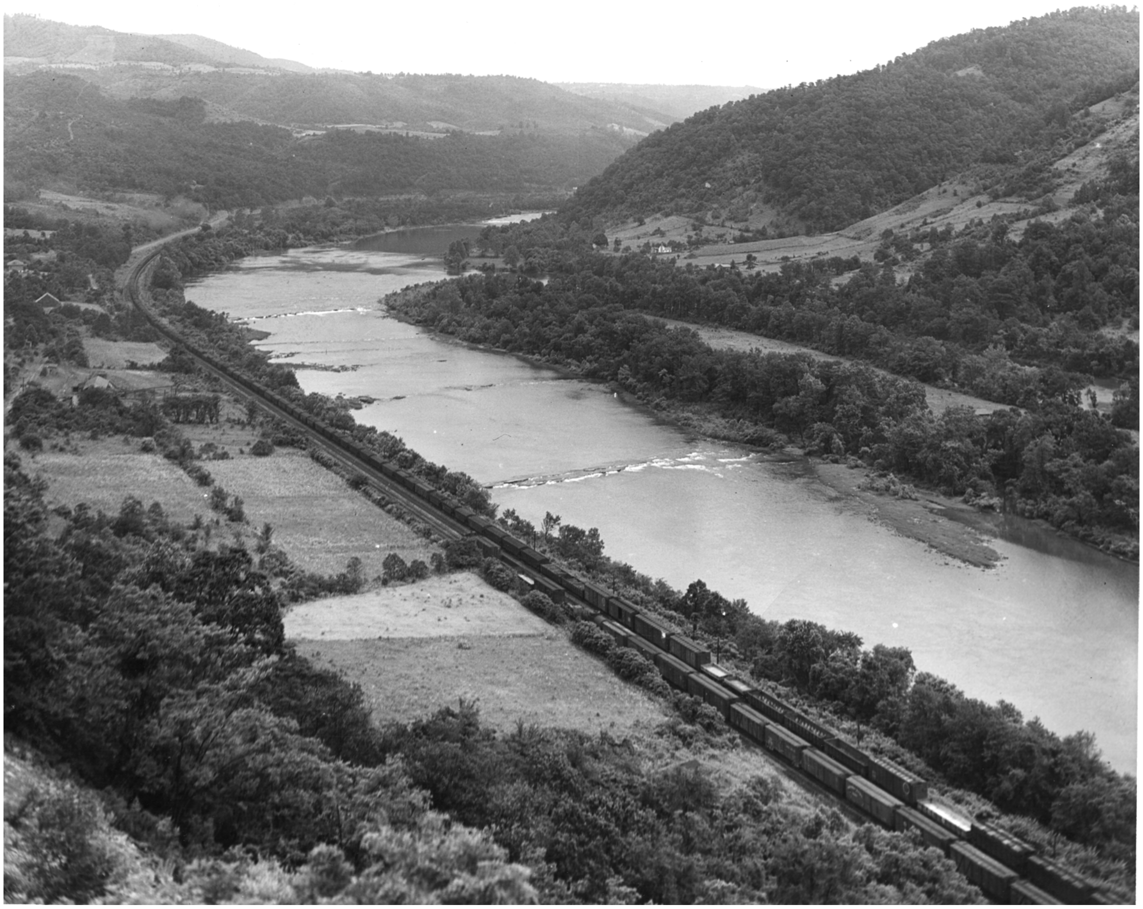
science for a changing world

Environmental Setting and Its Relations to Water Quality in the Kanawha River Basin

National Water-Quality Assessment Program

Water Resources Investigations Report 00-4020



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

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

Environmental Setting and Its Relations to Water Quality in the Kanawha River Basin

By Terence Messinger and C.A. Hughes

Water-Resources Investigations Report 00-4020

National Water-Quality Assessment Program

Charleston, West Virginia

2000

U.S. Department of the Interior
Bruce Babbitt, Secretary

U.S. Geological Survey

Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
11 Dunbar Street
Charleston, WV 25301

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

Information regarding the National Water-Quality Assessment (NAWQA) Program is available on the Internet via the World Wide Web. You may connect to the NAWQA Home Page using the Universal Resource Locator (URL): http://water.usgs.gov/nawqa/

Cover photo--The New River. Printed with permission from Charleston Newspapers, 1001 Virginia Street E. Charleston, WV 25301.

Foreword

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

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

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

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

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

The goals of the NAWQA Program are being achieved through investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

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

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

Robert M. Hirsch
Chief Hydrologist

Contents

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
acre	4,047	square meter
British thermal unit per pound	2,326	Joules per kilogram
cubic feet per second (ft^3/s)	0.02832	cubic meter per second
cubic feet per second per square mile ($ft^3/s/mi^2$)	0.01093	cubic meter per second per square kilometer
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.0929	meter squared per day
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
fluid ounce	29.57	milliliter (mL)
million gallons per day (Mgal/d)	1.547	cubic foot per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
pound (lb)	0.4536	kilogram
square mile (mi^2)	2.590	square kilometer
ton	0.9072	megagram

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F), and conversely, by use of the following equations:

$$^{o}F = (1.8 \times {}^{o}C) + 32 \qquad {}^{o}C = ({}^{o}F-32) \times 0.5555$$

Sea level: In this report, “sea level” refers to the 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 Sea Level Datum of 1929.

Abbreviated water-quality units: Chemical concentrations and water temperature are given in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Bacteria concentrations in water are given in colonies per 100 milliliters of sample (col/100 ml) for samples whose concentrations were determined by a membrane filtration method. Radon concentrations are expressed in picocuries (1×10^{-12} curies) per liter.

OTHER ABBREVIATIONS AND ACRONYMS USED IN THIS REPORT

GIRAS	Geographic Information and Analysis Systems
GIS	Geographic Information System
MRLC	Multi-Resolution Land Characteristics
NAWQA	National Water-Quality Assessment
OSM	Office of Surface Mining Reclamation and Enforcement
PAH	Polycyclic aromatic hydrocarbon
SMCRA	Surface Mine Control and Reclamation Act
USEPA	U. S. Environmental Protection Agency
USGS	U. S. Geological Survey
WVDEP	West Virginia Division of Environmental Protection
WVGES	West Virginia Geological and Economic Survey
>	greater than
<	less than

Scientific names of selected organisms present within the Kanawha River Basin

FUNGI

chestnut blight	*Cryphonectria parasitica*

PLANTS

MONOCOTS

corn	*Zea mays*
sorghum	*Sorghum propinquum*
wheat	*Triticum* sp.
rice	*Oryza sativa*

GYMNOSPERMS

red spruce	*Picea rubens*
pitch pine	*Pinus rigida*
table mountain pine	*Pinus pungens*
scrub pine	*Pinus albicaulis*

ANGIOSPERMS

sugar beet	*Beta procumbens*
cotton	*Gossypium* sp.
grape	*Vitis* sp.
aspen	*Populus* sp.
birch	*Betula* sp.
yellow birch	*Betula alleghaniensis*
sugar maple	*Acer saccharum*
beech	*Fagus grandifolia*
white oak	*Quercus alba*
post oak	*Quercus stellata*
blackjack oak	*Quercus marilandica*
scarlet oak	*Quercus coccinea*
black oak	*Quercus nigra*
chestnut oak	*Quercus prinus*
American chestnut	*Castanea dentata*
tulip poplar	*Liriodendron tulipifera*
white basswood	*Tilia americana*
tobacco	*Nicotiana* sp.
potato	*Solanum tuberosum*
tomato	*Lycopersicon esculentum*
strawberry	*Fragaria* sp.
cherry	*Prunus* sp.
apple	*Malus sylvestris*
almond	*Prunus dulcis*
pear	*Pyrus communis*
peach	*Prunus persica*
bean	*Phaseolus* sp.
soybean	*Glycine max*
alfalfa	*Medicago sativa*

ANIMALS

MOLLUSKS

pink mucket pearly mussel	*Lampsilis orbiculata*
giant floater	*Anodonta grandis*
squawfoot	*Strophitus undulatus*
pistolgrip	*Tritogonia verrucosa*
white wartyback	*Plethobasus cicatricosus*
clubshell	*Pleuroblema clava*
northern riffleshell	*Epioblasma torulosa rangiana*
fanshell	*Cyprogenia stegaria*
Asiatic clam	*Corbicula fluminea*
zebra mussel	*Dreissena polymorpha*

CRUSTACEANS

New River crayfish	*Cambarus chasmodactylus*
Appalachian brook crayfish	*Cambarus bartoni*

FISH

gizzard shad	*Dorosoma cepedianum*
common carp	*Cyprinus carpio*
rosyside dace	*Clinostomus funduloides*
blacknose dace	*Rhinichthys atratulus*
longnose dace	*Rhinichthys cataractae*
central stoneroller	*Campostoma anomalum*
creek chub	*Semotilus atromaculatus*
bigmouth chub	*Nocomis platyrhynchus*
river chub	*Nocomis micropogon*
spotfin shiner	*Cyprinella spiloptera*
white shiner	*Luxilus albeolus*
striped shiner	*Luxilus chrysocephalus*
rosyface shiner	*Notropis rubellus*
emerald shiner	*Notropis atherinoides*
silver shiner	*Notropis photogenis*
telescope shiner	*Notropis telescopus*
mimic shiner	*Notropis volucellus*
bluntnose minnow	*Pimephales notatus*
northern hog sucker	*Hypentelium nigricans*
smallmouth buffalo	*Ictiobus bubalus*
river redhorse	*Moxostoma carinatum*
golden redhorse	*Moxostoma erythrurum*
white sucker	*Catostomus commersoni*
channel catfish	*Ictalurus punctatus*
flathead catfish	*Pylodictis olivaris*
mottled sculpin	*Cottus bairdi*
rock bass	*Ambloplites rupestris*
smallmouth bass	*Micropterus dolomieu*
sharpnose darter	*Percina oxyrhynchus*
variegate darter	*Etheostoma variatum*
greenside darter	*Etheostoma blennioides*
banded darter	*Etheostoma zonale*
johnny darter	*Etheostoma nigrum*
rainbow darter	*Etheostoma caeruleum*
fantail darter	*Etheostoma flabellare*
freshwater drum	*Aplodinotus grunniens*

Environmental Setting and Its Relations to Water Quality in the Kanawha River Basin

by Terence Messinger and C. A. Hughes

Abstract

The Kanawha River and its major tributary, the New River, drain 12,233 mi^2 in West Virginia, Virginia, and North Carolina. Altitude ranges from about 550 ft to more than 4,700 ft. The Kanawha River Basin is mountainous, and includes parts of three physiographic provinces, the Blue Ridge (17 percent), Valley and Ridge (23 percent), and Appalachian Plateaus (60 percent). In the Appalachian Plateaus Province, little of the land is flat, and most of the flat land is in the flood plains and terraces of streams; this has caused most development in this part of the basin to be near streams. The Blue Ridge Province is composed of crystalline rocks, and the Valley and Ridge and Appalachian Plateaus Provinces contain both carbonate and clastic rocks. Annual precipitation ranges from about 36 in. to more than 60 in., and is orographically affected, both locally and regionally. Average annual air temperature ranges from about 43ºF to about 55ºF, and varies with altitude but not physiographic province. Precipitation is greatest in the summer and least in the winter, and has the least seasonal variation in the Blue Ridge Province.

In 1990, the population of the basin was about 870,000, of whom about 25 percent lived in the Charleston, W. Va. metropolitan area. About 75 million tons of coal were mined in the Kanawha River Basin in 1998. This figure represents about 45 percent of the coal mined in West Virginia, and about seven percent of the coal mined in the United States. Dominant forest types in the basin are Northern Hardwood, Oak-Pine, and Mixed Mesophytic. Agricultural land use is more common in the Valley and Ridge and Blue Ridge Provinces than in the Appalachian Plateaus Province. Cattle are the principal agricultural products of the basin.

Streams in the Blue Ridge Province and Allegheny Highlands have the most runoff in the basin, and streams in the Valley and Ridge Province and the southwestern Appalachian Plateaus have the least runoff. Streamflow is greatest in the spring and least in the autumn. About 61 percent of the basin's population use surface water from public supply for their domestic needs; about 30 percent use self-supplied ground water, and about nine percent use ground water from public supply. In 1995, total withdrawal of water in the basin was about 1,130 Mgal/d. Total consumptive use was about 118 Mgal/d. Surface water in the Blue Ridge Province is usually dilute (less than 100 mg/L dissolved solids) and well aerated. Dissolved-solids concentrations in streams of the Valley and Ridge Province at low flow are typically greater (150-180 mg/L) than those in the Blue Ridge Province. The Appalachian Plateaus Province contains streams with the most dilute (less than 30 mg/L dissolved solids) and least

dilute (more than 500 mg/L dissolved solids) water in the basin.

Coal mining has degraded more miles of streams in the basin than any other land use. Streams that receive coal-mine drainage may be affected by sedimentation, and typically contain high concentrations of sulfate, iron, and manganese. Other major water-quality issues include inadequate domestic sewage treatment, present and historic disposal of industrial wastes, and logging, which results in the addition of sediment, nutrients, and other constituents to the water.

One hundred eighteen fish species are reported from the Kanawha River system downstream from Kanawha Falls. Of these, 15 are listed as possible, probable, or known introductions. None of these fish species is endemic to the Kanawha River Basin. The New River system has only 46 native fishes, the lowest ratio of native fishes to drainage area of any river system in the eastern United States, and the second-highest proportion of endemic fish species (eight of 46) of any river system in the eastern United States.

Introduction

In 1991, the U.S. Geological Survey (USGS) began a National Water-Quality Assessment (NAWQA) Program to (1) document the quality of the Nation's water resources (2) define water-quality trends, and (3) identify major factors that affect water quality (Gilliom and others, 1995). In addressing these goals, the program produces water-quality information useful to national, State, and local policymakers and water managers.

The Kanawha-New River study unit is one of the 59 hydrologic systems that comprise NAWQA. Study units range from less than 1,000 to more than 60,000 mi^2 and represent about two-thirds of the Nation's water use and population. Assessment activities began in 20 study units in 1991, in 16 study units in 1994, and in 17 study units in 1997; assessment activities are not currently scheduled in the remaining six study units. Each study-unit investigation is to have a 10-year life cycle, which includes three years of continuous and intensive data collection and analysis and four years of intermittent and less intensive water-quality monitoring.

Assessment of the Kanawha-New River study unit began in 1994. The Kanawha-New River study unit consists of the Kanawha River Basin (fig.1). The Kanawha River and its major tributary, the New River, drain 12,233 mi^2 in West Virginia (8,424 mi^2), Virginia (3,044 mi^2), and North Carolina (765 mi^2) (Eychaner, 1994).

Purpose and Scope

This report describes the environmental setting of the Kanawha River Basin and the natural and human factors that are considered to affect current (1999) water-quality conditions within the basin. The first two sections of this report describe natural and cultural characteristics of the basin. The final section identifies the water-quality and ecological implications of these characteristics. This report is based on selected data and reports from Federal, State, and local agencies and industries.

Relation to Other Reports and Information on the World Wide Web

This report is the second of two that summarizes previously available information used for planning and design of sampling activities for the study unit. In the first, Messinger (1997) described and summarized the findings of interpretive studies of ground- and surface-water quality and aquatic ecology in the Kanawha River Basin. This report describes the natural and human factors that are believed to have large-scale or regional control or influence on the current (1999) water quality of the basin.

Most NAWQA study units maintain general public sites on the World Wide Web. The Kanawha-New River study unit site can be accessed at http://wv.usgs.gov/. This site provides information on the results of surface-water, ground-water, and ecological studies in the basin. It also provides links to other NAWQA study units and the USGS Water Resources Division site on the World Wide Web.

Acknowledgments

Appreciation is extended to USGS colleagues Matthew Cooke, Charleston, W. Va.; Michael Eberle, Columbus, Oh.; James Eychaner, Charleston, W. Va.; Lisa Ham, Baltimore, Md.; James Parnell, Columbus, Oh.; and James Sams, Pittsburgh, Pa. for their valuable comments and input during the preparation of this

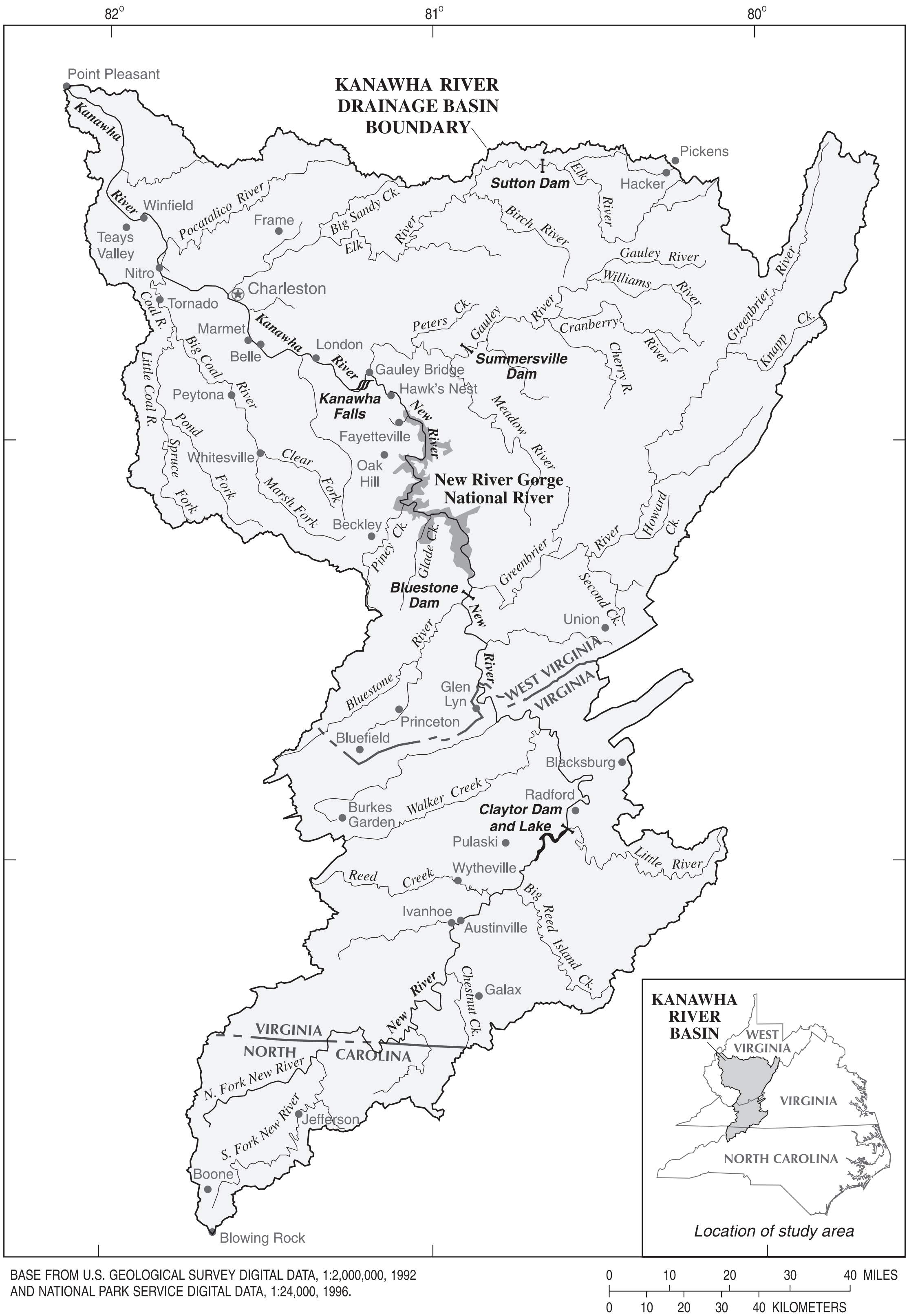


Figure 1. Streams, towns, and other selected features of the Kanawha River Basin.

document. Steve Bolssen and Katherine Paybins, USGS, Charleston, W. Va., provided geographic analysis and illustrations, and David Eaton, USGS, Charleston, W. Va., helped compile information presented in this report.

Environmental Setting of the Kanawha River Basin

A variety of natural conditions and human activities interact to determine water quality in the Kanawha River Basin. To understand water quality, an understanding of these conditions, activities, and interactions is needed. Natural conditions that affect background water-quality conditions include physiography, geology, soils, and climate. Human activities are determined or constrained by natural conditions, and include coal mining, forest management, agriculture, water use, and water management. Biological communities and water chemistry affect and are affected by both natural and human factors.

Physiography

The Kanawha River Basin is mountainous, and entirely within the Appalachian Highlands Division (Fenneman, 1938). The basin drains three physiographic provinces, from north to south the Appalachian Plateaus Province, the Valley and Ridge Province, and the Blue Ridge Province (fig. 2) (Fenneman and Johnson, 1946). The three physiographic provinces account for 60, 23, and 17 percent of the basin, respectively.

The Appalachian Plateaus Province is an area in which differential erosion of a thick, uplifted section of Paleozoic sedimentary rocks created a series of dissected plateaus capped by resistant rock layers, commonly sandstone (Fenneman, 1938). The rocks are only slightly deformed and have not undergone metamorphism. The Kanawha River Basin drains the Kanawha Section of the Appalachian Plateaus Province and a small part of the Allegheny Mountain Section, although most of the northeastern part of the basin is near the border between the Kanawha and Allegheny Mountain Sections. This border is indistinct and based on a separation of areas dendritically dissected (Kanawha Section) and areas where erosional forms are more or less controlled by structural features (Allegheny Mountains). The transition area between the sections is large. This subset of the Kanawha Section of the Appalachian Plateaus, in addition to the small area within the Allegheny Mountain Section, is referred to in this report as the “Allegheny Highlands,” and includes the part of the basin in Webster, Randolph, and Pocahontas Counties in West Virginia. When the term “Appalachian Plateaus” is juxtaposed in this report with the term “Allegheny Highlands,” it refers only to the rest of province. When topics are discussed in this report where differences between these two settings are not substantial, the settings are discussed together and referred to as the “entire Appalachian Plateaus Province.” Through the entire Appalachian Plateaus Province, streams follow a dendritic drainage pattern with stream-channel slopes being greatest in areas of greatest altitude.

The lowest altitudes in the Kanawha River Basin are about 550 ft, near Point Pleasant, W. Va. Ridge-top altitude at the western edge of the Kanawha Section, near the downstream outlet of the Kanawha River, is about 1,200 ft. Larger streams in this area generally have bed altitudes of less than 600 ft, but local relief generally is 300 ft to 500 ft. Plateau altitudes rise to about 3,000 ft near the southern border with the Valley and Ridge Province, near Princeton, W. Va., and is greatest in the Allegheny Highlands, where some peaks are at altitudes as high as 4,700 ft. Local relief is generally greatest in areas with the highest altitudes, and is more than 1,000 ft in much of the area near the Allegheny Front, the eastern boundary of the Appalachian Plateaus Province.

The Valley and Ridge Province consists of long, linear, narrow belts of northeast-trending ridges, tens of miles long, with separate intervening elongate valleys, that are strongly folded and faulted (Fenneman, 1938). The New River drains the Middle Section of the Valley and Ridge Province. Structurally, the province has been intensely deformed into tight, plunging folds where sedimentary rocks were thrust faulted by orogenic events (folding and deformation) at the end of the Paleozoic Era (Cook and others, 1979). Generally, coarse clastic sedimentary rock supports the ridges, and less resistant shale and limestone underlie the valleys. Stream drainage in the Valley and Ridge Province is generally trellised or parallel (Fenneman, 1938). Altitudes in the Valley and Ridge Province range from about 1,500 ft at Glen Lyn, Va., to more than 4,000 ft on one ridge near Burkes Garden in Tazewell County, Va. Valley floors are generally less than 1,000 ft lower than the adjacent ridges. The highest altitudes in the entire Valley and Ridge Province,

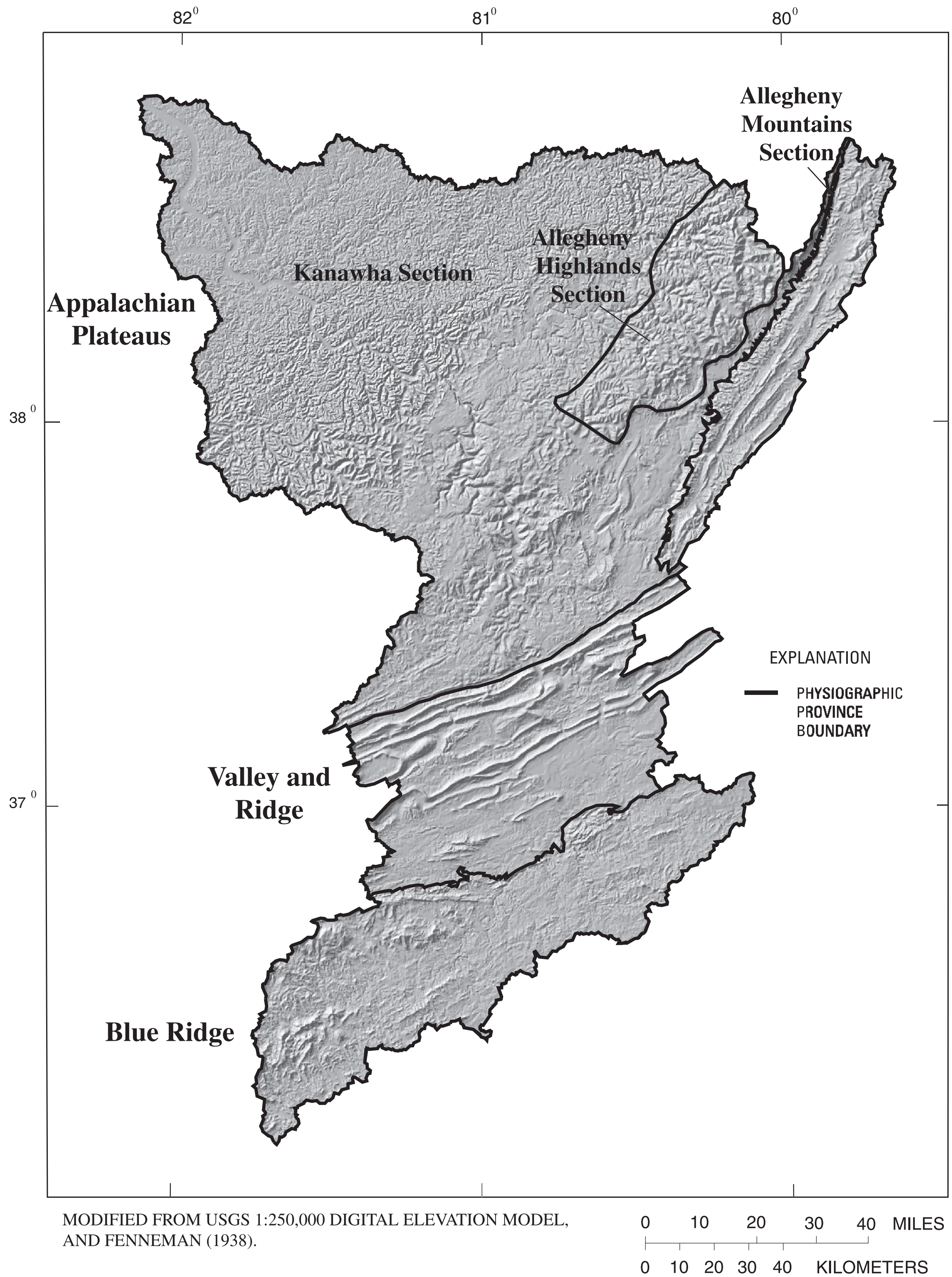


Figure 2. Physiography of the Kanawha River Basin.

which extends from New York to Alabama, are in the Kanawha River Basin. Within the basin, ridge altitudes are generally lower than the maximum elevations in the Blue Ridge and Appalachian Plateaus Provinces. The boundary between the Valley and Ridge Province and the Appalachian Plateaus Province is indistinct in the Kanawha River Basin, in contrast to the distinct boundary typical between these two provinces from Pennsylvania to Alabama.

The Blue Ridge Province contains a series of metamorphic and igneous (crystalline) rocks formed in mobile crustal belts. The New River drains the Southern Section of the Blue Ridge Province. Most of the Precambrian core of the region is gneiss and schist (LeGrand, 1988). The orientation of the Blue Ridge Province as a whole is generally independent of the orientation of structural features, because rocks are highly metamorphosed and similar in hardness (Fenneman, 1938). The Blue Ridge Province lies to the southeast of the Valley and Ridge Province. It is characterized by metamorphic rocks exposed in thrust sheets and by the absence of broad valleys between ridges. The border between the Blue Ridge and Valley and Ridge Provinces is determined by the limit of strong overthrust of metamorphosed rocks onto the unaltered sedimentary rocks of the Valley and Ridge Province. Altitude of the Kanawha River Basin within the Blue Ridge Province ranges from about 1,700 ft to 4,500 ft.

Although the oldest exposed rocks in the basin are in the Blue Ridge Province, younger rocks underlie these rocks (Cook and others, 1979). The Blue Ridge and neighboring Piedmont Provinces were thrust as a sheet about 150 mi over younger sedimentary rocks that are continuous with the strata that form the Valley and Ridge Province. In Mississippian, Pennsylvanian, and Permian time, about 360-240 million years ago, the African and North American plates of the earth's crust collided, in an event called the Alleghenian orogeny. This event formed the present Appalachian Mountains, caused the Blue Ridge Province to reach its present position relative to the Valley and Ridge Province, and caused the extensive folding and thrusting in the Valley and Ridge Province.

