WATER QUALITY AND PROCESSES AFFECTING DISSOLVED OXYGEN CONCENTRATIONS IN THE BLACKWATER RIVER, CANAAN VALLEY, WEST VIRGINIA

By Marcus C. Waldron and Jeffrey B. Wiley

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U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary
U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information
write to:

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

Copies of this report can be
purchased from:

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

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per hour (ft/h)	0.3048	meter per hour (m/h)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by use of the following equation:

$$C = 5/9\ (F^\circ - 32)$$

Abbreviated water-quality units used in this report: Chemical concentration is given in grams per liter (g/L), 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) of solute per unit volume (liter) of water. One thousand milligrams per liter is equivalent to one gram per liter. 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. 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.

Water Quality and Processes Affecting Dissolved Oxygen Concentrations in the Blackwater River, Canaan Valley, West Virginia

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ABSTRACT

This study assesses the quality of the Blackwater River in Canaan Valley, W. Va., and identifies environmental processes that could affect dissolved oxygen (DO) concentrations in the river during periods of low flow. Canaan Valley is an elongated, oval-shaped valley located in the Allegheny Mountains of northern West Virginia. It is the highest valley of its size east of the Rocky Mountains, with an average elevation of 3,200 feet above sea level. The Canaan Valley area has experienced significant increases in tourism, population growth, and real estate development in the past two decades.

Water from streams in Canaan Valley is a dilute calcium magnesium bicarbonate type. Stream water typically was soft and low in alkalinity and dissolved solids. Maximum values for specific conductance, hardness, alkalinity, and dissolved solids occurred during low-flow periods when streamflow was at or near base flow. Nitrogen and phosphorus were present at very low concentrations. Concentrations of nitrate-nitrogen, nitrite-nitrogen, and un-ionized ammonia-nitrogen were always below State water-quality limits. Concentrations of dissolved nitrite-nitrogen plus nitrate-nitrogen and dissolved ortho-phosphorus were highest during periods of high streamflow. Particulate forms of nitrogen were more abundant during summer low-flow periods and probably represent organic production within the streams. Dissolved oxygen concentrations usually were below the saturation concentrations and sometimes below State limits near the headwaters, and usually were at or above saturation at other mainstem locations. At discharges near those of the 7-day, 10-year low flow, the headwaters can have supersaturated DO concentrations. Fecal coliform bacteria counts periodically exceeded the State count of 200 colonies per 100 mL. Maximum concentrations during the warmest months of the year often were in the thousands of colonies per 100 milliliters. Concentrations of dissolved iron and manganese were high, and contamination from pesticide applications was not evident in Canaan Valley streams.

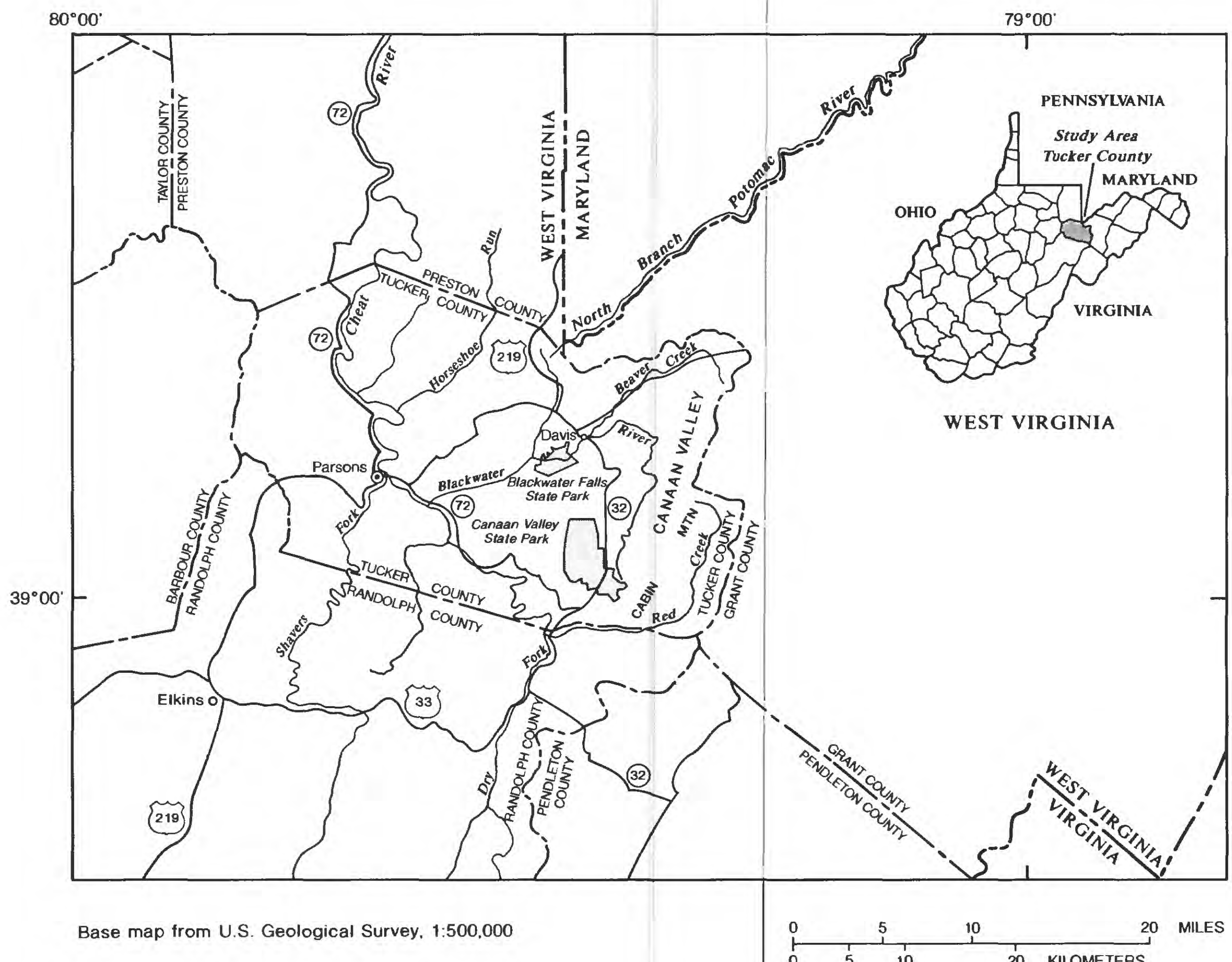
Dissolved oxygen concentrations are most sensitive to processes affecting the rate of reaeration. The rate of reaeration is affected by processes that determine dissolved oxygen solubility (the interactions among atmospheric pressure, water temperature, humidity, and cloud cover) and processes that determine stream turbulence (the interactions among stream depth, width, velocity, and roughness).

Additional processes play significant roles in determining DO concentrations in the headwaters and beaver pools. In the headwaters, photosynthetic DO production by benthic algae can result in supersaturated DO concentrations. In beaver pools, DO consumption from sediment oxygen demand (SOD) and carbonaceous biochemical oxygen demand (CBOD) can result in dissolved oxygen deficits.

INTRODUCTION

Canaan Valley is an elongated, oval-shaped valley located in the Allegheny Mountains of northern West Virginia. It is the highest valley of its size east of the Rocky Mountains with an average elevation of 3,200 ft above sea level. The valley is flanked by Canaan, Cabin, and Brown Mountains and is drained by the Blackwater River, a tributary of the Cheat River, northwestwardly through a narrow water gap (figs. 1 and 2). The climate is cool and humid because of the valley's altitude and position on the windward slope of the Allegheny Mountains. The northern-forest character and extensive wetlands support many that are unusual or rare in West Virginia and Eastern United States. The natural beauty, diverse ecology, and many recreational opportunities in Canaan Valley are enjoyed by seasonal and permanent residents and by more than 1.5 million visitors annually (Canaan Valley Task Force, 1992).

Canaan Valley has experienced rapid development in the past two decades. Much of the expansion is associated with recreational and tourism industries, particularly skiing, golfing, and associated real estate developments. There is no centralized wastewater-treatment facility in the valley. Domestic wastes are treated individually in septic systems or small "package" plants that discharge treated wastewater into the Blackwater



Base map from U.S. Geological Survey, 1:500,000

Figure 1. Location of Canaan Valley, Tucker County, West Virginia.

