During periods when streamflow reaches the $Q_{7\text{-}10}$, about 100 stream reaches in the study unit located downstream from wastewater discharges are likely to contain toxic compounds in concentrations that are predicted to be a health problem for aquatic life or humans (Cuong Duc Vu, Pennsylvania Department of Natural Resources, Bureau of Water Quality Management, written commun., several documents, 1988-91).

Ground Water

The ground-water flow system affects water quality in several ways. Not only does the flow path along which ground water moves influence its chemical character and susceptibility to contamination, but the large contributions of ground water to streams affect the chemical composition of streamflow.

Occurrence

Ground water is encountered at an average depth of about 35 ft beneath most parts of the study unit regardless of bedrock type. Depth to water typically (90 percent of all values) ranges between 10 and 100 ft below land surface—the median depth beneath valleys is about 20 ft and beneath hills about 45 ft. Ground water is present within the generalized geologic framework, which consists of fractured bedrock and the porous regolith that commonly covers it (fig. 17). Where the regolith is saturated, ground water is present under water-table conditions within the pore spaces between grains of unconsolidated material. These pore spaces typically provide a storage volume for ground water equal to about 8 to 24 percent of the regolith's bulk volume, which generally is several times greater than the storage capacity of the underlying bedrock (Swain and others, 1991, p. 24). The regolith frequently is more porous and permeable than the underlying bedrock, so it facilitates the infiltration of precipitation that otherwise might quickly run off the land surface to a nearby stream; because the regolith can store a large quantity of ground water, many streams are sustained by water slowly released from it.

Ground water in well-indurated or crystalline bedrock exists primarily in fractures, which are openings created along cracks, joints, faults, cleavage, schistosity, and bedding planes. The primary porosity of most rocks in the basin has been filled with mineral cement or destroyed during periods of structural deformation. The fracture space available for water storage typically ranges from much less than 1 to about 10 percent of the bulk rock volume. Ground water in bedrock of the study unit is difficult to label as either confined or unconfined. In many fractures, the water is physically confined from the atmosphere by nearly impermeable rock; however, these fractures are usually interconnected to others where the water is in free contact with the atmosphere. Gerhart and Lazorchick (1988, p. 10) describe this situation as a complex water-table aquifer. Ground water does occur in "classic" confined conditions in the Gettysburg-Newark Lowland and Appalachian Mountain Sections, where, in some cases, distinct water-bearing zones and confining units can be identified.

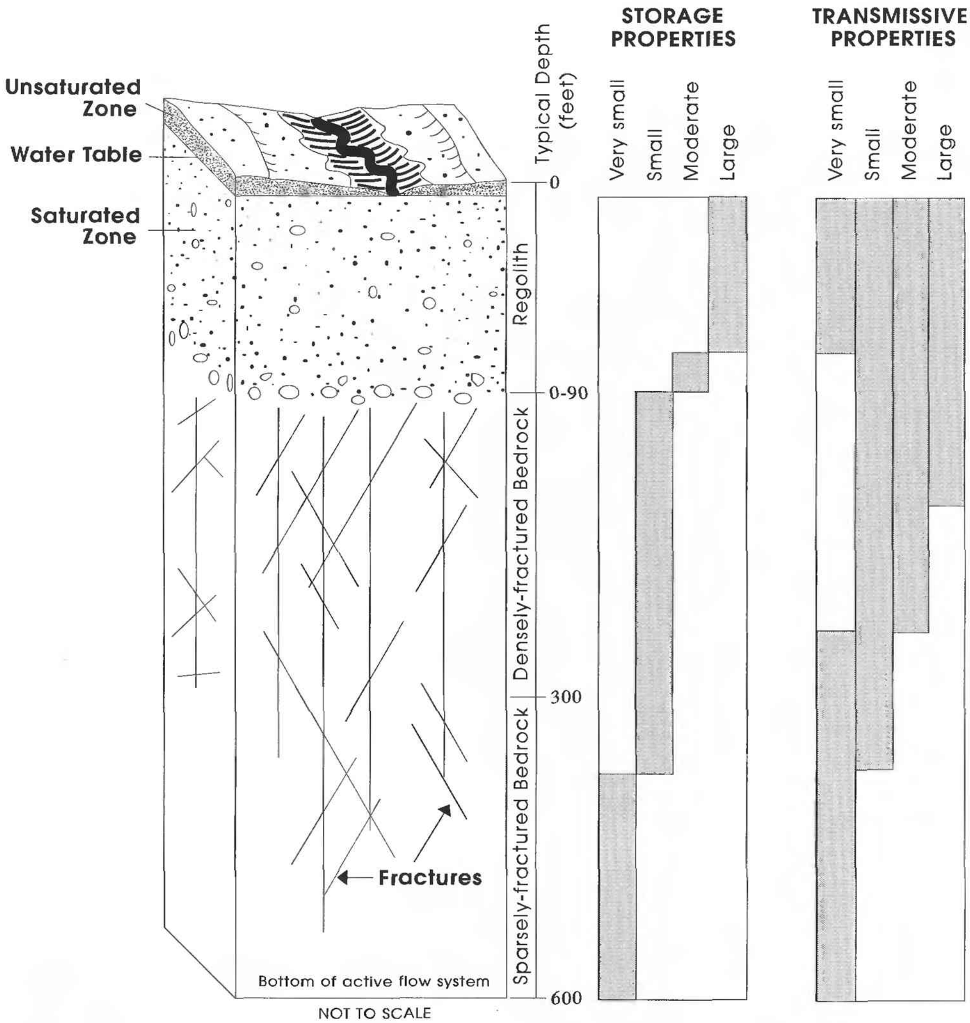


Figure 17. Geologic framework and relative hydraulic properties of fractured bedrock mantled by unconsolidated regolith. (Modified from Heath, 1984, fig. 3.)

Recharge, Movement, and Discharge

Ground water is recharged from the infiltration of precipitation and seepage of water from streams. The average basinwide ground-water recharge rate is 11 in/yr—about 28 percent of the average annual precipitation (fig. 12). However, recharge rates vary considerably throughout the basin depending on precipitation, evapotranspiration, slope, regolith, vegetation, land use, and rock type. Average annual recharge rates range from 8.4 in. for Triassic shale of the Gettysburg-Newark Lowland to 16.8 in. for carbonate rocks mantled by a thick regolith (Taylor and Werkheiser, 1984).

Recharge not only varies spatially but also seasonally. Recharge is greatest when vegetation is dormant and the ground is not frozen; thus, on average, significant amounts of ground-water recharge are most likely in October, November, March, and April. A lack of precipitation during these months will cause much more serious lowering of the water table than will a mid-summer drought, when most of the precipitation is utilized by vegetation. However, a detailed study of ground water in a carbonate-rock aquifer at a farm in Lancaster County showed that recharge can occur in any month provided that precipitation is great enough during a sustained period to exceed the field capacity of the soil (U.S. Department of Agriculture, 1992, p. 297).

The size of ground-water-flow systems is controlled mainly by topography and depth of fracturing. Stream density is great in most areas, consequently, ground-water flow systems are local and travel paths are short. Most ground-water movement is shallow because bedrock fracture density is greatest at depths less than about 300 ft below land surface. Tritium concentrations of water from the Susquehanna River indicate that only 20 percent of the water in the river has been out of contact with the atmosphere for more than 1 year (Michel, 1992).

Typical ground-water flow paths in the study unit are shown in figure 18. The principal flow paths are in the regolith and densely fractured bedrock. In areas of saturated regolith, ground water may travel to the nearest discharge point without leaving the regolith. The dissolved-solids concentration of ground water that remains in the regolith is less than in the deeper flow paths because the residence time is short and the rapid flushing of this shallow zone has leached many of the most soluble minerals. Drainage of water from regolith, where present, to the underlying bedrock provides a steady source of water to deeper flow systems. These flow pathways in the bedrock are longer, and flow is slower than along those in the regolith. In the bedrock, the density of water-bearing fractures decreases with depth. Most fractures are encountered at depths less than about 300 ft below the water table (Gerhart and Lazorchick, 1988). This interval is the zone of most ground-water flow within the bedrock; however, some ground water circulates slowly through long flow paths in sparsely fractured bedrock to depths of at least 500 to 600 ft below the water table. Gerhart and Lazorchick (1988, p. 32) estimate that less than 8 percent of ground-water flow is in this deep sparsely fractured bedrock.

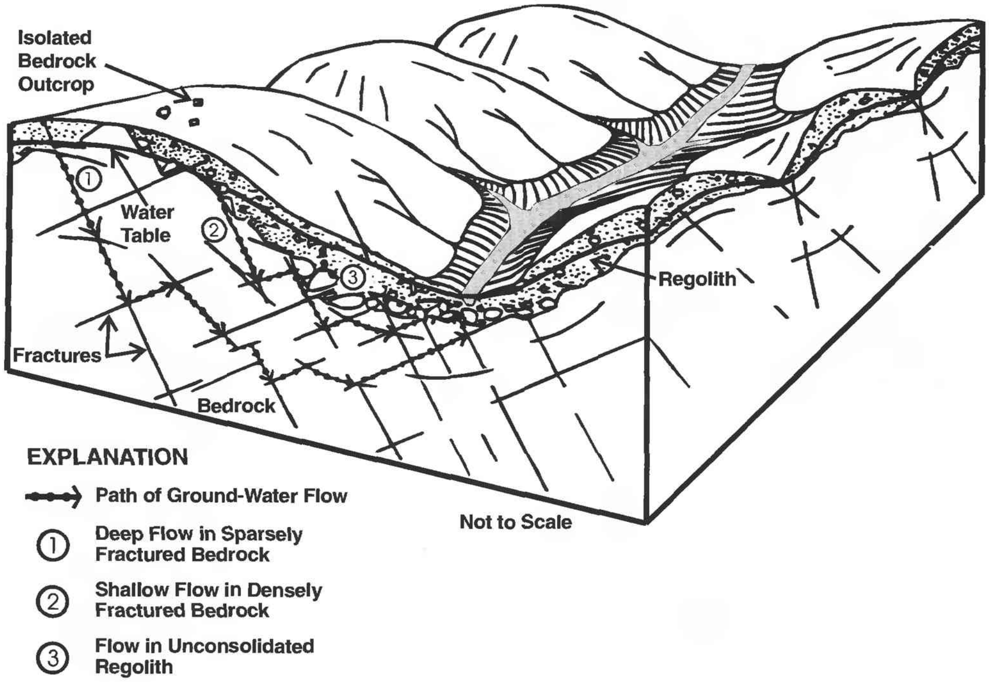


Figure 18. Generalized ground-water flow in unconsolidated regolith and fractured bedrock.

The water table generally is a subdued reflection of the land surface; thus, ground water generally moves from beneath hills toward streams. However, actual ground-water travel paths in fractured rock cannot usually be determined from the water-table configuration. The interconnection of fractures can produce an extremely heterogeneous, anisotropic flow system in which the determination of actual flow paths is not possible. This is especially true in karstic carbonate-rock terranes where ground-water and surface-water divides sometimes do not coincide.

Ground water discharges to nearby streams and springs. The median annual base-flow contribution to streams is 60 percent of streamflow basinwide (fig. 12) and ranges from 55 to 88 percent among 24 streams that were studied (table 4). Even for a particular stream, the percentage of base flow varies from year to year. During a dry year, ground-water contributions to streamflow are a much greater percentage of streamflow than during a wet year. During the 55 years of record on Penns Creek at Penns Creek, median annual base flow ranged from 55 to 82 percent of total streamflow.

Table 4. *Annual base flow at streamflow-gaging stations on nonregulated streams in the Lower Susquehanna River Basin, Pennsylvania, as a percentage of annual streamflow*

[Base flow computed by use of the sliding-interval method (White and Sloto, 1991)]

Streamflow-gaging station	Years of record	Maximum	Minimum	Median
Penns Creek at Penns Creek	1930-85	82	55	68
East Mahantango Creek near Dalmatia	1930-85	73	53	64
Standing Stone Creek near Huntington	1930-57	70	55	63
Buffalo Run Tributary near Manns Choice	1962-77	80	65	72
Dunning Creek at Belden	1940-85	69	51	59
Dunning Creek at Yount	1930-38	72	52	57
Brush Creek at Gapsville	1932-57	73	51	63
Raystown Branch of Juniata River at Saxton	1912-85	62	47	55
Great Trough Creek near Markesburg	1930-56	73	58	62
Raystown Branch of Juniata River near Huntington	1947-70	62	47	55
Aughwick Creek near Three Springs	1939-85	65	42	56
Little Lost Creek near Oakland Mills	1964-79	79	60	72
Cocolamus Creek near Millerstown	1931-57	65	49	55
Juniata River at Newport	1900-70	63	37	56
Bixler Run near Loysville	1955-85	82	58	72
Sherman Creek at Shermans Dale	1930-85	70	53	62
Stony Creek near Dauphin	1938-44	79	54	70
Conodoguinet Creek near Hogestown	1912-16; 1930-57; 1968-85	67	51	61
Paxton Creek near Penbrook	1941-49	73	54	66
Beck Creek near Cleona	1964-79	92	82	88
Manada Creek at Manada Gap	1938-57	84	67	75
Swatara Creek near Hershey	1976-86	67	50	57
Codorus Creek near York	1941-85	76	54	67
Bowery Run near Quarryville	1963-79	83	60	71

Vegetation and Aquatic Habitat

The vegetative cover and associated habitats of the study unit can be described in general terms by ecoregions, which are areas of relatively homogeneous ecological systems (Omernik, 1987). About 98 percent of the study unit is situated in the Central Appalachian Ridges and Valleys and Northern Piedmont ecoregions (map 8). Very small parts of the North Central Appalachians and Central Appalachians ecoregions are present on the basin margins in Bedford and Schuylkill Counties. The Blue Ridge Mountains are characterized by forest and woodlands dominated by oaks. The Central Appalachian Ridges and Valleys consist of low mountain ridges with a mosaic of cropland, pasture, and forest. The Northern Piedmont contains a mix of cropland, pasture, woodland, forest, and urban lands.

Potentially, the dominant natural vegetation in each ecoregion is oak. However, the natural vegetation in nearly every part of the study unit has been altered by human activities at some time. Presently, the forests in the study unit are about 71 percent oak; 23 percent maple, beech, birch, elm, ash, and aspen; and 6 percent pine (Pennsylvania Department of Environmental Resources, 1979, 1980, 1980a, 1980b). The major land uses are summarized in table 5 by percentage of total ecoregion area.

Vegetation and other biota affect the water chemistry in the study unit through the uptake, storage, and release of dissolved minerals and gases as shown schematically in figure 19. Biological activities are a primary natural control of dissolved gases, organic carbon, phosphorus, nitrogen, and potassium concentrations. In addition, evapotranspiration by vegetation affects the water budget. Approximately 55 percent of annual precipitation is returned to the atmosphere through evapotranspiration.

Vegetation acts as a land cover that retards erosion and promotes infiltration, which affects stream sedimentation and the quantity of ground-water recharge. Vegetation also exerts a dominant influence on stream ecology because stream temperatures are affected by the degree to which riparian vegetation shades the water, and plants consume water by transpiration. This effect is illustrated by stream temperatures in Stony Creek and Sherman Creek (fig. 20). Stony Creek, located in the Pennsylvania State Game Lands, is densely forested, thus its cool waters are shaded from direct sunlight. Sherman Creek, however, meanders through a mix of forest and agricultural land that allows sunlight to warm the air and water to a greater extent than at Stony Creek; Sherman Creek is classified as a warm-water fishery.

Table 5. *Major land uses within each ecoregion of the Lower Susquehanna River Basin, Pennsylvania and Maryland*

[Ecoregions from Omernik, 1987; land-use data are from the mid 1970's (Mitchell and others, 1977); LSRB, Lower Susquehanna River Basin; <, less than]

Ecoregion	Percentage of total LSRB area	Percentage of major land use in each ecoregion				
		Agriculture	Forest	Urban	Mining	Wetlands and water
Central Appalachian Ridges and Valleys	63	35	61	1	1	2
Northern Piedmont	35	70	20	8	<1	2
Blue Ridge Mountains	2	17	82	<1	<1	<1
Central Appalachians	<1	25	75	<1	<1	<1
North Central Appalachians	<1	0	42	10	46	2

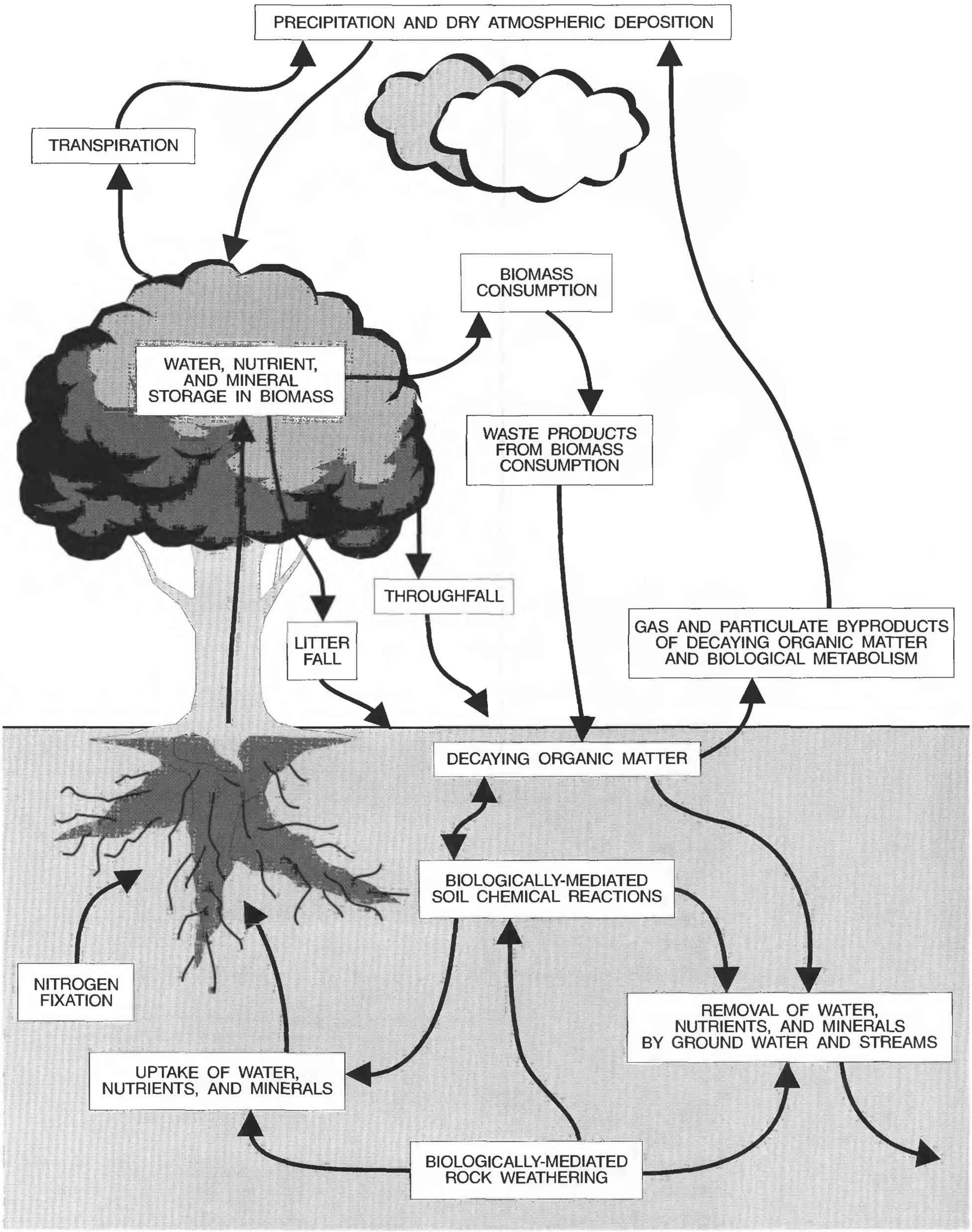


Figure 19. Schematic diagram showing role of biota in cycling of water, nutrients, and minerals. (Modified from Berner and Berner, 1987, fig. 4.2.)

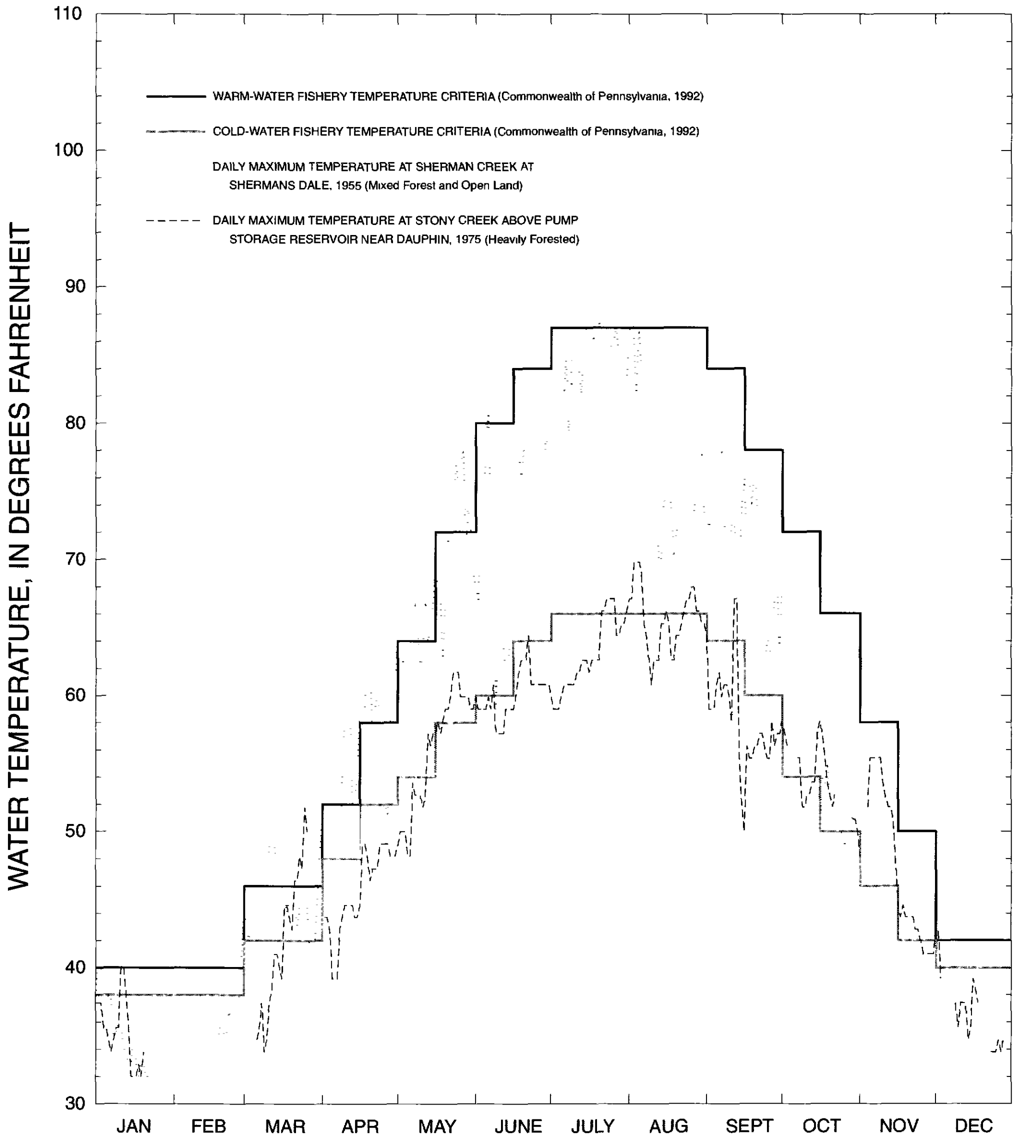


Figure 20. Water-temperature criteria for cold- and warm-water fisheries and values for two selected streams in the Lower Susquehanna River Basin.