Ecoregions

Ecoregions are considered to be regions of relative homogeneity in ecological systems or in relations between organisms and their environments (Omernik, 1987). The Kanawha River Basin drains four of Omernik's Level III ecoregions: the Blue Ridge Mountains, Central Appalachian Ridges and Valleys, Central Appalachians, and Western Allegheny Plateau (fig. 3). Ecoregions categorize homogeneous areas based on landscape features such as land-surface form, potential natural vegetation, land use, and soil classification. These features are discussed within this report.

Geologic Setting

About 90 distinct geologic formations are exposed in the basin (Cardwell and others, 1968; North Carolina Geological Survey, 1985; Virginia Division of Mineral Resources, 1963, 1993a, 1993b).[1] These formations include the crystalline, carbonate, and clastic rock types. Many of the formations are exposed in relatively small areas in the Valley and Ridge Province and are not discussed here. The stratigraphy in the Appalachian Plateaus and Valley and Ridge Provinces is similar, in that younger rocks consistently overlie older rocks. Older surface strata are generally to the south and younger strata to the north in these provinces (fig. 4). The stratigraphy of the Blue Ridge Province is more complex because of its tectonic history. As was discussed above, faulted, folded, and thrusted metamorphic and igneous Cambrian and Precambrian rocks overlie younger sedimentary rocks.

Marine and terrestrial sedimentary rocks in the basin range from Cambrian to Permian age and unconformably overlie an older crystalline basement. These stratified rocks form a large, wedge-shaped mass, which is thickest near the eastern edge of the basin and becomes progressively thinner to the west (Seaber and others, 1988).

Generally, within the Valley and Ridge Province the oldest rocks are to the south and east and the youngest rocks are to the north and west, although some exceptions have been caused by folding and subsequent erosion. Cambrian and Ordovician clastic and carbonate rocks are exposed in tightly folded and faulted layers in the Valley and Ridge Province. Generally west of these layers, Silurian and Devonian clastic rocks and lesser carbonate rocks lie in a complexly folded and faulted belt, which extends westward to the

[1]The formation names used in this report are those used in the State geologic maps, and may not be consistent across State boundaries or with names used by the U.S. Geological Survey. In cases where nomenclature is inconsistent among States, all the names used are given.

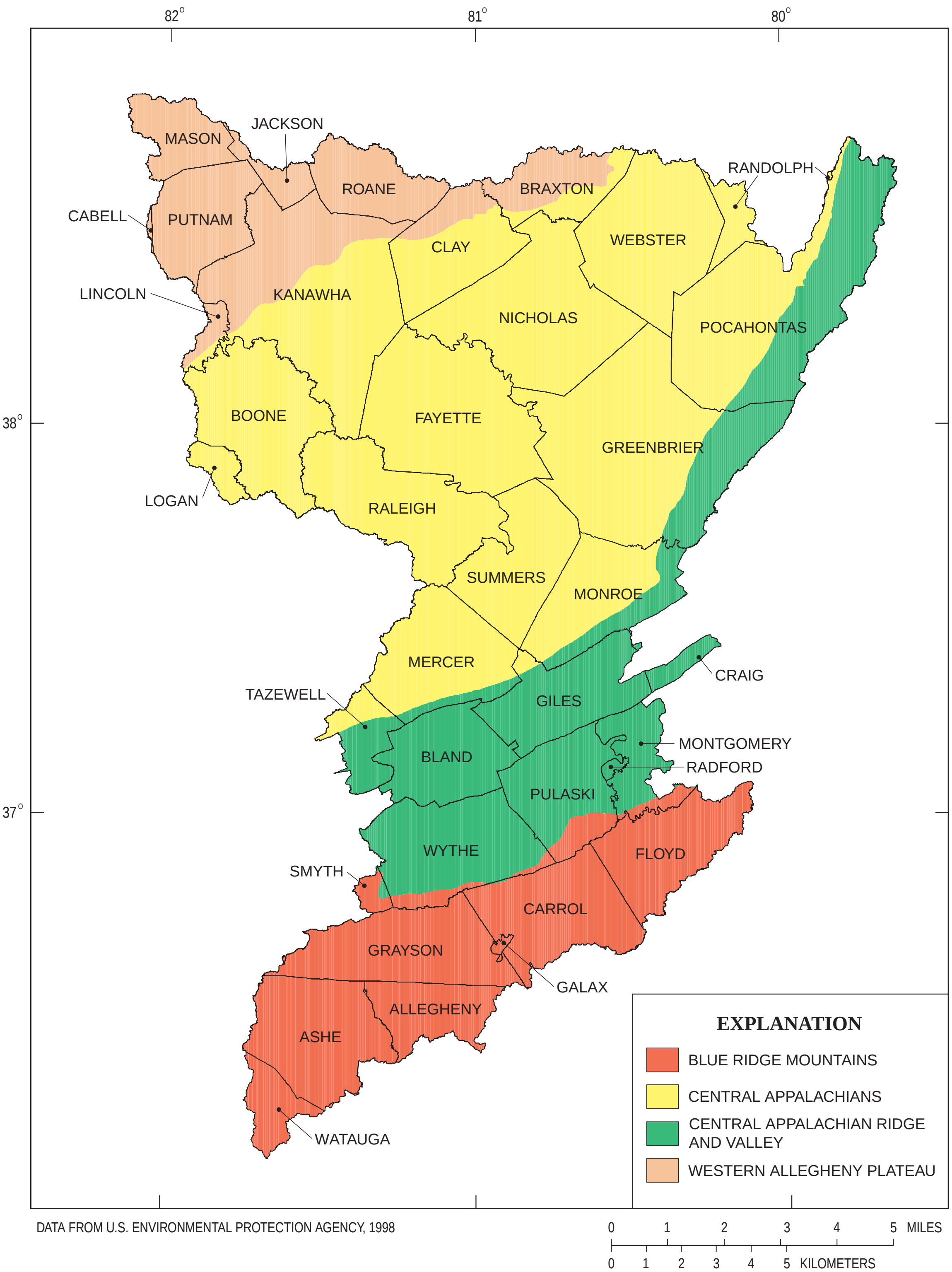
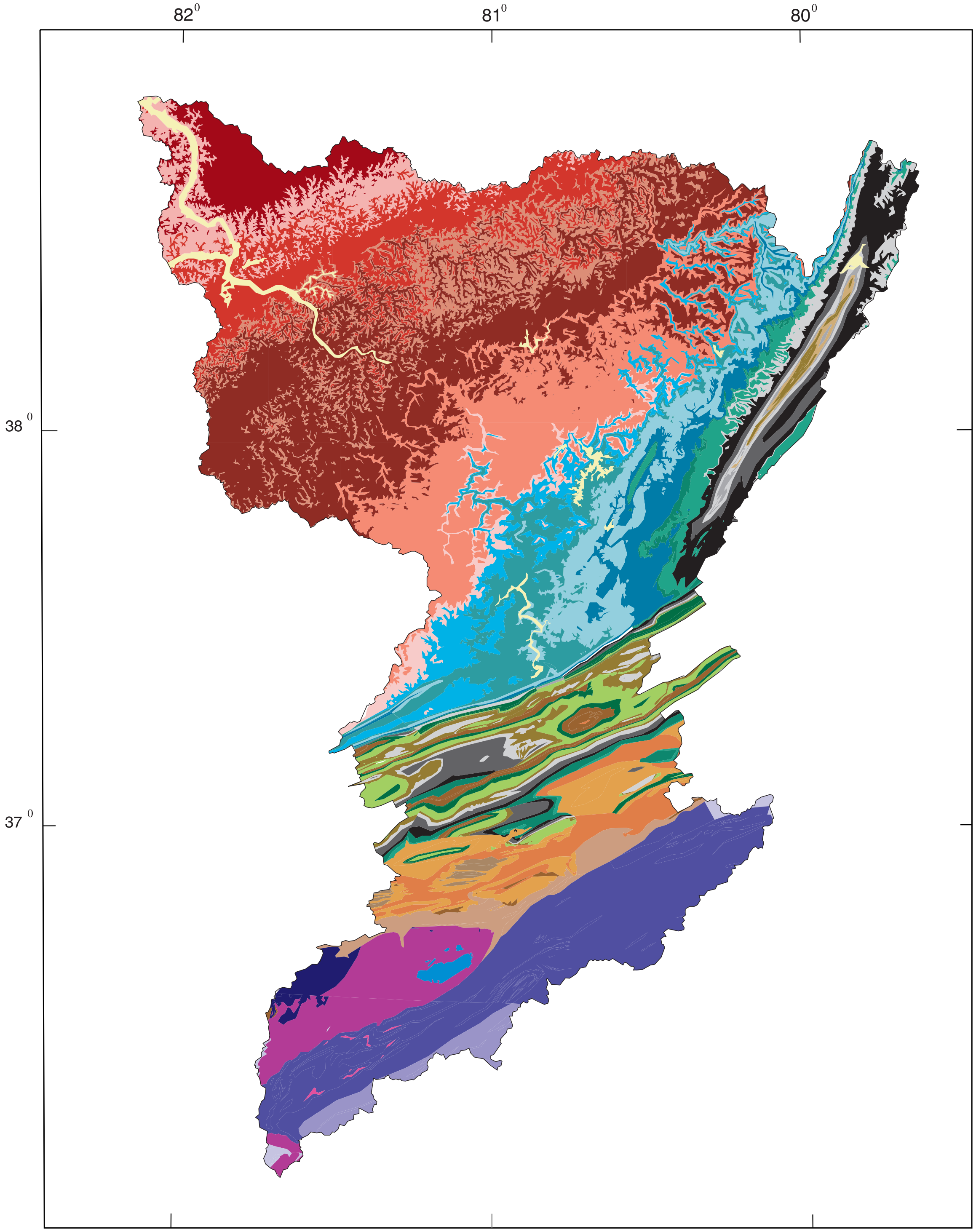


Figure 3. Ecoregions and counties of the Kanawha River Basin.



DATA FROM CARDWELL AND OTHERS (1968), VIRGINIA DIVISION OF MINERAL RESOURCES (1963), AND NORTH CAROLINA GEOLOGICAL SURVEY (1985). SMALLEST MAPPED FORMATIONS ARE ABOUT 7 MI^2, AND OTHER MAP UNITS ARE GROUPED BY AGE AND ROCK TYPE .

0 10 20 30 40 MILES
0 10 20 30 40 KILOMETERS

Figure 4. Selected geologic formations of the Kanawha River Basin.

EXPLANATION for Figure 4. Selected geologic formations of the Kanawha River Basin.

PERIOD		
Formation or Group		Rock type
QUATERNARY		
Alluvium		unconsolidated sediment
PERMIAN OR PENNSYLVANIAN		
Greene, Washington and Waynesburg Formations (Dunkard Group)		sandstone, shale
PENNSYLVANIAN		
Uniontown and Pittsburgh Formations (Monongahela Group)		sandstone, siltstone, shale, coal
Casselman and Glenshaw Formations (Conemaugh Group)		shale, siltstone, sandstone
Allegheny Formation	Pottsville Group	sandstone, siltstone, shale, coal
Kanawha Formation	Pottsville Group	sandstone, shale, coal
New River Formation	Pottsville Group	sandstone, shale, coal
Pocahontas Formation	Pottsville Group	sandstone, shale, coal
MISSISSIPPIAN		
Bluestone and Princeton Formations	Mauch Chunk Group	shale, sandstone
Hinton Formation	Mauch Chunk Group	shale, sandstone
Bluefield Formation	Mauch Chunk Group	shale, sandstone
Greenbrier Group		marine limestone, shale
sandstone, undivided		sandstone
shale, undivided		shale
DEVONIAN		
Chemung Group		shale, sandstone
Brallier Formation		shale, sandstone
sandstone, undivided		sandstone
shale, undivided		shale
SILURIAN		
limestone, undivided		limestone
sandstone, undivided		sandstone
ORDOVICIAN		
limestone-dolomite, undivided		limestone, dolomite
sandstone, undivided		sandstone
shale, undivided		shale
CAMBRIAN		
Rome Formation		limestone, dolomite, shale
Chilowhee Group		sandstone
Cambrian, undivided		limestone, dolomite
dolomite, undivided		dolomite
sandstone		sandstone
PRE-CAMBRIAN		
Late Proterozoic Igneous Rocks		granite
Intrusive meta-ultramafic rock		dunite
Metamorphic rocks		metamorphics, granite, volcanics
Mt. Rogers Formation		metafelsite, metagraywacke, volcanics
Alligator Back Formation		granite, granitic biotite gneiss
Ashe Metamorphic Suite		muscovite-biotite gneiss, amphibolite
Elk Park Plutonic Group		biotite quartz monzonite, biotite augen gneiss

Allegheny Front (Cannon and others, 1994). All layers east of the Allegheny Front were complexly folded and faulted during the Alleghenian orogeny, so that most beds in the Valley and Ridge Province include steep dips.

Mississippian rocks underlie the Allegheny Front and a broad belt to its west. These rocks consist mostly of mixed marine and nonmarine clastic rocks but include the Greenbrier Formation, a major marine limestone unit. The rocks are gently and broadly folded. The rest of the basin is underlain by cyclic sequences of mostly nonmarine sandstone, siltstone, shale, minor limestone, and coal, ranging from Pennsylvanian to Early Permian in age. These rocks constitute the major coal-producing sequences in the study unit.

Crystalline rocks. The oldest rocks in the study unit are metamorphic crystalline rocks exposed in northeast-trending belts in the Blue Ridge Province. They consist of granitic gneiss, schist, phyllite, slate, and metavolcanic rocks. The rocks range in chemical composition between that of granite (silica and silicates of aluminum and potassium) and that of gabbro (silicates of aluminum, iron, magnesium, and calcium).

Crystalline rocks can be divided into two chemical groups (LeGrand, 1988). The first group is made up of light-colored minerals, and includes granite, granite gneiss, mica schist, slate, and rhyolite flow and tuffs, and is similar to granite in composition. The second group is made up of dark-colored minerals, and includes gabbro, diorite, hornblende gneiss, and andesite flows and tuffs. These rocks resemble gabbro in composition. The granite group yields a soft, slightly acidic water that generally contains less than 100 mg/L of dissolved solids; the gabbro group yields a hard, slightly alkaline water that commonly contains more than 200 mg/L of dissolved solids.

The oldest unit cropping out extensively in the Blue Ridge Province in the basin is the Elk Park Plutonic Group, an exposed part of the crystalline basement (Virginia Division of Mineral Resources, 1993a). This formation consists of biotite quartz monzonite and biotite augen gneiss (North Carolina Geological Survey, 1985). These rocks are of the granitic rock group. Granitic rocks of other metamorphic basement formations are drained over a small area by the headwaters of the South Fork New River in North Carolina.

The Ashe Formation, or Ashe Metamorphic Suite of the stratified Blue Ridge Anticlinorium, is the most extensive formation in the Blue Ridge Province in the basin (fig. 4) (Virginia Division of Mineral Resources, 1993a; North Carolina Geological Survey, 1985). The Ashe Formation is at the surface in the southeastern part of the Blue Ridge Province in the basin. The two principal subunits of the Ashe Formation are a muscovite-biotite gneiss and an amphibolite. The muscovite-biotite gneiss is locally sulfidic, interlayered and gradational with mica schist, minor amphibolite, and hornblende gneiss, and contains intrusions of granitic rock. The amphibolite is equigranular, and massive to well-foliated. It contains Devonian to Silurian pegmatite intrusions, which were historically mined for mica, as well as some gemstones. The muscovite-biotite gneiss is of the granite group of rocks, and the amphibolite and hornblende gneiss are of the diorite group of rocks. Some Blue Ridge streams in Virginia drain granitic rocks in the Alligator Back Formation of the Blue Ridge Anticlinorium.

Carbonate rocks. Carbonate rocks, limestone and dolomite, are commonly associated and are formed by consolidation of carbonate sediments formed from living organisms. Carbonate sediments accumulate in a variety of environments, both marine and nonmarine (Seaber and others, 1988). Karst topography forms by dissolution, in areas where limestone and dolomite crop out. Karst topography is characterized by sinkholes, caves, and underground drainage systems. In the Kanawha River Basin, most carbonate rocks at land surface are in the Valley and Ridge Province and the southern part of the Appalachian Plateaus Province. Carbonate sequences of the Valley and Ridge Province were deposited during the Cambrian through Mississippian periods, and they appear in long, narrow belts of northeast-trending ridges and valleys. Most ground water flows in these carbonate rocks from ridge to valley, across strike until the water either discharges directly to local streams or is intercepted and routed along strike by a highly permeable layer or zone (Seaber and others, 1988).

The most extensive carbonate rock formation of the Valley and Ridge Province part of the basin is the Rome Formation (fig. 4; Virginia Division of Mineral Resources, 1993a). The Rome Formation is Cambrian, and includes dusky-red and green shale and siltstone, along with limestone and dolomite. It is mapped with an overlying shale formation. These formations are at the surface near Roseville, Va. Several other dolomite and limestone formations of various ages are located in the Valley and Ridge Province.

The Greenbrier Formation is the most important carbonate unit in the Appalachian Plateaus part of the basin (Cardwell and others, 1968). This Mississippian formation is at depth throughout the Appalachian Plateaus Province, and is at surface near the Greenbrier River (fig. 4; Cannon and others, 1994). This carbonate formation is about 900 ft thick in the area where it is at the surface. The Greenbrier Formation is principally marine limestone, and contains marine and nonmarine red and gray shale and some minor sandstone beds. It is known for many large, well-developed caves (Kastning and Kastning, 1995). About 60 total caves, and eight caves greater than 10 mi long, are known in the Greenbrier Formation within the basin.

Clastic rocks. Clastic rocks include sandstone, conglomerate, siltstone, and shale, and in the basin are associated with interbedded coal and minor limestone and dolomite. The ridges and some of the valleys of the Valley and Ridge Province are composed of resistant Cambrian to Mississippian clastic rocks. The oldest clastic rocks in the study unit are Cambrian rocks from the Valley and Ridge Province. The two most extensive clastic formations cropping out in the Valley and Ridge Province are Devonian shales, the Brallier and Chemung Formations (Cardwell and others, 1968; Virginia Division of Mineral Resources, 1993a). The Brallier Formation is made up of micaceous shale, sandstone, and siltstone. It is overlain by the Chemung Formation. The Chemung Formation is dark gray and greenish gray shale and fine-grained sandstone. It is the most widely exposed formation in the Valley and Ridge Province within the basin (about 380 mi^2), and is at the surface in Virginia and more extensively in West Virginia.

The Appalachian Plateaus Province is primarily clastic rocks that range in age from Mississippian to Upper Pennsylvanian or Lower Permian. Three clastic Mississippian formations are at the surface in more than 400 mi^2 of the basin: the Hinton, Bluefield, and Princeton Formations (Cardwell and others, 1968). All three formations are part of the Mauch Chunk Group, and at the surface in the southern part of the Appalachian Plateaus. The Hinton Formation is composed of red, green, and medium-gray shale and sandstone with a few thin limestone beds. The Bluefield Formation is red and green shale and sandstone, with scattered, thin limestone lenses. The Princeton Formation is mostly red, green, and medium-gray shale and sandstone.

The Pennsylvanian strata in the basin contain massive beds of sandstone separated by thinner beds of shale, siltstone, limestone, and coal (Cardwell, 1975). They range from 3,000 to 3,800 ft thick in the central part of West Virginia and contain more than 60 separate coal seams. The Pennsylvanian strata were deposited in a delta in cycles. The marine limestone formed at times when the delta surface was below sea level; the peat during long periods of swamp conditions when little sediment was deposited from mountains to the east (and later converted to coal, under pressure), and the clastic materials were washed in at times of vigorous clastic supply to the deltas. The two most extensive formations in the basin are Pennsylvanian-aged, the New River Formation (1,200 mi^2), and the Kanawha Formation (1,900 mi^2) (Cardwell and others, 1968). These two formations and a third, older one, the Pocahontas Formation, comprise the Pottsville Group, the oldest Pennsylvanian Group in the basin. The Pocahontas Formation is about 50 percent sandstone, with some shale, siltstone, and coal. It includes the Pocahontas Nos. 1-7 coal seams, which are highly desirable metallurgical coals, and have largely been mined out in the basin. The New River Formation is predominantly sandstone, with some shale, siltstone, and coal, although it grades to nearly all sandstone in the subsurface (Cardwell and others, 1968). It includes the Sewell and Fire Creek coal seams, which are mined extensively. The Kanawha Formation is at the surface in the basin in a band from Logan County northwest through Webster County. It is about 50 percent sandstone, and the rest is shale, siltstone, and coal. It contains several marine zones, and is more shaly westward at the surface. The Kanawha Formation contains 13 coal seams, including the Upper and Lower Mercer, Cedar Grove, Alma, No. 2 Gas, and Eagle, which are all mined extensively.

Other extensive Pennsylvanian units include the Allegheny Formation (680 mi^2), Conemaugh Group (780 mi^2), and the Monongahela Formation (400 mi^2). The Allegheny Formation is a cyclic sequence of sandstone, siltstone, shale, limestone, and coal, and includes the Upper Freeport and Upper and Lower Kittaning (No. 5 Block) coals, which are among the most extensively mined in West Virginia. The Conemaugh Group is at the surface in the northwest part of the basin. It is mostly nonmarine, and consists of cyclic sequences of red and gray shale, siltstone, and sandstone, with thin limestones and coals. The Monongahela Formation is a nonmarine cyclic sequence of sandstone, siltstone, red and gray shale, limestone, and coal. Although it contains the Pittsburgh coal seam, which is mined very extensively to the north of the basin, little coal is present in or mined from the Monongahela Formation within the basin.

The youngest rocks in the basin are the Upper Pennsylvanian or Lower Permian Dunkard Group that outcrop in the northwestern corner of the basin in Jackson and Mason Counties, W. Va. The group is about 450 ft thick and consists of interbedded sandstone, limey shale with thin limestone interbeds, and coal (Ehlke and others, 1982).

Mineral deposits and extraction. The Kanawha River Basin contains more than 650 industrial and metallic mineral deposits exclusive of coal, oil, and gas (Babitzke and others, 1982). Regionally, six major industrial commodities are currently produced from raw materials extracted from the basin (Cannon and others, 1994). These materials include clay and shale, construction sand and gravel, crushed stone, and lime. All these materials are present in large quantities and generally are widespread. Most of the gravel, crushed stone, and lime are produced from limestone deposits in the Greenbrier Formation and in the Valley and Ridge Province; production of the other commodities is scattered throughout the basin.

The basin contains other nonmetallic minerals in concentrations that are geochemically or commercially important. Since prehistoric times, mica was mined from more than 70 sites in the Jefferson-Boone area in North Carolina with mining ending around 1960 (Lesure and Shirley, 1968). Phosphate minerals containing as much as about 25 percent phosphorus are known in several minor shale, limestone, and dolomite formations of the Valley and Ridge Province (Wedow and Stansfield, 1968). Gypsum deposits are present in isolated masses along narrow outcrops of one Mississippian shale formation in Smyth, Wythe, Pulaski, and Montgomery Counties in Virginia; the active gypsum mine in Smyth County is not in the basin (Withington and Fish, 1968; U.S. Geological Survey, 1999a). Other small gypsum deposits are in Pocahontas County, West Virginia.

Historically, metal mining was important in the Austinville lead-zinc district of southwestern Virginia, in Wythe County. Lead was mined from this area since 1756, and this was one of the few lead sources for the Confederacy during the Civil War (Foley and Craig, 1989). After the war, zinc production from this district became more important than lead production and remained so until the mines closed. During 230 years of production, over one million tons of zinc metal and 200 thousand tons of lead metal were extracted from over 30 million tons of ore mined from Austinville. Some zinc was also mined in nearby Ivanhoe and Pulaski during the late nineteenth and early twentieth centuries (Wedow and others, 1968). Commercial zinc mining ended here in 1981 when an underground zinc mine at Austinville closed down because of a depressed market (Foley and Craig, 1989).

Copper, iron, sulfur, and manganese ores have also been mined in the basin (U.S. Geological Survey and U.S. Bureau of Mines, 1968). Copper sulfide was mined for its copper content from Ashe County, N.C. Iron was mined from igneous deposits in Ashe and Alleghany Counties, N.C., and Carroll and Grayson Counties, Va., and from sedimentary brown ore deposits in Pulaski and Smyth Counties, Va., in the late 1800’s and early 1900’s. Iron sulfide was mined for sulfur near Galax, Va., from 1905 until 1962. Manganese deposits in Smyth and Bland Counties, Va., and Monroe County, W. Va., have never been commercially viable, but were mined during World War I and II. Concentrated deposits of rare-earth minerals in Ashe County, N.C. have never been mined.

Commercially exploitable saline ground water is present beneath much of the basin, and is at relatively shallow depth in the northwest part of the basin (Foster, 1980). The salt industry was the first West Virginia mineral industry to be developed; by 1846, the Charleston area produced more than 3 million bushels of salt per year (Eggleston, 1996b). Although the Kanawha salt industry declined in importance after 1861, World War I increased demand for chemical products such as chlorine and hydrochloric acid, which can be derived from salt. The availability of chloride for conversion to chlorine was a major factor in the development of the chemical industry in the Charleston area.

Coal is the most economically important mineral extracted in the basin. Coal has been commercially mined in the basin since the early nineteenth century (Messinger, 1997). The most extensive and commonly-mined coal beds in the basin are in the Pennsylvanian-age rocks of the Allegheny, Kanawha, New River, and Pocahontas Formations (fig. 4). Coal mining practices, economics, regulation, and the effects of coal mining on streams and ground water are discussed in greater detail elsewhere in this report.

The oil and natural gas industry in West Virginia began as an outgrowth of the salt industry (Eggleston, 1996a). In the early 1800's, saltmakers frequently hit oil or gas in their drilling, but considered it a nuisance. Oil was diverted by salt manufacturers to the Kanawha River, which boatmen called "Old Greasy." Gas was first struck in a well drilled for salt at Charleston in 1815, and the Kanawha Valley region became a pioneer in the discovery of petroleum by drilling and the use of oil and gas on a commercial scale. The oil industry in West Virginia reached peak production of 16 million barrels in 1900. Although the oil industry then declined, natural gas production grew. From 1906 to 1917, West Virginia was the leader in gas production in the United States, and although production has fluctuated, natural gas production remains economically important in the Appalachian Plateaus in the 1990's. In 1997, counties in the Kanawha River Basin contained about 11,900 active gas wells that produced about 64.7 billion cubic feet of natural gas (West Virginia Geological and Economic Survey, 1999). The same year, the basin also contained about 2,300 active oil wells that produced 533 thousand barrels of oil.

Soil. Soil is a three-phase system of liquid, gas, and unconsolidated solids that is capable of growing plants (Singer and Munns, 1987). Soils have two solid components, minerals derived from weathered rocks, and organic materials derived from plants and microorganisms. Soil development is generally affected by bedrock composition, climate, biological activity, topography, and time. Relative amounts of sand, silt, and clay strongly affect the infiltration and drainage characteristics of a particular soil. Generally, a soil with a small percentage of silt and clay will have a high infiltration rate and good drainage.

Sandy soils are characteristic of steep slopes of the Valley and Ridge and Blue Ridge Provinces. Clay soils have developed on moderate to gentle slopes in the Blue Ridge Province and limestone valleys of the Valley and Ridge Province (Natural Resources Conservation Service, 1993). Soils in the Appalachian Plateaus Province are generally thin (less than 30 in. thick), sandy or silty (less than 30 percent clay), and generally acidic.

Soils are classified in a taxonomy from the soil series, the narrowest class, to soil order, the broadest class. Detailed soil maps that classify all soils into soil series have been prepared for most counties in the Kanawha River Basin. These maps are intended to provide sufficient information for decisions at the scale of a single farm or building. Soil science has developed throughout the twentieth century, and the present soil taxonomic system was adopted in the 1970's. County soil surveys are being completed and published on a continuing basis. Many counties have been re-surveyed since an original survey early in the twentieth century. These detailed maps are compiled in the Soil Survey Geographic (SSURGO) data base (Natural Resources Conservation Service, 1993). Recent soil surveys include information on soil permeability, density, and chemistry.

At the county level, soils are grouped into soil associations, which are unique natural landscapes with a distinct pattern of soils, relief, and drainage. The map of Kanawha County, for example, includes more than 20 soil series and seven soil associations. Soil associations are useful for regional planning and management.

The State Soil Geographic (STATSGO) data base and the National Soil Geographic (NATSGO) data base were generalized from the detailed soil survey maps (Natural Resources Conservation Service, 1993). Where detailed maps were not available, data on geology, topography, vegetation, and climate were assembled together with satellite images, and the classification and extent of soils in the unmapped areas were estimated. The NATSGO data base is used primarily for national and regional resource appraisal, planning and monitoring (Natural Resources Conservation Service, 1993). The boundaries of the major land resource areas (MLRA) and regions were used to form the NATSGO data base. The MLRA boundaries were developed primarily from the State general soil maps. Current data, along with a list of published soil surveys, is maintained on the World Wide Web at URL http://www.statlab.iastate.edu/soils/nsdaf/.

Population

The population distribution in the basin is rural. Most people live in towns and cities of less than 10,000 people (U.S. Census Bureau, 1991). In 1990, about 870,000 people lived in the basin, of whom about 25 percent lived in the Charleston, W. Va. metropolitan area (Eychaner, 1994). Blacksburg, Va. (34,000) is the only other city in the basin with a population greater than 20,000. Population density in most census blocks in the basin is less than 130 persons/mi^2 (fig. 5). County population densities range from less than 10 persons/mi^2 in Pocahontas County, W. Va., to more than 225 persons/mi^2 in Kanawha County, W. Va., and

Montgomery County, Va. (U.S. Census Bureau, 1991). Since 1940, the population of the basin has fluctuated within seven percent of the 1990 population.