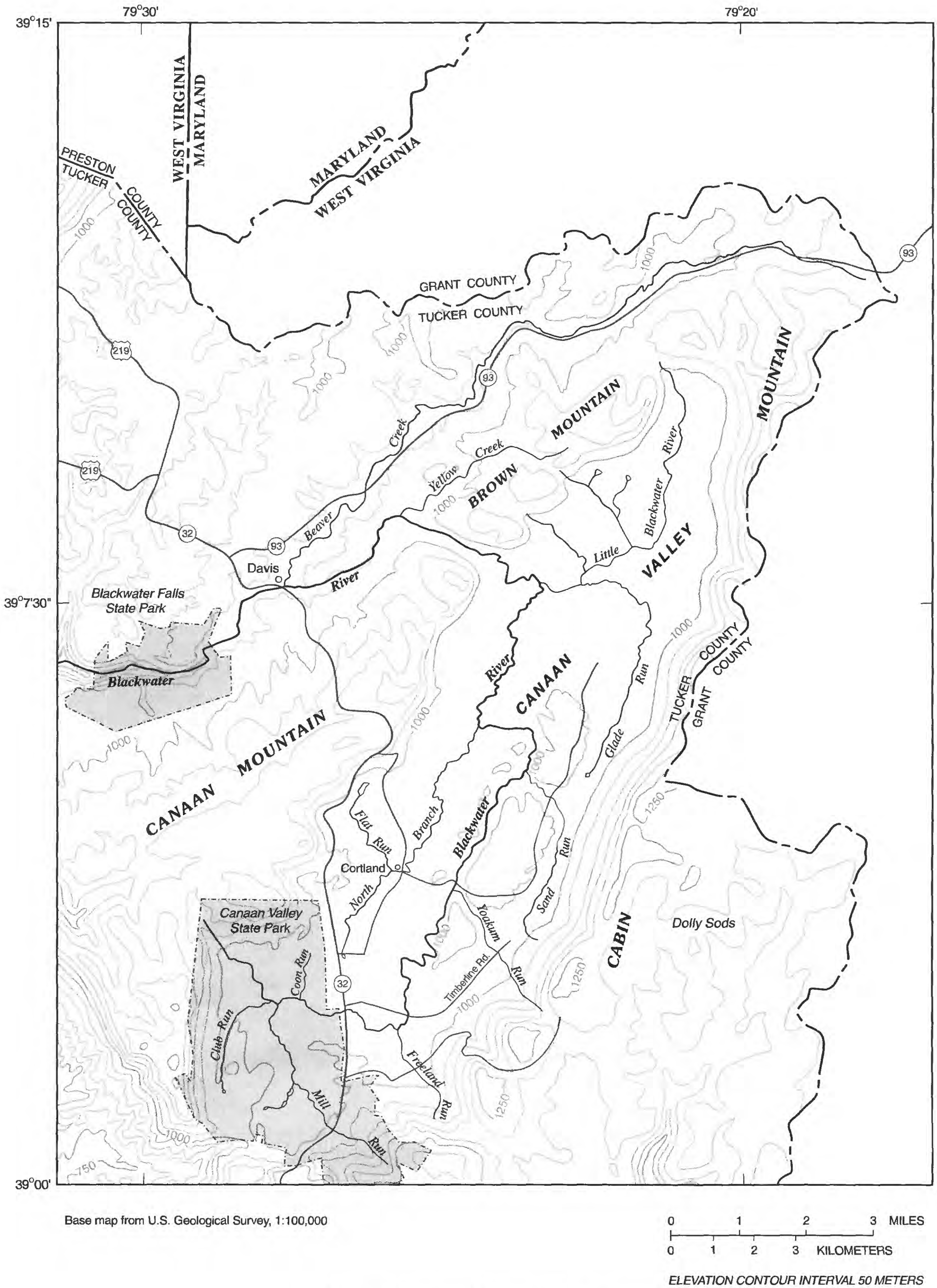


Figure 2. Location of Canaan Valley study area.

River or one of its tributaries. The State Division of Environmental Protection has restricted further development by limiting issuance of wastewater discharge permits based on estimates of the waste-assimilation capacity of the Blackwater River. Effective management of water resources in Canaan Valley requires a more detailed understanding of the ecological processes and interactions that determine the waste-assimilation capacities of the area streams.

In 1990, the U.S. Geological Survey (USGS), in cooperation with the West Virginia Division of Environmental Protection, the West Virginia Division of Tourism and Parks, and the Canaan Valley Task Force, began a comprehensive study of the surface-water and ground-water resources in Canaan Valley. This study was designed to provide basic hydrologic and ecological data that could aid in land-use planning and management. This report presents the surface-water findings; ground-water findings are presented in a separate report.

Purpose and Scope

This report discusses an assessment of the water quality of the Blackwater River and its major tributaries in Canaan Valley, W. Va., and identifies environmental processes that can affect dissolved oxygen (DO) concentrations in the river during periods of low flow. Data collected during a 30-month period at eight Canaan Valley monitoring sites were used to characterize existing flow and water-quality conditions in the valley. Each site was sampled manually at intervals of 1 to 2 months for 29 water-quality properties and constituents. Statistical analysis of the seasonal and flow-related changes in selected water-quality characteristics is discussed in this report, which also includes a discussion of possible cause-and-effect relations among water-quality characteristics and stream ecological processes.

Ecological processes thought to affect DO concentrations in the Blackwater River during periods of low flow are investigated. Synoptic streamflow and water-quality data were collected during low-flow periods of 2 to 4 days in mid-summer, at 35 sites on the mainstem and major tributaries of the Blackwater River. Synoptic-survey data were used to calibrate and verify a steady-state, one-dimensional water-quality model that represented the physical, chemical, and biological processes affecting dissolved oxygen (DO) concentrations in the river. The calibrated model was used to investigate low-flow conditions by simulating the river at the 7-day, 10-year low flow (7Q10).

Description of Study Area

The study area is the Blackwater River basin within Canaan Valley in northeastern Tucker County, West Virginia (fig. 1). Canaan Valley is the largest intermontane valley east of the Mississippi River. The valley floor is oval in shape, about 14 mi long by 5 mi wide, and has an average elevation of 3,200 ft.

Canaan Valley was formed by erosion of the Blackwater Anticline, one of a group of high-amplitude foldings of sedimentary rock that characterize this section of the Appalachian Plateaus Physiographic Province (Reger and others, 1923). The anticline originally was capped by resistant sandstones of the Pottsville and Allegheny Groups, with Mauch Chunk shales and Greenbrier limestone forming the next layer, and sandstones of the Pocono Group forming the base. Once the Pottsville cap was breached, the softer limestone layers were rapidly eroded and the resultant material distributed on the valley floor. The result is a bowl-shaped valley, with concentric rings of sandstone, shale, and limestone, surrounding a central ridge of Pocono sandstone. A sandstone ridge separates two branches of the Blackwater River in the southern half of the valley (fig. 2).

Canaan Valley has a cool, wet climate, with cold winters and cool summers. Fortney (1975) characterized the valley's climate as similar to that of northern New York and parts of Vermont, New Hampshire, and Maine. The frost-free season averages 92 days from May 31 through September 1; below-freezing temperatures can occur during any month of the year. Summer temperatures are moderate with daily maximum averages of 75 to 78°F; winters are cold with temperatures as low as -26°F.

The valley's location at the edge of the windward slope of the Allegheny Mountains places it in a position where weather fronts approaching from the northwest and moisture-laden air from the Gulf of Mexico converge and release large amounts of rain. Annual precipitation is about 53 in. Rainfall is distributed evenly throughout the year, about 4 to 5 in. each month, but June is consistently the wettest month, averaging about 5 in.

Types of land cover in Canaan Valley have changed considerably over time. The valley was logged and burned in the late 1800's and early 1900's and now supports extensive palustrine-emergent wetlands that result from the abundant precipitation and a layer of poorly drained soil derived from erosion of the Blackwater Anticline. The wetland complex includes wet meadows dominated by sedges and grasses, dense thickets of alder and spiraea, and extensive peat bogs (Fortney, 1975).

The study area is limited to the Blackwater mainstem and tributaries with drainages restricted to Canaan Valley. The Blackwater River and its major Canaan Valley tributaries, North Branch and the Little Blackwater River, are low-gradient streams. Other tributaries, such as Yoakum Run and Freeland Run, originate on mountain sides and fall rapidly to the valley floor before joining the Blackwater mainstem. Beavers have constructed dams on many Canaan Valley streams, flooding stream margins and forming deep pools and wet meadow-marshes. In other areas, particularly in the northern end of the valley, peat bogs have developed where a shallow confining layer of weathered limestone restricts drainage. Stream channels in these areas have cut down beneath the level of the bog, and at low flow there is little surface contact between the wetlands and the streams. The combined drainage area of the Little Blackwater River and Glade Run is 15.47 mi^2. Glade Run originates in the southern end of the valley and joins the Little Blackwater 0.8 mi upstream from its confluence with the Blackwater River. The Little Blackwater drains a large part of the northern end of the valley, including many acres of undeveloped wetlands. The study area ended on the mainstem 2.8 mi upstream from Davis, W. Va., and did not include Beaver Creek or Yellow Creek, tributaries that drain areas outside the valley (fig. 2).

Acknowledgments

The authors wish to thank Dr. Ronald Fortney, of the West Virginia Division of Tourism and Parks and Salem-Teikyo University, for advice on sampling and analysis of Canaan Valley ecosystems, and Steven Bolar, Superintendent of Canaan Valley State Park, for providing access to research sites and laboratory facilities. We also thank Karen Bonner, President of the Tucker County Planning Commission, and William Brannan, of the West Virginia Division of Environmental Protection, for their assistance in promoting and facilitating the study. We are grateful to the many Canaan Valley residents and business owners who generously granted us access to monitoring sites and private wastewater-treatment plants, and to John Kimbleton, who provided analyses of biochemical oxygen demand. The study benefited greatly from the contributions of Janet Fletcher, Lisa Gatens, Jane Hunnicutt, Terence Messinger, Edward Moore, Barton Paxton, Nancy Powers, Robin Waldron, and Naiming Wong, who participated through the USGS Volunteers for Science Program.

WATER QUALITY

A summary of the water-quality data collected during the study is presented including descriptions of the monitoring network, methods of data collection, and selected physical and chemical characteristics. Complete listings of data collected during each year of the study can be found in the West Virginia Water-Data Reports for water years 1990, 1991, and 1992 (Ward and others, 1991, 1992, and 1993). A water year is October of the previous year through September of the identified year.