Aquatic habitats change from the headwater of a stream to the valley with a corresponding succession of biologic communities (Vannote and others, 1980). In the headwaters, streams are small and have steep gradients. Trees generally line the banks, and leaves falling into the water provide an important energy source for biological communities. Shade covers most of the stream most of the day, helping to keep the water temperature cool. Because little sunlight hits the water, primary productivity (photosynthesis) in the stream is low. In downstream reaches, streams are wide and slow-moving. The water receives sunlight most of the day, and conditions are favorable for primary production in the stream. Attached algae and rooted aquatic plants flourish providing the major energy source.

Aquatic habitat is reflected in Pennsylvania's protected-use designation of streams (table 6). Water-quality criteria are assigned to these protected uses so that a stream's characteristic fish species and associated habitat can be maintained. The criteria differ primarily on the allowable limits for temperature and dissolved oxygen.

Table 6. Protected stream uses for aquatic life and special protection

[From Commonwealth of Pennsylvania, 1992, table 1.]

Fish Species:

Cold-Water Fishes—Maintenance and/or propagation of fish species including the family Salmonidae and additional flora and fauna which are indigenous to a cold-water habitat.

Trout Stocking—Maintenance of stocked trout from February 15 to July 31 and maintenance and propagation of fish species and additional flora and fauna which are indigenous to a warm-water habitat.

Warm-Water Fishes—Maintenance and propagation of fish species and additional flora and fauna which are indigenous to a warm-water habitat.

Special Protection:

High-Quality Waters—A stream or watershed which has excellent quality waters and environmental or other features that require special water-quality protection.

Exceptional-Value Waters—A stream of watershed which constitutes an outstanding national, state, regional or local resource, such as water of national, state, or county parks or forests, or waters which are used as a source of unfiltered potable water supply, or waters of wildlife refuges or State game lands, or waters which have been characterized by the Fish Commission's "Wilderness Trout Streams," and other waters of substantial recreational or ecological significance.

Streams designated as cold-water fisheries are typically low-order, headwater-type streams capable of maintaining trout year round. Brook trout (*Salvelinus fontinalis*) is the only trout native to the Lower Susquehanna region and thriving populations of this species still exist in the highest quality waters—primarily in those streams draining higher elevation, wooded, noncarbonate basins. Brown trout (*Salmo trutta*) were introduced in the region in the latter part of the 19th century and wild populations of this species exist in many streams, particularly valley streams draining carbonate areas. Rainbow trout (*Oncorhychus mykiss*) have also been introduced to the study unit, but populations of this species are maintained almost entirely through stocking. Other fish common in cold-water streams include several species of sculpins and darters. Invertebrates of cold-water streams include a very diverse assemblage of insects and crustaceans, but very few mollusks.

Most low-gradient, cold-water streams found in valley settings are "limestone streams," formed from large springs that discharge from carbonate bedrock. Limestone streams frequently are characterized by abundant populations of isopods (*Lirceus spp.*), sometimes called sow bugs, and amphipods (primarily *Gammarus spp.*), commonly referred to as "fresh water shrimp" and "scuds." White suckers (*Catostomus commersoni*) are also common in limestone-fed cold-water streams. Only 17 small streams in the study unit meet the Pennsylvania Fish Commission's definition for limestone streams (pl. 2). The waters of these limestone streams have a high acid-neutralizing capacity, a stable pH of 7.5 to 8.0, and constant temperature year around (Shaffer, 1991).

Streams designated as warm-water fisheries typically are in valleys. Smallmouth bass (*Micropterus dolomieui*) are dominant. Other game fish include rock bass (*Ambloplites rupestris*), walleye (*Stizostedion vitreum vitreum*), and pumpkinseed (*Lepomis gibbosus*). Muskellunge (*Esox masquinongy*) are found in the larger creeks and rivers. Nongame fish include a variety of minnows, carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), and brown bullheads (*Ameiurus nebulosus*). The invertebrate fauna of warm-water streams is also diverse; insects and crayfish are abundant. Mollusks thrive in these waters, with the introduced Asiatic clam (*Corbicula fluminea*) being among the most widespread and abundant.

The protected-use designations by the PaDER for selected streams in the study unit are shown in plate 2 and summarized in table 7. In plate 2, Maryland streams within the study unit were also assigned the Pennsylvania designations that most closely corresponded to the Maryland stream-classification system. The main stems of the Susquehanna and Juniata Rivers are designated as warm-water fisheries, as are most of the other major tributaries in the Great Valley Section of the Ridge and Valley and the Piedmont Physiographic Provinces. In the Appalachian Mountain Section of the Ridge and Valley, cold-water and trout-stockable fisheries dominate except in areas affected by mining or agriculture. High-quality and exceptional value waters are sparsely scattered throughout the study unit in areas that are heavily wooded or where streamflow is sustained by large limestone springs.

Stream reaches where a protected use for aquatic life or special protection cannot be attained because of a water-quality problem are shown in plate 3. Coal mining or agriculture is responsible for contamination in 80 percent of the streams that do not attain their designated use (fig. 4). The major contaminants are acid, metals, and suspended solids.

The primary effect of toxic contaminants on biological communities is a reduction in the number of species (biological diversity)—some species will be unable to tolerate the contaminant and will die, whereas other more tolerant species will be able to survive. Those species capable of withstanding the moderate contamination are frequently able to attain large numbers of individuals as competition is eliminated.

Nontoxic contaminants, such as sediment, affect the invertebrate community by reducing the amount of usable habitat. Sediment covers hiding places or eliminates suitable substrates. Sediment also causes a reduction in numbers of individuals when the organisms associated with the sediments are washed away during high flow. The result is a reduction in the number of individuals in the community, with little or no reduction in biological diversity.

Table 7. *Percentage of total stream miles in the Lower Susquehanna River Basin, Pennsylvania, assessed in each protected-use category*

Protected-use category	Percentage of total stream miles assessed[1]
Cold-water fishes	24.9
Trout stocking	17.5
Warm-water fishes	38.7
High-quality cold water	18.0
High-quality trout stocking	.4
High-quality warm water	.3
Exceptional value	.2

[1] From Frey, 1990.

HUMAN COMPONENTS OF THE ENVIRONMENTAL SETTING

Human activities are the source of many water-quality contaminants. Mine drainage, agricultural runoff, urban runoff, contaminated atmospheric deposition, septic-system effluent, landfill leachate, and point discharges of municipal and industrial wastes are all sources of anthropogenic contamination in the study unit. These factors are directly related to population density, land use, and waste disposal in the basin. The major contaminants associated with these activities are summarized in table 8. The locations of some of these activities and their effect on stream-water quality are shown in plate 3.

Population

According to the 1990 census, about 1.9 million people inhabit the study unit (U.S. Department of Commerce, 1991). The population is most dense in the lower third of the basin in the Piedmont Physiographic Province and Great Valley Section of the Ridge and Valley Physiographic Province in Dauphin, Cumberland, Lebanon, Lancaster, and York Counties (map 9). About 71 percent of the population lives in this area, which is only 39 percent of the study unit land area.

The major population centers are Harrisburg, Lancaster, York, and Altoona. The largest city in terms of inhabitants within the city limits is Altoona; however, Harrisburg, Lancaster, and York are metropolitan hubs that are surrounded by suburban townships and small boroughs with populations that far exceed the number of inhabitants within the city limits. The area surrounding Harrisburg is the nucleus of an urbanizing corridor that extends east to Lebanon and west to Carlisle. The connecting highways from Harrisburg to Lancaster, York, and south into Maryland also are corridors for residential and industrial development. The population of major cities from the 1990 census is listed in table 9 along with an estimate that includes the population of the surrounding metropolitan area.

The mountainous regions of the Blue Ridge, Ridge and Valley, and Appalachian Plateaus Physiographic Provinces are sparsely populated. Although these regions include about 61 percent of the study unit land area, only about 29 percent of population resides there.

Population has increased basinwide an average of about 26 percent from 1960 to 1990. Population growth not only affects water quality, but the distribution of that growth determines how water resources will be affected. In general, growth has been greatest in the lower basin and along the Susquehanna River valley (map 10). Population growth in the lower basin probably has a greater effect on water quality of Chesapeake Bay than growth in more distant parts of the basin (Horton and Eichbaum, 1991, p. 135).

Table 8. Cultural activities contributing to contamination of surface and ground water

Activity	Scope or number of sites	Contaminants frequently cited as results of activity	Remarks
(I) Land use activities			
Agricultural activities:			
Fertilizer, manure, and pesticide applications	17,000 farms[1]	Nitrate, phosphate, bacteria, and pesticides.	About 135 million pounds of nitrogen in the form of manure is applied annually. About 3 million pounds of pesticides are applied annually on corn, soybeans, alfalfa, apples, and peaches[2]
Mining activities:			
Mining and spoil disposal - coal mines	About 60 square miles of disturbed land[3]	Acids, iron, manganese, sulfate, uranium, thorium, radium, molybdenum, selenium, and trace metals.	Leachates from spoil piles of coal, metal, and nonmetallic mineral mining contain a variety of contaminants. Coal mines are sources of acid drainage. About 300 stream miles are severely impacted by coal mining.[4]
Urban activities			
Runoff	390 square miles of urban area[3]	Bacteria, hydrocarbons, dissolved solids, lead, cadmium, and trace metals.	Infiltration from detention basins and drainage wells can reach ground water. Karst areas particularly vulnerable.
Deicing chemical storage and use	--	Sodium chloride, calcium chloride, sodium ferrocyanide, phosphate, and chromate.	Winter 1991-92, 47,000 tons of salt, primarily NaCl, were applied to state roads in Pennsylvania.[5]
Storage tanks	Thousands	Petroleum products, acids, metals, organic compounds.	Useful life of steel tanks, 15-20 years. Leaks, spills and overflows may contaminate ground water. About 300 leaks or spills have been reported.[6]
(II) Waste disposal			
Land-based disposal:			
Septic systems	[7]260,000	Bacteria, viruses, nitrate, phosphate, chloride, and organic compounds such as trichloroethylene.	About 52 million gallons per day discharged to shallowest aquifers.[8]
Landfills (active)	[9]14	Dissolved solids, iron, manganese, trace metals, acids, organic compounds, and pesticides.	Traditional disposal method for municipal and industrial solid waste. Unknown number of abandoned landfills and dumps.
Surface impoundments	Hundreds	Manure, trace metals, and organic compounds.	Used to store agricultural wastes, industrial liquid wastes, municipal sewage sludge, and other wastes. About 300 impoundments for manure storage have been financed partly by State and Federal programs.[10]
Injection wells	[11]4	Dissolved solids, bacteria, sodium, chloride, nitrate, phosphate, organic compounds, pesticides, and acids.	Presently only nontoxic waters are injected. Hazardous wastes were injected in numerous wells in the past.
Land application of wastes	Hundreds	Bacteria, nitrate, phosphate, trace metals, and organic compounds.	Waste disposal from municipal sewage-treatment plants, septic systems, and municipal water treatment plants.

Table 8. Cultural activities contributing to contamination of surface and ground water—Continued

Activity	Scope or number of sites	Contaminants frequently cited as results of activity	Remarks
(II) Waste disposal—Continued			
Discharges to streams:			
Sewage treatment	[12]400	Bacteria, nitrate, ammonia, phosphate, organic compounds, suspended solids.	49 major facilities in basin discharge about 155 million gallons per day.[12]
Industrial discharge	[12]180	Organic compounds, trace metals.	23 major industrial facilities discharge about 93 million gallons per day.[12]

[1] County data prorated for percentage of agricultural land in the Lower Susquehanna River Basin from U.S. Department of Commerce (1990 and 1990b).

[2] Manure loads in Pennsylvania from Petersen and others (1991); Maryland loads estimated from 1987 animal population data on county basis by use of loading factors from Petersen and others (1991; p. 10). Pesticide use is from county data prorated by percentage of agricultural land in the Lower Susquehanna River Basin, from Gianessi and Puffer (1988).

[3] From Geographic Information and Retrieval System (GIRAS) land-use data of mid-1970's (Mitchell and others, 1977).

[4] From Susquehanna River Basin Commission (1973).

[5] County applications prorated by percentage of county area in the Lower Susquehanna River Basin, from Pennsylvania Department of Transportation District personnel.

[6] County data prorated by percentage of county area in the Lower Susquehanna River Basin, from Pennsylvania Department of Environmental Resources, Bureau of Water-Quality Management list of confirmed releases as of December 6, 1991.

[7] County data of septic systems prorated by percentage of county area in the Lower Susquehanna River Basin, from U.S. Department of Commerce (1991).

[8] Based on discharge of 200 gallons per day.

[9] From Pennsylvania Department of Environmental Resources, Water Management Division and Maryland Department of Environment, Solid Waste Division.

[10] Russell Wagner, Pennsylvania Department of Environmental Resources, oral commun., 1992.

[11] Nancy Spangenberg, Pennsylvania Department of Environmental Resources, Bureau of Water-Quality Management, written commun., 1992.

[12] National Pollution Discharge Elimination System permits from Pennsylvania Department of Environmental Resources and Maryland Department of Environment for 1990.

Table 9. Population of major cities in the Lower Susquehanna River Basin, Pennsylvania and Maryland, according to the 1990 census

City	1990 population within city limits	Estimate of population in the greater metropolitan area
Harrisburg	52,376	280,000
Lancaster	55,551	150,000
York	42,192	130,000
Altoona	58,881	85,000
Lebanon	24,800	54,000
Carlisle	18,419	28,000

Land Use

Land use is evenly divided between agriculture (47 percent) and forest (47 percent). Urban and built-up areas cover about 4 percent of the basin (map 11). The remaining 2 percent of the basin consists of water bodies (lakes, reservoirs, and streams) and barren land (primarily mines and quarries). These land-use statistics represent conditions in the mid 1970's (Mitchell and others, 1977).

The land-use pattern reflects the great differences in physical characteristics in the basin. Agriculture is the dominant land use in the Piedmont and Great Valley, where about 60 percent of the basin's agricultural activity is on 35 percent of the land area. Forest cover dominates in the mountainous regions of the Allegheny Mountains, Appalachian Mountains, and South Mountain, which contain 85 percent of the basin's forest cover. The majority (51 percent) of urban land uses are centered around four metropolitan areas in the Great Valley and Piedmont Lowland Sections. A summary of land-use distribution by physiographic section is shown in table 10.

The most significant change in land use in the past 20 years has been the increase of low-density residential areas at the expense of cropland. This change is greatest in the southeastern part of the basin. From 1975 to 1989 urban land in the Great Valley and Piedmont increased approximately 8 to 10 percent (Petersen and others, 1992); cropland decreased about 5-10 percent in the same area during a similar period (1978-85) (map 12).

Agricultural, mining, and urban land uses are those most often linked to major water-quality problems. Results of the 1990 Pennsylvania stream assessment (fig. 4) showed that mining and agriculture were responsible for contamination at 80 percent of the streams where designated water-quality standards were not attained (Frey, 1990). Activities associated with urban land use are responsible for contamination of surface and ground water with metals, nutrients, and organic constituents (U.S. Geological Survey, 1988; Cohn-Lee and Cameron, 1992).

Table 10. *Land use in the Lower Susquehanna River Basin, Pennsylvania and Maryland, by physiographic province and rock type, in square miles*

[From GIRAS land use data of mid 1970's (Mitchell and others, 1977).]

Rock type	Agriculture	Forest	Urban	Mining and barren	Water and wetlands	Total
	Piedmont Physiographic Province, Piedmont Upland Section					
Carbonate	1.52	0.05	--	--	--	1.57
Siliciclastic	.23	.87	0.03	--	--	1.13
Crystalline	906.44	334.41	39.32	1.97	37.10	1,319.24
Total	908.19	335.33	39.35	1.97	37.10	1,321.94
	Piedmont Physiographic Province, Piedmont Lowland Section					
Carbonate	445.42	12.44	79.60	3.48	8.55	549.49
Siliciclastic	53.39	2.34	4.04	.11	.13	60.01
Total	498.81	14.78	83.64	3.59	8.68	609.50
	Piedmont Physiographic Province, Gettysburg-Newark Lowland Section					
Carbonate	.92	--	--	--	.01	.93
Siliciclastic	452.42	162.47	33.77	.68	10.08	659.42
Crystalline	42.46	65.86	3.83	.39	1.94	114.48
Total	495.80	228.33	37.60	1.07	12.03	774.83
	Ridge And Valley Physiographic Province, Great Valley Section					
Carbonate	286.04	23.44	54.53	2.05	1.97	368.03
Siliciclastic	391.39	102.13	59.22	2.24	5.36	560.34
Crystalline	2.17	1.22	.13	--	--	3.52
Total	679.60	126.79	113.88	4.29	7.33	931.89
	Ridge And Valley Physiographic Province, Appalachian Mountain Section					
Carbonate	433.65	241.96	20.36	1.40	2.09	699.46
Siliciclastic	1,286.18	3,200.64	93.34	51.04	46.27	4,677.47
Total	1,719.83	3,442.60	113.70	52.44	48.36	5,376.93
	Blue Ridge Physiographic Province, South Mountain Section					
Carbonate	.22	7.24	.01	.19	.03	7.69
Crystalline	33.18	125.11	.53	.12	.10	159.04
Total	33.40	132.35	.54	.31	.13	166.73
	Appalachian Plateaus Physiographic Province, Allegheny Mountain Section					
Siliciclastic	3.90	129.08	1.30	2.64	.02	136.94
Total	3.90	129.08	1.30	2.64	.02	136.94
	New England Physiographic Province, Reading Prong Section					
Crystalline	.94	4.42	.14	--	--	5.50
Total	.94	4.42	.14	--	--	5.50
Grand totals for all sections	4,340.47	4,413.68	390.15	66.31	113.65	9,324.26

Agriculture

The effects of agricultural activities on sediment, nutrient, bacteria, and pesticide concentrations are major water-quality issues in the study unit (Frey, 1990). These effects exist to some extent at all 17,000 farms in the study unit; however, they are most severe in the Great Valley and Piedmont where agriculture is the dominant land use. According to the 1990 stream assessment, agriculture was the cause of degradation in 15 percent of the streams that did not attain designated water-quality standards assigned for the stream's designated use (fig. 4). The agricultural pollution potential of surface waters within the Pennsylvania part of the study unit was estimated by Petersen and others (1991) as shown in map 13. Three basins in Lancaster County are ranked as the most susceptible to agricultural contamination in the state.

The areas most susceptible to ground-water contamination, in general, are lands underlain by carbonate rocks (map 14) because contaminants can quickly infiltrate to the water table through permeable soil and enlarged fractures and solution cavities within the bedrock. In the study unit, agricultural activities cover 72 percent of the carbonate rocks. The high susceptibility of carbonate-rock terranes in Lancaster County to ground-water pollution from agricultural sources has been demonstrated by Fishel and Lietman (1986).

The general basinwide distribution of sediment yield is shown in map 15. The estimated average sediment load delivered to streams is as great as 8.5 (ton/acre)/yr in the southeastern part of the basin (Petersen and others, 1991). The large loads from these agricultural areas indicate the effects of a lack of vegetative cover on sediment production.

Loads of nitrogen and phosphorus to the land are greatest in agricultural areas because large amounts of chemical fertilizer and manure are applied. Nutrients from manure are a particular problem because animal densities are high (5 to 100 times greater than in the 1950's) (Horton and Eichbaum, 1991, p. 43). An estimate of the distribution of nitrogen from manure is shown in map 16. The loading is greatest in the southeastern part of the basin and is as large as 92 (lb/acre)/yr in the Chickies/Conewago Basin (Petersen and others, 1991).

Pesticides are applied to agricultural lands to control weeds, insects, and fungus. Applications to field crops and orchards are the dominant agricultural use of pesticides. Field crops of corn, soybeans, and alfalfa are planted throughout the basin. According to Resources for the Future data from 1982 to 1985 (table 11), the herbicides most commonly used on these crops are atrazine, cyanazine, alachlor, metolachlor, and 2,4-D (Gianessi and Puffer, 1988). Atrazine applications by county are shown in map 17. Herbicide applications are usually made in early to mid May. The insecticides typically used include carbofuran and malathion. Applications of fungicides, such as chlorothalonil, are made on potato, melon, squash, and tomato crops.

Orchards cover about 62 percent of the land used for agriculture in the South Mountain Section of Adams, Franklin, and Cumberland Counties. Apples and peaches are the principal fruit crops. (U.S. Department of Agriculture, 1987). Insecticides and fungicides play a more critical role than herbicides in management of these fruit crops. Frequently used insecticides include carbaryl, parathion, and methyl parathion (table 11). The fungicide metiram is heavily applied to apples. The greatest pesticide applications are in April and May, although additional applications are made throughout the summer.

The herbicide 2,4-D is an example of a compound used on more different crop types than any other of the most-used pesticides listed in table 11. According to Resources for the Future data from 1982 to 1985, apples, pears, barley, corn, oats, pasture, rye, sod, and small fruits such as strawberries are crops where 2,4-D (Gianessi and Puffer, 1988) is applied. Thus, the concept of widely-used pesticides in the study unit has several definitions. A compound, such as atrazine, used mostly on a single crop, has use defined primarily by the large acreages of corn. Carbaryl and parathion, like 2,4-D, are widely used with usage defined by smaller acreages of many crops.

Because atrazine is the most widely used pesticide, its distribution can be a general guide to areas where pesticide contamination may be a water-quality issue. Atrazine applications were greatest in the southeastern counties in the mid 1980's (map 17). In Lancaster County, about 300,000 lb of atrazine were applied, which was 24 percent of the basinwide total (Roeser, 1988).