Before 1940, population of the basin increased steadily, approximately doubling between 1900 and 1940 (fig.6) (U.S. Census Bureau, 1999b). The population trends for West Virginia appear to be independent of trends for Virginia and North Carolina, to dominate the overall population trends in the basin, and to be related to trends in employment in the coal industry. The population increase from 1900-1940 was during a period when West Virginia underwent a general increase in coal mining and growth in industries including steel and chemical manufacturing and a decrease in agriculture. Since the continuous mining machine was introduced in 1948, increasing mechanization in coal mining has caused a steady decrease in mining jobs in the basin while coal production has generally increased or remained steady (fig. 7) (Holmes, 1998). This trend continues; during 1993-1998 about 4,700 coal mining jobs were lost statewide in West Virginia, during a period when coal production increased by about seven percent (Office of Surface Mining Reclamation and Enforcement, 1999).

Particularly in the first decade after World War II, the decrease in coal mining jobs forced many Appalachians to move to midwestern industrial cities for employment (Brown and Hillary, 1967). In the decade 1940-1950, 19.4 percent of the population emigrated from West Virginia's southern coalfields (including areas outside the basin), and in the decade 1950-1960, another 23.7 percent emigrated. Many of these people always considered West Virginia home and are returning to West Virginia for retirement (Feather, 1998; Byers, 1999). In 1997, West Virginia ranked fourth among States in percentage of residents over 65 years of age and fiftieth in percentage of residents under 18 years of age (U.S. Census Bureau, 1998). Several West Virginia counties are actively recruiting retirees, although infrastructure, particularly sewers, is not being upgraded to accommodate population increases.

The poverty rate in the basin is about 150 percent of the national average (Appalachian Regional Commission, 1999). In 1990, 19.8 percent of people living in counties drained by the Kanawha River were in households with incomes below the poverty threshold, compared to a national average of 13.1 percent. The poverty threshold changes annually, and is determined by comparing the Consumer Price Index to household income, accounting for the number and ages of individuals making up the household; in 1998, the poverty threshhold for a household of two adults and two children was $16,530 (U.S. Census Bureau, 1999a). Poverty rates among the Kanawha River Basin counties in the three States were 20.7 percent in West Virginia, 17.7 percent in Virginia, and 20.2 percent in North Carolina. Some observers believe traditional customs, values, and lifestyles perpetuate poverty and are at the core of social and economic problems in the region (Weller, 1965), but the accuracy of these observations has been refuted (Branscome, 1971). Lewis and Knipe (1978), Eller (1982), Salstrom (1994), and Hennen (1996) discuss several historical factors that have contributed to contemporary Appalachian socioeconomic conditions.

Land Use and Land Cover

A summary of land-cover distribution by physiographic province (fig. 8) is based on 1991-93 Landsat Thematic Mapper satellite data (Multi-Resolution Land Characteristics Interagency Consortium, 1997). The Multi-Resolution Land Characteristics (MRLC) project was established to provide multi-resolution land-cover data of the conterminous United States. Using aerial photographs as reference data, the procedure involved interpreting and labeling Thematic Mapper data classes into 15 land-cover categories. The MRLC digital data system classifies land cover by 30 meter individual pixels (0.09 hectare or 0.22 acres); therefore, adjacent pixels can be classified in different categories. MRLC digital data offer a good general land cover classification for a large region, but differ in approach and spatial resolution from the 1970's GIRAS (Geographic Information and Analysis Systems) land use database (Kelly and White, 1993; Mitchell and others, 1977). Because of these differences, the two databases cannot be compared to accurately determine changes in land use/land cover.

The study unit is generally a patchwork of forest and agricultural land. In 1992, forested land (deciduous, mixed, and evergreen) covered approximately 9,810 mi^2, or 81 percent of the basin (Multi-Resolution Land Characteristics Interagency Consortium, 1997). Agriculture (cropland and pasture) covered approximately 1,960 mi^2 or 16 percent of the basin. The remaining land cover represents urban and built-up areas, water bodies (lakes, reservoirs, and streams), and barren land (primarily mines and quarries). In the Kanawha River Basin, some land uses, including coal

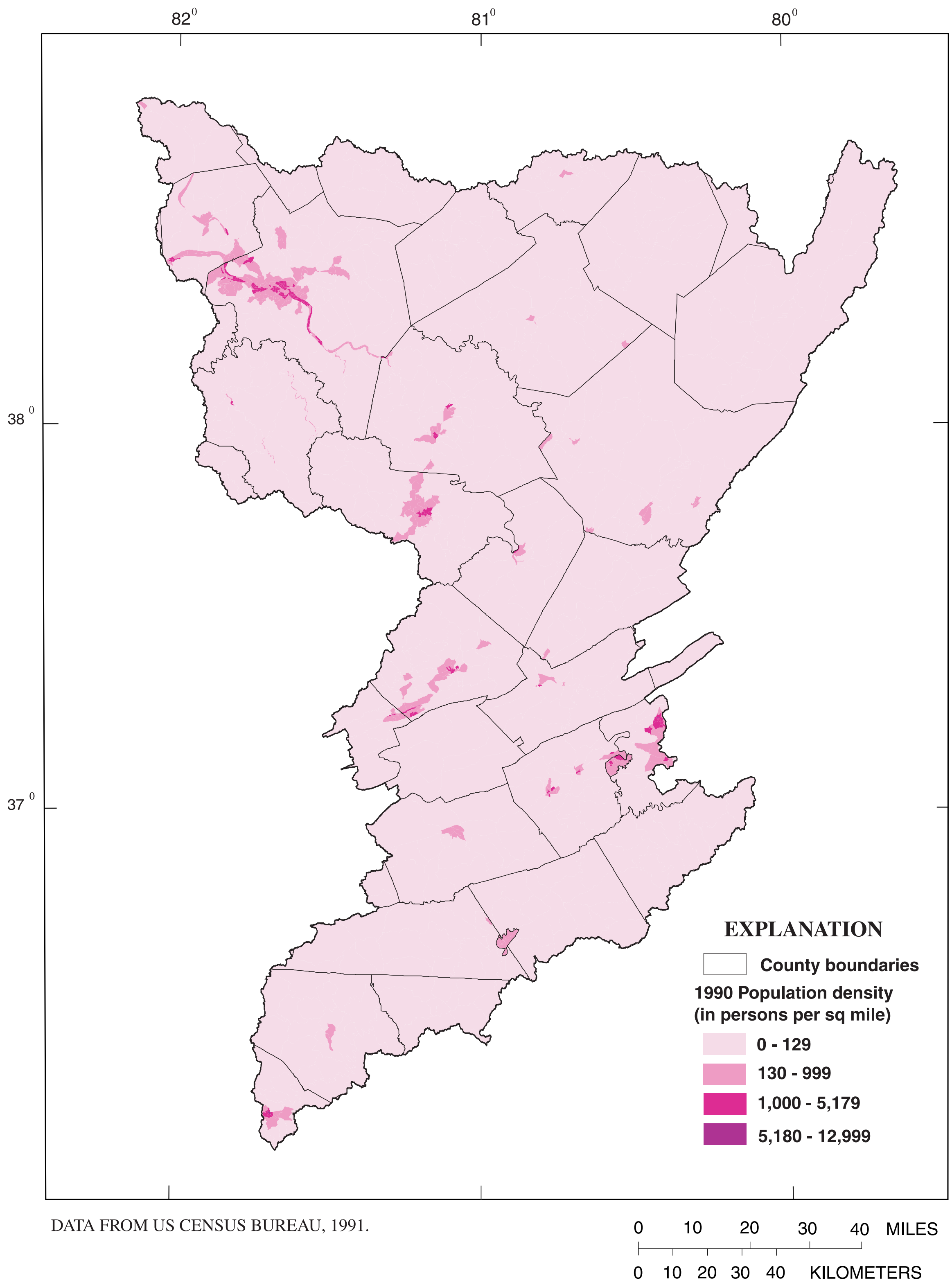


Figure 5. Population density in the Kanawha River Basin.

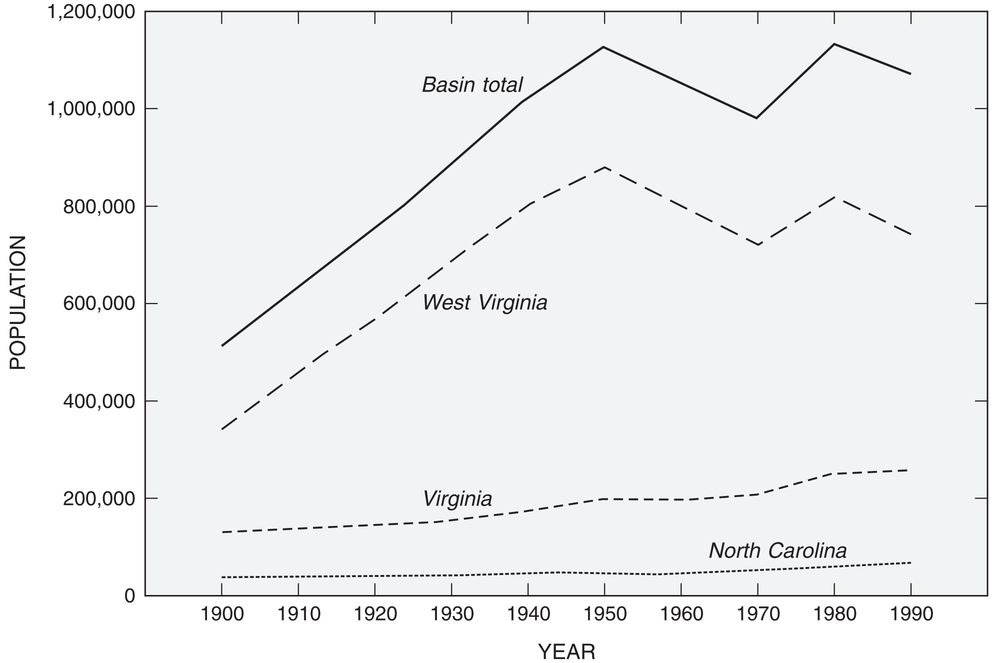


Figure 6. Population trends by state for counties partly or entirely within the Kanawha River Basin, 1900-1990.
(Data from U.S. Census Bureau, 1999.)

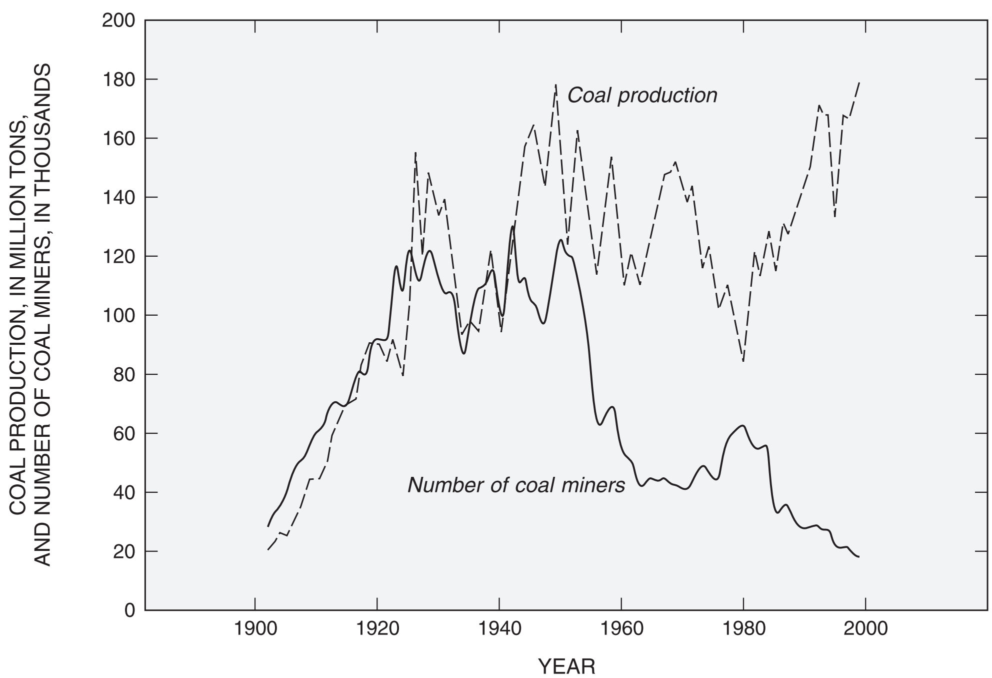


Figure 7. Coal production and mining jobs statewide in West Virginia, 1900-1998.
(Data from Holmes, 1998.)

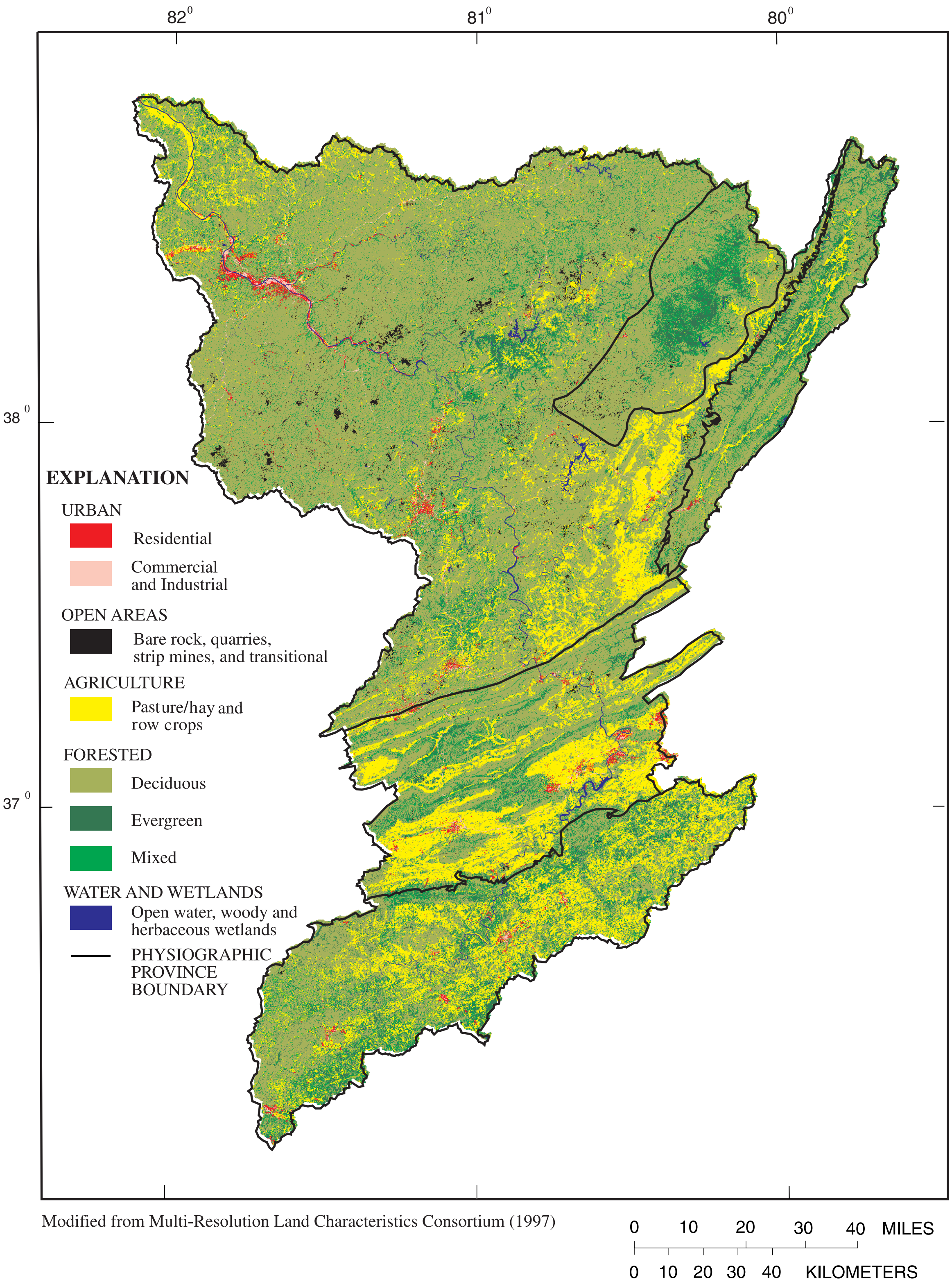


Figure 8. Land cover of the Kanawha River Basin.

mining, degrade water quality more than other land uses that occupy more area.

Coal mining. Within the basin, bituminous coal is extensive and economically important. Most of this coal is mined in the Appalachian Plateaus Province, although historically, some semi-anthracite coal was mined in the "Valley Coalfields" in the Valley and Ridge Province in Virginia (Sanda, 1998). Most mining is concentrated in West Virginia, in a band from Boone and Logan Counties northeast through Webster and Randolph Counties (fig. 9). During 1994-1998, West Virginia ranked second among U.S. States in tons of coal produced, after Wyoming, and led States in value of coal produced. The counties drained completely or partly by the Kanawha River produced almost 92 million tons of coal in 1998. Two of the counties with the greatest coal production, Logan and Raleigh, are only partly within the basin, and pro-rating coal production by area in these and other border counties gives an estimate of 75 million tons of coal produced in the basin in 1998. This production represents about 45 percent of the coal mined in West Virginia, and about seven percent of the coal mined in the United States.

The major use of coal in the United States is for producing electricity (Sanda, 1998). Most of the coal mined in the basin is burned to generate electricity (steam coal). A substantial amount is used to produce steel (metallurgical coal), which generally requires higher energy content than that produced from steam coal. The basin contains part of both the Northern and Southern West Virginia coal fields, which correspond to the Pennsylvanian or Permian Dunkard Basin and the Pennsylvanian Pocahontas Basin, respectively (fig. 10) (McColloch, 1998). Because coal from these two fields is from different depositional environments, it differs in energy content and purity. Coal from the Northern coalfield has a high average sulfur concentration (>1.5 percent) and coal from the Southern coalfield generally contains less sulfur (<1.5 percent), although sulfur concentration varies among coal seams in each field and therefore can vary substantially within a single mine. The border between the two coal fields is a belt of predominantly sandstone often referred to as the "Hinge Line" (Cardwell, 1975). The Northern coalfield extends to the border with Pennsylvania, and is continuous with the bituminous coalfield there; the Southern coalfield extends to the borders with Virginia and Kentucky, and is continuous with coalfields in those States. Much of the coal from the Southern field is classified in the coal industry as "compliance coal," or coal that can be burned at facilities that need to reduce sulfur dioxide emissions to comply with the Federal Clean Air Act of 1990 (McColloch, 1998). Since 1990, coal production in the Southern coalfield has increased while production from the Northern coalfield has generally remained constant, a trend that is widely attributed to the enactment and implementation of the Clean Air Act (fig. 11).

Southern West Virginia coal competes for its share of the electric utility market with low-sulfur coal from Wyoming. Extraction costs for West Virginia coal are greater than for Wyoming coal, but West Virginia coal commands a higher price because of its greater energy content and thus its suitability for metallurgical uses. In 1996, average mine price per ton of Southern West Virginia coal was $27.21, and the price of Wyoming coal was $6.41; the average delivered prices per ton to electrical utilities were $30.69 and $14.45 per ton, respectively. Average heat content of Southern West Virginia coal ranges from 12,000 to 15,000 Btu/lb, which compare to values of 7,700 to 9,400 Btu/lb for coals from Wyoming's most productive coalfield, in the Powder River Basin (McColloch, 1998; Glass, 1998).

Within the Kanawha River Basin, surface coal mining began in the 1920's, and by about 1960, had become a major method of coal production (Davies, 1968). Surface production increased steadily until about 1985, when the rate of increase accelerated (fig. 12). By 1998, surface mining accounted for nearly half of the overall production in the basin. During this period, underground coal production has been inconsistent, without any clear overall trend. The increase in surface mine production has followed a technological trend of increasing size and efficiency of earth-moving equipment. Surface mining allows extraction of coal from seams too thin to be mined using underground methods (Fedorko and Blake, 1998). Multiple seams are removed sequentially in many surface mines.

Early surface mining generally followed the contour of the coal outcrop, digging into the hillside until the economic limit of overburden (broken rock) to coal was reached. Overburden was pushed to the downhill side of the mine bench or more recently, replaced on the bench. A vertical highwall was left at the uphill side of some mines.

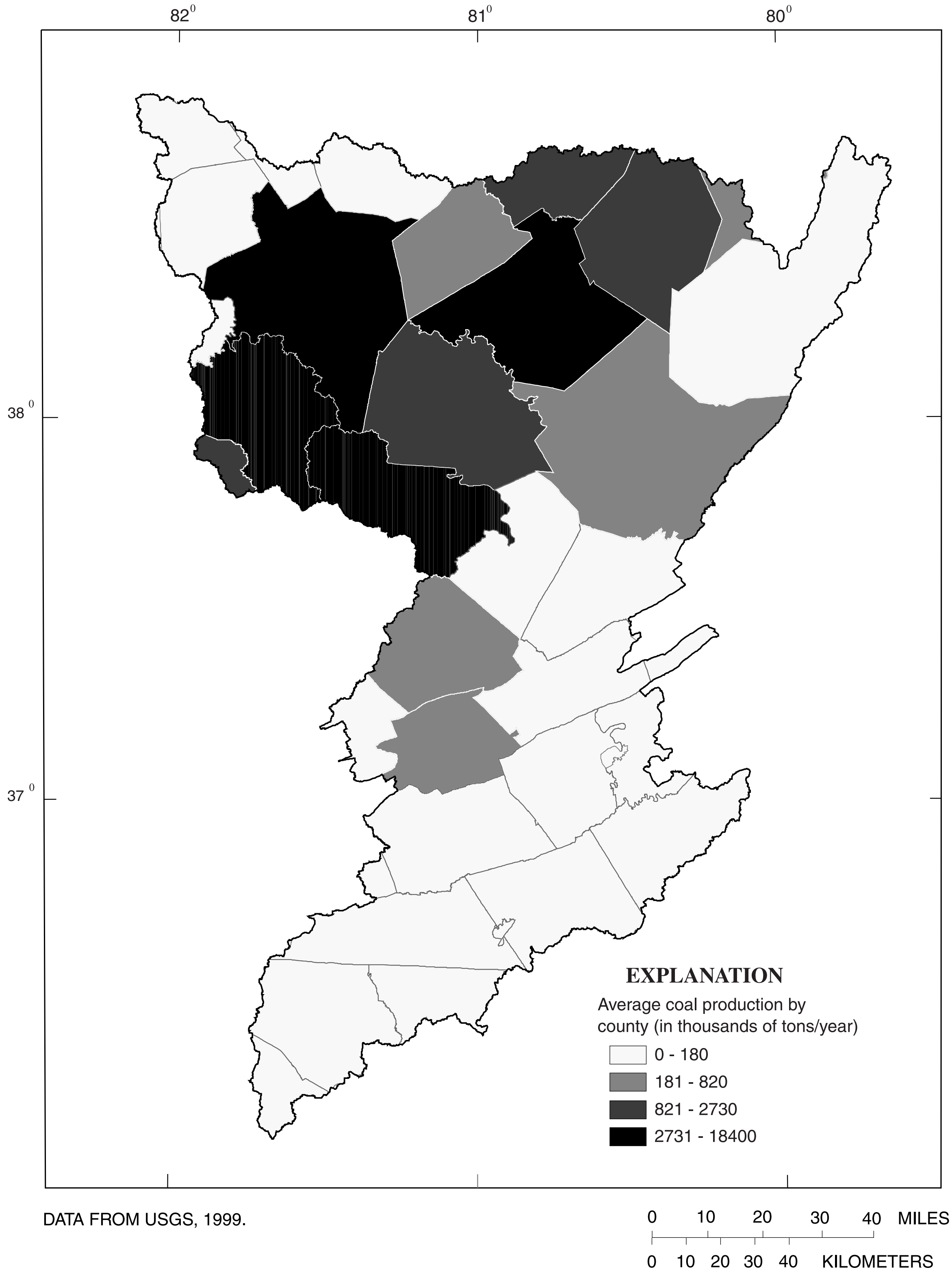


Figure 9. Coal production for counties in the Kanawha River Basin, 1980-1995.

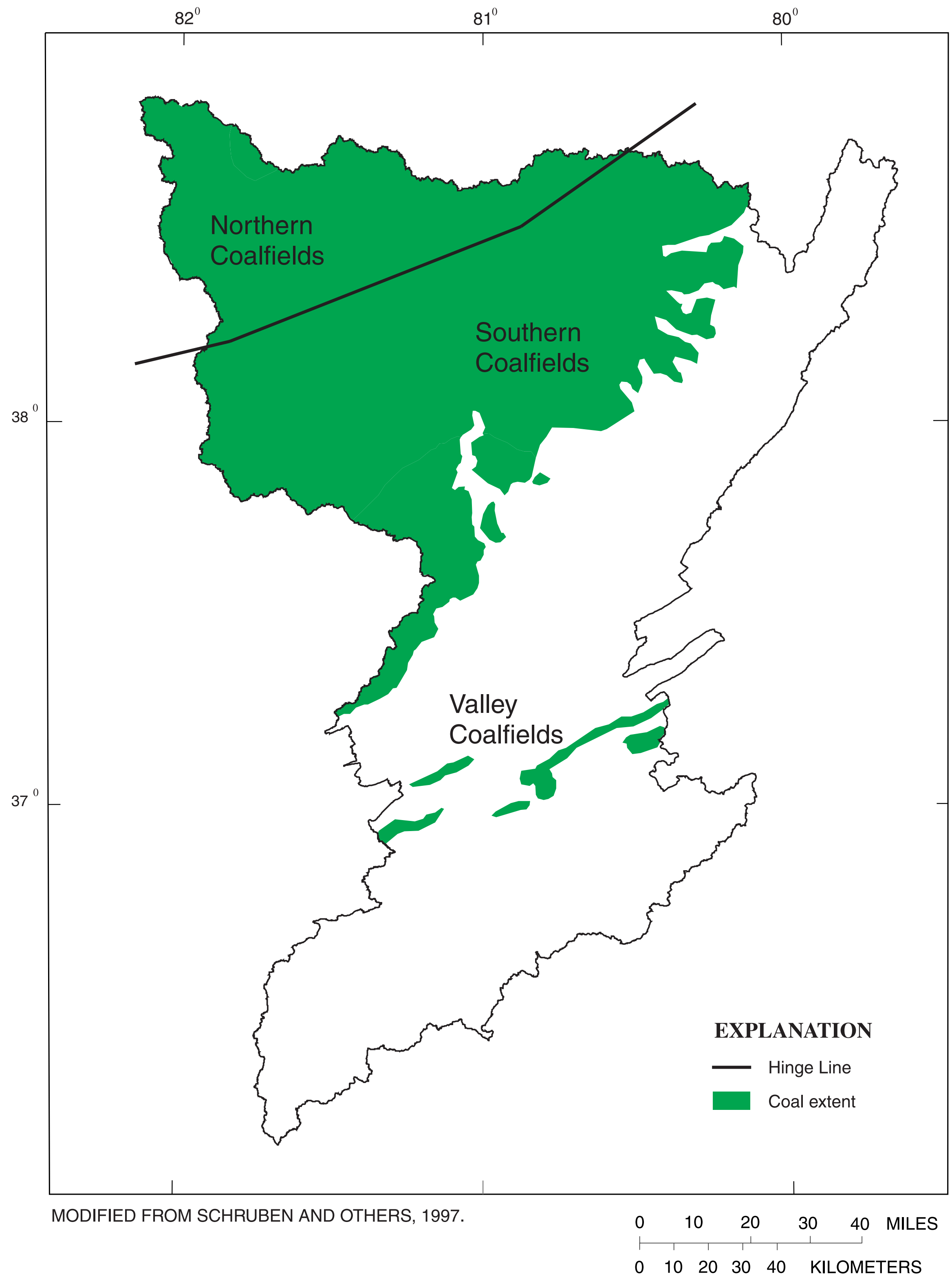


Figure 10. Coal fields in the Kanawha River Basin.

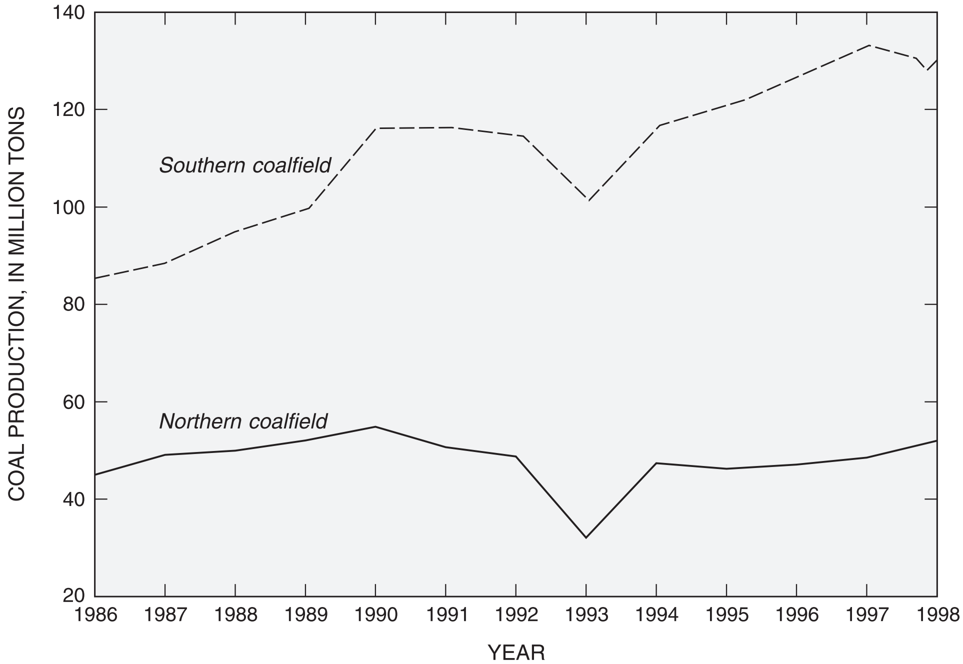


Figure 11. West Virginia coal production for the Northern and Southern coal fields, 1986-1998.
(Data from West Virginia Geological and Economic Survey, 1998.)

