Water-Quality Assessment of the Kanawha-New River Basin, West Virginia, Virginia, and North Carolina—Review of Water-Quality Literature Through 1996

By TERENCE MESSINGER

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BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

Chief, West Virginia District
U.S. Geological Survey
Water Resources Division
11 Dunbar Street
Charleston, WV 25301

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
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FOREWORD

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

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

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

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

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

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

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

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

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS

Multiply	by	To obtain
acre	4047	square meter
bushel (bu)	0.03524	cubic meter
cubic foot per second (ft^3/s)	0.02831	cubic meter per second
foot (ft)	3.048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
gallon (gal)	0.003785	cubic meter
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	25.4	millimeter
kilogram (kg)	2.205	pound
kilogram per hour (kg/hr)	2.205	pound per hour
micrometer (µm)	0.00003937	inch
mile (mi)	1.609	kilometer
milliliter (mL)	33.81	fluid ounce
million gallons per day (Mgal/d)	1.55	cubic foot per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
nanogram (ng)	0.000,000,001	gram
nanogram per kilogram (ng/kg)	0.001	part per billion
pound (lb)	0.4536	kilogram
pound per acre (lb/acre)	1.121	kilogram per hectare
square mile (mi^2)	2.590	square kilometer
ton	0.9072	megagram
ton per day (ton/d)	0.9072	metric ton per day

Water temperature is given in degrees Celsius, and air temperature in degrees Fahrenheit; these units can be converted according to the following equation:

$$^{\circ}F = 1.8(^{\circ}C) + 32$$

VERTICAL DATUM

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 the United States and Canada, formerly called Sea Level 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. Chemical concentration in sediment is given in nanograms per kilogram of sample (ng/kg). 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, or most probable number per 100 milliliters (MPN/100 mL) for samples whose concentrations were determined by a multiple-tube fermentation method.

Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

OTHER ABBREVIATIONS AND ACRONYMS USED IN THIS REPORT

BOD	biochemical oxygen demand
DDE	1, 1- dichloro-2, 2-bis(*p*-chlorophenyl)ethylene
DDT	1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane
DO	dissolved oxygen
NAWQA	National Water-Quality Assessment Program
NCDEM	North Carolina Department of Environmental Management
NPDES	National Pollutant Discharge Elimination System
NPS	U.S. Department of Interior, National Park Service
ORSANCO	Ohio River Valley Water Sanitation Commission
SWRA	Selected Water Resource Abstracts
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VDEQ	Virginia Department of Environmental Quality
VPI	Virginia Polytechnic Institute and State University
WVDEP	West Virginia Division of Environmental Protection
WVDNR	West Virginia Division (or Department, before 1993) of Natural Resources
>	greater than
<	less than

Water-Quality Assessment of the Kanawha-New River Basin, West Virginia, Virginia, and North Carolina—Review of Water-Quality Literature Through 1996

By Terence Messinger

Abstract

The Kanawha-New River drains 12,223 square miles in the Appalachian Mountains of West Virginia, Virginia, and North Carolina. More than 300 studies of water quality and related topics in the Kanawha-New River Basin were reviewed, and 105 of them are cited. Ground-water quality has been affected by agricultural activities in the Valley and Ridge Physiographic Province in Virginia; and by coal mining, upward flow of deep, saline ground water into shallow, freshwater aquifers, and improper disposal of human and animal wastes in the Appalachian Plateaus Physiographic Province in West Virginia. Surface-water quality has been affected by coal mining, improper disposal of human and animal wastes, and industrial activities in the Appalachian Plateaus Province.

INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) began a National Water-Quality Assessment (NAWQA) Program to (1) document the quality of a large, representative part of the Nation's water resources, (2) define water-quality trends, and (3) identify major factors that affect water quality (Hirsch and others, 1988). 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 are the building blocks of 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, are active in 16 study units that began in 1994, are scheduled to begin in 17 study units in 1997, and assessment activities are not presently scheduled in the remaining 6 study units. Assessment of the Kanawha-New River Basin began in 1994.

Purpose and Scope

This report describes and briefly summarizes the findings of interpretive studies of ground- and surface-water quality and aquatic ecology that have been done in the Kanawha-New River Basin. Reports and articles published by Federal, State, and local agencies, peer-reviewed journals, and private consulting firms were examined for content and relevance. The effects of water chemistry on biota and aquatic community composition also are examined. Literature summaries in this report will be used by the Kanawha-New River NAWQA team to help define the relations among land use, water use, water quality, and biological conditions. Summary statistics cited in this report are those reported by authors of the original reports; calculating additional or different summary statistics was considered outside the scope of this report. Literature that describes the part of the Kanawha-New River Basin within the Appalachian Plateaus Province was examined in more detail than literature that describes the other two physiographic provinces, in part because most of the basin is in this province. In addition, the available literature generally addresses a broader range of water-quality issues within this part of the basin. Studies of the Kanawha-New River Basin described in this report were conducted between 1770 and 1996.

Description of the Kanawha-New River Study Unit

The Kanawha-New River study unit (fig. 1, fig. 2) encompasses the 12,233 mi^2 drained by the Kanawha-New River system, and includes parts of West Virginia (8,424 mi^2), Virginia (3,044 mi^2), and North Carolina (765 mi^2) (Eychaner, 1994). The New River is formed in North Carolina by the confluence of the North and South Forks of the New River in the Blue Ridge Physiographic Province. Flowing generally northward for 250 mi, the New River joins the Gauley River at Gauley Bridge, W. Va., to form the Kanawha River. The Kanawha River flows 97 mi northwestward to the Ohio River at Point Pleasant, W. Va. In addition to the Blue Ridge Province, the Kanawha and New Rivers drain the Valley and Ridge and the Appalachian Plateaus Physiographic Provinces (Fenneman and Johnson, 1946).

The Kanawha River was first described by George Washington, who visited the area at the mouth of the Kanawha in 1770 on a trip to select land for a grant for service to Great Britain during the French and Indian War (Washington, 1770). Washington found the land near the river to be "very fine," a "pretty lively kind of land" grown up with hickory, oak, and walnut, containing many shallow ponds that supported "innumerable quantities of wild fowl." Buffalo and other wild game were found in abundance, and Washington described a sycamore tree "measuring 45 ft around, lacking two inches, and not 50 yards from it was another 31.4 round." Washington considered the Kanawha River flood plain to have great potential for agriculture and settlement, and he reserved 20,000 acres there for himself.

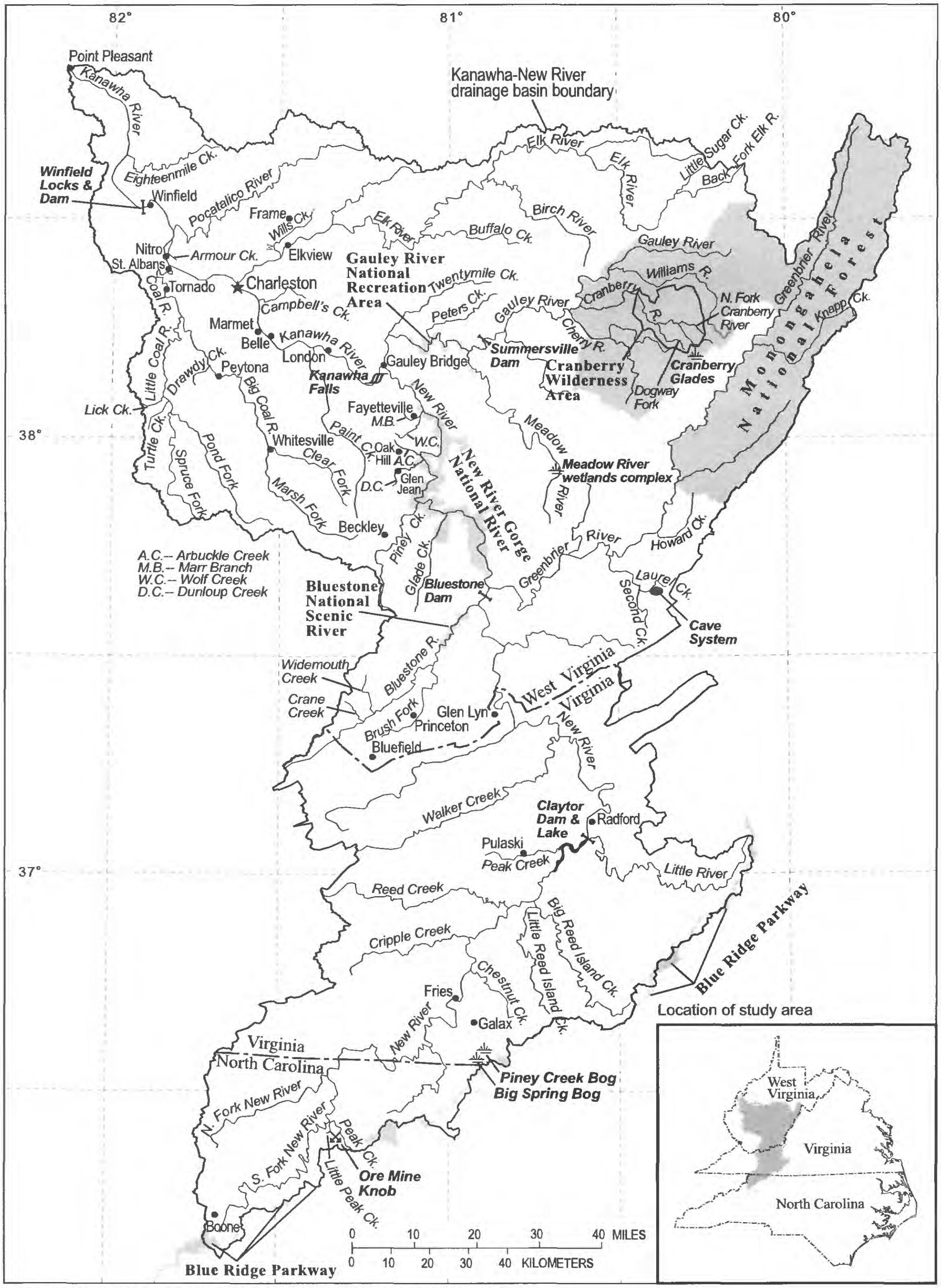
In 1990, about 870,000 people lived in the basin, about 25 percent of whom lived in the Charleston, W. Va., metropolitan area (Eychaner, 1994). Forests (71 percent) and agriculture (23 percent) are the major categories of land use. Urban areas occupy a small part of the basin (3 percent). The climate is continental; minimum winter temperatures in the northeast part of the basin average 20°F, and maximum summer temperatures in the western part average about 85°F. Average annual precipitation ranges from 36 in. in the central part of the basin to 56 in. near Boone, N.C., and 60 in. near the headwaters of the Elk River.