Table 11. *Estimated annual applications for the 12 most used pesticides in the Lower Susquehanna River Basin, Pennsylvania and Maryland*

[Data are from Gianessi and Puffer, 1988]

Pesticide used	Estimated application of active ingredient during mid 1980's, in pounds[1]
Herbicides:	
Atrazine	1,250,000
Alachlor	636,000
Cyanazine	602,000
Metolachlor	228,000
2,4-D	54,600
Insecticides:	
Carbofuran	218,000
Malathion	59,500
Carbaryl	53,300
Parathion	40,100
Methyl Parathion	14,100
Fungicides:	
Metiram	46,400
Chlorothalonil	16,000

[1] Pesticide use by county reported by Gianessi and Puffer (1988) was prorated for the percentage of agricultural lands in the parts of each county within the Lower Susquehanna River Basin to the agricultural lands in the entire county.

Urban

Urban and residential areas affect surface- and ground-water quality by altering the physical hydrology and by adding waste products. Streamflow and ground-water flow are altered where rooftops, paved surfaces, and sewers accelerate the movement of storm runoff to streams at the expense of ground-water infiltration. In urban areas underlain by carbonate rocks, infiltration basins that are designed to hold and slowly release storm runoff to streams often facilitate direct, rapid infiltration of contaminant-laden urban runoff to the ground water through sinkholes and solution-enlarged fractures.

Urban runoff frequently carries elevated nonpoint-source loads of sediment and inorganic and organic constituents from paved surfaces, lawns, parks, and golf courses. For example, Cohn-Lee and Cameron (1992) estimate that the load of copper, biological oxygen demand (BOD), phosphorus, and nitrogen in urban runoff from Harrisburg exceeds the load added by all large factories within the entire state. Also consider that 47,000 tons of sodium-chloride salt was applied to Pennsylvania state roadways in the study unit during the mild winter of 1991-92 (table 8). This salt infiltrates to the water table or washes off directly to streams.

Point sources of contamination from the populated urban environment include sewage-treatment facilities, industrial discharges, landfills, and leaking storage tanks. About 10 percent of the streams assessed by the Pennsylvania Department of Natural Resources (fig. 4) did not attain their designated water-quality standards because of point sources of contamination from urban sources (Frey, 1990). The most heavily affected major streams are Codorus Creek, Conestoga Creek, Octoraro Creek, Conodoguinet Creek, Frankstown Branch Juniata River, and the Little Juniata River near Altoona (pl. 3).

Ground-water contamination is also a significant problem (U.S. Geological Survey, 1988). Leaking storage tanks, surface impoundments, chemical plants, and landfills are responsible for some of the greatest ground-water contaminant problems basinwide (table 1). About 300 releases of toxic materials have been documented because of spills or leaks from storage tanks within the basin (map 18). Organic contamination of ground water by volatile organic compounds is a special concern because of its widespread occurrence in urban areas. For example, an effort to clean up contamination by petroleum products from ground water in carbonate rocks in a part of Cumberland County resulted in a recovery of 219,000 gal of petroleum products from the shallow ground-water system as of March 1974 (Becher and Root, 1981).

Mining

The extraction of mineral resources has greatly affected the water chemistry within the study unit. Primary problems associated with mining are the production of acid mine drainage and an increase of sedimentation to streams.

Coal

Coal has been extracted since the early 1800's in the study unit. Mining methods included underground mines, surface strip mines, culm-bank processing, and river dredging. Throughout the 1800's, coal was mined primarily by underground methods, but today surface mining of coal seams and reprocessing of old culm banks dominates. Coal was dredged from the Susquehanna River until the mid 1970's. The flood caused by Hurricane Agnes in 1972 scoured the streambed of coal wastes so that commercial extraction became impractical.

Acidic mine drainage from abandoned coal mines is the greatest cause of water-quality degradation in streams within the study unit. About 300 mi of streams in the basin have been "significantly degraded" by mine drainage (Susquehanna River Basin Commission, 1973). Mine drainage is responsible for acidity and metals contamination in 65 percent of all streams that did not attain their designated water-quality standards (Frey, 1990). The acidity and metals are toxic to aquatic life, making many stream reaches biologically barren.

Mine drainage has contaminated streams in all three coal-mining areas—the Anthracite, Broad Top, and Main Bituminous fields (pl. 3). The greatest effect is in the vicinity of the Western, Middle, and Southern Anthracite fields, where about 247 mi of streams within the Shamokin, Mahanoy, Mahantango, Wiconisco, and Swatara Basins are continuously contaminated (Susquehanna River Basin Commission, 1973). Growitz and others (1983) identified 125 mine drainages from the Anthracite fields that contribute about 130,000 lb of acidity per day (Susquehanna River Basin Commission, 1973) to receiving streams. Mine drainage from the Broad Top field significantly degrades about 36 mi of tributary streams to Aughwick Creek and Raystown Branch Juniata River in a small part of Huntingdon, Bedford, and Fulton Counties (Susquehanna River Basin Commission, 1973). Near Altoona, mine drainage from the Main Bituminous field contaminates about 25 mi of tributary streams to the Little Juniata River and the Frankstown Branch of the Juniata River.

Metallic Minerals

The mining of metallic minerals in the study unit was greatest from about 1850 through the early 1900's. Today all the metal mines in the study unit are abandoned. The principal metallic mineral deposits are chromium, copper, iron, lead, uranium, and zinc (pl. 1). The economic value of ore mined from the Cornwall-type iron mines (pl. 1) greatly exceeds the sum of all the other metallic minerals combined. Other large mines were associated with the Appalachian zinc deposits, Gap nickel deposit, and chromite district.

Waste Disposal

Disposal of wastes to streams, land, and in air can become a source of surface- and ground-water contamination in the study unit. Wastes have not always been properly handled, as evidenced by the 12 Federally funded (Superfund) and 9 State-funded Hazardous Sites Cleanup Act (HSCA) sites (pl. 3). Hundreds of other active or abandoned waste sites exist in the study unit. About 430 sites are on a list of potential hazardous-waste sites that is used to evaluate future candidates for Superfund consideration (map 19).

The major waste discharges to streams include sewage effluent and industrial wastewater. The most common land-based disposal methods are septic systems, landfills, surface impoundments, direct application to land, and injection wells (table 8).

Disposal to Streams

In the study unit, about 600 point-source discharges to streams (excepting small flows and those from single residences) currently are permitted by the PaDER. Of these, about 400 are municipal or private sewage-treatment facilities and the remainder are industrial dischargers. The sewage and industrial wastes can cause problems associated with bacteria, nutrients, oxygen demand, suspended solids, organic compounds, and trace metals in streams.

A total of about 155 Mgal/d of treated effluent is discharged by 49 major public-owned sewage-treatment facilities (pl. 3). About 75 percent of these plants reported some release of wastewater in 1989 that exceeded their allowed limits for bacteria, nutrients, oxygen demand, or suspended solids; about one quarter contributed to toxic hot spots caused by releases of organic or trace-metal contaminants (Chesapeake Bay Foundation, 1991). In Schuylkill County, some community sewage-collection systems are not connected to treatment plants. Three of these "wildcat" systems discharge raw sewage directly to tributaries of Mahanoy Creek (Robert Hollenbach, Pennsylvania Department of Environmental Resources, written commun., 1992).

Also contributing wastewater to streams are 23 major industrial dischargers in the basin, most of which are located in the Piedmont and Great Valley (pl. 3). Discharges from the major industrial sites total about 93 Mgal/d (table 8), the largest of which are from food processing, paper making, and steel-making industries.

Toxics screening reports were compiled by the PaDER to identify substances released from municipal and industrial waste discharges that, when mixed with the receiving stream's low flow, could contribute to acute or chronic toxicity of aquatic organisms and cancer in humans (Cuong Duc Vu and Edward Rawski, Pennsylvania Department of Natural Resources, written communs., 1988-91). Locations where at least one of the potentially harmful substances could occur were identified in about 100 streams within the study unit. The toxic substances most frequently cited are listed in table 12. Two of these, copper and lead, have been identified as a problem for aquatic life of the Chesapeake Bay (U.S. Environmental Protection Agency, 1991a).

Table 12. *Toxic substances most frequently cited as a potential health hazard in streams in the Lower Susquehanna River Basin, Pennsylvania*

[From unpublished Pennsylvania Toxics-Screening Reports, Cuong Duc Vu and Edward Rawski, Pennsylvania Department of Environmental Resources, written commun., 1988-91.]

Toxic substance	Number of sites where a health criterion is expected to be exceeded
Copper	106
Lead	44
Zinc	39
Silver	33
Beryllium	32
Cyanide	27
Aluminum	24

Disposal on Land

Wastes are disposed on lands within the study unit by several methods including septic systems, landfills, surface impoundments, and land application of treated substances. These methods generally have a more immediate potential to contaminate shallow ground-water resources than to affect stream water.

Septic systems provide the largest volume of land-applied wastes in the study unit. On the basis of 1990 census figures, about 260,000 septic systems discharge approximately 52 Mgal of wastewater each day. The county-wide average density of systems is greatest in the southeastern part of the study unit exceeding 35 systems per square mile (map 20). The septic wastewater contains bacteria, nutrients, organic carbon, chlorides, and contaminants from household wastes. Septic systems are designed to use the soil to filter bacteria and attenuate as many of the other constituents as possible. However, where soil is thin or clayey, or where carbonate rocks underlie the septic system, ground-water contamination is likely. In some homes in Centre County (and probably many other rural areas), on-lot septic effluent is disposed of directly into underground cesspools (Jon Eich, Senior Planner, Centre County Planning Office, oral commun., 1992). A cesspool pit can pose a serious contamination threat to the nearby well-water supply.

Land application is widely used to dispose of stabilized municipal sewage sludge, septic-tank wastes, sludge from drinking-water treatment plants, and composted leaves. Treated wastes are commonly applied directly to the land surface in the study unit. This disposal method employes natural properties of soil and biota to remove bacteria and excess nutrients in the waste (Metcalf and Eddy, Inc., 1972, p. 701). Care, however, must be exercised to assure that the ability of the soil to assimilate wastes is not overloaded; otherwise, ground-water contamination will result.

Landfills are the most common method of disposing of solid waste. Although the trash in landfills is covered and the pit bottoms of modern landfills are designed to be relatively impervious, contamination of surface and ground water is possible from storm runoff and infiltration of leachate. There are 14 large operational municipal landfills (pl. 3), all of which accept municipal wastes collected from a wide area—even from outside of Pennsylvania. No hazardous-waste landfills are currently operating, although 21 landfills are in the process of being permitted as residual-waste sites (pl. 3). Residual wastes are nonhazardous wastes from industrial, mining, and agricultural sources (Commonwealth of Pennsylvania, 1990, p. 260-13).

Surface impoundments are used primarily to store wastes; however, if the impoundments leak, ground-water contamination can result. Impoundments for manure storage have been built as an agricultural-management practice. The goal is to decrease nutrient loads to Chesapeake Bay (Horton and Eichbaum, 1991). About 300 manure-storage tanks have been constructed within the study unit with funding assistance from the Chesapeake Bay Program and many additional manure-storage tanks have been constructed by farmers without funding assistance (Russel Wagner, Pennsylvania Department of Environmental Resources, oral commun., 1992). Storage of manure can contribute ammonia to the atmosphere locally. Ammonia that volatilizes from open manure-storage lagoons has been shown to contribute as much as 4 to 5 mg/L of nitrogen to local rainfall (Langland, 1992).

Disposal in Air

The chemistry of precipitation falling on the Lower Susquehanna River Basin has been contaminated by releases of wastes to the atmosphere by humans. Emissions of sulfur and nitrogen oxides to the atmosphere from combustion of fossil fuels have caused some of the most acidic precipitation in the nation (Turk, 1983, fig. 6). Reported areal distribution of mean-annual pH in precipitation samples ranged from 4.08 to 4.20 during 1982-88 (map 21). These contaminants also are believed to contribute about 25 percent of the nitrogen load to Chesapeake Bay (Fisher and others, 1988). The chemistry of contaminated precipitation has had a deleterious effect on certain types of aquatic life (Sharpe, 1990) because its acidity is not significantly neutralized in headwater reaches of streams that drain areas underlain by noncarbonate rocks.

Water Use

Water is used in the study unit for power generation, industrial purposes, municipal supply, agriculture, and domestic supply. Most of the water used (about 96 percent) is returned to the basin from which it is withdrawn. The return flows commonly affect the temperature and suspended-solids, nutrient, and major-ion concentrations of the receiving stream water.

Water use totals 3,822 Mgal/d (Hollowell and others, 1991), about 87 percent of which is used for hydroelectric- or thermoelectric-power generation (fig. 21). Hydroelectric-power use is larger than the thermoelectric-power use but does not constitute a consumptive water use. About 37 Mgal/d of water is lost as steam at the thermoelectric facilities. Use of water by the major power-generating facilities is shown in table 13.

Nonpower use is about 483 Mgal/d—about 45 percent from surface-water sources and 55 percent from ground water. Industrial use of water is the largest nonpower category of use, and about 59 percent of that is from ground water (fig. 21). Municipal water supplies serve about 59 percent of all residents. About 70 percent of the municipal systems use ground water for part or all of their supply. The other residents rely on individual domestic water supplies (predominantly wells) to meet their needs. The greatest reliance on domestic wells is in Bedford, Fulton, Juniata, Perry, and Adams Counties in Pennsylvania and Cecil County in Maryland (map 22). Most of the agricultural water use is ground water that is needed for livestock. Very little water is used for irrigation.

Recreational uses, although important, are difficult to quantify. Many streams and lakes are heavily used for recreation, and the demand is increasing—affecting the water quality and aquatic organisms. In 1990, nearly 365,000 fishing licenses and 80,000 boat registrations were sold in the counties within the study unit. The cold-water fisheries program provided nearly 5 million trout for stocking Pennsylvania's waters. A large number of these were placed into high-quality cold-water streams.

Hundreds of small impoundments for water supply, recreation, power, and flood control have been constructed within the study unit, in addition to the major dams on the Susquehanna River. An inventory of dams and lakes (Pennsylvania Department of Environmental Resources, 1970) lists 442 man-made lakes in the study unit. Thirteen lakes in the study unit have a surface area greater than 300 acres (table 14).

Reservoirs have a dramatic effect on water quality and aquatic organisms. The nutrient-rich, stilled lake waters allow aquatic vegetation to flourish, which can greatly diminish oxygen through respiration and decomposition (Cole, 1983). Lakes can also be very effective sediment traps. The three major dams nearest the mouth of the Susquehanna River (Safe Harbor, Holtwood, and Conowingo) have trapped about 259 million tons of sediment (Hainly and others, 1995). Conowingo Dam presently traps about 2.4 million tons of sediment per year; however, the trap efficiencies for Safe Harbor and Holtwood Dams have decreased to nearly zero. In addition to sediment, about 913,000 tons of nitrogen and 226,000 tons of phosphorus have collected behind the dams (Hainly and others, 1995).

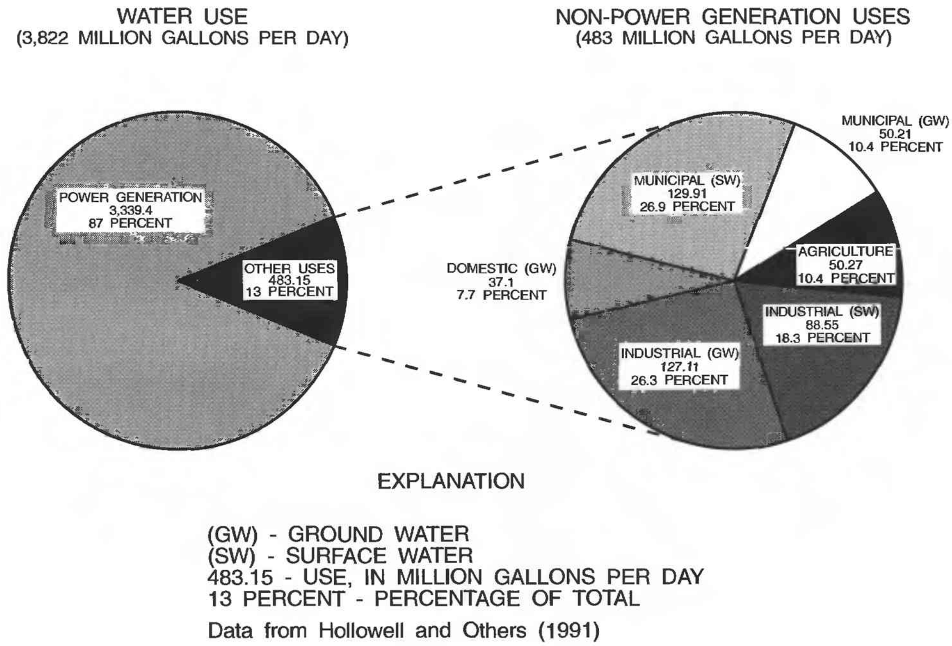


Figure 21. Estimated water use in the Lower Susquehanna River Basin.

Table 13. *Water use by major hydroelectric- and thermoelectric-power facilities in the Lower Susquehanna River Basin, Pennsylvania and Maryland, in 1990*

Hydroelectric facility	Withdrawal, in million gallons per day	Thermoelectric facility	Consumptive use, in million gallons per day
Conowingo	51,800 (hydraulic capacity)	Peach Bottom (nuclear)	19.2
Safe Harbor	28,649	Three-Mile Island (nuclear)	10.1
Holtwood	16,123	Brunner Island (coal)	5.2
York Haven	9,561	Sunbury (coal)	1.8
Muddy Run	3,770	Holtwood (coal)	.6
Raystown	Unknown	Williamsburg (retired in 1991)	.1

Table 14. *Largest lakes in the Lower Susquehanna River Basin, Pennsylvania and Maryland, by surface area*

Lake	Stream	County	Area (acres)
Conowingo Reservoir	Susquehanna River	Lancaster, Cecil, Harford	8,300
Raystown Reservoir	Raystown Branch	Huntingdon	8,300
Lake Clarke (Safe Harbor)	Susquehanna River	Lancaster	7,328
Lake Augusta (Fabridam)	Susquehanna River	Snyder	3,000
Lake Marburg	West Branch Codorus Creek	York	1,275
Lake Aldred (Holtwood)	Susquehanna River	Lancaster	1,260
Dehart Lake	Clark Creek	Dauphin	650
Muddy Run	Muddy Run	Lancaster	640
Octoraro Lake	Octoraro Creek	Chester	625
Shawnee Lake	Shawnee Branch	Bedford	451
Middle Creek Lake	Middle Creek	Lancaster	400
York Haven	Susquehanna River	York	377
Conewago Lake (Pinchot)	Beaver Creek	York	340

MAJOR ENVIRONMENTAL SUBDIVISIONS

The environmental setting of every watershed or ground-water basin is unique; however, similarities in the natural and human components allow areas to be classified together for the purpose of water-quality assessment. Subdivision of the study unit for water-quality studies in the NAWQA program is (1) part of a process for national consistency in study design, (2) a basis for comparisons between areas of differing environmental setting, and (3) for describing or estimating conditions in two or more similar settings where water-quality information is sparse or lacking altogether in at least one setting.

Because surface- and ground-water flow are controlled by the geologic framework of the basin, physiographic province and rock type are the natural components of the environmental setting used to classify the subdivisions. Five major subdivisions are identified (map 23). The major distinction in rock type is between carbonate and noncarbonate bedrock. Three noncarbonate subdivisions include crystalline rocks in the Piedmont and Blue Ridge Physiographic Provinces, siliciclastic rocks in the Piedmont Physiographic Province, and siliciclastic rocks in the Ridge and Valley Physiographic Province. Two carbonate subdivisions include carbonate rocks in the Piedmont and carbonate rocks in the Ridge and Valley. These subdivisions and other components of the environmental setting provide the framework for design of water-quality investigations of NAWQA.

Crystalline Rocks in Piedmont and Blue Ridge Physiographic Provinces

Topographic Setting.—The topography in the Piedmont is gently rolling with broad hills and some steep-sided valleys. The Blue Ridge is more mountainous, higher, and has greater relief than the Piedmont.

Dominant Rock Types.—Crystalline igneous and metamorphic rocks predominate. Major lithologies are schist, gneiss, diabase, gabbro, quartzite, phyllite, metavolcanics, slate, and serpentine-bearing rocks.

Regolith Characteristics.—Regolith thickness is generally 20 to 90 ft but has been reported to be as much as 450 ft thick along the western flank of South Mountain. Saturated thickness varies with topographic position but is typically 10-25 ft in valley settings. Specific yield typically is 8 to 24 percent. Hydraulic conductivity probably is greatest at the regolith-bedrock contact (Swain and others, 1991, p. 23).

Bedrock Characteristics.—Fractures decrease with increasing depth to about 250 ft below land surface. About 90 percent of all water-bearing zones are encountered at depths less than 250 ft. A lower boundary of most freshwater flow is at a depth of about 450 ft below land surface. Specific yield, including some regolith, ranges from 0.1 to 18 percent, but typical yields for bedrock probably are less than 5 percent.

Hydrologic Characteristics.—Precipitation ranges from about 38 to 46 in/yr. Ground-water recharge is about 22 to 25 percent of average precipitation. The permeable regolith greatly facilitates infiltration. Most base flow in streams is sustained by discharge from regolith and shallow weathered bedrock. Flow along the regolith-bedrock boundary may be large. Deep fractures typically yield only several gallons of water per minute to wells.

Water-Quality Characteristics.—Water in streams and from wells usually is very soft (hardness less than 50 mg/L as calcium carbonate). The low ionic strength makes stream headwaters in Blue Ridge Section susceptible to effects of acidic precipitation. Cold-water fishery habitats are found in South Mountain and where streams have steep-sided valley walls.

Land-Use Characteristics.—The area has an average population density of 210 people per square mile. The area contains about 11 percent of the urban, 23 percent of the agricultural, and 12 percent of the forest lands in the basin. Land uses are changing from agricultural to low-density residential, especially near York and the highway corridor between it and Baltimore.

Siliciclastic Rocks in Piedmont Physiographic Province

Topographic Setting.—The area is characterized by rolling hills, highlands, and isolated knobs.

Dominant Rock Types.—Triassic shale, siltstone, sandstone, and conglomerate comprise 85 percent of the area. Ordovician shale underlies about 15 percent of the area.

Regolith Characteristics.—Average thickness is about 40 ft. Specific yield and hydraulic conductivity are less than in other settings because weathering of shales produces a very clayey regolith.