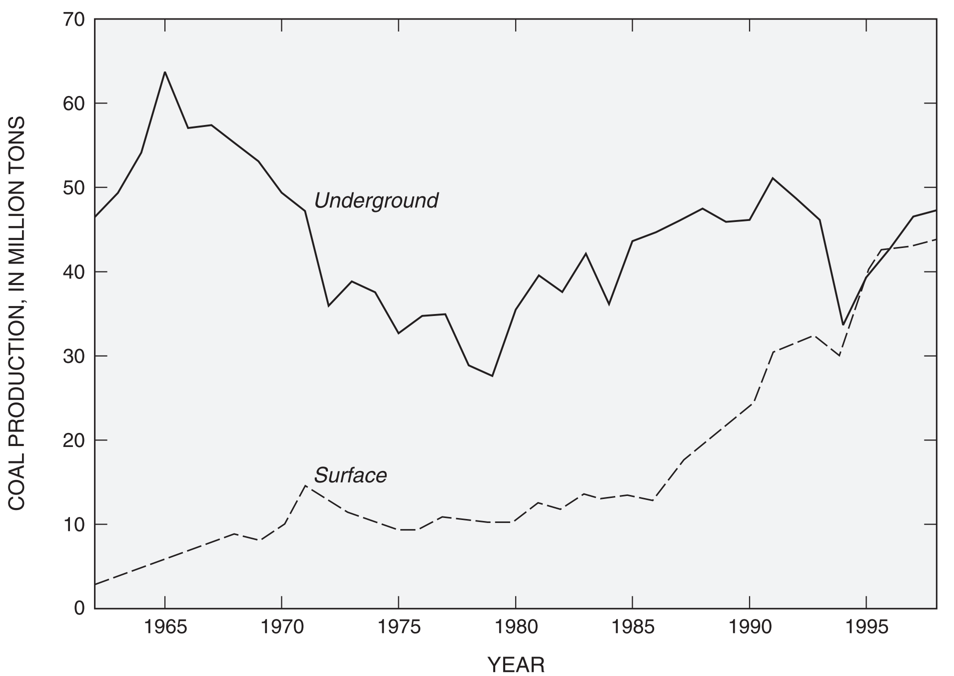


Figure 12. Underground and surface coal production in West Virginia counties entirely or partly within the Kanawha River Basin, 1961-1998.
(Data collected by West Virginia Office of Miners' Health, Safety, and Training and predecessor agencies, and compiled and published by U.S. Geological Survey, 2000.)

As the size and efficiency of earth-moving equipment increased, removal of coal and overburden entirely through a ridge became possible (Dulin and others, 1998). This method, called mountaintop removal mining, was first applied in the basin in 1967 and increased in importance during the 1980’s and 1990’s. Large mountaintop removal operations typically target several coal seams in the lower strata of the Allegheny Formation and the upper strata of the Kanawha Formation (Fedorko and Blake, 1998). These formations are at the surface in the basin in a band from Logan County to Webster County (fig. 4).

The coal industry is governed by a set of laws and regulations intended to protect the environment and worker safety while allowing the industry to earn profits. These laws and regulations, and enforcement practices, are important to water quality in the Kanawha River Basin. Laws and regulations commonly arise out of controversy; their interpretation and application is rarely simple and commonly leads to renewed controversy (Haught, 1997; McFerrin, 1998). Coal mining in Appalachia began in a period when few industries were regulated in any way. The history of regulation of mining, like that of many other industries, has been one of tension between critics of industry practices, and the industry’s expectations for rules that allow it to earn profits. The present regulatory environment for coal mining developed in a period when mining practices were highly controversial (McKelvey, 1968; Mine Safety and Health Administration, 1999; Moffat, 1987). Mine safety and environmental regulations have generally developed in parallel throughout the twentieth century, and in some cases, have been spurred by similar events.

The first mine safety inspector was appointed in West Virginia in 1883, with responsibility to oversee mine safety throughout the entire State (West Virginia Office of Miner’s Health, Safety, and Training, 1999). Safety was an important issue in the Mine Wars of 1911-1914 and 1920-21 (Savage, 1986; Corbin, 1990). Broad Federal authority to regulate mine safety was established in 1969 and extended in 1977 (Mine Safety and Health Administration, 1999). Overall from 1911-1997, the accidental death rate in coal mining in the United States declined from 329 to 25 deaths per 100,000 workers; the decline attributed to the Federal Coal Mine Health and Safety Act of 1969 was from about 180 to about 90 deaths per 100,000 workers (Centers for Disease Control and Prevention, 1999).

West Virginia’s early water-quality standards exempted the coal industry (Workman, 1951). The Federal Water Pollution Control Act of 1972 required neutralization of acid discharges from active coal mines. Safety issues sometimes merged with environmental issues. In 1972, a dam made of mine waste failed during a rainstorm and the resulting flood of Buffalo Creek (a Logan County stream adjacent to the Little Coal River Basin) killed 174 residents (Davies and others, 1972). Although State regulations prohibited this type of structure and related practices, these regulations had not been rigorously enforced (Nyden, 1972). Public concern following the Buffalo Creek disaster contributed to passage in 1977 of a Federal law governing coal mining, the Surface Mine Control and Reclamation Act (SMCRA). SMCRA contained provisions to regulate hydrologic and other environmental effects of surface and underground coal mining (Office of Surface Mining Reclamation and Enforcement, 1997).

Primary enforcement (primacy) of SMCRA in West Virginia is by the West Virginia Division of Environmental Protection (WVDEP) Office of Mining and Reclamation, and in Virginia by the Department of Mines and Mineral Resources. OSM maintains oversight on the State programs, and is required to assume primacy in enforcement when State deficiencies in enforcement are not addressed. West Virginia has maintained primacy in regulating coal mining since its program was initially approved in 1981, although OSM and WVDEP have at times disagreed as to whether or not the West Virginia enforcement program met the requirements of SMCRA (Office of Surface Mining Reclamation and Enforcement, 1999a, b).

Water resources objectives pursued under provisions of SMCRA and the Clean Water Act (through the National Pollutant Discharge Elimination System) include controlling erosion and sedimentation, decreasing iron, manganese, and sulfate in mine drainage, and maintaining a neutral stream pH. Land reclamation is usually the highest priority in mining reclamation plans. Successful land reclamation is considered sufficient to control stream sedimentation and includes creating channels to carry peak flows and revegetation, typically with grasses (Office of Surface Mining Reclamation and Enforcement, 1997). Water treatment and water-quality monitoring is required under most mine permits. Water quality is generally believed to have improved because of mining regulation by SMCRA and the Clean Water Act, although a quantitative assessment of regional changes in water quality caused by mining regulations has not been done.

Abandoned coal mines that predate SMCRA or were unsuccessfully reclaimed continue to affect water quality in the basin. OSM estimates the total requirement of the Abandoned Mine Lands Program in West Virginia to be more than $800 million, $225 million of which is for projects to remediate degraded water (Office of Surface Mining Reclamation and Enforcement, 1998a). Most of these costs are needed for reclaiming mines abandoned before implementation of SMCRA. A substantial part of this money, however, is needed to reclaim more recent mines where reclamation requirements were not met, and a performance bond posted as part of the permitting process was forfeited but did not cover reclamation expenses. More than twice as many coal mines forfeited performance bonds in West Virginia in 1998 as in any other State (Office of Surface Mining Reclamation and Enforcement, 1998b). Water is the most commonly affected resource at West Virginia bond forfeiture sites; the WVDEP Abandoned Mine Lands Reclamation Program is recognized as a leader in developing and applying acid mine drainage remediation technology.

Technological changes have led to development of coal mining methods, such as large-scale mountaintop removal mining, that were not considered in the original development of SMCRA and subsequent regulations. Public scrutiny of mountaintop removal mining has increased during the 1990's (Loeb, 1997; Ward, 1999). Litigation concerning recent practices of permitting and regulating surface mines is ongoing in 1999 *[BRAGG vs. ROBERTSON, Civil Action No. 2:98-636 (S.D. W. Va.)]*. Additionally, the U.S. Environmental Protection Agency and other agencies have begun an environmental impact assessment of permitting practices for mountaintop removal mining (U.S. Environmental Protection Agency, 1999b). Some observers believe that potential changes in the regulatory environment will decrease coal mining profitability and employment (Underwood, 1999). Readers will need to seek additional information to know the outcome of these processes (Charleston [W. Va.] Gazette, 1999; Coal Age, 1999; West Virginia Division of Environmental Protection, 1999).

Forest. Approximately 9,813 mi^2, or 81 percent, of the Kanawha River Basin was forest land in 1992 (fig 8; Multi-Resolution Land Characteristics Interagency Consortium, 1997). Forest type varies through the basin by physiography, altitude and aspect (position facing a particular direction). Principal forest types of the Allegheny Highlands, the headwaters of the Elk and Gauley River Basins, are Northern Evergreen and Northern Hardwood (Strasbaugh and Core, 1978). Mature Northern Evergreen forests were dominated by red spruce, but immature second- and third-growth stands are often dominated by several species of aspen and birch. Northern Hardwood forests are dominated by sugar maple, beech, and yellow birch, which are mixed differently in different areas. Dominant forest types of the lower-altitude parts of the Appalachian Plateaus are Oak-Pine forests in drier microhabitats on ridges and south-facing slopes, and Mixed Mesophytic forest in moist, north-facing slopes and coves. Oak-Pine forests are a mixture of species including scarlet oak, black oak, chestnut oak, pitch pine, and scrub pine. American chestnut dominated most of these forests before this tree was effectively eradicated by blight in the 1920's and 1930's. In Mixed Mesophytic forests, dominance is shared by up to 40 tree species, including beech, tulip poplar, and sugar maple. The Valley and Ridge Province is dominated by Appalachian Oak forests similar to the Oak-Pine forests in drier habitats of the Appalachian Plateaus Province (Küchler, 1964). Appalachian Oak and Northern Hardwoods forest types dominate the Blue Ridge Province.

About 100 years ago, the structure and function of forest ecosystems in the basin were profoundly altered by the logging of the virgin forest. No stands of virgin forest larger than a few acres remain in the basin. Stream conditions in this heavily forested area probably were just as profoundly altered, although virtually no useful predisturbance stream data are available.

In 1870, most of West Virginia west of the Allegheny Front, except river valleys, was covered in virgin forest and in 1900, 73 percent of this area was still covered in virgin forest (Clarkson, 1964). By 1920, the forest was almost completely logged. The Valley and Ridge Province was settled by the early nineteenth century, and the valleys were logged at settlement. Most high-altitude parts of the Blue Ridge Province were logged soon after the Appalachian Plateaus Province. Before the virgin forest was logged in the Appalachian Plateaus Province forest topsoil was typically one to three feet thick (Lewis, 1998). A 1930's soil study referred to by Lewis (1998) concluded that about 25 percent of West Virginia's land surface had lost more than 75 percent of its topsoil because of logging and associated widespread forest fires. Tree tops and other brush were left as a product of logging, and during dry periods, sparks from coal-fired locomotives or other sources started huge, hot brush fires that also burned humus and live trees. In many areas, more topsoil was burned in the forest fires that followed logging than was lost to erosion during logging (Clarkson, 1964).

Fish kills were widespread and common during the logging of the virgin forest, because sawdust was typically dumped directly into streams, where its breakdown caused anoxia. Any assumption that fish species became extinct as the Kanawha River Basin's virgin forest was logged would be speculative. But the New River today has a high proportion of endemic fish species, and such species, with limited abundance and range, would be most likely to become extinct because of a habitat disturbance. Brook trout were extirpated from many streams because of habitat disturbance from logging and related activities (Goldsborough and Clark, 1908). Rainbow and brown trout were stocked into these streams, in many early cases by timber companies, and have outcompeted the native brook trout in warmer, more productive streams (Constantz, 1994). Also, the first fish survey of the Appalachian Plateaus part of the Kanawha River Basin (Goldsborough and Clark, 1908) was done in response to residents' concerns that fish populations were being eradicated because of timbering and related activities.

Before about 1900, the rural economy of the Appalachian Plateaus Province was highly dependent on forest production, not only for wood, hunting, and forest foods, but also as pasture. Hogs, and especially cattle, the region's primary agricultural export, were allowed to forage on acorns and chestnuts on the forest floor (Lewis, 1998). The logging of the virgin forest, followed by a blight in the 1920's that destroyed all mature American chestnut trees, forced Appalachian farmers off their land to find industrial or mining jobs.

Forestry is now (1999) a major industry in the basin. Forest products are of particular importance in North Carolina, and forestry is also a large part of West Virginia's economy. North Carolina and Virginia have recently studied the sustainability of their forest industries, and concluded that current timbering rates may not be sustainable.

In North Carolina, forest industries are second in importance among major industrial categories only to textiles in total employment and wages (North Carolina Governor's Task Force on Forest Sustainability, 1996). Throughout North Carolina, a potentially large but unknown gap exists between gross and harvestable timberland acres. The average size of forest ownership tracts is decreasing; urbanization is decreasing the State's forested areas, and net growth may currently be less than drain (harvest, mortality, and loss of forest acreage to other land uses). In the mountain region of North Carolina, which includes the North Carolina part of the Kanawha River Basin, about 75 percent of the forest is categorized as upland hardwoods, and the rest as pine/hardwood or natural pine (as opposed to cultivated, or plantation pine).

The Virginia Department of Forestry (1999) has completed the first phase of a long-term assessment of the State's forest resources. This assessment considered land-use changes and population growth in determining how much of Virginia's forestlands were likely to remain available for long-term timber production. Statewide, although Virginia has 15.4 million acres of total forestland, only 55 percent of this area is likely to remain available for long-term harvest. The rest of Virginia's forest is either classified as "urban" (forestland with a substantial residential component), or else unsuitable for harvest because of slope, small acreage, or spatial arrangement. Virginia's forestland is considered inadequate to support the 1995 rate of harvest on a long-term, sustainable basis.

About 64 percent of the forest statewide in West Virginia is considered commercially harvestable (West Virginia Division of Forestry, 1997). Major forest reserves in West Virginia, reported as millions of board feet of timber, include red oak (15.3), white oak (14.4), and tulip poplar (12.7). West Virginia Division of Forestry (1997) reported a statewide growth-to-removal ratio of 1.3:1, although this figure does not account for forest loss to urbanization, tree mortality, or other components of forest drain.

Agriculture. In 1992, approximately 16 percent, or 1,960 mi^2, of the Kanawha River Basin was agricultural land (fig 9; Multi-Resolution Land Cover Interagency Consortium, 1997). Little row-crop agriculture (less than 300 mi^2), no commercial feed lots, and few poultry houses were in the basin. Pasture and hay are the largest areal agricultural activity. Cattle were the principal animals produced on farms in the basin, accounting for about $250,000,000 of about $340,000,000 of overall sales (National Agriculture Statistics Service, 1999). In 1997, cattle were on about

10,000 farms in the basin. About 535,000 cattle were overwintered, and about 356,000 cattle were sold in 1997 (fig. 13a). Only about 30,000 of the cattle were dairy cattle, on 650 farms. About 5,500 hogs were overwintered on 372 farms in the basin, and about 7,300 hogs were sold in 1997.

The Blue Ridge Province part of the basin contains the largest proportion of agricultural land (30.8 percent) (Multi-Resolution Land Characteristics Interagency Consortium, 1997). The Valley and Ridge and Appalachian Plateaus Provinces contain 14.7 and 14.8 percent agricultural land, respectively. In 1997, the primary crops under cultivation were grown as cattle feed: 391,000 acres of hay, 16,000 acres of corn for grain, and 9,000 acres of corn for silage (figs. 13b, c). Additionally, 4,600 acres of tobacco, 2,800 acres of wheat, and about 1,500 acres of apple, cherry, and peach orchards were harvested in the basin in 1995 (National Agriculture Statistics Service, 1999).

Pesticide use in the Kanawha River Basin is small relative to more intensively agricultural areas. Triclopyr was the only pesticide whose use in the basin accounted for more than 0.5 percent of national use (M. Majewski, USGS NAWQA Pesticide National Synthesis team, written commun., May 1997). The most used pesticides in the basin in 1992, based on pounds of active ingredients, included 1-3-D; atrazine; metolachlor; and oil (table 1). All 10 of the pesticides applied to 8,000 acres or more are commonly used in pasture or corn. Most of the pesticides used in the greatest quantity in the basin are also applied to corn and pasture. Pesticides used on tobacco and orchards were also among the substances of which more than 10,000 pounds were applied in the basin.

Christmas trees are grown extensively in the North Carolina part of the Blue Ridge Province. In 1996, about two million Christmas trees were sold from Ashe (1,000,000), Alleghany (700,000), and Watauga (280,000) Counties (Craig McKinley, North Carolina Cooperative Extension Service, Raleigh, oral commun., July 7, 1999). This represents more than six percent of national Christmas tree production, based on 32,000,000 Christmas trees sold in the U.S. in 1998. Actual Christmas tree production in the three North Carolina counties is thought to have been underestimated in the telephone survey. Christmas tree plantations are maintained with pesticides, and one major fish kill in a trout stream was caused by improper washing of a Christmas tree sprayer (David Lenat, North Carolina Division of Environmental Management, oral commun., January 1996).

Urban. Urban land accounts for the smallest percentage of land use in the study unit. Because of the scarcity of suitable land in much of the basin, building is concentrated on valley floors near rivers and is subject to periodic flooding. In the 1970’s, built-up land accounted for about 196 mi^2, or about 1 percent, of the total area of the study unit (Mitchell and others, 1977). This land use includes residential, commercial, and industrial areas, as well as cemeteries, airports, roadways, and railroads. Urban and suburban areas have grown since the mid-1970’s in the Charleston metropolitan area, and to a lesser extent, near Beckley, W. Va., between Wytheville, Va. and Blacksburg, Va., and near Boone, N.C. Because MRLC data are not directly comparable to the GIRAS data, the extent of this growth could not be quantified.

Climate

The climate of the Kanawha River Basin is classified as continental, with four distinct seasons and marked temperature contrast between summer and winter. Weather systems generally approach from the west and southwest. The basin is affected primarily by three major types of air masses: cool, dry, polar continental air from northern Canada; hot, dry continental air from the southwest and Mexico; and warm, moist tropical maritime air from the Gulf of Mexico and adjacent subtropical areas (Runner and Michaels, 1991). Throughout the spring and summer, the region is affected by maritime tropical air originating over the Gulf of Mexico. This tropical air transports considerable moisture as it moves northward along frontal systems. Typically, as a moisture-laden ocean air mass moves inland, it gains some water that has been recycled through the land-vegetation-air interface.

Temperature. The highly varied topography and elevation within the basin make air temperature variable (National Oceanic and Atmospheric Administration, 1992a, 1992b, 1992c). In the Appalachian Plateaus Province, recorded 30-year mean air temperature (1961-90) ranges from a minimum of about 48ºF at several locations above 2,000 ft elevation to a maximum of 55ºF near Charleston, W. Va., where elevation is 800-900 ft. Mean air temperature for the only two Allegheny Highlands sites is 50ºF, and is 51ºF for 16 other Appalachian Plateaus sites.

In the basin, mean annual air temperature for four Valley and Ridge sites ranges from 48ºF to 52ºF, and the overall mean is 50ºF. Among five Blue Ridge

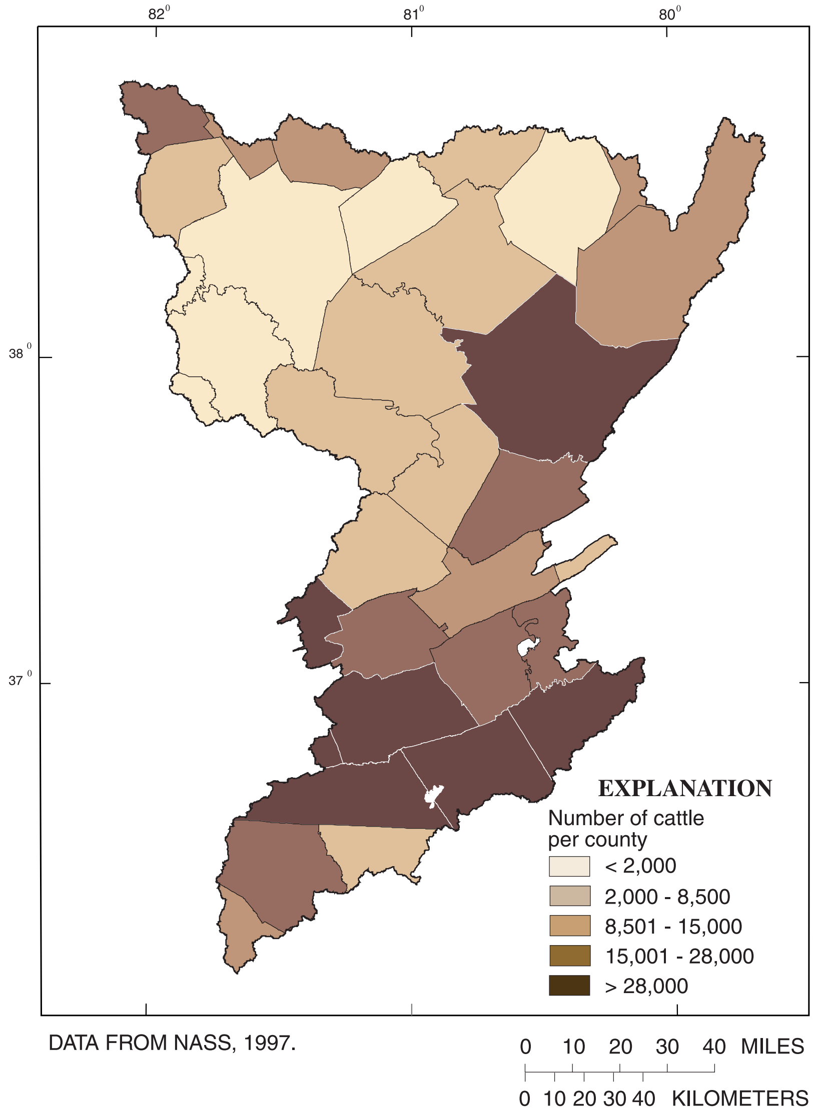


Figure 13a. Cattle in the Kanawha River Basin by county.

sites, mean annual air temperature ranges from 49ºF to 52ºF, and the overall mean is 51ºF. Mean annual air temperature within the basin generally decreases with elevation (fig. 14a), but does not vary significantly among physiographic provinces (fig. 14b). Normal monthly temperatures among all meteorological stations are strongly correlated; temperatures change seasonally throughout the basin the same way (fig. 14c). Minimum temperatures are in January and maximum temperatures are in July.

Precipitation. Precipitation is variable throughout the basin, even within each physiographic province (National Oceanic and Atmospheric Administration, 1992a, 1992b, 1992c). Precipitation in all three physiographic provinces is strongly affected by local orographic lifting with heaviest precipitation on windward sides of mountainous areas and rain shadows forming on leeward sides of mountainous areas. Generally, precipitation is greatest at the highest elevations, and less at lower elevations. Mean precipitation is different among some of the four physiographic settings (fig. 15a). Precipitation in the Allegheny Highlands is greater than in the rest of the Appalachian Plateaus or the Valley and Ridge Province, and precipitation in the Blue Ridge Province is greater than in the Valley and Ridge Province. Most precipitation in the basin comes from air masses that move from west to east. A regional rain shadow exists to the east of mountains near the eastern edge of the Appalachian Plateaus Province, and affects the entire

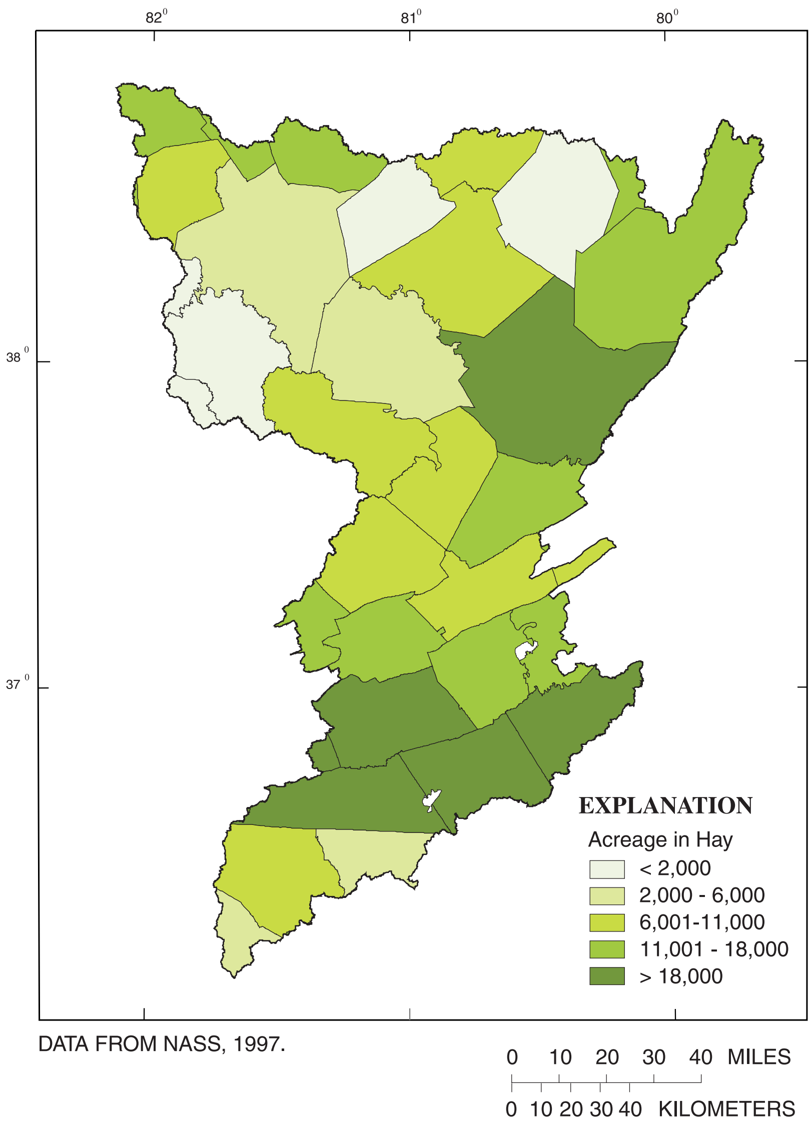


Figure 13b. Hay in the Kanawha River Basin by county.

Valley and Ridge Province, the southeastern edge of the Appalachian Plateaus Province, and the northeastern part of the Blue Ridge Province. The Blue Ridge Province receives a substantial amount of precipitation from air masses that move inland from the Atlantic Ocean, and average precipitation in the southern Blue Ridge Province is unaffected by the regional rain shadow.

At sites within the Appalachian Plateaus Province, mean annual precipitation (1961-90) ranges from a minimum of 35.7 in. within the regional rain shadow (Union, W. Va.) to 56.1 in. at a valley location in the Allegheny Highlands (Hacker Valley, W. Va.), to 64.0 in. at a mountain site about 2 mi northeast of the basin divide in Randolph County (Pickens, W. Va.). Mean annual precipitation for the five sites in the Allegheny Highlands is 54 in., and is 42 in. for the 23 sites in the rest of the Appalachian Plateaus (fig 15a.) The mean annual precipitation for all 28 sites in the Appalachian Plateaus part of the basin is 44 in. The least annual precipitation is received in and near the southern Greenbrier Valley, the area in the regional rain shadow. Otherwise, precipitation generally increases from west to east.

Virtually the entire Valley and Ridge Province is in the regional rain shadow (National Oceanic and Atmospheric Administration, 1992b). Precipitation in this province generally increases with altitude, but is orographically affected. Mean annual precipitation for the 10 sites in this province is generally least in the

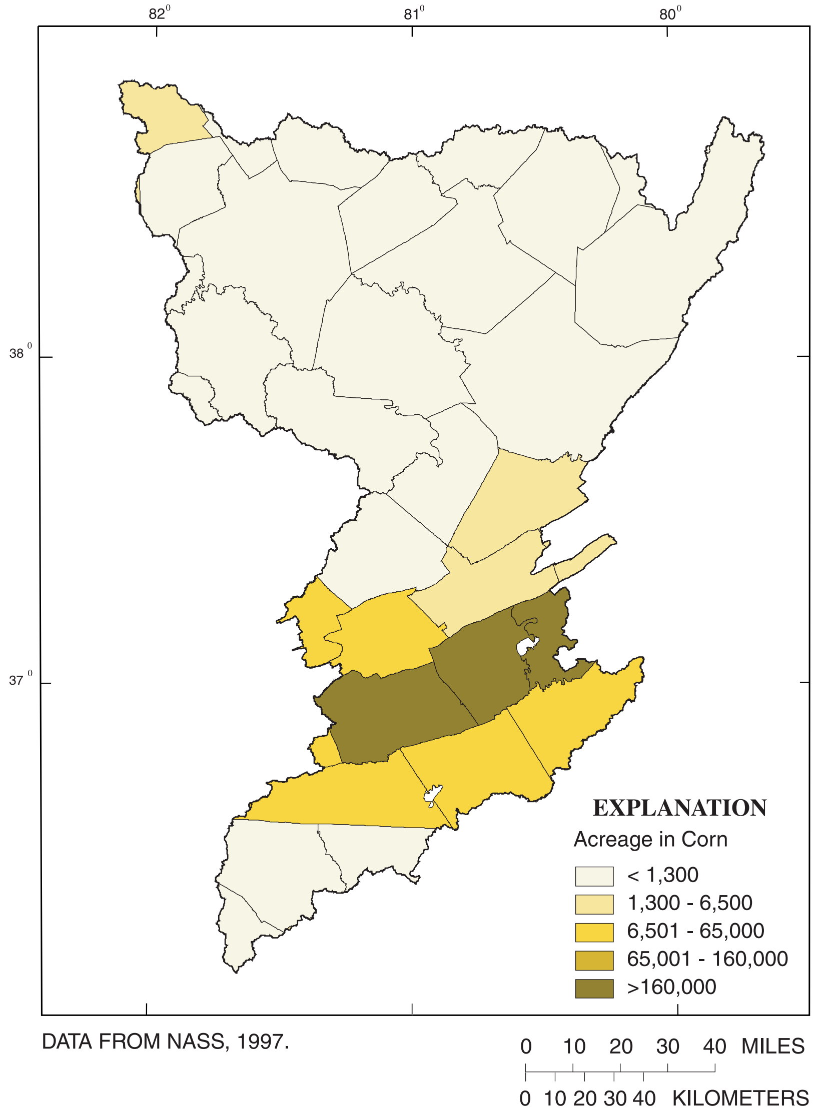


Figure 13c. Corn in the Kanawha River Basin by county.

basin, ranging from a minimum of 36.5 in. (Glen Lyn, Va., elevation 1,520 ft) to a maximum of 44.4 in. (Burkes Garden, Va., elevation 3,300 ft), with an overall mean of 38 in.