Description of Monitoring Network

A water-quality monitoring network was established in Canaan Valley in March 1990, when monitoring sites on Mill Run and the Blackwater River in Canaan Valley State Park were established. Two more mainstem sites, Blackwater River on Timberline Road and Blackwater River at Cortland, W. Va., and one tributary site, North Branch at Cortland, W. Va., were added in April

1990. The final two monitoring sites were established on Club Run and Yoakum Run in May 1990. All eight sites were sampled in May, June, July, August, and September 1990. In 1991, all sites except Club Run were sampled six times, at intervals of about 2 months, beginning in January and continuing through November. Club Run was sampled in March, May, and November 1991. Sampling was conducted in January, April, May, July, and August 1992, at all sites except Club Run, Mill Run, and the Blackwater River at Cortland. The latter three sites were sampled either three or four times in 1992. Brief descriptions of each network monitoring site follow. Locations of the monitoring sites are shown in figure 3 and sampling dates and times are listed in table 1.

Club Run near headwaters (390059079283401)--The farthest upstream of the eight monitoring sites was located in Canaan Valley State Park, near the headwaters of Club Run. The site was chosen to represent conditions of a first-order tributary of the Blackwater River, upstream from State Park treatment facilities. Club Run at this point is narrow (usually less than 2 ft wide) and has a low gradient. The stream runs along the edge of the Greenbrier limestone area of the park and is underlain by shale and sandstone of the Mauch Chunk Group. A small impoundment is upstream from the monitoring site and a wastewater treatment plant discharges about 0.1 mi downstream from the site. Surrounding vegetation is mostly hardwood forest interspersed with small lowland marshes. Most of the watershed was used for farming, but now is part of Canaan Valley State Park. Club Run joins the Blackwater River about 2.6 mi downstream from the monitoring site. Total drainage area of Club Run is about 1.6 mi^2.

Mill Run at Canaan Valley State Park, W. Va. (390136079273301)--The monitoring site on Mill Run was located near the center of Canaan Valley State Park, at the southern boundary of an 18-hole golf course. The site was selected because of the range of recreational activities in its watershed, which includes golfing, camping, skiing, hiking, and other park activities. Just downstream from the site, the stream passes through a culvert under the main park road, and then meanders for about 1.6 mi through wet meadow-marsh and shrub-type vegetation before joining the Blackwater River. The site is underlain by Greenbrier limestone. Two wastewater discharges and the park ski area are upstream from the site. Beaver dams caused adjacent lowlands upstream and downstream from the site to be flooded; the park also supports large populations of white-tailed deer and Canada geese. Total drainage area of Mill Run is about 4.1 mi^2.

Blackwater River at Canaan Valley State Park, W. Va. (03065050)--The first monitoring site on the Blackwater mainstem was located in Canaan Valley State Park, about 0.8 mi upstream from the State Route 32 bridge. The site is downstream from wastewater discharges on Mill Run and Club Run, and from a small reservoir used for drinking water and golf-course irrigation in the park. Drainage area at the site is 9.48 mi^2. Although the headwaters of the river are on the slopes of Canaan Mountain and are underlain by sandstone and shale, most of the mainstem in Canaan Valley State Park is within the band of Greenbrier limestone that encircles the valley floor. The streambed is predominantly sand and silt, and usually maintains extensive beds of filamentous green algae (*Spirogyra*), eelgrass (*Vallisneria americana*), and pondweed (*Potamogeton*) in summer. Bank vegetation consists primarily of dense alder and spirea thickets. The sampling point was 30.9 mi upstream from the mouth of the river. River stage was recorded continuously at the site from January through August 1992.

Blackwater River on Timberline Road (390211079253601)--This site is located where Timberline Road crosses the Blackwater River, about 2.1 mi downstream from the Route 32 crossing (mainstem river mile 28.0). The site is underlain by limestone and is surrounded by alder thickets and old-field vegetation. Samples were collected on the upstream side of Timberline Road. The streambed is mostly sand, with beds of eelgrass and pondweed. There are two wastewater discharges in the watershed between the Timberline Road site and the next upstream site in Canaan Valley State Park. The site includes the drainage from Freeland Run and was chosen to represent conditions in the southern and most heavily developed part of the valley. Drainage area at the site is about 13.5 mi^2.

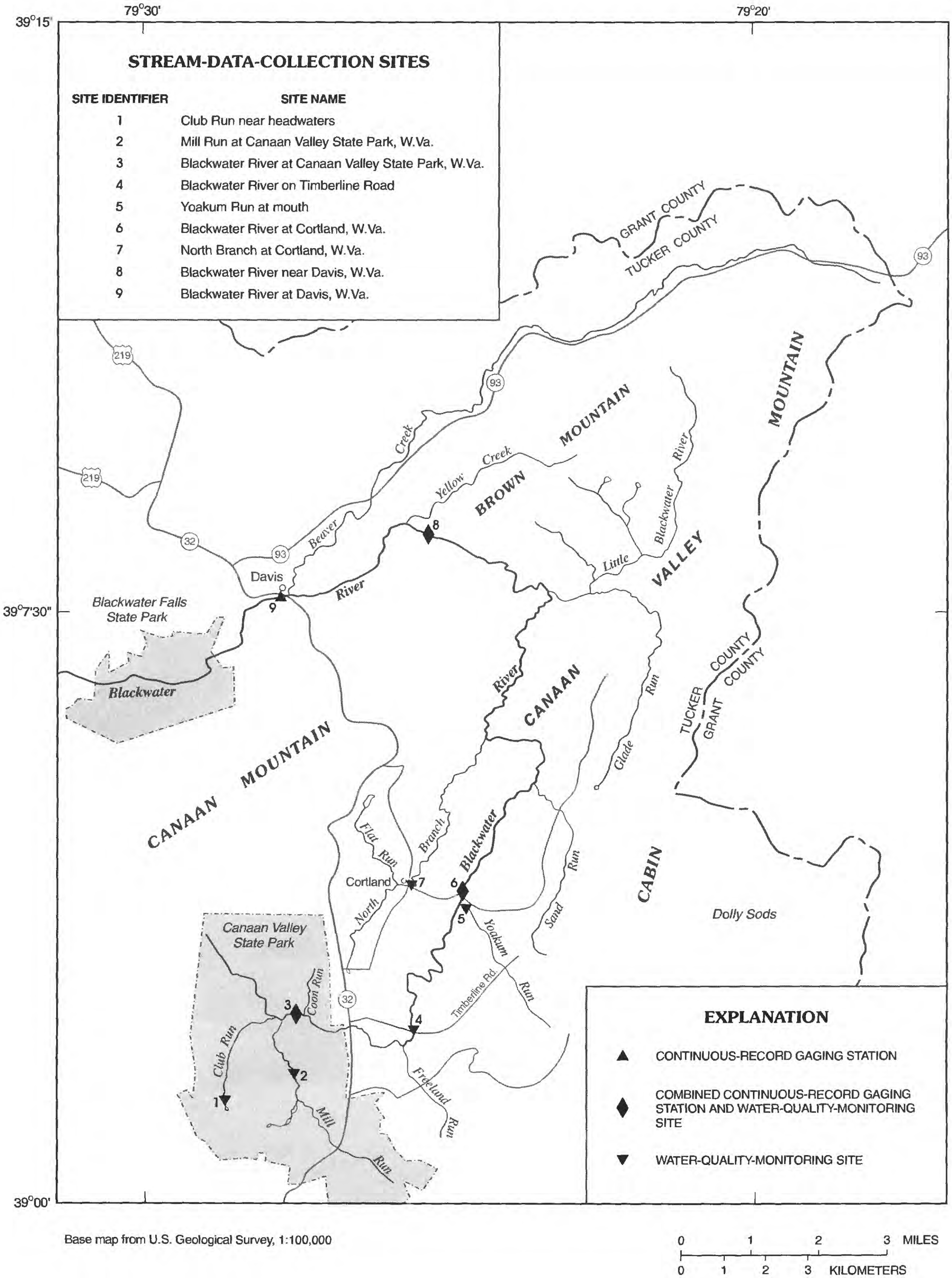


Figure 3. Locations of Canaan Valley streamflow and water-quality-monitoring sites.

Table 1. Sampling dates and times for Canaan Valley stream-data-collection sites

Date	Time	Date	Time	Date	Time
		Club Run Near Headwaters - 390059079283401			
May 14, 1990	1800	March 6, 1991	0800	May 29, 1992	0819
June 25, 1990	1730	May 13, 1991	1845	July 14, 1992	1315
July 18, 1990	1615	November 20, 1991	1540	August 19, 1992	1100
August 24, 1990	0845				
September 25, 1990	1630				
		Mill Run at Canaan Valley State Park, W.Va. - 390136079273301			
March 1, 1990	0900	January 8, 1991	1300	January 29, 1992	1715
April 4, 1990	1330	March 6, 1991	1000	May 29, 1992	1158
May 14, 1990	1615	May 13, 1991	1700	July 14, 1992	1415
June 25, 1990	1600	July 30, 1991	1115	August 18, 1992	1100
July 18, 1990	1300	August 21, 1991	0815		
August 23, 1990	1715	November 21, 1991	0830		
September 25, 1990	1430				
		Blackwater River in Canaan Valley State Park, W.Va. - 03065050			
March 1, 1990	1130	January 8, 1991	1445	January 29, 1992	1515
April 6, 1990	0845	March 6, 1991	1145	April 1, 1992	1300
May 16, 1990	0915	May 15, 1991	0830	May 29, 1992	1027
June 27, 1990	0845	July 30, 1991	1400	July 14, 1992	1510
July 18, 1990	1445	August 21, 1991	1030	August 18, 1992	1600
August 24, 1990	1045	November 21, 1991	1000		
September 26, 1990	0830				
		Blackwater River on Timberline Road - 390211079253601			
April 5, 1990	1730	January 9, 1991	1440	January 30, 1992	0845
May 15, 1990	1830	March 5, 1991	1545	April 1, 1992	1100
June 26, 1990	1645	May 14, 1991	0800	May 28, 1992	1624
July 19, 1990	1500	July 31, 1991	1415	July 14, 1992	1433
August 23, 1990	1300	August 20, 1991	1630	August 18, 1992	1315
September 25, 1990	1220	November 20, 1991	1350		