During 1940–93, the average flow of the Kanawha River at Charleston, W. Va., was 15,030 ft^3/s; maximum instantaneous flow was 216,000 ft^3/s on August 15, 1940, and minimum instantaneous flow was less than 1,030 ft^3/s during October 1–5, 1953 (Ward and others, 1996). Major tributaries of the Kanawha and New Rivers are the Bluestone, Greenbrier, Gauley, Elk, and Coal Rivers (Mathes and others, 1982). The Kanawha River is navigable by barges for 91 mi upstream from the Ohio River, in part because of navigation locks and dams at Winfield, Marmet, and London, W. Va. (U.S. Army Corps of Engineers, 1983). Streamflow in the basin is also regulated by four major reservoirs whose combined capacity is 14 percent of the average annual flow at Charleston (U.S. Army Corps of Engineers, 1994). The reservoirs provide flood control, recreation, and hydropower, and during periods of low flow are managed to maintain navigation and water quality, primarily dissolved oxygen (DO).

The New River downstream from Bluestone Dam and the Gauley River downstream from Summersville Dam are used for commercial whitewater rafting (Mott and others, 1996). The New River Gorge National River includes 53 mi of the New River downstream from Bluestone Dam. The Gauley River National Recreation Area includes 25 mi of the Gauley River and 6 mi of its major tributary, the Meadow River. The Bluestone National Scenic River includes 10.5 mi of the Bluestone River. Recreational fishing and boating are common throughout the basin (Eychaner, 1994).

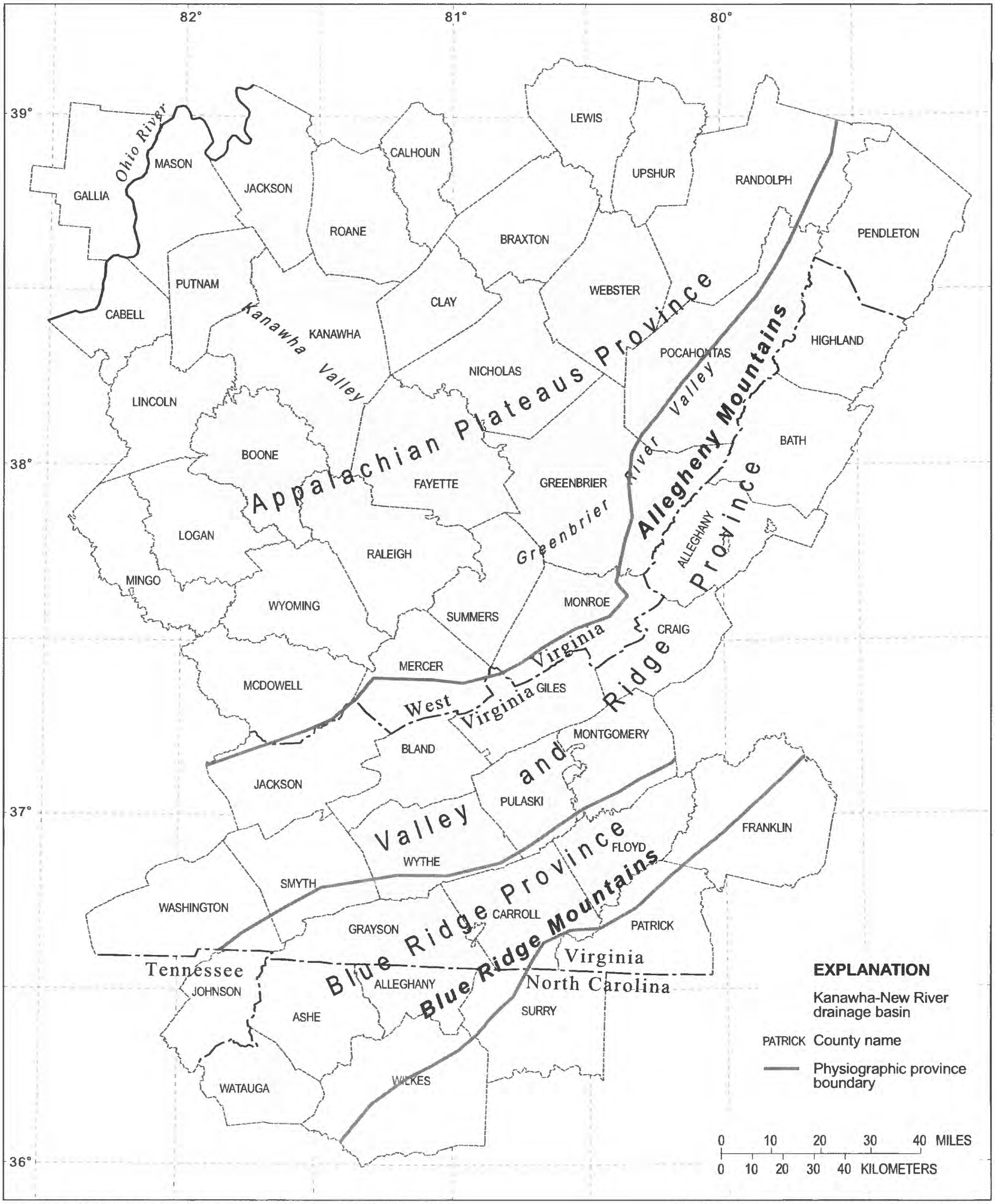
The Appalachian Plateaus and the Valley and Ridge Physiographic Provinces are underlain by sedimentary rocks, including layers of sandstone, shale, limestone, and coal (Johnson and Williams, 1969). The Blue Ridge Province is underlain primarily by crystalline rocks. Throughout the study unit, terrestrial bedrock is overlain by regolith (weathered material) typically less than 20 ft thick. Unconsolidated alluvial deposits are less than 70 ft thick along the Kanawha River and generally less than 30 ft thick along other rivers. Soils on the steep slopes typical of most of the study unit generally are thin and have low fertility and high erosion potential. The thickest soils in the study unit are in the limestone areas of the Valley and Ridge Province and river flood plains elsewhere.

Although claims that the New River is one of the oldest rivers in the world are no longer considered to be sound (Jenkins and Burkhead, 1994), this river has probably flowed in its present channel since the late Paleozoic, about 300 million years ago, during the uplift of the Appalachian Mountains (Fridley, 1950).



Base from U.S. Geological Survey digital data, 1:2,000,000, 1992 and National Park Service digital data, 1:24,000, 1996

Figure 1. Streams, towns, and other selected features of the Kanawha-New River Basin study area.



Base from U.S. Geological Survey digital data, 1:100,000, 1992

Modified from Fenneman and Johnson, 1946

Figure 2. Physiographic provinces, political boundaries, and selected features of the Kanawha-New River Basin study area.

The New River formed the headwaters of the Teays River, which followed the same course as the contemporary Kanawha-New River to about where Nitro, W. Va., is now located (Fridley, 1950). From there, the Teays River flowed to the northwest and flowed through what now is the western corner of West Virginia into Ohio, across central Indiana and Illinois into the Mississippi; the Teays River was the major tributary of the Mississippi River from the central Appalachians. Although the present Kanawha-New River Basin was unglaciated during the Pleistocene, the Teays River was dammed by glaciers in southwestern Ohio, and its upstream river valleys were ponded to an elevation about 900 ft above sea level (Welker, 1982). The ancient Monongahela River, formerly a tributary of the St. Lawrence, also was dammed at the same time, and the present course of the Ohio River was formed in an overflow channel from Lake Monongahela (Fridley, 1950). While the Teays River was dammed, deep beds of silt were deposited, raising the elevation of the streambed. Siltation had a lesser effect on the Pocatalico River, which passed within about 3 mi of the bend in the Teays. The Pocatalico remained in a lower channel after the recession of the glaciers, and then eroded away a weak divide between it and the Teays River. The Teays flowed down the divide and then cut a channel to the Ohio River that is now the channel of the Kanawha River.

Fishes that populate the New River, Gauley River, and other tributaries upstream from Kanawha Falls are distinctly different from those in the Kanawha River and its tributaries downstream from Kanawha Falls (Jenkins and Burkhead, 1994). The New River drainage has 46 native fish species, of which 6 are endemic (found only in the New River drainage). All of the 90 native fish species of the Kanawha River drainage are found elsewhere in the Ohio River system. The New River drainage is thought to have been isolated by Kanawha Falls, which today varies from about 23 to 25 ft in height; and today, few species other than the American eel negotiate the Falls. Teays Lake and the New River Gorge may also have isolated stocks which developed into endemic species (Hocutt, 1979, cited in Jenkins and Burkhead, 1994). Low temperature during glacial periods probably decreased fish species richness in the New River system (Jenkins and Burkhead, 1994).

Ground water occurs primarily in fractures in all rock types of the basin, in pore spaces of the unconsolidated alluvial sediments and regolith, and in solution cavities in carbonate rocks. Fractures are common near the land surface along valley sides and bottoms and near the crest of anticlines, which are folds in rock layers where the center is highest (Wyrick and Borchers, 1981). More water is withdrawn from Lower Pennsylvanian aquifers in the Appalachian Plateaus than from any other unit in the basin (Eychaner, 1994).

In 1990, water withdrawn from streams and aquifers in the Kanawha-New River Basin averaged 1,680 Mgal/d, more than 80 percent of which was surface water (U.S. Army Corps of Engineers, 1994). About 56 percent of the total was withdrawn from streams for thermoelectric production; 20 percent from streams for industrial use; and 12 percent from ground water for mining uses. Ground water is used for domestic water supply by almost all the rural residents in the basin. In addition to withdrawals, nearly 22,000 Mgal/d was used to generate hydroelectric power.

Wetlands in the Kanawha-New River Basin include Piney Creek Bog and Big Spring Bog in the Blue Ridge Province of Virginia (Hayes, 1996), and Cranberry Glades and the Meadow River wetland complex in the Appalachian Plateaus Province of West Virginia (Little and Waldron, 1996). Cranberry Glades is typical of Appalachian Plateaus Province peatlands and contains relict plant associations, such as cranberry glades interspersed with bog forests (Little and Waldron, 1996). The Meadow River wetland complex, the largest wetland in the Kanawha-New River Basin, contains about one-fourth of West Virginia's swamps (forested and scrub-shrub wetlands) and one-third of West Virginia's wet meadows (emergent wetlands). A section of an interstate highway was constructed across the Meadow River wetland complex in the 1980's. Although the West Virginia Department of Highways was required to mitigate the wetlands loss, concern remained that urbanization associated with the highway would cause further wetland loss. In response to this concern, the West Virginia Department of Natural Resources made acquisition of Meadow River wetlands its top acquisition priority, and it is including Meadow River wetland holdings in a wildlife management area (West Virginia Department of Natural Resources, 1988).

Water quality in the basin is related to lithology and land use. Several problems with water quality have been identified and studied by various investigators. Highly transmissive karstic aquifers in the Valley and Ridge and Appalachian Plateaus Provinces contain elevated nitrate and bacteria related to agricultural activities. Ground water in some parts of the Appalachian Plateaus Province has been adversely affected by metals and sulfate draining from coal mines. Upward flow of deep saline ground water has increased chloride concentrations in some shallow aquifers. Water in many alluvial deposits along the lower Kanawha River has been contaminated by industrial wastes. Surface-water quality has been affected by the same practices that have degraded ground water. The effect of coal-mine drainage is more far-reaching in surface water than in ground water. Improper disposal of human wastes has increased bacterial concentrations in streams, particularly in the Appalachian Plateaus Province.