Mean annual precipitation at sites in the Blue Ridge Province ranges from a minimum of 41.1 in. (Independence, Va.) to a maximum of 65.3 in. near the southern basin divide (Blowing Rock, N.C.). Mean annual precipitation for the 12 sites within the Blue Ridge part of the basin is 50 in. Precipitation in the Blue Ridge Province generally increases from north to south, with elevation.

The entire basin receives less precipitation in winter than in other seasons, although precipitation distribution during the other seasons was varied (fig. 15b). Mean monthly precipitation (1961-1990) from 49 meteorological stations was positively correlated among all sites (Pearson correlation coefficient, or *r*, ranging from 0.300 to 0.992, where a value of 1 indicates two sets of data increase or decrease proportionally with each other, 0 indicates no relation, and –1 indicates that one set of data increases proportionally as the other decreases). Correlations were strongest within the physiographic settings and between the two Appalachian Plateaus settings. Correlations were strong between the two Appalachian Plateaus settings and the Valley and Ridge Province, and between the Blue Ridge and Valley and Ridge Provinces. Correlations were weaker between the two Appalachian Plateaus settings and the Blue Ridge Province. The

Table 1. Most used pesticides in the Kanawha River Basin, by treated area and active ingredient, and their common uses in the United States

[Each pesticide is among the 10 most used in the basin either by area or by weight applied. "Major uses" are defined as crops to which 10 percent or more of the pesticide is applied nationwide. NA = Not Applicable]

Pesticide	Treated area, in acres	Active ingredient applied, in pounds	Type	Chemical Abstract Service number	Major uses in United States
1,3-D	1,175	82,228	fumigant	542-75-6	tobacco, potatoes, sugar beets
2,4-D	30,293	30,520	herbicide	94-75-7	pasture, wheat and grains, corn
Alachlor	13,288	24,282	herbicide	15972-60-8	corn, soybeans
Atrazine	31,304	42,282	herbicide	1912-24-9	corn, sorghum
Carbofuran	10,564	8,558	insecticide	1563-66-2	corn, alfalfa
Chloropyrifos	9,983	12,239	insecticide	2921-88-2	corn, cotton
Dicamba	13,173	4,674	herbicide	1918-00-9	corn, pasture
Methyl bromide	75	30,419	fumigant	74-83-9	tomatoes, tobacco, strawberries
Metolachlor	16,884	31,420	herbicide	51218-45-2	corn, soybeans
Oil	991	32,388	other	NA	citrus, apples, almonds, pears
Paraquat	8,521	4,520	herbicide	4685-14-7	corn, soybeans, cotton
Simazine	8,062	9,238	herbicide	122-34-9	corn, citrus, grapes
Sulfur	564	19,500	fungicide	7704-34-9	grapes
Triclopyr	8,807	4,404	herbicide	55335-06-3	pasture, rice, hay

Appalachian Plateaus and Valley and Ridge Provinces receive increasing precipitation from February through May and a decline (consistent among sites) in June. These regions receive the most monthly precipitation in July, and then receive decreasing precipitation so that October and November are among the driest months. In contrast, the Blue Ridge Province receives increasing precipitation from February through May, its rainiest month, and then receives consistently high precipitation through October. In autumn, the Blue Ridge Province receives more frequent (although occasional) torrential rain from hurricanes than do the other provinces. These occasional intense storms skew the monthly precipitation averages for the Blue Ridge Province and contribute to making its mean monthly precipitation differ from the rest of the basin.

Hydrologic Aspects of the Basin

The New River originates in North Carolina and flows northward through Virginia and into West Virginia. At the confluence of the Gauley River (drainage area of 1,421 mi^2) and the New River (6,943 mi^2), the name of the main stream changes to the Kanawha River. From that point, the Kanawha River flows northwestward and drains into the Ohio River at Point Pleasant, W. Va. Principal tributaries are the Bluestone River (363 mi^2), Greenbrier River (1,619 mi^2), Elk River (1,533 mi^2), and Coal River (892 mi^2) (Mathes and others, 1982).

Major impoundments in the Kanawha River Basin include Claytor Lake and Bluestone Lake on the New River, Summersville Lake on the Gauley River, and Sutton Lake on the Elk River (Messinger, 1997). These impoundments are managed for flood control, recreation, and downstream dissolved oxygen and water temperature. Collectively, they have a capacity of 14 percent of the average annual flow at Charleston. Additionally, the Kanawha River is maintained as a navigable stream for 91 miles with a series of dams at

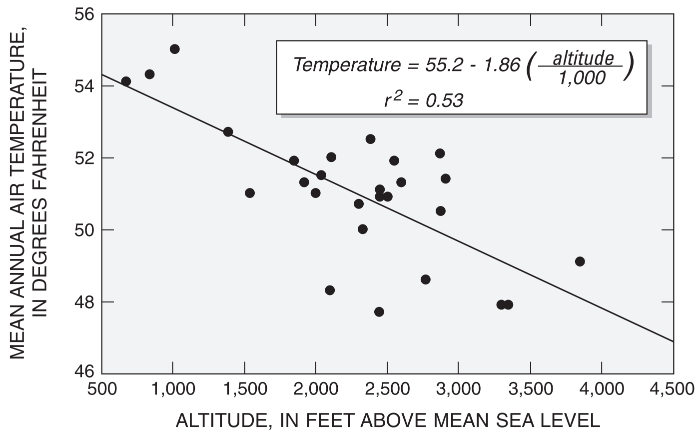


Figure 14a. Relation between altitude and 30-year (1961-90) mean annual annual air temperature at 28 sites in the Kanawha River Basin.

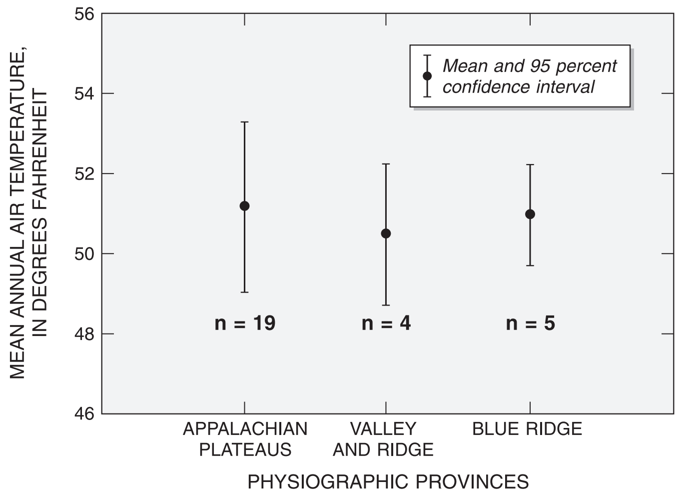


Figure 14b. 30-year mean (1961-90) annual air temperature for physiographic provinces in the Kanawha River Basin.
(Data from NOAA, 1992a,1992b, 1992c.)

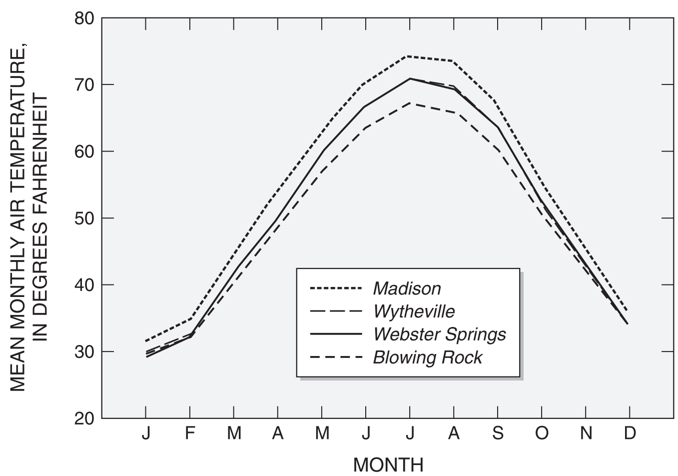


Figure 14c. 30-year (1961-90) mean monthly air temperature for four selected sites in the Kanawha River Basin.
(Data from NOAA, 1992a,1992b, 1992c.)

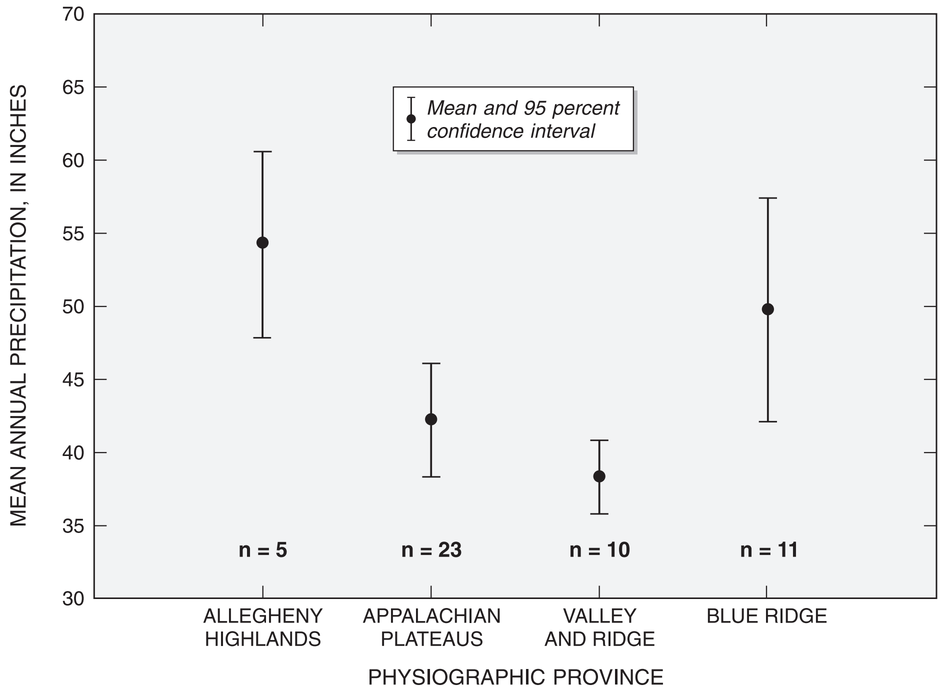


Figure 15a. 30-year mean (1961-1990) annual precipitation for physiographic settings in the Kanawha River Basin. *(Data from NOAA, 1992a, 1992b, 1992c.)*

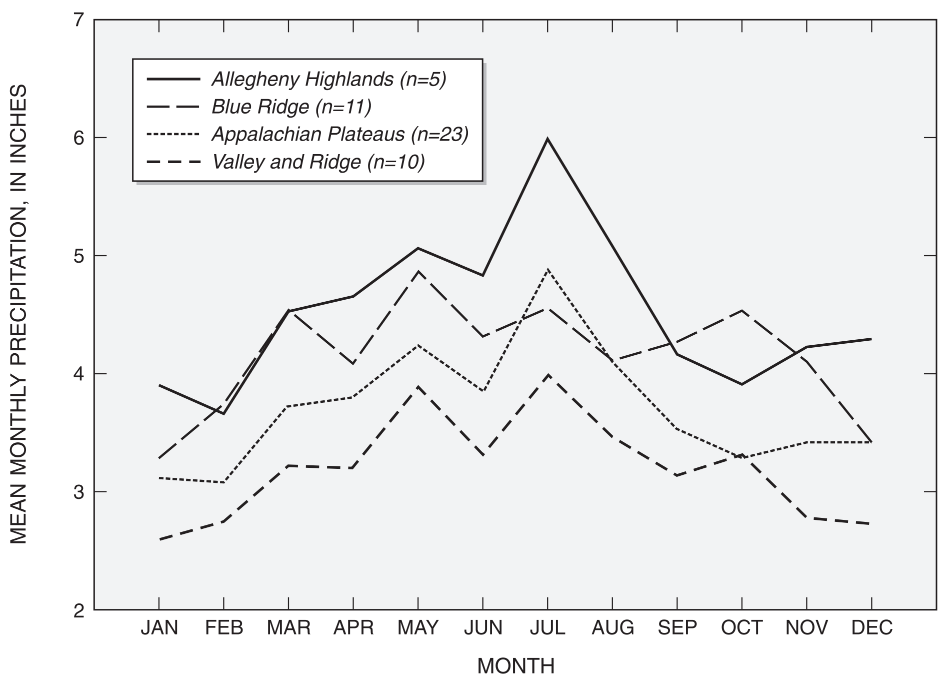


Figure 15b. 30-year mean (1961-1990) monthly precipitation for physiographic settings in the Kanawha River Basin. *(Data from NOAA, 1992a, 1992b, 1992c.)*

Gallipolis Ferry (on the Ohio River a few miles downstream from Point Pleasant), Winfield, Marmet, and London. A hydropower dam is operated at Hawk's Nest, W. Va., where much of the water of the New River is routed through a tunnel and bypasses the original river channel, known locally as "The Drys." Hydropower is also generated at Claytor Dam, Summersville Dam, and the navigation dams.

Streamflow

Streamflow has been continuously gaged at about 96 sites in the Kanawha River Basin; currently (1999), 40 of these sites are gaged. The average flow of the Kanawha River at Charleston is about 15,200 ft^3/s (Ward and others, 1999). Streamflow gages discussed in this report are listed in table 2 and shown in fig. 16. Flow statistics from some selected streams are shown in table 3. Streamflow was normalized by basin drainage area to give runoff, so that flow characteristics can be compared among streams of different sizes. Median, high, and low runoff vary throughout the basin in different patterns. The following discussion of regional streamflow patterns is based only on streams with more than 30 years of discharge records. Interpretations of long-term flow patterns based on shorter periods of record are unreliable because during a short period of record, floods and droughts may not be measured, although they are of great interest. Streams where shorter periods of record were collected illustrate other hydrologic aspects of the basin, however, which are discussed under the heading "Flow Duration."

The highest median runoffs in the basin are from a Blue Ridge stream (South Fork New River near Jefferson, N.C.), and two Allegheny Highlands streams (Gauley River near Craigsville, W. Va.; and Elk River below Webster Springs, W. Va.). The Blue Ridge Province and Allegheny Highlands are the parts of the basin that receive the most precipitation (fig. 15a). Lowest median runoff is from two streams in the southern part of the Appalachian Plateaus (Second Creek near Second Creek, W. Va., and Little Coal River at Danville, W. Va.), with low median runoff also at a stream in the Valley and Ridge Province (Walker Creek at Bane, Va.) and a stream that drains both southwestern Appalachian Plateaus and Valley and Ridge Provinces (Bluestone River near Pipestem, W. Va.) The southern Appalachian Plateaus and low-lying areas in the Valley and Ridge Province are the areas that receive the least precipitation in the basin.

Normal high flows, although not floods, can be described well by the 10 percent exceedence of flow, the flow that is equaled or exceeded ten percent of the time. ("Percent exceedence" is a variation of the more familiar percentile; it is obtained by subtracting a percentile scale value from 100 percent.) The three streams with greatest 10 percent exceedence runoff are all in the Allegheny Highlands (Williams River at Dyer, W. Va.; Gauley River near Craigsville, W. Va.; and Elk River below Webster Springs, W. Va.). The streams with lowest 10 percent exceedence runoff included a Blue Ridge stream as the lowest (Little River at Graysontown, Va.), and two Valley and Ridge streams (Reed Creek at Grahams Forge, Va.; and Walker Creek at Bane, Va.) and a southern Appalachian Plateaus stream (Second Creek near Second Creek, W. Va.). The 90 percent exceedence of flow, the flow that is exceeded or equaled by 90 percent of daily flows, describes sustained base flow. The greatest 90 percent exceedence of runoff were in four Blue Ridge streams (South Fork New River near Jefferson, N.C; Chestnut Creek near Galax, Va.; New River near Galax, Va.; and Little River at Graysontown, Va.), and the lowest 90 percent exceedence of runoff were in four Appalachian Plateaus streams (Little Coal River at Danville, W. Va.; Second Creek near Second Creek, W. Va.; Peters Creek near Lockwood, W. Va.; and Big Coal River at Ashford, W.Va).

On unregulated streams throughout the basin, discharge cycles somewhat smoothly between maxima in March and minima in September, before autumn leaf-fall (fig 17). Among six index streams, discharge seasonality was highly similar within two streams in the Blue Ridge and Valley and Ridge Province (not shown). Streamflow in the two Appalachian Plateaus streams (Williams River at Dyer and Big Coal River at Ashford) was more seasonally variable of all sites considered, with peak flows in March nearly 4 $ft^3/s/mi^2$ more than September low flows. The Blue Ridge site, South Fork New River near Jefferson, N.C., was least seasonally variable among sites, with high March flows exceeding low September flows by about 1 $ft^3/s/mi^2$. The seasonal variation in streamflow contrasts with the seasonal variation in precipitation in the basin (figs. 17, 15b). The difference in seasonal variation in precipitation and streamflow is caused by increased transpiration during the growing season, when deciduous trees are in leaf.

Table 2. Station numbers, physiographic settings, drainage areas, and period of record for selected Kanawha River Basin gaging stations discussed in this report

[BR = Blue Ridge; V&R = Valley and Ridge; M = Mixed physiography; AP = Appalachian Plateaus; AH = Allegheny Highlands.]

Station name	Station number	Physiographic setting	Drainage area, in square miles	Period of record, through 1999
South Fork New River near Jefferson, N.C.	03161000	BR	205	1924-1999
New River near Galax, Va.	03164000	BR	1,131	1929-1999
Chestnut Creek at Galax, Va.	03165000	BR	39.4	1944-1999
Glade Creek at Grahams Forge, Va.	03166800	V&R	7.15	1976-1993
Reed Creek at Grahams Forge, Va.	03167000	V&R	247	1908-1916; 1927-1999
Little River at Graysontown, Va.	03170000	BR	300	1928-1999
Walker Creek at Bane, Va.	03173000	V&R	305	1938-1999
New River at Glen Lyn, Va.	03176500	M	3,768	1927-1999
Bluestone River near Pipestem, W. Va.	03179000	M	395	1950-1999
Knapp Creek at Marlinton, W. Va.	03182000	V&R	108	1946-1958
Second Creek near Second Creek, W. Va.	03183000	AP	80.8	1945-1973; 1996-1998
Greenbrier River at Alderson, W. Va.	03183500	M	1,364	1895-1999
Williams River at Dyer, W. Va.	03186500	AH	128	1929-1999
North Fork Cranberry River near Hillsboro, W. Va.	03187300	AH	9.78	1969-1982
Gauley River near Craigsville, W. Va.	03189100	AH	529	1964-1982; 1985-1999
Peters Creek near Lockwood, W. Va.	03191500	AP	40.2	1945-1971; 1979-1982; 1996-1998
Kanawha River at Kanawha Falls, W. Va.	03193000	M	8,371	1877-1999
Elk River below Webster Springs, W. Va.	03194700	AH	266	1959-1983; 1985-1999
Kanawha River at Charleston, W. Va.	03198000	M	10,448	1939-1999
Clear Fork at Whitesville, W. Va.	03198350	AP	62.8	1996-1999
Drawdy Creek near Peytona, W. Va.	03198450	AP	7.75	1969-1977
Big Coal River at Ashford, W. Va.	03198500	AP	391	1908-1916; 1930-1999
Little Coal River at Danville, W. Va.	03199000	AP	269	1930-1984
Coal River at Tornado, W. Va.	03200500	AP	862	1908-1911; 1928-1931; 1961-1999

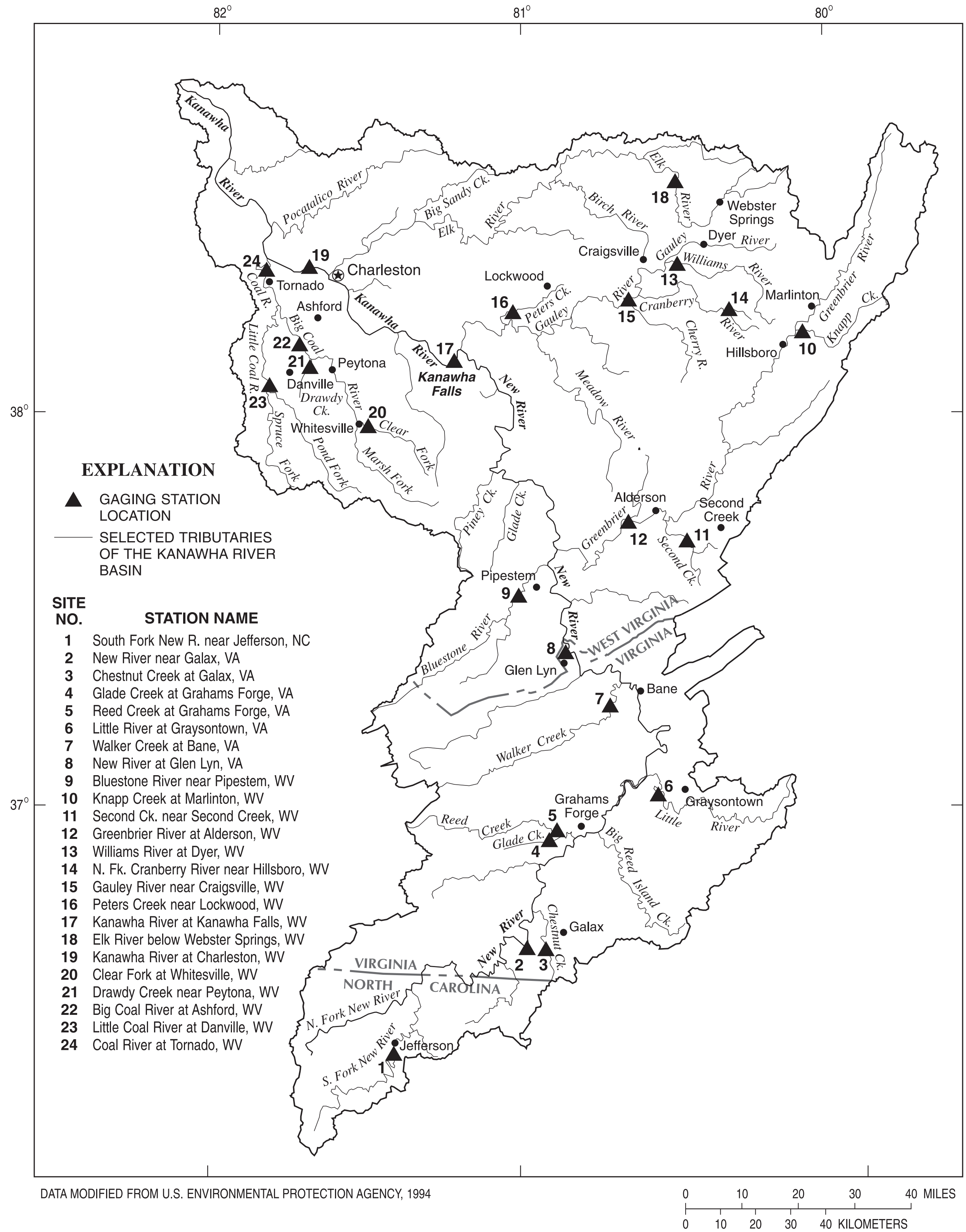


Figure 16. Selected streams, stream gages, and towns in the Kanawha River Basin.

Table 3. Streamflow statistics and other information for selected streams in the Kanawha River Basin

[ft^3/s = cubic feet per second; BR = Blue Ridge; V&R = Valley and Ridge; M = Mixed physiography; AP = Appalachian Plateaus; AH = Allegheny Highlands; * = regulated; percent exceedence is the streamflow or runoff that is equalled or exceeded on the indicated percentage of the days in the discharge record.]

Station name	Physiographic setting of tributary basin	Drainage area in square miles	Years of record	Streamflow, in ft^3/s			Runoff, in ft^3/s per square mile		
				Ten percent exceedence	Median	Ninety percent exceedence	Ten percent exceedence	Median	Ninety percent exceedence
South Fork New River near Jefferson, N.C.	BR	205	74	714	351	173	3.48	1.71	0.84
New River near Galax, Va.	BR	1,131	67	3,430	1,460	674	3.03	1.29	0.60
Chestnut Creek at Galax, Va.	BR	39.4	45	110	52	28	2.79	1.32	0.71
Glade Creek at Grahams Forge, Va.	V&R	7.15	18	1.3	0.27	0.08	0.18	0.04	0.01
Reed Creek at Grahams Forge, Va.	V&R	247	79	545	160	74	2.21	0.65	0.30
Little River at Graysontown, Va.	BR	300	70	622	270	128	2.07	0.90	0.43
Walker Creek at Bane, Va.	V&R	305	59	735	162	49	2.41	0.53	0.16
New River at Glen Lyn, Va.*	M	3,768	71	9,760	3,710	1,560	2.59	0.98	0.41
Bluestone River near Pipestem, W. Va.	M	395	48	1,120	205	38	2.84	0.52	0.10
Knapp Creek at Marlinton, W. Va.	V&R	108	13	346	62	12	3.20	0.57	0.11
Second Creek near Second Creek, W. Va.	AP	80.8	30	182	31	6	2.25	0.38	0.07
Greenbrier River at Alderson, W. Va.	M	1,364	103	4,830	948	145	3.54	0.70	0.11
Williams River at Dyer, W. Va.	AH	128	69	768	182	20	6.00	1.42	0.16

Table 3. Streamflow statistics and other information for selected streams in the Kanawha River Basin —Continued

[ft^3/s = cubic feet per second; BR = Blue Ridge; V&R = Valley and Ridge; M = Mixed physiography; AP = Appalachian Plateaus; AH = Allegheny Highlands; * = regulated; percent exceedence is the streamflow or runoff that is equalled or exceeded on the indicated percentage of the days in the discharge record.]

Station name	Physiographic setting of tributary basin	Drainage area in mi^2	Years of record	Streamflow, in ft^3/s			Runoff, in ft^3/s per square mile		
				Ten percent exceedence	Median	Ninety percent exceedence	Ten percent exceedence	Median	Ninety percent exceedence
North Fork Cranberry River near Hillsboro, W. Va.	AH	9.78	14	70	20	4.8	7.16	2.04	0.49
Gauley River near Craigsville, W. Va.	AH	529	32	3,300	833	122	6.24	1.57	0.23
Peters Creek near Lockwood, W. Va.	AP	40.2	31	150	27	3.2	3.73	0.67	0.08
Kanawha River at Kanawha Falls, W. Va.*	M	8,371	121	27,200	7,640	2,590	3.25	0.91	0.31
Elk River below Webster Springs, W. Va.	AH	266	37	1,660	395	60	6.24	1.48	0.23
Kanawha River at Charleston, W. Va.*	M	10,448	60	33,700	9,440	3,090	3.23	0.90	0.30
Clear Fork at Whitesville, W. Va.	AP	62.8	2	182	55	8.9	2.90	0.88	0.14
Drawdy Creek near Peytona, W. Va.	AP	7.75	8	22	4.1	0.61	2.84	0.53	0.08
Big Coal River at Ashford, W. Va.	AP	391	76	1,250	223	28	3.20	0.57	0.07
Little Coal River at Danville, W. Va.	AP	269	54	835	141	16	3.10	0.52	0.06
Coal River at Tornado, W. Va.	AP	862	44	2,730	656	110	3.17	0.76	0.13

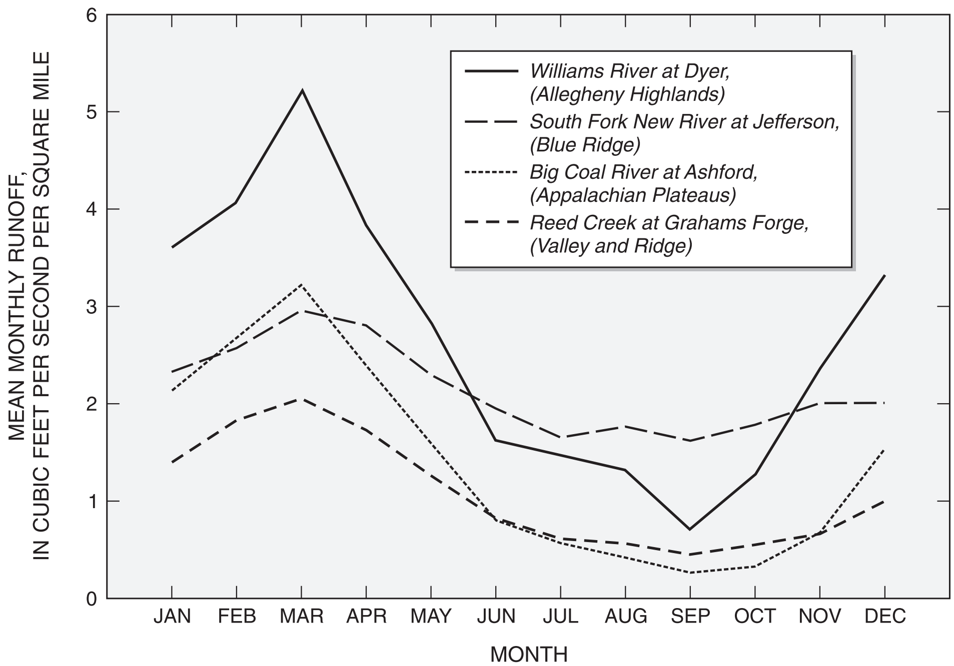


Figure 17. Seasonal variation in runoff in four selected streams in the Kanawha River Basin.