Bedrock Characteristics.—Beds of sparsely fractured siliciclastic rocks alternating with densely fractured rocks form multiple water-bearing zones and confining layers. The uppermost 100 ft is most densely fractured; however, water-bearing zones have been encountered at depths of at least 1,000 ft. Specific yield is low—about 0.007.

Hydrologic Characteristics.—Precipitation ranges from about 38 to 44 in. Recharge is 15-27 percent of precipitation. The ground-water flow system is a complex combination of shallow, unconfined and deeper confined, laterally limited water-bearing zones. Ground water is present in the regolith and the upper 100 ft of fractured bedrock and moves under unconfined conditions to the nearest stream. Some recharge to the deeper dipping sandstones moves beneath the local low-order streams under confined conditions to a depth of at least 1,000 ft. Discharge is by upward leakage to larger streams. Streamflow decreases rapidly after storms and base flow is small because ground-water storage is small.

Water-Quality Characteristics.—Water contains moderate concentrations of dissolved solids. Stream habitats are classified mostly as trout stockable and warm-water fisheries.

Land-Use Characteristics.—The area has an average population density of 305 people per square mile. The area contains about 10 percent of the urban, 12 percent of the agricultural, and 4 percent of the forest lands in the basin.

Carbonate Rocks in Piedmont Physiographic Province

Topographic Setting.—The area is characterized by broad, rolling valleys and hills. Karst features such as sinkholes and closed depressions are common.

Dominant Rock Types.—Limestone and dolomites are the major rock types—many of which contain shale.

Regolith Characteristics.—Thickness is generally 20 to 90 ft and averages 48 ft. Thickness varies greatly in short distances because of pinnacled weathering of carbonate bedrock. Saturated thickness is greatest in valleys, where it ranges from about 10 to 30 ft, depending on lithology. Specific yield ranges from about 8 to 24 percent.

Bedrock Characteristics.—Water-bearing characteristics and hydraulic properties vary greatly because some fractures have been enlarged by carbonate-rock dissolution. Most water-bearing zones are in the upper 400 ft of bedrock. Deepest zones were encountered about 630 ft below land surface. Specific yield ranges from 1.5 to 11 percent for a combination of shallow bedrock and regolith. Typical hydraulic conductivities average about 6 to 30 ft/day but range from less than 0.1 to 5,400 ft/day.

Hydrologic Characteristics.—Precipitation ranges from about 38 to 44 in/yr. Recharge is about 24-35 percent of precipitation—the low value for shaley bedrock and the larger for pure carbonate bedrock. Precipitation infiltrates rapidly to the carbonate bedrock through sinkholes and porous regolith. Most flow probably is in the shallow bedrock where fractures have been enlarged by dissolution. Flow may be rapid in conduit passages. Water discharges to nearby streams and springs.

Water-Quality Characteristics.—Ground water and base flow in streams contain high hardness (generally greater than 200 mg/L) and dissolved solids (greater than 400 mg/L) from the dissolution of carbonate rocks. Agricultural activity has caused elevated concentrations of nutrients in both surface and ground water. Most streams are classified as warm-water habitats.

Land-Use Characteristics.—This subdivision has the greatest average population density of 750 people per square mile. The area contains about 20 percent of the urban, 10 percent of the agricultural, and less than 1 percent of the forest lands in the basin. The area contains the greatest population density in the study unit but also has the greatest agricultural intensity. Agricultural lands comprise 81 percent of the area underlain by carbonate rocks in the Piedmont.

Carbonate Rocks in Ridge and Valley Physiographic Province

Topographic Setting.—Landscape characterized by narrow and broad valleys with rolling lowlands, hills, and swales. The Great Valley is the widest and longest of these valleys.

Dominant Rock Type.—Limestone and dolomite of Cambrian through Devonian age comprise this subdivision.

Regolith Characteristics.—Thickness ranges from 0 to 60 ft on the carbonate rocks. Pinnacled weathering causes extreme variability in thickness over short distances.

Bedrock Characteristics.—Fractures are abundant in upper 200 ft of rock units but decrease with depth. Many fractures have been enlarged by dissolution. Water-bearing zones are reported to depths of 600 ft, but most are less than 450 ft. The average specific yield is about 5 percent.

Hydrologic Characteristics.—Precipitation ranges from 38 to 42 in/yr. Recharge in the Great Valley is about 43 percent on the carbonate rocks. Additional recharge is provided by seepage from streams that emerge from the uplands adjacent to valleys. Precipitation infiltrates rapidly to the carbonate rocks through sinkholes and porous regolith. Most ground-water flow is in the upper 450 ft. Flow in carbonate rocks commonly crosses surface-water divides and discharges to major springs or seeps. Five of the 10 largest springs in Pennsylvania are in this environmental subdivision.

Water-Quality Characteristics.—Ground water and base flow in streams contain high hardness (generally greater than 200 mg/L) and dissolved solids (greater than 400 mg/L). High-quality cold-water fishery habitats are abundant because many streams are sustained by large springs.

Land-Use Characteristics.—The area has an average population density of 288 people per square mile. The area contains about 19 percent of the urban, 17 percent of the agricultural, and 6 percent of the forest lands in the basin.

Siliciclastic Rocks in Ridge and Valley Physiographic Province

Topographic Setting.—Landscape characterized by long, narrow valleys bounded by steep ridges and broader valleys located in the noses of plunging folds.

Dominant Rock Types.—Mixed—sandstone, shale, siltstone, and coals of Ordovician through Pennsylvanian age comprise this subdivision.

Regolith Characteristics.—Mantle is thin in valleys and thicker on toe slopes of bounding uplands. Bouldery colluvium is common, but thickness varies greatly from valley to valley.

Bedrock Characteristics.—Bedrock dips steeply. Valleys may be in a structural setting along the axis of a syncline or anticline or may be formed in less resistant rocks in the flank of a fold. Fractures decrease with depth; most are in the upper 300 ft. Wells generally yield 5 to 50 gal/min.

Hydrologic Characteristics.—Ground water is present under unconfined conditions in the shallow fractured rocks and moves toward streams in small, local flow systems. Some water moves deeper into confined water-bearing fractures within steeply dipping units. The deeper confined water may move under small streams but discharges by upward leakage to major streams in the same valley.

Water-Quality Characteristics.—Ground water and base flow in streams on the mountain flanks underlain by quartz sandstone contain low concentrations of dissolved solids (less than 50 mg/L). The low buffering capacity of these streams makes them susceptible to acid deposition. Drainage from coal mining has lowered the pH and contaminated many streams with metals and sediment. Most streams are classified as cold-water or trout-stockable fisheries in this environmental subdivision.

Land-Use Characteristics.—The population density of the subdivision is sparse—130 people per square mile. The area contains about 39 percent of the urban, 39 percent of the agricultural, and 75 percent of the forest lands in the basin.

SUMMARY

The environmental setting of the Lower Susquehanna River Basin study unit includes natural and human components that influence surface- and ground-water quality. The major natural components are physiography, geology, soil, climate, hydrology, and vegetation and aquatic habitat; the human components are population density, water use, land use, and waste disposal.

Natural Components.—The physical characteristics of the study unit affect the water budget, sediment availability, minerals available for dissolution, and chemical reactions that are likely to take place. The study unit contains 9,350 mi^2 from where the West Branch joins the main stem of the Susquehanna River near Sunbury, Pa., downstream to the Chesapeake Bay at Havre de Grace, Md. The basin lies predominantly in the Ridge and Valley and Piedmont Physiographic Provinces and is underlain by parts of 156 geologic formations ranging in age from Precambrian to Triassic. Regolith overlies the bedrock in most places and is as much as 450 ft thick along the western flank of South Mountain. Soil formed on the regolith and bedrock has infiltration capacities ranging from excellent in carbonate-rock terranes to very poor along river valleys. Three ecoregions comprise most of the study unit—Blue Ridge Mountains, Central Appalachian Ridges and Valleys, and Northern Piedmont. Precipitation averages about 40 in/yr and its pH averaged between 4.08 and 4.20 during 1982-88; this precipitation is some of the most acidic in the nation.

The hydrologic pathway by which water travels determines to a great extent the types and concentrations of sediment and dissolved ions that the water will contain. The water budget shows that water is added to the basin in equal amounts (40 in/yr) from precipitation on the study unit and inflow from the Susquehanna River upstream from the study unit. The water in the main stem of the Susquehanna River, therefore, is greatly affected by conditions in the upper basin. Of the 18 in. of precipitation not lost to evapotranspiration, about 11 in. infiltrates to the water table and 7 in. runs off to the nearest stream. However, before leaving the basin, nearly all 11 in. of infiltration returns to the Susquehanna River as streamflow.

The average annual discharge of the Susquehanna River into Chesapeake Bay (38,300 ft^3/s) contributes about 45 percent of the Bay's freshwater, 40 percent of its sediment, 39 percent of its nitrogen, and 24 percent of its phosphorus load. Before entering Chesapeake Bay, the Susquehanna flows past four major dams; the three nearest the river's mouth have trapped 259 million tons of sediment, 913,000 tons of nitrogen, and 226,000 tons of phosphorus.

Ground water in regolith and fractured bedrock is present at median depths of about 20 ft beneath valleys and 45 ft beneath hills. In most areas, ground water moves from highland areas to streams. Flow paths are controlled mainly by the topography and depth of fracturing and are local and shallow—generally less than about 300 ft deep. Ground-water discharge to streams accounts for about 60 percent of total streamflow. In carbonate-rock terranes, where base flow can exceed 80 percent of streamflow, the ground-water contributions to streams not only sustain streamflow but provide the quality of water needed to create the exceptional value, cold-water fishery habitats for which "limestone streams" in the study area are well known.

Human Components.—Human factors affect concentrations of sediments, nutrients, pesticides, and volatile organic compounds in water, primarily by disrupting natural conditions, especially soil and vegetation, and by directly adding contaminants to surface water or the land surface.

About 1.9 million people inhabit the study unit, 71 percent live in the Piedmont and Great Valley. The major metropolitan areas surround the cities of Harrisburg, Lancaster, York, and Altoona. Water use for power generation, industry, public supply, agriculture, and domestic supply totals 3,822 Mgal/d. About 87 percent of this is used for power generation.

Land use is about 47 percent agriculture, 47 percent forest, and 4 percent urban; the remaining 2 percent consists of bodies of water and barren land. Some of the most intensive agriculture in Pennsylvania is in the southeastern part of the study unit, where annual nitrogen applications from manure reach 92 (lb/acre)/yr. Coal mining is the greatest cause of stream-water-quality degradation in the study unit—about 300 stream miles have been significantly degraded by contamination from mine drainage. The urban and suburban environment provides contaminants from nonpoint-source runoff, sewage-treatment facilities, industrial discharges, landfills, and leaking storage tanks. The study unit includes about 600 permitted point-source discharges of wastes (excluding discharges from single residences and small flows). Of these, 49 major public-owned sewage treatment plants discharge about 155 Mgal/d of treated sewage. Discharges from 23 major industries in the study unit total about 93 Mgal/d, the largest of which are wastewater from food processing, paper making, and steel making. Other methods of waste-disposal and storage that affect water quality include surface impoundments, septic systems, and land application.

Five major subdivisions of the study unit are made to facilitate assessments of water quality. Physiographic province and rock type are the natural components used to classify the subdivisions. The major distinction in rock type is that between carbonate and noncarbonate bedrock. The noncarbonate-rock subdivisions include crystalline rocks in the Piedmont and Blue Ridge Physiographic Provinces, siliciclastic rocks in the Piedmont Physiographic Province, and siliciclastic rocks in the Ridge and Valley Physiographic Province. The remaining two subdivisions are carbonate rocks in the Piedmont and Ridge and Valley Physiographic Provinces. These subdivisions and other components of the environmental setting will help guide the design of water-quality investigations and the interpretation of results for the U.S. Geological Survey's National Water-Quality Assessment program in the Lower Susquehanna River Basin.

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

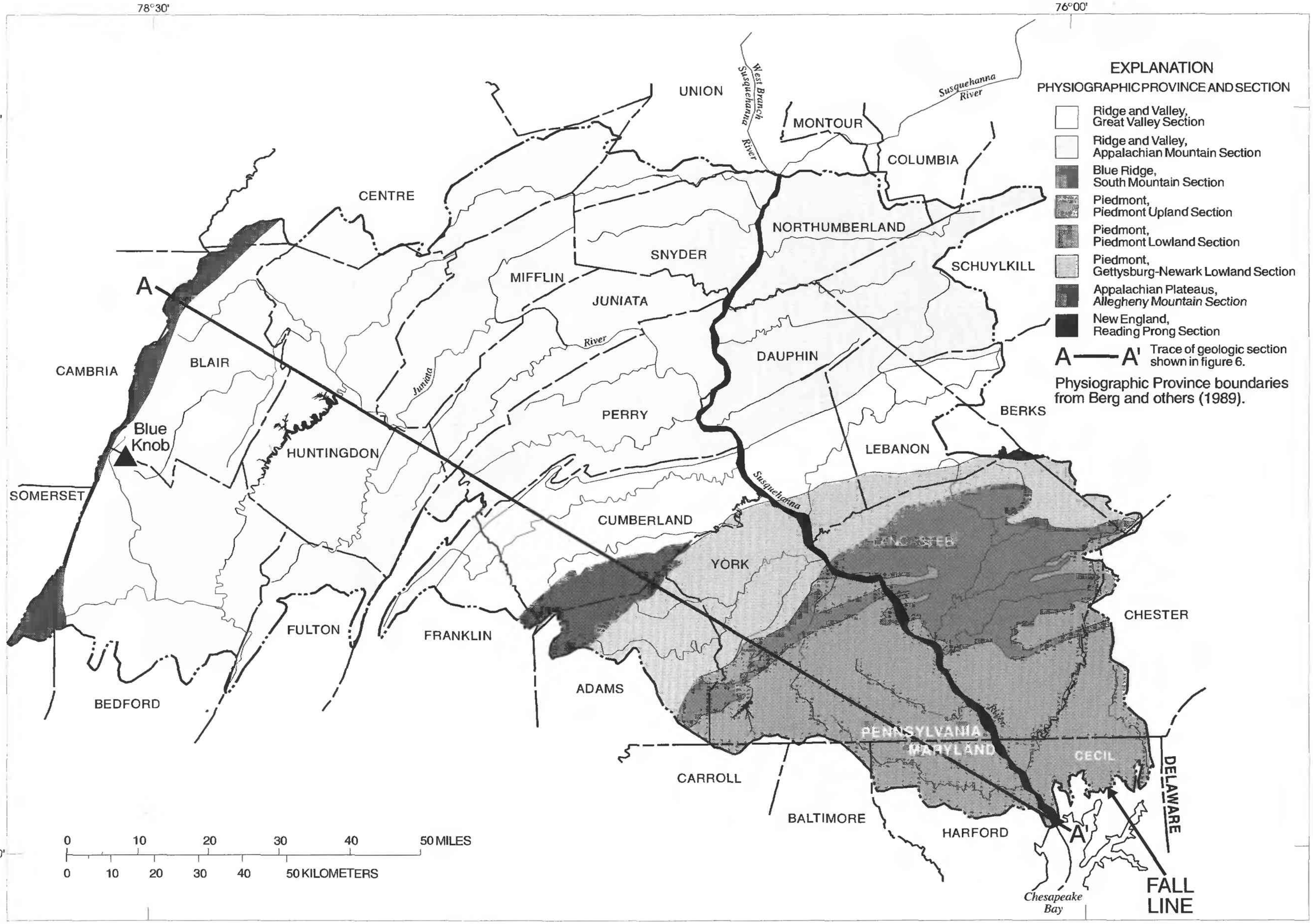
Dennis W. Risser and Steven F. Siwiec

U.S. Department of the Interior
U.S. Geological Survey
Water-Resources Investigations Report 94-4245