Acknowledgments

The author thanks the individuals and agencies who shared unpublished bibliographies of water-quality and ecological studies. Bibliographies were provided by Paul Angermeier of Virginia Polytechnic Institute and State University and the staff of the New River Gorge National Scenic River. Larry George, of Barth, Thompson, and George in Charleston, W. Va., provided information on the history of coal mining in West Virginia.

LITERATURE SEARCH

Relevant documents were identified through computerized and manual literature searches. Each publication was screened for relevance by examination of title, abstract, or the full document. A file of citations and abstracts is maintained at the USGS district office in Charleston, W. Va., and is to be updated as documents pertinent to NAWQA become available. On June 1, 1996, the file contained 337 citations. Readers are encouraged to submit additions or corrections to the citations in this report.

Electronic searches were made in Water Resources Abstracts (SWRA) on SilverPlatter and the American Geological Institute's GeoRef database. In each search, a geographic and topical qualifier were used. These searches yielded 8,457 titles, which were manually screened and reduced to about 1,350 titles, for which abstracts were obtained. The abstracts were used to further screen the retrieval for relevance, and 153 were selected for inclusion in the file of citations. These data-base searches under-represented documents prepared by State agencies, documents written before 1970, and biological documents.

An unpublished bibliography from a comprehensive review of scientific literature relevant to the New River Gorge National River was obtained from the National Park Service (NPS) office in Glen Jean, W. Va. For quality assurance, this bibliography was compared to the NAWQA bibliographic file. Eighty-seven titles were selected from the NPS bibliography as relevant to NAWQA; 49 (56 percent) had been identified through the electronic search and 38 (44 percent) had not. To supplement the results of the electronic search, manual searches of scientific literature were done in the USGS district library in Charleston, the individual files of study-team members, libraries of Marshall University and the Virginia Polytechnic Institute and State University (VPI), and the West Virginia Library Commission Reference Library. Discussion with Kanawha-New River NAWQA liaison committee members also was useful in identifying publications cited in this report.

BLUE RIDGE PHYSIOGRAPHIC PROVINCE

The headwaters of the New River form in North Carolina and Virginia in the Blue Ridge Physiographic Province. The Blue Ridge Province is underlain by crystalline igneous and metamorphic rock. Important land uses include forest and agriculture, which is primarily pasture. Relatively little information is available regarding ground- and surface-water quality in the Blue Ridge Province, although this may be partly due to the perception that few water quality problems exist in this province.

Ground Water

The principal aquifers in the Blue Ridge Province generally consist of fractured rock with low porosity and low storage capacity (Coble and others, 1984; Meng and others, 1984). Though dilute (median dissolved solids concentration 96 mg/L in

North Carolina), some of the water from this aquifer is sufficiently acidic (pH ranging from 6.0 to 7.4 at the 10th and 90th percentiles) to leach copper and lead from pipes and plumbing connections (Powell and Hamilton, 1986; Giese and others, 1986). Data from North Carolina (1932–86) indicate that 90th-percentile concentrations of nitrate (1.4 mg/L) and fluoride (0.2 mg/L) in water from the crystalline rock aquifer met drinking-water standards set by the U.S. Environmental Protection Agency (Giese and others, 1986). Concentrations of iron and manganese in ground water vary with mineral composition of the host rock, according to the same data set (Giese and others, 1986). In the crystalline rock aquifer in North Carolina, iron concentrations ranged from 100 µg/L at the 10th percentile to 1,000 µg/L at the 90th percentile, whereas manganese concentrations at the same percentiles ranged from 50 to 110 µg/L. Hardness as calcium carbonate is generally less than 60 mg/L in water from crystalline rock aquifers in North Carolina. (The sources cited in this report discussed ground water of the Blue Ridge Province as a unit with aquifers in geologically similar areas in the nearby Piedmont Province, and summary statistics from these sources were calculated from the combined data.)

Surface Water

Surface water in the Blue Ridge Physiographic Province tends to be dilute (less than 50 mg/L dissolved solids), with little mineralization from contact with gneiss and schist underlying much of the area (Johnson and Williams, 1969). The high gradient of the New River and its tributaries in the Blue Ridge Province promotes aeration. The North Fork of the New River, 35 mi long, falls an average of 59 ft/mi, and the South Fork, 65 mi long, falls an average of 14 ft/mi (Johnson and Williams, 1969). Land use in this part of the basin is primarily agriculture and forest (North Carolina Division of Environmental Management, 1994). A segment of the New River in North Carolina and Virginia has been designated as a Wild and Scenic River, and several tributary streams in the Blue Ridge Province support reproducing trout populations.

Water quality, assessed by the North Carolina Division of Environmental Management (NCDEM) on the basis of benthic invertebrate indices, is generally "Excellent" (37 percent of 70 sites sampled) or "Good" (33 percent of 70 sites sampled) (North Carolina Division of Environmental Management, 1994). At 15 sites where benthic data have been collected more than once (1983–92), 11 had no change in bioclassification, whereas 4 showed improvement. DDE, a DDT metabolite, and low concentrations of metals were detected in fish tissue collected in the New River basin in North Carolina in 1981 and 1984. Some water-quality concerns exist in the headwaters of the New River basin. Acidic drainage from an abandoned copper mine at Ore Mine Knob has adversely affected Peak Creek and Little Peak Creek, in Ashe County, N.C. (North Carolina Division of Environmental Management, 1994). Conversion of agricultural land to golf-course-based housing developments in the basin could potentially increase pesticide and herbicide concentrations in streams of this area (David Lenat, North Carolina Division of Environmental Management, oral commun., 1996).

The benthic macroinvertebrate population of Chestnut Creek near Galax, Va., was limited to a stream segment upstream from three mine-water-affected tributaries in a 6-mile study reach (Hoehn and Sizemore, 1977). The tributaries, draining a large area where pyrite (FeS_2) is mined, entered Chestnut Creek within a 2.6-mile segment of the study reach. Alkalinity decreased from approximately 25 to 5 mg/L, and pH decreased from 7.2 to 6.3 through the study reach. Iron concentration (the authors did not state whether dissolved or total) increased from less than 10 to more than 4,000 µg/L, and coatings of iron hydroxide as much as 0.25 in. thick were deposited in the stream bed. Bioassays, involving study organisms placed in cages in the stream, showed that streamwater affected by acid mine drainage was not toxic to bluegill sunfish (*Lepomis macrochirus*) after 192 hours, while snails (*Goniobasis* sp.) survived 96 hours. Fish placed in cages directly in a channel of a mine outfall all died within 11 hours.

VALLEY AND RIDGE PHYSIOGRAPHIC PROVINCE

The Valley and Ridge Physiographic Province is a folded series of roughly parallel, alternating ridges and valleys that stretches almost the entire length of the Appalachian Mountains (Constantz, 1994). Erosion-prone rocks, such as limestone, underlie the valleys, whereas erosion-resistant rocks, such as sandstone, cap the ridges. The number of valleys and ridges is constant from north to south. Stream drainage is trellised, or parallel. Land in the valleys is commonly used for agriculture, typically low-intensity pasture, although fertilizer and pesticides are applied to a few of the wider valleys where crops are grown. The steep ridges are heavily forested, and development of pasture, housing, or roads is minimal. The most pressing water-quality issues in the Valley and Ridge part of the New-Kanawha River Basin are related to agriculture and affect both ground water and surface water, although a few point sources discharge to streams in this area.

Ground Water

The principal aquifers of the Valley and Ridge Province of Virginia and West Virginia are in limestone and dolomite and are used for industrial, public, and domestic water supply (Meng and others, 1984; Powell and Hamilton, 1986). Because of the high transmissivity of solution cavities and fractures in these carbonate rocks, wells typically have high yields (commonly 50–500 gal/min). Water is conveyed rapidly at zones of recharge (such as sinkholes, sinking streams, vertical fractures in the rock or through solution cavities), and emerges at the surface in springs, seeps or wells (Kastning and Kastning, 1994). Water moves in open subsurface channels, much like surface water, but is unexposed to the solar radiation that can break down some contaminants in surface water (Kastning, 1989). The rapid inflow and movement of water and the lack of filtration in the karst openings allow infiltrating contaminants to be carried efficiently through the ground-water system. In parts of West Virginia, wells drilled into caves have been used as drains for highway runoff, permitting the direct flow of contaminants, such as road salt and spilled materials, into the ground water (Ferrell, 1986).

The Greenbrier River Subbasin, which drains an area spanning the border between the Valley and Ridge and Appalachian Plateaus Provinces, includes large areas of karst terrane, characterized by numerous sinkholes, caves, and interrupted and underground streams (Jones, 1973). Laurel Creek, at a typical flow of 1 ft^3/s, dissolved and removed 46 kg/hr of calcite from the Laurel Creek-Cross Road cave system in northeastern Monroe County, W. Va. (Groves, 1992). Basin boundaries, areas, and flow directions can differ from those indicated by topography. Karst aquifers draining highways in northern Pocahontas County were capable of transmitting contaminants into springs (Werner, 1977). Slightly elevated chloride concentrations were found in the highway-affected springs year-round, whereas shorter, more intense "spikes" in chloride concentration were measured in these springs during snowmelt. Nitrate and fecal bacteria concentrations in water from karst springs in the southern Greenbrier Subbasin correlated with percentage of land used for agriculture (Boyer and Pasquarell, 1995; Pasquarell and Boyer, 1995). Density of cattle had a significant effect on ground-water quality. Nitrate concentration and agricultural land use were strongly correlated; in karst watersheds, drainage areas consisting of 79, 51, 16, and 0 percent agriculture corresponded to mean nitrate concentrations of 15.8, 12.2, 2.7, and 0.4 mg/L, respectively in the receiving streams (Boyer and Pasquarell, 1995). Fecal coliform densities in streams receiving water from karst springs peaked in the summer and declined in the fall (Pasquarell and Boyer, 1995). Minimum concentrations occurred in late winter before the typical spring introduction of seasonally grazed cattle. The amount of soil water available to transport bacteria to karst conduits appeared to have a greater bearing on the fecal coliform densities than did the presence or absence of cattle. Fecal bacteria concentrations increased significantly in a sampling reach in a surface stream downstream from a spring.