Flow duration. Streamflow duration is one measure of the variability of discharge at a site. Duration analysis identifies the discharge that was equaled or exceeded on a selected percentage of the days during a given period of record. A flow-duration curve is a graphical depiction of flow duration, in which discharge is plotted as a function of cumulative exceedence probability, in percent. The shape of a flow-duration curve is a function of the basin hydrological and physical characteristics, such as size, precipitation, topography, and geology.

Flow duration of unregulated streams varies principally with basin size, but also with physiography; index streams were selected for this discussion based on physiography and stream size (fig. 18). Within four physiographic settings in the basin, the shapes of flow-duration curves are generally independent of stream size. Curves for Appalachian Plateaus streams are slightly concave downward, showing high medium flows relative to extremes. This indicates that although rainfall is quickly absorbed into the ground, it is quickly discharged from the fractured aquifer system. Curves for Valley and Ridge and Blue Ridge streams are slightly concave upward, indicating just the opposite--low medium flows relative to extremes. This suggests that aquifer systems absorb water less readily but retain water longer than in the Appalachian Plateaus. Blue Ridge streams are least variable among the four settings, as would be expected because of the relatively even rainfall they receive throughout the year. In some settings, the extreme low flows of medium-sized streams appear to be less than of small streams, but this is an artifact of the streams under comparison having different periods of record, with the smallest streams not having been gaged during drought years. The earliest major dam built on the New River, Claytor Dam, is operated primarily for generating electricity, but is also operated for flood control. The second dam, Bluestone Dam, is operated for flow regulation, recreation, and to dampen daily flow fluctuations caused by peak-demand releases from Claytor Dam. The third and fourth dams, Sutton Dam on the Elk River and Summersville Dam on the Gauley River, were designed for augmenting low

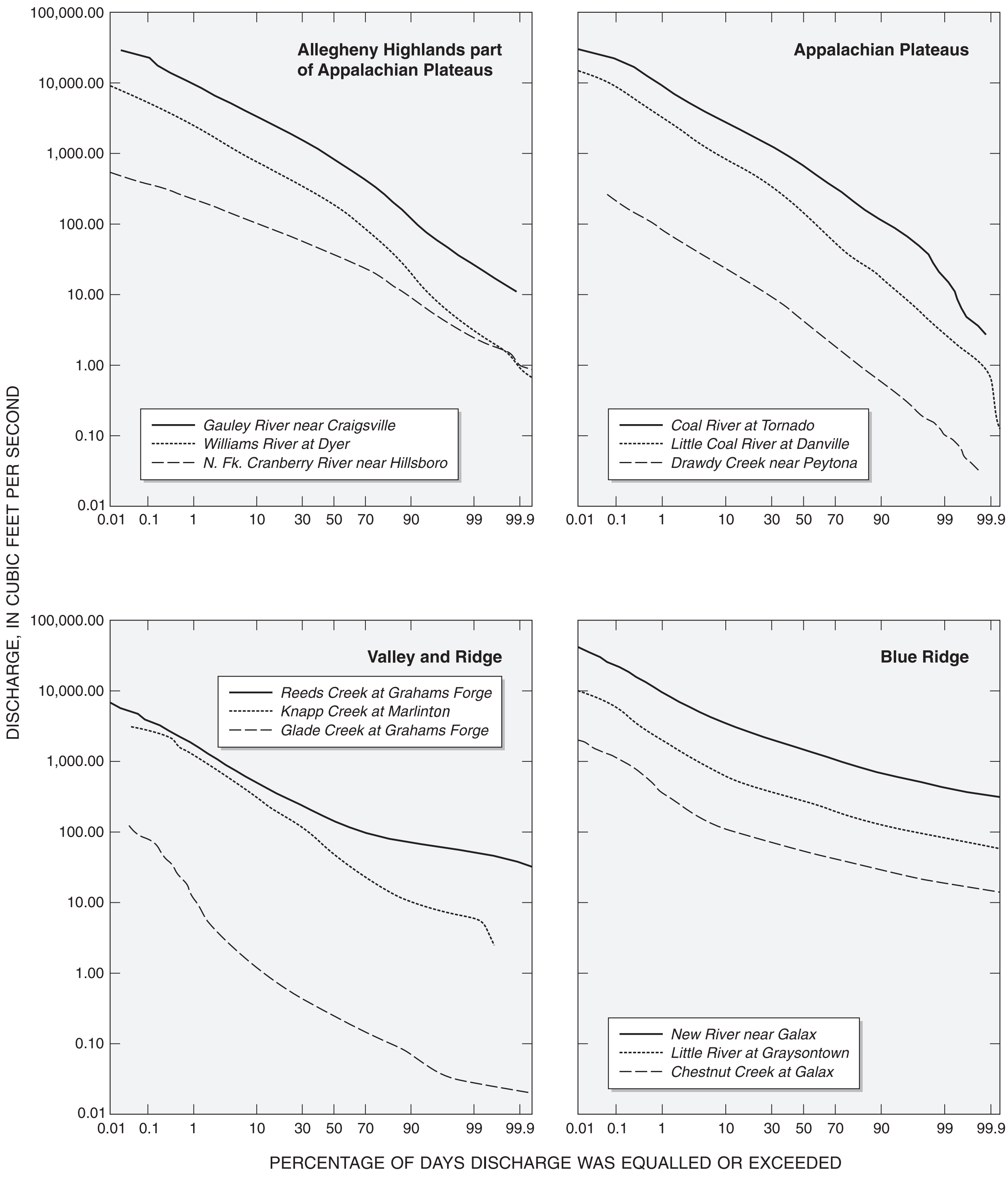


Figure 18. Flow duration curves for selected large, medium, and small streams in the Kanawha River Basin.

flows in the Kanawha River, in addition to recreation and controlling floods. Since Summersville Dam began operating in 1965, extreme high and low flows on the Kanawha River have been substantially different (fig. 19). Discharge at Kanawha River at Kanawha Falls was greater than 146,000 ft^3/s on 0.1 percent of the days during 1880-1938, or about one day every three years. During 1939-64, when Claytor and Bluestone Dams were regulating flows, the 0.1 percent discharge was decreased to 104,000 ft^3/s. Since Summersville Dam began operating in 1965, the 0.1 percent discharge at Kanawha Falls has been decreased to 94,000 ft^3/s. During these same periods, low flow was changed more of the time at Kanawha Falls. During 1880-1938, discharge was greater than 1,350 ft^3/s 99 percent of the time, and remained about the same during 1939-64. Since 1965, 99 percent flow has been increased to 1,950 ft^3/s.

Floods. Recurring floods range from common high flows that barely overtop a stream channel to unusually high flows that inundate large areas and cause extensive damage. Flood-producing rain is generally received from three types of weather systems (Runner and Michaels, 1991): (1) frontal systems in winter or early spring (2) thunderstorms during late afternoon and evening in summer, and (3) hurricanes and tropical storms in late summer or early fall. June and July thunderstorms commonly yield intense local rainfall and cause flash flooding on small streams along narrow valleys. Severe local flooding caused by heavy thunderstorm rainfall is likely in some part of the basin every year. Larger streams typically flood during the winter and spring months from December through April. Ideal conditions for cold-season floods require soil that is well saturated from previous precipitation, a thick snow cover, and a storm front that moves northeastward and produces warm rains that last for several days. Flooding is a particular concern in the Kanawha River Basin because of the basin's mountainous topography, especially in the Appalachian Plateaus Province, where most of the flat land available for development is in low-lying areas near streams.

The Kanawha River main stem flooded in 1861, 1878, 1901, 1940, 1985, and 1996. The highest flow measured on the Kanawha River at Charleston was 216,000 ft^3/s, on August 15, 1940, although the flood of September 29, 1861 reached an elevation 15.6 ft higher (Ward and others, 1999). The maximum flow recorded on the Kanawha River at Kanawha Falls, 40 mi upstream from Charleston, was 320,000 ft^3/s in September 1878. The 1940 flood was a headwater

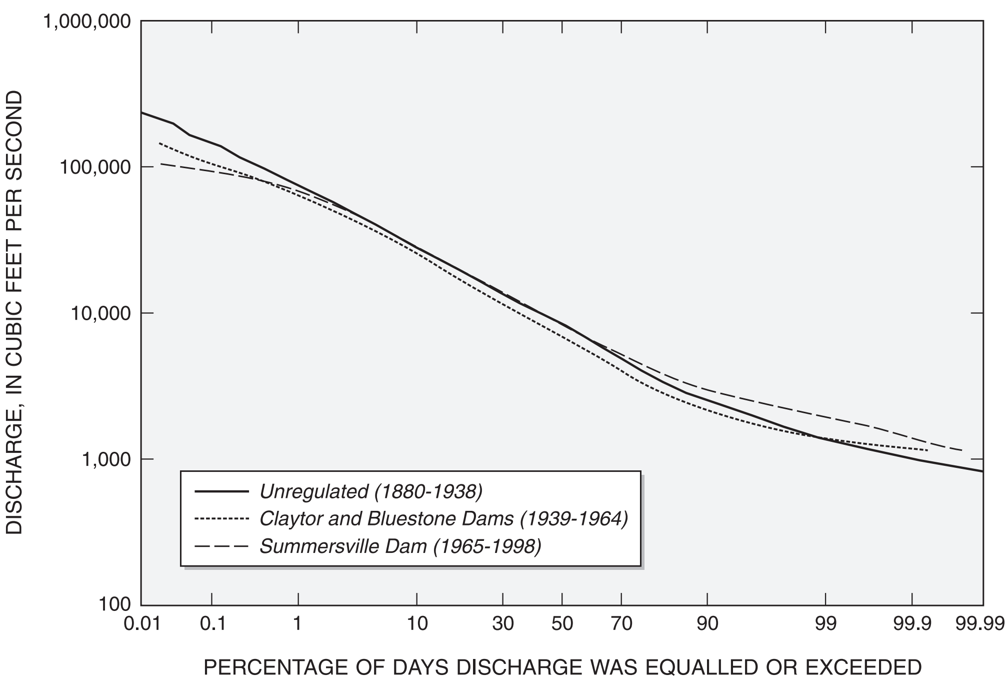


Figure 19. Flow duration curves for Kanawha River near Kanawha Falls, for periods when the the river was unregulated, regulated by Claytor and (after 1949) Bluestone Dams on New River, and then also by Summersville Dam on the Gauley River.

flood caused by heavy rains in the Blue Ridge Province, and is the greatest flow on record for South Fork of the New River near Jefferson, N.C. (Zembrzuski and others, 1991).

The November 1985 flood was the peak of record for gages on several unregulated streams in the basin, and happened when Hurricane Juan crossed the Allegheny Front and stalled over the headwaters of the Greenbrier, Elk, and Gauley Rivers (Carpenter, 1988). Recorded rainfall was as much as 11 in. in W. Va. and 18 in. in Virginia's Blue Ridge Mountains outside the Kanawha River Basin. Flooding was particularly severe on Greenbrier River, causing extensive damage to several towns and setting new peak-discharge records that exceeded the 100-year recurrence interval at all five gages then operating in the subbasin. The January 1996 flood exceeded the 1985 flood in the Greenbrier River Basin, where up to two inches of warm rain fell on as much as four feet of snow cover (Ward and others, 1997). Flooding exceeded the 100-year recurrence interval at the Williams River at Dyer and Elk River below Webster Springs, in addition to four Greenbrier River gages.

Droughts. Unlike floods, droughts can last for several years. Like floods, droughts cause extensive economic damage, although floods generally affect more people in the Kanawha River Basin. The Kanawha River Basin had major droughts in 1930-31, 1940-42, 1953-54, 1963-64, 1965-66, and 1987-88 (Runner and Michaels, 1991). Another major drought is ongoing in 1998-99. The lowest instantaneous flow recorded from the Kanawha River at Kanawha Falls (period of record 1877-present) was 640 ft^3/s on August 15, 1930, before any major reservoirs in the basin were completed. The 1930-31 drought is considered the most severe drought on record for the Appalachian Plateaus part of the basin, with the lowest rainfall on record throughout West Virginia. Municipal water supplies were critically short; streamflow from the Elk River was insufficient to meet the needs of Charleston, and extremely polluted water from the Kanawha River backed about a quarter mile up the Elk River into the city's water intake. The Big Coal River at Ashford, W. Va., with a drainage area of 391 mi^2, had zero flow on 12 days in September and October, 1930. The Blue Ridge Province had severe droughts in 1925-29, when South Fork New River near Jefferson, N.C., experienced a record-setting low flow in September 1925; in 1953, when the New River at Galax, Va., had its record low flow; and in 1981, when several Blue Ridge streams in Virginia had record low flows (Zembrzuski and others, 1991; Nuckels and others, 1991). Valley and Ridge streams were most severely affected by droughts in 1942 and 1964.

Ground Water

Rock composition, land shape, and structural features control the flow, storage, and chemical character of ground water. Because the basin has no shallow regional aquifer system, ground-water flow paths are short. Aquifers in the basin can be grouped into three different aquifer types--unconsolidated alluvial aquifers, sedimentary bedrock aquifers, and crystalline bedrock aquifers (Messinger, 1997). Unconsolidated alluvial aquifers are in major river valleys, and are the only aquifers in the basin with substantial primary permeability. Sedimentary bedrock aquifers can be subdivided into fractured bedrock aquifers and carbonate aquifers. Fractured sedimentary bedrock aquifers have formed in the sandstone/shale/coal strata in the Appalachian Plateaus Province. Carbonate aquifers are those in solution openings in the karstic carbonate rock of the Valley and Ridge Province and Greenbrier River Basin. Crystalline bedrock aquifers are in the Blue Ridge Province, and most of their permeability is secondary permeability through fractures. The characteristics of the principal aquifers are described below.

Alluvial aquifers. The alluvial aquifers are Quaternary deposits consisting of sand and gravel interbedded with silt and clay (Doll and others, 1960; Wilmoth, 1966). Most alluvium in the basin is in valleys of the Kanawha River and its largest tributaries (fig. 4). Alluvium is also in Teays Valley, the channel of the preglacial Teays River, formerly the master stream of the basin (Fridley, 1950; Tight, 1903). The thickest alluvial deposits in the Kanawha River Basin are in Teays Valley, where deposits average about 45 ft thick, and some local deposits are 100 ft thick (Wilmoth, 1966). The water table in the alluvium ranges from 11 to 30 ft below land surface, averaging 18 ft below land surface. The average saturated thickness of alluvium is about 31 ft (Schultz and others, 1996). Measured yields of industrial and (now abandoned) public-supply wells ranged from 10 to 150 gal/min; some of the larger yields resulted from induced infiltration from the Kanawha River (Doll and others, 1960). The water level beneath the alluvium depends on the stage of the Kanawha River, although ground water flows toward the river about 90 percent of the time (Schultz and others, 1996). The Kanawha River alluvium is recharged by inflow from fractures in bedrock beneath the alluvium, infiltration of Kanawha River water at high stage, inflow from tributary streams, and precipitation on the flood plain. These poorly sorted alluvial deposits yield large amounts of water to wells because of their high transmissivity; but, for the same reason, these deposits also transmit contaminants freely and rapidly (Messinger, 1997).

Sedimentary bedrock aquifers. Sedimentary bedrock aquifers are in the Appalachian Plateaus and Valley and Ridge Provinces. Fractured aquifers are in all the noncarbonate sedimentary rocks in the basin. Carbonate aquifers are in Mississippian, Cambrian, and Ordovician rocks, the only extensive carbonate rocks in the basin. Aquifers in Virginia are categorized by lithologic unit (Meng and others, 1985; Coble and others, 1985). The major aquifers of West Virginia have been categorized informally by geologic age because a typical well has only the top 10 to 30 ft cased, and the rest of the well is an open borehole that ranges from 10 to several hundred feet in depth. Well water may be derived from several chemically and hydraulically distinct strata (Mathes and others, 1998).

Upper and Lower Pennsylvanian aquifers are nearly horizontal layers of sandstone, siltstone, shale, limestone, and coal. The Lower Pennsylvanian aquifers consist of massive, coarse-grained sandstone with interbeds of shale, siltstone, coal, and limestone (Puente, 1985). Locally, regolith is thin and poorly permeable, and provides little ground-water storage. Ground-water flow is primarily through fractures or bedding-plane separations. Secondary permeability in joints and stress-relief fractures accounts for most of the porosity and permeability in these rocks, because calcium carbonate or silica cementation has filled the original intergranular pores. Stress relief, the removal of compressional stress on underlying rocks by erosion of overlying rocks, results in secondary fracturing and enhanced permeability and transmissivity in valleys (Wyrick and Borchers, 1981). Transmissivity decreases with increasing depth (Harlow and LeCain, 1993). Most rock types are permeable to a depth of about 100 ft, but only coal seams are consistently permeable (transmissivity greater than .001 ft^2/d) at depths greater than 200 ft.

Common well yields from Upper Pennsylvanian aquifers range from 1-30 gal/min, and Lower Pennsylvanian aquifers from 1-100 gal/min (Puente, 1985). Clastic Mississippian aquifers (fig. 4) are similar in lithology and permeability to the Pennsylvanian aquifers, but the rocks are moderately folded. These sandstone units are saturated and confined by overlying and underlying shales (Meng and others, 1985). Mississippian carbonate aquifers that span the border between the Valley and Ridge and Appalachian Plateaus Provinces include large areas of karst formations, characterized by numerous sinkholes, caves, and interrupted and underground streams. Because of the high transmissivity of solution cavities and fractures in these carbonate rocks, wells here may have relatively high yields (100 gal/min), although wells finished in undissolved rock may have very low yields (1 gal/min) (Puente, 1985).

Crystalline bedrock aquifers. Ground water is in crystalline bedrock primarily in fractures and joints in rocks characterized by low porosity and low storage capacity (LeGrand, 1988). Unlike the sedimentary aquifers in the rest of the basin, the Blue Ridge Province contains no flat-lying, “layer-cake” formations. A complex two-media ground-water system prevails. The system includes a mantle of residual soil and soft weathered rock, as well as the fractured bedrock at greater depth. Well yields are sustained by water stored in the saturated mantle. This mantle frequently ranges in thickness from about five to 60 ft, although it is absent in some places and thicker in others. The fractured bedrock generally grades downward to unfractured rock below a depth of about 300 ft, so that the base of the ground-water system is indistinct. Ground water is typically recharged from areas above the flood plain, and discharged as seepage springs, which are common near the base of slopes. Well yields in North Carolina in the Blue Ridge Province and adjoining Piedmont (discussed as a unit) commonly range from five to 35 gal/min; above-average well yields (up to 200 gal/min) are dependent on intercepting interconnected fractures (Coble and others, 1985). In Virginia, well yields for the Blue Ridge commonly range from 1-15 gal/min and exceed 40 gal/min in a few cases (Meng and others, 1985).

Water Use

About 61 percent of the population of the Kanawha River Basin uses surface water from public supply for their domestic needs (Solley and others, 1998). About 30 percent of the basin’s population uses self-supplied ground water, and the other nine percent of the population uses ground water from public supply. In 1995, total withdrawal of water in the basin was about 1,130 Mgal/d; total consumptive use was about 118

Mgal/d. Total instream water use was about 16,300 Mgal/d, for hydroelectric power generation. For comparison, average flow of the Kanawha River at Charleston is about 9,870 Mgal/d. Instream hydroelectric use can exceed the total flow at one site because the same water can be used at more than one generating plant. Of withdrawals, about 60.3 Mgal/d were from ground water, and 1,070 Mgal/d were from surface water. By use category, withdrawals were 624 Mgal/d thermoelectric power generation, 362 Mgal/d industrial, 20.6 Mgal/d domestic, 16.6 Mgal/d commercial, 11.2 Mgal/d livestock, 4.32 Mgal/d mining, and 4.15 Mgal/d irrigation.

In 1990, five years earlier, West Virginia was listed as having the highest per capita water use of any state east of the Mississippi, and as one of only two states (with Florida) that withdrew more than 300 Mgal/d of freshwater for use in mining (Solley and others, 1993). Although West Virginia's actual water use may not have changed substantially in five years, its statistical water use and ranking among States changed because water pumped to dewater mines was not included as water used in 1995 (Solley and others, 1998).

Relations of Water Quality to Environmental Setting

Previous sections of this report describe the natural and human features that make up the general environmental setting of the Kanawha River Basin. In this section, the major natural and human factors that affect water quality are described in the context of the environmental setting.

Relation of Water Quality to Natural Factors

Natural processes can affect the quality of water at each phase of the hydrologic cycle. Geologic processes largely control background variations in water chemistry of the Kanawha River Basin.

Three weathering processes summarize the principal pathways by which major ions and trace elements are released from rocks or sediment to waters in the study unit. Sulfide weathering is a normally slow oxidation-reduction reaction (Hem, 1985). When oxygen and water come in contact with pyrite, the reaction yields water, sulfuric acid, and iron. Sulfide weathering is important when pyritic material is disturbed by coal mining or through natural erosional processes.

Carbonate weathering involves dissolution and reaction. When acidic ($pH < 7$) water comes into contact with calcite or dolomite, the reaction can yield dissolved calcium, magnesium, and bicarbonate. Carbonate weathering is affected by water chemistry, flow rate, and rock solubility. In parts of the Valley and Ridge Province and in the Greenbrier Formation in the Appalachian Plateaus Province, carbonate weathering processes have formed distinctive karst landforms that can yield large quantities of ground water (Ford and others, 1988).

Silicate weathers by dissolution. When acidic ($pH < 7$) water comes into contact with silicate minerals, the reaction produces dissolved sodium, calcium, magnesium, potassium, bicarbonate, and silicate. Silicate weathering is typified by slow reaction rates, which can produce a clay-rich layer, commonly referred to as regolith, through the breakdown of silicate minerals. This weathering has created a porous regolith over fractured or intact bedrock in the Blue Ridge Province. The regolith stores recharge that would otherwise be rapidly diverted to overland runoff, and it slowly releases this water to underlying crystalline bedrock aquifers.

Surface water. Surface water in the Blue Ridge part of the basin is typically dilute (commonly less than 100 mg/L dissolved solids) and well aerated under background conditions (Messinger, 1997). Much of the Blue Ridge part of the basin is underlain by granite and granite gneiss, which are not very soluble. Median dissolved solids concentration (as residue on evaporation) was 52 mg/L, from USGS samples from Little River at Graysontown, Va. (1997-98). Shale and carbonate rocks underlie much of the Valley and Ridge part of the basin. Background dissolved-solids concentrations at low flow are typically greater (150-180 mg/L) than those in the Blue Ridge Province. Background surface-water quality in the Appalachian Plateaus Province is highly variable because of the varied underlying rocks which contain many types of minerals. The Greenbrier River, the largest tributary to the New River, drains parts of the Valley and Ridge and Appalachian Plateaus Provinces. The Greenbrier River is a well-buffered, alkaline stream, underlain by limestone (Clark and others, 1976). The Gauley and Elk Rivers form in the heavily forested Allegheny Highlands in the northeast part of the basin. Their water is typically dilute, soft, and poorly buffered; dissolved-solids concentrations at low flow are less than 30 mg/L in many headwater tributaries in these subbasins (Ehlke and others, 1982). The rocks at the surface in this area are primarily sandstone and shale of the Bluefield, New River and Kanawha Formations. The Bluestone and Coal Rivers drain areas underlain by sandstone, shale, and coal, and have high background concentrations of dissolved solids. In the northern part of the basin, the Pocatalico River drains hills underlain by sandstone and shales and has been affected by interactions with saline ground water. Dissolved-solids concentrations in the Coal and Pocatalico River subbasins are the highest in the basin and commonly exceed 500 mg/L in some streams. The Coal River streams drain rocks of the Kanawha and Allegheny Formations, and the Pocatalico River drains rocks of the Allegheny Formation and the Conemaugh Group. Shale is more prevalent in these regions than in the Gauley and Elk River subbasins, which contributes to the difference in background water quality. In the late 1970's, water from small streams draining unmined areas in the Coal River basin typically had dissolved solids concentrations less than 100 mg/L (Dyer, 1982). Field reconnaissance done by Kanawha-New River NAWQA study unit staff in 1998 suggests that few if any streams in these subbasins that drain areas greater than a few square miles are undisturbed by coal mining or oil and gas development, however, and can therefore be said to represent background water quality.

Ground water. The chemical composition of ground water depends on the chemistry of the precipitation that recharges the aquifer, the chemical and physical properties of the soil and rock through which the water moves, and the amount of time the water is in the ground-water system. Generally, ground water becomes more mineralized as it moves through the flow system.

Ground water sampled from 30 wells in the Blue Ridge Province in 1997 for the NAWQA program was dilute, with a median dissolved solids concentration of 80 mg/L (Ward and others, 1998). The median pH of these same samples was 6.2.

Water that drains carbonate rocks commonly contains calcium, magnesium, and bicarbonate as the principal solutes. Carbonate rocks are more soluble than clastic rocks. Usually, waters draining limestone contain more dissolved solids, hardness, and acid-neutralizing ions than waters draining sandstone, and in some cases, shale. Nitrate concentrations were elevated above background in carbonate valleys of the nearby Potomac River Basin in 1993-95 (Ator and others, 1998).

Chemistry of ground water in clastic rocks varies most with the relative abundance of shale, coal, and calcareous minerals. Specific conductance and concentrations of total iron, total manganese, dissolved sulfate, and dissolved solids are typically greater in coal-mined areas than unmined basins. Ground water sampled from 30 wells in 1997 from the Appalachian Plateaus Province for the NAWQA program had a median pH of 7.0 and dissolved-solids concentration of 212 mg/L (Eychaner, 1998).

Dissolved manganese and iron are two natural constituents typically present in ground water from the Appalachian Plateaus Province, and their concentrations vary widely (Mathes and others, 1998). Common concentrations (tenth and ninetieth percentiles of three subunits) of iron and manganese in rocks of Pennsylvania age in West Virginia range from about 10 to 10,000 µg/L for iron and from about 10 to 800 µg/L for manganese. Generally, ground water from valley settings contains greater concentrations of iron and manganese than ground water from hilltop settings (Ferrell, 1988). Elevated concentrations of these ions in ground water in the Appalachian Plateaus Province has traditionally been thought to indicate contamination from coal mine drainage (Rauch, 1987). Wells with unmined recharge zones, however, also had relatively high concentrations of iron and manganese in the 1997 samples.

Radon is another natural constituent of concern in ground water in the Kanawha River Basin (Kozar and Sheets, 1997). The U. S. Environmental Protection Agency (USEPA) has proposed a maximum contaminant level (MCL) for radon in drinking water of 300 pCi/L for States without plans to reduce indoor air risks from radon, and an MCL of 4,000 pCi/L for States with approved plans to reduce indoor air risks from radon (U.S. Environmental Protection Agency, 1999c). Radon concentrations exceeded the more restrictive proposed MCL for water in 25 of 29 wells (86 percent) sampled in the Blue Ridge Province and 15 of 30 wells (50 percent) sampled in the Appalachian Plateaus Province. Median and maximum radon concentrations were 1,800 and 31,000 pCi/mL for the Blue Ridge Province and 290 and 2,500 pCi/mL for the Appalachian Plateaus Province. Nine of the 10 Blue Ridge wells producing water with relatively high concentrations of radon (greater than 3,500 pCi/L) were on or adjacent to known faults.

Relation of Water Quality to Human Factors

Water quality, quantity, and land use are highly integrated. How land is used and how the associated waste by-products are managed largely define the type, location, and amount of contaminants in surface and ground waters in the study unit. Water quantity and quality also have an effect on land uses. In many cases, such as saline ground-water incursions in the basin, adverse water-quality influences from human activities are synergistic with or difficult to distinguish from natural factors. Land-use activity that affects ground-water quality can affect surface-water quality as well. Concerns related to streams and consolidated aquifers of the study unit include water degradation from coal mining, bacterial contamination of rural wells, saline water, and industrial contamination.

Coal mining. Coal has been commercially mined in the basin since the early 1800's, and many of the hydrologic effects of mining have been recognized for years (Messinger, 1997). Coal mining has degraded more miles of streams in the basin than any other land use (West Virginia Division of Environmental Protection, 1994). (Water-quality regulations concerning coal mining are discussed earlier in this report. p. 22-23). Mining affects streams by altering the timing and volume of runoff and the chemical and physical quality of the runoff. Puente and Atkins (1989) identified three changes in streamflow caused by mining: reduced base flow in streams underlain by underground mines, increased base flow in streams down dip and lower in elevation than mined coal beds, and changed flow because of interbasin transfer of water through underground mines. Simulations indicated that total annual runoff in mined basins would decrease because of surface and subsurface flow losses and increased recharge of precipitation to ground water. Amount and duration of low flows during summer and fall would substantially increase in response to increased ground-water storage, and extreme high flows caused by intense rainstorms would be negligibly affected by mining. The effects of mining on ground-water flow and thus, on base streamflow, depend on the hydraulic connection of mines to the stress-relief fracture system or to the stream itself (Borchers and others, 1991).