Table 1. Sampling dates and times for Canaan Valley stream-data-collection sites--Continued

Date	Time	Date	Time	Date	Time
		Yoakum Run at Mouth - 390346079244801			
May 15, 1990	1615	January 9, 1991	1330	January 30, 1992	1300
June 26, 1990	1445	March 5, 1991	1315	April 1, 1992	1700
July 19, 1990	1315	May 14, 1991	1200	May 28, 1992	1314
August 23, 1990	1030	August 1, 1991	1245	July 14, 1992	1500
September 25, 1990	1030	August 20, 1991	1400	August 19, 1992	1430
		November 30, 1991	1130		
		Blackwater River at Cortland, W.Va. - 03065200			
April 5, 1990	1530	January 9, 1991	1230	January 30, 1992	1100
May 15, 1990	1500	March 5, 1991	1115	April 1, 1992	1515
June 26, 1990	1345	May 14, 1991	1045	May 28, 1992	1510
July 19, 1990	1200	August 20, 1991	1200		
August 23, 1990	0900	November 20, 1991	1010		
September 25, 1990	0900				
		North Branch at Cortland, W.Va. - 390400079253301			
April 5, 1990	1215	January 9, 1991	0830	January 29, 1992	0815
May 15, 1990	1200	March 5, 1991	0830	April 1, 1992	0825
June 26, 1990	1115	May 15, 1991	1130	May 28, 1992	1120
July 18, 1990	1745	July 31, 1991	0948	July 15, 1992	1030
August 23, 1990	1500	August 20, 1991	0830	August 18, 1992	1015
September 24, 1990	1700	November 20, 1991	0815		
		Blackwater River near Davis, W.Va. - 03065400			
March 1, 1990	1600	January 7, 1991	1615	January 29, 1992	1145
April 5, 1990	0915	March 4, 1991	1645	March 31, 1992	1550
May 15, 1990	0930	May 14, 1991	1715	May 28, 1992	0745
June 26, 1990	0930	August 1, 1991	1358	July 16, 1992	1415
July 19, 1990	0930	August 19, 1991	1745	August 19, 1992	1030
August 22, 1990	1530	November 19, 1991	1530		
September 24, 1990	1420				

Yoakum Run at mouth (390346079244801)--The headwaters of Yoakum Run are located on the slopes of Cabin Mountain near a large ski area and real-estate development. The stream has a steep gradient for the first 0.8 mi and then flattens as it passes first through the Mauch Chunk band, then through limestone, and finally joins the Blackwater River in the Pocono sandstone area. The drainage area of Yoakum Run at the mouth is 2.1 mi^2 and includes numerous beaver dams and pools with shrub-swamp communities. The monitoring site was about 300 ft upstream from the mouth. The streambed is sand and gravel; bank vegetation consists of hardwood trees and shrubs. A wastewater treatment facility discharges into a small stream that empties into Yoakum Run about 1.3 mi upstream from the monitoring site.

Blackwater River at Cortland (03065200)--The Blackwater mainstem runs close to the Cortland area but is separated from it by a ridge of Pocono sandstone. Further downstream, the river flows westward and is joined by North Branch. The sampling point was at river mile 24.3, just downstream from the mouth of Yoakum Run. Drainage area at the sampling point is 18.5 mi^2. The streambed is primarily rock and gravel; surrounding vegetation consists of upland hardwood trees and shrubs. River stage was recorded continuously at the site from October 1991 through August 1992.

North Branch at Cortland (390400079253301)--The North Branch of the Blackwater River is underlain by limestone and receives water from numerous springs and seeps. The monitoring site is surrounded by agricultural land and cattle frequently enter the water to drink upstream. Two developments discharge treated wastewater into the upper North Branch; other developments discharge into small streams that empty into North Branch. The headwaters of the stream is heavily developed, whereas downstream is primarily undeveloped with limited access provided only by jeep trails. Beaver dams impound the stream at several points in the headwaters, producing deep pools even during low-flow periods. The downstream reach of the stream is shallow, creating favorable conditions for algae growth. Sampling was conducted near the headwaters, about 4.5 mi upstream from the confluence with the Blackwater mainstem. Drainage area at the sampling point is 5.6 mi^2. The streambed is sand in the shallow reaches and silts in the beaver pools. There are two wastewater treatment plants discharging into North Branch and two others discharging into tributaries that flow into North Branch. The sampling site is representative of conditions in the headwaters where land use is primarily recreational and farming.

Blackwater River near Davis, W. Va. (03065400)--The most downstream site in the monitoring network was at mile 14.0 on the Blackwater mainstem, about 2.8 mi upstream from Davis, W. Va. The streambed is rocky; surrounding vegetation is upland forest and shrubs. The Blackwater River at this point drains about 55.0 mi^2. River stage was monitored continuously at the site from November 1991 through August 1992.

Methods of Data Collection

Each monitoring site was sampled periodically for streamflow and 29 water-quality properties and constituents. Some properties were determined at the site, either in situ or immediately after collection of a water sample. Other constituents were determined from water samples that were collected, preserved, and shipped to the USGS National Water-Quality Laboratory (NWQL) in Arvada, Colo., for analysis. Water samples collected in August 1991 at seven of the eight monitoring sites were analyzed for several commonly-used pesticides and herbicides. Samples were preserved and shipped to the NWQL for analysis.

Field Methods

Discharge, specific conductance, pH, water temperature, air temperature, barometric pressure, DO concentration, concentrations of fecal-coliform and fecal-streptococcus bacteria, and alkalinity were measured at each water-quality monitoring site. Discharge was measured with current meters according to methods described by Rantz and others (1982). Continuous-discharge records were calculated at the three gaging stations by recording water levels and developing stage-discharge relationships to convert water levels to discharge. Discharges at the Timberline Road site usually were estimated by subtracting the Yoakum Run discharge from that of the Blackwater River at Cortland. Specific conductance was measured with a Labline Model MC-1 or a YSI Model 33 S-C-T meter; pH was measured with an Orion 250A pH meter, and water temperature was measured either with a mercury thermometer or a thermistor on water samples collected from the center of the streamflow. Dissolved oxygen concentration was determined at most sites by Winkler titration (American Public Health Association and others, 1989, p. 4-152). For some samples, a YSI Model 55 DO-temperature meter was used to measure DO concentration and water temperature. Methods for field measurements are described in Fishman and Friedman (1989). Fecal streptococcus and fecal coliform bacteria concentrations were determined by the membrane-filter method (coliforms: 0.65 μm, M-FC media incubated at 44.5°C; streptococci: 0.45 μm, KF agar incubated at 35°C), in water collected in a sterile bottle from the center of the streamflow (Britton and Greeson, 1987).

Water samples for laboratory analysis were grab samples, collected by dipping an acid-washed glass bottle or plastic bucket into the center of the streamflow. Whenever stream depths were greater than 1 ft, water samples were collected by the equal-transit-rate/equal-width increment method (U.S. Geological Survey Quality of Water Service Unit, 1990). Samples were prepared for analysis of dissolved constituents by filtering through a nitrocellulose membrane filter of 0.45 μm porosity.

Laboratory Analyses

Water samples were analyzed at the NWQL for concentrations of dissolved calcium, magnesium, sodium, and potassium; dissolved sulfate, chloride, and fluoride; dissolved solids (residue on evaporation at 180°C); total and dissolved nitrite-nitrogen plus nitrate-nitrogen, total and dissolved ammonia-nitrogen, total organic-nitrogen; total phosphorus and dissolved orthophosphorus; dissolved iron, dissolved manganese, and dissolved organic carbon. Note that hardness was calculated from the sums of the concentrations of calcium and magnesium, sampling for dissolved organic carbon was discontinued after the first year (1990), and analyses of dissolved iron and manganese did not begin until March 1991. Analytical methods are described in detail by Fishman and Friedman (1989) and by Fishman (1993).

Once during August 1991, additional water samples were collected at seven of the eight monitoring sites and transmitted to the NWQL for analysis for 24 triazine herbicides and other nitrogen-containing compounds, 17 organochlorine compounds, 11 organophosphate insecticides, and 6 chlorophenoxy-acid herbicides. Common names of the organic contaminants are listed in table 2, together with the minimum reporting limits for the methods used.

Quality-Assurance Procedures

Assurance of reliable field data was accomplished by maintaining calibrated instruments, preparing records of calibration and other pertinent data, and conducting blind-sample surveys. Assurance of reliable laboratory data was accomplished by preparing blank samples and relying on established laboratory quality-assurance procedures.

Field procedures.--All field instruments were calibrated before use according to the manufacturers' recommended procedures, to standards prepared by the USGS Quality of Water Service Unit in Ocala, Fla. Thermistor and thermometer responses were compared with responses from a standard thermometer calibrated at the National Institute of Standards and Technology. Barometric pressure was measured with an analog barometer calibrated by adjustment to pressure measured by a mercury barometer maintained by the National Weather Service in Charleston, W. Va. Sterility of equipment and media used to determine concentrations of fecal bacteria was verified by filtering a volume of sterile dilution water and culturing the resulting filter at each site. There were no instances of bacterial contamination during the study period. Instrument calibration and other quality-assurance data were recorded on USGS surface water-quality field forms and stored permanently at the USGS West Virginia District Office. Field personnel involved in routine monitoring were required to participate in a blind-sample survey for water-quality-measurement procedures.