Surface Water

Streams such as Cripple Creek and Reed Creek drain areas underlain by dolomite and limestone typical of the Valley and Ridge Province (Johnson and Williams, 1969). Dissolved solids concentrations at low flow in these streams are greater (150–180 mg/L) than those in Blue Ridge Province streams (less than 50 mg/L). Most tributaries entering the New River between Radford and Glen Lyn drain areas underlain by Paleozoic sandstones, shales, and limestones, and their waters are more mineralized (200–300 mg/L dissolved solids at low flows) than streamwater entering the New River upstream from Radford. Land use in the New River Basin in Virginia (which includes areas in the Blue Ridge and the Valley and Ridge Provinces) is 59 percent forest, 35 percent cropland and pasture, and 3 percent urban (Virginia Department of Environmental Quality, 1994). Streams in most of this part of the New River Basin fully support designated uses under the Clean Water Act, although high metal concentrations and low pH were found in small parts (9.8 and 60 stream miles, respectively, of a total of 3,130 mi of mainstem and tributary streams) of the basin. The Peak Creek watershed near Pulaski, Va., is being managed to reduce nutrient loading to eutrophic Claytor Lake, Va.

Water-quality data were collected regularly by the USGS at a station near the downstream physiographic province boundary, the New River at Glen Lyn, Va., from 1965 until 1994 (Prugh and others, 1995). This station's long water-quality record and position at the outlet of the physiographic province make it useful for assessing water-quality trends. An upward trend in dissolved solids during 1975–89 was the only statistically significant long-term trend reported for this site (Belval, 1993).The background alkalinity (median 52 mg/L) indicates the basin's partly carbonate lithology. Effects of agriculture (45 percent of basin area) at this site are indicated by relatively high concentrations of nitrite plus nitrate (median 0.81 mg/L) and fecal coliform bacteria (median 92 col/100 mL). In addition to episodes of elevated bacteria concentrations, water-quality problems at this site have included high concentrations of zinc, copper, lead, iron, and cadmium. Elevated metals concentrations are probably caused by drainage from abandoned copper and iron mines in the Iron Ridge District in Grayson County, Va., or from zinc and lead mines in the Ivanhoe and Austinville Districts in Wythe County, Va. (Currier, 1935).

Ecology

Stream ecology has been much studied in this part of the basin, largely because Virginia Polytechnic Institute and State University, a major research university, is located here. Most of these ecological studies have been limited in scope, and have typically addressed diverse topics. Particular areas of research emphasis have included fish fauna, macroinvertebrates (especially with regard to effects of water quality on populations and behavior), and sources and transport of organic matter.

Fish

The New River system, comprising all Kanawha River tributaries upstream from Kanawha Falls, includes portions of the Blue Ridge and Appalachian Plateaus Provinces as well as the Valley and Ridge. Of the 89 fish species found in the New River system, 46 are considered to be native (Jenkins and Burkhead, 1994). The New River fish fauna is generally characterized as depauperate, having the lowest ratio of native species to drainage area of any river system in the eastern United States. Unfilled ecological niches are present, and the New River system has been extremely susceptible to invasion. It has the largest number and proportion (42 of 89) of introduced freshwater species of all major eastern and central North American drainage systems. Many introductions of game fish or forage fish were deliberate; of the game fish present in the system, only the American eel, channel catfish, flathead catfish, and green sunfish are regarded as native. Most distribution patterns of native fishes within the basin are categorized on the basis of physiographic provinces occupied, water chemistry, stream-size preference, or water temperature, although a few anomalies have been noted. Of the 46 native fish species, 8 are endemic, or found only in one drainage system (Jenkins and Burkhead, 1994). The New River system has the second highest percentage (17.4 percent) of endemic fish species of any drainage system east of the Rocky Mountains.

Kanawha Falls, which probably formed about a million years ago during the late Pliocene or early Pleistocene, generally is thought to have played the crucial isolating role in fish evolution in the New River system (Jenkins and Burkhead, 1994). After Kanawha Falls formed, fish were isolated upstream as fish downstream in the Kanawha (or Teays) system were apparently able to negotiate Kanawha Falls only rarely. Although continental glaciers never entered the present Kanawha-New River Basin, glacial regimes are thought to have been severe in the high-altitude parts of the New River system. Recurrent cold climate probably extirpated species and prevented others from approaching routes of entry to the drainage. Successful range shifts to lower, sufficiently warm elevations were probably impossible for some warmwater species. Downslope retreat would have been northward into colder climates and could have led to fish exiting the drainage over Kanawha Falls. Population fragmentation occurred simultaneously, in response to the same habitat changes, as did the evolution of the endemic fishes.

One Federally listed fish species of special concern, the candy darter (*Etheostoma osburni*), is endemic to the New River system, and it is found in rocky, clear, cold creeks as well as warm streams, principally in the Valley and Ridge Province (Jenkins and Burkhead, 1994).

Spawning activities of smallmouth bass (*Micropterus dolommieui*) were shown to be affected by streamflow and water temperature at three New River sites in Virginia and West Virginia and at tributary sites on Walker Creek and Little River in Virginia (Graham and Orth, 1986). Young-of-year bass were collected between May 30 and October 20, 1982, and aged by counting rings that grow daily on their otolith (a small bone in the inner ear of fish). Bass were spawning in June, when high streamflow occurred and interrupted the spawn. Spawning resumed when flows receded. Daily mean water temperatures explained most of the variation in spawning activities. A model based on temperature and discharge was developed, which correctly classified 72 percent of the days on which spawning did or did not occur.

Invertebrates

Two species of net-spinning caddisflies (*Chimarra* sp. and *Hydropsyche morosa*) were found to be significantly more vulnerable to stonefly predation in copper-treated artificial streams than in untreated ones (Clements and others, 1989). Water collected from the New River at Glen Lyn, Va., has contained copper in concentrations known to be biologically active (Belval, 1993). Stoneflies (*Paragnetina media*) and their prey were collected on trays with pebble/cobble substrate placed in the New River for 30 days (Clements and others, 1989). The trays were collected after colonization, then dosed with copper (target concentrations were 6 µg/L copper) in indoor, artificial streams. Predation of caddisflies by stoneflies was 2 to 3 times greater in the dosed streams than in control streams. Gut analysis of stoneflies showed that caddisflies were their preferred prey (70 percent and 81 percent of stonefly stomach contents in untreated and treated streams, respectively). Exposure of predatorless macroinvertebrate colonies to copper reduced macroinvertebrate abundance by 12 percent but did not reduce the number of taxa present.

Macroinvertebrate community colonies were collected from the Clinch River, a stream in Virginia just west of the Kanawha-New River Basin (Clements and others, 1989). Colonies were treated with copper in two systems of artificial streams, one receiving water from the Clinch River and the other receiving water from the relatively poorly buffered New River. Alkalinity concentrations were on the order of 2 to 3 times greater in Clinch River artificial streams than in New River artificial streams. Although total macroinvertebrate abundance was reduced in both stream systems, the decline was greater in New River systems. After 4 days, total macroinvertebrate abundance was reduced by 32 percent in New River streams containing 6 µg/L dissolved copper but only by 25 percent in Clinch River streams containing 15 µg/L dissolved copper. The most sensitive, and dominant, species studied, *Tanytarsini* chironomids, were eliminated from New River artificial streams containing 13 µg/L copper after 10 days, but they were only reduced by 35 percent in Clinch River systems containing the same amount of copper.

The Asiatic clam (*Corbicula fluminea*) invaded the New River near Glen Lyn by 1975 (Rodgers and others, 1977a). Two years later, clam populations had reached 1,000 per square meter. Assays for several toxic elements found low concentrations (<1 mg/L) of selenium, mercury, and arsenic in clam tissues (Rodgers and others, 1977b). Researchers noticed that clam populations remained virtually constant in the thermal discharge of a coal-fired electric-generating plant despite an unusually cold winter. In the next 8 years, response to this thermal plume varied seasonally (Cairns and Cherry, 1983). Clams were more numerous in the vicinity of the thermal discharge than in unheated waters, and their populations declined with winter temperature drops. Clams proved resistant to high temperatures (36°C), intermittent chlorination and exposure to elevated zinc and copper concentrations in laboratory studies. Heated discharges appear to have provided refugia and helped Asiatic clams in expanding their range northward in the United States.

Organic Matter

Leaf decomposition in the middle reaches of the New River, in Virginia, proceeds at rates similar to those reported for small temperate streams (Paul and others, 1978). Leaf decomposition, referred to as "leaf processing" by stream ecologists, is typically thought of as being a less important energy source for large streams than for small, heterotrophic streams, where terrestrial vegetation may provide up to 99 percent of organic matter present (Brewer, 1988). Initial stages of leaf processing in the New River were microbially mediated and enhanced by mechanical fragmentation, but the macroinvertebrates typically crucial to leaf processing in small streams played a smaller role in the New River (Paul and others, 1978). Differences in processing rates were caused by differences in initial proportions and distributions of leaf chemical constituents and the speed of chemical constituent loss during incubation. Seasonal reductions in chemical constituent losses, microbial activity, and processing rates occurred during the winter but gradually increased during the spring, an indication that seasonal temperature regulated all processing mechanisms studied.

Organic matter transported in the New River between Fries and Glen Lyn in 1976–77 was largely leaf detritus (Newbern and others, 1981). Organic matter is broadly categorized as particulate or dissolved organic matter, terms that are used interchangeably with the terms "particulate carbon" or "organic carbon," respectively (Cole, 1983). Particulate organic matter and dissolved organic matter are separated by use of a 0.45- to 0.5-µm filter; Newbern and others (1981) filtered their samples with 0.45 µm filters. Dissolved organic matter concentrations ranged from 1 to 50 mg/L near Fries and 11 to 19 mg/L downstream, near Glen Lyn; similar concentrations were reported at other similar-sized rivers world-wide (Newbern and others, 1981). Highest dissolved organic matter concentrations were recorded during low flows, but no statistically significant correlation was found between concentration and discharge. Concentrations of fine particulate organic matter (particle size > 0.45 µm but < 0.60 µm) were generally lowest in the winter (< 2 mg/L), somewhat higher in the summer, and exhibiting erratic, sharp peaks in spring and fall (>7 mg/L maxima). No statistically significant correlations between fine particulate organic matter and river discharge were detected, either over the year or seasonally. However, fine particulate organic matter concentrations increased fifteen-fold during a storm. Concentrations of coarse particulate organic matter (particle size > 0.59 µm) was highest during autumnal leaf fall and constituted 13 percent of the total particulate organic matter samples, although coarse materials made up less than 1 percent of the total particulate organic matter throughout most of the year. Municipal and industrial treatment facilities apparently supplemented the concentration of dissolved organic matter in the river (Newbern and others, 1981). Total organic load at Glen Lyn was 13 percent greater than at Fries, although fine particulate organic matter load decreased from more than 24,000 ton/d at Fries to 18,000 ton/d at Glen Lyn, a decrease attributed to settling in Claytor Lake.

APPALACHIAN PLATEAUS PHYSIOGRAPHIC PROVINCE

Streams in the Appalachian Plateaus have eroded the once-flat plateau into a series of steeply sloping hills and narrow ridges and valleys. The streams generally follow a dendritic drainage pattern. Two principal types of aquifers, sedimentary bedrock aquifers and unconsolidated alluvial deposits, underlie the Appalachian Plateaus part of the Kanawha-New River Basin. The Appalachian Plateaus are not underlain by a regional aquifer. Most ground water in consolidated aquifers is found in joints, bedding-plane separations, and fractures. Alluvial aquifers, although found only in a small part of the basin (underneath the Kanawha River and ancient Teays River floodplains) are in the most densely populated part of the basin. These poorly sorted formations yield large amounts of water to wells because of their high transmissivity; but for the same reason, these formations also conduct contaminants freely and rapidly. Because streams at base flow contain principally water that has passed through the ground-water system, streamwater chemistry is strongly affected by local lithology.