Chemical composition of drainage emanating from underground mines or backfills of surface mines is dependent on the balance between acid- or alkaline-producing materials (Skousen, 1995). When exposed to oxygen and water, pyrite (FeS_2) oxidizes to form iron hydroxide, sulfate, and hydrogen ions. The rate of this natural process is often accelerated by coal mining, because more pyrite is exposed to water and oxygen. Pyrite oxidation often results in increased sulfate concentrations, even in the low-sulfur southern coal field in the basin, where acid mine drainage is not generally considered to be the major water-quality problem associated with coal mining. Mine drainage usually increases dissolved-solids concentrations and often decreases pH, which in turn makes many trace elements soluble. In surface mines, the composition of the overburden and host rock affect mine drainage quality; in underground mines, coal composition also is considered to have a major effect on mine-drainage quality. The effect on shallow ground water caused by surface mines is generally greater than the effect on shallow ground water caused by underground mines in the nearby Monongahela River Basin in north-central West Virginia (O'Steen, 1982). Underground mines generally are deeper than the shallow aquifers, and, in many cases, would flood if not pumped. In the Monongahela River Basin, underground mines were shown to cause ground-water contamination for longer periods of time than surface mines and to a greater areal extent than surface mines, although surface mines have increased in size since this study (Rauch, 1987).

In a two-year study (1973-75), active underground mines were shown to be the principal source of mineralized water in streams in the Coal River Basin (Bader and others, 1976; Messinger, 1997). Another study in West Virginia's southern coalfield before SMCRA was implemented found that mine-discharge water contributed a large percentage of the dissolved chemical load from mined basins (Borchers and others, 1991). During a low-flow period when streams, domestic wells, and mine discharges were sampled, mine discharges contributed nearly 60 percent of the dissolved calcium load in two mined basins, and 41 percent and 30 percent of the sulfate load in the same two basins.

Major ground-water issues traditionally associated with coal mining include mining-land disturbance and reclamation, waste disposal, and water withdrawals (Hudson, 1989). Coal mining can also affect ground water by adding trace metals and other constituents to the water. Ground water affected by coal mining typically contains elevated concentrations of iron, manganese, and sulfate (U. S. Environmental Protection Agency, 1980). The effects of coal mining on ground water are most pronounced near the mine, and they usually diminish with increasing distance from the mine (Ferrell, 1988). Seventy-eight percent of wells in the Coal River Basin whose water contained 10 mg/L of sulfate or more were within 1.6 mi of an underground coal mine (U. S. Environmental Protection Agency, 1980). Eighty-two percent of wells more than 1.6 mi from an underground mine produced water containing less than 10 mg/L of sulfate.

Early coal washing practices supplied large amounts of small coal particles (fines) to streams, where they became part of the bedload. One suspended sediment sample collected during high flow on the Kanawha River main stem in 1958 contained 254 mg/L of combustible materials, considered to be primarily coal (Doll and others, 1960). Through the 1990's, the Kanawha River still contained enough streambed coal fines to support commercial dredging of the fines. Coal mining and handling still puts some coal into streams, although in much smaller amounts. In West Virginia, many coal tipples, or loading facilities, are in the small flat areas near streams, as are roads and railroads. Rain can wash coal fines from near-stream sources into the streams. Coal contains polycyclic aromatic hydrocarbons (PAHs), a large group of semivolatile hydrophobic organic compounds (Lopes and others, 1998). In sufficient concentrations, PAHs in stream-bed sediments are carcinogenic to fish (Baumann and others, 1987). Stream-bed sediment samples were collected from coal-mining areas with PAHs in concentrations thought harmful to aquatic life (Messinger and Chambers, 1998).

Coal mining can also mobilize sediment. Excess sediment can fill interstitial spaces in stream beds and degrade habitat for stream organisms. Increased sediment loads in streams was considered one of the most important water-quality effects of surface mining before SMCRA was passed (Hudson, 1989). SMCRA placed regulatory emphasis on erosion and sediment control, and other aspects of land reclamation (OSM, 1997). Although suspended-sediment monitoring networks neither before nor after SMCRA were adequate to quantify relations among mining, reclamation practices, and sediment yield, regulation is widely believed to have decreased the suspended sediment yields from land disturbed by mining. But some evidence suggests that despite the effort that has gone into mine reclamation, increased stream-sediment loads remain one of the most important water-quality effects of surface mining. Preliminary analysis from the USEPA's assessment of stream ecology in the Mid-Atlantic Highlands, the part of the Appalachian Mountains between Pennsylvania and Virginia, indicate that sedimentation is the most ecologically important effect of coal mining in this area (J.L. Stoddard, U.S. Environmental Protection Agency, oral commun., Feb. 1998).

Domestic waste disposal. Bacterial contamination from human and animal waste continues to be one of the most widely noted water-quality problems in the basin and has been documented since at least 1947 (West Virginia State Water Commission, 1947; Messinger, 1997). Although some pasture agriculture is in the basin, much of the fecal contamination is thought to result from untreated or inadequately treated domestic sewage. Many residences in the Appalachian Plateaus Province remain unserved by public sewers, largely because of physical factors. Most flat land available for development in the Appalachian Plateaus Province is near streams, so communities are scattered and linear, which increases the expense of constructing sewer lines. Many economic and social factors, among them the basin's high poverty rate, also have contributed to the lack of infrastructure adequate to safeguard water sanitation.

Ground-water quality in rural areas in the Appalachian Plateaus Province has been affected by improper disposal of domestic wastes in combination with improper construction, siting, and abandonment of wells (Kozar and Brown, 1995). Most wells contaminated with bacteria were improperly constructed. Occasionally, contaminants that enter aquifers through improperly constructed wells may be transported short distances into other nearby wells constructed in the same fracture system. Although water-well design standards adopted by the West Virginia Board of Health (1984) call for sealing well heads, many wells finished before 1984 remain in use. Ground-water studies done as part of Kanawha-New River NAWQA used samples collected only from domestic wells that were recently constructed and conformed to design standards. Samples collected from 30 wells meeting these criteria in the Appalachian Plateaus Province during the summer of 1997 were analyzed for fecal coliform bacteria, but none were detected (Sheets and Kozar, 1997). In 1974, ten years before well construction standards were adopted, fecal coliform bacteria were detected in water from nine of 19 wells (47 percent) sampled by USGS in the Coal River Basin, and five of the wells (26 percent) had water with at least 30 col/100 mL (Morris and others, 1976).

Contamination of karst aquifers through improperly constructed wells has also been noted in the basin (Messinger, 1997). Such contamination is a particular concern in these types of ground-water systems, where contaminants can move relatively long distances rapidly.

Industrial activities. With some scattered exceptions, manufacturing in the basin is concentrated in the Kanawha River terrace within about 20 mi of Charleston, W. Va. The Kanawha River and water in the adjacent alluvium have been adversely affected by industrial activities (Messinger, 1997). The reach of the Kanawha River Valley between Belle and Nitro is known locally as the "Chemical Valley," which, at its peak in the late 1950's and early 1960's, was the leading producer of chemicals in the world (Henry, 1974). Production of a broad range of agricultural and industrial chemicals remained high through the 1970's but has declined steadily since. The defoliant Agent Orange was one of the chemicals manufactured in the Kanawha Valley. Before the beginning of systematic monitoring in 1974 through implementation of the 1972 Federal Clean Water Act, the Kanawha River downstream from Charleston was severely polluted and supported little life (Henry, 1974). Dissolved oxygen concentrations in summer rarely exceeded 1 mg/L during this period. Since the 1980's, oxygen concentrations rarely, if ever, fall below the State standard of 4 mg/L, and the Kanawha River supports a fish community including pollution-intolerant species such as smallmouth bass and several round-bodied suckers. But water-quality problems remain in the lower Kanawha River (Waldron, 1993; Messinger, 1997; West Virginia Division of Environmental Protection, 1998). A fish consumption advisory issued in 1986 and reissued every two years since warns against consuming any bottom-feeding fish from the Kanawha River because of dioxin contamination (Janice Smithson, WVDEP, written commun., 1998). Contamination of sediments and biota by persistent organic compounds is considered the most serious water-quality concern in the lower Kanawha River in 1999.

Ground-water contamination from industrial activities has been most extensive in the alluvial aquifers along the Kanawha River at Charleston, W. Va. Several known contaminant plumes are present in the Kanawha River alluvium (Ferrell, 1988). Contaminants detected in alluvial ground water have included chloride, mercury, phenol, carbon tetrachloride, chloroform, trichloroethylene, and benzene. One USEPA Superfund site within 2,000 ft of the Kanawha River has been included on the National Priorities List of sites requiring extensive, long-term cleanup to eliminate or reduce hazards to public health and the environment (U. S. Environmental Protection Agency, 1999d).

Logging. Most of the Appalachian Plateaus Province is forested. Although forested land cover usually has a favorable effect on water quality, pesticides are occasionally applied to trees for weed and insect control. Logging can affect water quality by resulting in the addition of sediment, nutrients, and other constituents to the water.

Continued logging, especially in West Virginia, is expected over the next two or three decades. Logging and related activities can cause large increases in sediment transport when best management practices are not followed, because a lack of vegetation increases sediment runoff (West Virginia Department of Natural Resources, 1989). Logging is typically the first step of surface mining, and streams that are affected by surface mining are also affected by logging. Sawmills and lumber-treatment plants produce waste materials that can contaminate surface and ground waters. Several wood processing plants have begun operating since 1992, and more are expected to begin operations (West Virginia Division of Forestry, 1997).

Agriculture. Agricultural activities can add nutrients, sediment, bacteria, and synthetic chemicals to streams and aquifers. Animal grazing produces excess nutrients that can leach to the ground water or wash off to streams, resulting in nutrient enrichment in water. Farm animal waste has increased nitrate concentrations in karst springs in southeastern West Virginia (Boyer and Pasquarell, 1996). Pasture effects on aquatic systems depend directly on land management. Pasture management for appropriate ground cover, high infiltration rates, and protected streambanks yield minimum effects on aquatic systems. Pastures may be overgrazed, have compacted soils, and allow animals free access to riparian area and streams. Riparian areas are commonly more heavily grazed than upland areas because they are flatter and provide water and sometimes, more shade (Platts, 1991).

Urban activities. Urban land makes up a small part of the mostly rural Kanawha River Basin. Sources of contaminants from urban and built-up land include discharge from wastewater-treatment plants, leachate from septic systems, solid-waste disposal, leaking underground storage tanks, industrial-chemical discharges, and storm runoff through combined sewers (Waldron, 1993). West Virginia's 1995-97 305b report (WVDEP, 1998) lists "urban runoff/storm sewers" as a source of impairment for 80.4 stream miles in the Upper Kanawha River watershed, which is the part of the basin downstream from the Gauley River and upstream from the Elk River. West Virginia has recently changed its 305b monitoring program to a watershed-based, rotational system that allows all streams in the State to be assessed. Other watersheds in the basin with more urban land use have not yet been assessed.

Oil and gas extraction. Shallow ground water has become contaminated with salt in conjunction with oil and gas production in the Appalachian Plateaus Province (Bain, 1970). Saline ground water underlies fresh ground water in most of the basin and is commonly under artesian pressure (Foster, 1980). The extent to which excessive salt in shallow ground water results from oil and gas extraction is difficult to quantify. This is partly because saline water is naturally near the surface in some areas, particularly along the axes of anticlines, which are among the areas where oil and gas wells have been most heavily developed, and partly because many of the oil and gas wells in the basin were drilled in the first half of the twentieth century, and few pre-development ground-water quality data were collected. In most of the northwestern part of the Kanawha River Basin, saltwater (defined as water containing between 1,000 and 35,000 mg/L dissolved solids) is common at depths as shallow as 200 ft and is at the surface in a few locations. But deep saltwater under pressure has been shown to migrate upward along improperly sealed gas wells and to mix with fresh ground water (Bain, 1970). A domestic well can be drilled and finished in a high-quality, fresh aquifer and then become contaminated with excessive salt following oil and gas development. For example, the Frame area of Kanawha County underwent natural gas development in the 1980's, to which residents attributed decreased quality of their domestic wells (Allen, 1987). In a follow-up study, water in 37 of 39 domestic wells (95 percent) contained sodium concentrations greater than 20 mg/L, the maximum drinking-water concentration recommended by the American Heart Association for consumption by persons on a sodium-restricted diet.

Fish and Invertebrate Distribution

The NAWQA Program focuses its ecological studies on how land-use practices affect water quality, including stream chemistry and habitat structure, which in turn affects distribution and relative abundance of fish, algae, and benthic macroinvertebrates. Many ecological studies that have been done in the basin fall outside this scope. This discussion focuses on the distribution of fish, mussels, and crayfish in the Kanawha River Basin. No large-scale studies in the basin have used algae as indicators of environmental quality. Most benthic invertebrate studies have been site-specific. No reviews of basin-wide benthic insect distribution are yet available. All three States in the basin, however, have shifted emphasis of their 305b monitoring program from fixed-site chemical monitoring to rotating watershed-based invertebrate collection, and all use comparable methods. When a full cycle of this extensive monitoring has been completed, synthesis of these data should provide a description of invertebrate distribution throughout the basin. Also, the USEPA's Environmental Monitoring and Assessment Program has completed invertebrate and fish sampling in the Mid-Atlantic Highlands Area, which includes most of the basin (U. S. Environmental Protection Agency, 1999a). Its synthesis report, which should also provide a useful overview of invertebrate distribution and relative abundance in the basin, was not yet published when this report was being written.

The New River system, which fisheries biologists consider to include the Gauley River and its tributaries, has a fish fauna distinct from the Ohio River system to which the lower Kanawha River system belongs (Jenkins and Burkhead, 1994). Kanawha Falls has been a major (but not completely impassable) barrier to upstream fish movement since the Pleistocene. The New River system has only 46 native fishes and the lowest ratio of native fishes to drainage area of any river system in the eastern United States. The New River fish fauna is generally characterized as depauperate (lacking species diversity), and having unfilled niches. The fish fauna of the New River system has been extremely susceptible to invasion, and is not presently in a state of equilibrium. In a comprehensive review by Jenkins and Burkhead (1994), the system was listed as having the largest number and proportion (42 of 89) of introduced freshwater species of all major eastern and central North American drainages. The native status of several fish species in the New River system is uncertain, and species that had been considered native or probably native by some researchers are now considered to be introduced or probably introduced (Jenkins and others, 1972; Hocutt and others, 1978; Hocutt and others, 1979; Hocutt and others, 1986; Jenkins and Burkhead, 1994). The first researcher to make an extensive survey of the basin (during the 1930's) collected only 28 species of fish upstream from Kanawha Falls, although he collected only in the West Virginia part of the basin (Addair, 1944). Range expansions of non-native fish species continue, largely because of bait-bucket introductions (Cincotta and others, 1999).

Isolation of the New River system by Kanawha Falls, or, during Pleistocene glaciation, by a glacial lake, has led to a high rate of speciation (differentiation into new species) and endemism among fishes (Jenkins and Burkhead, 1994). Sandstone Falls and other rapids in the New River Gorge were also formidable barriers to fish migration. Eight of the 46 native fishes of the New River system are endemic (live nowhere else in the world), the second-highest proportion in any North American river system east of the Rocky Mountains.

Widespread in small to large streams of the New River are longnose dace, central stoneroller, white shiner, telescope shiner, white sucker, northern hog sucker, rock bass, and smallmouth bass (Jenkins and Burkhead, 1994). Widespread in small to medium streams are rosyside dace, blacknose dace, creek chub, mottled sculpin, and fantail darter. Widespread in medium and large streams or chiefly the New River are bigmouth chub, spotfin shiner, silver shiner, rosyface shiner, mimic shiner, bluntnose minnow, sharpnose darter, and greenside darter.

One hundred eighteen fish species are reported from the Kanawha River system downstream from Kanawha Falls (Stauffer and others, 1995). Of these species, 15 are listed as possible, probable, or known introductions. None of these fish species are endemic to the Kanawha River Basin. Widespread and abundant in streams of all sizes are longnose dace, central stoneroller, white shiner, white sucker, northern hog sucker, rock bass, smallmouth bass, and greenside darter (Ward and others, 1999). Widespread and abundant in small to medium streams are blacknose dace, creek chub, mottled sculpin, fantail darter, and johnny darter. Widespread and abundant in medium to large streams are river chub, silver shiner, striped shiner, bluntnose minnow, common carp, channel catfish, flathead catfish, variegate darter, rainbow darter, and banded darter. Abundant mostly in the main stem or other large streams are gizzard shad, emerald shiner, smallmouth buffalo, river redhorse, golden redhorse, and freshwater drum.

Thirty-four species of mussels are known from the Kanawha River downstream from Kanawha Falls, including the Federally-listed endangered pink mucket pearly mussel and fanshell (Morris and Taylor, 1979). Common mussel species include the giant floater, squaw foot, pistol grip, white wartyback, and three ridge. Mussels in the Kanawha River main stem were limited to the 5-mile reach of river immediately downstream from Kanawha Falls, and absent from the reach of the stream regulated for navigation.

Twenty-four species of mussels are known from the Elk River, including three Federally-listed endangered species (Clayton, 1994). Fifteen of these species are present in Big Sandy Creek, a major tributary of Elk River in Clay and Kanawha Counties (R.L. Harris, 1998, unpublished data on file with West Virginia Division of Natural Resources, Elkins). The endangered species, the pink mucket pearly mussel, clubshell, and northern riffleshell are all present in the Elk River downstream from Sutton Dam, and the clubshell population is reproducing and fairly abundant (Clayton, 1994). In contrast to the high mussel diversity in the upper Kanawha and lower Elk Rivers, only seven species of live mussels and shells of an eighth mussel were collected in the New River Gorge National River in a 1984-85 study (Jirka and Neves, 1987). The New River mussel populations were healthy and abundant, and excellent habitat for mussels was available. Some of the same barriers that prevent fish migration upstream of Kanawha Falls may directly prevent mussel migration. Although adult mussels are sessile (attached to substrate), larval mussels go through a free-swimming life stage (veligers), and have a parasitic life stage when they are attached to specific fish hosts. Mussels probably can move the greatest distance while they are attached to fish, although sometimes mussel eggs can be moved by birds or other organisms. Because mussels require a specific host to mature, however, the depauperate nature of the fish community of the New River probably causes the depauperate mussel community.

An exotic mollusk species, the Asiatic clam, has been established in the Kanawha River Basin since at least 1964 (Taylor and Hughart, 1981). Zebra mussels have been well established in the Kanawha River since at least 1992 (U. S. Geological Survey, 1999c). As of

1999, zebra mussels were not yet reported from the New River.

Seventeen species of crayfish (which often do not have common names) have been collected in the West Virginia part of the basin (Jezerinac and others, 1995). Of these, three are believed to be introduced to the basin, and others have been moved from one part of the basin to another. One species, *Cambarus chasmodactylus* (New River crayfish), is endemic to the New River Basin from its headwaters to the upstream end of the New River Gorge. *Cambarus elkensis* is endemic to the upper Elk River subbasin, and *C. nerterius* is endemic to the Greenbrier River subbasin and live only in caves. *Orconectes sanbornii*, *Cambarus robustus*, and three subspecies of *C. bartoni* (Appalachian brook crayfish) are the most widely distributed and abundant crayfish species within the West Virginia part of the basin.

Summary

The Kanawha River and its major tributary, the New River, drain 12,233 mi^2 including parts of West Virginia, Virginia, and North Carolina. Major water-quality issues in the basin include effects of coal mining, inadequate domestic sewage treatment, industrial point- and nonpoint-sources, agricultural nonpoint sources, and logging.

The Kanawha River Basin includes parts of the Appalachian Plateaus, Valley and Ridge, and Blue Ridge Physiographic Provinces. Elevation ranges from about 550 ft above sea level in the northwest part of the basin near Point Pleasant, W. Va., to more than 4,700 ft at Shaver Mountain near Marlinton, W. Va. Topography in the basin consists of areas of sloping, uplifted, dissected plateaus; a sequence of strongly folded and faulted valleys and ridges; and broad upland slopes commonly bordered by flood plains. The Allegheny Highlands of the Appalachian Plateaus Province, although in the Kanawha Section, constitutes a transition area with the nearby Allegheny Mountains Section. In the Appalachian Plateaus Province, little of the land is flat, and most of the flat land is in the flood plains and terraces of streams; this has caused most development in this part of the basin to be near streams.

The clastic, carbonate, and crystalline rocks that make up the bedrock aquifer systems range in age from Precambrian to Pennsylvanian or Permian. Over 90 named geologic formations are in the basin, and about 15 of them account for most of the basin's area. The Blue Ridge Province is composed of crystalline rocks, and both the Valley and Ridge and Appalachian Plateaus Provinces contain both carbonate and clastic rocks. Most of the crystalline rocks are metamorphic, but igneous intrusions are present and have been economically important. Most of the crystalline rocks are granitic, include granite and several types of granitic gneiss, but also include amphibolite. The carbonate rocks are limestone and dolomite with interbedded clastic rocks. The clastic rocks include sandstone, siltstone, and shale, and many are interbedded with coal and minor limestone. Several metals, salt, and mica were once mined in the basin, but at present coal, sand and gravel, limestone, and oil and gas are the only minerals that are commercially extracted.

In 1990, the population of the basin was about 870,000, of whom about 25 percent lived in the Charleston, W. Va. metropolitan area. The population of the basin more than doubled from 1900 until 1940, and this increase is correlated with employment in coal mining in the Appalachian Plateaus Province. Since 1940, the decade when mechanization of coal mining began, the population of the basin has fluctuated within seven percent of the 1990 population.

Most of the land in the basin is forested (81 percent). Agriculture is the second most prevalent land use (16 percent). Intensive land uses which have the greatest adverse effects on water quality are coal mining, urban, low-intensity residential, and commercial/industrial, but cumulatively occupy less than three percent of the basin. About 75 million tons of coal were mined in the Kanawha River Basin in 1998. This amount represents about 45 percent of the coal mined in West Virginia, and about seven percent of the coal mined in the United States. Dominant forest types in the basin are Northern Hardwood, Oak-Pine, and Mixed Mesophytic. Agricultural land use is more common in the Blue Ridge Province than in the Valley and Ridge and Appalachian Plateaus Provinces. Cattle are the principal agricultural product of the basin. Major crops produced are hay, corn, and tobacco.

The climate of the basin is continental. Annual precipitation ranges from about 36 in./year to over 60 in./year, and is orographically affected, both locally and regionally. The Blue Ridge Province and the Allegheny Highlands receive the most precipitation; the Valley and Ridge Province receives the least precipitation. Seasonal variation in precipitation is different among the physiographic settings in the basin.

Throughout the basin, precipitation is greatest in summer and least in winter, but precipitation in the Blue Ridge Province has significantly less seasonal variation than in the rest of the basin. Average annual air temperature ranges from about 43ºF to about 55ºF, and varies with altitude but not by physiographic province.

The average flow of the Kanawha River at Charleston is 15,200 ft^3/s. The Blue Ridge Province and Allegheny Highlands yield the most runoff to streams in the basin, and the Valley and Ridge Province and the southwestern Appalachian Plateaus yield the least runoff. Throughout the basin, streamflow is greatest in March and least in September. The difference in seasonal variation in precipitation and streamflow is caused by increased transpiration in growing season, when deciduous trees are in leaf. Streamflow is most variable in the Appalachian Plateaus Province, and most consistent in the Blue Ridge Province. Major floods took place in the basin in 1861, 1940, 1985, and 1996; the 1861 flood was the most severe flood on the main stem. The basin had major droughts in 1930-31, 1965-66, and 1987-88; the 1930-31 drought was the most severe since reliable records have been kept. Regulation by four major dams has decreased extreme high flows and increased extreme low flows on the Kanawha River.

The Kanawha River Basin contains three principal aquifer types: (1) unconsolidated alluvial aquifers, composed of sand, silt, gravel, and clays, (2) sedimentary bedrock aquifers, composed of sedimentary and carbonate rocks, and (3) crystalline bedrock aquifers, composed of fractured igneous and metamorphic rock. Wells in alluvial aquifers commonly yield 10 to 150 gal/min. Sedimentary bedrock aquifers (which include carbonate aquifers) commonly yield 1 to 100 gal/min. Wells completed in crystalline bedrock aquifers generally yield from 1 to 35 gal/min, but greater yields are possible where wells intercept interconnected fractures in the bedrock.

About 61 percent of the basin's population uses surface water from public supply; about 30 percent uses self-supplied ground water, and about nine percent uses ground water from public supply. In 1995, total withdrawal of water in the basin was about 1,130 Mgal/d; total consumptive use was about 118 Mgal/d. Total instream water use for hydroelectric power generation was about 16,300 Mgal/d.

Surface water in the Blue Ridge Province is typically dilute (less than 100 mg/L dissolved solids) and well aerated. Shale, limestone, and dolomite underlie much of the Valley and Ridge part of the basin. Dissolved-solids concentrations at low flow are typically greater (150-180 mg/L) than those in the Blue Ridge Province. Streams draining the Appalachian Plateaus Province contain water with the smallest (< 30 mg/L) and greatest (>500 mg/L) concentrations of dissolved solids in the basin. The most dilute streams drain areas that are predominantly sandstone, and the least dilute streams drain areas with larger proportions of shale that have also undergone extensive coal mining and oil and gas development.

Coal mining degrades more miles of streams in the basin that any other land use. Mining changes hydrology in the basin when it intercepts streams or the fractured aquifer system. Effects include increase or decrease in base flow, but generally do not include changes in runoff from intense storms. Streams that receive coal-mine drainage typically contain high concentrations of sulfate, iron, and manganese. Other major water-quality effects of coal mining include sedimentation and enrichment of sediment with trace metals and PAHs.

One hundred eighteen fish species are reported from the Kanawha River system downstream from Kanawha Falls. Of these, 15 are listed as possible, probable, or known introductions. None of these fish species are endemic to the Kanawha River Basin. The New River drainage system, which fisheries biologists consider to include the Gauley River and its tributaries, has fish and mussel faunas distinct from the Ohio River system to which the lower Kanawha River system belongs. Kanawha Falls has been a major (but not impassable) barrier to upstream fish migration since the Pleistocene. The New River system has only 46 native fishes, the lowest ratio of native fishes to drainage area of any river system in the eastern United States, and the second-highest proportion of endemic fish species of any river system in the eastern United States. Thirty-four species of mussels are known from the Kanawha River downstream from Kanawha Falls, and 21 species are known from the Elk River subbasin. Only eight species of mussels are known from the New River system. Seventeen species of crayfish have been collected in the West Virginia part of the basin. Benthic insect and algal distribution data have not been compiled for the basin.

References Cited

Addair, John, 1944, The fishes of the Kanawha River system in West Virginia and some factors which influence their distribution: Columbus, Ohio State University, Ph. D. dissertation, 225 p.

Allen, R.A., 1987, Investigation of sodium intrusion into drinking water supplies, Frame area, Kanawha County: Kanawha-Charleston Health Department, 2 p.

Appalachian Regional Commission, 1999, Socioeconomic data, regional statistics and reports: accessed September 9, 1999, at URL http://www.arc.gov/data/datamain.htm.

Ator, S.W., Blomquist, J.D., Brakebill, J.W., Denis, J.M., Ferrari, M.J., Miller, C.V., and Zappia, H., 1998, Water quality in the Potomac River Basin, Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia, 1992-96: U.S. Geological Survey Circular 1166, accessed September 1, 1999, at URL http://water.usgs.gov/pubs/circ1166/, updated June 10, 1998.

Babitzke, H.R., Barsotti, A.F., Coffman, J.S., Thompson, J.G., and Bennett, H.J., 1982, The Bureau of Mines Minerals Availability System: an update of Information Circular 8654: U.S. Bureau of Mines Information Circular 8887, 54 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 5, (unpublished report on file with the West Virginia Geological and Economic Survey).

Bain, G.L., 1970, Salty ground water in the Pocatalico River Basin: West Virginia Geological and Economic Survey, Circular 11, 31 p.

Baumann, P.C., Smith, W.D., and Parland, W.K., 1987, Tumor frequencies and contaminant concentrations in brown bullheads from an industrialized river and a recreational lake: Transactions of the American Fisheries Society, v. 116, p. 79-80.

Borchers, J.W., Ehlke, T.A., Mathes, M.V., Jr., and Downs, S.C., 1991, The effects of coal mining on the hydrologic environment of selected stream basins in southern West Virginia: U.S. Geological Survey Water-Resources Investigations Report 84-4300, 119 p.

Boyer, D.G., and Pasquarell, G.C., 1996, Agricultural land use effects on nitrate concentrations in a mature karst aquifer: Journal of the American Water Resources Association, v. 32, no.3, p. 565-573.

Branscome, J.G., 1971, Annihilating the hillbilly—the Appalachians’ struggle with America’s institutions: Journal of the Committee of Southern Churchmen, Winter 1971, p. 211-227.

Brown, J.S., and Hillary, G.A. Jr., 1967, The great migration, *in* Ford, T.R., ed., The Southern Appalachian Region—a survey: Lexington, University of Kentucky Press, p. 54-78.

Byers, R.J., 1999, West Virginia's battle with time—loss of generation, retirees' return push state into the gray: Charleston, W. Va., Charleston Gazette, July 4, 1999, p. 1-4.

Cannon, W.F., Clark, S.H.B., Lesure, F.G., Hinkle, M.E., Taylor, R.L., King, H.M., Simard, C.M., Ashton, K.C., and Kite, J.S., 1994, Mineral Resources of West Virginia: U.S. Geological Survey Miscellaneous Investigations Series Map I-2364-A, scale 1:500,000.

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

Cardwell, D.H., Erwin, R.B., and Woodward, H.P., and Lotz, C.W., comps., 1968, Geologic map of West Virginia: West Virginia Geological and Economic Survey, 2 sheets, scale 1:250,000.

