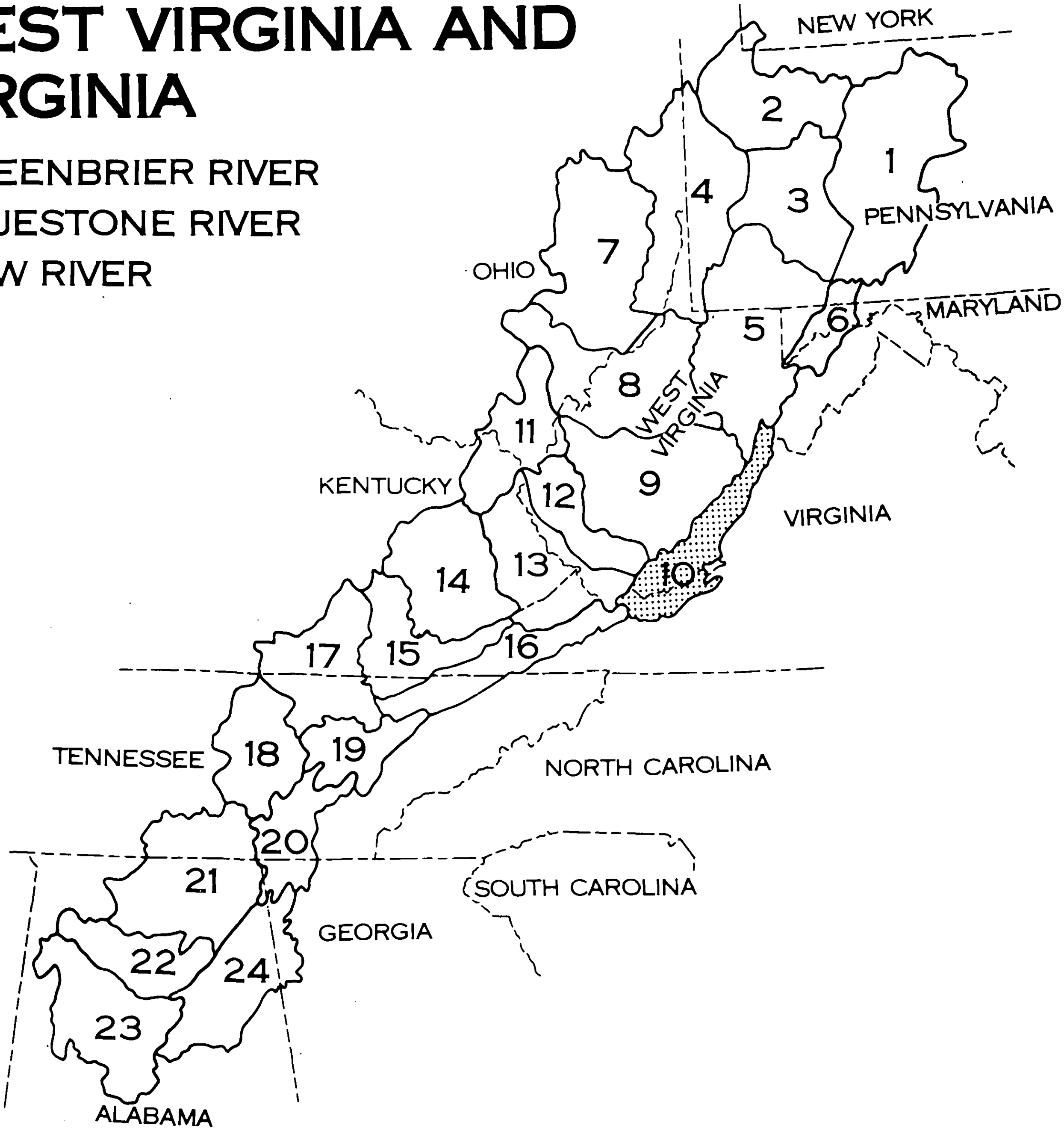
HYDROLOGY OF AREA 10, EASTERN COAL PROVINCE, WEST VIRGINIA AND VIRGINIA

- GREENBRIER RIVER
- BLUESTONE RIVER
- NEW RIVER



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 82-864

HYDROLOGY OF AREA 10, EASTERN COAL PROVINCE, WEST VIRGINIA AND VIRGINIA

BY
THEODORE A. EHLKE AND OTHERS

U.S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 82-864

CHARLESTON, WEST VIRGINIA
SEPTEMBER 1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, *SECRETARY*

GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

For additional information write to:

U.S. Geological Survey
603 Morris Street
Charleston, West Virginia 25301

CONTENTS

FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

For convenience of readers who may want to use the International System of Units (SI), the data may be converted by using the following factors:

Multiply	By	To obtain
inches (in)	25.40	millimeters (mm)
inches per hour (in/h)	25.4	millimeters per hour (mm/h)
	2.54	centimeters per hour (cm/h)
feet (ft)	0.3048	meters (m)
feet per mile (ft/mi)	0.1894	meters per kilometer (m/km)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
	3785.	cubic meters per day (m^3/d)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
cubic feet per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meters per second per square kilometer [$(m^3/s)/km^2$]
tons per square mile per year [$(ton/mi^2)/yr$]	0.3503	metric tons per square kilometer per year [$(t/km^2)/a$]
micromhos per centimeter at 25° Celsius (μmho/cm)	100	microsiemens per meter at 25° Celsius (μS/m)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

HYDROLOGY OF AREA 10, EASTERN COAL PROVINCE, WEST VIRGINIA AND VIRGINIA

BY THEODORE A. EHLKE AND OTHERS

Abstract

A nationwide need for information characterizing hydrologic conditions in mined and potential mine areas has become paramount with the enactment of the Surface Mining Control and Reclamation Act of 1977. This report is designed to be useful to the mine owners, operators, and others by presenting information about the existing hydrologic conditions and by identifying sources of hydrologic information. General hydrologic information is presented using a brief text with an accompanying map, chart, graph, or other illustration for each of a series of water-resources-related topics. The summation of the topical discussions provides a description of the hydrology of the area.

Study Area 10 is located in the New River basin in southeastern West Virginia and western Virginia, and has a surface area of about 3,337 square miles. The New River, and two major tributaries, the Greenbrier and Bluestone Rivers, drain most of the area. The drainage pattern is influenced by folding and faulting of the rock strata, differential erosion of rock strata of various lithology, and by the presence of karst areas.

Rocks underlying the area consist primarily of alternating beds of sandstone, siltstone, shale, limestone, and mudstone. Mineable coal is contained within rocks of the Pottsville Group in a small area (119 square miles) at the southwestern corner of the study area. In 1980, three surface and ten underground coal mines produced 0.8 million tons of coal, less than 1 percent of the West Virginia 1980 total. Limestones of Mississippian, Devonian, and older ages outcrop in Area 10. Limestones of the Greenbrier Group of Mississippian age are the most extensive and have an important effect on hydrology. Soils in the area are moderately deep and well drained. Soils overlying limestone areas are generally the most fertile. The principal land uses are forest and agriculture, which comprise about 97 percent of the land. Agriculture is largely located in the southern part of the study area.

Precipitation averages about 40 inches annually, with distribution affected by topography. The largest amount of rainfall occurs at higher altitudes along the western boundary of the basin, and the smallest amount of rainfall occurs along the eastern boundary near Virginia.

Water use in 1979 was estimated at 26.6 million gallons per day, most of which was from ground water. Public supply was the major use category.

The U.S. Geological Survey operated a network of 23 surface-water sites (1980) in Area 10. Streamflow and water-quality data were collected at all sites. Data are also available for an additional 126 sites not currently active. These data are available from computer storage through WATSTORE (National Water Data Storage and Retrieval System) and NAWDEX (National Water Data Exchange).

Surface-water quality is generally good. The specific conductance of most streams ranged from about 100 to 300 micromhos per centimeter. Mining caused a 2- to 10-fold increase in specific conductance in several streams in Mercer County, West Virginia. The pH of most streams was alkaline, primarily because of extensive limestone outcrops of the Greenbrier Group. Surface water draining mined areas tended to be more alkaline than nearby unmined areas. The alkalinity of surface water was affected by extensive limestone outcrops and was lowest in the upper Greenbrier River basin, generally less than 50 milligrams per liter. The concentration of sulfate in streams draining the Greenbrier River basin was generally less than 10 milligrams per liter. Sulfate concentrations were highest in the headwaters of the Bluestone River basin, where surface and underground coal mining occurs.

Total iron concentration in streams ranged from 10 to 1,928 micrograms per liter. No significant difference was found in the total iron concentrations of surface water affected and unaffected by coal mining in the Bluestone River basin. Total manganese concentration of surface water in the Greenbrier River basin was generally less than 30 micrograms per liter. No significant difference was found in the total manganese concentration of surface water affected and unaffected by coal mining in the Bluestone River basin.

The yield of wells ranged from 1 to 400 gallons per minute. Well depth, topography, geologic structure, and geology were the most important factors affecting well yields. Wells in valleys yielded about twice as much water as wells on hillsides and several times as much as wells on hilltops. Ground water generally contained high dissolved solids and tended to be very hard, owing largely to limestone in the area. Shallow water in rocks of the Greenbrier Group was often contaminated by wastes in surface water which entered through sinkholes and other solution openings in karst areas.

1.0 INTRODUCTION

1.1 Objective

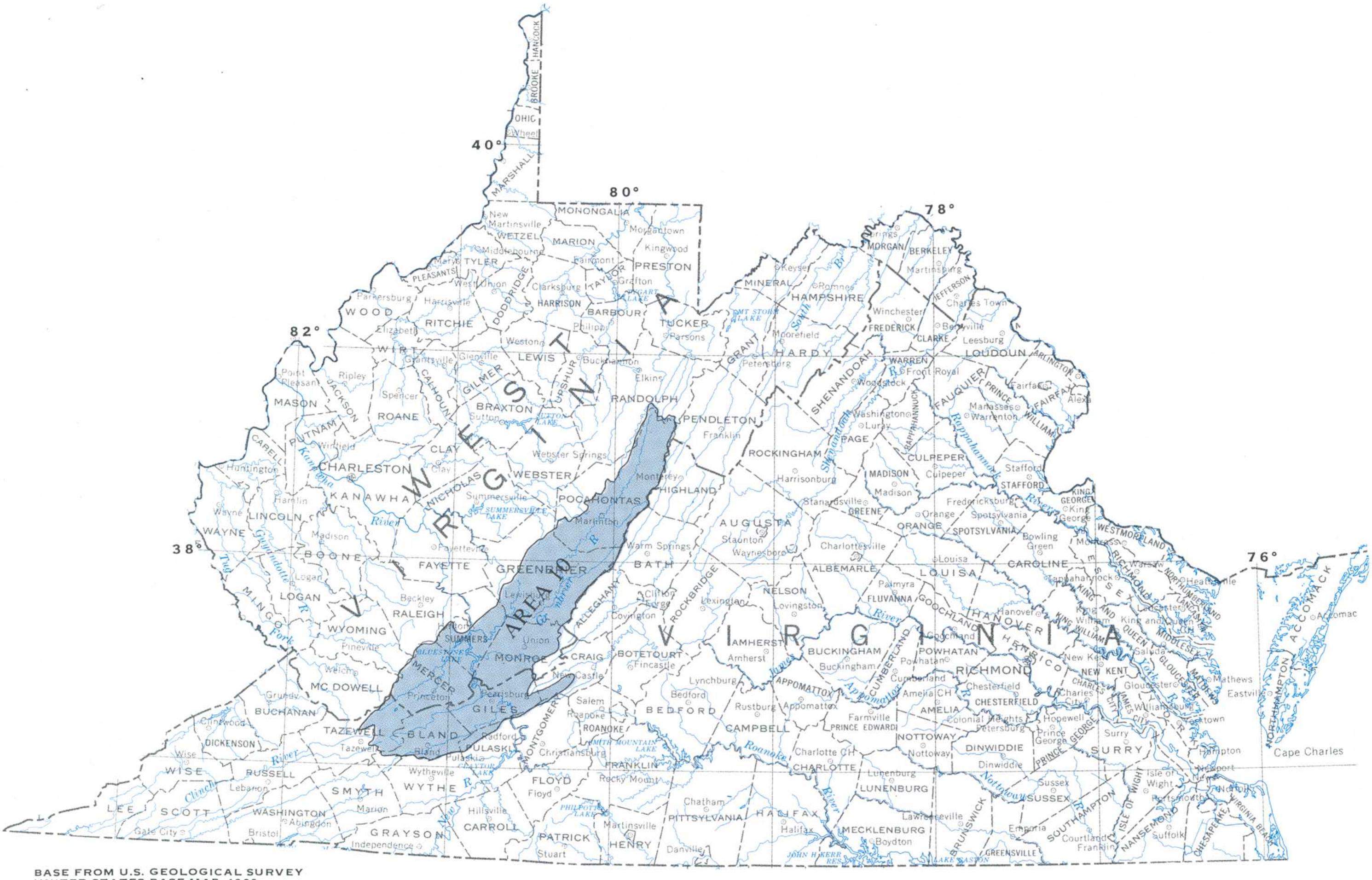
Area 10 Report to Aid Permitting

This report describes current hydrologic conditions in Area 10 and identifies other sources of hydrologic information.

A need for hydrologic information and analysis on a scale never before required nationally was initiated when the "Surface Mining Control and Reclamation Act of 1977" was signed into law as Public Law 95-87, August 3, 1977. The need is partially met by this report which broadly characterizes the hydrology of Area 10, a part of the Eastern Coal province in West Virginia and Virginia. This report is one of a series which describes the hydrology of coal provinces nationwide. The report provides general hydrologic information, principally surface water, using a brief text with an accompanying map, chart, graph, or other illustration for each of a series of related topics. The summation of the topical discussions provides a description of the hydrology of the area as shown in figure 1.1-1.

The hydrologic information presented or available through sources identified in this report, may be used in describing the hydrology of the "general area" of any proposed mine. Furthermore, it is expected that this hydrologic information will be supplemented by the lease applicant's specific site data as well as data from other sources to provide a more detailed picture of the hydrology in the vicinity of the mine and the anticipated hydrologic consequences of the mining operation.

The information contained in this report should be useful to surface mine owners, operators, and consulting engineers in the preparation of permits and to regulatory authorities in appraising the adequacy of permit applications.



BASE FROM U.S. GEOLOGICAL SURVEY
UNITED STATES BASE MAP, 1980

SCALE 1:3,750,000

0 50 100 MILES

0 50 100 KILOMETERS

Figure 1.1-1 Location of study area.

Area 10 is Divided into Two Physiographic Provinces

The study area is located in the New River basin in southeastern West Virginia and western Virginia, and has a surface area of about 3,337 square miles. It lies within the Valley and Ridge and Appalachian Plateaus physiographic provinces.

Area 10 lies within the New River basin in southeastern West Virginia and western Virginia. The study area covers about 3,337 mi^2 (square miles), of which 2,442 mi^2 lie in West Virginia and about 895 mi^2 in Virginia. The area lies partly within the boundary of the Eastern Coal Province (figure 1.2-1), is oriented northeast-southwest, is about 150 miles long, and varies from about 12 to 38 miles in width.

The area is divided into two physiographic provinces, the Valley and Ridge province and the Appalachian Plateaus province, Kanawha section. The Valley and Ridge province comprises much of the area east of the Greenbrier River in Pocahontas County, the eastern parts of Greenbrier and Monroe Counties and the southeastern part of Mercer County in West Virginia, and the part of Area 10 extending into Virginia. The remainder of the area lies in the Appalachian Plateaus province.

The Valley and Ridge province is characterized by northeast-southwest trending mountains and valleys. The valleys and lowlands are generally underlain by less resistant shale and limestone, and the ridges are composed of more resistant sandstone. Typically, streams in the province have a trellis drainage network, with major streams occupying deep valleys trending northeast-southwest and minor streams intersecting them at right angles. In large parts of Pocahontas, Greenbrier, and Monroe Counties the land is dominated by numerous sinkholes typical of karst topography. In karst areas, land slopes are gentle and local relief is about 50-100 feet, except near major river valleys. Underground drainage is extensive, and most streams, other than major tributaries, are dry during much of the year.

The Appalachian Plateaus province is a high upland dissected by many streams. It is characterized by high, rounded or flat topped ridges, rolling hills, and steep V-shaped valleys. The ridges range from 500 to 2,000 feet in height above the streams. The eastern edge of the Appalachian Plateaus province rises abruptly 1,000-3,000 feet above the valley which bounds it to the east. Maximum altitudes at the eastern edge of the Appalachian Plateaus are generally several hundred feet greater than the ridges of the Valley and Ridge province to the east. This eastern ridge is the highest part, 4,600 feet altitude (National Geodetic Vertical Datum of 1929), of the Appalachian Plateaus province in Area 10. Stream drainage in the Appalachian Plateaus province generally follows a dendritic pattern.

Area 10 includes parts of Pocahontas, Greenbrier, Summers, Monroe, and Mercer Counties in West Virginia and parts of Craig, Giles, Pulaski, Bland, and Tazewell Counties in Virginia. Larger towns include Bluefield, Princeton, Hinton, Lewisburg, White Sulphur Springs, and Alderson in West Virginia and Pearlsburg and Narrows in Virginia.

The hydrology of parts of Area 10 have been described in previous investigations. Streamflow and basin characteristics of the Greenbrier basin were described in a series of reports (DePaulo and Baloch, 1968; Baloch and others, 1969; and Islam and Baloch, 1973). Hydrology of the Ohio River basin, which includes the New River basin, was described in a comprehensive study by Deutsch and others (1966). Water resources and basin characteristics for the Kanawha River basin were described in a later study by the U.S. Army Corps of Engineers (1971). Hydrology of the Upper New River basin in West Virginia was described by Clark and others (1976). Hydrology of the Virginia portion of the New River basin was described in a series of reports by the Virginia Department of Conservation and Economic Development, Division of Water Resources, (1966, 1967a, 1967b, 1967c, 1967d, 1967e), and the Virginia State Water Control Board (1972).

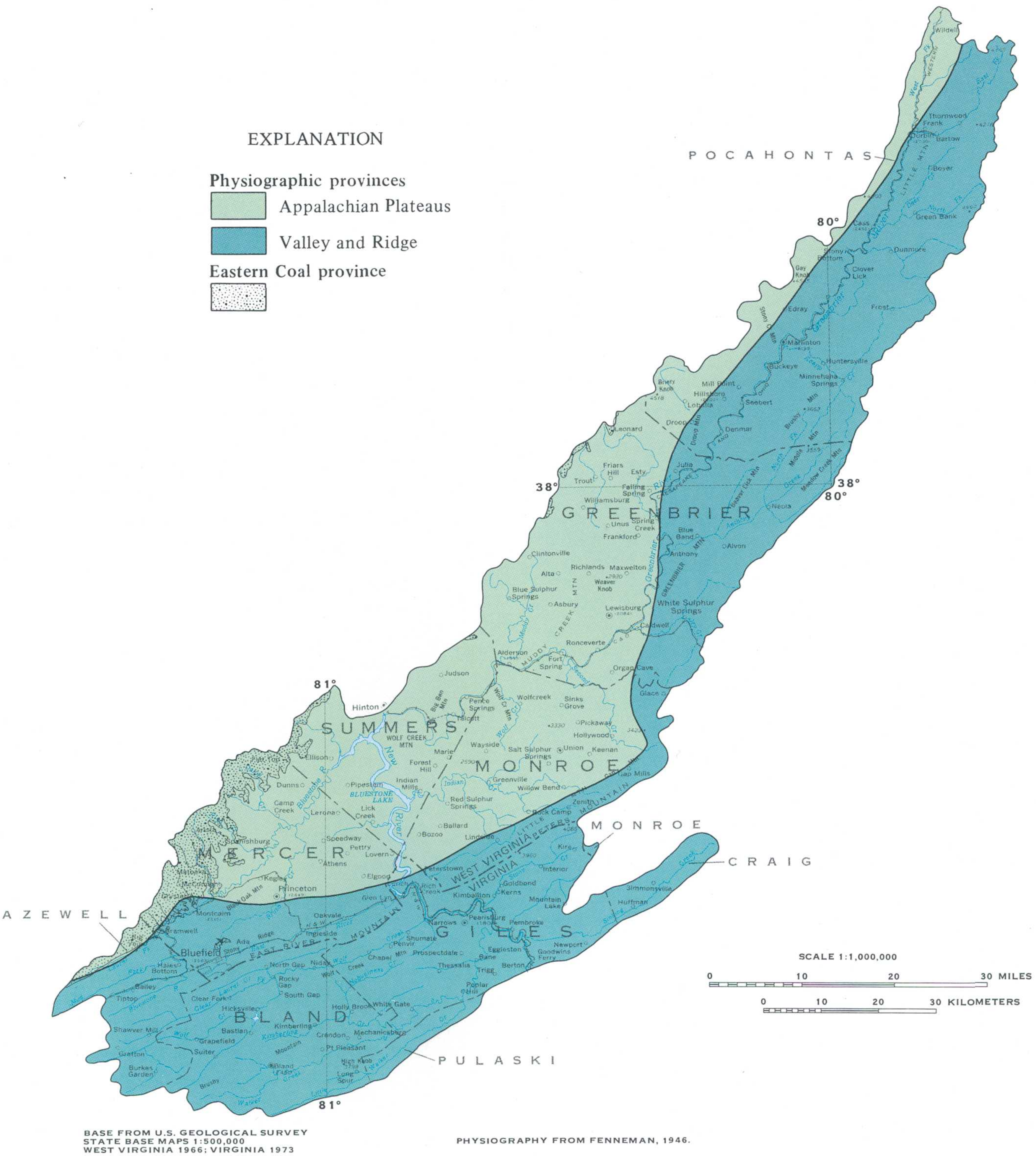


Figure 1.2-1 Physiographic division and Eastern Coal province.

The New River Drains Area 10

The New River and two major tributaries, the Greenbrier and Bluestone Rivers, drain most of the area. The drainage pattern is influenced by geologic structure and lithology.

The New River is the largest river in Area 10, draining about 3,337 mi^2 (square miles) within the area and about an additional 3,000 mi^2 in Virginia and North Carolina outside Area 10. Major tributaries of the New River include the Greenbrier and Bluestone Rivers, which drain 1,641 and 462 mi^2 respectively. Smaller tributaries of the New River include Indian Creek and the East River in West Virginia, and Walker and Wolf Creeks in Virginia.

The drainage pattern and topography of the area is influenced by the geologic structure and lithology. In the Appalachian Plateaus physiographic province, which includes all of Summers and parts of Greenbrier, Pocahontas, Monroe, Mercer, and Tazewell Counties, the topography is dominated by mountainous terrain, which is oriented in a northeast-southwest direction and gradually decreases in elevation towards the west. Streams in this area tend to form a dendritic pattern and flow into the New River. Major streams north of the New River flow generally in a southwest direction, while major streams south of the New River flow northeast.

The drainage pattern in the Valley and Ridge physiographic province, which includes much of the area, is greatly influenced by the folding and faulting of the rock strata and by differential erosion. The axes of the rock deformation largely trend northeast-southwest. Differing erosion resistance characteristics of the rocks has, over geologic time, resulted in erosion of the less resistant strata, forming the valley bottoms; the more resistant rocks formed the ridgetops that parallel and separate the northeast-southwest trending valleys. Small streams tend to intersect major streams at right angles, forming a typical trellis drainage network (figure 2.1-1).

Much of the study area is underlain by limestone. In this area, which includes southern Pocahontas, central Greenbrier, and Monroe Counties, the topography is dominated by sinkholes typical of karst areas. Surface drainage in these areas is limited to major streams because precipitation tends to enter the ground-water flow system through sinkholes and other solution openings. Subsurface flow in karst areas is described by Clark and others (1976) and by Jones (1973). Subsurface flow through fractures and solution openings is probably responsible for water losses in the New River in the reach from Glen Lyn to Hinton (Clark and others, 1976).

The only large lake in Area 10 is Bluestone Reservoir, formed by the impoundment of the New River near Hinton, one mile upstream from the junction with the Greenbrier River. Bluestone reservoir is maintained by the U.S. Army Corps of Engineers and has a maximum storage capacity of 631,000 acre-feet.

Figure 2.1-1 Surface drainage basins and physiographic divisions.

Mean Land Slope for Much of the Area is 20 to 25 Percent

Overland slopes for much of Area 10 range from 10 to 30 percent. Landslides are most common where land slopes range between 20 and 33 percent. Stream channel slopes generally are greatest in areas of greatest relief.

Overland slopes for Area 10 can be characterized by three categories: (1) relatively flat land (less than 10 percent slopes), (2) hilly land (10 to 30 percent slopes), and (3) severe slopes (greater than 30 percent slope). The West Virginia portion of the area contains approximately 13 percent relatively flat land, 64 percent hilly land, and 23 percent severe slopes. No data were available for Virginia slopes.

Mean land slopes for West Virginia counties within the area range from 20.8 to 24.8 percent (table 2.2-1 and fig. 2.2-1). Land slopes greater than 20 percent are often unstable and have a high landslide potential in Area 10, as indicated by a study done on landslide frequency adjacent to West Virginia highways (fig. 2.2-2). Most slope failures in West Virginia involve only a thin veneer of soil and weathered rock, especially where clay-rich soil layers reduce infiltration and allow saturation of the clay and other soil layers above the clay. Slope failures can result from removal of vegetation, increased loading of the slope, undercutting the slope, or rapid soil saturation following heavy rains.

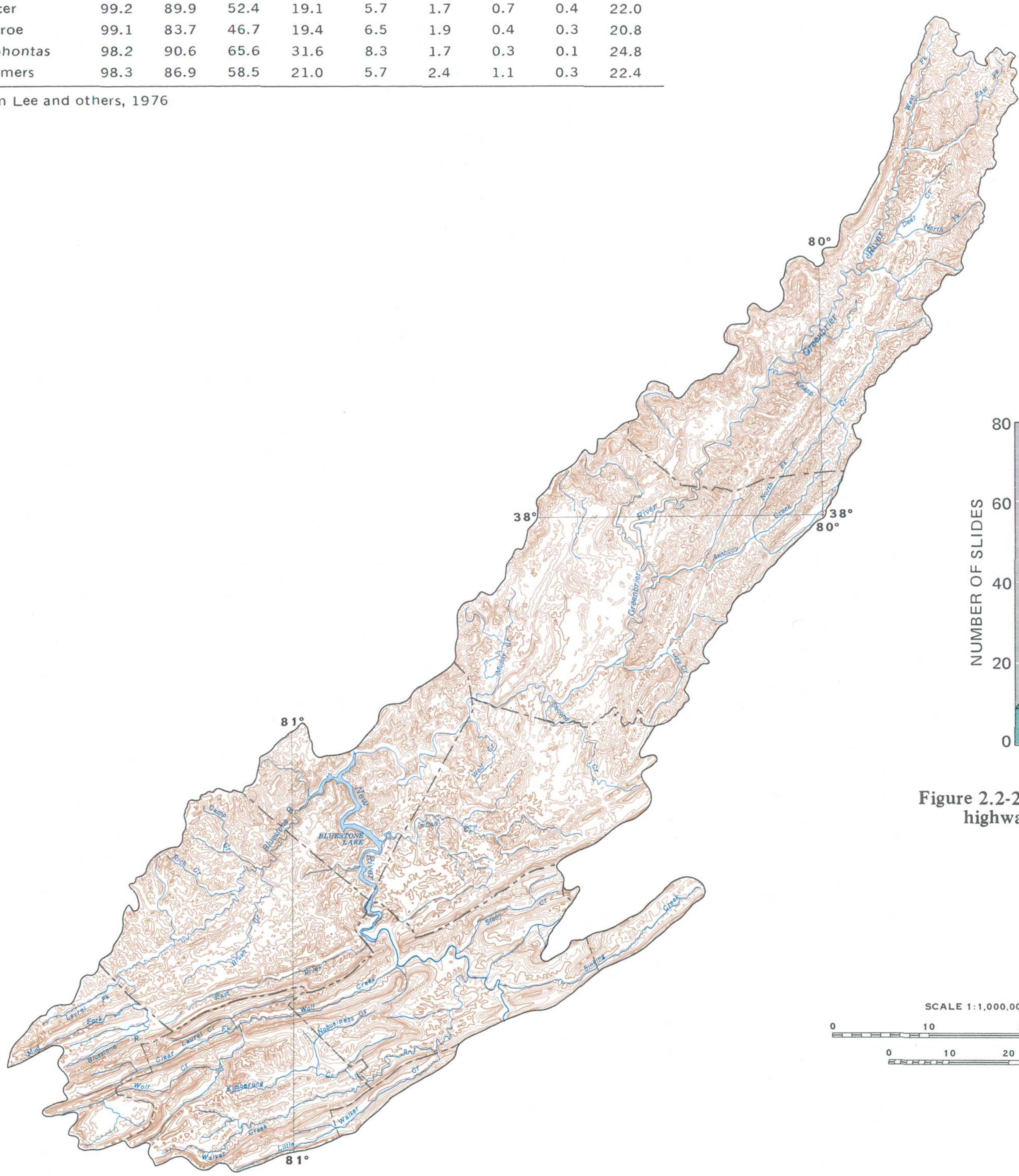
A good correlation has been found between unstable slopes and slide-prone soil (Lessing and others, 1976). Soils present in Area 10 which are considered slide prone include the Clarksburg, Ernest, and Westmoreland soils.

Stream-channel slopes for selected streams are shown in figure 2.2-3. Stream channel slopes are generally greatest in areas of greatest relief. The channel slope for the Greenbrier River north of Wildell, West Virginia to Durbin, West Virginia is 23.8 ft/mi (feet per mile) and decreases to 15.2 ft/mi in the reach from Durbin to Marlinton, West Virginia. The channel slope for the entire Greenbrier River (about 174 miles) is 9.0 ft/mi. The channel slope for the Bluestone River is steeper, ranging from 31.6 ft/mi upstream of Bluefield West Virginia, to 5.4 ft/mi for its entire reach (about 84 miles). In both cases, channel slopes are steeper in headwaters areas where relief is greatest. The New River in Area 10, far from its headwaters, flows through an area of lesser relief. The channel slope differs only slightly from 8.03 ft/mi from Eggleston, Virginia to Glen Lyn, Virginia to 6.72 ft/mi from Glen Lyn to Hinton. Channel slopes for selected smaller streams in the area range from 15.3 to 87.3 ft/mi (fig. 2.2-3).

Table 2.2-1 Percentage of area in West Virginia exceeding indicated mean land slopes.

COUNTY	2.5	10	20	30	40	50	60	70	MEAN SLOPE
Greenbrier	97.8	84.2	52.4	24.1	8.5	2.3	0.4	0.0	22.0
Mercer	99.2	89.9	52.4	19.1	5.7	1.7	0.7	0.4	22.0
Monroe	99.1	83.7	46.7	19.4	6.5	1.9	0.4	0.3	20.8
Pocahontas	98.2	90.6	65.6	31.6	8.3	1.7	0.3	0.1	24.8
Summers	98.3	86.9	58.5	21.0	5.7	2.4	1.1	0.3	22.4

From Lee and others, 1976



BASE FROM U.S. GEOLOGICAL SURVEY
STATE BASE MAPS 1:500,000
WEST VIRGINIA 1966; VIRGINIA 1973

Figure 2.2-1 Topography.

SCALE 1:1,000,000

0 10 20 30 MILES

0 10 20 30 KILOMETERS

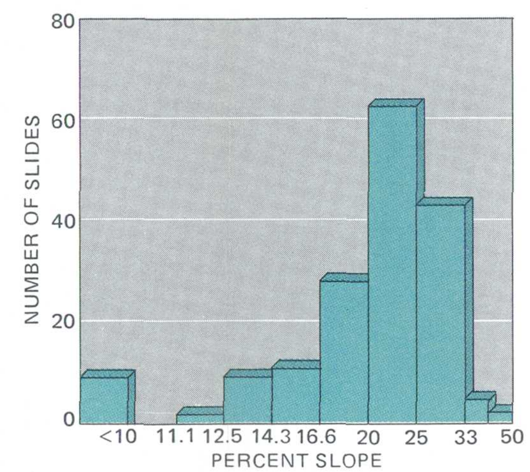
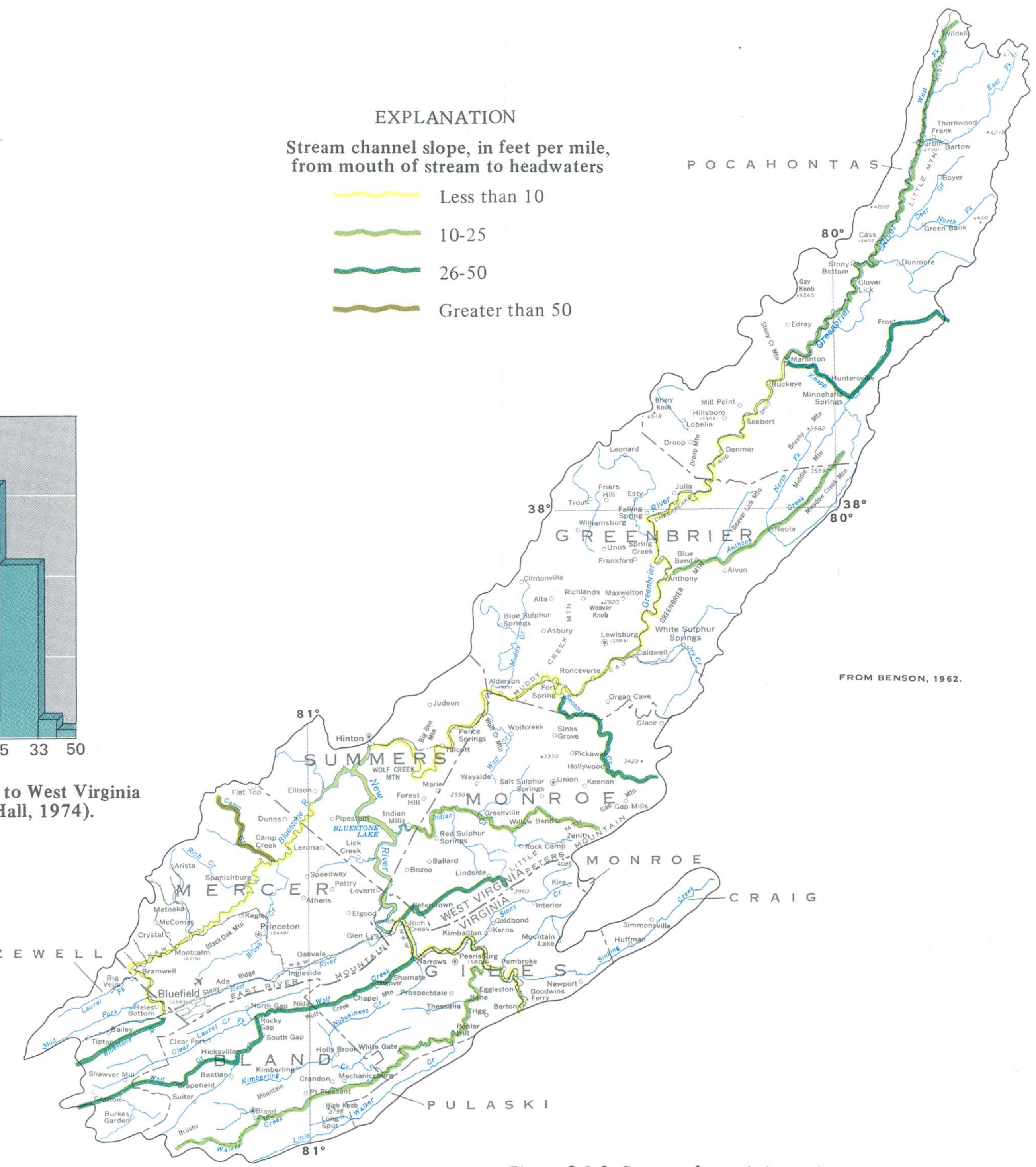


Figure 2.2-2 Landslide frequency adjacent to West Virginia highways versus slope percent (from Hall, 1974).