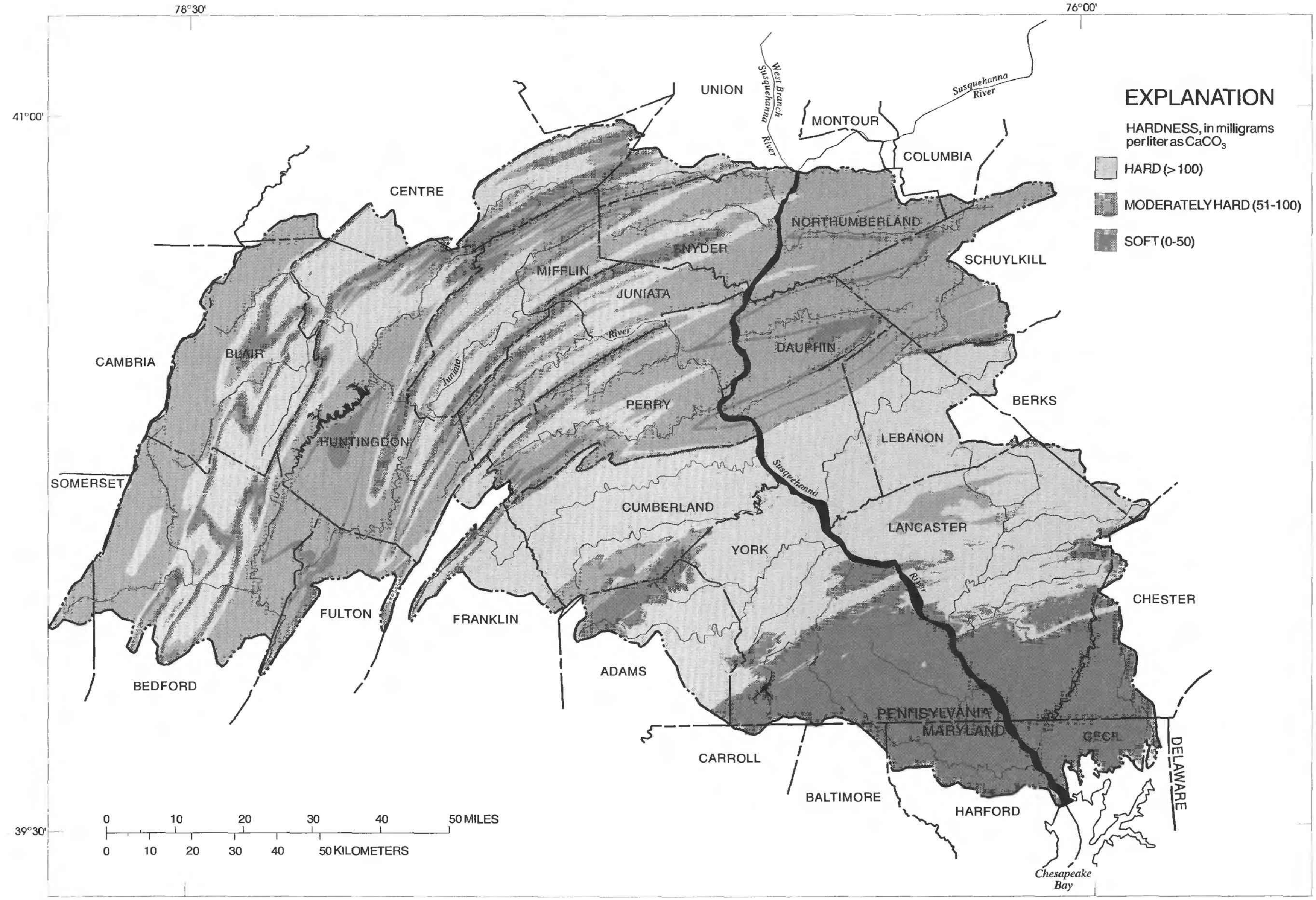
SUPPLEMENTAL MAPS

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

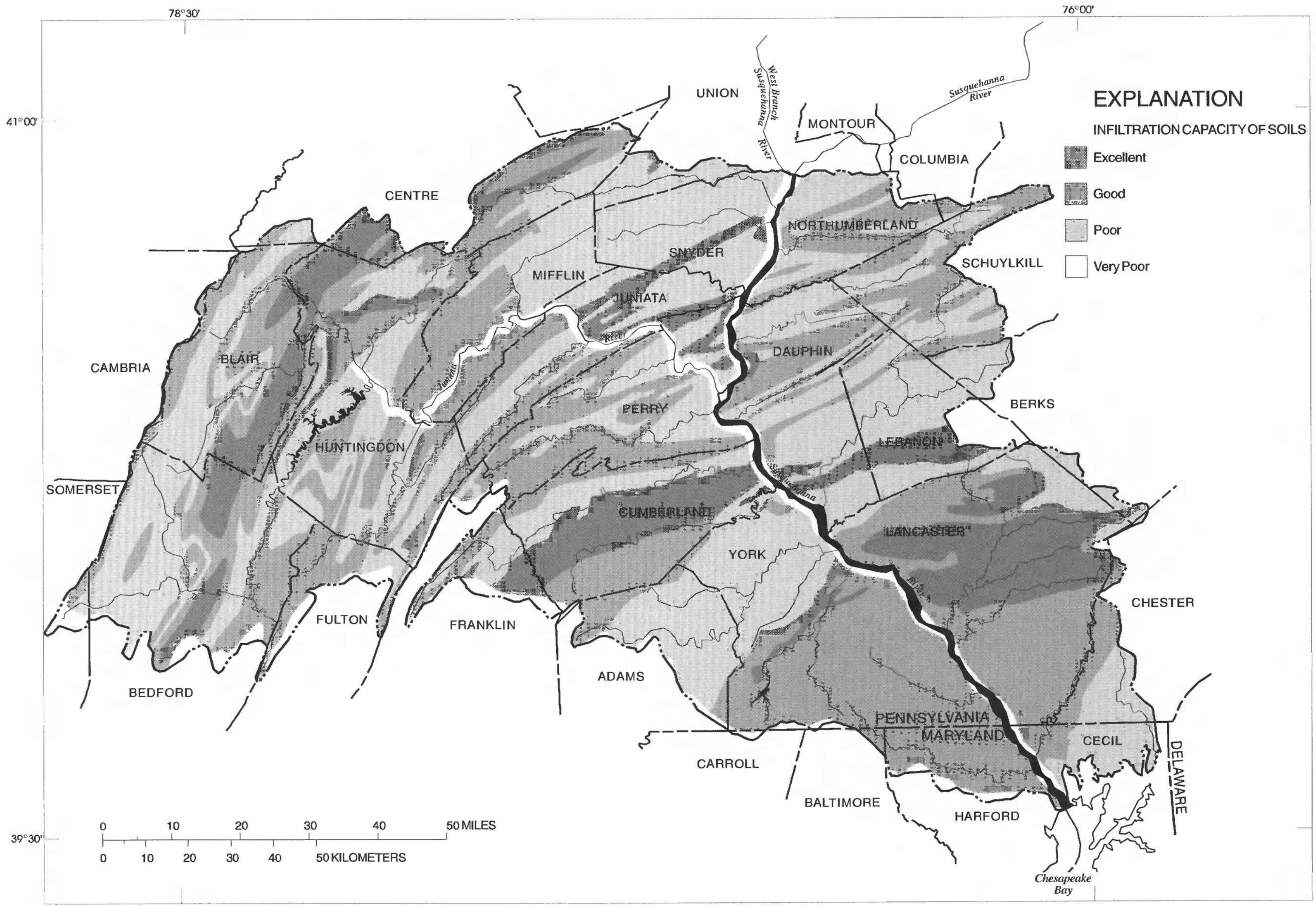
Lemoyne, Pennsylvania
1996



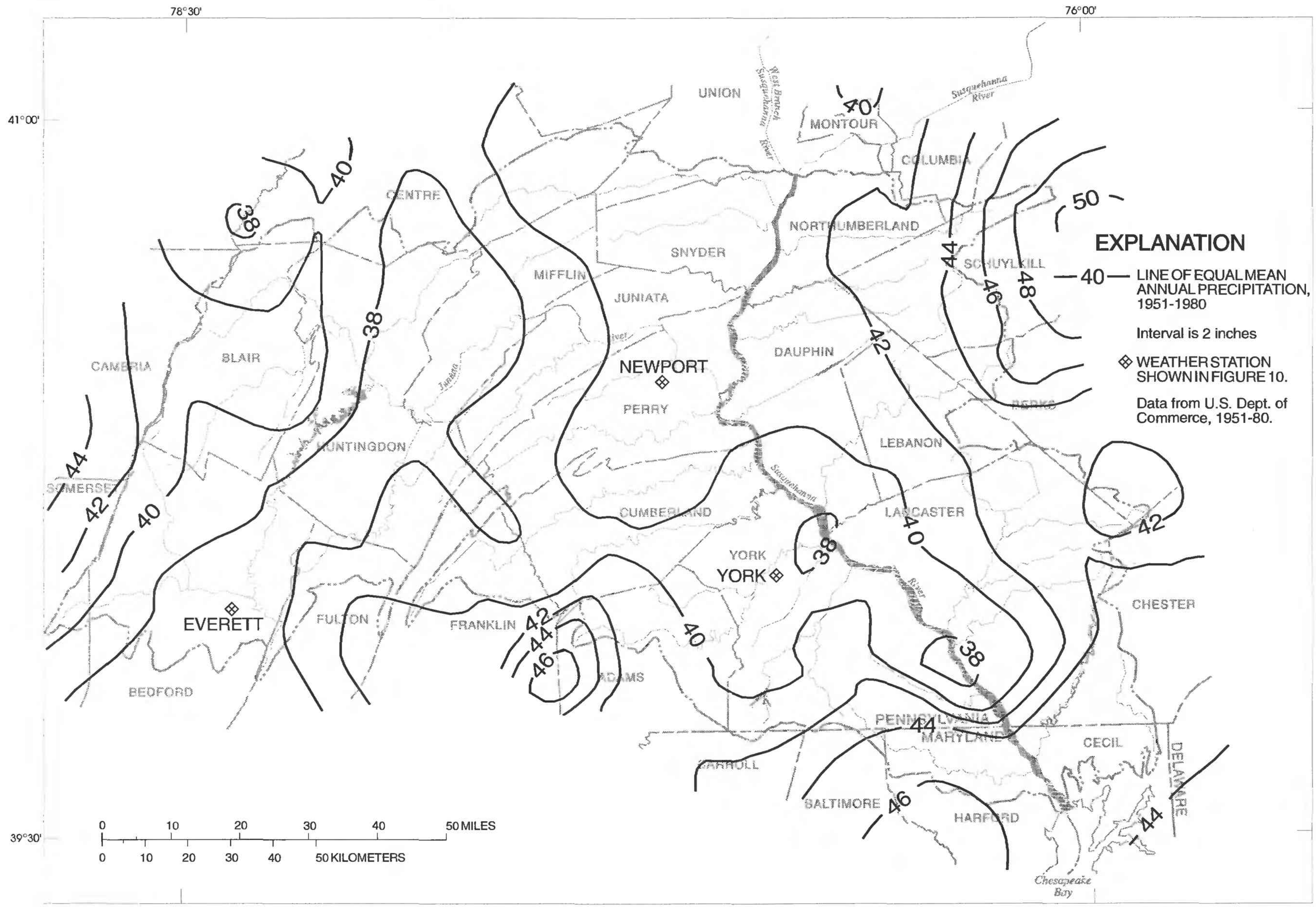
Map 1. Physiographic provinces in the Lower Susquehanna River Basin.



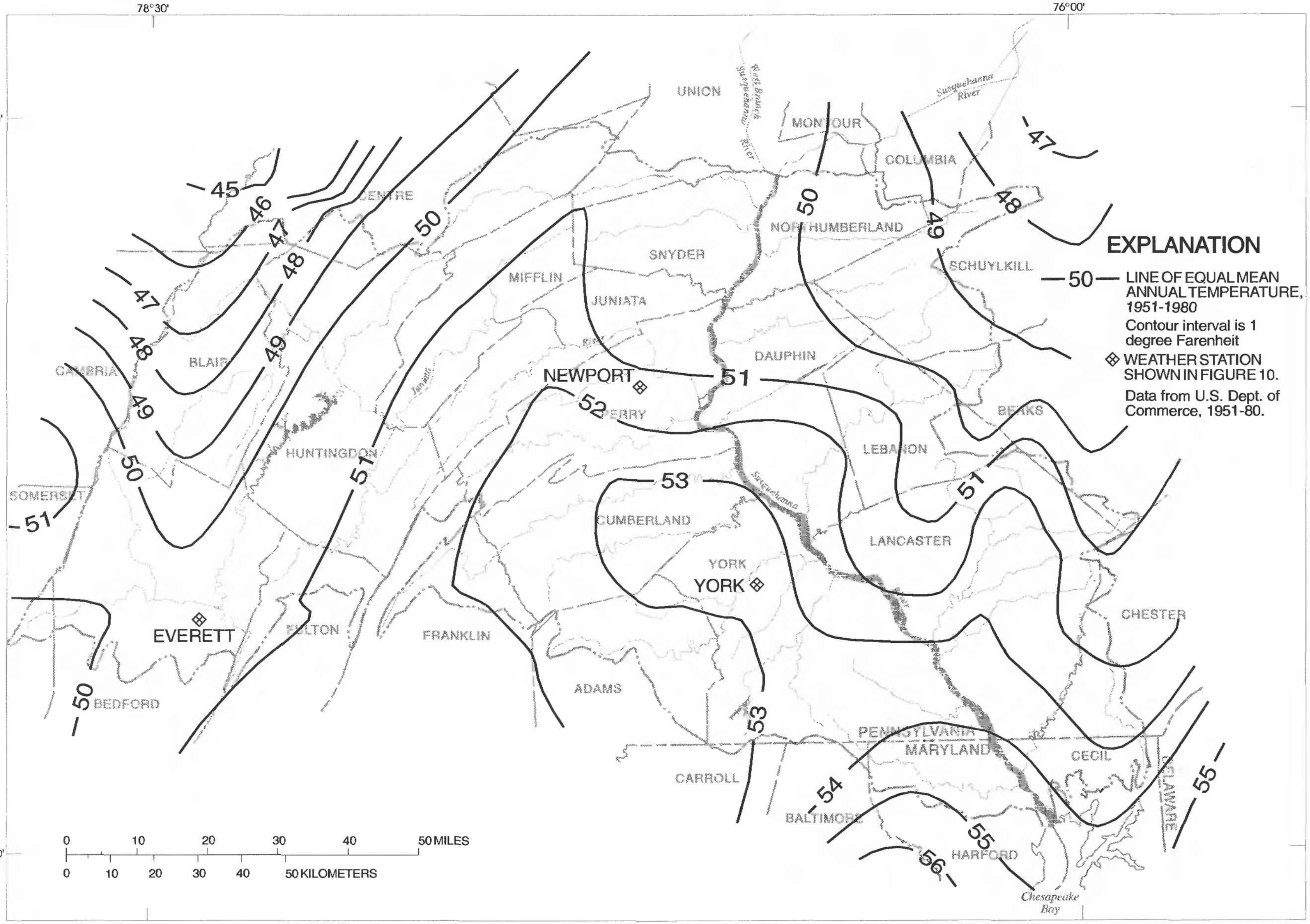
Map 2. Generalized hardness of ground water in the Lower Susquehanna River Basin (modified from Taylor and Werkheiser, 1984, pl. 1, and Taylor and others, 1982, pl. 1).



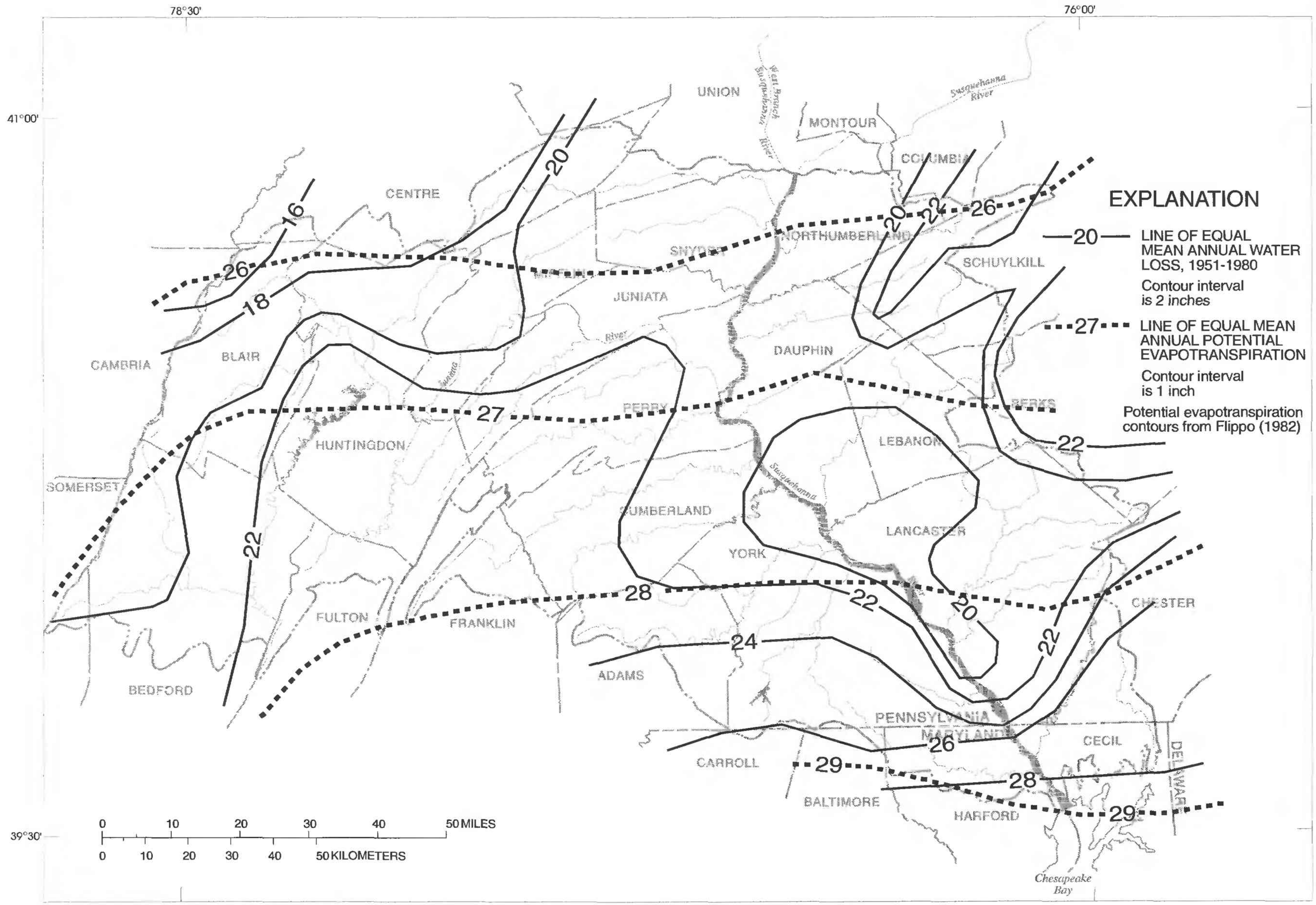
Map 3. Infiltration capacity of soils in the Lower Susquehanna River Basin (after Armbruster, 1976).



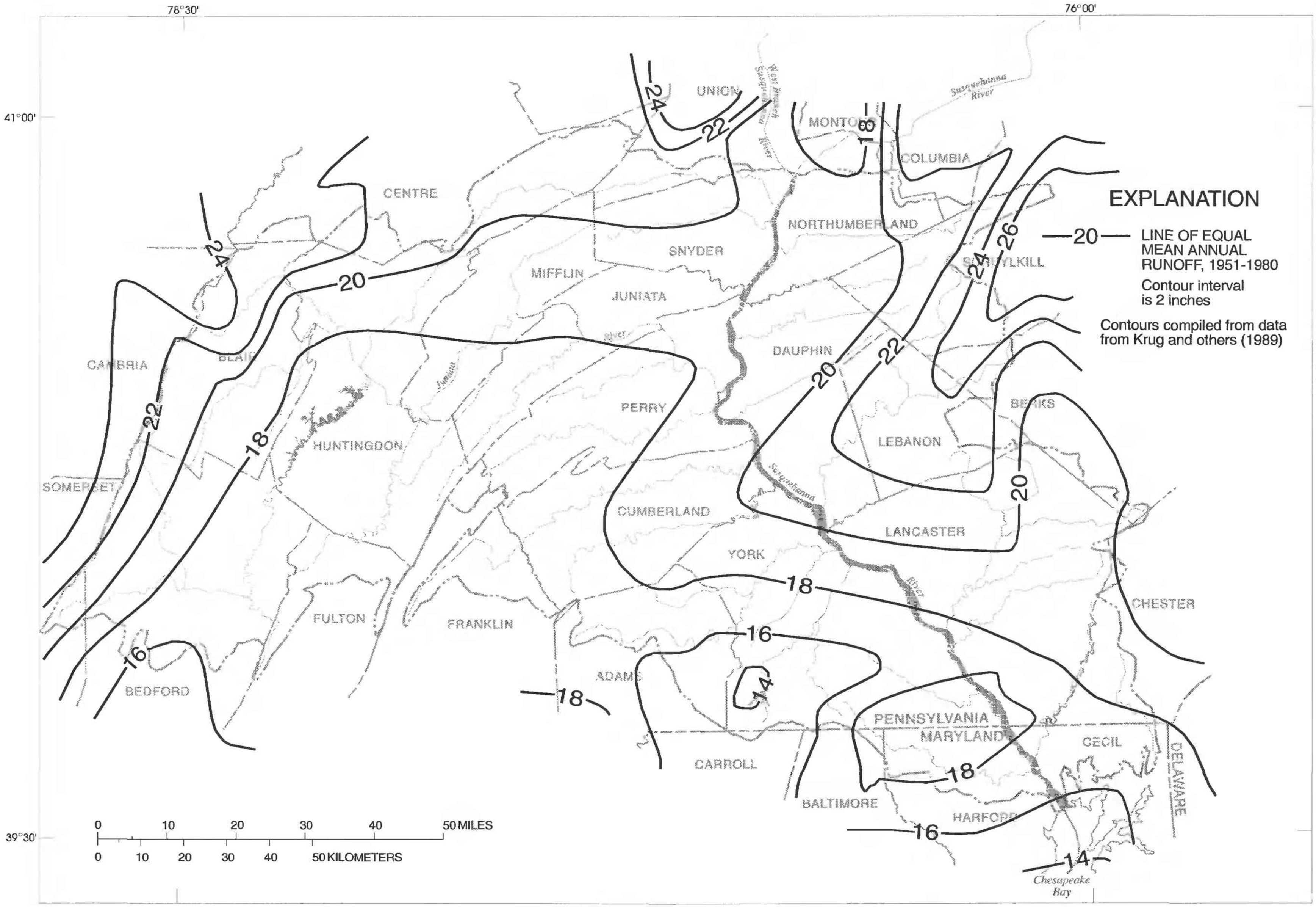
Map 4. Areal distribution of mean-annual precipitation in the Lower Susquehanna River Basin, 1951-80.



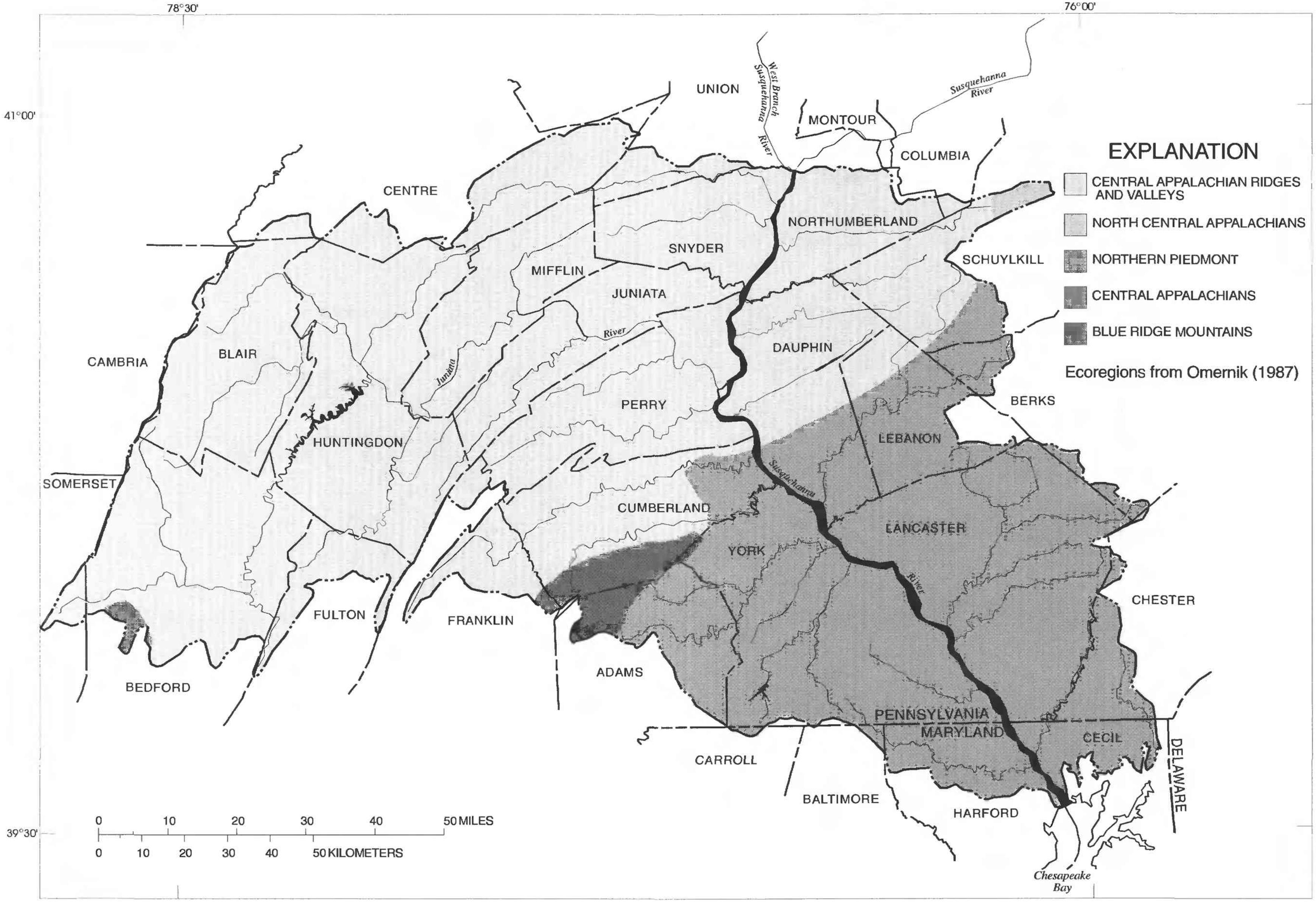
Map 5. Mean annual temperature in the Lower Susquehanna River Basin, 1951-80.



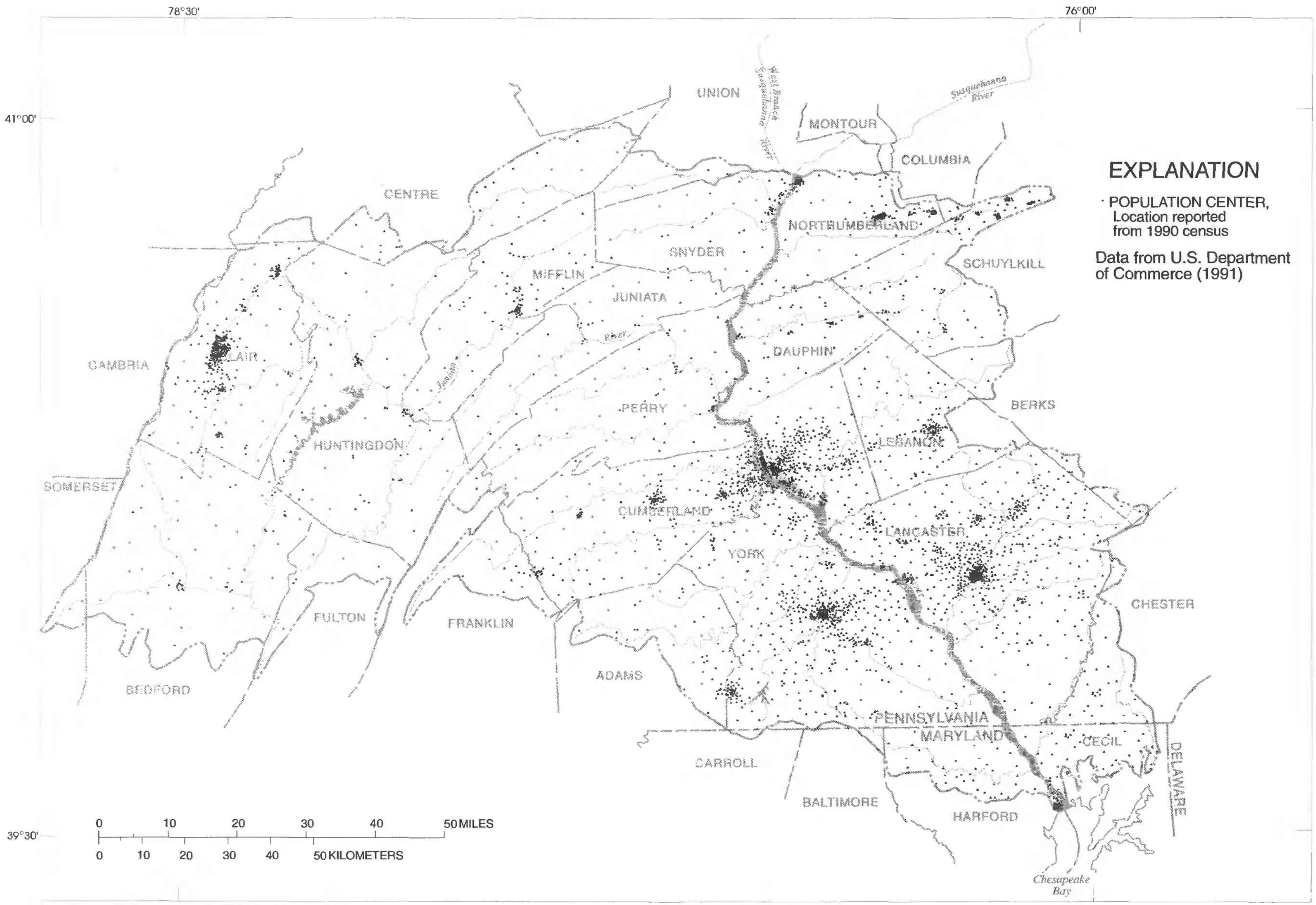
Map 6. Areal distribution of mean annual potential evapotranspiration and water loss in the Lower Susquehanna River Basin, 1951-80.