Table 2. Pesticides and other organic contaminants studied at Canaan Valley stream-data-collection sites, August 1991

[µ/L = micrograms per liter; tot. = total; tot. rec. = total recoverable]

Analyte, common name	Laboratory reporting level (µ/L)	Analyte, common name	Laboratory reporting level (µ/L)
Triazines and Other Nitrogen-Containing Herbicides			
Prometryne, tot. rec.	0.10	Terbacil, tot. rec.	0.20
Atrazine, tot. rec.	.10	Bromacil, tot. rec.	.20
Prometone, tot. rec.	.20	Carboxin, tot. rec.	.20
Simazine, tot, rec.	.10	Diphenamid, tot. rec.	.10
Simetryn, tot. rec.	.10	Hexazinone, tot. rec.	.20
Propazine, tot. rec.	.10	Vernolate, tot. rec.	.10
Cyanazine, tot. rec.	.20	Butachlor, tot. rec.	.20
Ametryne, tot. rec.	.10	Cycloate, tot. rec.	.10
Alachlor, tot. rec.	.10	Butylate, tot. rec.	.10
Trifluralin, tot. rec.	.10	Propachlor, tot. rec.	.10
Metribuzin, tot. rec.	.10	De-ethyl atrazine, tot. rec.	.20
Metalochlor, tot, rec.	.10	De-isopropyl atrazine, tot. rec.	.20
Organochlorine Compounds and Organophosphorus Insecticides			
Perthane, tot.	.1	Mirex, tot.	.01
Chlordane, tot.	.1	Endosulfan, tot.	.001
Toxaphene, tot.	1	Aldrin, tot.	.001
DDD, tot.	.001	Diazanon, tot.	.001
DDE, tot.	.001	Ethion, tot.	.01
DDT, tot.	.001	Malathion, tot.	.01
Dieldrin, tot.	.001	Methylparathion, tot.	.01
Endrin, tot.	.001	Parathion, tot.	.01
Heptachlor, tot.	.001	Trithion, tot.	.01
Heptachlor epoxide, tot.	.001	Fonofos, tot. rec.	.01
Lindane, tot.	.001	DEF, tot.	.01
PCB's, tot.	.10	Chlorpyrifos, tot. rec.	.01
PCN's, tot.	.10	Disyston, tot.	.01
Methoxychlor, tot.	.01	Phorate, tot.	.01
Chlorophenoxy Acid Herbicides			
2,4-D, tot.	.01	2,4-DP, tot.	.01
2,4,5-T, tot.	.01	Picloram, tot.	.01
Silvex, tot.	.01	Dicamba, tot.	.01

Laboratory procedures.--Quality-assurance of analytical-sample collection and preparation procedures consisted of processing several field blanks containing deionized water. The deionized water was produced by the USGS West Virginia District Office in Charleston and was also used for final rinsing during all cleaning procedures. Twelve sets of blanks were analyzed during the study--nine in 1991 and three in 1992. Blanks were tested for all inorganic constituents; blanks were not analyzed for pesticides, organic contaminants, or dissolved organic carbon. All blanks were contaminated with small amounts of dissolved calcium. The median dissolved-calcium concentration of the blank (0.06 mg/L) was less than 2 percent of the minimum sample concentration and less than 0.05 percent of the median sample concentration. Dissolved ammonia-nitrogen contaminated 80 percent of the blanks. In this case, the median blank concentration (0.02 mg/L) was equal to the median sample concentration. Therefore, dissolved ammonia-nitrogen concentrations in this report should not be considered reliable. Total ammonia-nitrogen analyses were not contaminated, indicating that the dissolved ammonia-nitrogen contamination could have come from improperly rinsed cellulose-nitrate filters that were used to prepare the sample for analysis of dissolved constituents. Dissolved chloride contaminated 70 percent of the blanks. The median concentration of the blank (0.3 mg/L) exceeded the minimum sample concentration and was about 10 percent of the median sample concentration. Fewer than 30 percent of the blanks were contaminated with dissolved fluoride at a concentration (0.1 mg/L) equal to the median sample concentration and also equal to the minimum reporting level for that constituent. Other blanks contained small amounts of dissolved magnesium, sulfate, iron, and manganese. Each of these constituents was present in fewer than 30 percent of the blanks, with a concentration lower than 8 percent of the minimum sample concentration. The source of the contamination could have been the deionized blank water.

Quality-assurance procedures conducted by the analytical laboratory are described by Pritt and Raese (1992). In some sample analyses, the concentrations of one or more dissolved constituents exceeded the total concentrations of the same constituents. This difference was generally much lower than 10 percent and is not unusual, considering the low concentrations of these constituents.

Selected Physical and Chemical Characteristics

Water-quality data collected from March 1990 through August 1992 are summarized in table 3 (at end of report) for eight sites in the water-quality monitoring network. Summary statistics, including median, maximum, and minimum values, for all samples at each of the monitoring sites are discussed below. Additionally, relations among selected constituents and seasonal changes in streamflow are examined in separate report sections. Where appropriate, measured concentrations and values are compared to State water-quality limits for rivers and streams. Values obtained for most water-quality properties and constituents determined for Canaan Valley streams were within State water-quality limits.

Highest median values and highest maximum values for specific conductance, hardness, and concentrations of dissolved calcium, magnesium, sodium, potassium, alkalinity, sulfate, chloride, and dissolved solids were recorded for the Mill Run and North Branch monitoring sites (table 3). Lowest median values and lowest minimum values for the same characteristics were recorded for Club Run and Yoakum Run. Ionic concentrations at the four mainstem monitoring sites usually were intermediate between those of the two groups of tributaries. These statistics indicate that water quality in Canaan Valley streams is influenced by the underlying geology and by land use in the drainage area. Stream chemistry in the valley is strongly affected by ground-water chemistry, especially during periods of low flow when ground water contributes most of the streamflow. The effect of ground water on the chemistry of Canaan Valley surface water is demonstrated by differences in the concentrations of major ions and other chemical properties at the eight monitoring sites.

Weathering of limestone generally results in higher concentrations of ionic constituents than does weathering of sandstone and shale. Mill Run and North Branch receive most of their ground water inflows from the Greenbrier limestone. The other two tributaries, Club Run and Yoakum Run, are fed mainly by ground water from the Mauch Chunk and Pocono Groups and concentrations of most ionic constituents were lower. Ionic concentrations at the four mainstem monitoring sites indicate the combination of tributary flows and local groundwater inflows.

Of the major ionic constituents measured, only chloride concentration is regulated by State water-quality limits. The highest dissolved chloride concentration determined in this study (15 mg/L in Mill Run) was well below the State water-quality limit of 250 mg/L (West Virginia Water Resources Board, 1991).

Specific Conductance, Hardness, Alkalinity, and Dissolved Solids

Specific conductance, hardness, alkalinity, and the concentration of dissolved solids are properties that are related to the concentrations and types of dominant ions in a water sample (Hem, 1985). Conductance is the ability of water to conduct an electrical current. Its value increases as the total ionic concentration increases. Hardness is calculated from the concentrations of dissolved calcium and magnesium ions. Alkalinity is a measure of the acid-neutralizing capacity of a water sample and is mainly dependent on the quantities of carbonate and bicarbonate ions in Canaan Valley streams. Both hardness and alkalinity are expressed in terms of equivalent concentrations of calcium carbonate ($CaCO_3$). In Canaan Valley streams, these properties are directly related to the geochemistry of ground-water inflows.

Median values for specific conductance ranged from 57 µS/cm in Yoakum Run to 121 µS/cm at the North Branch site (table 3). The median specific conductance of the mainstem sites increased downstream from Canaan Valley State Park to Timberline Road and then decreased further downstream. The decrease probably was due to the addition of tributary water with lower specific conductance, but could also result from inflows of ground water with lower specific conductance. Specific conductance was inversely correlated to streamflow at all monitoring sites. The relation was similar for the four mainstem sampling locations.

Based on the classification given by Durfor and Becker (1964, p. 27), water in Canaan Valley streams is soft to moderately hard. Median values for hardness measured during the study period ranged from 20 mg/L in Club Run to 56 mg/L in Mill Run (table 3). Maximum values as high as 94 mg/L and 100 mg/L were determined for Mill Run and North Branch, respectively, which had the highest percentage of limestone underlying their drainage basins. The highest values were measured during low-flow periods in late summer 1991. The State of West Virginia does not set a limit for hardness of surface water. State limits for cadmium, copper, lead, nickel, silver, and zinc, however, are based on the hardness of the water. Allowable concentrations of these metals increase as hardness increases (West Virginia Water Resources Board, 1991), because the presence of calcium and magnesium ions reduces toxicity of the metals to aquatic organisms.

Most alkalinity measurements in the streams were low (median value for all monitoring sites equaled 26 mg/L), but seem to reflect the effect of the underlying geology. Median alkalinities were highest in Mill Run and North Branch (39 and 34 mg/L, respectively). Maximum values also were highest for these sites (63 and 83 mg/L, respectively). The lowest median alkalinity measured was 9 mg/L in Club Run, which has a mixture of carbonate and noncarbonate rocks in its drainage basin. The generally low alkalinity of Canaan Valley surface water indicates that streams in the valley would not be resistant to chemical changes resulting from increases in acid deposition.