Ambient Ground-Water Quality

Ground-water chemistry in the Appalachian Plateaus Province, as elsewhere, is primarily determined by the rocks the water contacts and the length of time it is in contact with these rocks. Ground water typical of the Appalachian Plateaus will contact various sedimentary rocks, and its residence time will be determined by the location and elevation where it infiltrates.

Bedrock Aquifers

Appalachian Plateaus bedrock aquifer systems are typically composed of alternating layers of sedimentary rock such as sandstone, siltstone, shale, limestone, and coal (Puente, 1984). The most important carbonate aquifers of this region are in the Greenbrier River Subbasin and have been mentioned in the discussion of carbonate aquifers of the Valley and Ridge Province. Because most water-bearing units in the Appalachian Plateaus Province include strata composed of various types of rocks, aquifer units are usually designated by geologic age rather than lithologic composition (Ferrell, 1986). Principal consolidated aquifers are of the Upper, Middle, and Lower Pennsylvanian and Mississippian periods. Permeability of these noncarbonate sedimentary rocks is extremely low, and ground-water flow is primarily through fractures or bedding-plane separations. The rocks are extensively fractured along the axes of anticlines, because of tension during folding (Wyrick and Borchers, 1981). Fracture zones along the anticlines are among the most significant water-bearing zones in the area. Fracturing is also caused locally by unloading effects due to erosion of valleys. Fracturing caused by unloading is confined to valley sides and bottoms, and it significantly affects the occurrence and flow of ground water. The dissected topography of the Appalachian Plateaus Province affects the shallow ground-water flowpath; the flow of ground water is typically toward the nearest valley, so the youngest water is generally found in hilltop wells and the oldest water in valley wells (Ferrell, 1986).

Concentrations of iron and manganese in rocks of Pennsylvanian age generally are larger in ground water from valley settings than in ground water from hilltop settings (Ferrell, 1986). Generally, where limestone is common (as in Upper Pennsylvanian aquifers) hardness decreases and sodium concentration increases along the ground-water flowpath. The relation between sodium concentration and hardness is due to sodium-calcium ion exchange (Borchers and others, 1991). Calcium leached from limestone units is adsorbed by marine sandstone and shale units by clay minerals, which then release sodium.

Alluvial Aquifers

Alluvium is present in the valleys of the Kanawha River and its tributaries (Doll and others, 1960; Wilmoth, 1966). Gravel and sand lenses are the principal aquifers. The water table in the alluvium ranges from 11 to 30 ft below the surface, averaging 18 ft below land surface. The average saturated thickness of alluvium is about 34 ft. The thickest alluvial deposits in the Kanawha River Basin are in the middle and lower reaches of the Kanawha River, where the maximum thickness is about 70 ft and the average thickness about 50 ft. Measured yields of industrial and public-supply wells ranged from 10 to 150 gal/min; some of the larger yields may have been be due to induced infiltration from the Kanawha River (Doll and others, 1960). The water level in alluvium and the bedrock fracture system beneath the alluvium depends on the Kanawha River stage, although ground-water flow is 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. The most common water types found in wells in the Kanawha River flood plain were sodium bicarbonate (25 percent), calcium bicarbonate (19 percent), and sodium chloride (10 percent). Constituents found in objectionable concentrations in a study done in the early 1980's (Schultz and others, 1996) included dissolved iron (median, 11,000 μg/L; maximum, 58,000 μg/L), manganese (median, 750 μg/L; maximum, 1,900 μg/L), barium (range of 22 to 16,000 μg/L), cadmium (range of less than 1 to 15 μg/L), and lead (range of less than 10 to 630 μg/L).

Ambient Surface-Water Quality

The Kanawha-New River Basin's largest tributaries are in the Appalachian Plateaus Province. The Greenbrier River, the largest tributary in the entire study unit, drains part of the Valley and Ridge Province in addition to Appalachian Plateaus areas. The Greenbrier River is well-buffered, highly alkaline stream, because it is underlain by limestone. The Gauley and Elk Rivers drain the heavily forested Allegheny Highlands in the northeast part of the basin. Their waters typically are dilute, soft, and poorly buffered. Problems related to mining, acidic deposition, or sewage discharge exist in some of their tributaries. The Bluestone and Coal Rivers flow into the New-Kanawha River from the west, drain areas underlain with sandstone, shale, and coal, and carry less runoff per unit area than streams in the rest of the basin. Water from these two streams, which are affected by coal mining, has high background concentrations of dissolved solids. In the northern part of the basin, the Pocatalico River drains foothills underlain by sandstone and shale, and it has been affected by interactions with saline ground water. In its lower reaches, the Pocatalico River has been degraded by historical chemical-industry disposal practices. The New River provides habitat for diverse biological communities as it flows through the New River Gorge to its confluence with the Gauley River. Seven miles downstream from Kanawha Falls, the Kanawha River enters the reach regulated for navigation. In the navigable reach, river gradient decreases, depth and width increase, and average velocity decreases. The change in hydraulic properties is accompanied by changes in land use that affect mainstem river quality, particularly as the river passes through the urban, industrial area near Charleston. Little information about baseline conditions in the Kanawha River is available because the industrial development generally preceded water-quality studies.

Greenbrier River Subbasin

Water quality in the Greenbrier River and its tributaries reflects the geologic diversity in the subbasin (Clark and others, 1976). The distribution of specific conductance in the Greenbrier River and its tributaries is bimodal: values around 70 µS/cm and 190 µS/cm are recorded with the greatest frequency. Streams draining the highlands of Pocahontas and Greenbrier Counties, where rocks are highly weathered, usually are dilute, and their alkalinity concentrations range from 7 to 20 mg/L. Southern Greenbrier River tributaries drain relatively low-lying limestone areas and have higher specific conductances than do northern tributaries; alkalinity concentrations are as high as 150 mg/L. Typical concentrations of constituents such as sulfate (<10 mg/L) and manganese (<30 µg/L) are much lower than in streams draining parts of the Appalachian Plateaus Province where coal mining is common. The median pH of streams of the Greenbrier River Subbasin was 7.5 in the winter and spring, and 7.8 in the summer and fall during the most extensive study done there (1972–73).

Forest (71 percent) and agriculture (21 percent) are the dominant land uses in the Greenbrier River Subbasin (West Virginia Department of Natural Resources, 1989). Nonpoint sources of contamination, including erosion from cropland and cattle grazing and inadequate disposal of human and(or) animal wastes, are considered to have adversely affected water quality in Second Creek (29 percent agriculture) and Howard Creek (7.7 percent agriculture). Knapp Creek (12 percent agriculture) is also affected by erosion from timbering and agriculture, but to a lesser degree.

Gauley River Subbasin

The Gauley River forms in the Allegheny Mountains at altitudes greater than 4,000 ft (Ehlke and others, 1982). The subbasin is heavily forested (83 percent); much of the subbasin, including the Cranberry Wilderness Area, is within the Monongahela National Forest (West Virginia Department of Natural Resources, 1989). Channel gradients of the Cherry and Cranberry Rivers are greater than 60 ft/mi. The altitude, slope, and forest cover in the headwaters of the subbasin contribute to low stream temperatures and high DO concentrations. Headwater streams in the Gauley River Subbasin typically contain less than 10 mg/L dissolved solids; and in a 1979–80 subbasin-wide synoptic study (Ehlke and others, 1982), a mean specific conductance of 60 µS/cm was determined. During the same study, median pH was 6.4, a reflection of low buffering capacity. Coal mining is extensive in parts of the Gauley River Subbasin.

Elk River Subbasin

Much of the Elk River Subbasin is similar to the Gauley River Subbasin in topography, geology, and rainfall, although coal mining and, (in its lower reaches) oil and gas development are more common (Mathes and Ward, 1990). Water in the Elk River and its major tributaries typically is a dilute calcium magnesium sulfate type or calcium magnesium bicarbonate type. Surface water in the lower part of the subbasin is typically more mineralized than in the remainder of the subbasin. Streams in the Elk River Subbasin are poorly buffered, with a typical background alkalinity less than 30 mg/L. Specific conductance ranged from 15 to 6,100 µS/cm in 632 samples from the Elk River Subbasin (1978–86), the maximum being measured at Wills Creek, near Elkview. The maximum chloride concentration in 181 samples from the subbasin (1978–86), 1,100 mg/L, was also found in water from Wills Creek. In the

Appalachian Plateaus, upward flow of deep saline ground water is often associated with gas and oil production, common in the Wills Creek Subbasin. Stream pH in the Elk River Subbasin ranged from 4.0 to 8.2; of 39 sites sampled, sites with the two lowest median pH's (4.3 and 6.1) were both on Buffalo Creek (Mathes and Ward, 1990). Buffalo Creek had been previously shown to be affected by acid mine drainage (U.S. Environmental Protection Agency, 1980b). Concentrations of dissolved iron ranged from less than 10 to 370 µg/L (Mathes and Ward, 1990). Published concentrations of dissolved manganese ranged from 0 to 1,400 µg/L, the maximum manganese concentrations being found in Buffalo Creek (Mathes and Ward, 1990). Water from an upstream site on Buffalo Creek also contained the greatest concentration of dissolved sulfate in the subbasin, 170 mg/L. Sulfate concentrations less than 10 mg/L were typical in unmined, headwater areas, with a study minimum of 3.8 mg/L measured at Little Sugar Creek.

Bluestone River Subbasin

The Bluestone River headwaters drain a section of the Valley and Ridge Province, but most of the subbasin is in the Appalachian Plateaus Province. Like other tributaries that enter the middle reach of the New River from the west, the Bluestone River has a chemical composition that has been strongly influenced by coal mining and waste-disposal practices (Clark and others, 1976). The most economically important coal fields of the subbasin contain the No. 3 Pocahontas coal beds, thick seams of coal with such desirable coking properties that most of the coal was extracted before 1970 (Rehbein and others, 1981). In 1972, streams draining the Pocahontas coal fields had the highest dissolved solids and sulfate concentrations in the Bluestone drainage, with maximums of 330 mg/L dissolved solids and 129 mg/L sulfate in the Crane Creek watershed (Clark and others, 1976). Mine drainage in the Pocahontas coal fields typically is alkaline, partly because of the low sulfur content of the coal and partly because of the presence of carbonate rocks in the overburden. The pH of Widemouth Creek, draining an area containing reclaimed surface mines, ranged from 7.3 to 10.0, while the pH of nearby unmined streams ranged from 7.1 to 8.0. High flows increased specific conductance and dissolved solids concentration in streams receiving runoff from active mines, but decreased these constituents in streams receiving runoff from abandoned mines. Total iron concentrations in the subbasin ranged from 10 to 1,900 µg/L in 1972; the median was 445 µg/L. In the same study, total manganese concentrations ranged from less than 1.0 to 1,300 µg/L; the median was 70 µg/L.