BASE FROM U.S. GEOLOGICAL SURVEY
STATE BASE MAPS 1:500,000
WEST VIRGINIA 1966; VIRGINIA 1973

Figure 2.2-3 Stream channel slopes for selected streams.

Soils are Moderately Deep and Well Drained

Soils in Area 10 are grouped into associations on the basis of composition, slope, drainage, erosion characteristics, and land-use suitability.

Soils vary in composition and land-use suitability and are greatly influenced by geologic features and topography. Soils on steep slopes are typically shallow and suitable for woodlands, whereas soils on upland flats and in valleys are moderately deep and suitable for agricultural and domestic uses. All soils in Area 10 are acidic, but variable in fertility, permeability, moisture capacity, and depth.

Soils in the area within West Virginia are grouped into associations termed Land Resource Areas (LRA) by the U.S. Soil Conservation Service (1979). A Land Resource Area is a geographic area characterized by a unique combination of soils, slope, erosion characteristics, climate, vegetation, water resources, and land uses. Soils in the area within Virginia have been similarly grouped and termed soils of Appalachian Ridges and Valleys. The soil series and associations within Area 10 are shown in figure 2.3-1. General descriptions and summaries of some soil characteristics are given in tables 2.3-1 and 2.3-2.

Soils of the Eastern Allegheny Plateaus and Mountains Land Resource Area (LRA 127) cover only a very small portion of the area (1.8 percent) and lie entirely in western Pocahontas County. The soils are moderately deep, well-drained, strongly sloping to steep soils underlain by shale and siltstone of Mississippian and Pennsylvanian age. Because of the rugged terrain, the primary land use in LRA 127 is woodland. Fertility is moderate to low and erosion potential is moderate to severe.

Soils of the Southern Appalachian Ridges and Valleys Land Resource Area (LRA 128) cover about 71 percent of the area. Soils of the Appalachian Ridges and Valleys association in Virginia are similar to LRA 128 soils and cover the remaining portion of Area 10. The soils are well-drained, and have moderate to rapid permeability except those soils containing fragipans, where permeabilities are low (table 2.3-2). These soils are underlain by shale, siltstone, sandstone, and limestone of Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician age.

The soil associations in LRA 128 and in Virginia can be divided into two groups: (1) those occurring in the dissected highlands and (2) those occurring in the limestone underlain valleys and their immediate upland slopes.

Soils in the first group are suitable for crops, pastureland, and homesites on the wide upland flats and in some valleys, but the steep-sided hillsides and mountaintops are mostly in woodland. Fertility and erosion potential range from moderate values on upland flats to low fertility and high erosion potential on steep slopes. Many of the soils on footslopes are colluvial and contain low permeability fragipans. Alluvial soils are found in most valleys and range in depth from moderately deep to shallow. Shallow soils occur on many mountain and ridge tops. These soils are acidic and have moderate to high permeability and moisture capacity values, except for soils with fragipans and/or high clay content.

Soils in the second group are suitable for extensive farming and homesites in the flatland areas and pastureland on slopes. These soils are often well-drained, fertile, deep, and less acidic than those of the first group. Karst topography is present in the limestone-underlain valleys. Much of the area containing soil series associations D4, D7, D8, D12, D13, and A-10 fits this category and is shown in figure 2.3-1.

Much of the above information was taken from Soil Conservation Service Soil Surveys (U.S. Soil Conservation Service 1965 and 1972), and from soil maps of Virginia and West Virginia (U.S. Soil Conservation Service 1979a, 1979b). The soils maps and soils association descriptions are generalized. Detailed information for site-specific analysis can be obtained from the U.S. Soil Conservation Service.

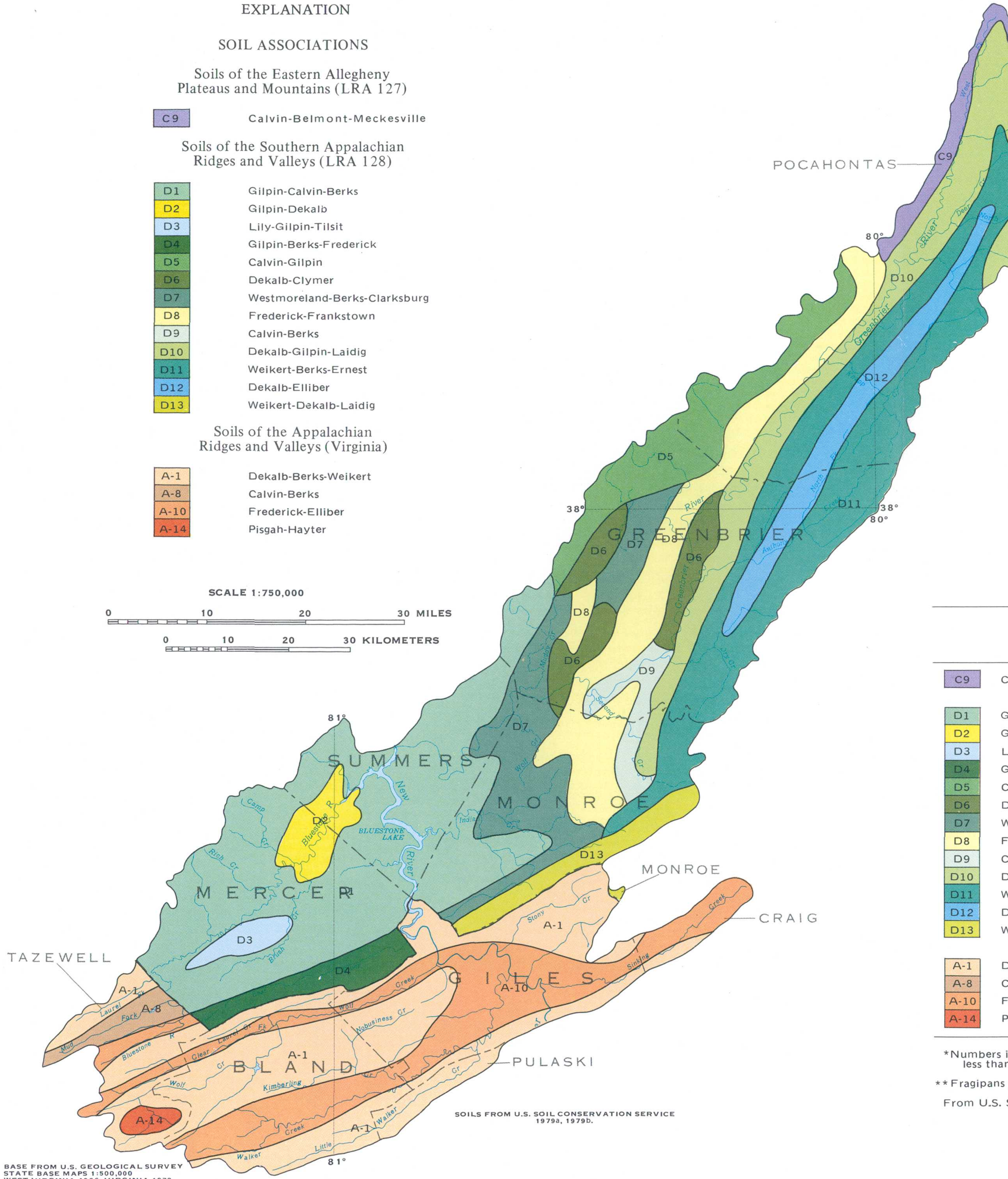


Figure 2.3-1 Generalized soil series associations.

Table 2.3-1 Soil Associations descriptions.

C9	Calvin-Belmont-Meckesville Moderately deep, well drained, strongly sloping soils on dissected uplands.
D1	Gilpin-Calvin-Berks Shallow to moderately deep, well-drained soils in areas of dissected plateaus; strongly sloping to very steep soils underlain by shale, siltstone and some thin-bedded sandstone.
D2	Gilpin-Dekalb Moderately deep, well-drained, gently-sloping to very steep soils on uplands and mountain slopes. Underlain by shale, siltstone, and sandstone.
D3	Lily-Gilpin-Tilsit Deep, moderately well-drained, residual soils in weathered material from shale and sandstone from uplands. Fragipan at depth of two feet in Tilsit soils.
D4	Gilpin-Berks-Frederick Moderately deep to deep, well-drained, moderately steep to very steep cherty soils found on mountain slopes and upland slopes of limestone valleys.
D5	Calvin-Gilpin Moderately deep, well-drained, strongly sloping to steep soils underlain by shale and siltstone, in areas of dissected plateau.
D6	Dekalb-Clymer Moderately deep and deep, well-drained, gently sloping to very steep soils underlain by sandstone and shale, on broad ridges and adjoining side slopes.
D7	Westmoreland-Berks-Clarksburg Moderately deep and deep, well-drained and moderately well-drained, gently sloping to steep soils underlain by shale and limestone, in areas of dissected plateau.
D8	Frederick-Frankstown Deep, well-drained, mostly gently sloping and some strongly sloping soils of limestone valleys and immediate upland slopes.
D9	Calvin-Berks Shallow to moderately deep, well-drained, strongly sloping to steep soils underlain by shale and siltstone, in areas of dissected plateau.
D10	Dekalb-Gilpin-Laidig Shallow to moderately deep, wet to well-drained, strongly sloping to very steep, very stony soils underlain by massive sandstone and shale, on mountain slopes, ridges, and some foot slopes.
D11	Weikert-Berks-Ernest Shallow to deep, excessively-drained to well-drained, very steep soils underlain by shale and siltstone, on mountain slopes and flat slopes.
D12	Dekalb-Elliber Moderately deep and deep, well-drained, steep, cherty, and very stony soils underlain by sandstone, limestone, and shale, on mountain ridges and side slopes.
D13	Weikert-Dekalb-Laidig Deep, well-drained soils of limestone valleys and stony soils of lower mountain slopes, underlain by limestone, sandstone, shale, and siltstone.
A-1	Dekalb-Berks-Weikert Shallow to deep, often very steep soils formed generally in residuum from sandstone, shale, and limestone, on mountains.
A-8	Calvin-Berks Moderately deep, gently sloping to steep soils formed in residuum from shale; on uplands of dissected valleys.
A-10	Frederick-Elliber Shallow to very deep, gently sloping to steep soils formed in residuum from limestone or interbedded limestone, sandstone, and shale; on uplands and limestone valleys.
A-14	Pisgah-Hayter Shallow to deep, gently sloping to steep soils formed in residuum from sandstone and shale, on uplands of limestone valleys.

Table 2.3-2 Selected physical characteristics of dominant soils.

	SOIL SERIES ASSOCIATION*	DOMINANT SLOPE RANGE, IN PERCENT	SOIL DEPTH, IN FEET	PERMEABILITY RANGE, IN INCHES/HOUR	MOISTURE CAPACITY RANGE, IN INCHES OF WATER PER INCH OF SOIL	pH RANGE, IN UNITS
C9	Calvin(60)-Belmont(15)-Meckesville(10)	40-60	1.5-2.5	0.63-2.0	0.12-0.18	5.1-5.5
D1	Gilpin(35)-Calvin(25)-Berks(20)	20-65	1.5-2.5	0.63-6.3	0.12->.18	4.5-5.5
D2	Gilpin(40)-Dekalb(35)	5-65	1.5-3.5	2.0-6.3	0.08->.18	4.5-5.5
D3	Lily(35)-Gilpin(30)-Tilsit(15)	3-15	3.0-6.0	0.63-6.3**	0.15-0.18	4.5-5.0
D4	Gilpin(35)-Berks(30)-Frederick(15)	8-30	3.0-10.0	0.63-6.3	0.15->.18	4.5-6.0
D5	Calvin(45)-Gilpin(20)	5-65	1.5-2.5	0.63-2.0	0.12-0.18	4.5-5.5
D6	Dekalb(70)-Clymer(10)	5-65	2.0-4.0	0.63-6.3	0.08-0.18	4.5-5.5
D7	Westmoreland(55)-Berks(15)-Clarksburg(10)	10-65	1.5-4.0	0.20-6.3	0.12->.18	4.5-6.0
D8	Frederick(70)-Frankstown(15)	8-25	3.0-10.0	0.63-6.3	0.15-0.21	5.6-6.5
D9	Calvin(45)-Berks(15)	20-65	1.5-2.5	0.63-2.0	0.12-0.18	4.5-5.5
D10	Dekalb(40)-Gilpin(25)-Laidig(20)	5-70	1.5-4.0	0.20-6.3**	0.08-0.18	4.5-5.5
D11	Weikert(40)-Berks(30)-Ernest(10)	30-65	1.0-4.0	2.0-6.3	0.08->.18	4.5-5.5
D12	Dekalb(45)-Elliber(30)	5-65	2.0-6.0	2.0->6.3	0.08-0.18	4.5-5.0
D13	Weikert(30)-Dekalb(25)-Laidig(20)	3-65	2.0-30.0	0.63-6.3	0.12-0.18	4.5-5.5
A-1	Dekalb-Berks-Weikert	8-60	1.5-3.0	2.0-6.3	0.08 0.18	4.5-5.5
A-8	Calvin-Berks	5-30	1.5-2.5	0.63-6.3	0.12-0.18	3.6-6.0
A-10	Frederick-Elliber	3-25	3.0-10.0	0.63-6.3	0.12->.18	3.6-5.5
A-14	Pisgah-Hayter	2-35	4.0-6.0	not available	not available	5.1-6.5

*Numbers in parentheses refer to the percent of each soil type in the association. Totals for each soil series association are less than 100 percent because of soil types occurring in a small percentage of the area and are not included in the total.

**Fragipans permeability range is 0.20-0.63

From U.S. Soil Conservation Service 1965, 1972, 1979a, and 1979b.

Area 10 has a Continental Climate

Geography and topography combine to give Area 10 a continental climate. Temperatures average from the mid-30's in winter to near 70 degrees in summer. Annual precipitation averages about 40 inches, with the northern half of the basin affected by a rain shadow. Approximately 13 inches more precipitation than normal fell during the period April 1979 to August 1980.

The two most important influences on the climate of Area 10 are geography and topography. The area lies too far inland for the climate to be influenced by the Atlantic Ocean; and therefore, it has a continental climate. There are four distinct seasons. Winters are moderately severe and summers are warm and showery. Orographic influences cause variations on the temperatures and amount of precipitation within the area.

Mean daily temperatures in the area range from the mid-30's in winter to near 70 degrees in summer. Differences in mean temperature occur within the area due to differences in elevation. Burkes Garden, Virginia, at an altitude of 3,300 feet has a mean annual temperature 6°F cooler than Glen Lyn, Virginia, at an altitude of 1,524 feet. Figure 2.4-1 shows the monthly temperature variations between the two sites.

Winter conditions can be quite harsh; cold waves with near or subzero temperatures occur on an average of three times each winter and last for two or three days. The temperature in Lewisburg, West Virginia, on an unknown date fell to minus 37°F. Freezing temperatures are likely to occur from late September through mid-May. On the other hand, very warm conditions can occur in summer. All recording stations in West Virginia within Area 10 boundaries have attained 100°F; and those in Virginia have either reached it or have come very close.

Based on the period 1941-70, average annual precipitation is about 40 inches, with amounts at recording stations varying from 35.22 inches at Union, West Virginia, to 43.35 inches at Flat Top, West Virginia. July is the wettest month and October the driest. Figure 2.4-2 shows the precipitation distribution for the area.

The area north of White Sulphur Springs, West Virginia lies within a "rain shadow." Winds from the west descend after rising over the Allegheny Mountains, are warmed, and can hold more water vapor. The effect is to suppress precipitation and cloud cover.

The amount of snowfall depends greatly on the elevation. White Sulphur Springs, at an altitude of 1,920 feet, received an average annual snowfall of 25.7 inches during 1951-73; while Burkes Garden, Virginia, at an altitude of 3,300 feet, had an average annual snowfall of 38.5 inches during 1951-75. Much higher yearly snowfalls are possible. Flat Top, West Virginia, averaged 80.7 inches of snow per year for the period October 1974 through April 1980, with a maximum of 105.7 inches during the winter of 1976-77.

During the study period of April 1979 - August 1980, the recording stations with long-term records received an average total of 68.61 inches of precipitation. Normally, an average of 55.11 inches of precipitation falls during that 16-month period.

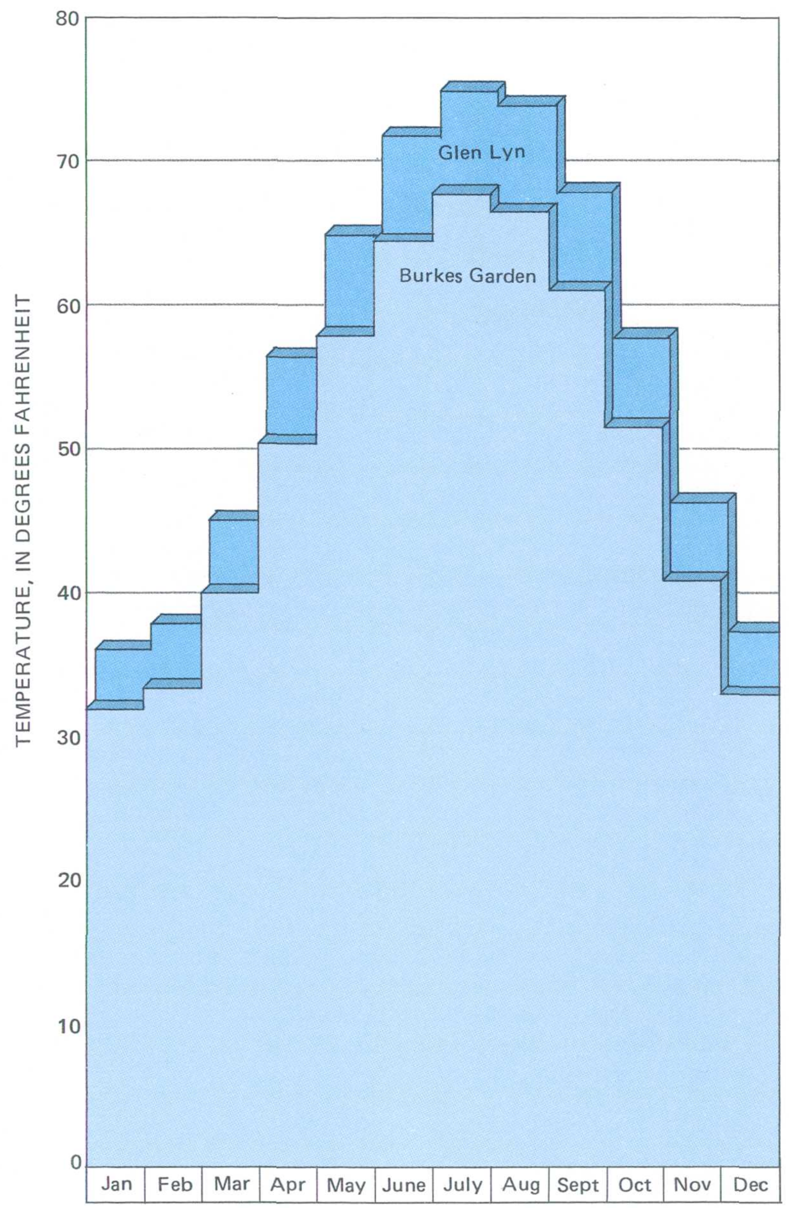


Figure 2.4-1 Monthly normals of temperature for Burkes Garden (altitude 3300 feet) and Glen Lyn (altitude 1524 feet), Virginia, 1941-70.

CLIMATOLOGICAL DATA FROM NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, 1973a, 1973b.

BASE FROM U.S. GEOLOGICAL SURVEY STATE BASE MAPS 1:500,000 WEST VIRGINIA 1966; VIRGINIA 1973

Figure 2.4-2 Average annual precipitation distribution, 1941-70.

Forest Covers Majority of Area 10

Forest land covers approximately 78 percent of Area 10; agricultural land covers approximately 19 percent; with the remainder divided between urban land, barren land, and water.

Land use in Area 10 is greatly influenced by topography. Much of the area contains rugged, steep slopes where forest is the prevalent land use (fig. 2.5-1), covering about 78 percent of the area. Valleys and areas with less steep slopes allow agricultural and residential uses of the land. Approximately 97 percent of the land in Area 10 is classified as either forest or agriculture.

Much of the area lies within the Monongahela, George Washington, and Jefferson National Forests. The National Forest land is managed following multiple use criteria, which includes silviculture, wildlife management, watershed protection, and outdoor recreation (U.S. Forest Service, 1976). Logging operations are carried out throughout the area. The forests are classified as dominantly Appalachian Oak Forest and Northern Hardwoods (West Virginia Department of Natural Resources, Division of Reclamation, 1980).

Agriculture is the second dominant land use, comprising 19.4 percent of the basin area. Monroe, Craig, and Tazewell Counties have about one-third of their area in agricultural use. These counties have significant land area in the undulating valleys of the Valley and Ridge physiographic province. In comparison, Pocahontas County, which also has land area in the Valley and Ridge province, has only about 10.8 percent of its area in agriculture. Much of its more rugged terrain lies within the National Forests. A more detailed description of land use is given in table 2.5-1.

Urban and residential land uses account for about 1.3 percent of the area, clustered near Bluefield, Princeton, and other communities in valleys or along major transportation corridors.

Surface-mining areas account for less than 0.6 percent of Area 10. The primary mining activity is limestone quarrying. Several quarries are located along the New River in both states. The smallest land use category is water. The major water areas are those of the Bluestone Reservoir and the New River.

Sources of information include the U.S. Geological Survey 1:250,000 scale land-use maps and the West Virginia Geological and Economic Survey's statistical land-use summary (U.S. Geological Survey, 1973, 1977, and 1978, and West Virginia Geological and Economic Survey, 1980).

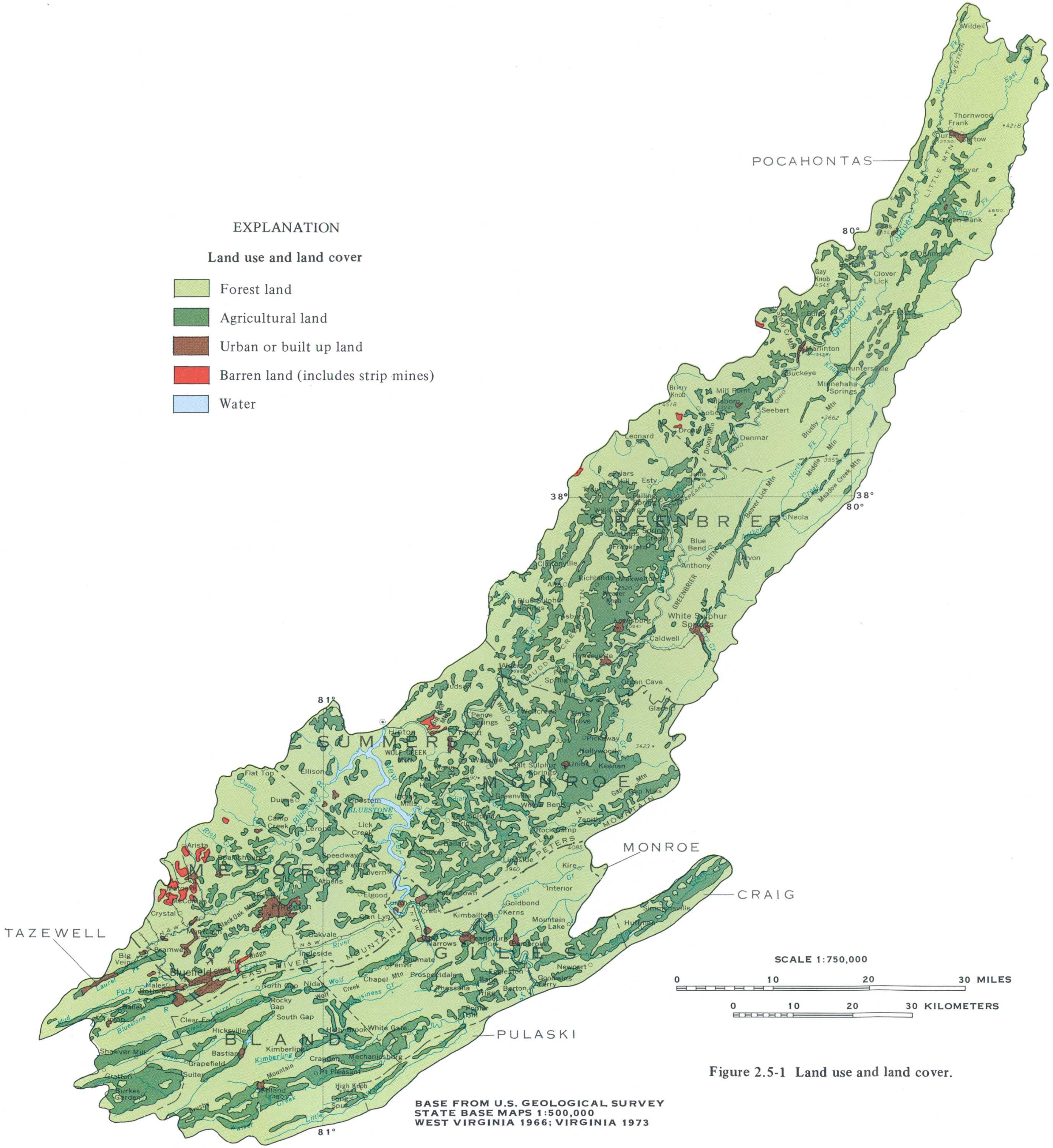


Figure 2.5-1 Land use and land cover.

Table 2.5-1 Summary of land use in Area 10.

	COUNTY*	FOREST COVER (PERCENT)	AGRICULTURAL LAND (PERCENT)	URBAN AND RESIDENTIAL (PERCENT)	MINING AND BARREN (PERCENT)	WATER (PERCENT)
West Virginia	Greenbrier	80.6	17.5	1.1	0.7	0.1
	Mercer	76.7	16.7	4.8	1.6	0.2
	Monroe	65.2	34.1	0.6	0.0	0.1
	Pocahontas	88.5	10.8	0.3	0.3	0.1
	Summers	81.6	15.3	1.2	0.1	1.8
Virginia	Craig	73.5	26.0	0.4	0.0	0.1
	Giles	81.1	14.5	2.0	0.4	2.0
	Pulaski	87.7	12.2	0.1	0.0	0.1
	Tazewell	61.0	33.6	3.9	0.5	1.0

*Percentages for Virginia Counties are for the region of the Virginia Counties within Area 10 only. Percentages for West Virginia Counties are for the entire county.

From U.S. Geological Survey, 1973, 1977, and 1978, and West Virginia Geological and Economic Survey, 1980.

Ground Water is Principal Water-Supply Source

Water use in Area 10 during 1979 was about 28 million gallons per day. Approximately 20 million gallons per day (71 percent) was derived from ground-water sources.

Ground water was the principal source of water used in Area 10 during 1979, estimated at 20 Mgal/d (million gallons per day) or 71 percent of total water use (28 Mgal/d). Water for domestic use from private ground-water systems was about 12 Mgal/d or 60 percent of total ground-water usage (table 2.6-1). Domestic water-use estimates are based on an assumed average water-use rate of 75 gallons per day per capita for estimated percentages of county populations using ground-water sources for water supply (Clark and others, 1976; Virginia State Water Control Board, 1979; Ms. Hall, U.S. Census Bureau, oral communication, 1981). Because much of the populace resides in rural communities, most of the ground water is obtained from private systems such as wells and springs. Individually, these private systems produce relatively small quantities of water, but their collective production is large (fig. 2.6-1). Ground water used for public supply, and for mining and industry amounted to 4.19 Mgal/d and 3.50 Mgal/d respectively. Considerably greater quantities of ground water are available for water-resource development in Area 10. For example, other investigators (DePaulo and Baloch, 1968, p. 93-103) have indicated that about 132 Mgal/d discharges from springs in the Greenbrier River basin.

More water for public supply is derived from surface-water sources than from ground water. Surface-water sources include streams and impoundments; these sources supplied 7.90 Mgal/d for public supply use compared to 4.19 Mgal/d from ground water. Surface water for public supply ranged from 4.49 Mgal/d in Mercer County to zero in the portions of Craig and Pulaski Counties that are within Area 10. Water use for agriculture and irrigation, all reported as surface water, was 0.79 Mgal/d. Water for mining and industrial use (3.50 Mgal/d) in Area 10 was entirely derived from ground-water sources.

Data on water use is scarce. The figures presented in table 2.6-1 are conservative estimates, as water use data from many industrial, commercial, and domestic private systems were not reported. Information was compiled from the following sources: Clark and others, 1976; Landers, 1976; Virginia State Water Control Board, 1979; Lessing and others, 1981; D. M. McLeod, Virginia State Water Control Board, written communication, 1981.

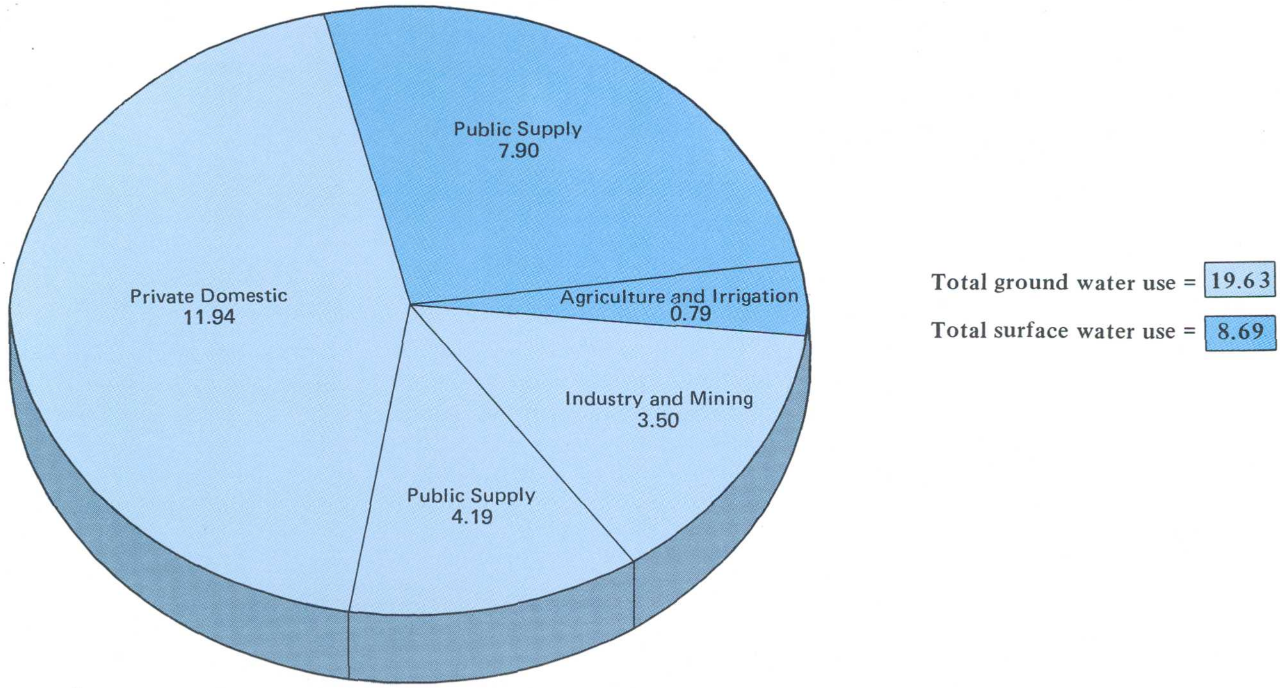


Figure 2.6-1 Water use, in million gallons per day.

Table 2.6-1 Water use, in million gallons per day.

	COUNTY *	PUBLIC SUPPLY SURFACE WATER	PUBLIC SUPPLY GROUND WATER	AGRICULTURE** AND IRRIGATION SURFACE WATER	MINING AND INDUSTRY*** GROUND WATER	ESTIMATED DOMESTIC USE GROUND WATER
West Virginia	Greenbrier	1.03	2.06	0.30	0.23	1.4
	Mercer	4.49	0.02	0.05	1.17	2.8
	Monroe	—	0.30	0.24	—	0.68
	Pocahontas	0.39	—	0.12	—	0.52
	Summers	0.66	—	0.08	0.01	0.73
	Subtotals	6.57	2.38	0.79	1.40	6.13
Virginia	Bland	0.10	0.13	—	0.41	0.34
	Craig	—	—	—	—	0.27
	Giles	—	1.56	—	1.69	1.2
	Pulaski	—	0.04	—	—	1.3
	Tazewell	1.23	0.08	—	—	2.7
	Subtotals	1.33	1.81	—	2.10	5.81
	Area 10 Totals	7.90	4.19	0.79	3.50	11.94

*Figures for West Virginia Counties are for entire county. Figures for Virginia Counties are for region of county within Area 10, except for domestic ground-water usage, which is for entire county.

**Agricultural figures are from 1976 and 1978.

***West Virginia figures apply to mining use only.

— No data.

Sedimentary Rocks Underlie the Area

Rocks underlying the area are primarily alternating beds of sandstone, shale, limestone, and mudstone.

Area 10 is situated on a segment of the western edge of a long northeastward-trending trough which extends from northeastern Alabama to Newfoundland. Sediment accumulated in the trough through most of Paleozoic time, about 600 to 240 million years ago, and reached a total thickness of 40,000 to 50,000 feet in Virginia. The depth of water in the trough was nearly always shallow, but the weight of the accumulating sediments caused the floor to sink at a rate commensurate with the rate of sediment deposition. Eventually, since the late Paleozoic time, the region became uplifted and compressed laterally, causing the folded mountain ridges which are now the Appalachians. The geology of Area 10 includes rocks of all the Paleozoic systems from the Cambrian to the Pennsylvanian. The area has been involved in complex folding and faulting, thus causing many of the older rock units to crop out on the present land surface. The geology of the Appalachian area in Virginia is described in detail in Butts (1940), and shown on the geologic map by Butts (1933).