Relations among specific conductance, alkalinity, and streamflow during the 30-month sampling period are shown for the four Blackwater mainstem monitoring sites in figure 4. Highest flows each year were during late winter and early spring (January through April). These periods usually had the lowest specific conductances and alkalinities. Hardness and concentrations of dissolved solids, though not shown in figure 4, followed similar patterns. Maximum specific conductances and

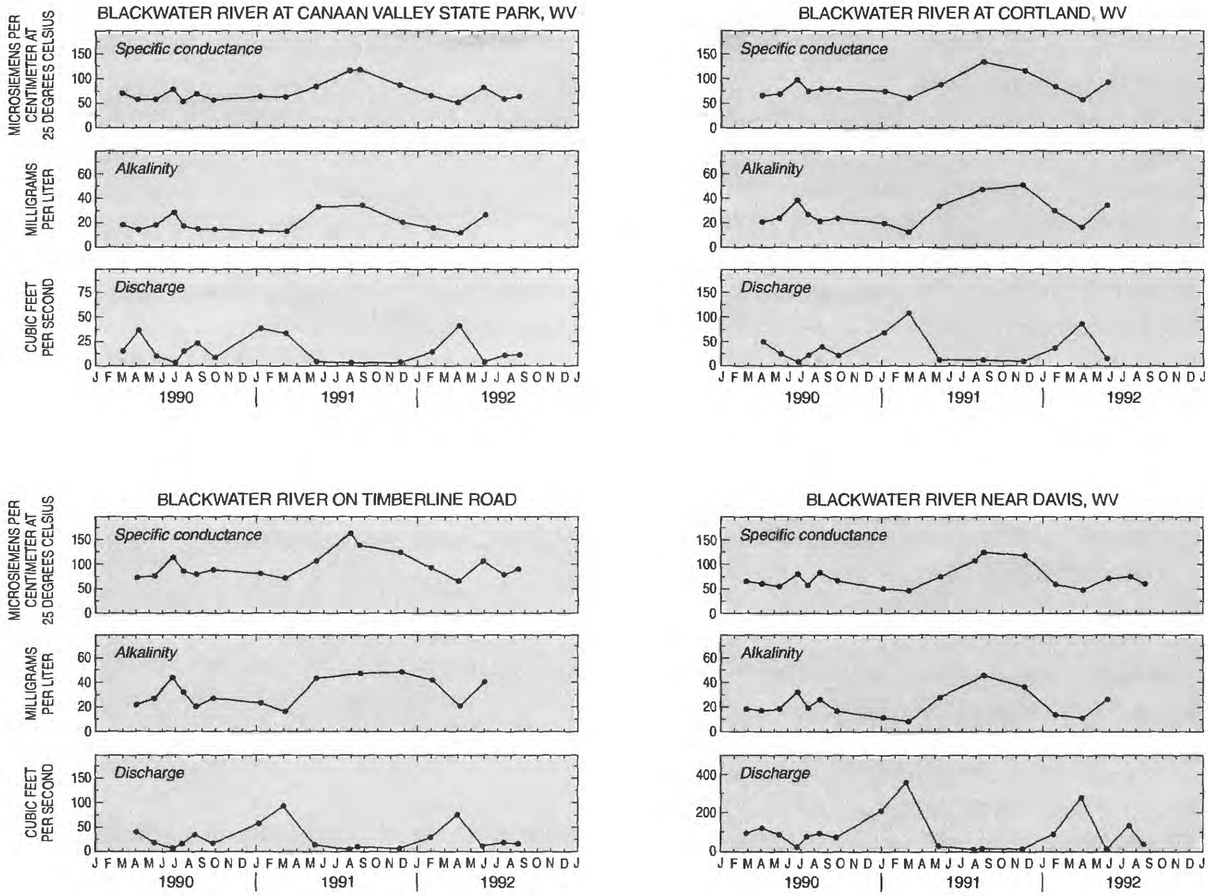


Figure 4. Data collected from March 1990 to August 1992 at the Blackwater River water-quality-monitoring sites for discharge, specific conductance, and alkalinity.

alkalinities occurred during periods when streamflow was at or near base flow, usually in late summer and early fall (July through November). At base flow, all water in streams is derived from ground water and surface-water chemistry is determined by ground-water chemistry. As flows increase, the contributions from diluted surface runoff and tributary inflows increase, and properties derived from ionic concentrations decrease.

Nitrogen and Phosphorus

Nitrogen and phosphorus are plant nutrients that can, in sufficient quantities, cause algal blooms and excessive growth of higher plants in streams. Ecologically significant forms of nitrogen include nitrate-nitrogen and ammonia-nitrogen present in runoff from fertilized fields and in wastewater discharges, nitrogen oxides produced by combustion and subsequently dissolved in precipitation, and organic nitrogen produced by microbial processes. Phosphorus is common in some types of rock and is present in forms that are available for plant uptake in municipal and industrial wastewater discharges. Nitrogen and phosphorus are important components of living tissue and enter into complex cycles that include metabolic transformations.

The Blackwater River, upstream from Davis, W. Va., is subject to State water-quality limits of 10 mg/L for dissolved nitrate-nitrogen, 0.06 mg/L for dissolved nitrite-nitrogen, and 0.05 mg/L for the un-ionized form of dissolved ammonia-nitrogen (NH_3) (West Virginia Water Resources Board, 1991). The maximum measured concentration of dissolved nitrite-plus-nitrate nitrogen was 0.60 mg/L and that of un-ionized ammonia-nitrogen was 0.01 mg/L. Concentrations of un-ionized ammonia-nitrogen are calculated from total ammonia-nitrogen concentrations, taking the effects of temperature and pH on the equilibrium between the ionized and un-ionized forms into account. Concentrations of dissolved orthophosphorus were low (median for all monitoring sites equaled 0.01 mg/L) compared to regional values (0.1 mg/L for the Ohio River, Hem, 1985, p. 128).

Volume-weighted mean concentrations of dissolved nitrate-nitrogen and dissolved ammonia-nitrogen samples of precipitation collected at Fernow Experimental Forest in Parsons, W. Va. (fig. 1), were 1.6 mg/L and 0.20 mg/L during 1991, respectively (Adams and others, 1993). For Canaan Valley water-quality monitoring sites, the median concentrations of dissolved nitrite-plus-nitrate nitrogen and that of dissolved ammonia-nitrogen were 0.2 mg/L and 0.02 mg/L respectively from March 1990 through August 1992, although the latter value is uncertain because of possible contamination during sample preparation. These data indicate that precipitation was a major source of inorganic nitrogen in Canaan Valley streams during the study period. Precipitation that eventually falls on the Canaan Valley side of the Allegheny Mountains contains high concentrations of nitrogen and sulfur oxides, derived mainly from industrial sources in the Ohio River Valley (Miller, 1988, p. 329). Precipitation could be a significant source of nitrate in many Canaan Valley wetlands and streams. Much of the sulfate in streams, however, is probably derived from dissolution of pyrite by ground water. The median concentration of dissolved sulfate for all water-quality monitoring sites (6.2 mg/L) was more than twice that of the mean concentration for 1991 precipitation (2.8 mg/L, Adams and others, 1993).

Seasonal changes in the dissolved nitrite-nitrogen plus nitrate-nitrogen and the total ammonia-nitrogen plus organic-nitrogen concentrations are compared to changes in streamflow for the four Blackwater River mainstem monitoring sites shown in figure 5. In all cases, the dissolved nitrogen was highest during periods of high streamflow, indicating that the main source of dissolved nitrate-nitrogen was surface runoff and lending further support to the idea that precipitation is an important source of nitrate. A similar pattern was determined for dissolved orthophosphorus. Changes in total ammonia-nitrogen plus organic-nitrogen concentrations are mainly because of changes in nitrogen-containing particulate organic matter, including organic matter produced within the stream and wastes discharged to the stream. Highest concentrations of these particulate materials were present in the Blackwater River during summer months (fig. 5), when rates of production of organic matter would be expected to be high.

pH and Dissolved Oxygen

Stream pH is a measure of the effective concentration (activity) of hydrogen ions in water. An increase in hydrogen ion concentration causes water to become more acidic, but results in a lower pH value because the pH scale is inversely related to hydrogen ion content. The pH of stream water in most areas that have not been affected by pollution ranges from about 6.5 to 8.5 (Hem, 1985, p. 64). Median pH values in Canaan Valley streams ranged from 6.7 at the Canaan Valley State Park mainstem site to 7.6 at the mainstem site near Cortland, W. Va. (table 3). Maximum pH during the sampling period was 8.7 at Mill Run; minimum pH was 5.8 at the mouth of Yoakum Run. The acidic minimum pH values are probably due to dissolved organic acids, the presence of which also imparts a yellow brown color to the Blackwater River and other Canaan Valley streams, and could also result from inflows of acidic ground water or precipitation. The median pH of ground water from 50 Canaan Valley wells and springs sampled in July 1991 was 7.3, and the minimum was 3.8 (Mark Kozar, U.S. Geological Survey, written commun., 1994). The mean pH of precipitation falling at Fernow Experimental Forest in 1991 was 4.2 (Adams and others, 1993).