Coal River Subbasin

Streamwater chemistry in the Coal River Subbasin was dominated by the effects of coal mining when last studied, 1973–75 (Bader and others, 1976). Specific conductance generally decreased downstream as highly mineralized water in headwater streams draining coal mines was diluted with inflows. Measured low-flow specific conductance (1973–75) in Spruce Fork, a tributary of the Little Coal River, typically decreased from 3,000 µS/cm in the headwaters to 1,500 µS/cm at its mouth. Average dissolved solids concentrations ranged from 114 mg/L at one Big Coal River site to 459 mg/L at a headwater site on Spruce Fork. Sulfate was the dominant anion in the subbasin at 99 percent of 125 sites sampled at low flows. When the same sites were sampled later at high flows, sulfate was the dominant anion in 80 percent of streams. Sulfate concentrations ranged from 7 mg/L to 920 mg/L in the two synoptic surveys. Although a few exceptions were found in the headwater tributaries of Clear Fork, Marsh Fork, and Pond Fork, mine drainage in most of the area is not acidic because coal in the subbasin generally contains less than 1.5 percent sulfur. In addition, limestone strata common throughout the subbasin impart a high buffering capacity to ground water.

New River Main Stem

Improper treatment and disposal of human sewage adversely affect the New River in West Virginia (Mott and others, 1996). Water temperature typically remains below 30°C; background alkalinity has ranged from 65 to 100 mg/L, and iron and sulfate concentrations have averaged 0.4 and 15 mg/L, respectively (U.S. Environmental Protection Agency, 1980a). The New River generally has low turbidity except during floods or large releases of water from Bluestone Dam. The New River main stem supports a diverse community of game fish (Mott and others, 1996).

Near shore, structurally complex habitats separated fish into five dominant habitat-use guilds downstream from Bluestone Dam, in a reach of the New River ranging in width from 200 to 1,200 ft (Lobb and Orth, 1991). Fish species, life-stage composition, and densities differed among the five guilds (edge pool, middle pool, edge channel, riffle, and generalist). Large sunfish, including smallmouth bass, used deep habitats with slow velocities, whereas young sunfish used shallow habitats. Juvenile and adult smallmouth bass were nearly ubiquitous in the habitats of the study area, although densities were highest among snags. Minnows and darters used shallow areas, but the range of velocity used differed among species and life stages. Vegetated and channel edge habitats served as nursery areas. Total fish densities were highest in edge pool, backwaters, snags, edge riffles, and riffles. This community-assemblage structure was thought to be typical of large pool-and-riffle streams.

Water-Quality Issues

Water-quality issues most studied in the Appalachian Plateaus part of the Kanawha-New River Basin relate to human uses of environmental resourses. Land-use activity that affects ground-water quality generally affects surface-water quality as well. Concerns related to streams and consolidated aquifers of the Appalachian Plateaus have included contamination by saline water, coal mining, and sewage. Logging and acid deposition have adversely affected surface water in some areas, although effects on ground water are considered negligible. The Kanawha River and water in its alluvium have been adversely affected by industrial activities.

Saline Ground Water

Saline ground water underlies fresh ground water in most of the Appalachian Plateaus; this saline water is commonly under artesian pressure. Most of the rocks of Mississippian age and older contain brines (defined as waters containing more than 35,000 mg/L dissolved solids) of marine origin (Hinkle and others, 1994). In the northwestern part of the Kanawha-New River Basin, saltwater (defined as waters containing between 1,000 and 35,000 mg/L dissolved solids) is common at depths as shallow as 200 ft, and is present at the surface in a few locations. This shallow saltwater diffuses into fresh shallow ground water in much of the lower Kanawha River Basin (Doll and others, 1963; Foster, 1980).

Saline springs and seeps, where brines have migrated upward along natural zones of permeability found at the crests of anticlines, have been important to the development of the Kanawha Valley (Wilmoth, 1966). Mary Ingles, the first European known to travel down the New River from the first English settlements in the basin, near the present site of Radford, Va., to the mouth of the Kanawha River, reported helping her Shawnee captors evaporate brine to make salt in 1753 at Campbell's Creek, near Charleston (Price and others, 1937). By 1817, salt manufacturers in the Charleston area had drilled 20 brine wells, built 30 furnaces, and produced up to 700,000 bushels of salt per year. The first coal mines west of the Allegheny Mountains supplied fuel to the salt furnaces. Kanawha red salt was an important export of the area until the War Between the States. The ready availability of chloride, from brine, in close proximity to natural gas, initially attracted chemical manufacturers to the Kanawha Valley during World War I.

In the Pocatalico River Subbasin as well as elsewhere in the western part of the Appalachian Plateaus, natural gas, oil, and saline water, in order of relative depth, are layered in a stratum of coarse sandstone of the Pottsville Group (Bain, 1970). Most wells that produce oil or gas also yield saline water. Because all three fluids are typically under high pressure, an oil or gas well that was improperly sealed provides a conduit for saline water to migrate upward into shallow aquifers. During World War II, many well casings were removed and used for their steel. Injection of waste oil-field brines into shallow wells, formerly a common practice, has also contaminated shallow aquifers with saline water. Pumping a mixture with a brine:oil ratio of 80:1 was common in the Pocatalico oil field in the 1960's. In areas where fractures in the confining shale layer allowed oil and gas to escape, leaving behind the heavier brine, freshwater floats on the saline water. In this situation, overpumping of fresh aquifers can pull saline water toward the surface. In the Pocatalico River Subbasin, the boundary between fresh ground water and saltwater is in a zone of sandstones near the contact between the Conemaugh Group (Upper Pennsylvanian) and Allegheny Group (Middle Pennsylvanian).

Domestic wells contaminated with salt pose a potential health risk to area residents (Saber, 1995). In a study conducted in the Frame area of Kanawha County, 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 (Allen, 1987). The mean sodium concentration of Frame area wells sampled during the study was 160 mg/L, and the maximum was 760 mg/L. Although establishing the source of the sodium was outside the scope of the study, Allen noted that residents indicated the salinity of the wells had increased in recent years, accompanying oil and gas well development in the study area.

Coal Mining

Coal mining changes the hydrology of ground-water systems, physically and chemically, by altering the flowpath. Changes in the flowpath alter water chemistry by exposing the water to rocks with different composition. Underground coal mining can dewater rocks in the overburden (Schweitering, 1981). Changes in the ground-water system also affect surface-water systems because, at base flow, streamwater is primarily derived from ground water. Chemical composition of drainage emanating from underground mines or backfills of surface mines is dependent on the acid- or alkalinity-producing minerals contained in the disturbed geologic materials (Skousen, 1995). Coal-mine drainage in the Kanawha-New River Basin contains elevated concentrations of metals and sulfate but typically is not acidic (Ehlke and others, 1982). The effects of coal mining on ground water are generally found close to mines (O'Steen, 1982).

Coal has been commercially mined in the Kanawha-New River Basin since the early 19th century. In the mid-19th century, cannel coal (used to make lamp oil) was mined in the Coal River Subbasin. The first railroad in Virginia west of the Allegheny Mountains was an isolated rail line built in 1851–52 up Drawdy Creek from Peytona, the center of the cannel coal industry, to the Little Coal River (Peyton, 1853). A series of wooden navigation dams was built during about 1851–58, to make the Coal and Little Coal Rivers navigable by steamboats in order to ship cannel coal on to the Ohio and Mississippi waterways (Coal River Navigation Company, 1859). The navigation dams were destroyed during the War Between the States and the cannel coal industry collapsed when extraction of kerosene from petroleum became widespread (Krebs and others, 1915).

More coal is mined in 1996 in the Coal River Subbasin than in any other drainage of the Kanawha-New River Basin. Boone County, almost entirely within the Coal River Subbasin, has led West Virginia counties in coal production since 1985 and still has the greatest estimated recoverable reserves (more than 4 billion tons) of any West Virginia county (West Virginia Office of Miners' Health, Safety, and Training, 1992). In 1991, 25 percent of the coal produced in Boone County was mined at the surface and 75 percent was mined underground. The Coal River Subbasin contains 220 abandoned coal mines, 217 of which were abandoned before passage of the Surface Mine Control and Reclamation Act of 1977 (West Virginia Department of Natural Resources, 1989).

Coal is present in the Appalachian Plateaus in rocks of the Pennsylvanian System, a geologic system which is widely exposed at land surface. Two coal-bearing formations are present in the Kanawha-New River study unit. The Lower Pennsylvanian Pocahontas Basin is the older of the two and its rocks generally contain less sulfur than the rocks in the Upper Pennsylvanian/Lower Permian Dunkard Basin. These two basins generally correspond with West Virginia's southern and northern coal fields (Watts and others, 1994). The boundary between the two coal fields bisects the study unit from southern Braxton County through central Clay and central Kanawha County, to extreme northern Boone County (Barlow, 1974). The principal basis for the division of the coal fields was sulfur content of the coal, the coal from the northern coal field generally containing more than 1.5 percent sulfur and that from the southern coal field containing less than 1.5 percent sulfur, although significant variations in sulfur content can occur within a single mine. Most of the coal mined in the Kanawha-New River Basin is from the southern, low-sulfur coal field.

Pyrite (FeS_2) is generally the dominant sulfide mineral in coal (King and Renton, 1979). Pyrite and marcasite (also FeS_2) are the most reactive sulfur-containing minerals in coal and are the primary source of sulfate in mine drainage (Rauch, 1987). During mining, sulfides are exposed to air and water. Such exposure accelerates oxidation and releases sulfuric acid and iron. Generally, drainage from mined strata that contain more than 1 percent sulfur compounds is acidic, whereas drainage from strata that contain less than 1 percent sulfur compounds is neutral or alkaline. In surface mines, the chemical composition of the overburden and pavement rock bed most affect mine drainage quality; in underground coal mines, the coal also is considered to have a major effect on mine-drainage quality. Surface coal mines generally have a greater effect on the quality of shallow ground water than do underground coal mines. Underground mines generally are deeper than the shallow aquifers, and, in many cases, would flood if not pumped. In the Monongahela River Basin in north-central West Virginia, underground mines have been found to cause ground-water contamination for longer periods than surface mines and to cause a greater areal extent of deep ground-water contamination (O'Steen, 1982).

Acid mine drainage typical in high-sulfur coal fields contains iron, manganese, sulfate, and other constituents (U.S. Environmental Protection Agency, 1980a, b). Sulfate is a more conservative contaminant than metals are, and it is generally decreased in concentration only by dilution. In northern West Virginia, sulfate concentrations greater than 50 mg/L in wells and springs are considered indicative of mine drainage influence (Rauch, 1987). In surface mines in an area north of the Kanawha-New River Basin but within the Appalachian Plateaus Province, acid mine drainage was always found when overburden and pavement rock strata had a net neutralization potential of less than 1 percent by weight of equivalent calcium carbonate, and alkaline mine drainage was always produced when mines had a net neutralization potential of greater than 3 percent by weight of equivalent calcium carbonate (diPretoro and Rauch, 1988). When net neutralization potential was between 1 percent and 3 percent, about 70 percent of the mines produced alkaline drainage and about 30 percent produced acidic drainage.