For convenience, the geology in this report has been divided into seven units, and is described from oldest to youngest. The stratigraphic nomenclature follows the usage of the West Virginia Geological and Economic Survey (Cardwell and others, 1968) and differs from the usage of the U.S. Geological Survey. A chart correlating the names used in West Virginia with those used in Virginia is shown with the map (figure 2.7-1).

Rocks of Early Devonian age and older--older than about 400 million years--are combined as the lowest unit described in this report and consist of limestone, shale, and sandstone. These rocks are intricately folded and faulted in the southern part of the area. This unit contains no coal.

Shale, siltstone, sandstone, and limestone of Middle and Late Devonian age have been combined into the second unit. Those beds also have been folded and faulted rather extensively and contain no coal.

The Pocono Group of Early Mississippian age is about 200 to 600 feet thick and is predominantly hard gray sandstone with some shale. It has been affected by folding and some faulting. It contains a few lenticular coal seams but none are minable in Area 10.

The Maccrady Formation of Early Mississippian age is 25 to 550 feet thick and contains red shale and mudstone, red and green sandstone, and minor limestone. It contains no coal.

The Greenbrier Group of Middle and Late Mississippian age is 300 to 1,800 feet thick and contains massive marine limestone, nonmarine red and gray shale, and minor sandstone beds. It contains a few lenses of carbonaceous shale but no mineable coal. This unit contains many caves and sinkholes which significantly affect the hydrologic conditions in some parts of the basin.

The Mauch Chunk Group of Late Mississippian age is 1,500 to 3,500 feet thick and is composed of red, green, and medium-gray shale and sandstone, with a few stringers of thin limestone. The unit contains scattered, thin coal seams, but they have no economic importance.

The Pottsville Group of Early Pennsylvanian age is 0 to 465 feet thick in the area. It is composed predominantly of sandstone with thin interbeds of siltstone, shale, and coal. All coal production in Area 10 comes from this rock unit which is found only along the northern edge of the southwestern end of the basin. Coal production is confined to three of the nine Pocohontas coal seams in the lower part of the Pottsville Group.

The report "Geologic History of West Virginia", by Dudley H. Cardwell (1975) contains a thorough description of the rocks described above.

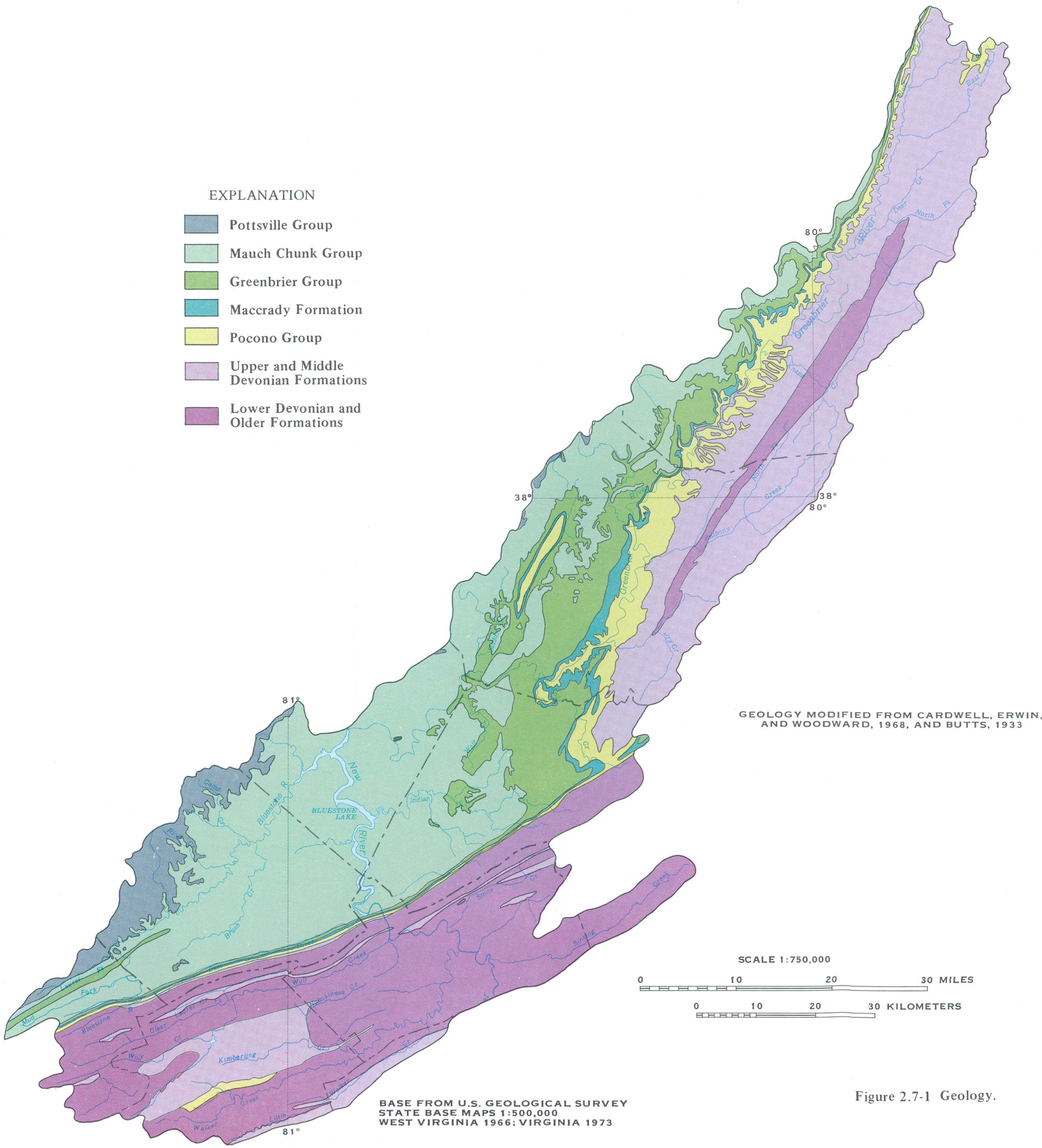


Figure 2.7-1 Geology.

GEOLOGIC SYSTEMS	SERIES		WEST VIRGINIA		VIRGINIA	
PERMIAN						
PENNSYLVANIAN	UPPER	?	Greene Formation	Dunkard Group		
			Washington Formation			
			Waynesburg Formation			
			Monongahela Group			
			Conemaugh Group			
	MIDDLE		Allegheny Formation		Harlan Formation	
	LOWER		Kanawha Formation	Pottsville Group	Wise Formation	
			New River Formation		Gladeville Sandstone	
			Pocahontas Formation		Norton Formation	
					Lee Formation	
MISSISSIPPIAN	UPPER	*Chesterian*	Bluestone Formation	Mauch Chunk Group	Bluestone Formation	Pennington Group
			Princeton Formation		Princeton Sandstone	
			Hinton Formation		Hinton Formation	
			Bluefield Formation		Bluefield Formation	Glen Dean Ls
			Alderson Limestone	Greenbrier Group	Girkin Limestone	Greenbrier Formation
			Greenville Shale			
			Union Limestone			
	MIDDLE	*Meramecian*	Pickaway Limestone		St. Genevieve Limestone	
			Taggard Formation			
			Denmar Formation			
			Hillsdale Limestone		St. Louis - Warsaw Ls	
	LOWER	*Osagean*	Maccrady Formation		Maccrady Formation	
		Kinderhookian	Pocono Group		Price Formation	
DEVONIAN	UPPER	*Chatautauquan*	Hampshire Formation		Hampshire Formation	Chemung
			Foreknobs Formation	Chemung		
			Scherr Formation			
			Parkhead Sandstone			
			Brallier Formation		Brallier Formation	
	MIDDLE	*Erian*	Harrell Shale		Millboro Shale	
			Mahantango Formation			
			Marcellus Formation			
			Onesquethaw: Onondaga Limestone, Huntersville Chert, Needmore Shale		Needmore Shale	
	LOWER	*Ulsterian*	Oriskany Sandstone (Ridgeley)		Oriskany Sandstone	
			Licking Creek Limestone	Helderberg Group	Rocky Gap Sandstone	
			New Scotland Formation		Licking Creek Limestone	
			New Creek Formation		Healing Springs Sandstone	
					Coeymans Limestone	
					Clifton Forge Sandstone	

820,745 Tons of Coal Mined in 1980

In 1980, Area 10 produced 820,745 tons of coal, 96 percent from ten underground mines and 4 percent from three surface mines. The number of mines is small because of the limited amount of coal-bearing rock in the area. Estimated recoverable reserves as of January 1, 1981 are almost 102 million tons.

Area 10 produced 820,745 tons of coal in 1980, slightly less than 1 percent of the State total. Nearly all the production, 96 percent was from 10 underground mines and 4 percent was from three surface mines. All mines were in Mercer County, West Virginia except for one underground operation in Tazewell County, Virginia. The number of mines is small because only about 119 mi^2 (square miles) or 4 percent of Area 10 contain coal-bearing rock, of which 89 mi^2 are in Mercer County. All of the coal in Area 10 is from the Pottsville Group, which is shown in figure 3.1-1. Section 2.7 of this report contains a more detailed discussion of geology. Three underground mines produced 82 percent of the underground production and one surface mine accounted for 92 percent of the surface production.

Recoverable reserves were difficult to estimate because the only figures available were on a county-wide basis. Mercer County is almost totally within Area 10 and therefore the county estimates could be used. Estimated recoverable reserves as of January 1, 1981 for Mercer County are listed at almost 102 millions tons (West Virginia Department of Mines, 1980). Original mineable reserves were estimated to have been near 507 million tons. A figure for the remaining 30 square miles of coal-bearing rocks in Area 10 was unavailable.

Six seams of coal in the Pottsville Group were mined during 1980: Pocahontas Nos. 2, 3, 4, 7 and 12 and the Welch. Most of the surface mining was done in the Pocahontas No. 4 coal bed, but Pocahontas No. 3 coal bed accounted for 86 percent of the total production in Area 10.

Babu and others (1973) indicated that coal in the area is low to medium volatile bituminous with carbon content greater than 75 percent, ash content of about 6 percent, and sulfur content less than 1.5 percent. Calorific values range from 13,500 btu/lb to 15,000 btu/lb. Because the coal is low in sulfur, it is ideal for utility-gas production and for making metallurgical coke.

Figure 3.1-1 Extent of Pottsville Group in Area 10 (shaded area).

Surface Mines Produced 4 Percent of the Coal in 1980

In 1980, three surface mines produced 29,661 tons of coal, accounting for 4 percent of the coal production in Area 10. The low production reflects the small amount of coal-bearing rock in the area.

In 1980, three surface mines operating in Mercer County, West Virginia, produced 29,661 tons, or 4 percent of the coal production in Area 10. Mercer County accounted for 0.12 percent of the West Virginia surface-mined coal, ranking 20th of the 30 coal-producing counties in the State. The rate of production in the area, 14.2 tons per man per day, differed slightly from the State average of 18.8 tons per man per day.

The low production reflects the small amount of coal-bearing rock in Area 10. There are approximately 119 mi^2 (square miles) of coal-bearing rock, of which 89 mi^2 are in Mercer County. All of the surface-mined coal in Area 10 in West Virginia is from the Pocahontas Nos. 3, 4, and 7 coal seams in the Pottsville Group, as shown in figure 3.2-1. Section 2.7 of this report contains a more detailed discussion of geology.

One mine produced 92 percent of the surface-mined coal in Area 10, all from the Pocahontas No. 4 seam. The remaining 8 percent came from the Pocahontas No. 3 and No. 7 seams. As of July 1, 1981 there were only two active surface mines in Area 10 with a total permitted area of 210 acres.

Surface mining within Area 10 in Virginia was in a small portion of Tazewell County, and ended in 1979. Mine listings for 1979 from the Virginia Department of Labor and Industry (1980) show one surface mine permitted for 147 acres in the Pocahontas No. 6 seam, but the only production figures available were on a countywide basis. Tazewell County production for 1979 from 4 surface mines was 172,171 tons. West Virginia 1979 coal-production statistics indicated that two surface mines in Mercer County produced 13,474 tons.

Figure 3.2-1 Extent of Pottsville Group and location of surface mines active during 1980.

Underground Mines Produced 96 Percent of the Coal in 1980

In 1980, 10 underground mines produced 791,084 tons, 96 percent of the coal production in Area 10. Only 119 square miles of coal-bearing rock lie in the area, most of it in Mercer County.

In 1980, 10 underground mines produced 791,084 tons of coal, or 96 percent of the coal production in Area 10. Figure 3.3-1 shows the location of the mines--nine in Mercer County, West Virginia and one in Tazewell County, Virginia. There are approximately 119 mi^2 (square miles) of coal-bearing rock in Area 10, of which 89 mi^2 are in Mercer County. All of the underground-mined coal is from the Welch (locally known as the Upper Horsepen) and Pocahontas Nos. 2, 3, and 12 coal seams in the Pottsville Group, as shown in figure 3.3-1. Section 2.7 of this report contains a more detailed discussion of geology.

Three mines produced 82 percent of the underground-mined coal in 1980. Approximately 90 percent of the 1980 underground coal production came from the Pocahontas No. 3 seam, 9 percent from the Welch seam, and the rest from the Pocahontas Nos. 2 and 12 seams. These seams were the only ones mined during 1979 and 1980. Their average thickness was 46 inches.

Large quantities of spoil material are often discarded near mine portals. Figure 3.3-1 shows the location of refuse piles in West Virginia. The location of refuse piles in Virginia is unavailable. Refuse piles are an indication of present and past mining activity. These piles can cause water-quality problems in nearby streams by contributing sediment and by leaching of iron, manganese, sulfate, magnesium, aluminum, and calcium from the refuse (Krothe and others, 1980).

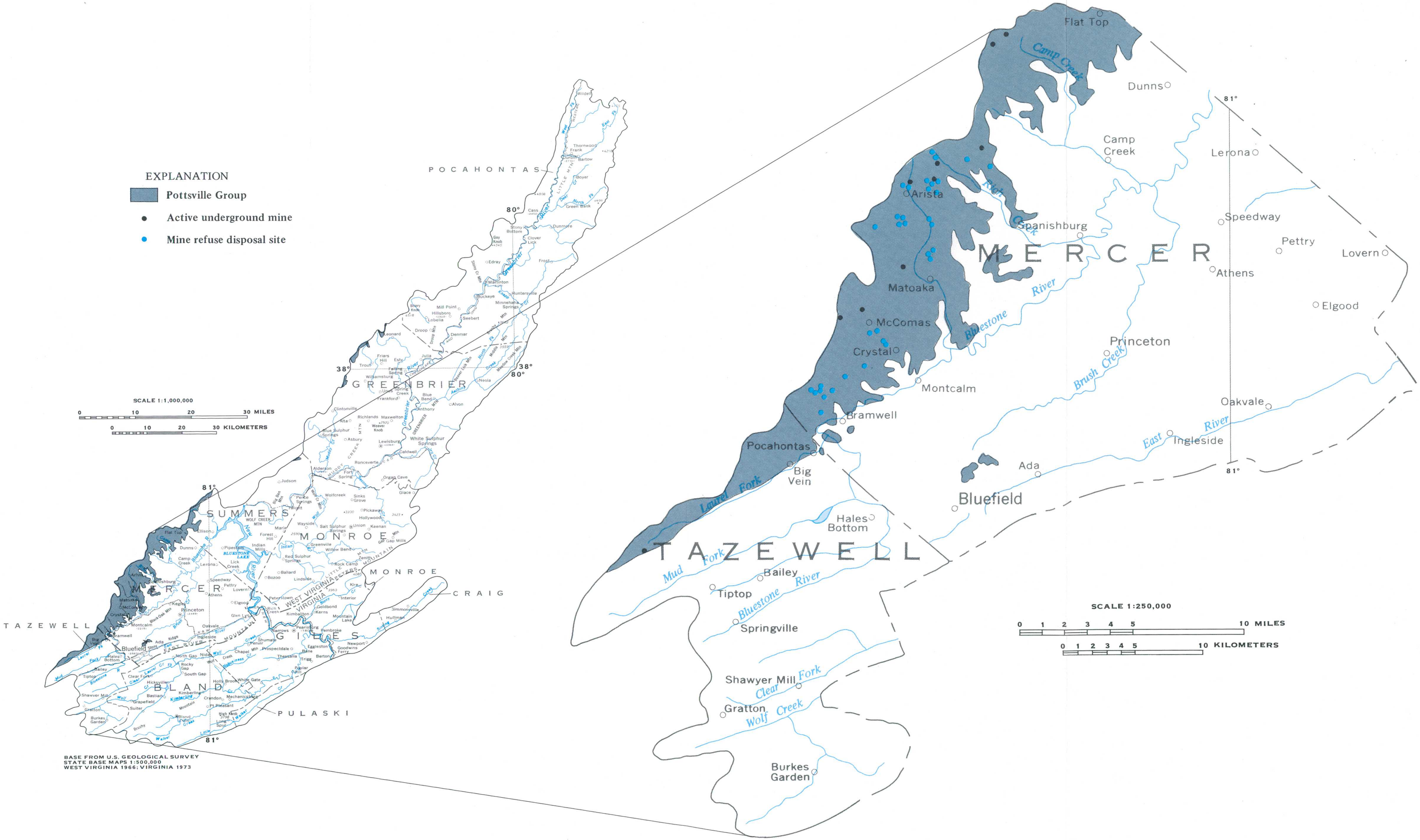


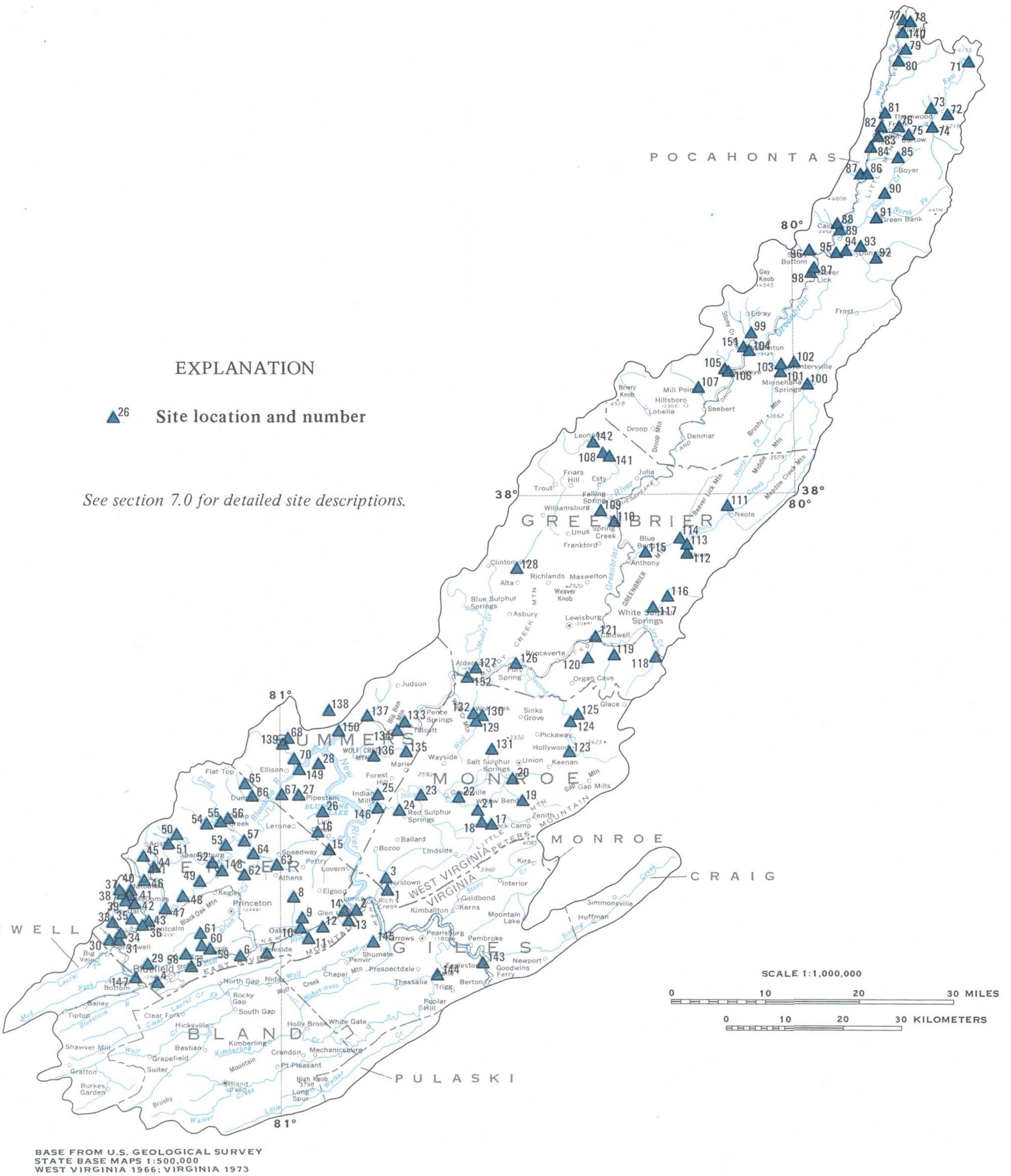
Figure 3.3-1 Extent of Pottsville Group, location of mine refuse disposal sites, and location of underground mines active during 1980.

Water Data are Available at 149 Sites

Surface-water quality or quantity data are available at 149 sites in Area 10. In 1980, the active network consisted of 23 sites. Data are available through NAWDEX (National Water Data Exchange) and U.S. Geological Survey reports published annually.

Streamflow and (or) water-quality data are available for 149 sites in Area 10. The hydrologic data network in 1980 consisted of 23 active sites. Location of sites are shown in figure 4.1-1; details concerning type of data collected and period of record are given in section 7.0. Most (136) sites were selected during a previous investigation of the upper New River basin in West Virginia. These data are available in a previously published report (Chisholm and Frye, 1976). Interpretative findings are discussed separately (Clark and others, 1976, and Jones, 1973).

Water-quality data are available at 140 sites, although all types of data are not necessarily available at all sites. The periods of record are nonconcurrent for many sites. Daily streamflow data are available at 32 sites and suspended-sediment data are available at 15 sites. Water-quality and quantity data collected after 1974 are available from computer storage through NAWDEX (National Water Data Exchange) and are published annually in U.S. Geological Survey reports "Water Resources Data for West Virginia" and "Water Resources Data for Virginia." For more detailed information concerning NAWDEX, see section 6.2.



EXPLANATION

▲26 Site location and number

See section 7.0 for detailed site descriptions.

Figure 4.1-1 Surface-water network.

Basin and Climate Characteristics Affect Low Flow of Streams

Low flow of streams in Area 10 is influenced by basin and climate characteristics as well as by activities of man. The flow of streams becomes very low during drought and many go dry. Low-flow data are available for 22 sites in the area.

Low flow statistics for streams are often used in the planning and design of water-supply facilities to assure an uninterrupted supply of water during dry periods. They are also used in the design of waste treatment facilities to ensure adequate dilution of wastewater discharged to streams during low-flow periods. Low-flow discharge is influenced by streamflow regulation, size of drainage area, geology, climate, wastewater discharge, mining, and withdrawals from streams for domestic, industrial, and agricultural purposes.

A commonly used low-flow statistic, particularly in pollution abatement, is the mean 7-day, 10-year low flow ($M_{7,10}$). It is defined as the annual lowest average rate of flow for 7 consecutive days that occurs at an average interval of once in 10 years. This streamflow normally represents ground-water discharge to the stream, but is often influenced by reservoir operation or mine discharge.

Low-flow statistics ($M_{7,2}$; $M_{7,10}$; $M_{7,20}$) at selected sites in Area 10 (fig. 4.2.1-1 and table 4.2.1-1) were calculated by fitting discharge values to a Log-Pearson type III frequency distribution (Hutchinson, 1975).

Based on available streamflow records within the area, a regression equation was developed to estimate the 7-day, 10-year low flow. The equation is of the form:

$$Y = aX^b$$

where **Y** is the 7-day, 10-year low flow in ft^3/s (cubic feet per second); **X** is the drainage area, in mi^2 (square miles); and **a** and **b** are the regression constant and coefficient.

Figure 4.2.1-2 shows the relationship between X and Y and the resultant regression equation: $Y = 0.0046 X^{1.405}$. The relation has a standard error of approximately 80 percent.

Table 4.2.1-1 Low-flow statistics for selected sites in Area 10.

SITE NUMBER	STATION NAME	PERIOD OF (LOW FLOW) RECORD	$M_{7,2}$ (FT^3/S)	$M_{7,10}$ (FT^3/S)	$M_{7,20}$ (FT^3/S)
1	Rich Creek near Peterstown, W. Va.	1943-1950	2.7	—	—
2	New River at Glen Lyn, Va.	1929-1980*	1523	1127	1043
55	Camp Creek near Camp Creek , W. Va.	1948-1971	0.4	0	—
67	Bluestone River near Pipestem, W. Va.	1952-1980	24.6	12.8	10.8
83	Greenbrier River at Durbin, W. Va.	1944-1980	9.7	2.2	1.3
99	Indian Draft near Marlinton, W. Va.	1970-1977	0.1	—	—
104	Knapp Creek at Marlinton, W. Va.	1947-1958	10.0	4.1	3.0
106	Greenbrier River at Buckeye, W. Va.	1931-1980	32.9	13.5	10.4
115	Anthony Creek near Anthony, W. Va.	1973-1980	10.4	—	—
124	Second Creek near Second Creek, W. Va.	1947-1973	4.8	3.3	3.0
134	Greenbrier River at Hilldale, W. Va.	1938-1980	104	53.1	44.6
137	Big Creek near Bellepoint, W. Va.	1971-1977	0.03	—	—
143	New River at Eggleston, Va.	1916-1976*	1237	882	804
144	Walker Creek at Bane, Va.	1939-1980	44.4	32.3	30.0
145	Wolf Creek near Narrows, Va.	1910-1980	34.5	22.5	20.0
146	Indian Creek at Indian Mills, W. Va.	1943-1950	6.4	—	—
147	Bluestone River at Bluefield, Va.	1967-1980	9.6	6.6	6.0
148	Bluestone River near Spanishburg, W. Va.	1946-1952	17.0	—	—
149	Bluestone River at Lilly, W. Va.	1910-1948	18.8	7.9	6.0
150	New River at Bluestone Dam (nearHinton, W. Va.)	1925-1949* 1951-1980**	1479 1352	981 1140	864 1113
151	Greenbrier River at Marlinton, W. Va.	1910-1916	31.7	—	—
152	Greenbrier River at Alderson, W. Va.	1897-1980	103	53.3	45.0

*Regulated by Claytor Reservoir
**Regulated by Claytor and Bluestone Reservoir

Figure 4.2.1-1 Location of gaging stations.

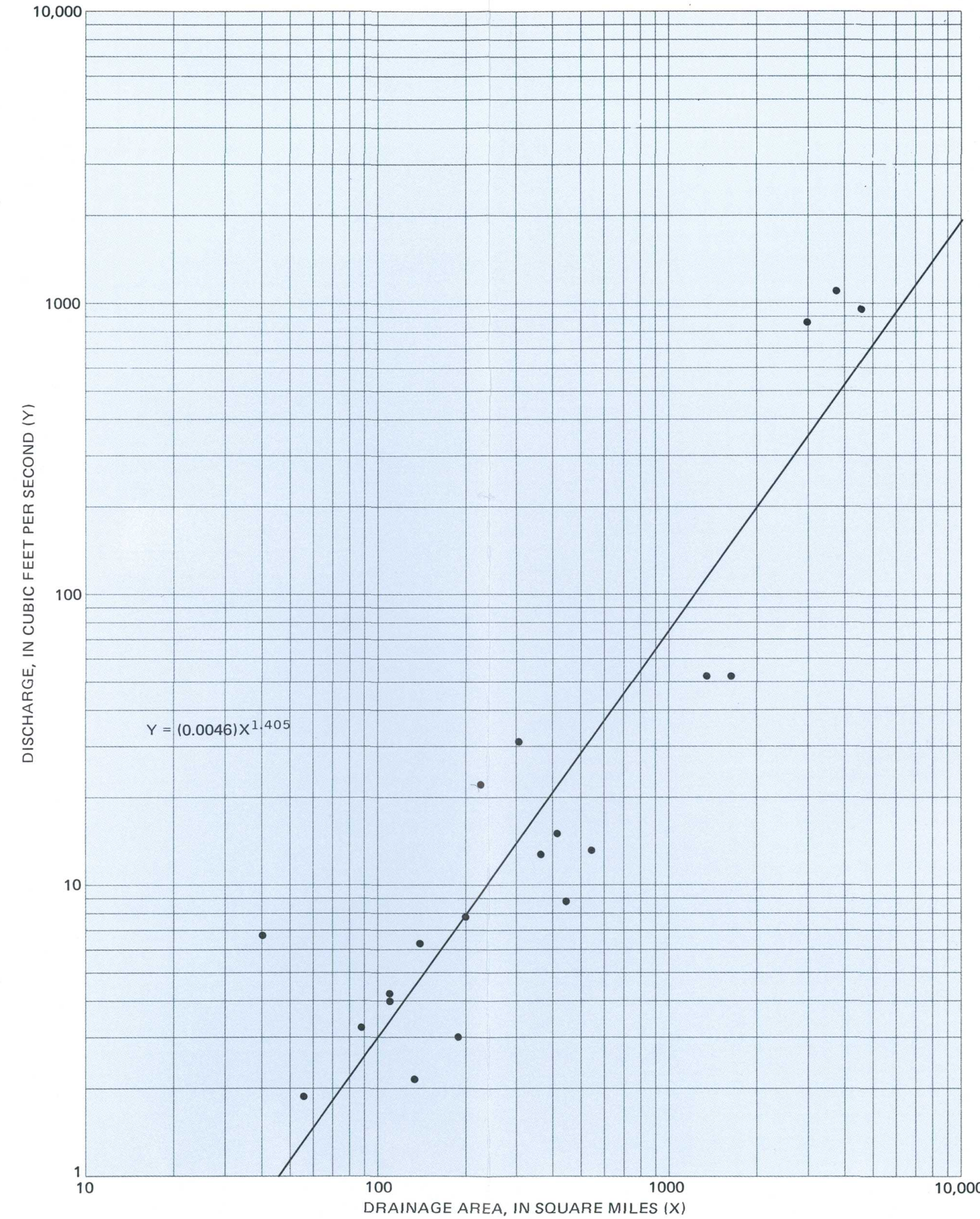


Figure 4.2.1-2 Relationship between drainage area and 7-day, 10-year low flow.

Basin Characteristics Affect Flooding

Drainage area and slope are the primary factors affecting the magnitude of floods in Area 10.

Estimates of the magnitude and frequency of floods are needed for safe and economical design of hydraulic structures and flood-plain management. Flood frequencies are generally expressed in terms of probability of occurrence or recurrence interval. For example, a flood having a 2 percent chance of being exceeded in any one year is also described as having a 50 (inverse of .02) year recurrence-interval flood (Q_{50}).

Regression equations for estimating the magnitude and frequency of floods at ungaged sites in West Virginia and Virginia were developed by Runner (1980) and Miller (1978), respectively.

The estimating equations for West Virginia are of the following form:

$$Q_i = cA^b$$

where Q_i is the peak discharge, in ft^3/s (cubic feet per second), at a given **i** year recurrence interval; **c** is the regression constant; **A** is the drainage area, in mi^2 (square miles); and **b** is the regression coefficient.

The equations for Virginia are of the form:

$$Q_i = cA^{b_1} S^{b_2} RF$$

where $\mathbf{Q_i}$, **c**, **A**, and **b** are same as listed above, **S** is channel slope, in feet per mile (10 percent and 85 percent of the river mile distance from the site to basin divide; and **RF** is a regional factor (RF = 1.00 for Area 10).

The equations developed for areas within West Virginia are applicable to streams with drainage areas ranging from 0.3 to 2,000 mi^2. The table below shows the equations for estimating Q_{10}, Q_{50}, Q_{100}, in Area 10 in West Virginia and Virginia.

Graphical solutions for estimating the 10-, 50-, and 100-year instantaneous peak discharges for streams in Area 10 in West Virginia are shown in figure 4.2.2-1. Examples of peak discharge determinations for a stream are also illustrated on figure 4.2.2-1. In the example, estimates of the Q_{10}, Q_{50}, and Q_{100} for a stream with a drainage area of 50 mi^2 are 4,100, 6,200, and 7,300 ft^3/s, respectively.

The relations presented here should not be used to estimate peak flows for streams draining urban areas, streams with significant regulation, or with drainage areas less than 0.3 or greater than 2,000 mi^2.

West Virginia

Q_{10}

Drainage area 0.3 to 549 mi^2, $Q_{10} = 201\ A^{0.771}$
Drainage area 549 to 2000 mi^2, $Q_{10} = 149\ A^{0.818}$

Q_{50}

Drainage area 0.3 to 529 mi^2, $Q_{50} = 354\ A^{0.733}$
Drainage area 529 to 2000 mi^2, $Q_{50} = 249\ A^{0.789}$

Q_{100}

Drainage area 0.3 to 530 mi^2, $Q_{100} = 437\ A^{0.719}$
Drainage area 530 to 2000 mi^2, $Q_{100} = 303\ A^{0.777}$

Average standard error of estimate for the West Virginia equations ranges from 27 to 44 percent (Runner, 1980).

Virginia

$$Q_{10} = 81\ A^{0.78}\ S^{0.22}\ RF$$
$$Q_{50} = 198\ A^{0.73}\ S^{0.22}\ RF$$
$$Q_{100} = 269\ A^{0.73}\ S^{0.21}\ RF$$

Average standard error of estimate for the Virginia equations ranges from 45 to 60 percent (Miller, 1978).

A WRI (Water Resources Investigation) report now in press entitled "Techniques for Estimating Streamflow Characteristics in the Eastern and Interior Coal Provinces" will soon be available to predict streamflow characteristics for basins that cross State lines. Until the report is available, the user is instructed to use an averaging technique, if the basin is divided by a State line.