Dissolved oxygen is required by many stream organisms and is a strong indicator of streamwater quality. Most DO concentrations measured at Canaan Valley monitoring sites were higher than the minimum State water-quality limit of 6.0 mg/L. Median recorded DO concentrations ranged from 7.6 mg/L in Club Run to 10.0 mg/L at

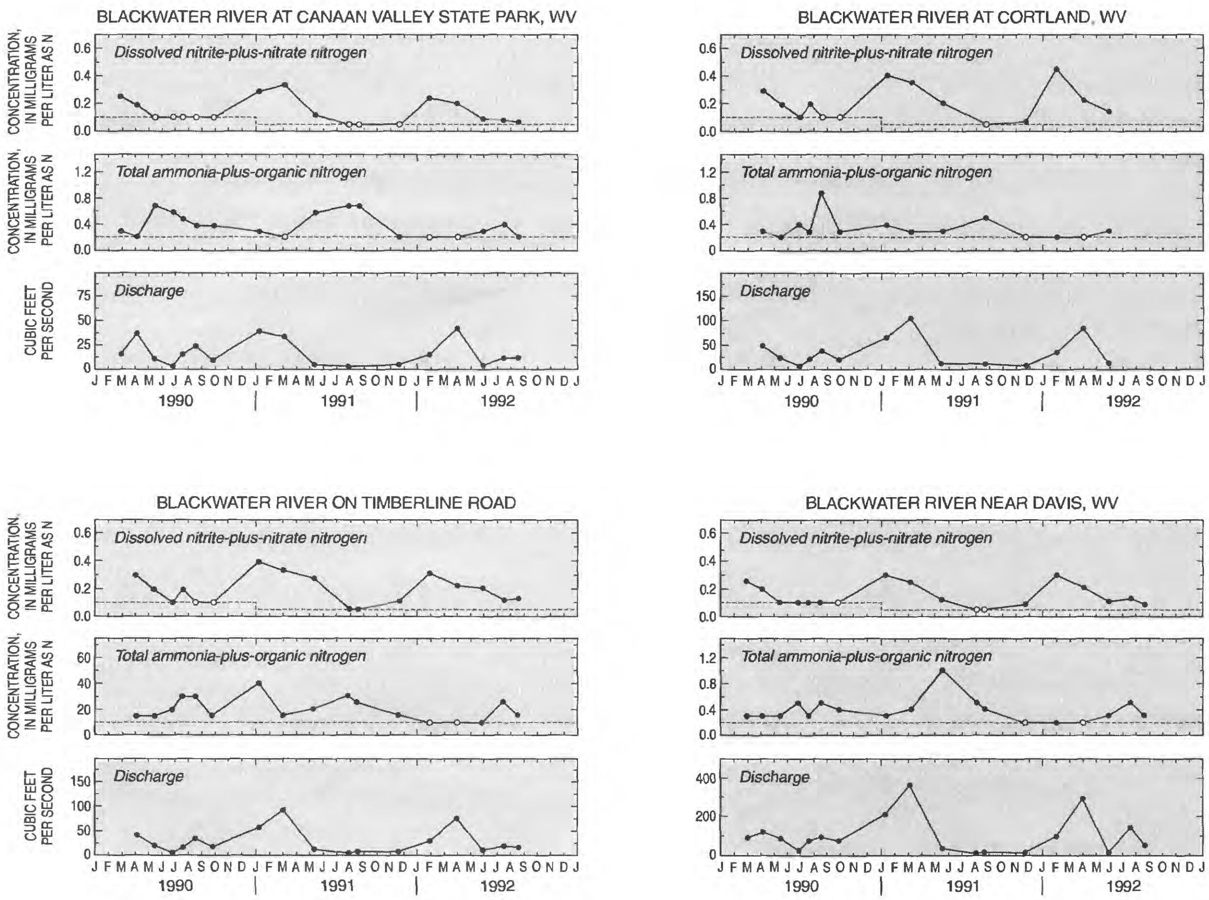


Figure 5. Data collected from March 1990 to August 1992 at the Blackwater River water-quality-monitoring sites for discharge, dissolved nitrite-plus-nitrate nitrogen, and total ammonia-plus-organic nitrogen. [Minimum reporting level (dashed line) for dissolved nitrite-plus-nitrate nitrogen was 0.1 milligrams per liter for samples collected in 1990 and was 0.5 milligrams per liter for all other samples; open circles are sample concentrations below the minimum reporting level.]

the Mill Run monitoring site (table 3). Maximum DO concentrations ranged from 10.3 mg/L in Club Run to 13.4 mg/L at the downstream mainstem monitoring site near Davis, W. Va. The maximum DO concentrations were 97 and 112 percent, respectively, of the saturation concentrations of DO at the corresponding water temperatures and atmospheric pressures. A concentration of 13.1 mg/L measured at the Timberline Road monitoring site in July 1991 was equal to 182 percent of the saturation concentration.

The DO concentration of a stream is affected by air and water temperature, atmospheric pressure, hydraulic characteristics of the stream, metabolic activity of stream organisms, and the amount of readily degradable organic matter present. Dissolved oxygen enters a stream by atmospheric exchange, by transport in inflowing water, or by photosynthesis. Losses of DO occur as a result of atmospheric exchange or by respiratory DO consumption by stream organisms. When the DO concentration of water is at equilibrium with that of the atmosphere, the water is said to be 100 percent saturated with DO. Removal of DO by respiration can cause the water to be lower than 100 percent saturation. A high rate of photosynthetic DO production, coupled with daytime warming, which lowers the solubility of oxygen in water, can result in DO concentrations that exceed the saturation concentration. Although there are physical processes that can result in DO supersaturation, it is likely that the supersaturation measured in Canaan Valley streams was due mainly to photosynthetic activity.

A DO concentration of 5.5 mg/L was measured on one occasion at the Club Run monitoring site and DO concentrations ranging from 5.3 to 5.8 mg/L were measured on five occasions at the Canaan Valley State Park mainstem site. No other monitoring sites had DO concentrations lower than the State water-quality limit of 6.0 mg/L. The low DO concentrations were measured in May, June, and August 1990, and in May and August 1991. Seasonal changes in DO concentrations and percent DO saturation at the four mainstem monitoring sites are presented in figure 6, together with corresponding changes in streamflow. Dissolved oxygen concentrations were below saturation for most samples at the Canaan Valley State Park site and were at or above saturation at the other mainstem sites.

It is unlikely that the low DO concentrations were due to improper operation of the treatment plants although Canaan Valley State Park has five permitted wastewater discharge sites near the mainstem monitoring site. Most treatment plants in the valley discharge wastewater into polishing

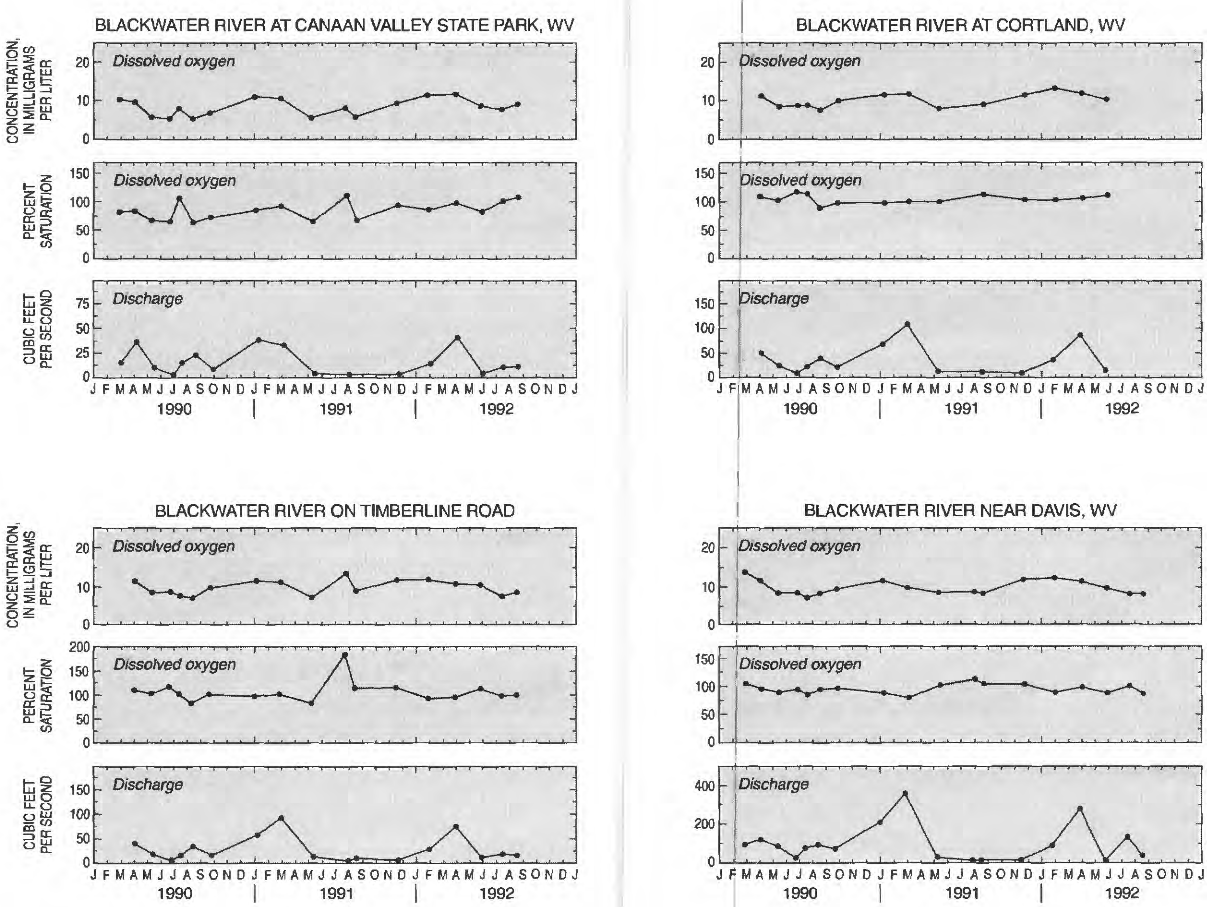


Figure 6. Data collected from March 1990 to August 1992 at the Blackwater River water-quality-monitoring sites for discharge, dissolved oxygen, and percent saturation.