Map 7. Areal distribution of mean annual runoff in the Lower Susquehanna River Basin, 1951-80.

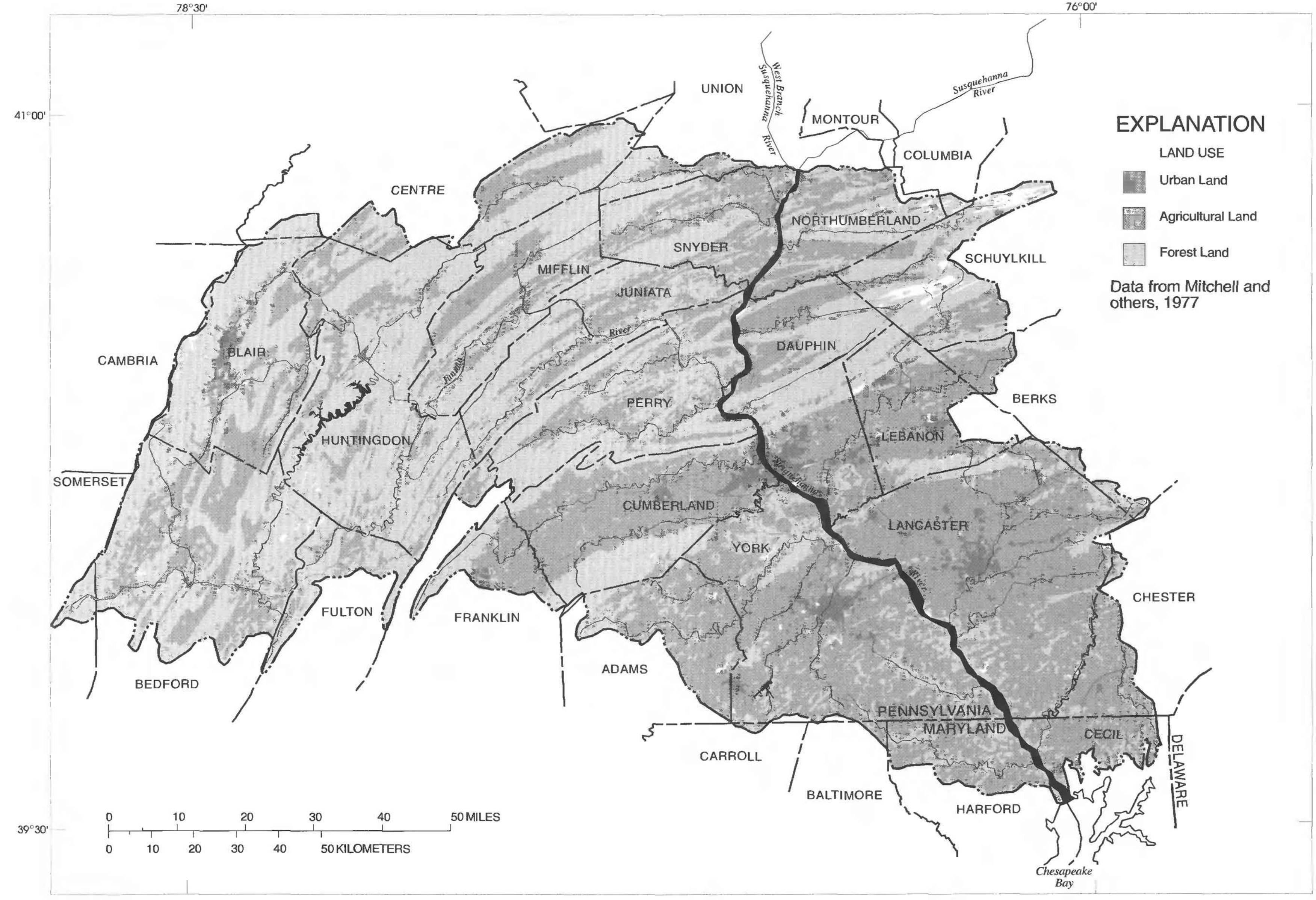


Map 8. Distribution of ecoregions in the Lower Susquehanna River Basin.

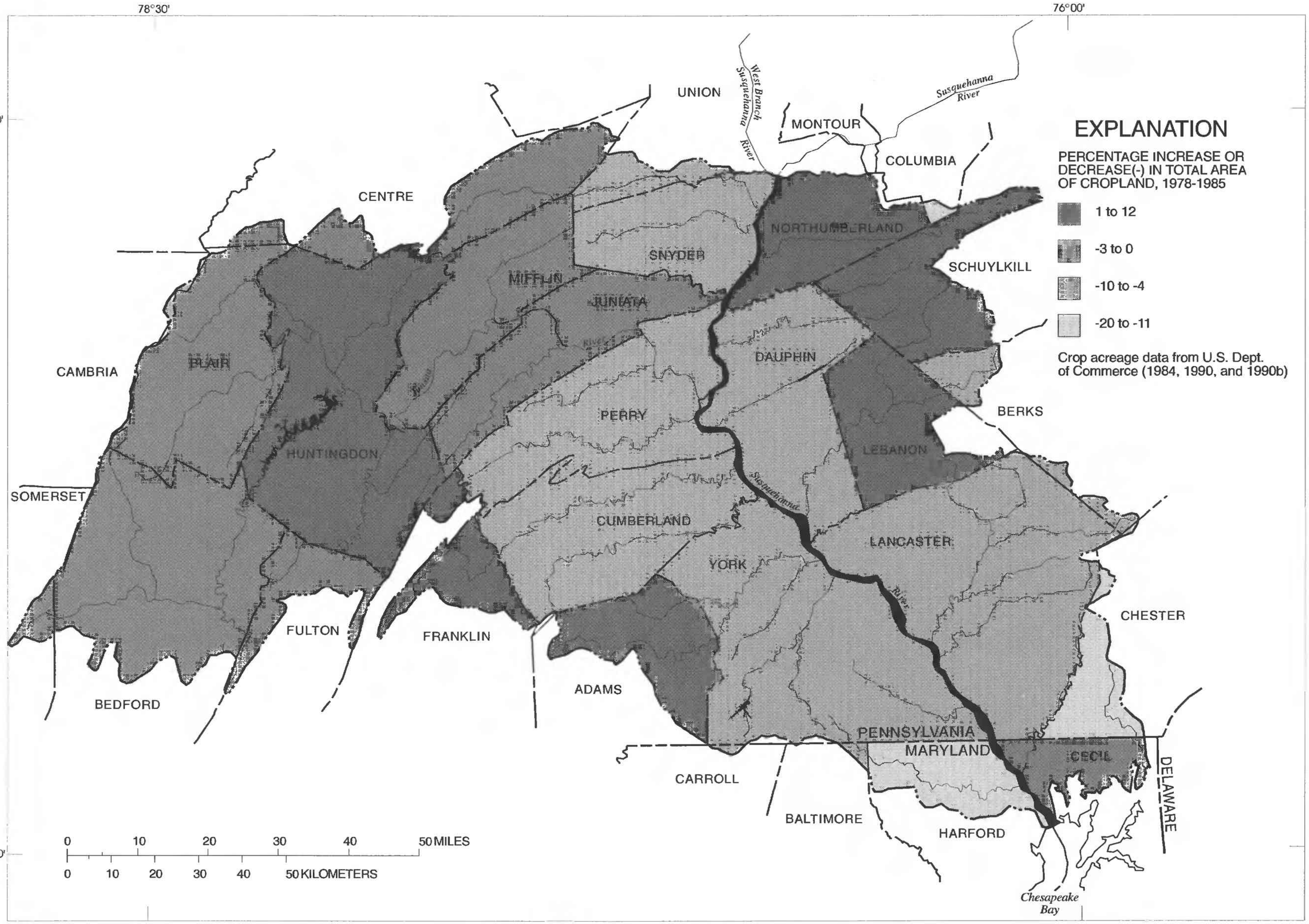


Map 9. Distribution of population centers in the Lower Susquehanna River Basin.

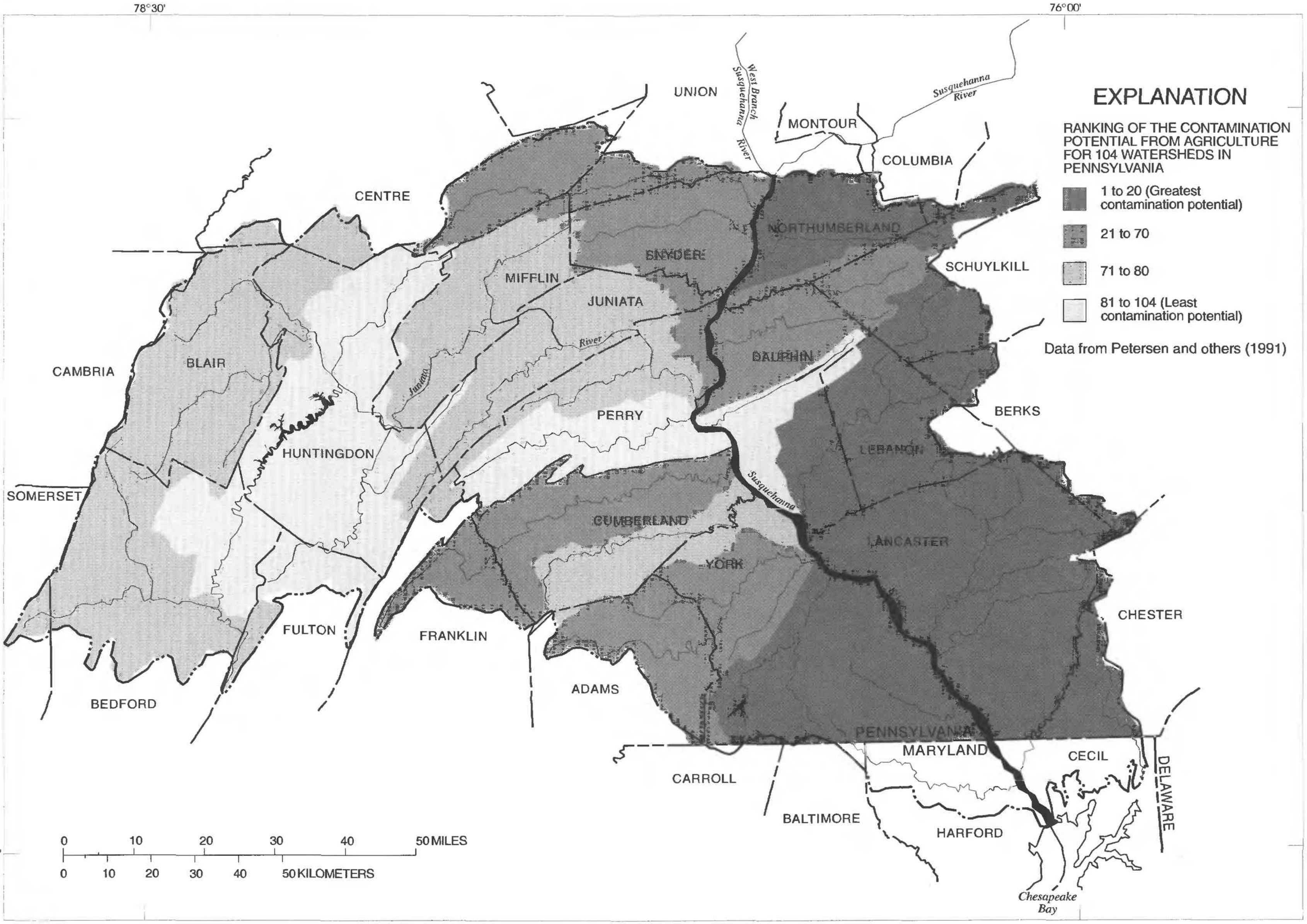
Map 10. Change in population in the Lower Susquehanna River Basin, 1960-90, by county.



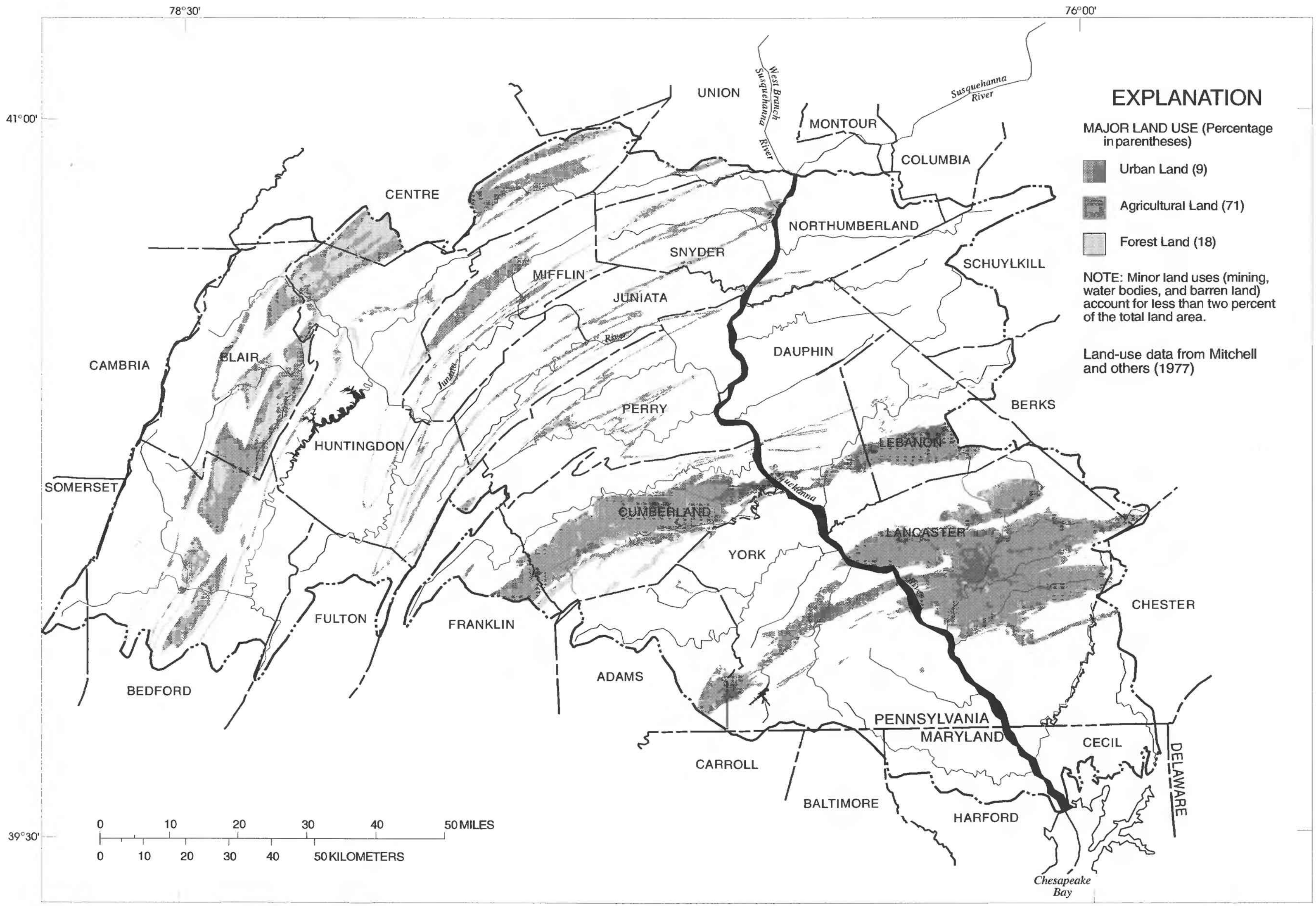
Map 11. Major land uses during the mid 1970's in the Lower Susquehanna River Basin.



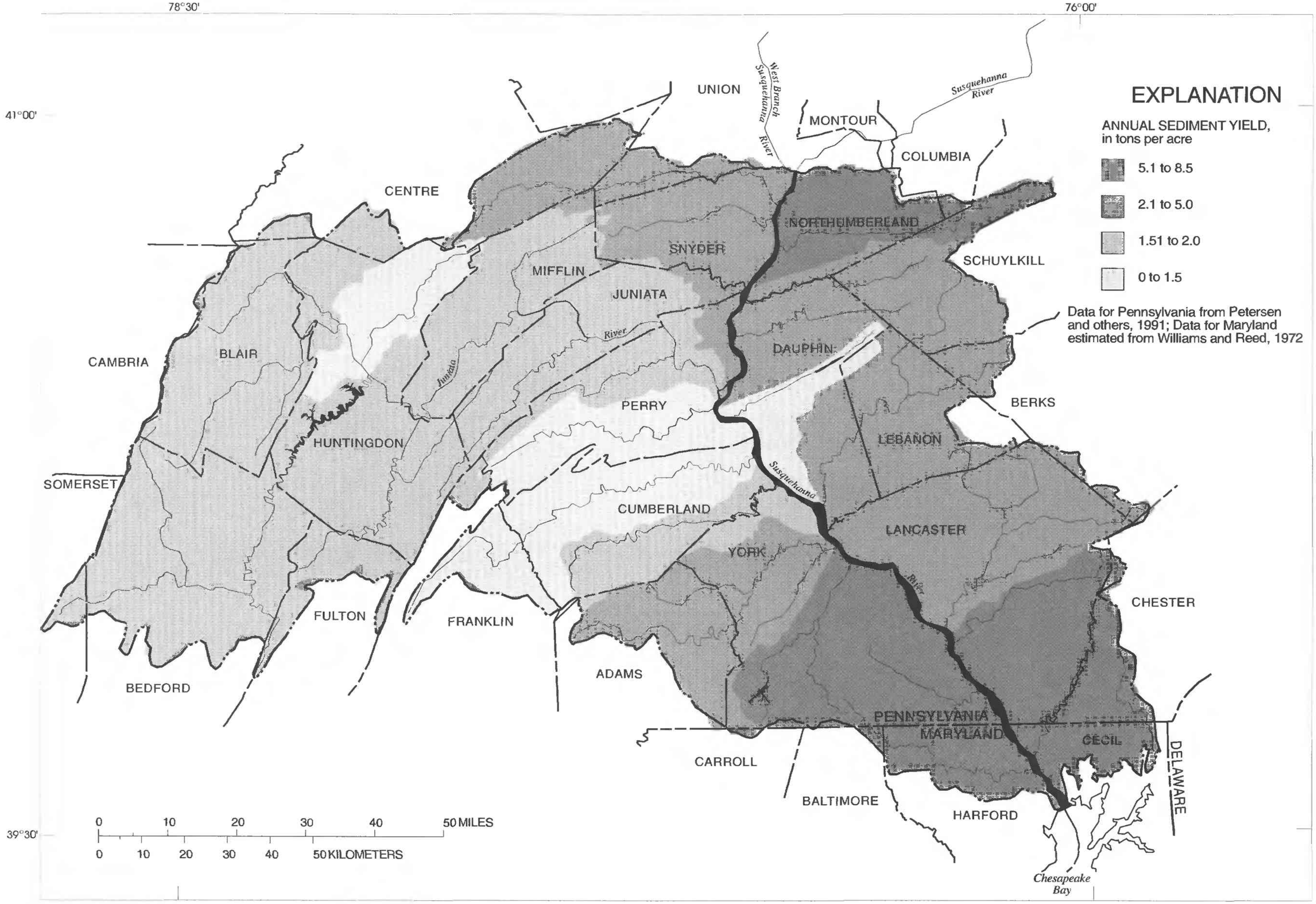
Map 12. Change in total cropland in the Lower Susquehanna River Basin, 1978-85, by county.