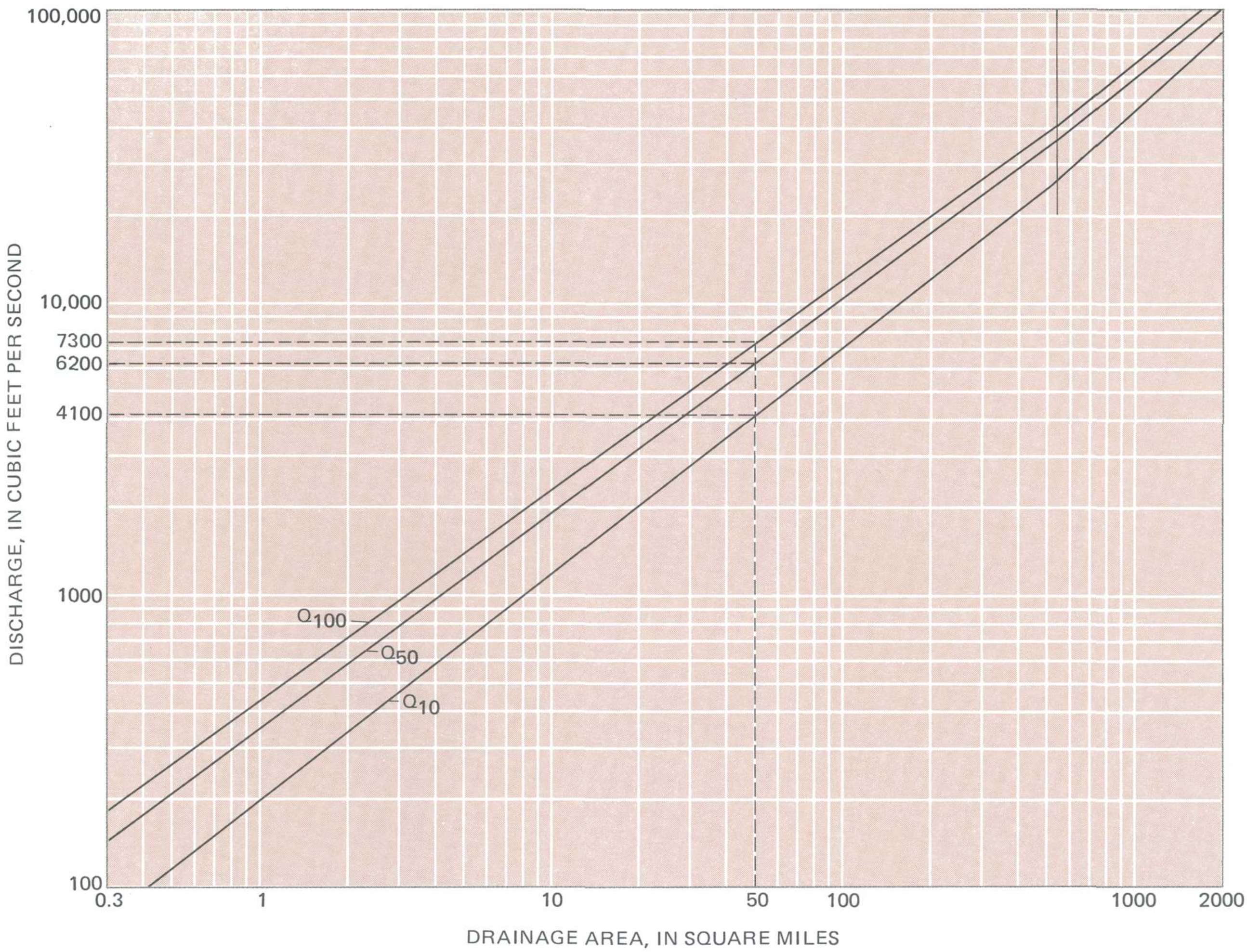


Figure 4.2.2-1 Relation of 10, 50, and 100-year peak discharge to drainage area for Area 10 in West Virginia (modified from Runner, 1980).

Flood-Prone Area Maps Available

The limits of the 100-year recurrence interval flood in Area 10 are delineated on 27 selected 7½-minute quadrangles.

The National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973 established programs for investigating the extent of flooding in urban areas and rural communities. Flood-prone area maps prior to 1969 were for "approximate areas occasionally flooded". In 1969 the project was changed to delineate the approximate boundaries of the 100-year flood. In 1969 the U.S. Geological Survey began a mapping program to delineate flood-prone areas for all affected communities, recreational areas, and areas with the potential for development. Maps were produced using stage-frequency relations at gaging stations, profiles of high-water marks, and regional flood-frequency curves. Also shown on the maps are areas where USGS hydrologic atlases are available, areas delineated in greater detail by other federal agencies, and flood-prone areas prior to reservoir construction. In general, the delineated areas are for natural stream conditions and give the user a quick way of identifying areas of potential flood hazards.

The locations of 27 flood-prone area maps in and adjacent to Area 10 are shown on figure 4.2.3-1. Completed flood-prone area maps are shown with the quadrangle name for each available 7½-minute map. The maps are available upon request from the appropriate U.S. Geological Survey District Office:

U.S. Geological Survey
Water Resources Division
603 Morris Street
Charleston, West Virginia 25301

or

U.S. Geological Survey
Water Resources Division
200 West Grace Street
Room 304
Richmond, Virginia 23220

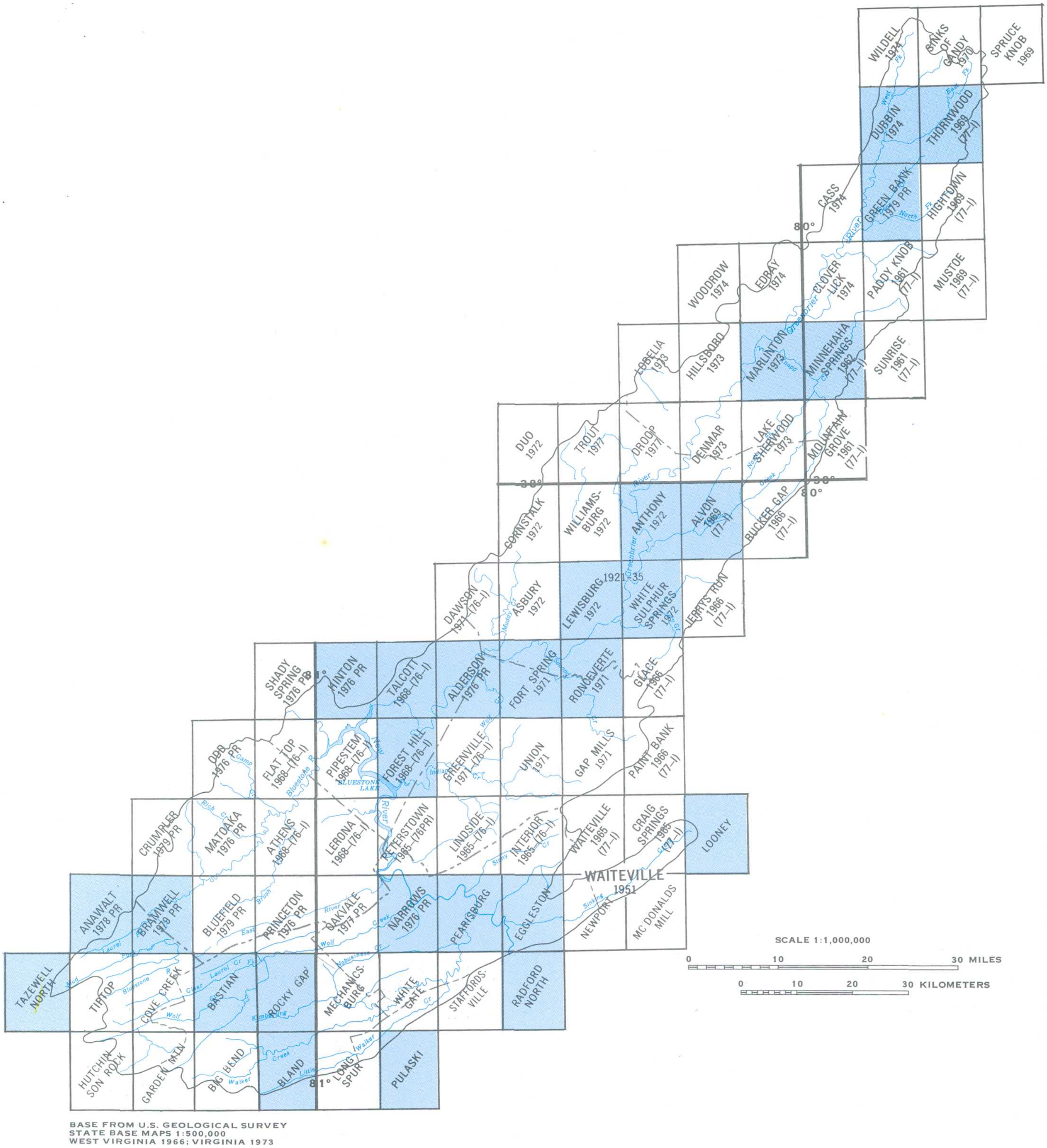


Figure 4.2.3-1 Flood prone area maps available for Area 10 (blue tint).

Flow-Duration Curves for Streams Summarize the Effects of Basin Characteristics on Long-Term Streamflow

Streamflow duration is affected by topography, geology, climate, drainage area, and by man's activities including streamflow regulation and mining. Streamflow-duration data are available for 22 stations in the area.

A streamflow duration curve is a cumulative frequency curve showing the percentage of time that a specific daily mean discharge was equaled or exceeded. The curves are often used to demonstrate streamflow distribution and variability. The flow-duration curve is one way of representing the flow characteristics of a stream throughout the range of discharge without regard to the sequence of occurrence. Flow-duration data are useful in studies involving power development, water supply, domestic and industrial waste disposal, and for computing an average annual suspended-sediment or dissolved-solute load if appropriate transport curves are known.

Streamflow duration data for selected gaging stations (fig. 4.2.4-1) are summarized in table 4.2.4-1 for unregulated and regulated periods. Data in table 4.2.4-1 represent streamflow from non-concurrent time periods and, therefore, are not suitable for comparisons between sites but are useful when analyzing data on a regional basis.

Discharges around the 25-35 percent duration usually correspond to the stream's mean flow, whereas streamflow occurring at or greater than 75 percent duration is generally considered low flow. Streamflow occurring at or less than 25 percent duration is generally considered high flow. Flow duration is affected by many natural basin characteristics such as topography, geology, size of drainage area, and climate, and by activities of man including streamflow regulation and mining.

Basin topography and geology have a major influence on the shape of the flow-duration curve. Streams receiving direct surface runoff with limited contribution from ground-water storage typically have flow-duration curves with a steep slope. Streams receiving delayed surface runoff and ground-water storage have flow-duration curves with flatter slopes, particularly in the low-flow portion. Examples of the effects of geology on the variability of flow-duration curves for streams draining Area 10 are shown on figure 4.2.4-2. The curve for site 55 reflects the lack of baseflow contributed by the relatively impermeable rocks (shale, siltstone, and sandstone) of the Pottsville and Mauch Chunk Groups. In contrast, the curve for site 124 reflects sustained baseflow contributed by permeable rocks (limestone) of the Greenbrier Group.

Surface and underground mines also affect streamflow duration when streamflow is augmented by increased ground-water infiltration, mine drainage, or mine pumpage. The effect on the low-flow portion of the curve is similar to streamflow sustained by ground-water discharge during dry periods. Melvin V. Mathes (written communication, 1981) indicated that in several small basins in the Guyandotte River basin, high streamflows were less and low flows were greater in heavily mined basins than in unmined basins.

Figure 4.2.4-1 Location of gaging stations.

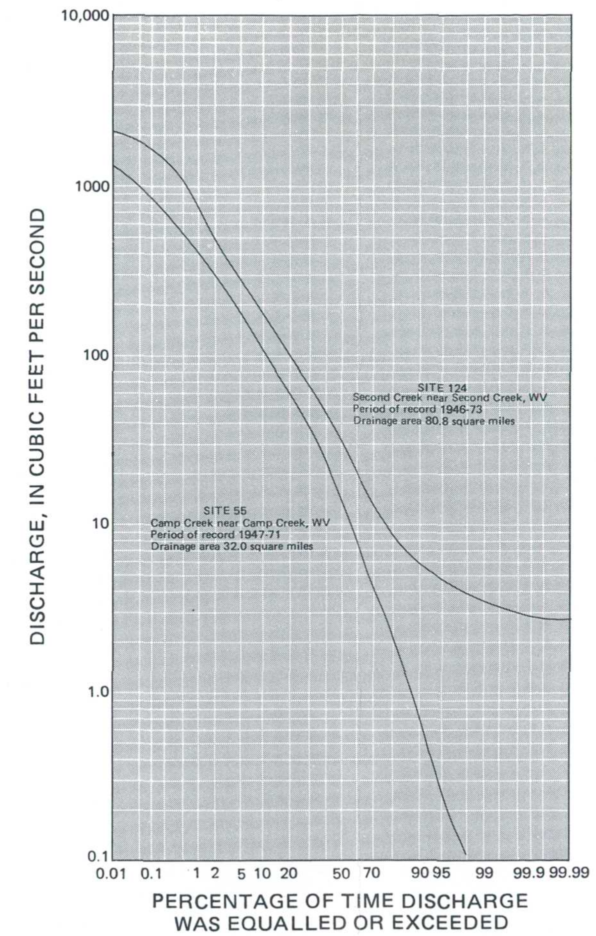


Figure 4.2.4-2 Streamflow duration curves for sites 55 and 124.

Table 4.2.4-1 Flow duration for selected stations.

SITE NUMBER	STATION NAME	PERIOD OF RECORD	MEAN DAILY DISCHARGE IN CUBIC FEET PER SECOND, THAT WAS EQUALLED OR EXCEEDED FOR INDICATED PERCENTAGE OF TIME						
			10	25	50	70	75	90	95
1	Rich Creek near Peterstown, W. Va.	1942-50	86	38	14	7.1	6.0	3.5	2.7
2	New River at Glen Lyn, Va.	1928-80*	9500	6000	3800	2600	2300	1600	1400
55	Camp Creek near Camp Creek, W. Va.	1947-71	110	48	16	4.6	3.3	0.7	0.3
67	Bluestone River near Pipestem, W. Va.	1951-80	1100	540	200	91	74	34	25
83	Greenbrier River near Pipestem, W. Va.	1944-80	620	320	140	60	47	18	10
99	Indian Draft near Marlinton, W. Va.	1969-77	13	6.1	2.1	0.7	0.5	0.2	0.1
104	Knapp Creek at Marlinton, W. Va.	1946-58	350	160	64	28	23	12	9.3
106	Greenbrier River at Buckeye, W. Va.	1930-80	2100	1000	410	180	140	55	35
115	Anthony Creek near Anthony, W. Va.	1971-80	480	240	92	41	33	15	10
124	Second Creek near Second Creek, W. Va.	1946-73	180	85	31	13	11	6	4.9
134	Greenbrier River, at Hildale, W. Va.	1937-80	5400	2700	1100	450	360	160	110
137	Big Creek near Bellepoint, W. Va.	1970-77	27	12	3.7	1.0	0.7	0.1	0.1
143	New River at Eggleston, Va.	1915-76*	7300	4800	3000	2100	1900	1300	1100
144	Walker Creek at Bane, Va.	1939-80	750	370	170	89	77	50	43
145	Wolf Creek near Narrows, Va.	1909-16 1939-80	690	360	160	80	67	40	32
146	Indian Creek at Indian Mills, W. Va.	1942-50	300	130	53	24	19	8.2	5.8
147	Bluestone River at Bluefield, Va.	1966-80	120	66	36	21	18	11	8.6
148	Bluestone River near Spanishburg, W. Va.	1945-52	500	260	120	47	40	22	17
149	Bluestone River at Lilly, W. Va.	1909-16 1930-47	1100	500	190	75	59	28	19
150	New River at Bluestone Dam (near Hinton, W. Va.)	1924-49* 1950-80**	11,000 11,000	6500 6800	4000 4000	2700 2600	2400 2300	1600 1600	1300 1400
151	Greenbrier River at Marlinton, W. Va.	1910-16	1800	870	390	180	140	52	38
152	Greenbrier River at Alderson, W. Va.	1897-1980	4800	2300	950	410	320	150	110

* Regulated by Claytor Reservoir
** Regulated by Claytor and Bluestone Reservoirs

Mean Flow is a Function of Basin and Climate Characteristics and Streamflow Regulation

Streamflow distribution varies seasonally in response to precipitation and evapotranspiration. Mean-monthly streamflow is generally greatest in March and lowest in September or October. Regulation affects streamflow in major streams throughout the area.

Flow in unregulated streams varies with basin size and changes in precipitation and evapotranspiration. The hydrograph (fig. 4.2.5-1), illustrating seasonal streamflow variation for the Bluestone River near Pipestem (site 67) during the period of October 1, 1978 to September 30, 1979 is typical of an unregulated river in Area 10. The lowest monthly-mean flow for water year 1979 was 24.8 ft^3/s (cubic feet per second) during October 1978; the highest monthly-mean flow was 1,351 ft^3/s in February 1979.

Mean-monthly and mean-annual streamflow at any site also varies in response to seasonal precipitation and evapotranspiration.

The greatest mean-monthly flow usually occurs during March because of snowmelt, increased precipitation, and relatively low evapotranspiration. Streamflow during spring and early summer is usually high because of increased thunderstorm activity. Streamflow decreases during late summer and early fall because of evapotranspiration losses and reduced precipitation. During November-December, streamflow usually increases because evapotranspiration decreases and precipitation increases.

Mean-monthly and mean-annual streamflows for selected streams (fig. 4.2.5-2) are given in table 4.2.5-1. Regulation of the New River usually results in increased discharges at sites 2, 143, and 150 during dry periods. Mean-monthly flows of regulated streams are generally less variable than those of unregulated streams and do not reflect natural streamflow characteristics.

Regression equations useful for estimating the mean-annual flow at ungaged sites in West Virginia and Virginia were developed by Frye and Runner (1970) and Nuckels (1970), respectively. The equation for West Virginia is:

$$Qa = 0.576\, A^{1.01}\, F^{0.10}\, (P\text{-}20)^{0.83}\, T^{-0.93}\, Sn^{0.18}$$

standard error of estimate 8.7 percent (Frye and Runner, 1970) and the equation for Virginia is:

$$Qa = 0.0162\, A^{0.993}\, St^{-0.245}\, E^{0.489}\, F^{0.134}\, (P\text{-}20)^{1.101}$$

standard error of estimate 7.6 percent (E. H. Nuckels, 1970)

where: **Qa** is mean-annual flow, in cubic feet per second; **A** is drainage area, in square miles; **F** is forest cover, in percent of drainage area; **T** is mean-minimum January temperature, in °F; **Sn** is mean-annual snowfall, in inches; **St** is storage, in percent of drainage area + 1.0 percent; **E** is elevation above National Geodetic Vertical Datum of 1929, in thousands of feet; and **P** is mean annual precipitation, in inches (minus 20).

Average annual streamflow on New River between Glen Lyn and Bluestone Dam may be affected by channel losses as reported by Clark and others (1976). No estimate was made of the quantity or location of the losses.

A WRI (Water Resources Investigation) report now in press entitled "Techniques for Estimating Streamflow Characteristics in the Eastern and Interior Coal Provinces" will soon be available to predict streamflow characteristics for basins that cross State lines. Until the report is available, the user is instructed to use an averaging technique, if the basin is divided by a State line.

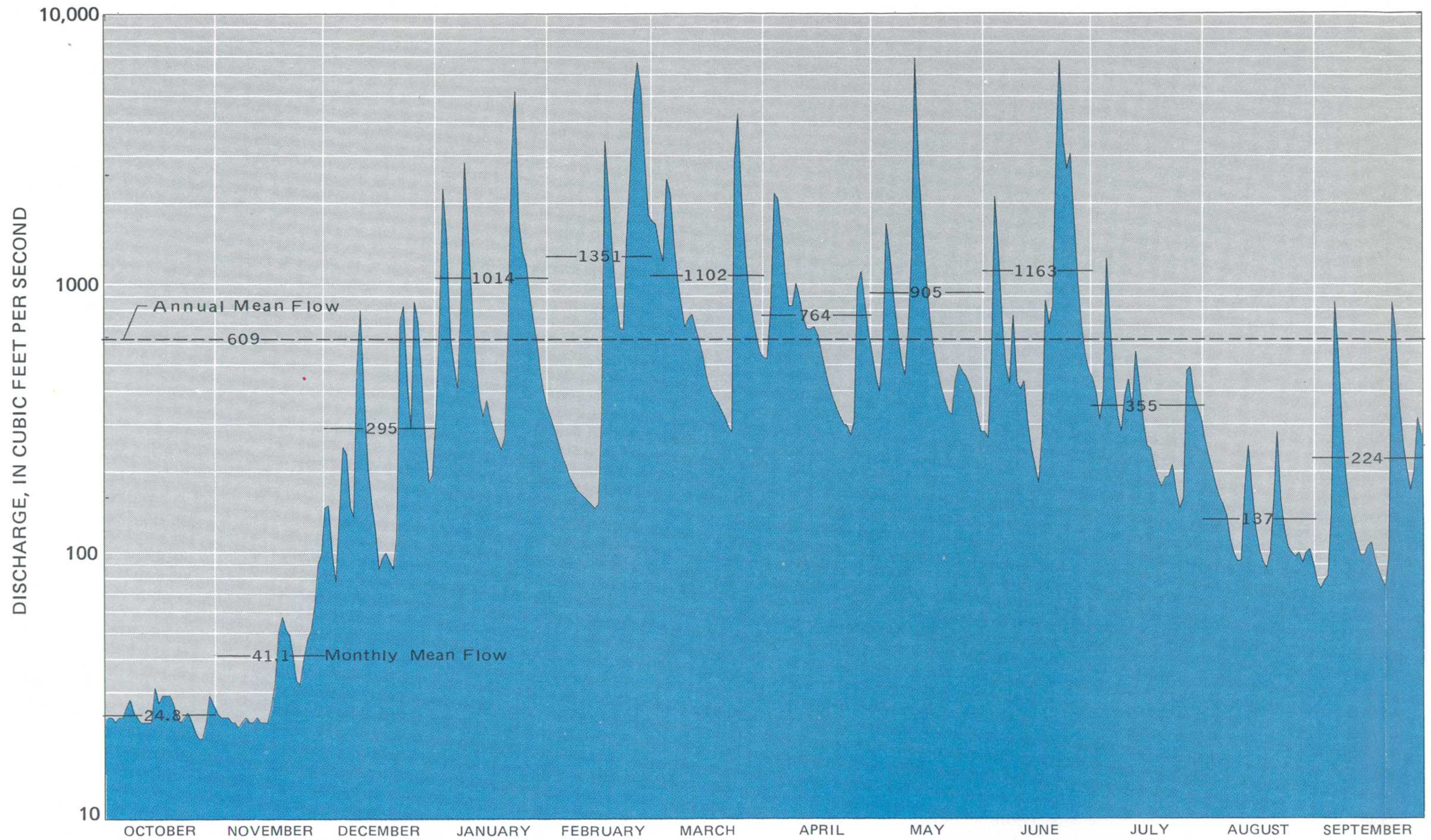


Figure 4.2.5-1 Daily hydrograph for Bluestone River near Pipestem, West Virginia.

Table 4.2.5-1 Mean annual and mean monthly streamflow for selected stations.

SITE NUMBER	PERIOD OF RECORD	STREAMFLOW, IN CUBIC FEET PER SECOND JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	MEAN ANNUAL FLOW
1	1942-51	60.5	76.8	80.7	46.0	37.9	23.7	12.5	22.8	10.5	8.79	17.0	48.0	36.8
2	1928-80*	6074	7075	8212	7283	5656	4268	3368	3371	3034	3557	3883	4741	5033
55	1947-72	68.9	91.3	108	74.5	56.0	20.1	12.1	7.25	4.31	6.51	20.5	52.3	43.3
67	1950-80	704	906	1136	830	610	267	153	119	91.7	158	255	516	477
83	1943-80	375	417	570	431	290	153	91.6	78.5	68.3	117	187	318	257
99	1968-77	7.3	9.17	9.43	8.40	5.50	2.95	1.75	1.31	1.25	3.48	4.73	8.95	5.37
104	1946-58	228	288	318	231	168	88.0	54.1	37.4	36.3	46.4	103	194	149
106	1930-80	1310	1495	1970	1390	1016	498	348	294	213	371	568	1058	875
115	1972-80	343	340	464	306	256	157	79.3	35.5	26.7	140	174	301	218
124	1946-74	107	158	201	134	99.8	43.7	22.9	15.2	12.5	26.1	41.1	87.7	78.7
134	1936-80	3443	4038	5186	3586	2661	1377	798	738	473	881	1277	2649	2254
137	1969-77	16.7	24.3	18.5	21.5	11.8	8.78	2.78	1.22	0.75	3.55	5.84	17.3	11.2
143	1915-76*	4826	5559	5905	5263	4303	3485	2989	2856	2513	2862	2907	3872	3937
144	1938-80	444	599	702	548	407	230	159	145	100	133	199	332	330
145	1909-80	448	551	658	486	361	196	149	123	75.2	113	168	314	302
146	1942-51	224	268	291	170	119	80.5	45.9	49.6	32.1	32.9	60.7	178	128
147	1966-80	80.8	92.0	99.4	84.5	71.0	38.5	28.2	24.8	21.6	32.8	41.2	57.6	55.9
148	1945-52	402	441	449	303	269	138	72.7	90.3	52.7	44.3	94.4	270	218
149	1908-48	856	904	1205	717	420	291	273	181	85.0	157	181	405	472
150	1924-49*	7634	8025	8684	7744	5911	4475	3927	4093	3410	3707	3949	5146	5548
	1950-80**	6626	8677	11,250	9214	6402	4398	3103	2768	2742	3660	4317	5564	5711
151	1909-16	1665	1353	1358	1177	696	639	361	215	171	447	448	689	770
152	1895-80	3105	3470	4576	3077	2308	1324	847	713	430	754	1203	2226	1998

* Regulated by Claytor Reservoir.
** Regulated by Claytor and Bluestone Reservoirs.

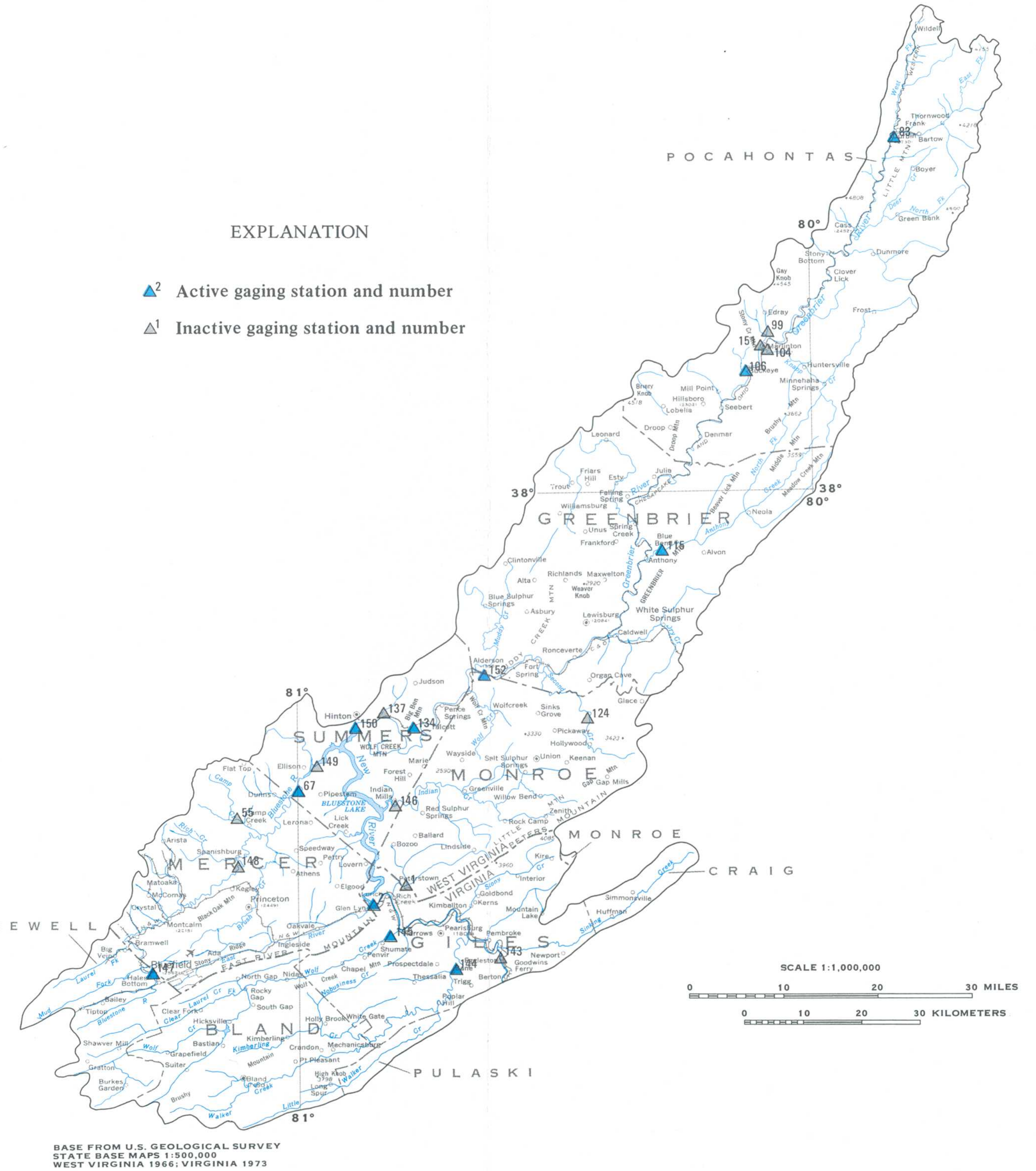


Figure 4.2.5-2 Location of selected gaging stations for mean flow determinations.

Water-Quality Investigations are Supported by Laboratory Analytical Services and a Quality Assurance Program

The U.S. Geological Survey uses field and laboratory analyses to describe water quality. Quality assurance is maintained by following set standards of technique. Data are stored in computer files for retrieval through WATSTORE and STORET.

Water quality is described by the U.S. Geological Survey using a variety of instruments and techniques. Parameters subject to rapid change after collection are measured on site by electrometric or physical methods as shown in table 4.3.1-1. Parameters determined on site include pH, specific conductance, water temperature, dissolved-oxygen concentration, alkalinity, acidity, and microbiological analyses such as fecal coliform and fecal streptococci density. Chemical methods are described in Skougstad and others (1979), Garbarino and Taylor (1979), and Fredericks (1968). Suspended-sediment methods are described by Guy (1969). Biological methods are described by Greeson and others (1977) and Greeson (1979). Table 4.3.1-1 is a listing of water-quality parameters which may be available at sites listed in section 7.0 and shown in figure 4.1-1. Not all parameters were determined at all stations.

Chemical determinations were performed for dissolved, suspended, and total-recoverable concentrations of constituents in water as well as total-recoverable concentrations of constituents in bottom material. The term "dissolved" refers to material that passes through a 0.45 μm (micrometer) pore size membrane filter. "Suspended" refers to that material which is retained by a 0.45 μm membrane filter. "Total recoverable" refers to the amount of a given constituent that is in solution after a representative water-suspended sediment sample has been digested by a method (usually using a dilute acid solution) that results in dissolution of only readily soluble substances (Skougstad and others, 1979). Major constituent (calcium, magnesium, sodium, potassium, chloride, sulfate, fluoride, and bicarbonate) concentrations were determined on the dissolved phase as were most trace-element concentrations. Dissolved and total recoverable concentrations of iron, manganese, and other selected constituents are also available.

Laboratory and field analyzed water-quality data are stored in WATSTORE and STORET computer files and can be retrieved through terminals having access to these files (see section 6.3 for information about WATSTORE).

Quality assurance of field and laboratory analytical results is maintained by a series of reference samples, analysis of replicate samples, and by review of analytical results. The quality-assurance program is maintained by a section of the U.S. Geological Survey water-quality laboratory in Denver and by individual district offices responsible for sample collection and field determinations.

Table 4.3.1-1 Field measurements and laboratory analyses used to describe water-quality conditions.

FIELD MEASUREMENTS	METHOD	REFERENCE	WATSTORE CODE
specific conductance	electrometric	Skougstad and others, 1979	00095
pH	do	do	00400
water temperature	thermometric or electrometric	do	00010
dissolved oxygen	electrometric, polarographic probe	do	00300
alkalinity	electrometric titration	do	00410
acidity	do	do	71825
total coliform	membrane filter	Greeson and others, 1977	31501
fecal coliform	do	Greeson, 1979	31625
fecal streptococci	do	do	31673
LABORATORY ANALYSES			
Major Ions (dissolved)			
calcium	atomic absorption spectrometric	Skougstad and others, 1979	00915
magnesium	do	do	00925
sodium	do	do	00930
potassium	do	do	00935
bicarbonate	normally calculated from field alkalinity	do	00440
carbonate	normally calculated from field alkalinity	do	00445
sulfate	automated colorimetric	do	00945
chloride	do	do	00940
silica	ICAP (inductively coupled argon plasma)	Garbarino and Taylor, 1979	00955
Minor Ions (dissolved)			
barium	ICAP	Garbarino and Taylor, 1979	01005
beryllium	do	do	01010
cadmium	do	do	01025
cobalt	do	do	01035
copper	do	do	01040
iron	atomic absorption spectrometric	Skougstad and others, 1979	01046
lead	ICAP	Garbarino and Taylor, 1979	01049
lithium	do	do	01130
manganese	atomic absorption spectrometric	Skougstad and others, 1979	01056
molybdenum	ICAP	Garbarino and Taylor, 1979	01060
strontium	do	do	01080
vanadium	do	do	01085
zinc	do	do	01090
Minor Elements In Water (total recoverable)			
iron	atomic absorption spectrometric	Skougstad and others, 1979	01045
manganese	do	do	01055
Minor Elements In Bottom Material (total recoverable)			
arsenic	atomic absorption spectrometric	Skougstad and others, 1979	01003
cadmium	do	do	01028
chromium	do	do	01029
cobalt	do	do	01038
copper	do	do	01043
iron	do	do	01170
lead	do	do	01052
manganese	do	do	01053
mercury	do	do	71921
selenium	do	do	01148
zinc	do	do	01093
Organic Constituents			
total organic carbon	carbon organic wet oxidation	Fredericks, 1968	00680
coal in bottom material	gravimetric	Skougstad and others, 1979	82031
Physical Properties of Water			
dissolved residue on evaporation at 180°C.	gravimetric	Skougstad and others, 1979	70300
suspended sediment	do	Guy, 1969	80154
turbidity	nephelometric	Skougstad and others, 1979	00076

Lithology, Land Use, and Precipitation were Major Influences on Specific Conductance of Surface Water

The specific conductance of most surface waters in the area ranged from about 100 to 300 micromhos per centimeter. Differing lithology, land use (particularly mining) and precipitation distribution were major factors influencing specific conductance.

Specific conductance is the ability of water to carry an electrical current and is reported in μmho/cm (micromhos per centimeter) at 25°C. Specific conductance is proportional to the quantity of ionized minerals in solution and is used as a general indicator of water-quality conditions.