The collapse of roofs of underground mines can result in the propagation of vertical fractures and land subsidence (Hobba, 1981). Such fractures increase hydraulic conductivity and permit greater recharge from precipitation or surface water, and mines often function as a reservoir for the infiltrating water. Drainage along subsidence cracks eventually lowers water levels upgradient, even in nearby wells finished in unfractured rock.

Sulfate concentration in ground water was negatively correlated with distance from underground mining activity in the Coal River Subbasin, within the southern, low-sulfur coal field (U.S. Environmental Protection Agency, 1980a). Water samples from 35 wells, at various distances from coal mines that had been operating at least 6 months, were analyzed for sulfate. Seventy-eight percent of wells whose water contained 10 mg/L of sulfate or more were within 1.6 mi of an underground coal mine. Eighty-two percent of wells more than 1.6 mi from an underground mine produced water containing less than 10 mg/L of sulfate.

Active underground mines were found to be the principal source of mineralized waters in streams in the Coal River Subbasin (Bader and others, 1976). In a 2-year (July 1973–June 1975) study of the Coal River Subbasin, the highest specific conductances and highest sulfate concentrations were found in small streams receiving discharges from active underground mines. Discharge from one active underground mine in the subbasin contained 3,600 mg/L dissolved solids and 2,800 mg/L sulfate. Dissolved solids concentration in Marsh Fork increased from 200 to 720 mg/L downstream from this inflow. Small streams draining abandoned underground mines and both active and inactive surface mines were sampled at high and low flow. Most of this streamwater contained less than 300 mg/L dissolved solids, and water from many streams contained less than 150 mg/L. Active underground mines were thought to produce large amounts of dissolved solids because previously water-saturated rocks are dewatered and exposed to air during mining. The newly exposed strata are especially susceptible to oxidation and leaching.

In low-sulfur coal fields, water from both active and inactive mines is used for public, industrial, and commercial supplies (Kozar and Brown, 1995). The chemical composition of water from some of these mines meets drinking-water standards before treatment, although treatment to decrease iron and manganese content is often required. Contamination of mine water is possible from chemicals used directly or indirectly in the mining process. Such chemicals include acrylamide (used in coal-cleaning processes); oil, grease, and solvents used in mine equipment; and polychlorinated biphenyls from transformers formerly used to power mining equipment (Ferrell, 1986).

Bacterial Contamination

Bacterial contamination of ground water and surface water in the Appalachian Plateaus Province has been documented since at least 1947 (West Virginia State Water Commission, 1947). In 1946, coliform bacteria concentrations in the Kanawha River downstream from Charleston were greater than 20,000 MPN/100 mL, with a maximum of 80, 000 MPN/100 mL near St. Albans. Even after construction of municipal wastewater treatment facilities, bacterial contamination has remained more widespread in the Appalachian Plateaus Province than many other parts of the United States, partly because of physiographic factors. Most of the flat land in the basin is in valleys eroded into the plateau by streams, so much of the Province's population lives scattered along the valley floor rather than in more concentrated communities, a settlement pattern that increases costs of transporting wastewater to a treatment facility and decreases the likelihood that wastewater will be treated. In areas lacking sewer services, waste is often disposed of in septic tanks; however, raw-sewage discharge directly into streams still occurs, and in some parts of the Kanawha-New River Basin these "straight pipes" are installed and maintained by municipalities (Mott and others, 1996).

In rural areas, ground-water problems are commonly associated with improper construction, siting, and abandonment of wells (Ferrell, 1986). Wells drilled prior to State regulation of well construction commonly were located near septic fields or were improperly sealed. Improperly constructed wells can permit percolation of contaminants into aquifers and can contaminate water in nearby wells. Most cases of bacterial contamination in ground water in the Appalachian Plateaus Province are related to problems with wellheads (Lewis Baker, West Virginia State Department of Health, oral commun., May 1996). Improper abandonment of wells can lead to problems, as when dug wells are filled with debris (Ferrell, 1986).

High bacterial concentrations have been common in the New River (West Virginia State Water Commission, 1947; Federal Water Pollution Control Administration, 1970; Clark and others, 1976; West Virginia Department of Natural Resources, 1986; Wood, 1990; West Virginia Division of Environmental Protection, 1994). Bacterial contamination in the New River Gorge National River is of particular concern because of the heavy use of the river by whitewater enthusiasts (Mott and others, 1996). Concentrations and sources of bacteria in the New River have been studied by the National Park Service and the WVDNR since 1980 (Wood, 1990). Dilution and die-off usually keep bacteria concentrations below 400 col/100 mL in the New River (Mott and others, 1996). However, along stream segments where full mixing from contaminated tributaries or sewage outfalls has not occurred, point samples containing bacteria concentrations as great as 20,000 col/100 mL are often collected from near the stream bank (Mott and others, 1996). New River tributaries including Piney Creek, Dunloup Creek, Arbuckle Creek, and Marr Branch carry enough human and(or) animal waste to elevate mainstem bacteria concentrations downstream from their confluences. Storm-induced urban runoff can overload sewage treatment plants, which then discharge large volumes of untreated sewage (Wood, 1990).

Several streams in the Bluestone River Subbasin have been found to contain fecal coliform concentrations above the State contact standard of 200 col/100 mL (West Virginia Department of Natural Resources, 1989). The Bluestone River Subbasin is unusual in the study unit in that most of its urban areas are in watersheds of small headwater streams, including Brush Creek (Doug Wood, West Virginia Division of Environmental Protection, written commun., 1996). Treated wastewater from the Princeton-Bluefield area, located in the headwaters of the Bluestone River Subbasin, is discharged into small streams that have little waste-assimilation capacity. The lower Bluestone River, designated a National Scenic River, has been protected from these discharges by dilution from relatively clean tributary water and by a long traveltime to the river's mouth.

The Coal River Subbasin has been affected by improper domestic sewage disposal as much as any subbasin in the Kanawha-New River Basin. A 1946 reconnaissance of surface water in the Coal River Subbasin found coliform concentrations as high as 195,000 MPN/100 mL (West Virginia State Water Commission, 1947). In the 1970's, fecal coliform concentrations of 54,000 col/100 mL and fecal streptococcus concentrations of 13,500 col/100 mL measured in samples from Marsh Fork at Whitesville were considered typical of the bacterial contamination of streams in the subbasin (Bader and others, 1976). High bacteria concentrations were associated with high flows and high sediment concentrations. The highest bacteria concentrations in the Coal River Subbasin were found in small streams in the St. Albans area at times of high streamflow and were attributed to rainfall-related increases in septic field leaching. High fecal bacteria concentrations persist in the Coal River Subbasin (West Virginia Division of Environmental Protection, 1994). At Tornado, near the mouth of the Coal River, 46 percent of samples collected during 1989–1991 were in violation of the state fecal coliform contact standard of 200 col/100 mL.

Industrial Activities

Effects on Surface Water.--The degradation and partial recovery of the lower Kanawha River main stem during the 20th century parallels the history of many industrial basins. During the 1950's and 1960's, the Kanawha River downstream from Charleston was widely regarded as one of the most polluted rivers in the Nation (Henry, 1974). Upstream, near Kanawha Falls, the river's ecosystem remained healthy, supporting diverse fish and macroinvertebrate communities, including two Federally listed endangered mussel species (the tuberculed blossom pearly mussel, *Epioblasm torulosa torulosa*, and the pink mucket pearly mussel, *Lampsilis orbiculata orbiculata*) (U.S. Environmental Protection Agency, 1980a). Until about 1983, the Kanawha River downstream from Charleston was severely polluted. The river in this reach was typically anoxic during the summer, and supported few, if any fish, and only pollution-tolerant invertebrates such as midges and earthworms (Henry, 1974). Morris and Taylor (1978) reported finding as many as 13 species of unionid clams at stations upstream from Charleston and none downstream from Charleston. Eighteen of the 19 mussel species collected in the Kanawha River in the autumns of 1981 and 1982 were collected in the 7 mi reach downstream from Kanawha Falls (Schmidt and Zeto, 1983). Cleanup efforts began with voluntary, phased effluent reductions in the 1950's and 1960's. Federally mandated effluent reductions in the 1970's restored enough dissolved oxygen (DO) to the Kanawha River for game fish populations to reestablish by the early 1980's. Despite significant progress, concentrations of persistent organic contaminants, including dioxin (2,3,7,8-tetrachlorodibenzo-*p*-dioxin), remain high enough so that fish consumption advisories remain in effect (West Virginia Division of Environmental Protection, 1994).

The Kanawha River downstream from Charleston was degraded during World War II, when the Kanawha Valley chemical manufacturing complex operated under a Federal mandate to "produce and forget about pollution" (Workman, 1951). Effluent discharge at some chemical plants increased fourfold during the 1940's. In response to the perception that the lower Kanawha River had become unsuitable for water supply, fish habitat, or recreational uses, the West Virginia Legislature in 1946 authorized the State Water Commission to study water quality in the basin as a first step toward recovery (West Virginia State Water Commission, 1947). As expected, the most severe water-quality problems in the basin were found in the Kanawha River from Belle to the river's mouth at Point Pleasant. During the 1946 survey, DO concentrations in this entire reach of the river were less than 1.0 mg/L, and the subreach for 20 mi downstream from Charleston was completely anoxic. The same survey found biochemical oxygen demand (BOD) in the Kanawha River downstream from Belle ranging from 5.0 to 15 mg/L, and toxic substances, oil slicks, and odiferous materials were observed in the river. Chemical industries were given more of the blame for water-quality problems than were municipal wastewater treatment plants, but both types of dischargers were targeted for corrective actions.

In 1953, West Virginia water pollution control laws were amended to establish a permit system for industrial dischargers, which required the State Water Commission to approve discharges associated with manufacturing expansions (Henry, 1974). A year later, "Minimum Water Quality Objectives" were set for West Virginia streams by the Water Commission, calling for water discharged to contain a minimum of 3.0 mg/L DO and to be free of floating or settleable materials. Point sources and their respective loads to the Kanawha River were identified in 1958. These loads were set as baseline loads in 1959, with future loads controlled as some fraction of the baseline; chemical plants were initially instructed to reduce their BOD loads to 60 percent of the baseline by 1963. Primary sewage treatment plants and industrial treatment systems were built in an effort to achieve the minimum objectives, but the Kanawha River cleanup required additional measures. In the second phase of cleanup, cities were required to adopt secondary treatment practices, and chemical plants were generally required to reduce BOD discharges to 30 percent of baseline.