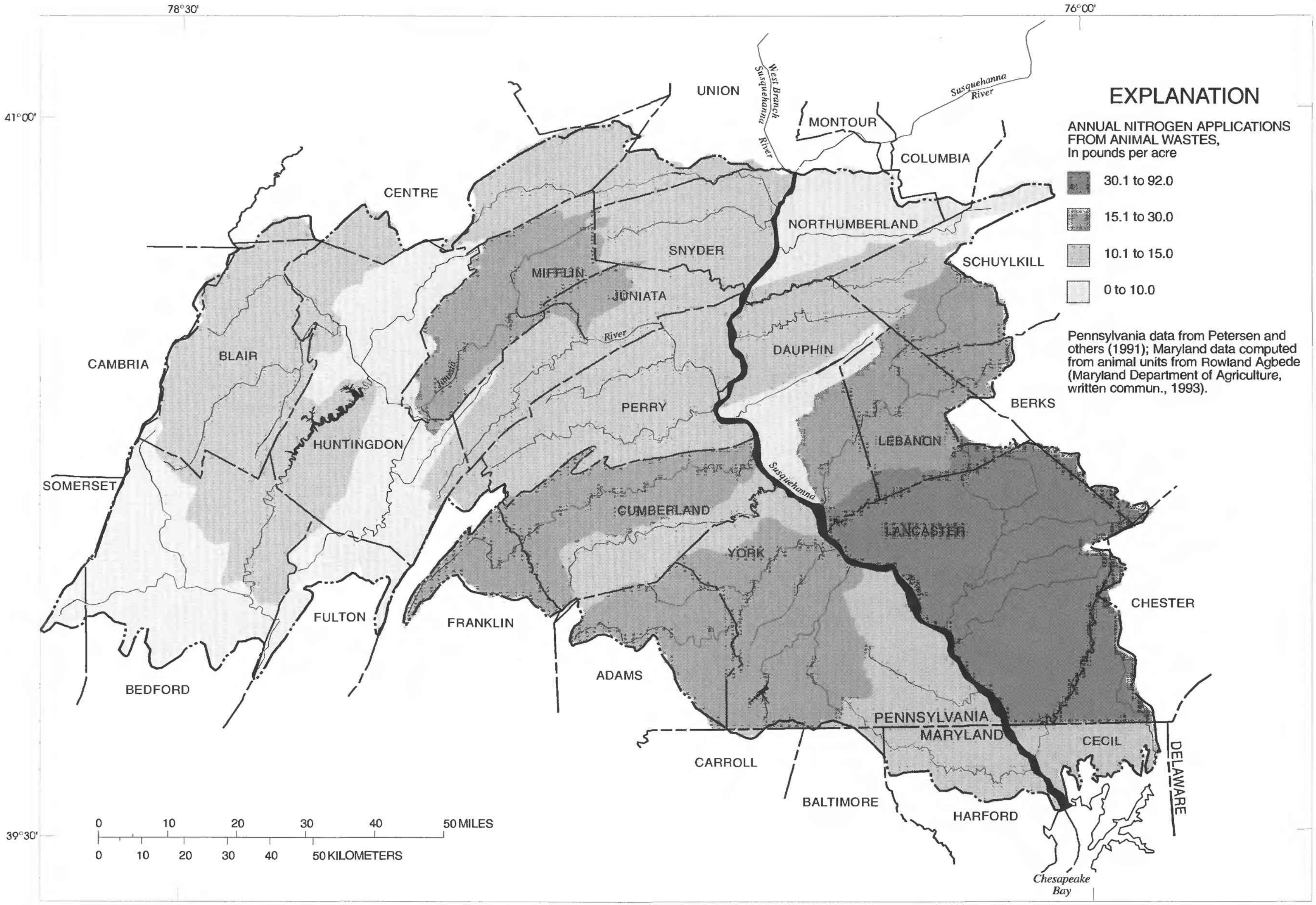
Map 13. Potential for contamination of surface water in Pennsylvania from agricultural activities, by watershed.



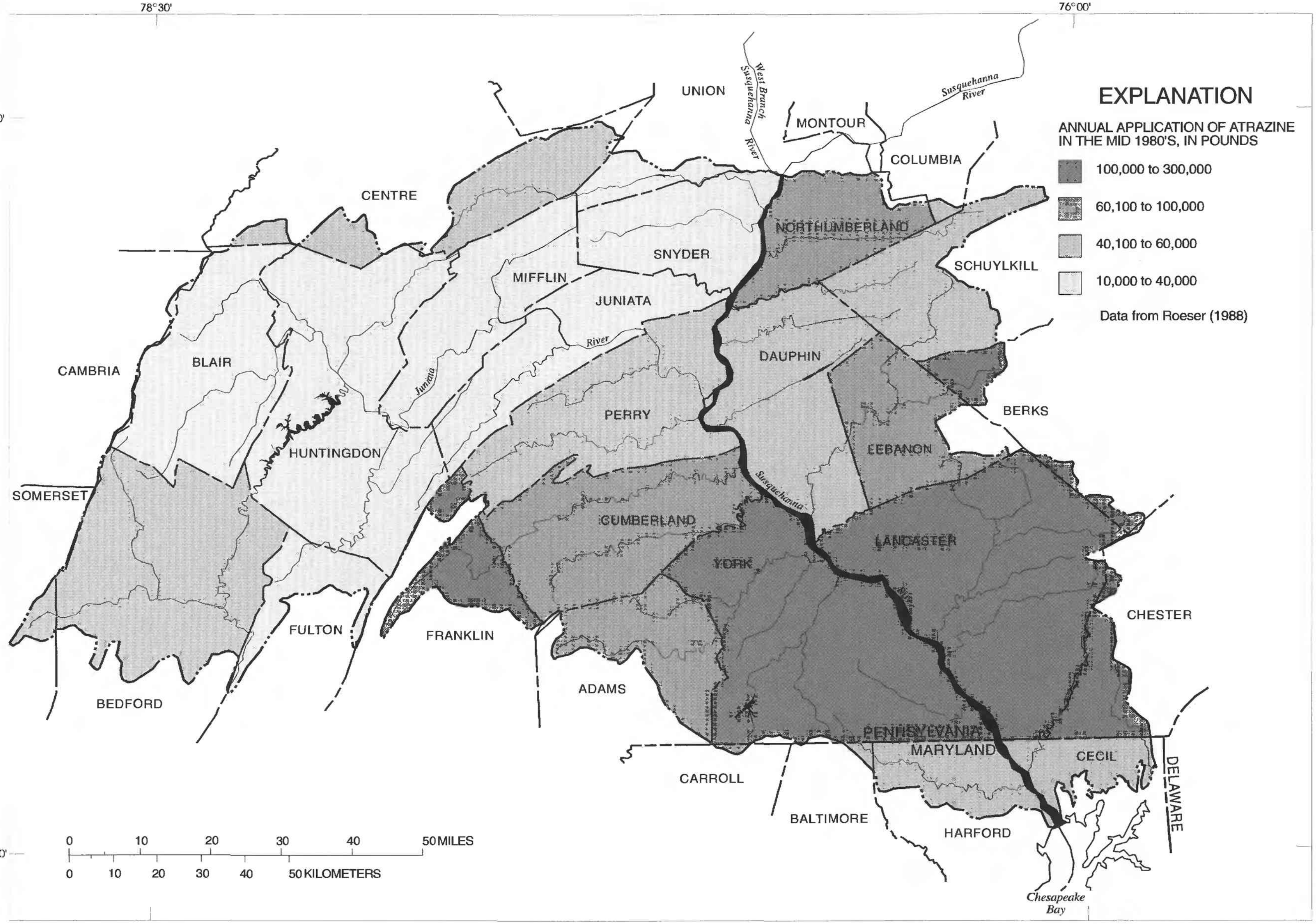
Map 14. Major land uses in areas underlain by carbonate rocks in the Lower Susquehanna River Basin.



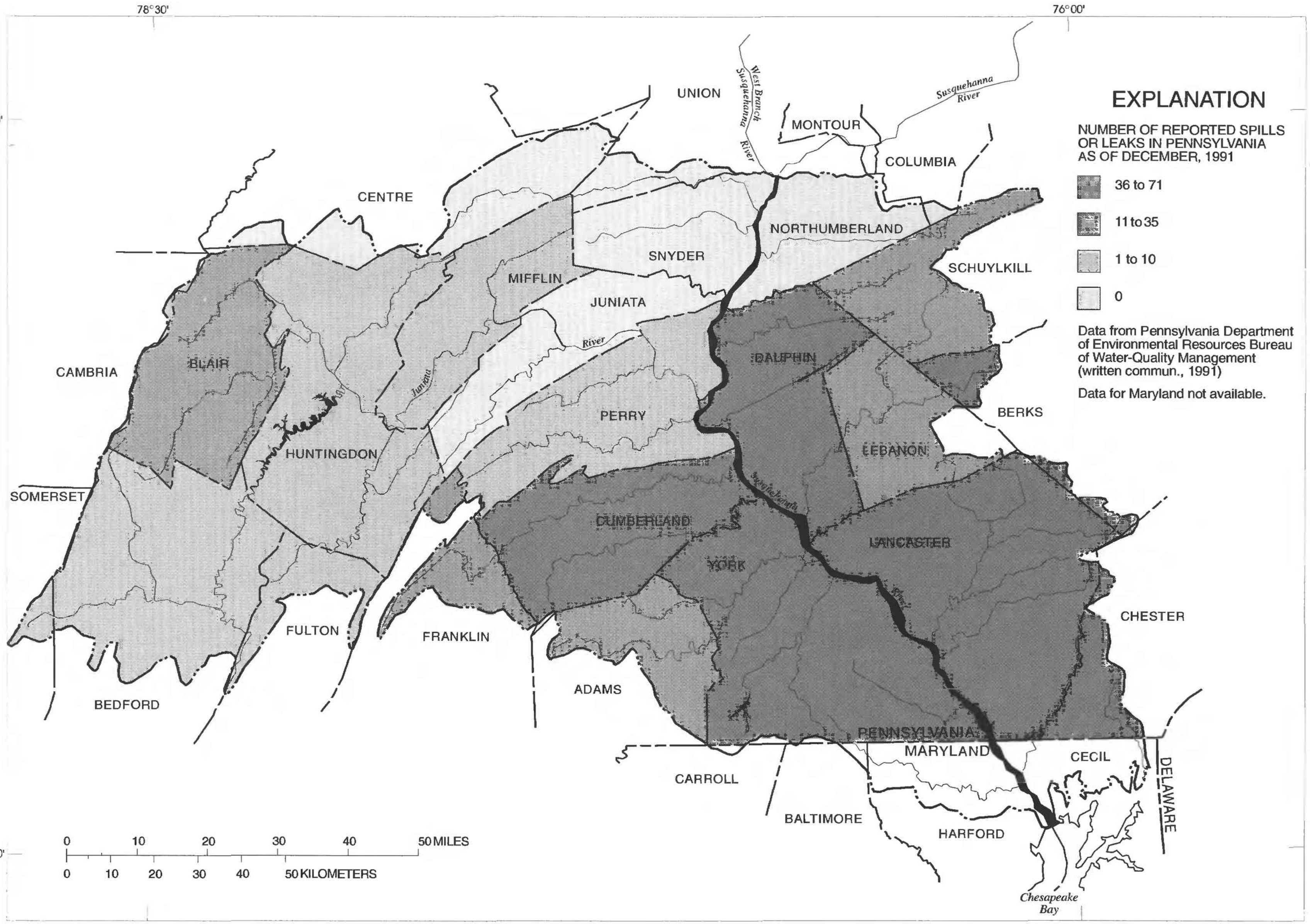
Map 15. Estimated sediment yield to streams in the Lower Susquehanna River Basin, by watershed.



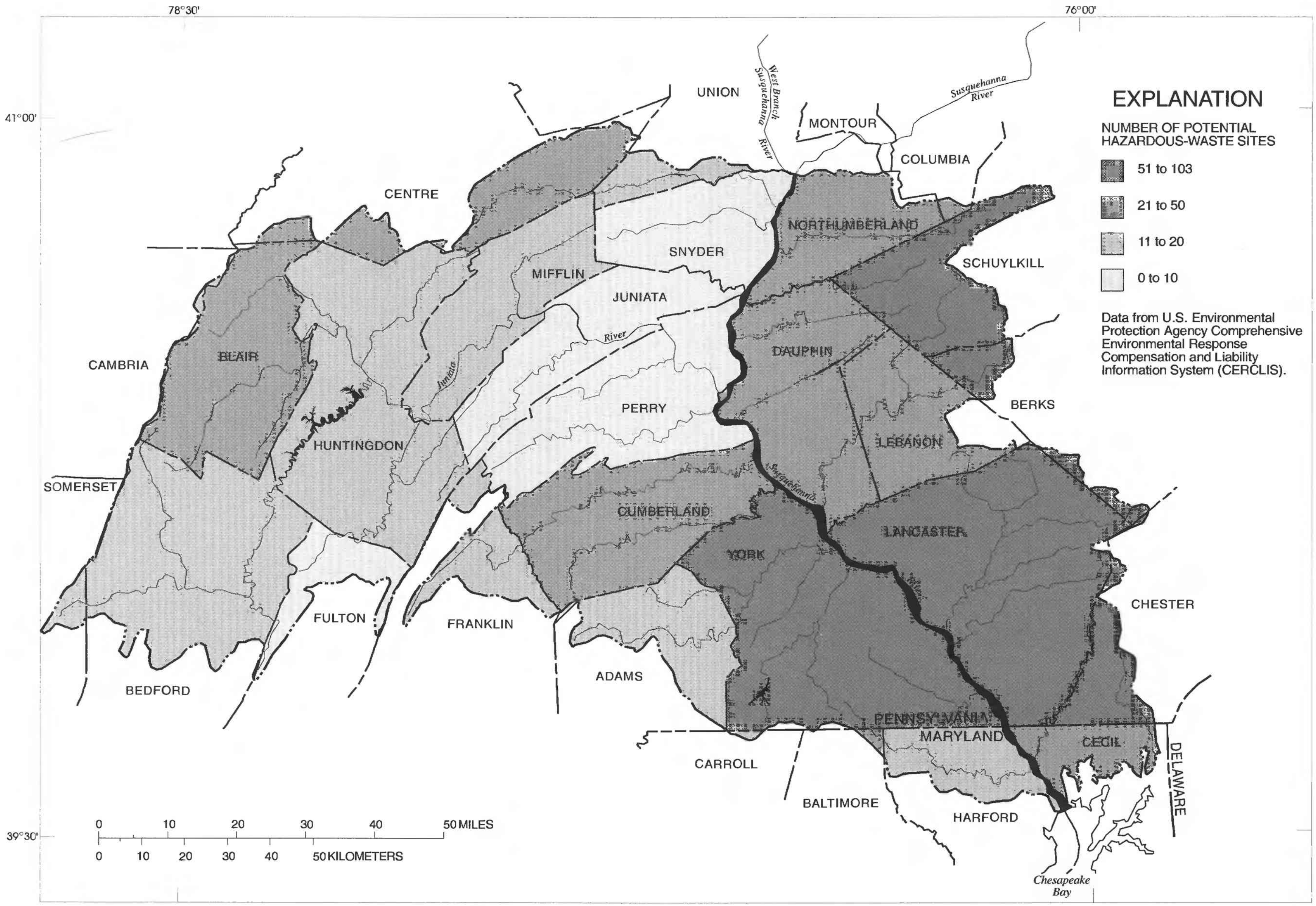
Map 16. Estimated applications of nitrogen from animal waste in the Lower Susquehanna River Basin in 1987, by watershed.



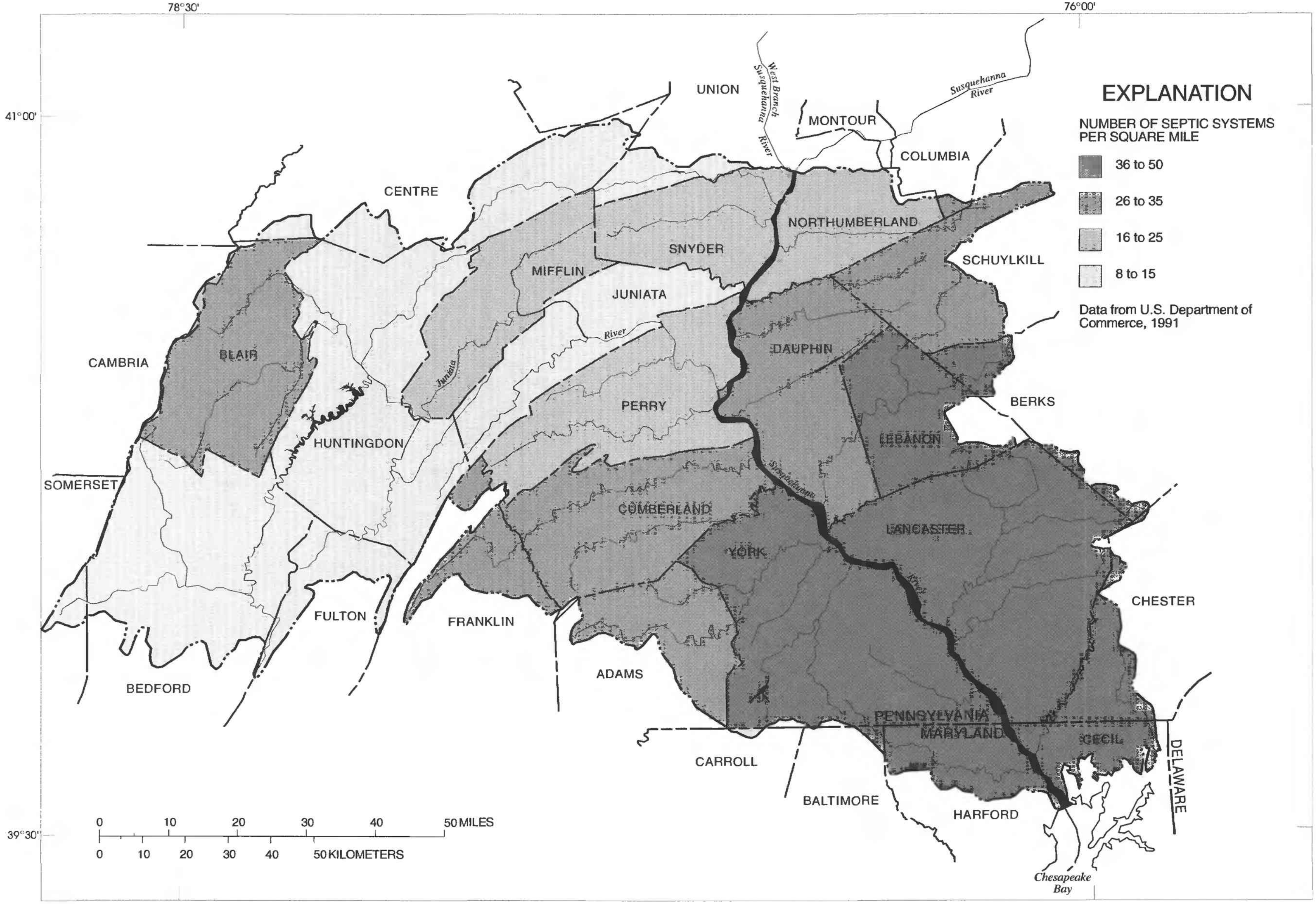
Map 17. Applications of the herbicide atrazine in the Lower Susquehanna River Basin, by county.



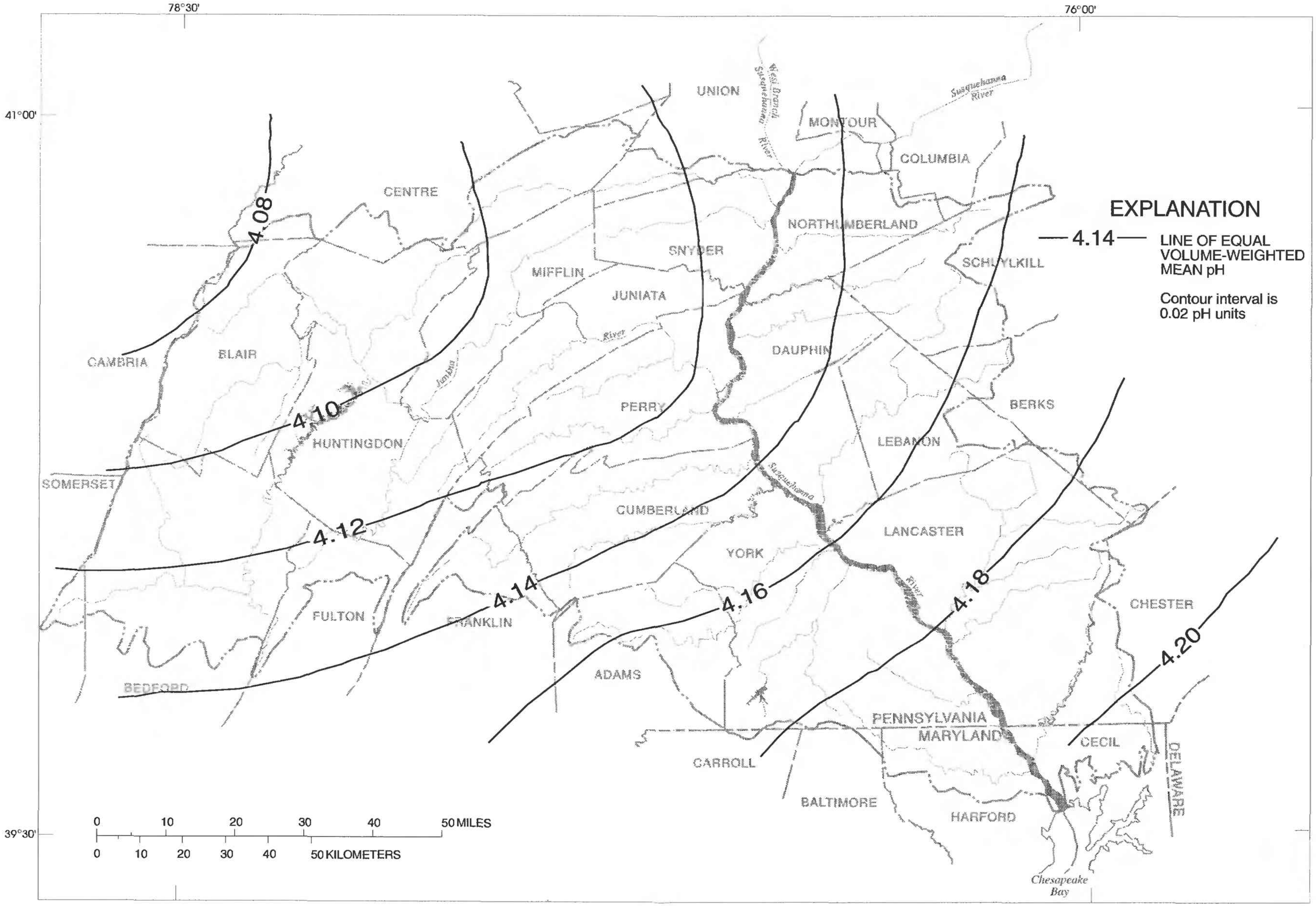
Map 18. Reported spills and leaks from storage tanks, by county, in the Lower Susquehanna River Basin.