Precipitation generally has a specific conductance of less than 50 μmho/cm. Duration and intensity of precipitation affect the specific conductance of surface water. In general, the specific conductance was lowest during periods of high flow and highest during periods of low flow. Streamflow during the sampling periods was mostly low to moderate. The lithology of rock outcrops, land use (particularly mining) and wastewater discharges all have an influence on specific conductance of surface water. Streams draining rocks such as silica cemented sandstone typically have very low specific conductance, whereas drainage from more soluble rocks such as limestone and dolomite usually have greater specific conductance. Wastewater discharges are another source of high specific-conductance water.

The specific conductance of surface water in the area ranged from 35 to 1,700 μmho/cm with most between 100 to 300 μmho/cm. The specific conductance of surface waters at sites sampled in the area is shown in figure 4.3.2-1. The Greenbrier River basin, which drains 49 percent of the area (1,647 mi^2), had specific conductance values ranging from 35 to 650 μmho/cm, reflecting differing lithology, land use, streamflow, and types of wastewater discharges in the basin. Specific conductance of streams in the Greenbrier River headwaters from Widell to Cass (sites 71 to 88) were generally less than 100 μmho/cm. Much of the area is underlain by sandstone and siltstone of the Chemung Group and Hampshire Formation of Devonian age which are well leached (Clark and others, 1976). Very little development has occurred in this area.

In the reach from Cass to Buckeye, specific conductance in the Greenbrier River indicates increased mineralization. The major tributary in this reach is Knapp Creek, which drains limestone outcrops east of the Greenbrier River.

In the reach from Buckeye to Caldwell, the major tributaries of the Greenbrier River are Anthony, Spring, and Howard Creeks. The median specific conductance of Anthony and Spring Creeks were 73 and 100 μmho/cm, respectively, but Howard Creek had a much higher specific conductance, 310 μmho/cm. Wastewater discharge from upstream municipalities was probably responsible for this increase in specific conductance.

From Caldwell to mouth, the Greenbrier River flows across massive limestone beds of the Greenbrier Group, and sandstone, shale, mudrock, and thin limestone lenses of the Pocono Group, and Maccrady, Bluefield, and Hinton Formations. The major tributary in this reach is Wolf Creek which had relatively high specific conductance water (greater than 240 μmho/cm).

Bluestone River, the second largest subbasin in the area (461 mi^2), is the only basin with coal mining. Specific conductance varied greatly, ranging from 43 to 1,700 μmho/cm. Surface and underground mining occur or have occurred in Mercer (West Virginia) and Tazewell (Virginia) Counties. Drainage from mining areas (sites 30 - 51) affects the specific conductance of surface water in the Bluestone River basin. Most mining has occurred near Crane, Flipping, and Widemouth Creeks. The specific conductance in surface water downstream from mining areas during 1972-1973 increased 2 to 10 times over unmined upstream areas (table 4.3.2-1). The increase in conductance was most pronounced in actively (1972-1973) mined areas during periods of high runoff (Clark and others, 1976). The specific conductance of surface water in unmined areas of the Bluestone River basin (sites 53 - 70) was generally less than 200 μmho/cm.

The East River drains an area near the West Virginia - Virginia boundary which is generally underlain by shale and sandstone of the Hinton, Princeton, and Bluestone Formations. Surface water in this area generally had a high specific conductance (greater than 300 μmho/cm) which Clark and others (1976) attributed to a combination of soluble geologic strata (Greenbrier Group limestone) and sewage effluent.

Specific conductance, because it is a measure of the ionic strength of the water, is often related to the dissolved-solids content. Figure 4.3.2-2 shows the relationship between specific conductance and dissolved solids at selected surface-water sites and can be used to estimate the dissolved-solids concentration when the specific conductance is known.

EXPLANATION

Specific conductance, in micromhos per centimeter

- △ Less than 100
- △ 100 - 199
- △ 200 - 299
- △ 300 - 399
- △ Greater than 400
- △2 Site and number

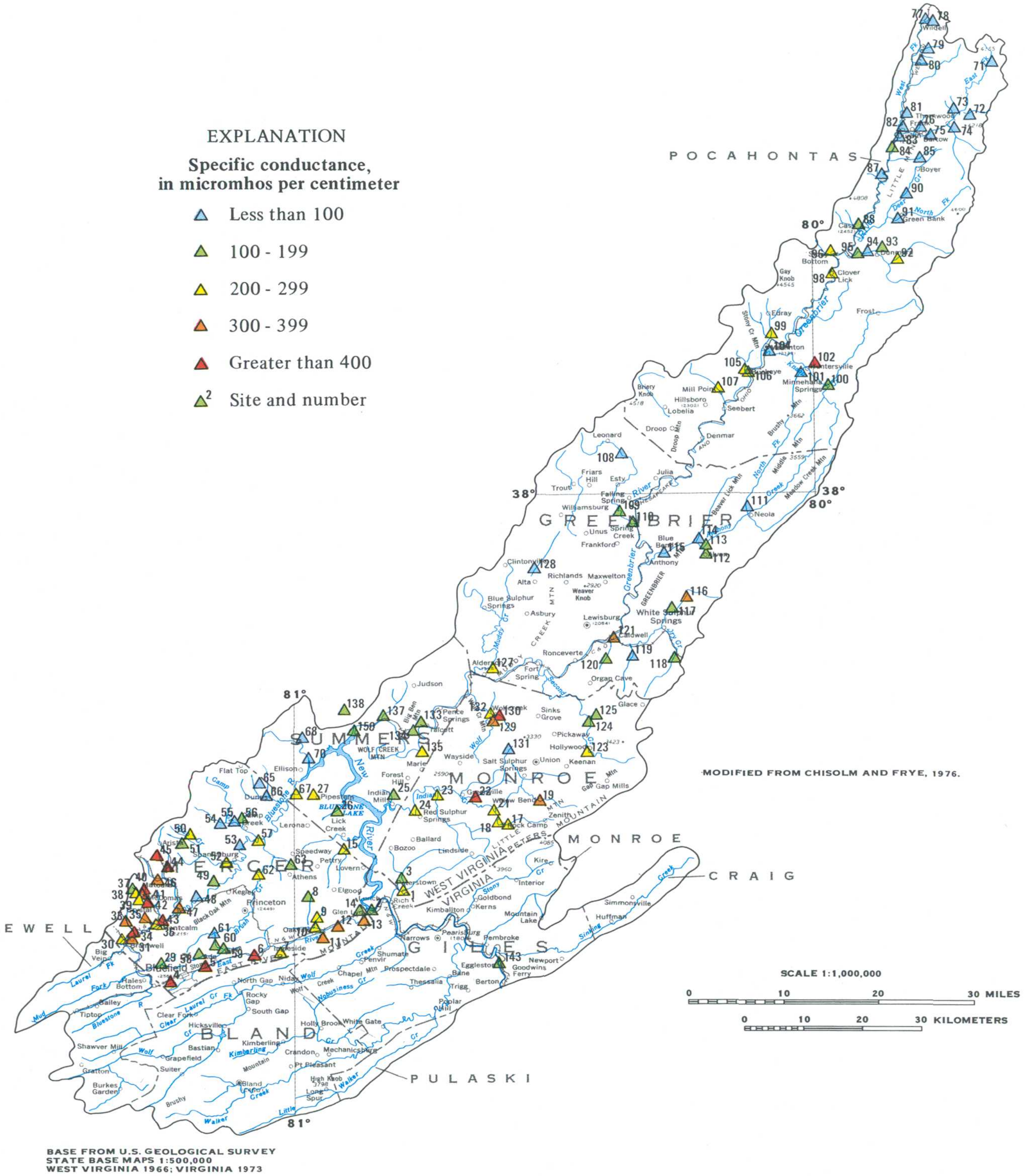


Figure 4.3.2-1 Specific conductance at surface-water sites.

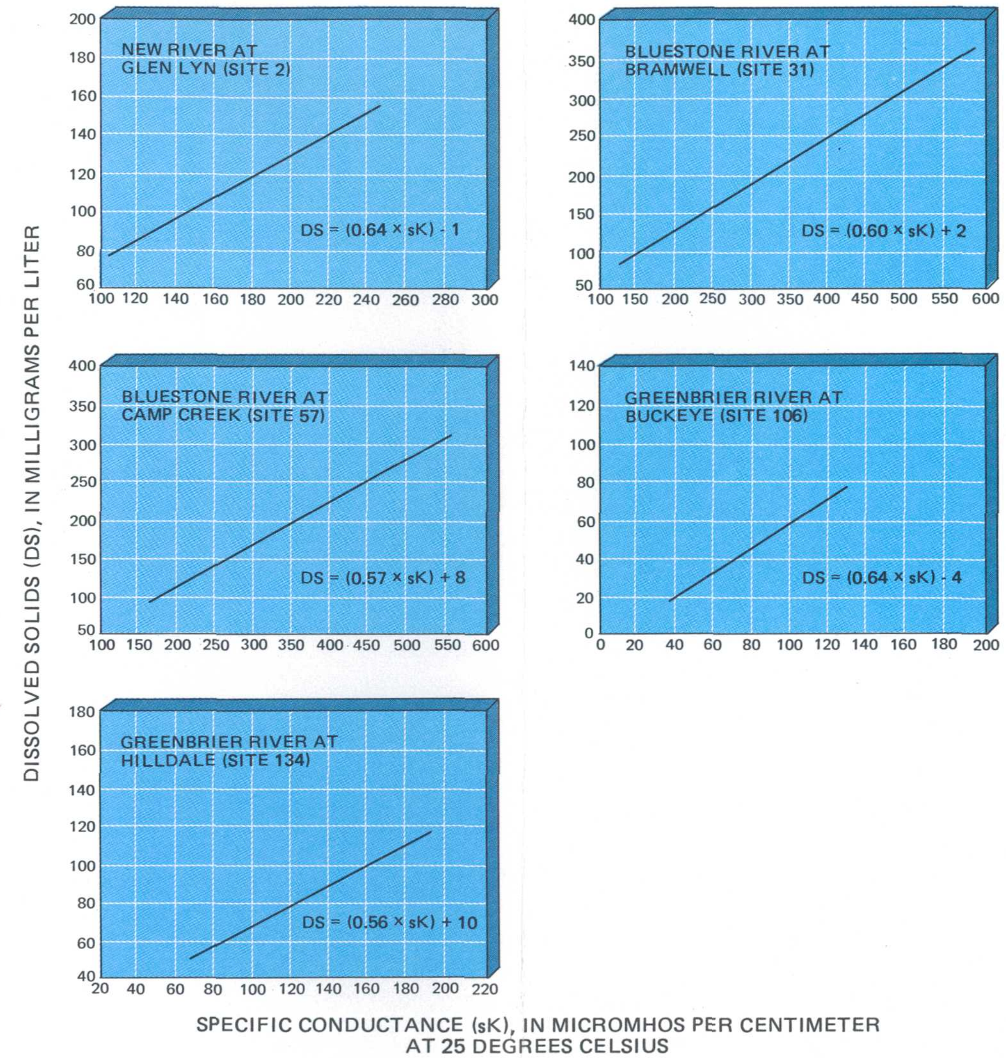


Figure 4.3.2-2 Relation between specific conductance and dissolved solids at selected sites, (modified from Clark and others, 1976).

Table 4.3.2-1 Specific conductance of selected streams upstream and downstream from coal-mining areas in Mercer County, West Virginia.

STREAM	SAMPLE DATE	FLOW	SPECIFIC CONDUCTANCE IN μMHOS/CM ABOVE MINING	BELOW MINING
Tolliver Branch	8/72	low	130	240
	1/73	high	120	1700
West Fork Crane Creek	8/72	low	160	210
	1/73	high	140	610
East Fork Crane Creek	8/72	low	128	600
	1/73	high	95	470
Flipping Creek	8/72	low	110	360
	1/73	high	90	220

Modified from Clark and others, 1976

Surface Water pH is Primarily Alkaline

The pH of water is largely controlled by the mineralogy of sedimentary rocks in the area. The most widespread rocks are limestones of the Greenbrier Group, which are alkaline in solution.

pH is an expression of the hydrogen ion (H^+) activity in water. The pH is expressed as the negative base 10 logarithm of the hydrogen-ion activity in moles (M) per liter. Thus a solution with (H^+) of 1×10^{-7}M has a pH of 7. The pH can have any value from 0 to 14 with values less than 7 being acidic and values over 7.0 being alkaline. A value of 7.0 indicates neutral pH. The pH of water is influenced by the solution of gases and minerals. Precipitation usually is acidic because of the solution of atmospheric carbon dioxide (CO_2) and emissions from the combustion of fossil fuels, principally sulfur dioxide (SO_2) and oxides of nitrogen. The solution of carbonates such as limestone ($CaCO_3$) in surface and ground water raises the pH to alkaline levels (pH >7.0). The occurrence of extensive limestone outcrops within the area is the most important influence on the pH of water in the area and results in the predominance of alkaline conditions in streams nearly everywhere.

Limestone rocks of Mississippian, Devonian, and older ages, interbedded with calcareous shale, siltstone, and sandstone have been described in the area (Hare, 1939). The most extensive limestone outcrops belong to the Greenbrier Group of Mississippian age (fig. 4.3.3-1). Limestone areas are discussed in greater detail in section 2.7, and by Hare (1939), Haught (1968), Jones (1973), Clark and others (1976), McCue, Lucke, and Woodward (1939), and Rauch and Werner (1974). Water coming into contact with limestone dissolves the rock, causing the pH of the water to become alkaline as follows:

$$CaCO_3 + H_2O \rightleftharpoons Ca^{+2} + HCO_3^- + OH^-$$

and

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3$$

The pH of surface water in the area ranged from 6.5 to 9.2, with most between 7.1 and 8.2. The pH of surface water at selected sites in the area is shown in figure 4.3.3-1. The Greenbrier River subbasin, which drains much of the area (1,647 mi^2), had pH values that ranged from 6.7 to 9.0, reflecting widely differing geology within the basin. The pH of surface water in the West Fork of the Greenbrier River was generally near neutral or slightly alkaline, whereas the East Fork Greenbrier River (sites 71 - 76) was more strongly alkaline. The East Fork Greenbrier River is underlain by the Chemung Group, a marine sandstone and siltstone of Devonian age. From Durbin to Cass, the Greenbrier River receives flow from western tributaries which drain limestone outcrop areas. From Cass to Buckeye, drainage to the Greenbrier River reflects greater exposure to Greenbrier limestone and tends also to be alkaline. In the reach from Buckeye to Caldwell, the Greenbrier River receives drainage from western tributaries, and drainage from Anthony and Howard Creeks, which drain outcrops of the Brallier Formation, Millboro Shale, and Oriskany Sandstone to the east, which tend to be alkaline. From Caldwell to mouth, the Greenbrier River flows across limestone of the Greenbrier Group and sandstone of the Bluefield Formation. The pH of surface water in this reach was generally in the range of 7.5 - 7.8.

Bluestone River, the second largest subbasin in the area (461 mi^2), is the only basin with extensive coal mining. The pH of surface water varied widely, ranging from 5.4 to 10.0. Surface and underground coal mining have occurred in Mercer and Tazewell Counties. Drainage from these mining areas (sites 30 - 51) affects the pH of surface water. According to Clark and others (1976), the pH of Widemouth Creek, which drains surface-mined areas, ranged from 7.3 to 10.0, while nearby streams draining unmined areas had less alkaline (pH 7.1 - 8.0) water. The area is underlain by limestone, siltstone, and shale rocks. Surface mining operations probably results in greater exposure of rocks in spoil to weathering, and hence higher pH of surface drainage from spoil areas. In active underground mines the coating of mine surfaces with powdered limestone (rock dust) to reduce the likelihood of dust explosions, can increase the pH of underground mine drainage.

Wolf Creek and the East River drain areas near the West Virginia-Virginia boundary underlain primarily by shales and sandstone of the Hinton, Princeton, and Bluestone Formations of Mississippian age. Surface water draining these areas is generally slightly alkaline, with pH ranging from 7.1 to 7.8. Sites 1 through 8 largely drain outcrops of the Hinton Formation and tend to be very alkaline with pH values exceeding 7.9.

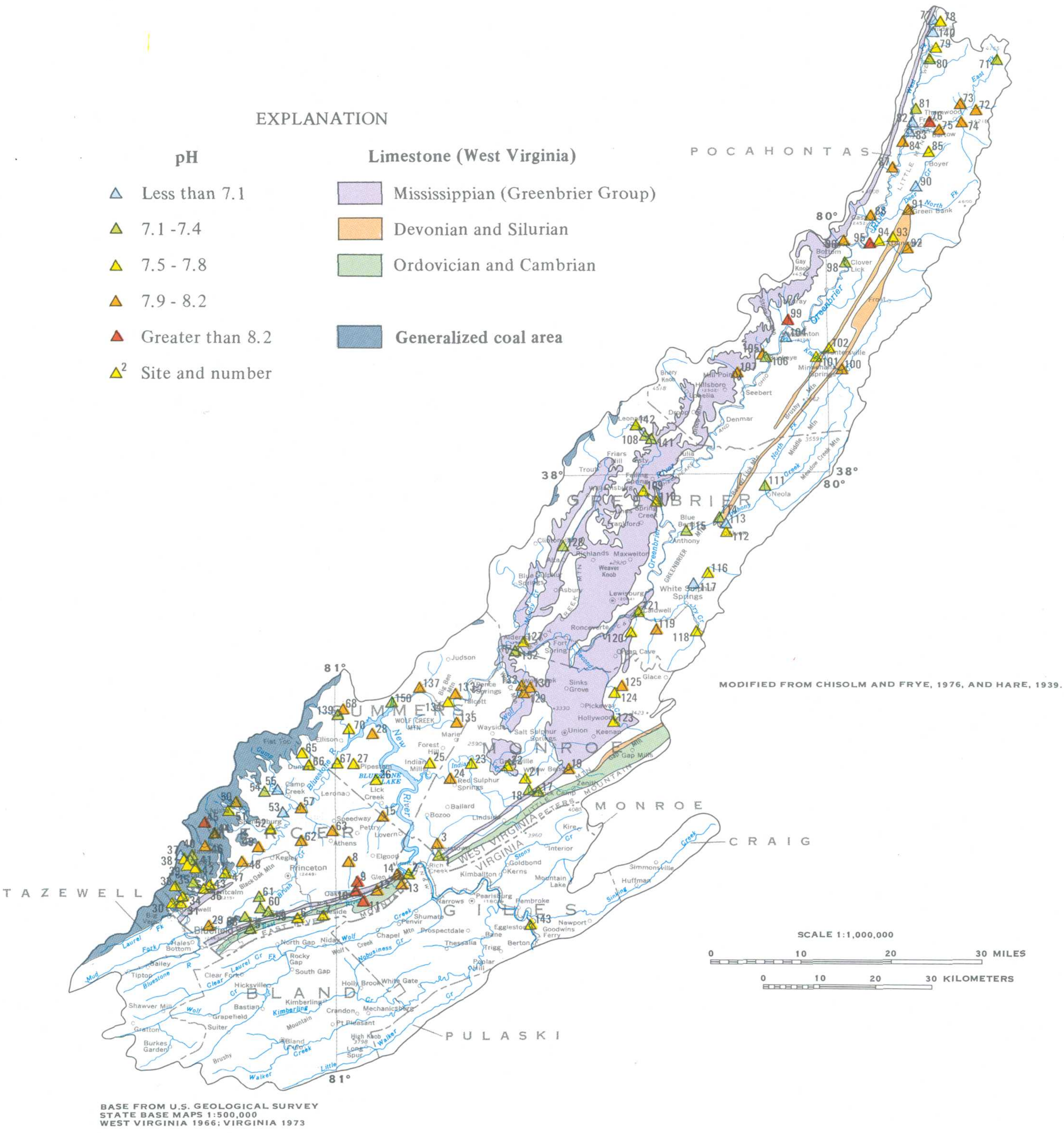


Figure 4.3.3-1 pH at surface-water sites and major limestone areas.

Alkalinity Exceeded Acidity Everywhere in the Area

Alkalinity was influenced by extensive limestone outcrops in the area. The alkalinity of surface water in the upper Greenbrier River basin was generally less than 50 milligrams per liter and generally ranged from 30 to 150 milligrams per liter in the Bluestone River.

Alkalinity is the ability of water to resist pH change brought about by addition of strong acid and is a measure of the buffering capacity of water. Alkalinity is due to the presence of carbonate, bicarbonate, and hydroxyl ions. Surface water in the area varied widely in alkalinity content. Rainfall has very little or no alkalinity, typically less than 1 mg/L (milligram per liter), while surface waters draining undisturbed parts of Area 10 generally have alkalinity values less than 50 mg/L. Ground water generally has higher alkalinities because of its greater bicarbonate concentration. The lithology of an area has an important bearing on the alkalinity of surface and ground water. Bicarbonate, carbonate, and hydroxyl ions in water result from the solution of limestone in shallow geological strata as follows:

$$CaCO_3 \text{ (limestone)} + H_2O \rightleftharpoons Ca^{+2} + HCO_3^- + OH^-$$

and

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3$$

Any land disturbance, such as surface coal mining and quarrying, which results in exposure of limestone-containing rocks, can influence the alkalinity of surface water, if suitable reclamation is not followed.

Acidity is defined as "the quantitative capacity of an aqueous media to react with hydroxyl ions" (American Society for Testing and Materials, 1979) and is expressed in mg/L as hydrogen ion (H^+). Acidity is an important parameter to measure in areas affected by surface coal mining, because when present in significant quantities, it indicates that oxidizable sulfur compounds are present and will adversely affect the quality of water if suitable reclamation is not followed.

The alkalinity of surface water in the Greenbrier River basin, which drains much of the area (1,647 mi^2), ranged from 6 to 160 mg/L, and had a median of 38 mg/L. Alkalinity concentrations for selected sites in Area 10 are shown in figure 4.3.4-1. In general, alkalinity was lowest, 7-20 mg/L, in the basin headwaters. Alkalinity values in the upper Greenbrier River probably reflect the lesser extent of the limestone of the Greenbrier Group. The alkalinity of surface water in the lower Greenbrier River basin generally ranged from 50 to 150 mg/L. Surface waters in the lower Greenbrier River basin drain large limestone outcrop areas of the Greenbrier Group, particularly from Lewisburg to Hilldale, and tend to have high alkalinity. For example, the Greenbrier River at Alderson (site 152) had a median alkalinity of 50 mg/L in comparison to 25 mg/L at Buckeye (site 106).

Acidity at nine sites in the Greenbrier River basin (sites 77, 83, 90, 106, 121, 134, 140, 141, and 142) ranged from 0 to 8.9 mg/L. The median was 1.2 mg/L, indicating that acidity probably is not a major problem in the basin. No coal mining occurs in this basin because it lies outside the coal-bearing areas in Area 10 (fig. 4.3.4-1).

Bluestone River, the second largest basin in the area (461 mi^2), is the only basin having significant coal mining in Area 10. The alkalinity of surface water varied widely, ranging from 7.0 to 221 mg/L. The median was 52 mg/L. Most values of alkalinity were between 30 and 150 mg/L. Sites 30 - 51 lie within or immediately downstream from coal-bearing areas and have widely differing alkalinity. For example, Big Branch at Piedmont (site 45) had a median alkalinity of 221 mg/L compared to 82 mg/L at site 47. The large difference probably reflects differing lithology. Site 45 drains outcrops of the New River and Pocahontas Formations (Pottsville Group) while site 47 drains outcrops of the same and outcrops of the Bluestone and Princeton Formations (Mauch Chunk Group). Differing mining and reclamation techniques can also affect the alkalinity of any surface drainage. For example, if significant quantities of limestone are exposed during surface mining, weathering can result in high alkalinity content of any surface drainage. In addition, the sulfur content of the coal in Area 10 is very low, generally less than 1.5 percent (Barlow, 1974). The sulfur content in coal and in overburden mainly determine the acidity (largely H_2SO_4, sulfuric acid) of drainage from coal-mining areas. Acidity at 7 sites in the Bluestone River basin (sites 31, 47, 52, 54, 55, 67, and 139) ranged from 0.4 to 1.25 mg/L, and had a median of 1.2 mg/L. Acidity is considered to be a problem when it exceeds the total alkalinity. Therefore, acidity is probably not a significant problem in the Bluestone River basin.

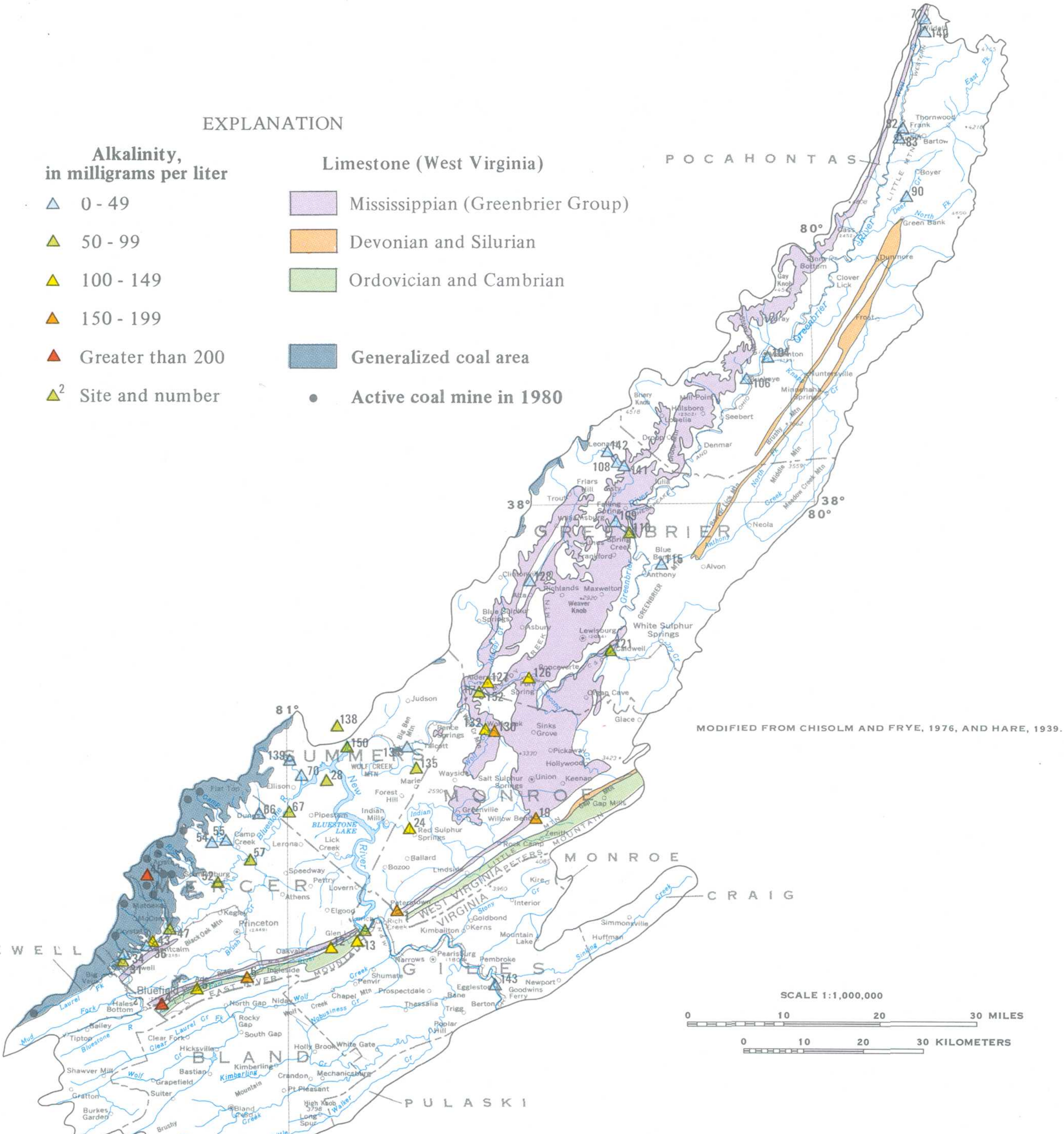


Figure 4.3.4-1 Alkalinity at surface-water sites and major limestone areas.

Sulfate Concentrations were Highest Near Mined Areas

The concentration of sulfate in streams draining the Greenbrier River basin was generally less than 10 milligrams per liter. Sulfate concentrations were highest in streams draining coal-mine areas in the headwaters of the Bluestone River basin.

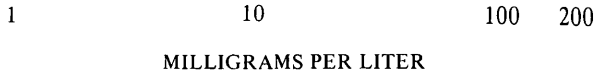
Sulfate is frequently used as an indicator of coal mining because it is usually the dominant anion in drainage from mined areas. Because concentrations of sulfate exceeding 250 mg/L (milligrams per liter) have a laxative effect, the recommended limit in drinking water is 250 mg/L (U.S. Environmental Protection Agency, 1979). Sulfur occurs in coal and in overburden as metal sulfides, largely in the form of pyrite (FeS_2) and marcasite. Oxidation of pyrite by air, water, and autotrophic bacteria, principally *Thiobacillus*, yields sulfate, hydrogen ion (H^+), and iron as follows:

$$FeS_2 + H_2O + 7/2\,O_2 \xrightarrow{\text{bacteria}} Fe^{+2} + 2H^+ + 2SO_4^{-2}$$

The solution of gypsum ($CaSO_4$) is another source of sulfate but is probably of lesser importance than the oxidation of pyrite in Area 10. Precipitation is a minor source of sulfate in most areas. Typically, precipitation in the area contains 3 to 8 mg/L sulfate.

The median concentration of sulfate in streams draining the Greenbrier River basin, the largest basin in the area (1,647 mi^2), was 8.4 mg/L and ranged from 3.7 to 130 mg/L. In general, sulfate concentrations were lowest in the basin headwaters, 4 to 7 mg/L. Sulfate concentrations at selected sites are shown in figure 4.3.5-1. The low sulfate concentration in the basin headwaters probably reflects the limited availability of sulfides in rocks which underlie the area. Limestone quarrying occurs in the Greenbrier River basin but no coal is mined there. Browns Creek (site 102), which drains Devonian shales near Marlinton, contained water having a high sulfate concentration (130 mg/L). Other streams with sulfate concentrations exceeding 30 mg/L include Stamping and Howard Creeks (sites 107 and 121). Clark and others (1976) attributed the relatively high sulfate concentration in these streams to inflow from springs which drain shales of Devonian and Mississippian age.

Bluestone River, the second largest basin (461 mi^2), is the largest basin having significant coal mining in Area 10. Surface and underground mining occur in the Bluestone River basin headwaters in Mercer (West Virginia) and Tazewell (Virginia) Counties. The sulfate concentration in streams draining these areas ranged from 4.8 to 150 mg/L, and had a median of 14 mg/L. Sites 30-51 lie either within or immediately downstream from coal-mining areas and were affected by mining. Other sites in the Bluestone River basin were considered to be unaffected by mining. The sulfate concentrations in streams draining mined and unmined areas were compared statistically to determine if differences existed between affected and unaffected sites.



The results of analysis of variance (ANOVA) indicate that significant differences in mean concentration of sulfate exist between affected and unaffected sites at the .05 level. The mean sulfate concentration (59 mg/L) and the range (4.8 to 150 mg/L) were significantly greater for the affected sites (sites 30-51) than the mean (8.7 mg/L) and the range (5.8 to 23 mg/L) for the unaffected sites. Similar results have been reported for streams affected by coal mine drainage in Illinois by Toler (1980). Differences between affected and unaffected sites probably reflect the increased exposure of pyrite in the mined area. Sulfate concentrations in the East River generally ranged from 10 to 30 mg/L.

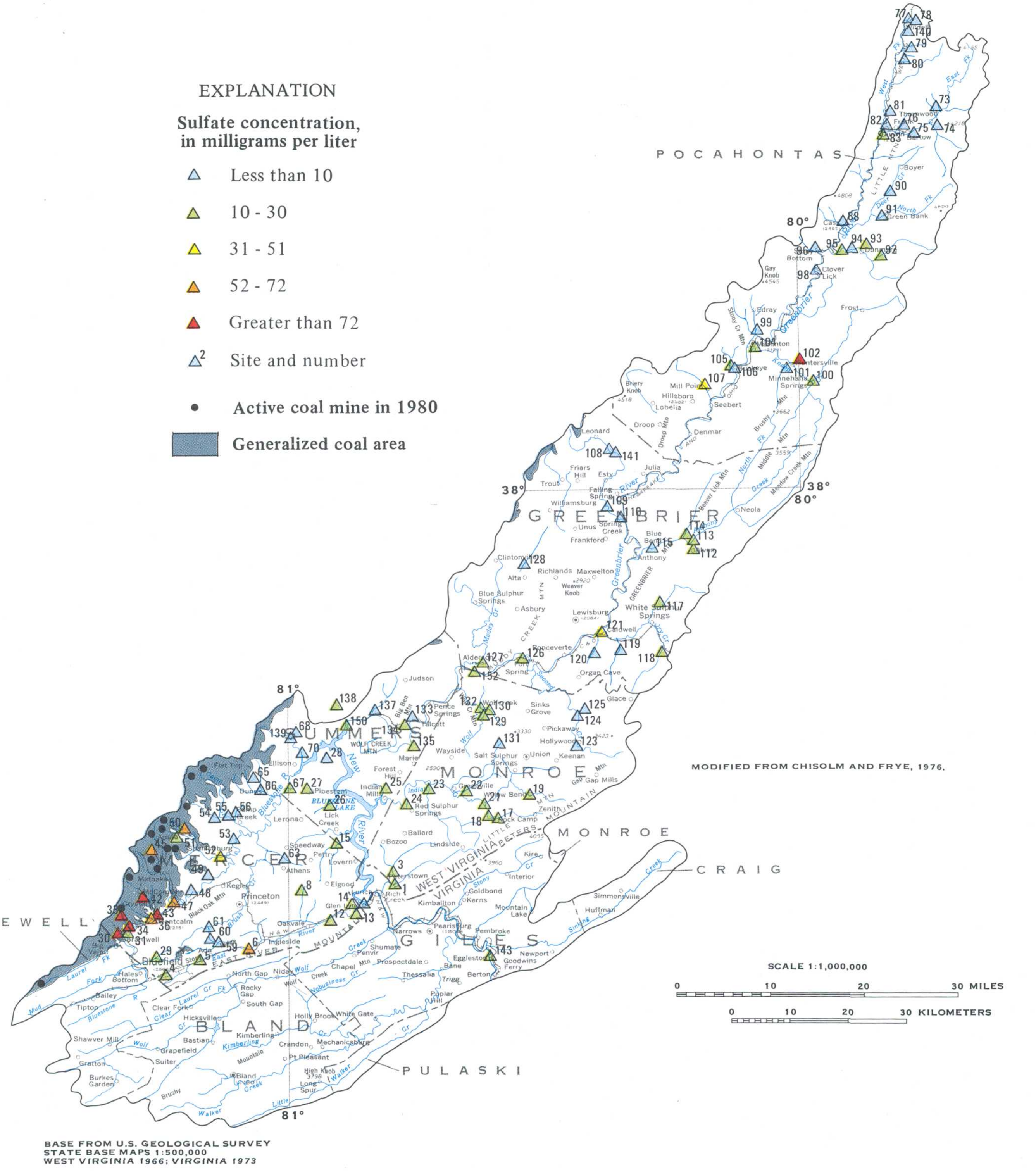


Figure 4.3.5-1 Sulfate concentration at surface-water sites.