Dissolved oxygen concentrations less than 1 mg/L in a 25-mile reach of the Kanawha River downstream from Charleston continued to be considered the most serious water-quality problem in the basin, according to field research conducted during 1963–65 by the Federal Water Pollution Control Administration (1970). In the 1950's, the chemical complex between Belle and Nitro had grown to become the largest chemical manufacturing complex in the United States. Industrial wastes made up about 98 percent (2 million pounds per day 20-day BOD) of the average carbonaceous load and nearly 100 percent (400,000 pounds per day 20-day BOD) of the average nitrogenous load in this reach of the Kanawha River.

Phase III of the Kanawha River cleanup was delayed until 1971, because financial restraints slowed cities in installing secondary treatment facilities and because federal requirements to formulate and publish water-quality regulations occupied State officials (Henry, 1974). Generally, Phase III goals required chemical plants to reduce BOD discharges to 15 percent of the 1959 baseline and to reduce nitrogenous waste discharges toward a goal of 65 percent of the mean of the amount used in the plant. Although passage of the 1972 Federal Water Pollution Control Act changed the basis of regulation from water quality standards to treatment efficiency, Phase III planning was essentially implemented, because State regulatory officials generally based the first round of NPDES permits on existing Phase III permits. The Kanawha River at Winfield Dam contained oxygen most of the summer in 1972 (West Virginia Department of Natural Resources, 1986; U.S. Army Corps of Engineers, 1983). By 1974, the State standard for DO of 4.0 mg/L typically was being met in the Kanawha River, although DO occasionally dropped as low as 3.0 mg/L during periods of low flows in 1975–82. Game fish populations were re-established and in 1982, a bass tournament was held in the Kanawha River. The overall BOD of effluents discharged to the lower Kanawha River has continued to decrease (U.S. Army Corps of Engineers, 1994).

Despite the progress made in reducing industrial discharge to the Kanawha River, serious water-quality problems remain (West Virginia Department of Natural Resources 1986, 1988; West Virginia Division of Environmental Protection, 1994; Waldron, 1993). High concentrations of chlorinated hydrocarbons, including methylene chloride (0.25 μg/L, mean; maximum 73.5 μg/L) and chloroform (0.90 μg/L, mean; maximum 219 μg/L) have been detected in the Kanawha River at St. Albans, although a statistically significant decreasing trend in their concentrations was found for the period of record (1980–84, 1987–1989) (Ohio River Valley Water Sanitation Commission, 1992). Dioxin was detected in whole-fish samples of smallmouth and spotted bass, and in fillets of largemouth bass and smallmouth buffalo in 1984 (Kanetsky, 1988). Followup studies found that sediments of the lower Kanawha River generally contained dioxin concentrations of about 100 nanograms per kilogram. In addition, sediments in the Kanawha River backwater areas at the mouths of the Pocatalico River and Armour Creek contained dioxin from an unknown source. Sediments collected upstream and downstream from the Kanawha Valley chemical manufacturing complex, and from Armour Creek, contained substances mutagenic to bacteria (Waldron and White, 1989; White and Waldron, 1988). More mutagens were extracted with polar solvents (acetone and methanol) than with methylene chloride. An advisory against consuming bottom-feeding fish from the Kanawha River, or any fish from near the mouths of the Pocatalico River and Armour Creek, was issued in 1986 and remains in effect in 1996 (Janice Smithson, West Virginia Division of Environmental Protection, written commun., 1996).

Effects on Alluvial Aquifers.--Although discharge of wastes from chemical facilities is regulated under National Pollutant Discharge Elimination System and primarily affects surface water, the impoundments commonly used during treatment processes and for storage of liquid hazardous wastes have contaminated ground water (Ferrell, 1986). Contaminants such as chloride, lead, arsenic, chromium, and various organic compounds have leaked from impoundments, particularly unlined ones. Under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund), the USEPA has listed 204 sites in the West Virginia part of the Kanawha-New River Basin, 105 of them in Kanawha County (West Virginia Division of Environmental Protection, 1996). Contaminants found in ground water at these sites have included chloride, mercury, phenol, carbon tetrachloride, chloroform, trichloroethylene, and benzene.

One 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, 1996). This plant was a small-volume batch formulator that specialized in the development of more than 60 chemicals, custom chemical processing, and production of specialty chemicals. The plant was added to the National Priority List in 1982, purchased by another firm in 1986, and abandoned in 1988. Site activities that contributed to contamination include improper storage of drums containing hazardous substances, onsite disposal of hazardous waste through drum burial and unlined surface lagoons, and tank storage of chemical stock, products, and wastes. The first phase of the investigation into the nature and extent of contamination of soil, sludge, and ground water has been completed. More than 25 toxic substances have been detected in ground water from the site, including arsenic, cadmium, chloroform, benzene, and trichloroethylene, and dioxin has been detected in soil at the site (West Virginia Division of Environmental Protection, 1996). The investigation is expected to be completed in 1997, at which time cleanup alternatives will be identified (U.S. Environmental Protection Agency, 1996).

Logging

The Appalachian Plateaus are heavily wooded with second- or third-growth forest, and as the forest matures, logging activities are likely to increase (West Virginia Department of Natural Resources, 1989). The most significant water-quality problem associated with logging is sedimentation related to poor logging practices, still a contemporary problem, but perhaps more significant as an historical disturbance of stream ecosystems. The forest in much of the Appalachian Plateaus was virtually virgin in 1870, 73 percent virgin in 1900, and almost completely logged by 1920 (Clarkson, 1964). Forest fires appear to contribute more to soil erosion and sedimentation than logging does (West Virginia Department of Natural Resources, 1989). During the initial logging of Appalachian Plateaus forests, wildfires were frequent, as slash left as waste by loggers dried and burned (Clarkson, 1964). Stream ecology was poorly documented during the logging of the virgin forest, but there is little doubt that sedimentation and temperature changes related to loss of shade permanently changed stream communities. Brook trout (*Salvelinus fontinalis*), for instance, were known to have been common at elevations as low as 2,100 ft before widespread logging, but by 1900 were restricted to relatively infertile, high-altitude headwater streams by sedimentation, warmed water, and introduction of more aggressive, warmwater-tolerant rainbow trout to streams at lower altitudes (Constantz, 1994).

Best management practices can reduce logging-associated sedimentation and temperature changes in Appalachian Plateaus streams (West Virginia Department of Natural Resources, 1989). When best management practices are followed, haul-road building is the principal cause of increased sedimentation. Logging takes place in all the Kanawha-New River tributary subbasins in the Appalachian Plateaus, and it is particularly prevalent in the Gauley and Elk River Subbasins (7.0 and 4.6 percent of total land use, respectively).

Acid Deposition

The low buffering capacity of streams in the Allegheny Highlands, including the headwaters of the Gauley and Elk River Subbasins, make them susceptible to the effects of acid deposition (West Virginia Department of Natural Resources, 1989). The Cranberry River drains a mostly pristine watershed including the Cranberry Wilderness Area. Between 1957 and 1987, the Cranberry River became less productive, a condition attributed to acidification. Fish biomass collected from 5 sites over 20 mi of the river decreased from 15 lb/acre to less than 5 lbs/acre, while diversity decreased from 15 to 8 species. In 1985, the mean pH of these five sites on the Cranberry River main stem was 5.6, with a range of 4.7 to 5.6 (Raymond Menendez, West Virginia Division of Natural Resources, oral commun., November 1996). Annual atmospheric deposition of 15 kg/ha nitrate and 24 kg/ha sulfate (1984–1995) was measured at a site in Fayette County, W. Va., operated by the USGS (National Acid Deposition Network/National Trends Network, 1996). Although no definite causal relation between acid deposition and decreased fish-community health was established, no other factors that could account for the decrease were apparent.

To neutralize the acidification of the Cranberry River, a flow-driven drum liming station began operating in December 1988 on Dogway Fork, a tributary of the Cranberry River (Zurbuch and others, 1996). A second, larger limer went into operation near the mouth of the North Fork of the Cranberry River in

January 1993 (Raymond Menendez, West Virginia Division of Natural Resources, oral commun., November 1996). Slurry derived from a limestone aggregate (approximately 98 percent calcium carbonate) is released in proportion to flow (Zurbuch and others, 1996). Since the start of liming, 13 additional macroinvertebrate species have been collected on Dogway Fork, and a fishable brook trout population has become reestablished there (Clayton and Menendez, 1996; Menendez and others, 1996). Smallmouth bass and rock bass have become more numerous in downstream reaches of the Cranberry River, and their populations are reestablished throughout the treated part of the river (Raymond Menendez, West Virginia Division of Natural Resources, oral commun., November 1996).

Highway Construction

The benthic macroinvertebrate community of Turtle Creek, a small tributary in the Coal River Subbasin, was severely depleted during and shortly after highway construction upstream (Chisholm and Downs, 1978). Community degradation was greatest in the headwaters of Turtle Creek, because of erosion of sediment resulting from high streamflow velocity. After sediment loads diminished as the disturbance ceased, the benthic community recovered rapidly, because of tributary inflow from undisturbed tributaries and organism drift. Within 1 year after highway construction, the benthic community of Turtle Creek was similar to that of Lick Creek, a nearby, undisturbed stream.

SUMMARY

This report summarizes 105 water-quality studies, from a set of over 300 studies that were reviewed, of the Kanawha-New River Basin. Studies addressed geochemical reconnaissance, effects of specific disturbances on the hydrologic environment, and basic ecological processes. Local lithology determines background water chemistry. Water in the Blue Ridge Mountains and the highlands of the Appalachian Plateaus has low mineral content. Water in the Valley and Ridge Province and in the Greenbrier River Basin of the Appalachian Plateaus Province, areas largely underlain by limestone, is well buffered. Water in the parts of the Appalachian Plateaus Province west of the Kanawha-New River and north of the mouth of the Elk River has a higher background mineral content than water in any other part of the basin.

The most-studied disturbance in the part of the basin in the Valley and Ridge Province has been effects of agricultural practices. Ground-water systems in these largely carbonate areas contain elevated concentrations of nutrients and bacteria because of the rapid recharge typical of karst. Disturbances in the part of the basin in the Appalachian Plateaus Province are more diverse, and have been examined in more detail in this report because these areas comprise the majority of the basin. Upward flow of saline ground water (which underlies most of the Appalachian Plateaus) along the axes of anticlines and in areas where gas and oil wells have been improperly sealed has caused mixing with fresh, shallow ground water. Coal mining is common in the Kanawha-New River Basin in the Appalachian Plateaus, and drainage from the mines is typically alkaline or neutral. Streams that receive coal-mine drainage typically contain elevated concentrations of sulfate, iron, and manganese. High concentrations of fecal bacteria have been found throughout streams of the Appalachian Plateaus. The Kanawha River passes through a highly industrialized area near Charleston, W. Va., the only urban, industrial part of the basin. The main stem of the Kanawha River has recovered from anoxia, generally thought the result of industrial effluent, which was typical before 1972. Fish and macroinvertebrates are reestablished in the river, but synthetic organic compounds persist in the river sediments and alluvium.

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