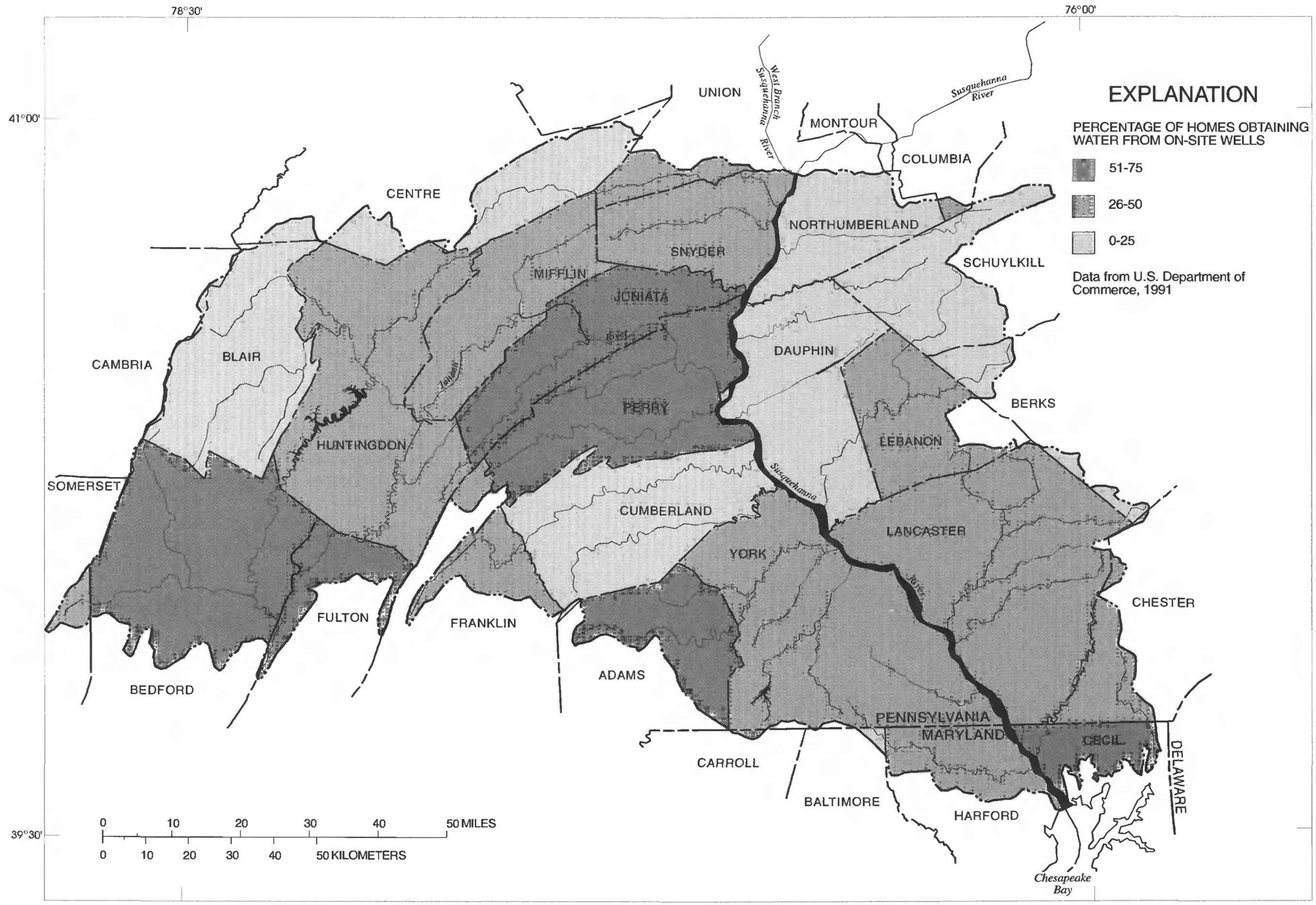
Map 19. Potential hazardous-waste sites in the Lower Susquehanna River Basin, by county.



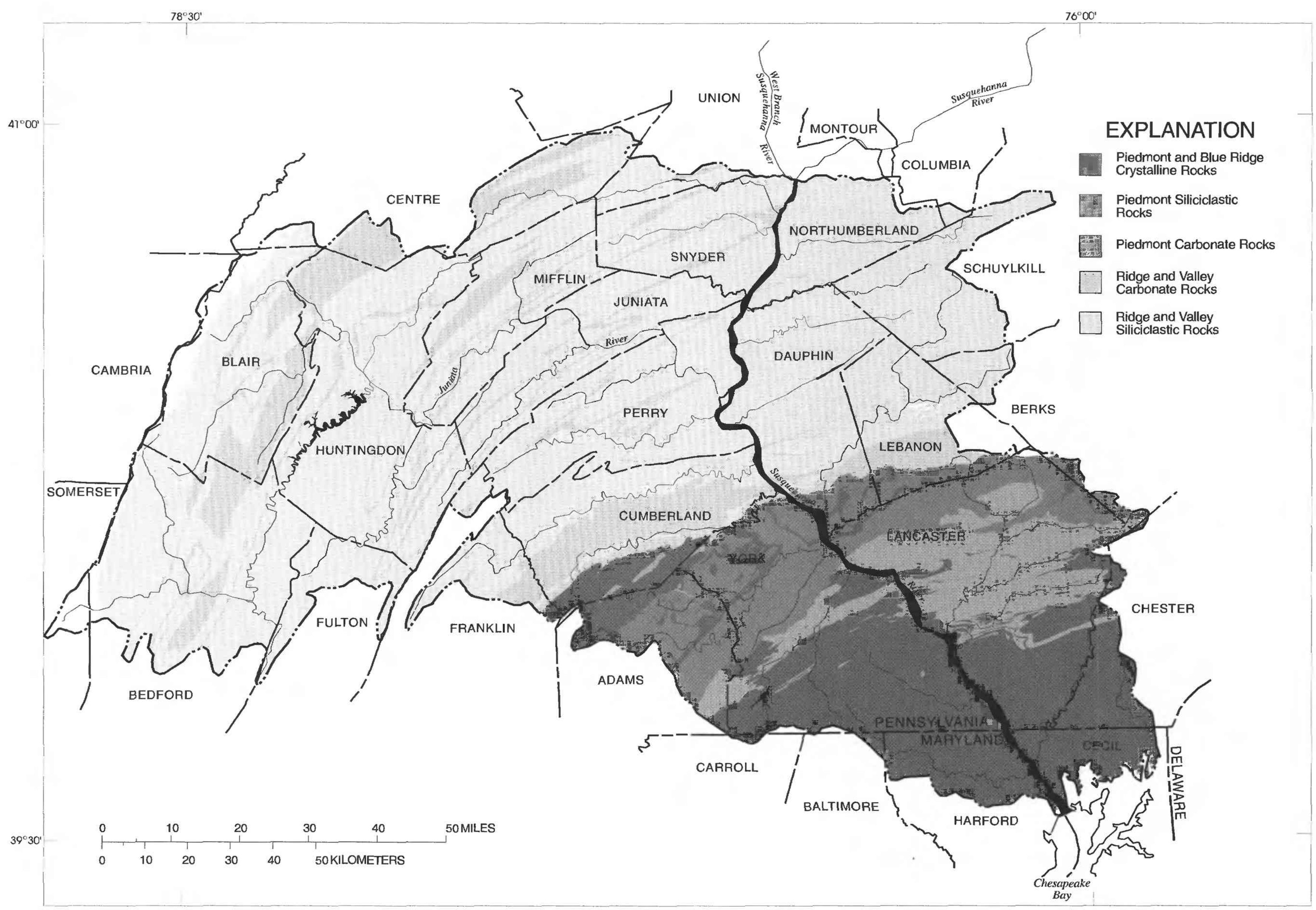
Map 20. Septic-system density in the Lower Susquehanna River Basin, by county.



Map 21. Areal distribution of volume-weighted mean annual pH of precipitation in the Lower Susquehanna River Basin, 1982-88 (from Lynch, 1990, fig. 4).

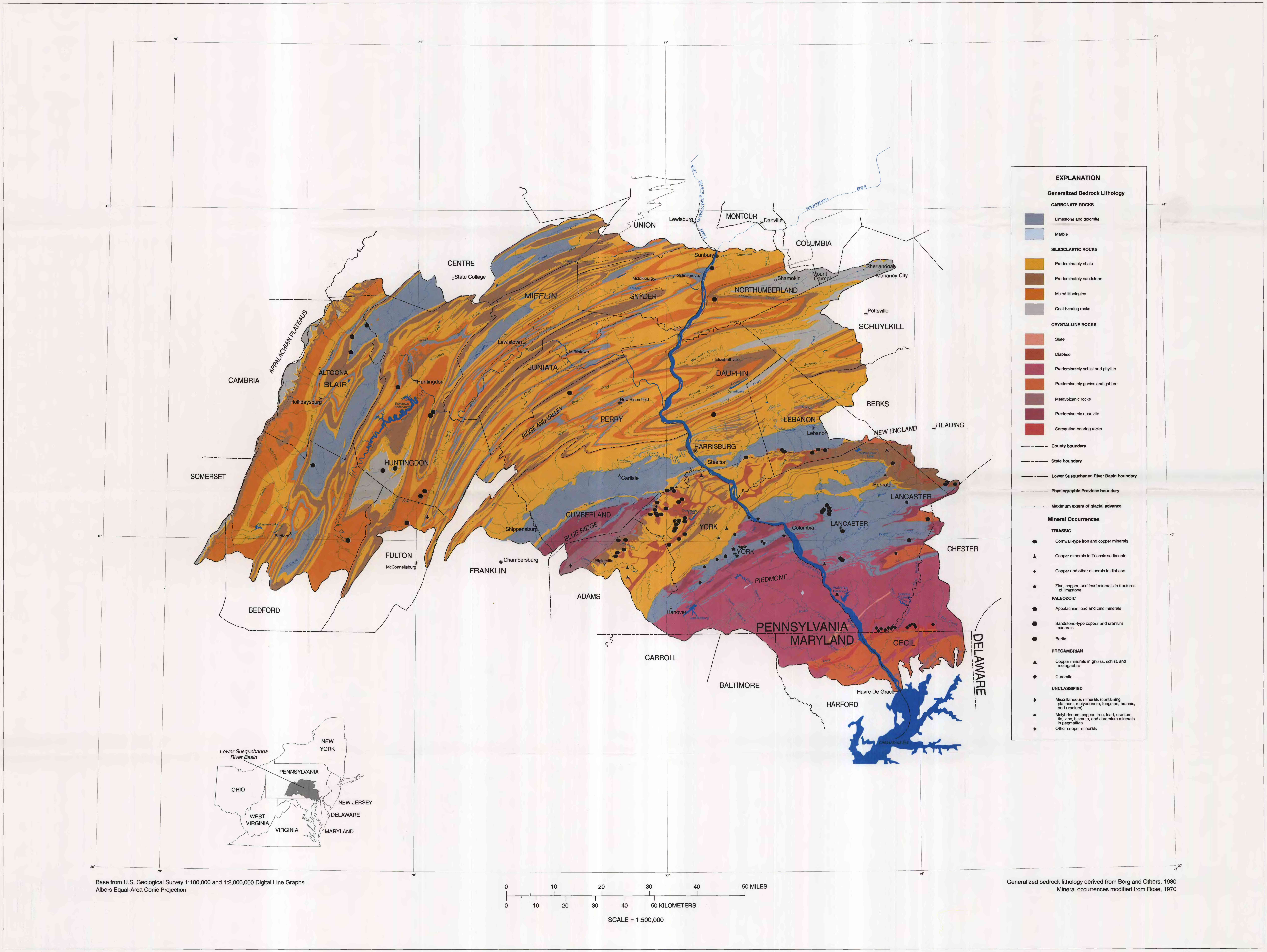


Map 22. Percentage of homes obtaining water from on-site wells in the Lower Susquehanna River Basin, by county.



Map 23. Major environmental subdivisions in the Lower Susquehanna River Basin.

Risser, D.W., and Siwiec, S.F., 1996, Water-quality assessment of the Lower Susquehanna River Basin, Pennsylvania and Maryland: Environmental setting



MAP SHOWING GENERALIZED BEDROCK LITHOLOGY AND MINERAL OCCURRENCES IN THE LOWER SUSQUEHANNA RIVER BASIN, PENNSYLVANIA AND MARYLAND

By Dennis W. Risser and Steven F. Siwiec

1996

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS REPORT 94-4245
Uses and characteristics of major streams—PLATE 2
Risser, D.W., and Siwiec, S.F., 1996, Water-quality assessment of the Lower Susquehanna River Basin, Pennsylvania and Maryland: Environmental setting

EXPLANATION

Designated Stream Use[1]

- Cold Water Fishes
- Warm Water Fishes
- Trout Stocking
- Exceptional Value
- High Quality
- County boundary
- State boundary
- Basin boundary
- Physiographic Province boundary
- ▲1 Active streamflow-gaging station in 1991 (Identification number refers to table below)

[1] Designated stream uses subject to chsnge. Refer to Chapter 93 of Pennsylvania Department of Environmental Protection's Rules and Regulations for updates.

Active Streamflow-Gaging Stations in 1991

Map Identifier	Site Identifier	Site Name
1	01540500	Susquehanna River at Danville, Pa.
2	01553500	West Branch Susquehanna River at Lewisburg, Pa.
3	01554000	Susquehanna River at Sunbury, Pa.
4	01554500	Shamokin Creek near Shamokin, Pa.
5	01555000	Penns Creek at Penns Creek, Pa.
6	01555400	East Mahantango Creek at Klingerstown, Pa.
7	01555500	East Mahantango Creek near Dalmatia, Pa.
8	01556000	Frankstown Branch Juniata River at Williamsburg, Pa.
9	01557500	Bald Eagle Creek at Tyrone, Pa.
10	01558000	Little Juniata River at Spruce Creek, Pa.
11	01559000	Juniata River at Huntingdon, Pa.
12	01559795	Bobs Creek near Pavia, Pa.
13	01560000	Dunning Creek at Belden, Pa.
14	01562000	Raystown Branch Juniata River at Saxton, Pa.
15	01563200	Raystown Branch Juniata River below Raystown Dam near Huntingdon, Pa.
16	01563500	Juniata River at Mapleton Depot, Pa.
17	01564500	Aughwick Creek near Three Springs, Pa.
18	01564997	Kishacoquillas Creek at Lumber City, Pa.
19	01567000	Juniata River at Newport, Pa.
20	01567500	Bixler Run near Loysville, Pa.
21	01568000	Sherman Creek at Shermans Dale, Pa.
22	01568500	Clark Creek near Carsonville, Pa.
23	01569800	Letort Spring Run near Carlisle, Pa.
24	01570000	Conodoguinet Creek near Hogestown, Pa.
25	01570500	Susquehanna River at Harrisburg, Pa.
26	01571490	Cedar Run at Eberlys Mill, Pa.
27	01571500	Yellow Breeches Creek near Camp Hill, Pa.
28	01572025	Swatara Creek near Pine Grove, Pa.
29	01572190	Swatara Creek near Inwood, Pa.
30	01573000	Swatara Creek at Harper Tavern, Pa.
31	01573095	Bachman Run at Annville, Pa.
32	01573160	Quittapahilla Creek near Bellegrove, Pa.
33	01573560	Swatara Creek near Hershey, Pa.
34	01573810	Brush Run, Site 2, near McSherrystown, Pa.
35	01574000	West Conewago Creek near Manchester, Pa.
36	01574500	Codorus Creek at Spring Grove, Pa.
37	01575000	South Branch Codorus Creek near York, Pa.
38	01575500	Codorus Creek near York, Pa.
39	01576000	Susquehanna River at Marietta, Pa.
40	01576085	Little Conestoga Creek near Churchtown, Pa.
41	01576500	Conestoga River at Lancaster, Pa.
42	01576540	Mill Creek near Lyndon, Pa.
43	01576754	Conestoga River at Conestoga, Pa.
44	01577300	Muddy Creek at Muddy Creek Forks, Pa.
45	01578310	Susquehanna River at Conowingo, Md.
46	01580000	Deer Creek at Rocks, Md.

DRAINAGE BASINS GREATER THAN 100 SQUARE MILES

DRAINAGE BASIN	AREA, in square miles	ANNUAL PRECIPITATION, in inches	SOIL INFILTRATION CAPACITY	ROCK TYPE, in percent			LAND USE/COVER, in percent		
				Carbonate	Crystalline	Siliciclastic	Agriculture	Forest	Urban
RIDGE AND VALLEY PHYSIOGRAPHIC PROVINCE									
Shamokin	137	40-50	Poor to Good	0	0	100	33	58	6
Middle	175	40-42	Poor	12	0	88	40	58	1
Penns	533	40-42	Poor	20	0	80	41	58	1
Mahanoy	157	40-50	Poor to Good	0	0	100	24	58	4
Mahantango	164	40-48	Poor to Good	0	0	100	24	58	4
Wiconisco	116	40-48	Poor	0	0	100	40	57	3
Frankstown Branch Juniata	387	40-46	Good to Excellent	30	0	70	32	61	6
Spruce	109	42-46	Excellent	84	0	16	43	57	0
Little Juniata	343	40-46	Poor to Good	41	0	59	28	68	3
Standing Stone	132	40-42	Poor	5	0	95	15	84	0
Dunning	197	40-46	Poor to Good	5	0	95	41	58	1
Raystown Branch Juniata	961	38-46	Poor to Good	12	0	88	32	65	2
Aughwick	322	40-42	Poor to Good	8	0	92	35	61	3
Kishacoquillas	190	40-42	Poor to Good	75	0	25	35	61	3
Tuscarora	270	40-42	Poor to Good	10	0	90	26	74	0
Juniata	3,400	38-46	Poor to Excellent	16	0	84	29	68	2
Sherman	244	40-42	Poor to Good	10	0	90	34	65	0
Conodoguinet	506	40-42	Poor to Excellent	38	2	60	66	27	6
Yellow Breeches	219	40-42	Good to Excellent	35	44	21	41	52	7
Swatara	571	40-46	Poor to Excellent	16	2	82	56	33	8
PIEDMONT PHYSIOGRAPHIC PROVINCE									
Bermudian	110	40-42	Poor	1	31	68	81	18	1
Conewago	515	38-44	Poor	6	29	65	72	24	3
South Branch Codorus	117	40-42	Good	2	98	0	79	18	3
Codorus	278	38-44	Good to Excellent	18	80	2	71	17	11
Chickies	126	38-42	Poor	41	5	55	83	11	5
Cocalico	140	38-42	Poor to Excellent	32	4	64	62	31	6
Conestoga	277	40-42	Poor to Excellent	59	8	33	70	18	12
Pequea	154	40-42	Good to Excellent	56	44	0	72	19	2
Muddy	139	38-44	Good	0	100	0	72	27	1
Octoraro	210	42-46	Good	4	96	0	79	18	2
Deer	170	42-44	Good	0	100	0	72	26	2

Base from U.S. Geological Survey 1:100,000 and 1:2,000,000 Digital Line Graphs
Albers Equal-Area Conic Projection

0 10 20 30 40 50 MILES
0 10 20 30 40 50 KILOMETERS
SCALE = 1:500,000

Designated stream uses in Pennsylvania from Commonwealth of Pennsylvania, 1988
Designated stream uses in Maryland from Maryland Department of the Environment, 1991

MAP SHOWING USES AND CHARACTERISTICS OF MAJOR STREAMS IN THE LOWER SUSQUEHANNA RIVER BASIN, PENNSYLVANIA AND MARYLAND

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1996

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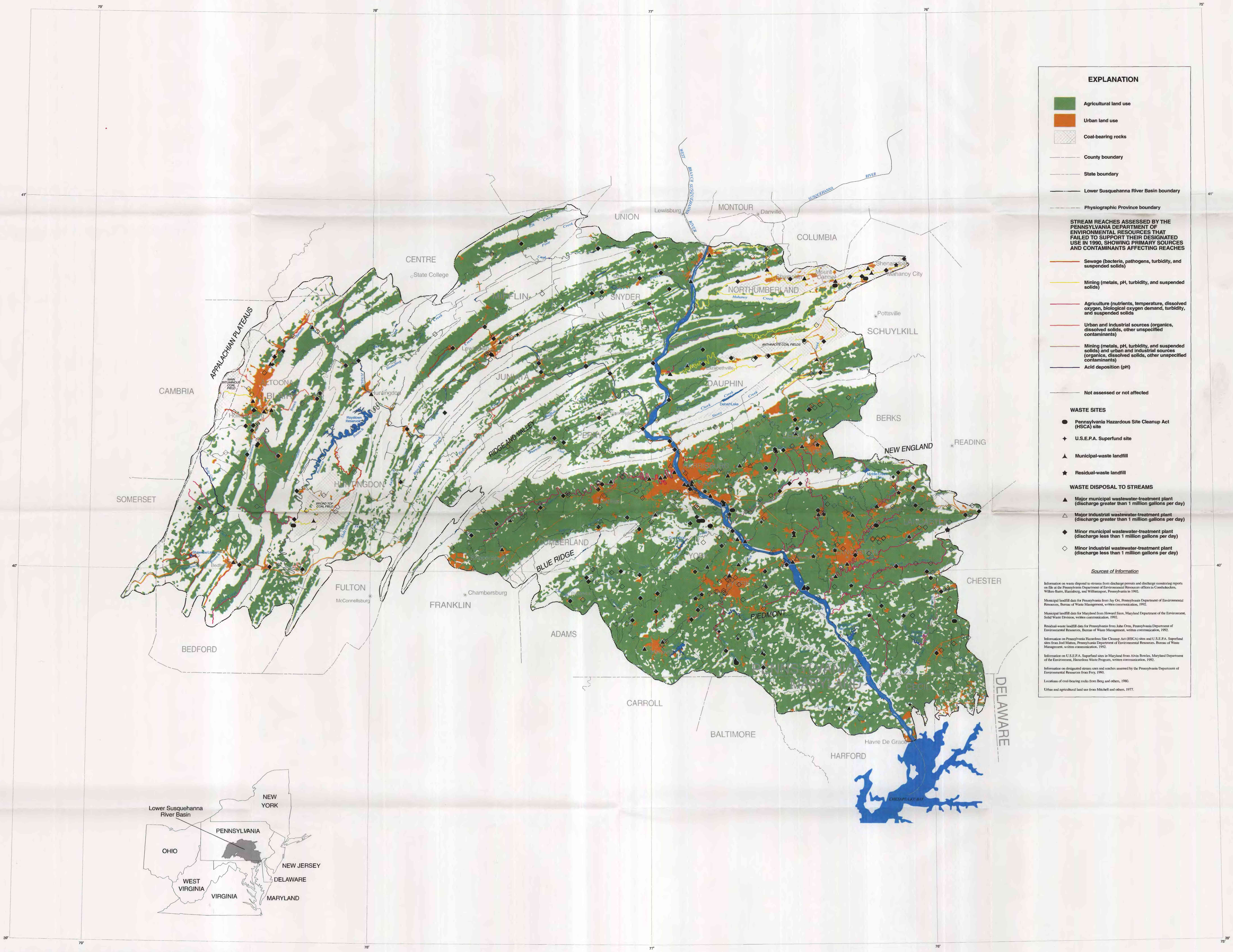
WATER-RESOURCES INVESTIGATIONS REPORT 94-4245
Land use and related water-quality issues—PLATE 3
Risser, D.W., and Siwiec, S.F., 1996, Water-quality assessment of the Lower Susquehanna River Basin, Pennsylvania and Maryland: Environmental setting



Base from U.S. Geological Survey 1:100,000 and 1:2,000,000 Digital Line Graphs
Albers Equal-Area Conic Projection

MAP SHOWING LAND USE AND RELATED WATER-QUALITY ISSUES IN THE LOWER SUSQUEHANNA RIVER BASIN, PENNSYLVANIA AND MARYLAND

By Dennis W. Risser and Steven F. Siwiec

1996