Highest Iron Concentrations Occurred in the Bluestone River Basin

Total iron concentrations were generally lowest in streams draining the Greenbrier River basin, and highest in the Bluestone River basin. The mean concentration of total iron at sites affected by coal mining in the Bluestone River basin was not significantly different from the mean concentration at unaffected sites.

Iron is a common trace element in surface and ground water throughout the area. High concentrations can add a disagreeable taste to the water and can also clog pipes and stain fixtures. Excessive concentrations affect fish and other aquatic life. The recommended maximum concentration of iron in drinking water is 300 μg/L (micrograms per liter) (U.S. Environmental Protection Agency, 1979). Present West Virginia water-quality standards for trout streams permit a maximum of 500 μg/L total iron (sum of dissolved and suspended concentrations), while all other streams are permitted a maximum of 1,000 μg/L. A more detailed description of the West Virginia water-quality standards is available from the West Virginia State Water Resources Board (West Virginia State Water Resources Board, 1980).

Iron is abundant in the sedimentary rocks underlying Area 10 and occurs mainly as pyrite (FeS_2), and siderite ($FeCO_3$). Weathering of rock outcrops containing these minerals probably accounts for much of the iron in surface water. Because drainage from coal mines and spoil piles often contain excessive concentrations of iron (Martin and others, 1980, Helgesen and Razem, 1980, Gale and others, 1976), iron is required to be monitored under NPDES (National Pollution Discharge Elimination System) regulations.

The concentration of total iron in streams throughout the area ranged from 10 to 1,928 μg/L. The total iron concentration at selected sites in Area 10 is shown in figure 4.3.6-1. The Greenbrier River basin, which includes much (1,647 mi^2) of the area, had total iron concentrations that ranged from 20 to 1,100 μg/L. The median concentration was 140 μg/L. The West Fork Greenbrier River and tributaries (sites 77, 78, 79, 80, 81, 82, and 140) generally had total iron concentrations exceeding 400 μg/L. This area is mostly underlain by shale and sandstone of the Pocono Group and Hampshire Formation which contain high iron concentrations (Clark and others, 1976). The East Fork Greenbrier River and tributaries (sites 71 - 76) generally contained less than 250 μg/L total iron. This area is mostly underlain by siltstone, sandstone, and shale of the Chemung Group which is well leached. From Durbin to the mouth of the Greenbrier River, most surface water contained less than 250 μg/L total iron, reflecting the generally low suspended-sediment concentration, lithology, and high pH of drainage from the Greenbrier Group, which underlies much of the basin.

Surface water in the Bluestone River Basin, the second largest subbasin in the area (461 mi^2), contained higher total iron concentrations than did the Greenbrier River. The median was 445 μg/L and the range was from 10 to 1,928 μg/L. Surface and underground coal mining have occurred in the Bluestone River basin, chiefly in the basin headwaters in Tazewell and Mercer Counties. Sites 30-51 lie within or adjacent to coal-mining areas and were affected by mining. Other sites in the Bluestone River basin were considered to be unaffected by coal-mine drainage. The total-iron concentrations of each group were compared statistically to determine if differences existed between affected and unaffected groups. The results of analysis of variance tests (ANOVA) indicate the means of each group were not significantly different (.05 level of significance) from each other. Mining probably influences the total iron concentration of surface water in the Bluestone River basin less than other factors. The relatively high pH (7.6 median) of streams and the low suspended-sediment concentration in most waters probably are major factors. The solubility of iron decreases with increasing pH, thus iron is much less soluble in alkaline than in acidic water. Studies have shown that the majority of iron transport occurs in association with suspended sediment (Ehlke and others, 1981 a, b, and Feltz, 1980). Thus, dissolved and total iron concentrations in surface water are low when the water is alkaline and contains little suspended sediment.

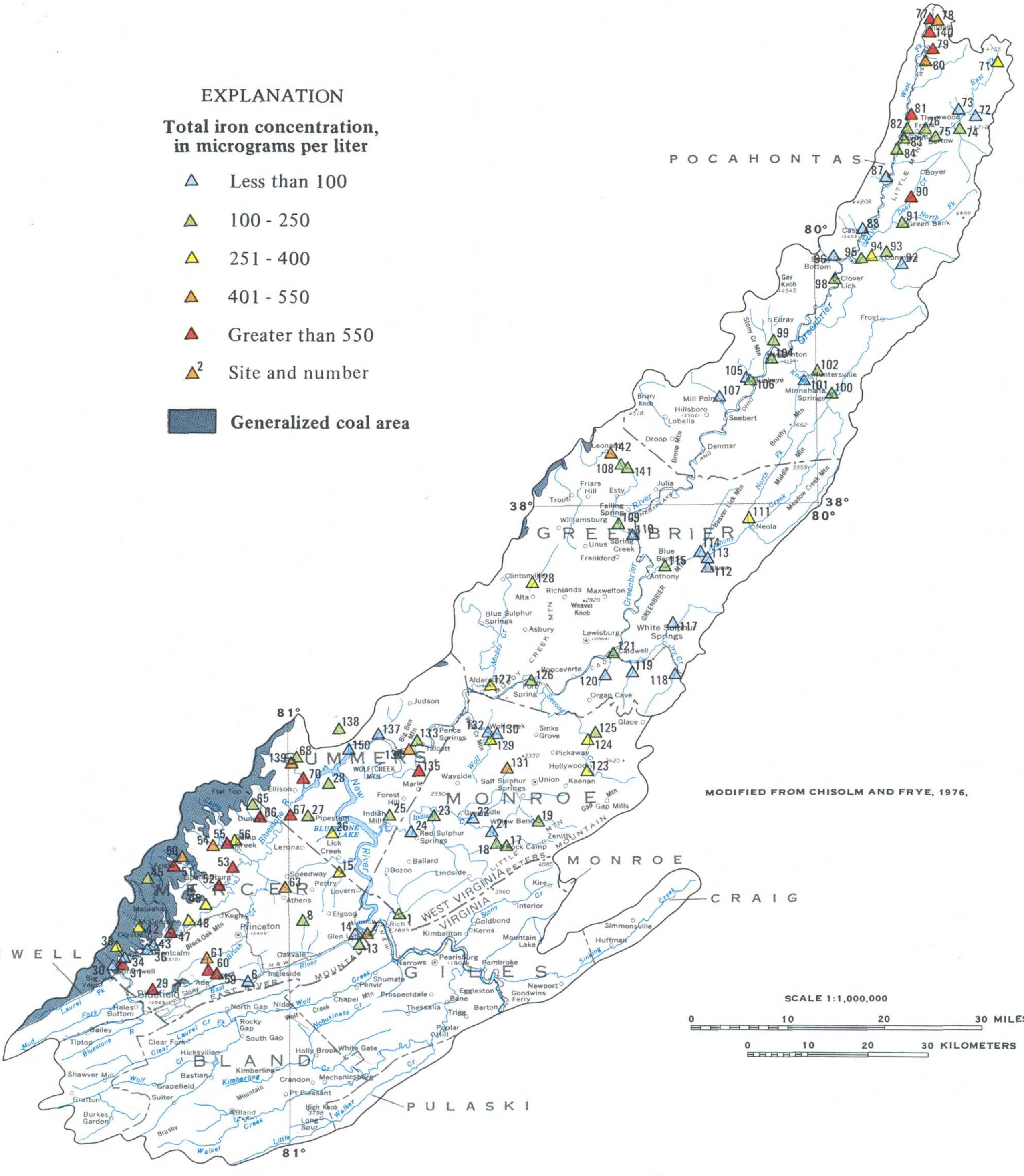


Figure 4.3.6-1 Total iron concentration at surface-water sites.

Highest Manganese Concentrations were Found in the Bluestone River Basin

The lowest total manganese concentrations were found in streams draining the Greenbrier River basin, generally less than 1 microgram per liter. Streams in the Bluestone River basin generally contained higher concentrations of total manganese (median 70 micrograms per liter).

Manganese is a trace element which is widely distributed in waters throughout the area. Dissolved concentrations exceeding 50 μg/L (micrograms per liter) impart a disagreeable taste to water and stain fixtures. The maximum recommended concentration of manganese in drinking water is 50 μg/L (micrograms per liter) (U.S. Environmental Protection Agency, 1979). A limit of 1,000 μg/L has been recommended for all streams in the area (West Virginia Water Resources Board, 1980). Surface waters, except in the Bluestone River basin, generally contained less than 50 μg/L total manganese.

Manganese occurs in the rocks as oxide (MnO_2), hydroxide [$Mn(OH)_2$] forms, and rhodochrosite ($MnCO_3$) (Hem, 1970). Manganese enters surface water by the weathering of these minerals and is also often present in high concentrations in leachate from coal mines. Anderson and Youngstrom (1976) reported that the mean concentration of manganese in coal-pile drainage could be as high as 17,000 μg/L. James W. Borchers, 1981 (written communication) reported that the mean concentration of dissolved manganese in drainage from 22 mines in the Guyandotte River basin in West Virginia was 1,300 μg/L.

The concentration of total manganese in streams draining the Greenbrier River basin, the largest basin in the area (1,647 mi^2), was generally less than 1 μg/L and ranged from 0 to 90 μg/L. Nearly all surface water contained less than 30 μg/L total manganese. The West Fork Greenbrier River headwaters (sites 77, 78, and 140) which are underlain by shales and sandstone of the Pocono Group and Hampshire Formation, contained higher total manganese concentrations, 60 to 90 μg/L. Total manganese concentrations at selected sites are shown in figure 4.3.7-1.

Surface water in the Bluestone River basin, the second largest basin in the area (461 mi^2), generally contained much higher total manganese concentrations than did the Greenbrier River. The median was 70 μg/L and ranged from 0 to 1,300 μg/L. Surface and underground mining have occurred in the Bluestone River basin, chiefly in the basin headwaters in Mercer (West Virginia) and Tazewell (Virginia) Counties. The general extent of the coal-bearing areas is shown in figure 4.3.7-1. Sites 30-51 lie within or adjacent to coal-mining areas and were affected by mining. Other sites in the Bluestone River basin were considered to be unaffected by coal-mine drainage. The total manganese concentrations of each group were compared statistically to determine if differences existed between affected and unaffected groups. The results of analysis of variance tests (ANOVA) indicate that the means of each group were not significantly different at the .05 level.

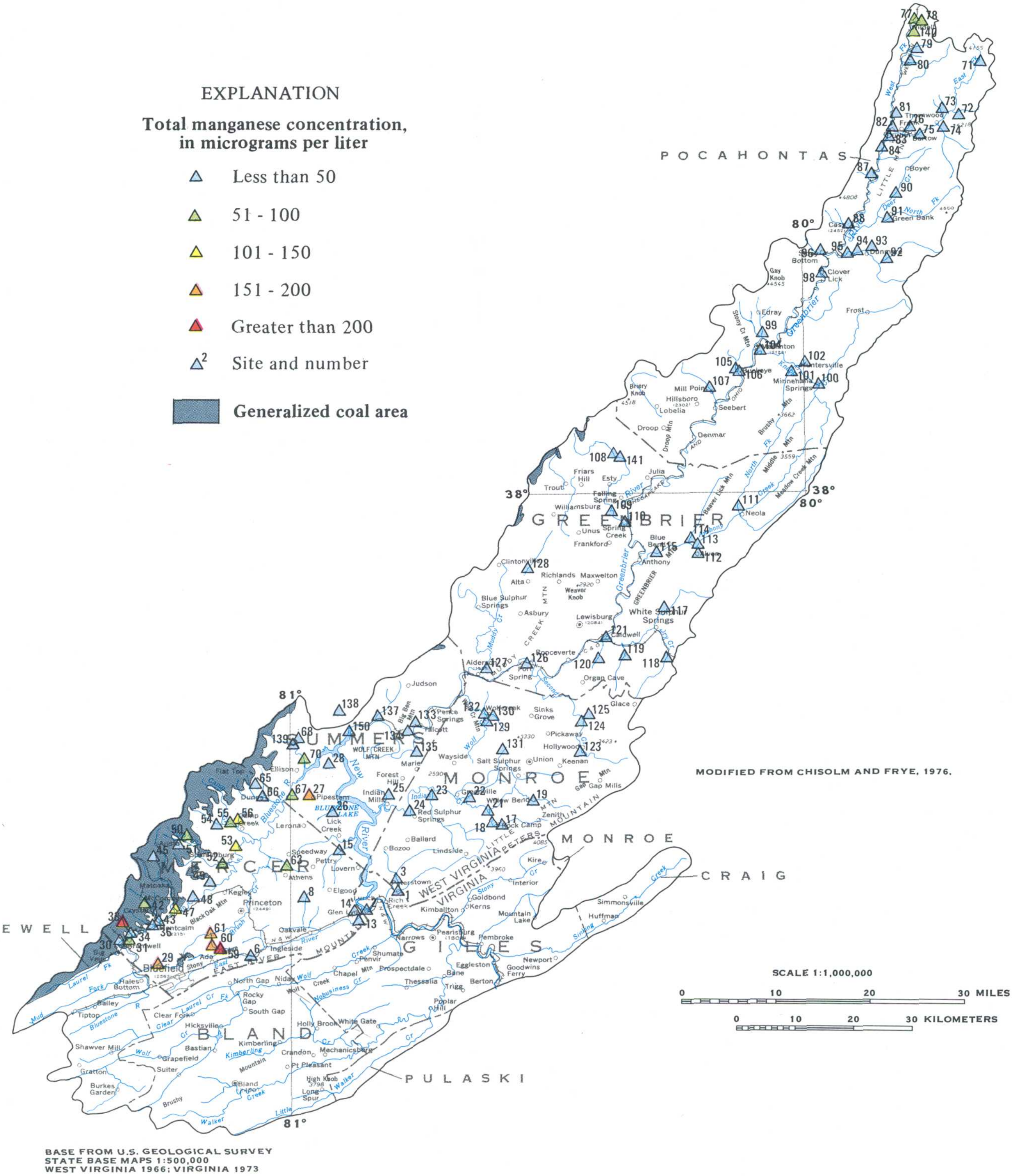


Figure 4.3.7-1 Concentration of total manganese at surface-water sites.

Sediment Yields Ranged from 0 to 8.86 Tons per Day per Square Mile

Sediment yields from selected streams in Area 10 were relatively low and ranged from 0 to 8.86 tons per day per square mile. The majority of suspended-sediment discharge occurred during periods of high flow.

Average suspended-sediment concentrations of selected streams draining Area 10 were very low and ranged from 0 to 480 mg/L. Sediment yields ranged from 0 to 8.86 [(tons/day)/mi^2] (tons per day per square mile). Differences in topography, land use, and streamflow characteristics in the area affect suspended-sediment yields. Most of the area is characterized by hilly terrain with moderate to steep slopes and easily erodible soil. These characteristics produce rapid runoff with high erosion potential. Most of the area, however, has dense forest or pasture cover that generally lowers runoff velocities and thus decreases the influence of topography on erosion and sediment yields. Agricultural and forested lands make up 97 percent of the land use in Area 10 (see section 2.5).

Land-use activities such as forest clearing, silviculture, road construction, and quarrying drastically alter natural sediment yields. Eckhardt (1976) reported that highway construction contributed as much as 66,000 [(tons/mi^2)/yr] of sediment. Limestone quarrying has been reported to produce more than 5,000 tons per square mile of sediment per year (Gammon 1968). The Bluestone basin has the greatest amount of surface and deep mining. During August 1980, instantaneous sediment concentrations of 229 and 166 mg/L were observed at sites 47 and 55 respectively. During this period an average of 1.94 inches of precipitation occurred at nearby national weather service stations and produced sediment yields of 9.7 and 8.8 [(tons/day)/mi^2]. The lowest yield was .02 [(tons/day)/mi^2], observed at site 52.

Suspended-sediment concentration ranges, loads, and drainage areas for selected sites in Area 10 are given in table 4.3.8-1. The sites are primarily underlain by indurated rocks (sandstone, siltstone, and limestone) of Pennsylvanian, Mississippian, and Devonian age. Most of the suspended-sediment loads were generally transported during high-flow periods.

Suspended-sediment yield curves for selected streams (sites 121, 134, and 2) are shown in figure 4.3.8-1. The location of these sites is shown in figure 4.3.8.2. Sites 121 and 134 have similar upstream overland slopes, land use (97 percent agriculture and forest use), and sediment yield. Average annual suspended-sediment yields for these sites are shown in table 4.3.8-1. Particle-size distribution of suspended-sediment transported during high flows at site 2 are predominantly in the silt and clay range (finer than 0.062 mm). The particle-size distribution for this site averaged 86 percent silt and clay and ranged from 50 to 100 percent finer than 0.062 mm, by dry weight, while the sand fraction ranged from 0 to 50 percent.

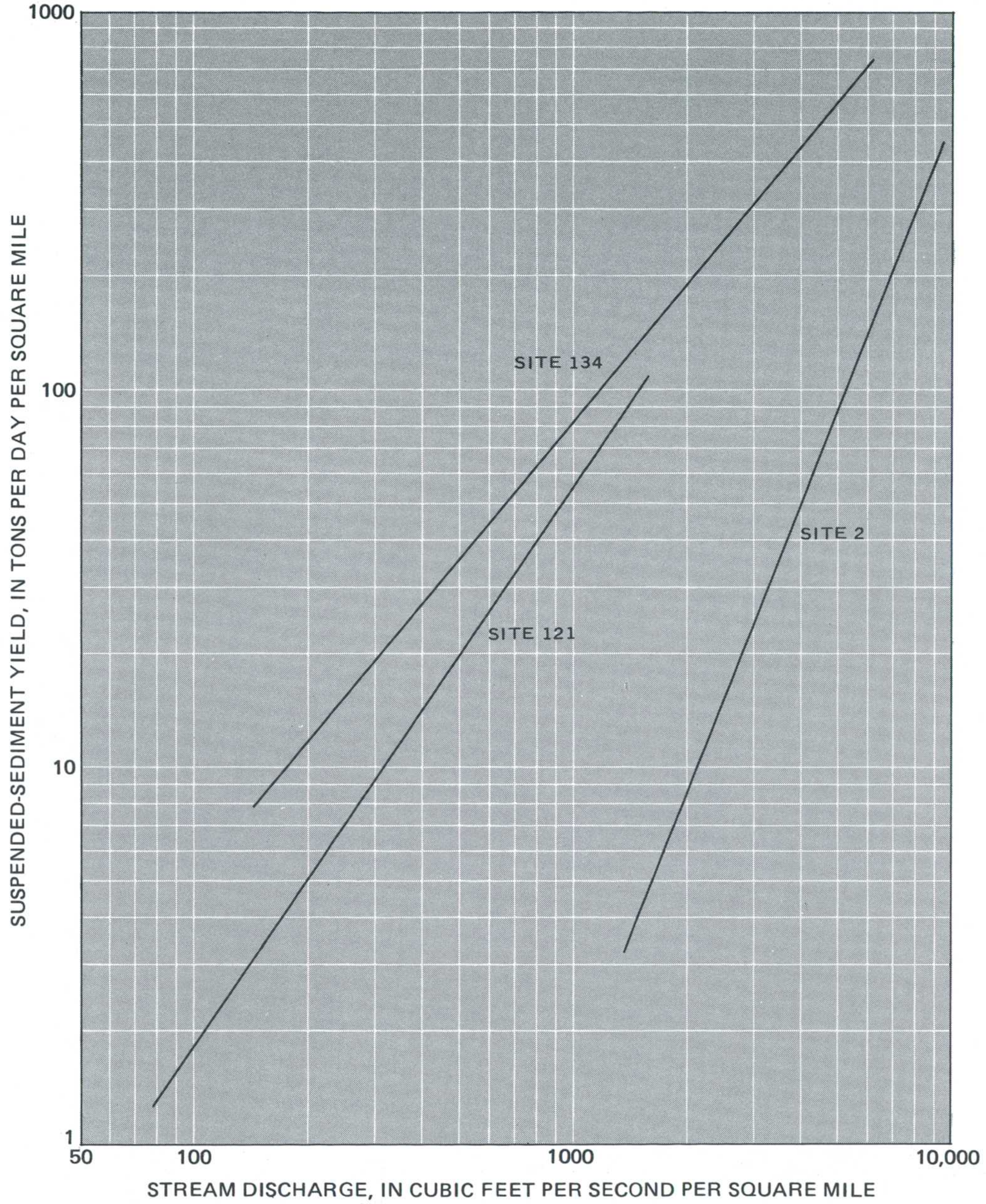


Figure 4.3.8-1 Relation between stream discharge and suspended-sediment yield.

Table 4.3.8-1 Summary of suspended sediment at selected sites.

SITE NUMBER	STATION NAME	DRAINAGE AREA (MI²)	PERIOD OF SEDIMENT RECORD	RANGE OF INSTANTANEOUS SUSPENDED-SEDIMENT CONCENTRATION (MG/L)	MAXIMUM SUSPENDED-SEDIMENT LOAD (TONS/DAY)	MAXIMUM SUSPENDED-SEDIMENT YIELD [(TONS/DAY)/MI²]	PERIOD OF SURFACE-WATER RECORD (YEARS)	ESTIMATED AVERAGE ANNUAL SEDIMENT YIELD (TONS/MI²/YR)
2	New River at Glen Lyn, VA	3768	1978-81	0-98	3600	1.06	1929-80	30
121	Howard Creek at Caldwell, WV	84.4	1973-77	0-126	260	3.58	1971-78	20
134	Greenbrier River at Hillsdale, WV	1625	1967-74	0-480	14,400	8.86	1937-80	60

Figure 4.3.8-2 Selected suspended-sediment sites.

Fractures are Major Openings for Accumulation and Movement of Ground Water

Fracture zones on anticlines, stress-relief fractures in valleys, and solution channels in karst areas are the major openings for accumulation and movement of ground water in Area 10.

Ground water in Area 10 is mainly derived from precipitation, chiefly in the form of rain. On steep hillsides the amount of water that runs off is large compared to the amount that infiltrates the ground. When water infiltrates, a part is retained at shallow depth as soil moisture (later to be available for withdrawal by transpiration or evaporation), and a part moves downward to the zone of saturation. Locally, perched water bodies exist above the zone of saturation. They may be found above nearly impermeable rock layers which impede the downward percolation of water (fig. 5.1-1). Where the zone of saturation is overlain by permeable rocks that allow water from precipitation to enter directly by downward percolation, unconfined or water-table conditions exist. Where water-bearing zones lie between or beneath relatively impermeable rock, so that the water is confined under pressure, artesian conditions exist.

Two types of rock openings are of principal importance for the storage and circulation of ground water -- intergranular openings and fractures. Intergranular openings or pores are generally of primary origin, having been formed when the rocks were deposited as sediment. In Area 10, compaction and cementation with mineral matter have nearly eliminated connected pores in consolidated rocks. Although unconsolidated alluvium along major streams has been only slightly affected by compaction and cementation, it has such low permeability that it is effectively a confining layer in many parts of the area (Wyrick and Borchers, 1981).

Rock fractures such as faults and joints are cracks caused by rock deformation after deposition and consolidation and, hence, are of secondary origin. Faults are fractures along which rocks have moved, and there are several faults in the southern part of the area. Joints are breaks in the rock cutting across the bedding and along which virtually no movement has occurred. They are sets of approximately parallel linear cracks spaced several inches to many feet apart. In Area 10, fractures are the major openings for accumulation and movement of water.

The rocks in the area are fractured extensively on anticlines, because of tension during folding. Synclines, on the other hand, are under compression, so fractures there are generally tightly closed. Fracture zones on the anticlines are probably among the more significant water-bearing zones in Area 10. For example, according to Bader and others (1976), the flow of Rock Creek in another basin, the Coal River basin, doubled after crossing the axis of the Warfield anticline when measured on October 3, 1974.

Another probable cause of fractures in the area is the unloading effect (stress relief) caused by erosion of the valleys as described by Wyrick and Borchers (1981). Fracturing caused by unloading is local and confined to the valley sides and bottom. It significantly affects the occurrence and movement of ground water in those areas.

In parts of the basin where thick limestone units occur close to land surface, solution openings have developed along bedding planes or fractures (karst areas). They are developed when water of low pH percolates through fractures and dissolves the limestone. Some of them have become large caves and many are interconnected by passages large enough to divert substantial streamflow from the surface. Although many of the openings are not as large as caves, they are still capable of transmitting large volumes of water. Karst areas contain many stream reaches in which water is lost to caves and many springs from which the "lost" flow returns to the land surface.

Topography has a bearing on the location of successful water wells in the area. The water table is generally shaped like the topography (fig. 5.1-1); that is, the altitude of the water table is highest under hills and lowest in valleys. However, the section of unsaturated rock on the hill is generally thicker, necessitating a deeper well. By contrast, a valley well typically penetrates a thinner unsaturated section and has a static water level closer to land surface.

The dewatering of mined areas generally causes a decline in water level in some areas. Sometimes the decline is permanent and at other times the water level recovers when mining ceases.

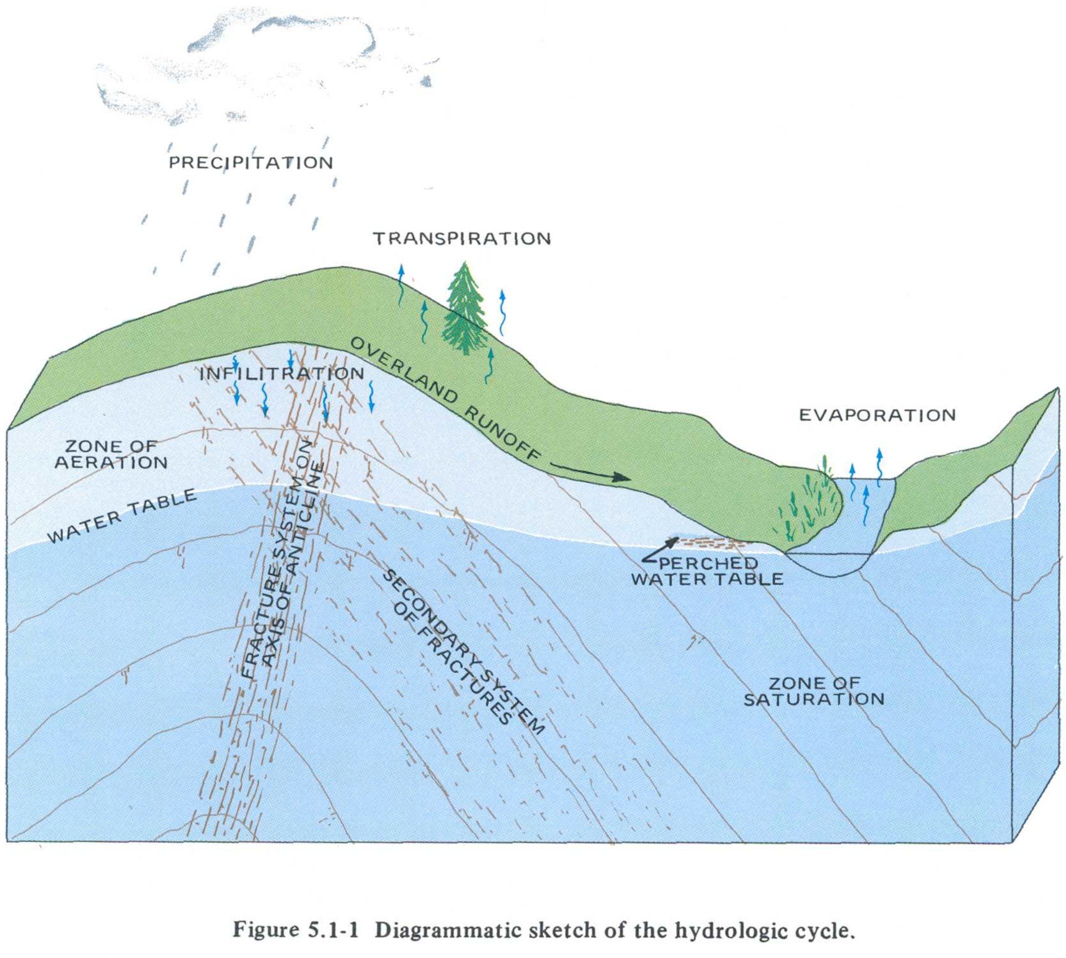


Figure 5.1-1 Diagrammatic sketch of the hydrologic cycle.

Yield of Wells Ranges from 1 to 400 Gallons per Minute

The factors most affecting well yield in Area 10 include well depth, topography, geologic unit, and geologic structure.

The yield of more than 200 wells in the basin was measured or reported and is included in the well-data tabulation in Chisholm and Frye (1976). Well yield ranged from 1 to 400 gal/min (gallons per minute), and averaged 38 gal/min.

Well yield varied with geologic unit, most of which would supply adequate water for domestic and small public-supply demands. However, the topographic setting of the well site was more significant than the geologic unit, and tended to overshadow the variation of yield between the geologic units.

Specific capacity is a useful method of comparing well yields. It is defined as the ratio of the discharge of a well to the drawdown of the water level in the well. Specific-capacity data of wells in an area may be compared against those in other areas by the use of specific-capacity-frequency curves. Differences in the shape, slope, and relative position between the curves indicate variations in the yield of the wells being analyzed. For instance, the curve for a group of wells yielding more water will plot higher on the graph than the curve for a group of wells yielding less water. Also, the curves may be used to compare the variability of well yield. The steeper the slope of the curve, the greater the variability of the yield of wells in the group.

The specific-capacity-frequency curves shown in figure 5.2-1 indicate the well yield in the area increases with well depth. Comparison between specific-capacity-frequency curves for valley wells with a depth of more than 100 feet and wells less than 100 feet (fig. 5.2-1) indicates that 50 percent of the deeper wells have a specific capacity of at least 780 (ft^3/d)/ft (cubic feet per day per foot) [4.1(gal/min)/ft] (gallons per minute per foot) compared to at least 300 (ft^3/day)/ft [1.5(gal/min)/ft] for wells less than 100 feet.

Topographic setting is an important factor affecting well yield. Wells in valleys generally yield about twice as much water as wells on hillsides and several times as much as wells on hilltops. As shown in figure 5.2-2, 50 percent of the wells in valleys have a specific capacity of at least 130 (ft^3/d)/ft [0.65 (gal/min)/ft], 50 percent of wells on hillsides have a specific capacity of at least 65 (ft^3/d)/ft [0.34 (gal/min)/ft], and 50 percent of wells on hilltops have a specific capacity of at least 2.5 (ft^3/d)/ft [0.0013 (gal/min)/ft]. Yield of wells in valleys is greater than wells located on hillsides or hilltops because rocks in valleys tend to be more fractured and more water for recharging the rock fractures is available in valleys than in upland areas.

Similarly, the geologic structure at the well site has an important effect on the yield of the well. Wells located near the axis of an anticline generally yield more water than wells located near the axis of a syncline. For instance, Clark and others (1976) reported 50 percent of wells near the axes of anticlines in the area have a specific capacity that equals or exceeds 120 (ft^3/d)/ft [0.62 (gal/min)/ft], whereas wells located near the axes of synclines have a specific capacity that equals or exceeds 47 (ft^3/d)/ft [0.24 (gal/min)/ft]. Figure 5.2-3 shows specific-capacity-frequency curves of wells in three structural settings: wells near the axes of anticlines, wells near the axes of synclines, and wells about midway between the axes anticlines and synclines.

The data used in constructing the specific capacity frequency curves shown in figure 5.2-1 are from wells drilled primarily for domestic water supplies. The specific capacities (yield/drawdown) used in preparing the graphs were calculated from reported yields, water levels, and drawdown, supplemented by estimated minimum specific capacities. The minimum specific-capacity data were estimated for wells having both acceptable yield and water-level data (but no drawdown) by assuming drawdown to the bottom of the well for the given yield. The estimated minimum specific capacities were adjusted to reported specific capacities on the basis of comparisons with reported specific capacity frequency curves using data from the same wells.

The analyses discussed above are described in greater detail in Clark and others (1976), and the data are published in Chisholm and Frye (1976).

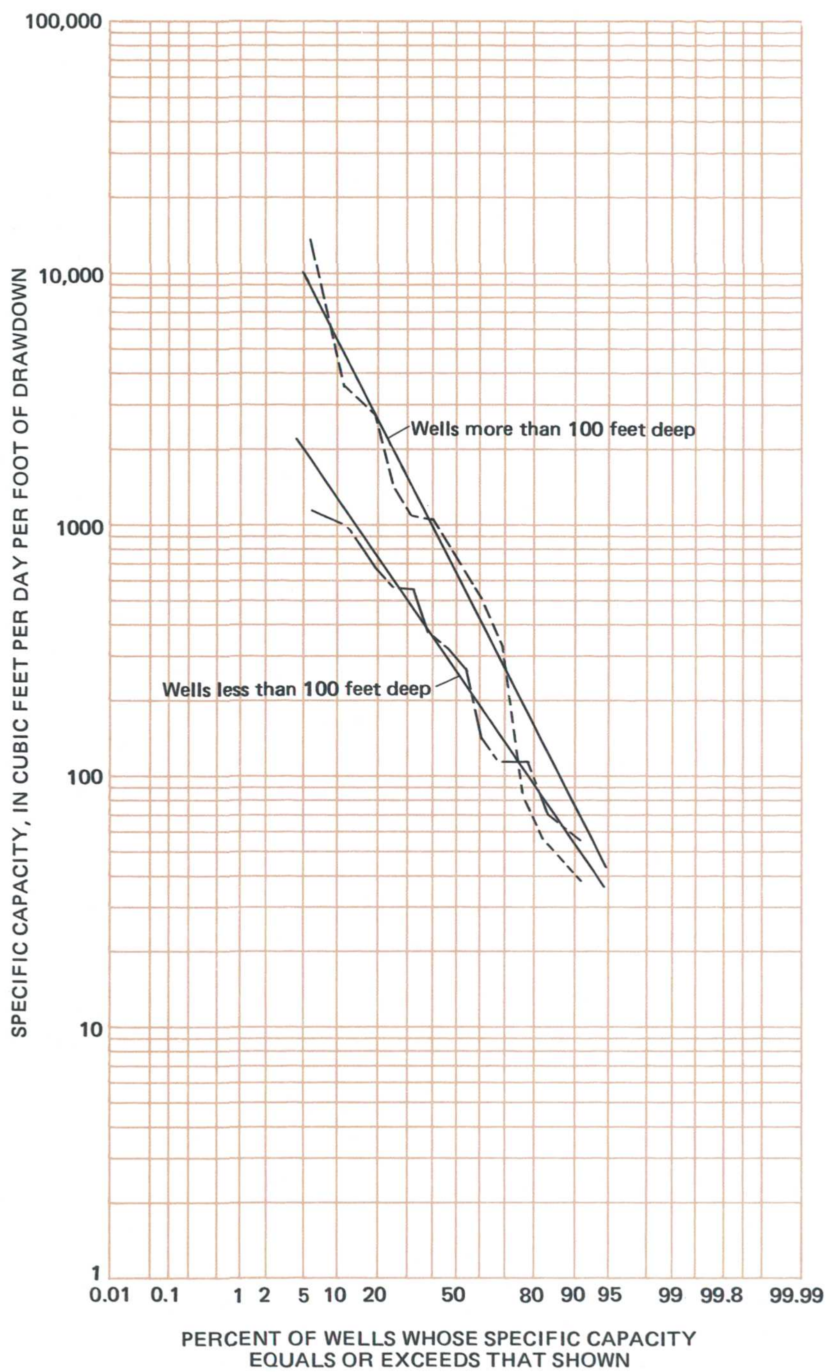


Figure 5.2-1 Specific-capacity-frequency curves for valley wells (modified from Clark and others, 1976).