Carpenter, D.H., 1988, Floods in West Virginia, Virginia, Pennsylvania, and Maryland, November 1985: U.S. Geological Survey Water-Resources Investigations Report 88-4213, 86 p.

Centers for Disease Control and Prevention, 1999, Achievements in public health, 1900-1999—improvements in workplace safety—United States, 1900-1999: Morbidity and Morality Weekly Report, v. 48, no. 22 p. 461-469.

Charleston Gazette, 1999, Mining the mountains: accessed online August 27, 1999, at URL http://www.wvgazette.com/mining/index.html.

Cincotta, D.A., Chambers, D.B., and Messinger, T., 1999, Recent changes in the distribution of fish species in the New River Basin in West Virginia and Virginia *in* National Park Service, ed., Proceedings of the New River Symposium, April 15-16, 1999, Boone, N.C., p. 98-106.

Clark, W.E., Chisholm, J.L., and Frye, P.M., 1976, Water resources of the Upper New River Basin, West Virginia: Morgantown, West Virginia Geological and Economic Survey River Basin Bulletin RBB-4, 87 p.

Clarkson, R.B., 1964, Tumult on the mountains: Parsons, W. Va., McClain Publishing Company, 401 p.

Clayton, J.L., 1994, Freshwater bivalves in Elk River, West Virginia with emphasis on Federally endangered species: Elkins, W. Va., West Virginia Division of Natural Resources, 18 p.

Coal Age, 1999, Coal Age home page: accessed online August 27, 1999, at URL http://www.coalage.com.

Coble, R.W., Giese, G.L., and Eimers, J.L., 1985, North Carolina ground water resources, *in* National Water Summary 1984, Hydrologic events, selected water-quality trends, and ground water resources: U.S. Geological Survey Water-Supply Paper 2275, p. 329-334.

Constantz, George, 1994, Hollows, peepers, and highlanders—an Appalachian Mountain ecology: Missoula, Mt., Mountain Press Publishing Company, 267 p.

Cook, F.A., Albaugh, D.S., Brown, L.D., Kaufman, S., Oliver, J.E., and Hatcher, R.D.Jr., 1979, Thin-skinned tectonics in the Crystalline Southern Appalachians: Geology, v. 7, p. 563-567.

Corbin, D.A., ed., 1990, The West Virginia Mine Wars—an anthology: Martinsburg, W. Va., Appalachian Editions, 165 p.

Davies, W.E., 1968, Engineering geology, *in* U.S. Geological Survey and U.S. Bureau of Mines, eds., Mineral resources of the Appalachian Region: U.S. Geological Survey Professional Paper 580, 492 p.

Davies, W.E., Bailey, J.F., and Kelly, D.B., 1972, West Virginia's Buffalo Creek Flood—a study of the hydrology and engineering geology: U.S. Geological Survey Circular 667, 32 p.

Doll, W.L., Wilmoth, B.M., and Whetstone, G.W., 1960, Water resources of Kanawha County, West Virginia: Morgantown, West Virginia Geological and Economic Survey Bulletin 20, 189 p.

Dulin, B., Greene, B., Samuel, D., Callaghan, D., Peng, S., and Calhoun, R., 1998, [West Virginia] Governor's task force on mountaintop removal and related activities—Report of the committee on the impact to the environment: accessed November 8, 1999, at URL http://www.marshall.edu/mtop.

Dyer, K.L., 1982, Stream water quality in the coal region of West Virginia and Maryland: Berea, Ky., U.S. Dept. of Agriculture, Forest Service, Northeastern Forest Experiment Station, 215 p.

Eggleston, J.R., 1996a, History of West Virginia mineral industries, oil and gas: accessed October 1, 1999, at URL http://www.wvgs.wvnet.edu/www/geology/geoldvog.htm.

Eggleston, J.R., 1996b, History of West Virginia mineral industries, salt: accessed October 1, 1999, at URL http://www.wvgs.wvnet.edu/www/geology/geoldvsa.htm.

Ehlke, T.A., Runner, G.S., and Downs, S.C., 1982, Hydrology of Area 9, Eastern Coal Province, West Virginia: U.S. Geological Survey Water-Resources Investigations Water-Resources Investigations Open-File Report 81-803, 63 p.

Eller, R.D., 1982, Miners, millhands, and mountaineers—industrialization of the Appalachian South, 1880-1930: Knoxville, University of Tennessee Press, 272 p.

Eychaner, J.H., 1994, National Water-Quality Assessment Program--the Kanawha-New River Basin, W. Va., Va., and N.C.: U.S. Geological Survey NAWQA Fact Sheet 94-019, 2 p.

---1998, What's normal -- Constituent concentrations in West Virginia streamflow, ground water, streambed sediment, and fish tissue, *in* West Virginia NPS Conference, Charleston, W. Va., Oct. 1-3, Proceedings: Charleston, W. Va., West Virginia NPS Conference, p. 38-53.

Feather, C.E., 1998, Mountain people in a flat land—a popular history of Appalachian migration to northeast Ohio, 1940-1965: Athens, Ohio University Press, 255 p.

Fedorko, Nick, and Blake, Mitch, 1998, A geologic overview of mountaintop removal mining in West Virginia: accessed October 20, 1999 at URL http://www.wvgs.wvnet.edu/www/mtrm/fa02mtrm.htm.

Fenneman, N.M., 1938, Physiography of Eastern United States: New York, McGraw-Hill, 714 p.

Fenneman, N.M., and Johnson, D.W., 1946, Physical divisions of the United States: U.S. Geological Survey Physiography Committee Special Map, scale 1:7,000,000.

Ferrell, G.M., 1988, West Virginia ground-water quality, *in* National Water Summary 1986, Hydrologic event and ground water quality: U.S. Geological Survey Water-Supply Paper 2325, p. 523-530.

Foley, N.K., and Craig, J.R., 1989, Mineralogy and geochemistry of the lead-zinc ores of the Austinville-Ivanhoe district, Wythe County, Virginia, *in* Evans, N.H., ed., Contributions to Virginia geology—VI: Charlottesville, Virginia Division of Mineral Resources, 91 p.

Ford, D.C., Palmer, A.N., and White, W.B., 1988, Landform development; Karst, *in* Back, William., Rosenshein, J.S., and Seaber, P.R., eds., Hydrogeology: Boulder, Colo., Geological Society of America, The Geology of North America, v. O-2.

Foster, J.B., 1980, Fresh and saline ground-water map of West Virginia: West Virginia Geological and Economic Survey Map WV-12, 4 sheets.

Fridley, H.M., 1950, The geomorphic history of the New-Kanawha River system: West Virginia Geological and Economic Survey Report of Investigations No. 7, 12 p.

Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program--Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 112, 33 p.

Glass, G.B., 1998, Coal geology of Wyoming, *in* Sanda, A.P., ed., Keystone coal industry manual, 1998: Chicago, Intertec Publishing, p. 718-738.

Goldsborough, E.L., and Clark, H.W., 1908, Fishes of West Virginia: U.S. Bureau of Fisheries Bulletin 27, p. 29-39.

Harlow, G.E. Jr., and LeCain, G.D., 1993, Hydraulic characteristics of, and ground-water flow in, coal-bearing rocks of southwestern Virginia: U.S. Geological Survey Water-Supply Paper 2388, 36 p.

Haught, J.A., 1997, Decisions on disaster puzzling: Charleston, W. Va., Gazette, March 1, 1997, p. 1. accessed

October 1, 1999, at URL http://www.wvgazette.com/static/series/buffalocreek/buff301.html.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water, (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 264 p., 2 plates.

Hennen, J.C., 1996, The americanization of West Virginia—creating a modern industrial state, 1916-1925: Lexington, Ky., University Press of Kentucky, 214 p.

Henry, E.N., 1974, The phased clean-up program, Kanawha River: West Virginia Division of Water Resources, Department of Natural Resources [variously paged].

Hocutt, C.H., Denoncourt, R.F., and Stauffer, J.R., 1978, Fishes of the Greenbrier River, West Virginia, with drainage history of the Central Appalachians: Journal of Biogeography, v. 5, no. 1, p. 59-80.

Hocutt, C.H., Denoncourt, R.F., and Stauffer, J.R., 1979, Fishes of the Gauley River, West Virginia: Brimleyana, no. 1, p. 47-80.

Hocutt, C.H., Jenkins, R.E., and Stauffer, J.R., 1986, Zoogeography of the fishes of the Central Appalachians and Central Atlantic Coastal Plain, *in* Hocutt, C.H., and Wiley, E.O., eds., The zoogeography of North American freshwater fishes: New York, John Wiley and Sons, p. 161-211.

Holmes, D.E., 1998, West Virginia Blue Book 1998: Charleston, W. Va., Chapman Printing, 969 p.

Hudson, H.H., 1989, Hydrologic issues related to coal development, *in* Britton, L.J., Anderson, C.L., Goolsby, D.A, and Van Haveren, B.P., eds, Summary of the U.S. Geological Survey and U.S. Bureau of Land Management National Coal-Hydrology Program, 1974-84: U.S. Geological Survey Professional Paper 1464, p. 11-18.

Jenkins, R.E., and Burkhead, N.M., 1994, Freshwater fishes of Virginia: Bethesda, Md., American Fisheries Society, 1079 p.

Jenkins, R.E., Lachner, E.A., and Schwarz, F.J., 1972, Fishes of the central Appalachian drainages—their distribution and dispersal, *in* Holt, P.C., ed., The distributional history of the biota of the southern Appalachians, Part III—Vertebrates: Blacksburg, Va., Virginia Polytechnic Institute and State University, p. 43-117.

Jezerinac, R.F., Stocker, G.W., and Tarter, D.C., 1995, The crayfishes (Decapoda: Cambaridae) of West Virginia: Columbus, Oh., Bulletin of the Ohio Biological Survey, vol. 10, no. 1, 193 p.

Kastning, K.M., and Kastning, E.H., 1995, Caves and karst of Virginia and West Virginia: Radford, Va., Radford University, 1 p.

Kelly, P.M., and White, J.M., 1993, Preprocessing remotely sensed data for efficient analysis and classification, applications of artificial intelligence, 1993--Knowledge-based systems, *in* Aerospace and industry, Proceedings: SPIE [International Society for Optical Engineering], 1993, p. 24-30.

Kozar, M.D., and Brown, D.B., 1995, Location and site characteristics of the ambient ground-water-quality-monitoring network in West Virginia: U.S. Geological Survey Open-File Report 95-130, 48 p.

Kozar, M.D., and Sheets, C.J., 1997, Radon in ground water in the Kanawha-New River Basin, West Virginia, Virginia, and North Carolina [abs]: Ohio River Basin Consortium for Research and Education, 13th Annual Scientific Symposium, Programs and Abstracts. [Document not paginated.]

Küchler, A.W., 1964, Potential natural vegetation of the conterminous United States: New York, American Geographical Society, 116 p.

LeGrand, H.E., 1988, Region 21, Piedmont and Blue Ridge, *in* Back, W., Rosenshein, J.S., and Seaber, P.R., eds., Hydrogeology: Boulder, Colo., Geological Society of America, The Geology of North America, v. O-2, p. 201-208.

Lesure, F.G., and Shirley, L.E., 1968, Mica, *in* U.S. Geological Survey and U.S. Bureau of Mines, eds., Mineral resources of the Appalachian Region: U.S. Geological Survey Professional Paper 580, 492 p.

Lewis, H.L., and Knipe, E.E., 1978, The colonialism model—the Appalachian case, *in* Lewis, H.L., Johnson, Linda, and Askins, Donald, eds, Colonialism in America, the Appalachian case: Boone, N.C., The Appalachian Consortium Press, 371 p.

Lewis, R.L., 1998, Transforming the Appalachian countryside—railroads, deforestation, and social change in West Virginia, 1880-1920: Chapel Hill, N.C., University of North Carolina Press, 348 p.

Loeb, Penny, 1997, Shear madness: U.S. News and World Report, August 11, 1997, accessed October 1, 1999, at URL http://www.usnews.com/usnews/issue/970811/11coal.htm.

Lopes, T.J., Furlong, E.T., and Pritt, J.W., 1998, Occurrence and distribution of semivolatile organic compounds in stream bed sediments, United States, 1993-95, *in* Little, E.E., DeLonay, A.J., and Greenberg, B.M., eds., Environmental Toxicology and Risk Assessment—Seventh Volume: American Society of Testing and Materials, Symposium on Environmental Toxicology and Risk Assessment, 7th, St. Louis, Mo., p. 105-119.

Mathes, M.V., Kirby, J.R., Payne, D.D. Jr., and Schultz, R.A., 1982, Drainage areas of the Kanawha River Basin, West Virginia: U.S. Geological Survey Open-File Report 82-351, 222 p.

Mathes, M.V., Jr., Kozar, M.D., and Brown, D.P., 1998, Summary of ground-water quality in West Virginia: West Virginia Division of Environmental Protection, Office of Water Resources, Ground-Water Program, 54 p.

McColloch, G.H., Jr., 1998, Coal geology of West Virginia, *in* Sanda, A.P., ed., Keystone coal industry manual, 1998: Chicago, Intertec Publishing, p. 708-717.

McFerrin, John, 1998, Governor's task force on mountaintop removal and related activities—Report from John McFerrin, member of the Committee on the Impact to the Economy, to the task force: accessed at URL http://www.marshall.edu/mtop.

McKelvey, V.E., 1968, Appalachia—problems and opportunities, *in* U.S. Geological Survey and U.S. Bureau of Mines, eds., Mineral resources of the Appalachian Region: U.S. Geological Survey Professional Paper 580, p. 3-13.

Meng, A.A., III Harsh, J.F., and Kull, T.K., 1985, Virginia ground water resources, *in* National Water Summary 1984, hydrologic events, selected water-quality trends, and ground water resources: U.S. Geological Survey Water-Supply Paper 2275, p. 427-432.

Messinger, Terence, 1997, Water-quality assessment of the Kanawha-New River Basin, West Virginia, Virginia, and North Carolina--Review of water-quality literature through 1996: U.S. Geological Survey Water-Resources Investigations Report 97-4075, 27 p.

Messinger, Terence, and Chambers, D.B., 1998, Selected trace metals and organic compounds in stream-bed sediments of the Kanawha River Basin [abs.]: West Virginia Academy of Science Abstracts with Program, v. 73.

Mine Safety and Health Administration, 1999, Mining disasters—an exhibition: United States Department of Labor, accessed online August 26, 1999, at http://www.msha.gov/disaster/disaster.htm.

Mitchell, W.B., Guptill, S.C., Anderson, K.E., Fegeas, R.G., and Hallam, C.A., 1977, GIRAS - a geographic information retrieval and analysis system for handling land use and land cover data: U.S. Geological Survey Professional Paper 1059, 16 p.

Moffat, C.H., 1987, Ken Hechler—maverick public servant: Charleston, W. Va., Mountain State Press, 372 p.

Morris, F.O., Bader, J.S., Chisholm, J.L., and Downs, S.C., 1976, Hydrologic data for the Coal River Basin, West Virginia: Morgantown, West Virginia Geological and Economic Survey Basic Data Report 5, 215 p.

Morris, J.O., and Taylor, R.W., 1979, A survey of the freshwater mussels of the Kanawha River of West Virginia: The Nautilus, v. 92, no. 4, p. 153-155.

Multi-Resolution Land Characteristics Interagency Consortium, 1997, Federal regional land cover data sets: accessed September 19, 1999, at URL http://www.epa.gov/mrlc/Regions.html.

National Agriculture Statistics Service, 1999, Census of agriculture, 1997: accessed September 10, 1999, at URL http://www.nass.usda.gov/census/.

National Oceanic and Atmospheric Administration, 1992a, Monthly station normals of temperature, precipitation, and heating and cooling degree days, 1961-1990, North Carolina: Climatography of the United States, monthly station normals, no. 81, unpaginated.

--- 1992b, Monthly station normals of temperature, precipitation, and heating and cooling degree days, 1961-1990, Virginia: Climatography of the United States, monthly station normals, no. 81, unpaginated.

--- 1992c, Monthly station normals of temperature, precipitation, and heating and cooling degree days, 1961-1990, West Virginia: Climatography of the United States, monthly station normals, no. 81, unpaginated.

Natural Resources Conservation Service, 1993, State soil geographic (STATSGO) data base—data use information: Natural Resources Conservation Service Miscellaneous Publication Number 1492, 113 p.

--- 1999, National Soil Survey Center: accessed November 8, 1999, at URL http://www.statlab.iastate.edu/soils/nssc/.

North Carolina Geological Survey, 1985, Geologic Map of North Carolina: North Carolina Department of Natural Resources and Community Development, scale 1:500,000.

North Carolina Governor's Task Force on Forest Sustainability, 1996, Report of the governor's task force on forest sustainability: Raleigh, 64 p. [Available from the North Carolina Division of Forest Resources, Raleigh.]

Nuckels, E.H., Prugh, B.J. Jr., Michaels, P.J., and Jones, D.R., 1991, Virginia floods and droughts, *in* Paulson, R.W., Chase, E.B., Roberts, R.S., and Moody, D.W., National Water Summary 1989, Hydrologic events and floods and droughts: U.S. Geological Survey Water-Supply Paper 2325, p. 541-550.

Nyden, Paul, 1974, Miners for democracy—struggle in the coalfields: New York, Columbia University, Ph.D. dissertation: excerpts accessed August 26, 1999, at URL http://www.wvgazette.com/buffalocreek/NYDEN.html.

Office of Surface Mining Reclamation and Enforcement, 1997, Twentieth anniversary, Surface Mining Control and Reclamation Act: accessed September 15, 1999, at URL http://www.osmre.gov/annivrep.htm, 75 p.

Office of Surface Mining Reclamation and Enforcement, 1998a, Abandoned Mine Lands Program overview: accessed October 19, 1999, at http://www.osmre.gov/zovervw.htm.

Office of Surface Mining Reclamation and Enforcement, 1998b, State and Indian regulatory program inspection and enforcement—1998: accessed September 15, 1999, at http://www.osmre.gov/proginspect98.htm.

Office of Surface Mining Reclamation and Enforcement, 1999a, Annual evaluation summary report for the Regulatory and Abandoned Mine Land Programs administered by the state of West Virginia for Evaluation Year 1998, October 1, 1997 to September 30, 1998:

accessed September 15, 1999, at URL http://www.osmre.gov/wvirginia98.htm.

Office of Surface Mining Reclamation and Enforcement, 1999b, History: accessed November 17, 1999, at URL http://www.osmre.gov/history.htm.

Omernik, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, no. 77, p. 118-125.

O'Steen, W.N., 1982, Effect of coal mining on groundwater quality in northern Preston County, West Virginia: Morgantown, West Virginia University, Department of Geology and Geography, M.S. Problem Report, 119 p.

Platts, W.S., 1991, Livestock grazing, *in* Meehan, W.R., ed., Influences of forest and rangeland management on salmonid fishes and their habitats: American Fisheries Society Special Publication 19, p. 389-423.

Puente, Celso, 1985, West Virginia ground-water resources, *in* National Water Summary 1984, hydrologic events, selected water-quality trends, and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, p. 439-446.

Puente, Celso, and Atkins, J.T., 1989, Simulation of rainfall-runoff response in mined and unmined watersheds in coal areas of West Virginia: U.S. Geological Survey Water-Supply Paper 2298, 48 p.

Rauch, H.W., 1987, Groundwater impacts of surface and underground mining, *in* West Virginia Ground Water 1987--Status and future directions, August 13-15, 1987, Proceedings: West Virginia University: p. XXV-1-21.

Runner, G.S., and Michaels, P.J., 1991, West Virginia floods and droughts, *in* Paulson, R.W., Chase, E.B., Roberts, R.S., and Moody, D.W., National Water Summary 1989, Hydrologic events and floods and droughts: U.S. Geological Survey Water-Supply Paper 2325, p. 559-566.

Salstrom, Paul, 1994, Appalachia's path to dependency—rethinking a region's economic history, 1730-1940: Lexington, Ky., University Press of Kentucky, 204 p.

Sanda, A.P., Keystone coal industry manual, 1998: Chicago, Intertec Publishing, 818 p.

Savage, Lon, 1986, Thunder in the mountains—the West Virginia mine war, 1920-21: Pittsburgh, Pa., University of Pittsburgh Press, 195 p.

Schruben, P.G., Arndt, R.E., and Bawiec, W.J., 1997, Geology of the conterminous United States at 1:2,500,000 scale—a digital representation of the 1974 P.B. King and H.M. Beikman map: U.S. Geological Survey Digital Data Series DDS-11, Release 2.

Schultz, R.A., Mathes, M.V., and Bader, J.S., 1996, Groundwater hydrology of the area bordering the Kanawha River in West Virginia: U.S. Geological Survey Open-File Report 95-712, 55 p.

Seaber, P.R., Brahana, J.V., and Hollyday, E.F., 1988, Region 20, Appalachian Plateaus and Valley and Ridge, *in* Back, W., Rosenshein, J.S., and Seaber, P.R., eds., Hydrogeology: Boulder, Colo., Geological Society of America, The Geology of North America, v. O-2, p. 189-200.

Sheets, C.J., and Kozar, M.D., 1997, Bacteria in water from domestic wells in fractured bedrock within the Kanawha-New River basin in West Virginia, Virginia, and North Carolina [abs.]: Proceedings of the Ohio Basin Consortium for Research and Education, 13th Annual Scientific Symposium. [Document not paginated.]

Singer, M.J., and Munns, D.N., 1987, Soils, an introduction: McMillan Publishing Company, New York, 492 p.

Skousen, J.G., 1995, Acid mine drainage, *in* Skousen, J.G., and Ziemkiewicz, P.F., eds., Acid mine drainage, control and treatment: Morgantown, West Virginia University and the National Mine Land Reclamation Center, p. 9-12.

Solley, W.B., Pierce, R.B., and Perlman, H.A., 1993, Estimated use of water in the United States in 1990: U.S. Geological Survey Circular 1081, 76 p.

--- 1998, Estimated use of water in the United States in 1995: U. S. Geological Survey Circular 1200, 71 p. [Tabular data are available online at http://water.usgs.gov/watuse/.]

Stauffer, J. R. Jr., Boltz, J.M., and White, L.R., 1995, The fishes of West Virginia: Academy of Natural Sciences of Philadelphia, 389 p.

Strasbaugh, P.D., and Core, E.L., 1978, Flora of West Virginia: Seneca Books, Inc., Grantsville, W. Va., 1079 p.

Taylor, R.W., and Hughart, R., 1981, The freshwater naiads of the Elk River, West Virginia, with a comparison of earlier collections: The Nautilus, v. 95, no. 1, p. 21-25.

Tight, W.G., 1903, Drainage modifications in southeastern Ohio and adjacent parts of West Virginia and Kentucky: U.S. Geological Survey Professional Paper 13, 111 p.

Underwood, C.H., 1999, Position paper, Patricia Bragg et. al. vs. Col. Dana Robertson et. al.; accessed November 4, 1999, at URL http://www.state.wv.us/governor/pp102999.htm.

U.S. Census Bureau, 1991, 1990 Census of population: accessed June 30, 1999, at URL http://www.census.gov/prod/www/abs/decenial.html.

--- 1998, Statistical abstract of the United States: accessed June 30, 1999, at URL http://www.census.gov/datamap/www/54.html.

--- 1999a, Poverty—how the Census Bureau measures poverty: accessed December 29, 1999, at URL http://www.census.gov/hhes/poverty/povdef.html.

--- 1999b, Selected historical census data, population and housing starts: accessed June 30, 1999, at URL http://

www.census.gov/population/www/censusdata/pop-hc.html.
U.S. Environmental Protection Agency, 1980, Supplemental information document to the area-wide environmental assessment for issuing new source NPDES permits on coal mines in the Coal/Kanawha River Basin, West Virginia: Philadelphia, USEPA Region III, 872 p.
---1994, River reach file version 3.0 (RF3): Office of Water.
---1998, Level III ecoregions of the continental United States: accessed November 18, 1999, at URL ftp://130.11.50.153/pub/kjh/natcov/useco.e00.gz.
---1999a, EMAP Mid-Atlantic Highlands Stream Assessment: accessed October 1, 1999, at URL http://www.epa.gov/owowwtr1/ecoplaces/part1/site7.html.
---1999b, Mountaintop mining: accessed August 27, 1999, at URL http://www.epa.gov/region3/mtntop/.
---1999c, National Primary Drinking Water Regulations; Radon-222; proposed rule: accessed November 22, 1999, at URL http://www.epa.gov/safewater/radon/radfr1.html.
---1999d, Superfund site information, accessed August 18, 1999, at http://www.epa.gov/superfund/sites/index.htm.
U.S. Geological Survey, 1999a, Minerals Yearbook (Volume II—Area reports, domestic): accessed August 25, 1999, at URL http://minerals.usgs.gov/minerals/pubs/state/index.html.
--- 1999b, USGS geospatial data clearinghouse—national mapping and remotely sensed data: accessed November 18, 1999, at URL http://edcwww.cr.usgs.gov/nsdi/gendem.htm.
---1999c, Zebra mussel information: accessed September 10, 1999, at http://nas.er.usgs.gov/zebra.mussel/.
---, 2000, Coal production data for West Virginia, 1900-1998: U.S. Geological Survey data available on the World Wide Web at URL http://wv.usgs.gov/nawqa/coal.html
U.S. Geological Survey and U.S. Bureau of Mines, eds., 1968, Mineral resources of the Appalachian Region: U.S. Geological Survey Professional Paper 580, 492 p.
Virginia Department of Forestry, 1999, Forest resource assessment: online document accessed August 16, 1999 at http://www.dof.state.va.us/fraexct.htm.
Virginia Division of Mineral Resources, 1963, Geologic map of Virginia—expanded explanation: Virginia Division of Mineral Resources, scale 1:500,000.
Virginia Division of Mineral Resources, 1993a, Geologic map of Virginia: Virginia Division of Mineral Resources, 80 p.
Virginia Division of Mineral Resources, 1993b, Geologic map of Virginia: Virginia Division of Mineral Resources, scale 1:500,000.
Waldron, M.C., 1993, West Virginia stream water quality, in National Water Summary 1990-91, hydrologic events and stream water quality: U.S. Geological Survey Water-Supply Paper 2400, p. 547-554.
Ward, Ken Jr., 1999, Mining the mountains—critics, industry look for another way: Charleston, W. Va., Gazette, June 6, p. 1. accessed at URL http://www.wvgazette.com/mining/index.html.
Ward, S.M., Taylor, B.C., and Crosby, G.R., 1997, Water resources data, West Virginia, water year 1996: U.S. Geological Survey Water-data Report WV-96-1, 258 pp.
---1998, Water resources data, West Virginia, water year 1997: U.S. Geological Survey Water-data Report WV-97-1, 414 pp.
---1999, Water resources data, West Virginia, water year 1998: U.S. Geological Survey Water-data Report WV-98-1, 476 pp.
Wedow, Helmuth, Jr., Heyl, A.V., and Sweeney, J.W., 1968, Zinc and lead, *in* U.S. Geological Survey and U.S. Bureau of Mines, eds., Mineral resources of the Appalachian Region: U.S. Geological Survey Professional Paper 580, 492 p.
Wedow, Helmuth, Jr., and Stansfield, R.G., 1968, Fertilizer raw materials, *in* U.S. Geological Survey and U.S. Bureau of Mines, eds., Mineral resources of the Appalachian Region: U.S. Geological Survey Professional Paper 580, 492 p.
Weller, J.E., 1965, Yesterday's people—life in contemporary Appalachia: Lexington, University of Kentucky Press, 163 p.
West Virginia Board of Health, 1984, Water well design standards: West Virginia Board of Health Interpretive Rules, Chapter 16-1, Series III, 9 p.
West Virginia Division of Forestry, 1997, The forest industry of West Virginia: 82 p.
West Virginia Department of Natural Resources, 1989, West Virginia nonpoint source assessment [variously paged].
West Virginia Division of Environmental Protection, 1994, West Virginia water-quality status assessment 1989-91 305(b) report: 95 p.
---1998, West Virginia's water quality assessment 305b report, 1995-1997: 142 p.
---1999, West Virginia Division of Environmental Protection: accessed August 27, 1999, at URL http://www.dep.state.wv.us/.
West Virginia Geological and Economic Survey, 1999, Summary oil and gas production data, 1979-1997: Data available on the World Wide Web, accessed October 1, 1999, at URL http://www.wvgs.wvnet.edu/www/datastat/datastat.htm.
West Virginia State Water Commission, 1947, Kanawha Basin zoning report: Charleston, W. Va., 41 p. [Available at West Virginia Library Commission Reference Library, West Virginia Cultural Center, Charleston, W. Va.]

Wilmoth, B.M., 1966, Ground water in Mason and Putnam Counties, West Virginia: Morgantown, West Virginia Geological and Economic Survey Bulletin 32, 152 p.

Withington, C.F., and Fish, G.E. Jr., 1968, Gypsum and anhydrite, *in* U.S. Geological Survey and U.S. Bureau of Mines, eds., Mineral resources of the Appalachian Region: U.S. Geological Survey Professional Paper 580, 492 p.

Workman, R.W., 1951, Shame of our streams: Charleston, West Virginia State Water Commission, reprinted from the Charleston (W. Va.) Gazette, 31 p. [Available at West Virginia Library Commission Reference Library, West Virginia Cultural Center, Charleston, W. Va.]

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.

Zembrzuski, T.J. Jr., Hill, C.L., Weaver, J.C., Coble, R.W., Gunter, H.C., and Davis, J.M., 1991, North Carolina floods and droughts, *in* Paulson, R.W., Chase, E.B., Roberts, R.S., and Moody, D.W., National Water Summary 1989, Hydrologic events and floods and droughts: U.S. Geological Survey Water-Supply Paper 2325, p. 425-434.