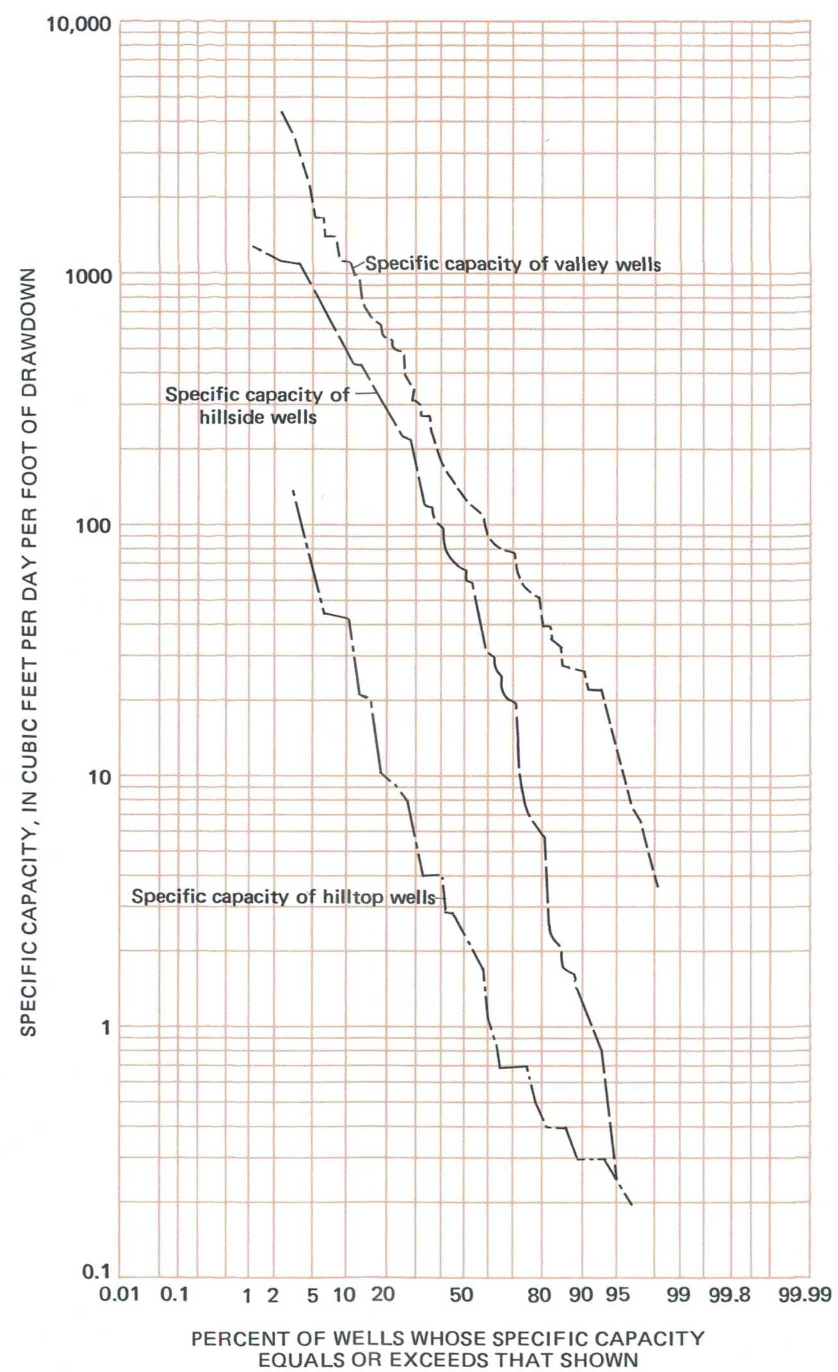


Figure 5.2-2 Specific-capacity-frequency curves for valley, hillside, and hilltop wells (modified from Clark and others, 1976).

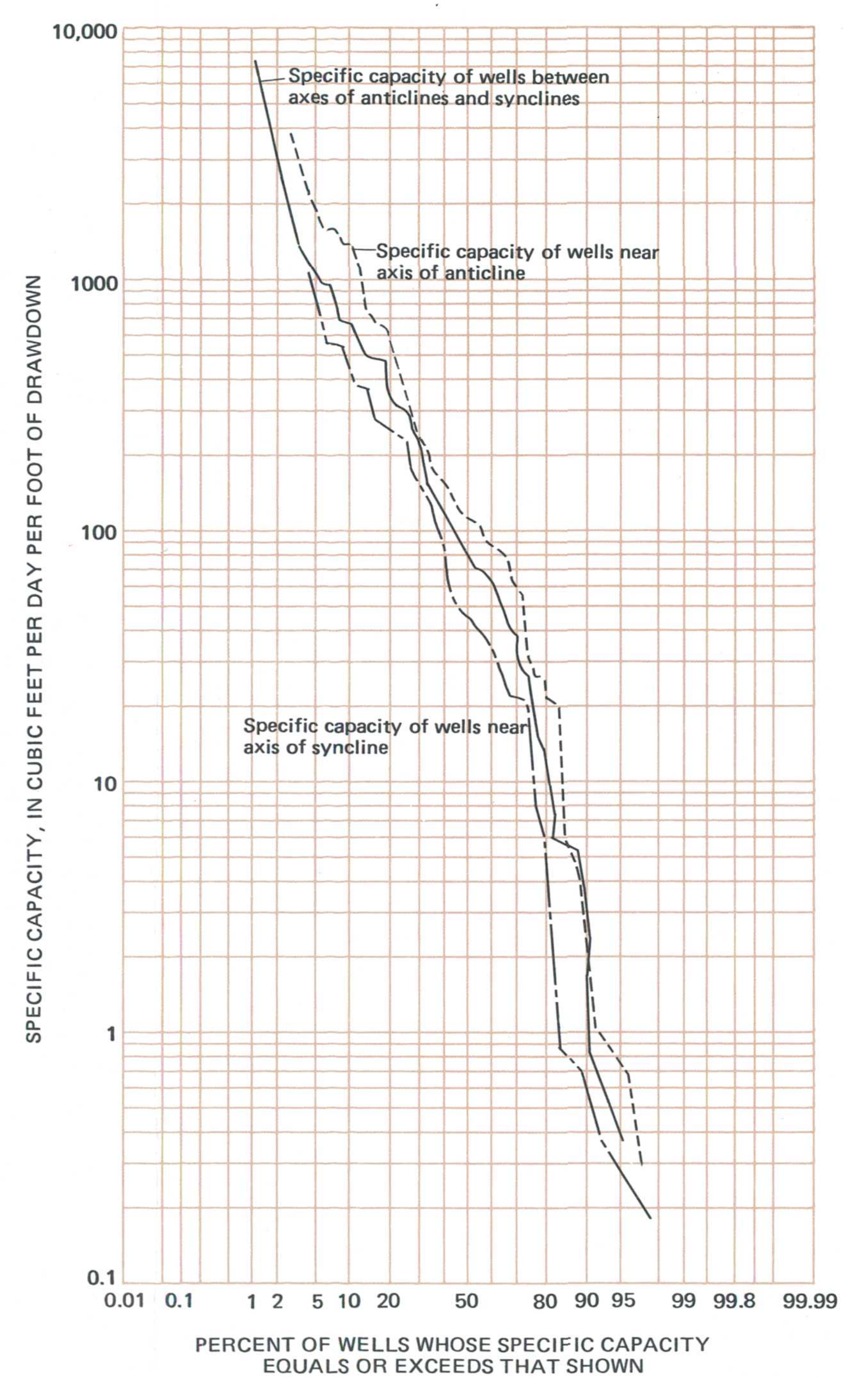


Figure 5.2-3 Specific-capacity-frequency curves for wells near anticlinal and synclinal axes, and wells approximately between axes of anticlines and synclines (modified from Clark and others, 1976).

Ground Water is Subject to Widespread Quality Problems

Water from the Pocono and Mauch Chunk Groups is highly mineralized. Shallow water in the Greenbrier Group is often contaminated by waste injection and surface runoff.

The chemical quality of ground water in Area 10 varies greatly, both in type and in concentration of dissolved constituents. As determined from about 100 chemical analyses of water from wells in the area, the minimum concentration of dissolved solids was 22 milligrams per liter (mg/L), the maximum was 17,103 mg/L, and the median was 196 mg/L. About half the samples were classified as calcium bicarbonate type, about 15 percent were sodium bicarbonate type, and the rest contained approximately equal proportions of calcium and sodium in combination with varying amounts of chloride, sulfate, and bicarbonate.

The major factors controlling the quality of ground water in the area are the mineralogy of the rocks containing the water and local topographic and subsurface features. Water percolating through the more soluble rocks such as limestone, dissolves some of the rock. Some of the rocks in the karst areas contain caverns which connect to the surface through sinkholes making it possible for runoff and municipal and agricultural waste to recharge zones that supply water to wells (Clark and others, 1976). Although fine-grained permeable rocks which are rare in Area 10, alter the dissolved minerals in the water only slightly by dissolution, they do filter the water and remove sediment and suspended matter. Such filtration doesn't occur in caverns because the water and sediment move easily through the large openings.

Coal is mined in only a small area along the northern edge of the southwest end of the basin. Consequently, analyses of water from rocks of the Pottsville Group, the only rock unit with mineable coal deposits in the basin, are scarce. The available data indicate that acid mine drainage is not a problem. The high alkalinity of most ground water causes neutralization of acid water from the mine drainage in the basin.

Figure 5.3-1 summarizes the ground-water quality in Area 10. It shows the number of samples which fall in certain ranges of concentration for the concentrations of dissolved solids, hardness, sulfate, iron, and manganese in six rock units. The most frequently occurring dissolved-solids content of water in most of the geologic units shown on the chart occured in the range of 101 to 250 mg/L. With the exception of the Greenbrier Group (the major limestone unit in the basin) the most frequently occurring range of concentration of hardness was 61 to 120 mg/L. For the Greenbrier Group, hardness generally exceeded 181 mg/L. Sulfate most frequently was found in the 0 to 25 mg/L range in all the units except the Brallier Formation, in which it was in the 26 to 50 mg/L range. Iron and manganese most commonly were found in the 0 to 0.20 mg/L range in all the units.

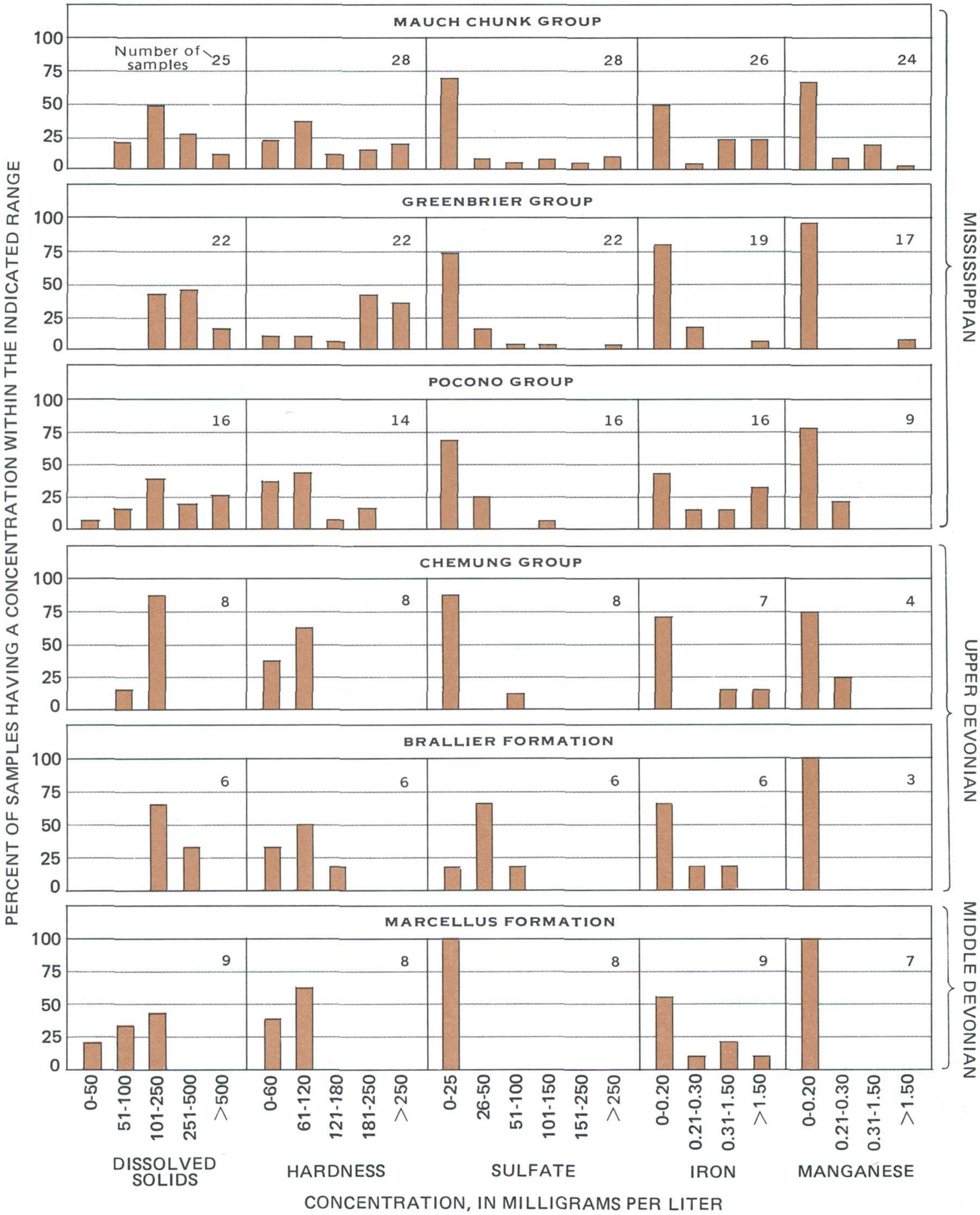


Figure 5.3-1 Summary of ground-water quality in six rock units in Area 10 (modified from Clark and others, 1976).

NAWDEX, WATSTORE, OWDC have Water-Data Information

Water data are collected in coal areas by a large number of organizations in response to a wide variety of missions and needs. The data are indexed by the National Water Data Exchange. Data collected by the U.S. Geological Survey are stored on computer disk by the National Water Data Storage and Retrieval System.

Within the U.S. Geological Survey there are three activities that help to identify and improve access to the vast amount of existing water data:

(1) The National Water Data Exchange (NAWDEX), which indexes the water data available from over 400 organizations and serves as a central focal point to help those in need of water data to determine what information already is available.

(2) The National Water Data Storage and Retrieval System (WATSTORE), which serves as the central repository of water data collected by the U.S. Geological Survey and which contains large volumes of data on the quantity and quality of both surface and ground waters.

(3) The Office of Water Data Coordination (OWDC), which coordinates Federal water-data acquisition activities and maintains a "Catalog of Information on Water Data." To assist in identifying available water-data activities in coal provinces of the United States special indexes to the Catalog are being printed and made available to the public.

A more detailed explanation of these three activities is given in sections 6.2, 6.3, and 6.4.

NAWDEX Matches User Needs to Available Data

NAWDEX (National Water Data Exchange) is a national confederation of water-oriented organizations working together to improve access to water data. Objectives of NAWDEX are to assist users of water data in the identification, location, and acquisition of needed data. The U.S. Geological Survey manages NAWDEX through Survey headquarters in Reston, Virginia, and local assistance centers in major cities.

The function of NAWDEX is to index the data held by NAWDEX members and participants so as to provide a central source of water-data information available from a number of organizations (fig. 6.2-1). A central Program Office located at U.S. Geological Survey national headquarters in Reston, Virginia, provides data-exchange policy and guidelines for participants. The major functions of the Program Office are to: (1) maintain a computerized Master Water Data Index (fig. 6.2-2) which identifies sites for which data are available and the organization responsible for the data; (2) provide access to water-data bases held by participants; and (3) maintain a Water-Data Sources Directory (fig. 6.2-3) that identifies participating organizations and locations from which data may be obtained.

Services are available through the Program Office in U.S. Geological Survey headquarters in Reston, Virginia, and through a network of 59 centers located in 45 states and Puerto Rico. A directory is available upon request which lists organizations, personal contacts, addresses, telephone numbers and office hours for each NAWDEX assistance center [Directory of Assistance Center of National Water Data Exchange (NAWDEX), U.S. Geological Survey Open-File Report 79-423 (Revised)].

Charges for NAWDEX services may be assessed at the option of the organization providing the requested data or data service. Charges will be assessed for computer and extensive personnel time, duplicating services, or other costs encountered by NAWDEX in the course of providing services. In any case, charges will not exceed the actual direct costs involved. Estimates of cost will be provided by all NAWDEX assistance centers upon request and in all cases when costs are expected to be substantial.

For additional information concerning the NAWDEX program or its services contact:

Program Office
National Water Data Exchange (NAWDEX)
U.S. Geological Survey
421 National Center
12201 Sunrise Valley Drive
Reston, Virginia 22092

Telephone: (703) 860-6031
FTS 928-6031

Hours: 7:45 - 4:15

or

NAWDEX ASSISTANCE CENTER - West Virginia
U.S. Geological Survey
Water Resources Division
603 Morris Street
Charleston, West Virginia 25301

Telephone (304) 347-5130
FTS 930-5130

Hours: 7:45 - 4:30

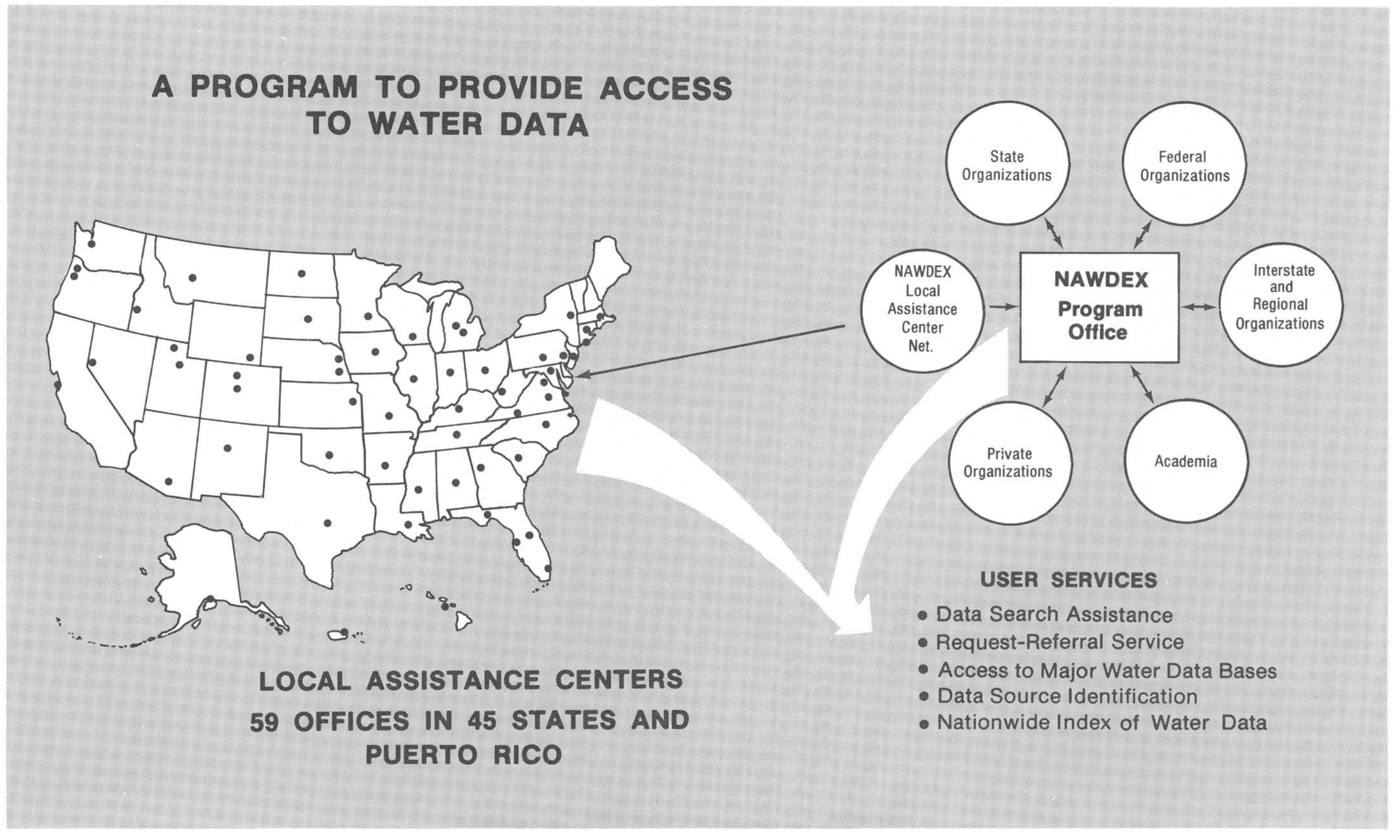


Figure 6.2-1 Access to water data.

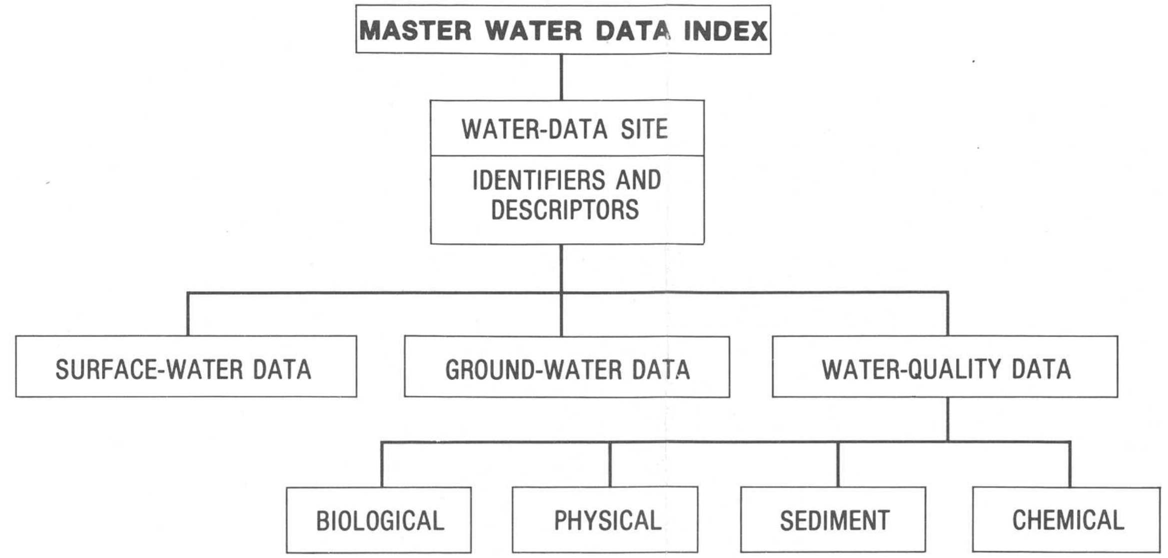


Figure 6.2.2 Master water-data index.

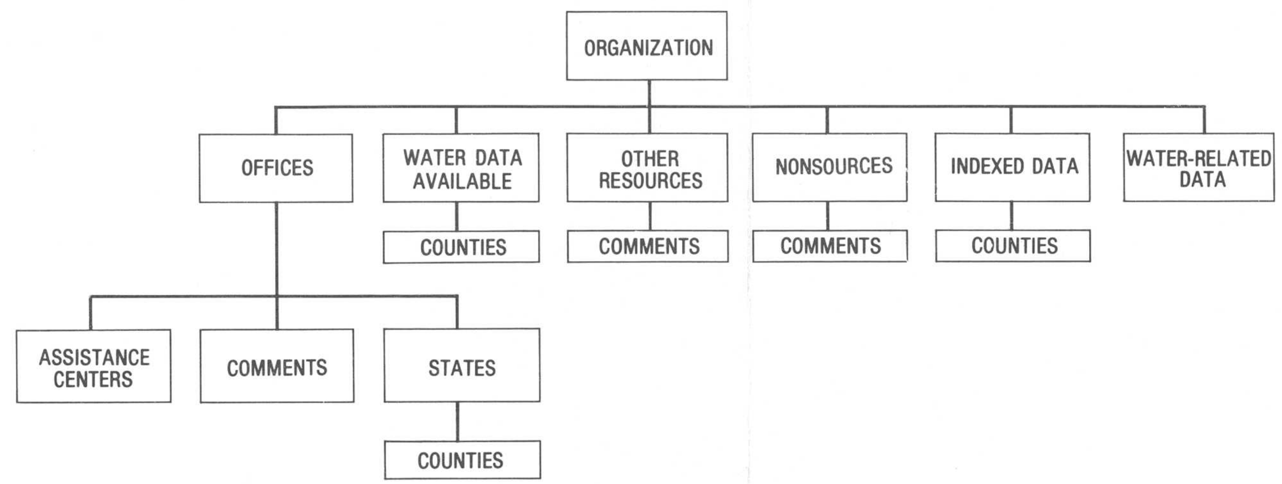


Figure 6.2-3 Water-data sources directory.

WATSTORE Automated Data System

The National Water Data Storage and Retrieval System (WATSTORE) of the U.S. Geological Survey provides computerized procedures and techniques for processing water data and provides effective and efficient management of data-releasing activities.

The National Water Data Storage and Retrieval System (WATSTORE) was established in November 1971 to computerize the U.S. Geological Survey's existing water-data system and to provide for more effective and efficient management of its data-releasing activities. The system is operated and maintained on the central computer facilities of the Survey at its National Center in Reston, Virginia. Data may be obtained from WATSTORE through the Water Resources Division's 46 district offices. General inquiries about WATSTORE may be directed to:

Chief Hydrologist
U.S. Geological Survey
437 National Center
Reston, Virginia 22092

or

U.S. Geological Survey
Water Resources Division
603 Morris Street
Charleston, West Virginia 25301

The Geological Survey currently (1980) collects data at approximately 16,000 streamgaging stations; 1,000 lakes and reservoirs; 5,200 surface-water quality stations; 1,020 sediment stations; 30,000 water-level observation wells; and 12,500 ground-water quality wells. Each year many water-data collection sites are added and others are discontinued; thus, large amounts of diversified data, both current and historical, are amassed by the Survey's data-collection activities.

The WATSTORE system consists of several files in which data are grouped and stored by common characteristics and data-collection frequencies. The system also is designed to allow for the inclusion of additional data files as needed. Currently, files are maintained for the storage of: (1) surface-water, quality-of-water, and ground-water data measured on a daily or continuous basis; (2) annual peak values for streamflow stations; (3) chemical analyses for surface- and ground-water sites; (4) water parameters measured more frequently than daily; and (5) geologic and inventory data for ground-water sites. In addition, an index file of sites for which data are stored in the system is also maintained (fig. 6.3-1). A brief description of each file is as follows.

Station Header File: All sites for which data are stored in the Daily Values, Peak Flow, Water-Quality, and Unit Values files of WATSTORE are indexed in this file. It contains information pertinent to the identification, location, and physical description of nearly 220,000 sites.

Daily Values File: All water-data parameters measured or observed either on a daily or on a continuous basis and numerically reduced to daily values are stored in this file. Instantaneous measurements at fixed-time intervals, daily-mean values, and statistics such as daily maximum and minimum values also may be stored. This file currently contains over 200 million daily values including data on streamflow, river stages, reservoir contents, water temperatures, specific conductance, sediment concentrations, sediment discharges, and ground-water levels.

Peak Flow File: Annual maximum (peak) streamflow (discharge) and gage height (stage) values at surface-water sites comprise this file, which currently contains over 400,000 peak observations.

Water-Quality File: Results of over 1.4 million analyses of water samples that describe the chemical, physical, biological, and radiochemical characteristics of both surface and ground waters are contained in this file. These analyses contain data for over 185 different constituents.

Unit Values File: Water parameters measured at intervals more frequent than daily are stored in this file. Rainfall, stream discharge, and temperature data are examples of the types of data stored in the Unit Values File.

Ground-Water Site-Inventory File: This file is maintained within WATSTORE independent of the files discussed above, but it is cross-referenced to the Water-Quality File and the Daily Values File. It contains inventory data about wells, springs, and other sources of ground water. The data included are site location and identification, geohydrologic characteristics, well-construction history, and one-time field measurements such as water temperature. The file is designed to accommodate 255 data elements and currently contains data for nearly 700,000 sites.

All data files of the WATSTORE system are maintained and managed on the central computer facilities of the Geological Survey at its National Center. However, data may be entered into or retrieved from WATSTORE at a number of locations that are part of a nationwide telecommunication network.

Remote Job Entry Sites: Almost all of the Water Resources Division's district offices are equipped with high-speed computer terminals for remote access to the WATSTORE system. These terminals allow each site to put data into or retrieve data from the system, with turnaround times of from several minutes to overnight, depending upon the priority placed on the request. The number of remote job-entry sites is increased as the need arises.

Digital Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river stages, conductivity, water temperature, turbidity, wind direction, and chlorides. Data are recorded on 16-channel paper tape, which is removed from a recorder and transmitted over telephone lines to a receiver in Reston, Va. The data are recorded on magnetic tape for use on the central computer. Extensive testing of satellite data collection platforms indicates their feasibility for collecting real-time hydrologic data on a national scale. Battery-operated radios are used as the communication link to the satellite. About 200 data relay stations are being operated currently (1980).

Central Laboratory System: The Water Resources Division's two water-quality laboratories, located in Denver, Colorado, and Atlanta, Georgia, analyze more than 150,000 water samples per year. These laboratories are equipped to automatically perform chemical analyses ranging from determinations of simple inorganic compounds, such as chlorides, to complex organic compounds, such as pesticides. As each analysis is completed, the results are verified by laboratory personnel and transmitted via a computer terminal to the central computer facilities to be stored in the Water-Quality File of WATSTORE.

Water data are used in many ways by decision makers for the management, development, and monitoring of our water resources. In addition to its data processing, storage, and retrieval capabilities, WATSTORE can provide a variety of useful products ranging from simple data tables to complex statistical analyses. A minimal fee, plus the actual computer cost incurred in producing a desired product, is charged to the requester.

Computer-Printed Tables: Users most often request data from WATSTORE in the form of tables printed by the computer. These tables may contain lists of actual data or condensed indexes that indicate the availability of data stored in the files. A variety of formats is available to display the many types of data.

Computer-Printed Graphs: Computer-printed graphs for the rapid analysis or display of data are another capability of WATSTORE. Computer programs are available to produce bar graphs (histograms), line graphs, frequency-distribution curves, X-Y point plots, site-location map plots, and other similar items by means of line printers.

Statistical Analyses: WATSTORE interfaces with a proprietary statistical package (SAS) to provide extensive analyses of data such as regression analyses, analysis of variance, transformations, and correlations.

Digital Plotting: WATSTORE also makes use of software systems that prepare data for digital plotting on peripheral offline plotters available at the central computer site. Plots that can be obtained include hydrographs, frequency-distribution curves, X-Y point plots, contour plots, and three-dimensional plots.

Data in Machine-Readable Form: Data stored in WATSTORE can be obtained in machine-readable form for use on other computers or for use as input to user-written computer programs. These data are available in the standard storage format of the WATSTORE system or in the form of punched cards or card images on magnetic tape.

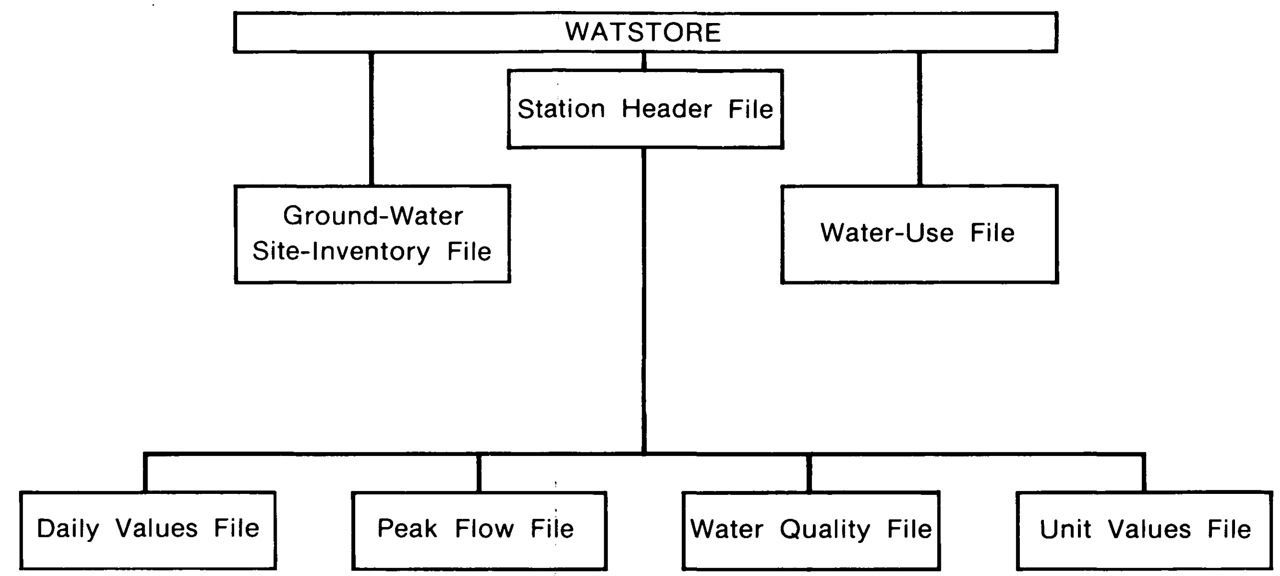


Figure 6.3-1 WATSTORE file system.

Water Data Indexed for Coal Provinces

A special index, "Index to Water-Data Activities in Coal Provinces of the United States," has been published by the U.S. Geological Survey's Office of Water Data Coordination (OWDC).

The "Index to Water-Data Activities in Coal Provinces of the United States" was prepared to assist those involved in developing, managing, and regulating the Nation's coal resources by providing information on the availability of water-resources data in the major coal provinces of the United States. It is derived from the "Catalog of Information on Water Data," which is a computerized information file about water-data acquisition activities in the United States, and its territories and possessions, with some international activities included.

This special index consists of five volumes (fig. 6.4-1): Volume I, Eastern Coal Province; Volume II, Interior Coal Province; Volume III, Northern Great Plains and Rocky Mountain Coal Provinces; Volume IV, Gulf Coast Coal Province; and Volume V, Pacific Coast and Alaska Coal Provinces. The information presented will aid the user in obtaining data for evaluating the effects of coal mining on water resources and in developing plans for meeting additional water-data needs. The report does not contain the actual data; rather, it provides information that will enable the user to determine if needed data are available.

Each volume of this special index consists of four parts: Part A, Streamflow and Stage Stations; Part B, Quality of Surface-Water Stations; Part C, Quality of Ground-Water Stations; and Part D, Areal Investigations and Miscellaneous Activities. Information given for each activity in Parts A-C includes: (1) the identification and location of the station, (2) the major types of data collected, (3) the frequency of data collection, (4) the form in which the data are stored, and (5) the agency or organization reporting the activity. Part D summarizes areal hydrologic investigations and water-data activities not included in the other parts of the index. The agencies that submitted the information, agency codes, and the number of activities reported by type are shown in table.

Those who need additional information from the Catalog file or who need assistance in obtaining water data should contact the National Water Data Exchange (NAWDEX) (See section 6.2).

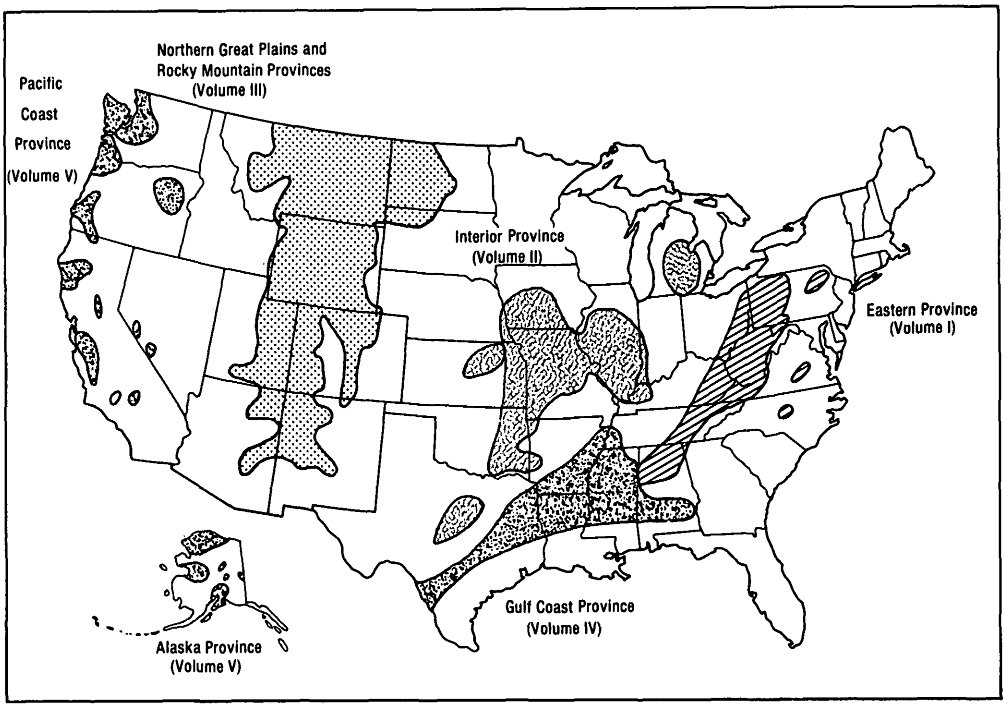


Figure 6.4-1 Index volumes and related provinces.

7.0 STATION IDENTIFICATION

Site number	Station number	Station name	Drainage area (mi²)	Location Latitude	Location Longitude	Type of record and period collected: Discharge	Chemical quality	Sediment
1	03177000	Rich Creek at Peterstown, W. Va.	50.6	37°23'48"	80°47'52"	1942-51	1972	
2	03176500	New River at Glen Lyn, Va.	3,768	37°22'20"	80°51'45"	1928-80	1931,1980, 1952,1955-56 1955-80	1978-80
3		Brush Creek near Peterstown, W. Va.		37°23'59"	80°47'59"		1972	
4		Grassy Branch at Cumberland Heights, W. Va.		37°15'48"	81°11'45"		1972	
5		Grassy Branch near Bluefield, W. Va.		37°16'44"	81°11'16"		1972	
6		East River near Ingleside, W. Va.		37°18'52"	81°03'12"		1972-73	
7		Peggy Branch at Hardy, W. Va.		37°18'26"	81°01'56"		1972	
8		Payne Branch at Hatcher, W. Va.		37°21'57"	80°58'43"		1972	
9		Hales Branch near Oakvale, W. Va.		37°21'09"	80°57'37"		1972	
10		Fivemile Creek at Oakvale, W. Va.		37°20'46"	80°58'00"		1972	
11		Pigeon Creek near Oakvale, W. Va.		37°19'35"	80°57'06"		1972	
12		East River at Kellysville, W. Va.		37°20'46"	80°55'16"		1973	
13		East River two miles above mouth, W. Va.		37°21'18"	80°32'21"		1972	
14		Adair Run near Willowtown, W. Va.		37°22'06"	80°52'57"		1972	
15		Island Creek near Lavern, W. Va.		37°27'35"	80°54'15"		1972	
16		Dry Fork Creek at Lick Creek, W. Va.		37°29'13"	80°55'21"		1972	
17		Lick Creek at Rock Camp, W. Va.		37°29'58"	80°36'18"		1972	
18		Rock Camp Creek at Rock Camp, W. Va.						
19		Turkey Creek at Willow Road, W. Va.		37°32'29"	80°32'29"		1972	
20		Burnside Branch at Salt Sulphur Springs, W. Va.		37°34'01"	80°33'22"		1972	
21		Rock Camp Creek at Raines Corner, W. Va.		37°30'59"	80°37'06"		1972	
22		Bark Creek near Greenville, W. Va.		37°33'22"	80°39'29"		1972	
23		Hans Creek near Greenville, W. Va.		37°32'33"	80°43'35"		1972	
24		Indian Creek at Red Sulphur Springs, W. Va.		37°30'57"	80°43'13"		1972	
25		Bradshaw Creek near Indian Mills, W. Va.		37°31'57"	80°49'07"		1972	
26		Toms Run near Farley, W. Va.		37°31'12"	80°54'42"		1972	
27		Pipestem Creek at Pipestem, W. Va.		37°32'40"	80°57'38"		1972	
28		Pipestem Creek near True, W. Va.		37°35'26"	80°54'52"		1972	
29		Brush Fork at Brush Fork, W. Va.		37°17'11"	81°15'22"		1972	
30		Mill Creek at Bramwell, W. Va.		37°19'25"	81°19'38"		1972	
31		Bluestone River at Bramwell, W. Va.	113	37°19'30"	81°18'35"	1979-80	1972-73 1979-80	 1980
33		Hunk Hollow Branch at Freeman, W. Va.		37°20'06"	81°18'46"		1972	
34		Simmons Creek near Simmons, W. Va.		37°19'32"	81°18'24"		1972	
35		Goodwill Branch at Goodwill, W. Va.		37°21'17"	81°17'28"		1972	
36		Flipping Creek at Duhring, W. Va.		37°20'50"	81°15'50"		1973	
37		West Fork Crane Creek near McComas, W. Va.		37°24'29"	81°18'54"		1972	
38		West Fork Crane Creek below Red Hollow, W. Va.		37°23'41"	81°18'19"		1972	
39		Tolliver Branch at mouth, W. Va.		37°23'32"	81°18'02"		1972	
40		East Fork Crane Creek near McComas, W. Va.		37°23'58"	81°17'07"		1972	
41		East Fork Crane Creek at McComas, W. Va.		37°23'42"	81°17'22"		1972	
42		Crane Creek at McComas, W. Va.		37°23'07"	81°16'58"		1972	
43		Crane Creek at Montcalm, W. Va.		37°21'13"	81°15'28"		1972-73	
44		Righthand Fork Widemouth Creek at Hiawatha, W. Va.		37°18'35"	81°22'17"		1972	
45		Big Branch at Piedmont, W. Va.		37°27'10"	81°15'50"		1972	
46		Lefthand Fork Widemouth Creek at Giatto, W. Va.		37°24'56"	81°15'53"		1972	
47		Widemouth Creek at Rock, W. Va.	23.5	37°22'39"	81°13'55"	1979-80	1972-73 1979-80	1980
48		Middleton Fork near Kale, W. Va.		37°15'58"	81°18'42"		1972	
49		Lashmeet Branch at mouth, W. Va.		37°17'10"	81°16'21"		1972	
50		Rich Creek at Beeson, W. Va.		37°20'45"	81°19'10"		1972	
51		Meadow Fork near Beeson, W. Va.		37°19'18"	81°19'23"		1972	
52		Rich Creek at Spanishburg, W. Va.	22.3	37°26'30"	81°08'08"	1979-80	1972,1979, 1980	1980
53		Wolf Creek near Camp Creek, W. Va.		37°28'19"	81°06'39"		1972	
54		Mash Fork near Camp Creek, W. Va.	12.5	37°30'12"	81°08'06"	1979-80	1972,1979 1980	1980
55	03178500	Camp Creek near Camp Creek, W. Va.	18.8	37°30'17"	81°08'02"	1947-72, 1979-80	1972,1979, 1980	1980
56		Trace Creek near Camp Creek, W. Va.		37°30'17"	81°06'14"		1972	
57		Bluestone River at Camp Creek, W. Va.		37°28'47"	81°04'26"		1972	
58		South Fork Brush Creek above Edison, W. Va.		37°17'47"	81°09'52"		1972	
59		South Fork Brush Creek at Ceres, W. Va.		37°18'28"	81°08'31"		1972	
60		Middle Fork Bursh Crek at Edison, W. Va.		37°18'24"	81°10'13"		1972	

Site number	Station number	Station name	Drainage area (mi²)	Location Latitude	Location Longitude	Type of record and period collected: Discharge	Chemical quality	Sediment
61		North Fork Brush Creek at mouth, W. Va.		37°20'05"	81°09'27"		1972	
62		Brush Creek at Gardner, W. Va.		37°25'25"	81°04'28"		1972	
63		Laurel Creek near Athens, W. Va.		37°26'11"	81°00'17"		1972	
64		Brush Creek 1 mile above mouth, W. Va.		37°27'53"	81°03'51"		1972	
65		Rockhouse Branch at Dumas, W. Va.		37°33'40"	81°03'55"		1972	
66		Mountain Creek at Dunns, W. Va.		37°32'36"	81°03'12"		1972	
67	03179000	Bluestone River near Pipestem, W. Va.	363	37°32'45"	81°00'30"	1950-80 1980	1972, 1979,	1980
68		Suck Creek at mouth, W. Va.		37°36'21"	80°59'07"		1972	
70		Little Bluestone River near Ellison, W. Va.		37°36'28"	80°59'14"		1972	
71		East Fork Greenbrier River at Route 51 bridge, W. Va.		38°39'01"	79°39'33"		1972	
72		Long Run near Thornwood, W. Va.		38°34'38"	79°42'13"		1972	
73		Gum Cabin Creek near Thornwood, W. Va.		38°34'11"	79°43'29"		1972	
74		Little River near Thornwood, W. Va.		38°33'23"	79°44'05"		1972	
75		East Fork Greenbrier River at Bartow, W. Va.		38°32'20'	79°46'30"		1972	
76		Johns Run at Frank, W. Va.		38°32'47"	79°47'57"		1972	
77		West Fork Greenbrier River at Widell, W. Va.	26.4	38°42'46"	79°46'45"	1979-80	1972,1979 1980	1980
78		Snorting Lick Run at Widell, W. Va.		38°42'44"	79°46'45"		1972	
79		Elklick Run near May, W. Va.		38°40'15"	79°47'08"		1972	
80		Little River near May, W. Va.		38°37'01"	79°48'30"		1972	
81		Lick Creek near Olive, W. Va.		38°33'57"	79°49'17"		1972	
82	03180400	West Fork Greenbrier River at Durbin, W. Va.		38°33'00"	79°49'54"		1971-72	
83	03180500	Greenbrier River at Durbin, W. Va.	134	38°32'35"	79°50'00"	1943-80	1971-73, 1979-80	
84		Elk Creek near Durbin, W. Va.		38°31'09"	79°50'40"		1972	
85		Brush Run near Boyer, W. Va.		38°30'10"	79°47'26"		1972	
86		Greenbrier River at Hosterman, W. Va.		38°28'19"	79°51'23"		1972	
87		Allegheny River at Hosterman, W. Va.		38°28'19"	79°51'35"		1972	
88		Leatherback River at Cass, W. Va.		38°24'29"	79°55'10"		1972	
89		Greenbrier River at Cass, W. Va.		38°23'46"	79°54'52"		1972	
90		Deer Creek near Arborvale, W. Va.	24.1	38°26'38"	79°49'49"	1979-80	1972,	1980
91		North Fork near Greenbank, W. Va.		38°25'04"	79°49'48"		1972	
92		Sitlington Gum Branch at Dummon, W. Va.		38°21'08"	79°51'25"		1972	
93		Moore Run at Dummon, W. Va.		38°21'57"	79°52'42"		1972	
94		Thomas Creek near Dummon, W. Va.		38°21'38"	79°54'12"		1972	
95		Sitlington Creek at Sitlington, W. Va.		38°21'35"	79°55'28"		1972	
96		Elklick Creek at Stony Bottom, W. Va.		38°21'49	79°58'02"		1972	
97		Greenbrier River at Clover Lick, W. Va.		38°19'53"	79°58'10"		1972	
98		Clover Lick Creek at Clover Lick, W. Va.		38°20'00"	79°58'12"		1972	
99	03181200	Indian Draft at Marlington, W. Va.	3.06	38°14'24"	80°05'09"	1968-77	1972	
100		Knapp Creek at Minnehaha Springs, W. Va.		38°09'48"	79°58'56"		1972	
101		Cummins Creek at Huntersville, W. Va.		38°11'21"	80°01'16"		1972	
102		Browns Creek near Huntersville, W. Va.		38°11'48"	80°00'12"		1972	
103		Knapp Creek at Huntersville, W. Va.		38°11'51"	80°01'39"		1972	
104	03182000	Knapp Creek at Marlington, W. Va.	108	38°12'40"	80°04'30"	1946-58	1971-72	
105		Swags Creek near Buckeye, W. Va.		38°11'10"	80°08'08"		1972	
106	03182500	Greenbrier River at Buckeye, W. Va.	540	38°11'15"	80°07'50"	1929-80	1971-73 1979-80	
107		Stamping Creek near Mill Point, W. Va.		38°09'50"	80°11'32"		1972	
108		Spring Creek at Oscar, W. Va.		38°03'44"	80°22'26"		1973	
109		Spring Creek at Route 219 bridge, W. Va.		37°58'36"	80°22'48"		1972-73	
110	03182650	Spring Creek at Spring Creek, W. Va.		37°57'24"	80°21'09"		1971-73	
111		North Fork Anthony Creek at Neola, W. Va.		38°58'02"	80°07'53"		1972	
112		Fleming Run at Avlon, W. Va.		38°54'35"	80°35'12"		1972	
113		Anthony Creek at Avlon, W. Va.		38°55'06"	80°12'48"		1972	
114		Little Creek near Avlon, W. Va.		38°55'36"	80°13'14"		1972	
115	03182700	Anthony Creek near Anthony, W. Va.	144	37°54'30"	80°17'30"	1972-80	1971-72, 1979-80	
116		Howard Creek near White Sulphur Springs, W. Va.		37°50'21"	80°15'16"		1972	
117		Jerico Draft near White Sulphur Springs, W. Va.		37°49'38"	80°16'57"		1972	
118		Tuckahoe Run near White Sulphur Springs, W. Va.		37°43'34"	80°17'52"		1972	
119		Harts Run at mouth, W. Va.		37°45'08"	80°21'15"		1972	
120		Monroe Draft at mouth, W. Va.		37°45'11"	80°24'20"		1972	

Map number	Station number	Station name	Drainage area (mi^2)	Location Latitude	Location Longitude	Type of record and period collected: Discharge	Chemical quality	Sediment
121	03182950	Howard Creek at Caldwell, W. Va.	84.4	37°46'54"	80°23'15"	1971-77	1971-74	1973-77
123		Second Creek at Hollywood, W. Va.		37°36'45"	80°25'38"		1972	
124	03183000	Second Creek near Second Creek, W. Va.	80.8	37°14'05"	80°27'25"	1946-73	1971-73	
125		Carpenter Creek near Second Creek, W. Va.		37°40'02"	80°25'24"		1972	
126		Greenbrier River at Fort Springs, W. Va.		37°44'38"	80°32'45"		1972	
127	03183520	Muddy Creek at Alderson, W. Va.		37°43'52"	80°39'25"		1971-72	
128		Sinking Creek at Alta, W. Va.		37°53'00"	80°33'16"		1973	
129		Wolf Creek near Wolf Creek, W. Va.		37°39'04"	80°37'28"		1972	
130		Broad Run near Wolf Creek, W. Va.		37°39'41"	80°36'18"		1972	
131		Laurel Creek at Knobs, W. Va.		37°36'41"	80°35'20"		1972	
132		Wolf Creek at Wolf Creek, W. Va.		37°39'49"	80°37'28"		1972	
133		Hungard Creek at Talcott, W. Va.		37°39'08"	80°45'44"		1972	
134	03124000	Greenbrier River at Hilldale, W. Va.	1,625	37°38'25"	80°48'20"	1936-80	1972,1979-80	1967-74
135		Stony Creek at Barger Springs, W. Va.		37°36'40"	80°45'44"		1972	
137	03184200	Big Creek near Bellepoint, W. Va.	8.27	37°39'35"	80°50'09"	1969-77	1972	
138		Madam Creek at Brooklyn, W. Va.		37°40'23"	80°53'41"		1972	
139		Little Bluestone River at Highway 27 bridge near Jumping Branch, W. Va.	26.4	37°36'28"	80°59'13"	1979-80	1972,1979-80	1980
140		Little River at highway 44 bridge near Widell, W. Va.	19.5	38°36'59"	79°48'24"	1979-80	1972,1979-80	1980
141		Robbins Run at highway 5 bridge at Oscar, W. Va.	11.1	38°03'28"	80°21'25"	1979-80	1972,1979-80	1980
142		Spring Creek at highway 5 bridge at Leonard, W. Va.	11.4	38°04'46"	80°24'25"	1979-80	1972,1979-80	1980
143		New River at Eggleston, Virginia	2,941	37°17'22"	80°37'01"	1915-76		
144		Walker Creek at Bane, Virginia	305	37°16'05"	80°42'35"	1938-80	1930-56	
145		Wolf Creek near Narrows, Virginia	223	37°18'20"	80°51'00"	1909-80		
146	03177500	Indian Creek at Indian Mills, W. Va.	189	37°31'55"	80°49'10"	1942-51		
147	03177700	Bluestone River at Bluefield, Va.	39.8	37°15'21"	81°16'55"	1966-80		
148	03178000	Bluestone River near Spanishburg, W. Va.	199	37°26'00"	81°06'40"	1945-52		
149	03179500	Bluestone River at Lilly, W. Va.	438	37°35'05"	80°57'55"	1908-48	1953-69, 1969-80	
150	03180000	New River at Bluestone Dam, W. Va.	4,604	37°38'35"	80°53'00"	1924-49 1950-80	1979-80	
151	03181500	Greenbrier River at Marlinton, W. Va.	408	38°14'10"	80°05'05"	1909-16		
152	03183500	Greenbrier River at Alderson, W. Va.	1,357	37°43'30"	80°38'30"	1895-80	1979-80	

8.0 SELECTED REFERENCES

American Society for Testing and Materials, 1979, Annual book of standards, part 31, water: Philadelphia, 1280 p.

Anderson, W. C., and Youngstrom, M. P., 1976, Coal pile leachate - quantity and quality characteristics: Journal Sanitary Engineering Division, American Society of Civil Engineers, v. 102, p. 1239.

Babu, S. P., Barlow, J. A., Craddock, L. L., Hidalgo, R. V., and Friel, E. A., 1973, Suitability of West Virginia coals to coal-conversion processes: West Virginia Geological and Economic Survey, Coal-Geology Bulletin No. 1, 32 p.

Bader, J. S., Chisholm, J. L., Downs, S. C., and Morris, F. O., 1976, Water resources of the Coal River basin, West Virginia: West Virginia Geological and Economic Survey River-Basin Bulletin No. 5, (in press).

Baloch, M. S., Henry, E. N., and Dickerson, W. H., 1969, Flow characteristics of Greenbrier River: West Virginia Department of Natural Resources, Division of Water Resources, 95 p.

Barlow, J. A., 1974, Coal and coal mining in West Virginia: West Virginia Geological and Economic Survey Coal-Geology Bulletin 2, 63 p.

Benson, M. A., 1962, Factors influencing the occurrence of floods in a humid region of diverse terrain: U.S. Geological Survey Water-Supply Paper 1580-B, 64 p.

Butts, Charles, 1933, Geologic map of the Appalachian Valley in Virginia: Virginia Geological Survey map, scale 1:250,000.

________1940, Geology of the Appalachian Valley in Virginia: Virginia Geological Survey Bulletin 52, part 1, 568 p.

Cardwell, D. H., 1975, Geologic history of West Virginia: West Virginia Geological and Economic Survey Educational Series Report ED-10, 64 p.

Cardwell, D. H., Erwin, R. B., and Woodward, H. P., compilers, 1968: Geologic map of West Virginia, scale 1:250,000.

Chisholm, J. L., and Frye, P. M., 1976, Records of wells, springs, chemical analyses of water, biological analyses of water, and standard streamflow data summaries from the upper New River basin in West Virginia: West Virginia Geological and Economic Survey Basic Data Report 4, 78 p.

Clark, W. E., Chisholm, J. L., and Frye, P. M., 1976, Water resources of the upper New River basin, West Virginia: West Virginia Geological and Economic Survey River Basin Bulletin 4, 142 p.

Commonwealth of Virginia, State Water Control Board, 1979, Ground water: 90 p.

DePaulo, J. R., Jr., and Baloch, M. S., 1968, Comprehensive water resources study of the Greenbrier River sub-basin: West Virginia Department of Natural Resources, Division of Water Resources, v. 1, 136 p.

Deutsch, Morris, Dove, G. D., Jordan, P. R., and Wallou, J. C., 1966, Ground-water distribution and potential in the Ohio River basin: U.S. Army Corps of Engineers, Appendix E, 167 p.

Eckhardt, D. V., 1976, Sediment discharge from an area of highway construction, Appleman Run basin, Columbia County, Pennsylvania: U.S. Geological Survey Water-Resources Investigations Report 76-111, 25 p.

Ehlke, T. A., Bader, J. S. Puente, Celso, and Runner, G. S., 1981a, Hydrology of Area 12, Eastern Coal Province, West Virginia: U.S. Geological Survey Water-Resources Investigations Report 81-902, 75 p.

Ehlke, T. A., Runner, G. S., and Downs, S. C., 1981b, Hydrology of Area 9, Eastern Coal Province, West Virginia: U.S. Geological Survey Water-Resources Investigations Report 81-803, 63 p.

Feltz, Herman, 1980, Significance of bottom material data in evaluating water quality, in Baker, Robert A., ed., Contaminants and sediments: Ann Arbor Science Publishers, Inc., p. 271-287.

Fenneman, N. M., and Johnson, D. W., 1946, Physical divisions of the United States: U.S. Geological Survey map prepared in cooperation with Physiographic Commission, U.S. Geological Survey, scale 1:7,000,000 (reprinted 1964).

Fredericks, A. D., 1968, Concentration of organic carbon in the Gulf of Mexico: Office of Naval Research, Report 68-27T, 65 p.

Frye, P. M., and Runner, G. S., 1970, A proposed streamflow data program for West Virginia: U.S. Geological Survey Open-File Report, 61 p.

Gale, W. F., Jacobsen, T. V., and Smith, K. M., 1976, Iron and its role in a river polluted from mine effluents, in Pennsylvania Academy of Science, Proceedings: v. 50, no. 2, p. 182-195.

Gammon, James R., 1968, The effect of inorganic sediment on stream biota: Second Year Proceedings Report, Greencastle, Indiana, Department of Zoology, DePaw University, 84 p.

Garbarino, J. R., and Taylor, H. E., 1979, An inductively coupled plasma atomic emission spectrometric method for routine water-quality testing: Applied Spectroscopy, v. 33, no. 3, p. 220-226.

Greeson, P. E., Ehlke, T. A., Irwin, G. A., Lium, B. W., and Slack, K. V., (editors), 1977, Methods

for collection and analysis of aquatic biological and microbiological samples: Techniques of Water-Resources Investigations of the U.S. Geological Survey Book 5, Chapter A4, Laboratory Analysis, 332 p.
Greeson, P. E., 1979, (A supplement to) Methods for collection and analysis of adequate biological and microbiological samples: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 5, Chapter A4, 92 p. (Open-File Report 79-1279).
Guy, H. P., 1969, Laboratory theory and methods for sediment analysis: Techniques of Water-resources Investigations of the U.S. Geological Survey, Book 5, Chapter C1, Laboratory Analysis, 58 p.
Hall, G. A., 1974, The development of design criteria for soil slopes on West Virginia highways: Unpublished Ph. D. dissertation, West Virginia University, 272 p.
Hare, Charles E., 1939, Map of West Virginia showing major limestone areas and sample localities: West Virginia Geological and Economic Survey Map, scale 1:500,000.
Haught, Oscar L., 1968, Structural contour map datum Greenbrier limestone in West Virginia: West Virginia Geological and Economic Survey Map, scale 1:500,000.
Helgesen, J. O., and Razem, A. C., 1979, Preliminary observations of surface-mine impacts on ground water in two small watersheds in Eastern Ohio, in Symposium on surface-mining hydrology, sedimentology, and reclamation, 1980, Proceedings: Lexington, University of Kentucky, p. 351-360.
Hutchinson, N. E., compiler, 1975, WATSTORE users' guide V.I.: U.S. Geological Survey Open-File Report 75-426.
Islam, M. N., and Baloch, M. S., 1973, Comprehensive study of the Greenbrier River basin, economic base study: West Virginia Department of Natural Resources, Division of Water Resources, v. 2, part 2, 133 p.
Jones, William K., 1973, Hydrology of limestone karst: West Virginia Geological and Economic Survey Bulletin 36, 49 p.
King, H. M., Smith, C. J., Jones, H. L., and Campbell, J. D., 1981, Surface mines in West Virginia as of July 1, 1981: West Virginia Geological and Economic Survey Publication MB-2, 38 p.
Krothe, N. C., Edkins, J. E., Schubert, J. P., 1980, Leaching of metals and trace elements from sulfide-bearing coal waste in southwestern Illinois, in Symposium on Surface-Mining Hydrology, Sedimentology and Reclamation, 1980, Proceedings: Lexington, University of Kentucky, p. 455.
Landers, R. A., 1976, A practical handbook for individual water-supply systems in West Virginia: West Virginia Geological and Economic Survey, Educational Series Report, 102 p.
Lee, R., Chang, M., and Hill, S. C., 1976, Land slope in West Virginia: West Virginia Agriculture and Forestry, v. 6, no. 3, p. 10-16.
Lessing, Peter, Behling, Mary, and Hilgar, Gary, 1981, Water use in West Virginia: West Virginia Geological and Economic Survey Circular C-18, 43 p.
Lessing, Peter, Kulander, B. R., Wilson, B. D., Dean, S. L., and Woodring, S. M., 1976, West Virginia landslides and slide-prone areas: West Virginia Geological and Economic Survey, Environmental Geology Bulletin no. 15, 64 p.
Martin, J. F., Hemmann, J. G., and Kearney, E. H., 1980, Water quality from regraded coal-mine sites, in Symposium on Surface-Mining Hydrology, Sedimentology, and Reclamation, 1980, Proceedings: Lexington, University of Kentucky, p. 219-224.
Miller, E. M., 1978, Techniques for estimating magnitude and frequency of floods in Virginia: U.S. Geological Survey Water Resources Investigations 78-5, 83 p.
McCue, J. B., Lucke, J. B., and Woodward, H. P., 1939, Limestones of West Virginia: West Virginia Geological Survey, v. 12, 560 p.
National Oceanic and Atmospheric Administration, 1973a, Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-70, West Virginia: Asheville, North Carolina, 7 p.
________1973b, Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-70, Virginia - District of Columbia: Asheville, North Carolina, 8 p.
________1977, Climate of West Virginia: Asheville, North Carolina, 19 p.
________1978, Climate of Virginia: Asheville, North Carolina, 19 p.
________April 1979 - August 1980 - August 1980 Climatological data, West Virginia: National Climatic Center, Asheville, North Carolina (issued monthly).
Nuckles, E. H., 1970, Virginia streamflow data program analysis: U.S. Geological Survey Open-File Report, 54 p.
Price, P. H., and Heck, E. T., 1939, (Detailed geologic report of) Greenbrier County: West Virginia Geological Survey County Report, 846 p.
Price, P. H., and Reger, D. B., 1929, (Detailed geologic report of) Pocahontas County: West Virginia Geological Survey County Report, 531 p.
Rauch, H. W., and Werner, E., eds., 1974, Proceedings of the fourth conference on Karst geology and hydrology: Morgantown, West Virginia,

West Virginia Geological and Economic Survey, 187 p.
Reger, D. B., and Price, P. H., 1926, (Detailed geologic report of) Mercer, Monroe, and Summers Counties: West Virginia Geological Survey County Report, 963 p.
Runner, G. S., 1980a, Hydrologic data for runoff studies on small drainage areas: U.S. Geological Survey Open-File Report 80-560, 169 p.
Runner, G. S., 1980b, Runoff studies on small drainage areas (Technique for estimating magnitude and frequency of floods in West Virginia): U.S. Geological Survey Open-File Report 80-1218, 44 p.
Skougstad, M. W., Fishman, J. J., Friedman, L. C., Erdmann, D. E., Duncan, S. S. (ed.), 1979, Methods for analysis of inorganic substances in water and fluvial sediments: U.S. Geological Survey Open-File Report 78-679, 1006 p.
Toler, L. G., 1980, Some chemical characteristics of mine drainage in Illinois: U.S. Geological Survey Open-File Report 80-416, 47 p.
U.S. Agricultural Research Administration, 1948, Soil survey of Tazewell County, Virginia: U.S. Department of Agriculture, 176 p.
U.S. Army Corps of Engineers, 1971, Kanawha River comprehensive basin study, v. III, Appendix C - Hydrology: 273 p.
U.S. Environmental Protection Agency, 1979, National secondary drinking water regulations: Federal Register, v. 44, no. 140, Thursday, July 19, 1979, p. 42195-42202.
U.S. Forest Service, 1976, Map of Monongahela National Forest: U.S. Department of Agriculture Map, scale 1:250,000.
U.S. Geological Survey, 1973, Land use and land cover 1972-1973, Charleston, West Virginia; Ohio: U.S. Geological Survey Open-File Map 76-033-1, scale 1:250,000, Land Use and Land Cover Series.
U.S. Geological Survey, 1978, Land use and land cover 1973-1976, Bluefield, West Virginia; Virginia; Kentucky: U.S. Geological Survey Open-File Map 78-415-1, scale 1:250,000, Land Use and Land Cover Series.
U.S. Department of Agriculture, 1965, Soil survey of Monroe County, West Virginia: U.S. Soil Conservation Service, 114 p.
________1972, Soil survey of Greenbrier County, West Virginia: U.S. Soil Conservation Service, 95 p.
________1979a, General soil map of Virginia: U.S. Soil Conservation Service, scale 1:750,000.
________1979b, General soil map of West Virginia: U.S. Soil Conservation Service, scale 1:750,000.
Virginia Department of Conservation and Economic Development, Division of Water Resources, 1966, New River basin comprehensive water-resources plan: Planning Bulletin 201, 78 p.
________1967a, New River basin comprehensive water-resources plan: Planning Bulletin 202, 139 p.
________1967b, New River basin comprehensive water-resources plan: Planning Bulletin 203, 170 p.
________1967c, New River basin comprehensive water-resources plan: Planning Bulletin 204, 144 p.
________1967d, New River basin comprehensive water-resources plan: Planning Bulletin 205, 131 p.
________1967e, New River basin comprehensive water-resources plan: Planning Bulletin 206, 30 p.
Virginia Department of Labor and Industry, 1979, Coal mines licensed in 1979: 79 p.
________1980a, Annual report for year 1979: 110 p.
________1980b, Coal mines licensed in 1980: 95 p.
________1981a, Annual report for year 1980: 110 p.
________1981b, List of licensed coal mines in Virginia during 1981: 42 p.
Virginia State Water Control Board, 1972, New River basin phase I addendum - State river basin water-quality plan: Planning Bulletin 267, 126 p.
West Virginia Department of Mines, 1980a, Annual report and directory of mines: 269 p.
________1980b, Map of approximate locations of active deep mines in West Virginia: scale 1:250,000
________1981, Annual report and directory of mines: 240 p.
West Virginia Department of Natural Resources, 1980, Abandoned mine lands and affected water: Division of Reclamation Map, scale 1:250,000.
West Virginia Department of Natural Resources, 1980, West Virginia's State Reclamation Plan: Section 884.13 (F), p. 315-372.
West Virginia Geological and Economic Survey, 1979, Land-use statistics for West Virginia, part 1: Environmental Geology Bulletin 18, 23 p.
West Virginia Geological and Economic Survey, 1980, Land-use statistics for West Virginia, part 2: Environmental Geology Bulletin 18-1, 31 p.
West Virginia State Water Resources Board, 1980, Proposed administrative regulations of the State of West Virginia for water-quality standards on inter- and intrastate streams: 70 p.
Wetzel, Kim L., and Bettandorff, James M., 1982, Techniques for estimating streamflow characteristics in the eastern and interior coal provinces: U.S. Geological Survey Water-Supply Paper. (In press.)
Wyrick, G. G., and Borchers, J. W., 1981, Hydrologic effects of stress-relief fracturing in an Appalachian valley: U.S. Geological Survey Water-Supply Paper 2177, 51 p.

☆U.S. GOVERNMENT PRINTING OFFICE: 1983— 656-598