ponds and release the water to receiving streams only when the stabilization ponds overflow. During summer periods, most treated wastewater remains in the polishing ponds, and only the largest discharges, such as that from the Park lodge, are active. The mainstem monitoring site in Canaan Valley State Park was upstream from the Park lodge discharge and downstream from a small reservoir (fig. 2) that is used as a source of drinking water for the lodge and irrigation for the golf course. One possible explanation for the low DO concentrations occasionally measured at the park monitoring site is that DO was lost due to respiration at night in the upstream reservoir. This, combined with lowered rates of aeration caused by reduced stream velocities, would tend to reduce the amount of DO transported downstream to the monitoring site. (Locations of all permitted Canaan Valley wastewater discharge sites are listed in the "Field Methods, Laboratory Analyses, and Quality-Assurance Procedures" section of this report.) Note that the model application discussed later in this report indicates that at discharges similar to those of the 7-day, 10-year low flow, DO concentrations at the Canaan Valley State Park mainstem site can be supersaturated, whereas at discharges similar to those of this assessment, DO concentrations can be lower than the State water-quality limit.

Fecal Bacteria

The presence of fecal bacteria in a stream indicates that the water has been contaminated with the feces of humans or other warm-blooded animals. Such contamination can introduce disease-causing viruses and other pathogens. Fecal bacteria can enter a stream from a point source such as a discharge of improperly treated wastewater, or from nonpoint sources such as runoff from pastures, feedlots, and urban areas. State water-quality limits set the acceptable count of fecal coliform bacteria in Canaan Valley streams at 200 colonies per 100 milliliters, measured as a monthly geometric mean based on at least five samples per month. There are no State limits for fecal streptococcus bacteria.

Counts of fecal coliform bacteria periodically exceeded the State limit at Canaan Valley monitoring sites, although the highest frequency of sampling during the study period was only one sample per month. Maximum measured counts of fecal coliform bacteria ranged from 310 colonies per 100 mL in Club Run to 3,200 colonies per 100 mL at the mouth of Yoakum Run (table 3). Corresponding maximum counts of fecal streptococcus bacteria were 290 colonies per 100 mL at Club Run and 3,300 colonies per 100 mL at Yoakum Run. Median counts, however, were much lower, ranging from 12 to 120 colonies per 100 mL for fecal coliform bacteria and from 12 to 69 colonies per 100 mL for fecal streptococcus bacteria, respectively, for Club Run and Yoakum Run.

The high maximum counts measured at the four Blackwater mainstem monitoring sites occurred during the warmest months of the year, usually during July and August (fig. 7), and fecal-coliform bacteria counts were well below the State limit during most of the rest of the year. Because less of the treated wastewater is discharged from stabilization ponds in summer months than in winter and spring, it is unlikely that the warm-weather increases in fecal-bacteria counts measured in Canaan Valley streams were the result of wastewater discharges. It is more likely that the peaks are due to nonpoint contamination from nonhuman sources, including livestock and populations of deer, beaver, and Canada geese, and the increased survival of fecal bacteria at warmer water temperatures. Further study is needed to confirm this hypothesis and to assess the health risks associated with episodic bacterial contamination of Canaan Valley streams.

Maximum fecal-bacteria counts were higher at all monitoring sites in 1990 than they were in 1991 or 1992 (fig. 7). One possible explanation for this difference is that streamflow and associated surface runoff were more variable in 1990 than in 1991 or 1992. More of the 1990 samples would have been collected immediately after local storms than would have been the case in the following two years. If the bacteria are associated with nonpoint source runoff, counts would have been elevated because of the greater number of summer storms in 1990. It is also true, however, that sampling was more frequent in 1990 than during subsequent years of the study, which could indicate that aver-

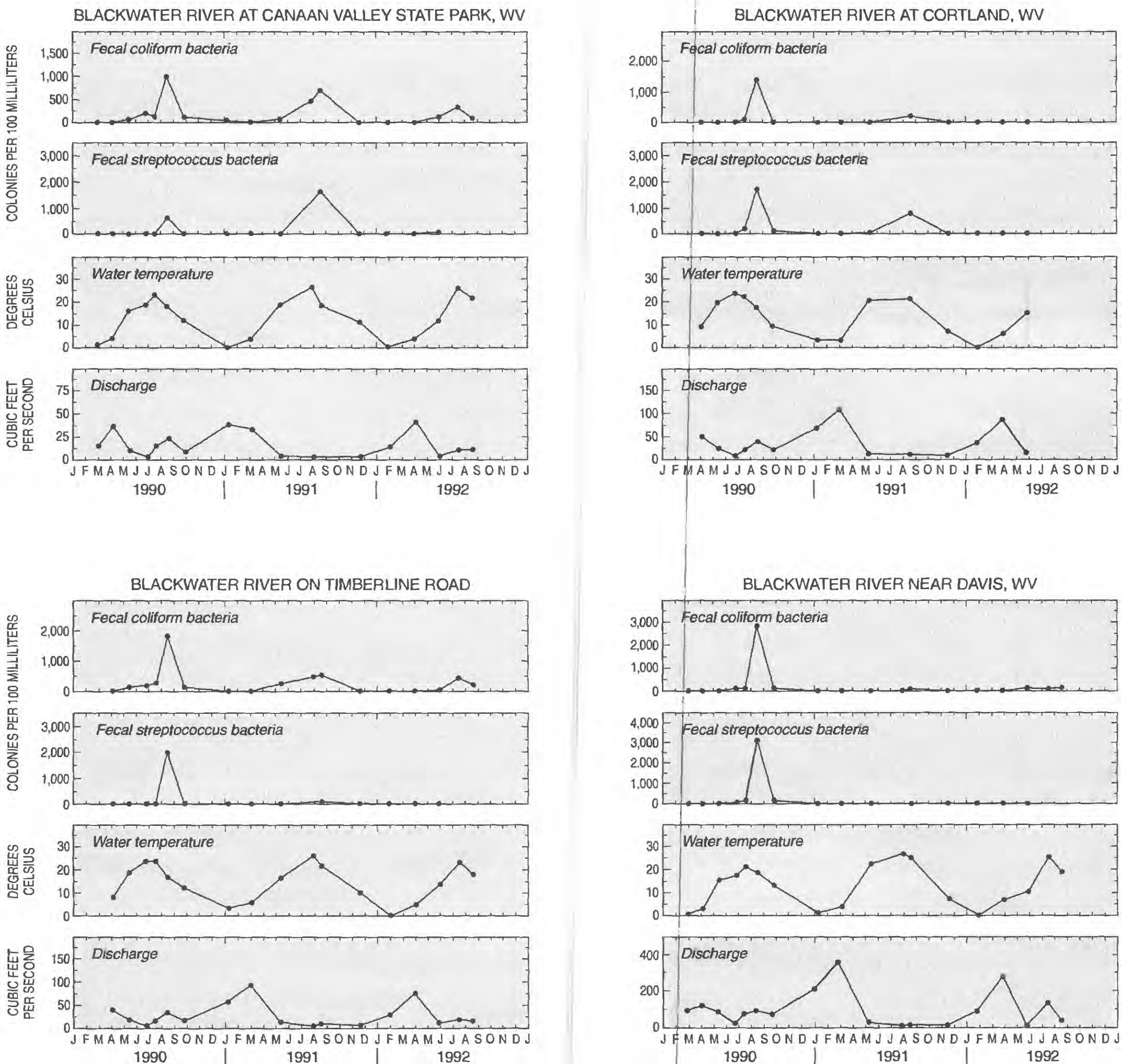


Figure 7. Data collected from March 1990 to August 1992 at the Blackwater River water-quality-monitoring sites for fecal coliform and fecal streptococcus bacteria, water temperature, and discharge.

age bacteria counts may have been within a small range for 1990-92, but that the sampling was not frequent enough to detect the peaks in 1991 and 1992.

Dissolved Iron and Manganese

Concentrations of dissolved iron and manganese were high in Canaan Valley streams during the study period. Dissolved-iron concentrations exceeded the State limit of 500 µg/L for trout streams at seven of the eight monitoring sites. Maximum concentrations ranged from 380 µg/L at the mainstem site near Cortland, W. Va., to 1,100 µg/L at the site near Davis, W. Va. (table 3). The lowest median concentration was 200 µg/L at the Cortland site; the highest median concentration was 495 µg/L at the mouth of Yoakum Run. Concentrations of dissolved manganese also were high. Maximum concentrations ranged from 38 µg/L at the site near Cortland to 440 µg/L in Mill Run. Although there is no State limit for manganese, the National Academy of Sciences (1972) recommends that the concentration of manganese in public water supplies not exceed 50 µg/L. Both iron and manganese are essential trace elements for metabolism. At high concentrations they can leave deposits on plumbing fixtures and can harm aquatic life (Landers, 1976).

Shallow streams with pH values and DO concentrations in the ranges of those reported for Canaan Valley normally contain no more than a few micrograms per liter of uncomplexed dissolved iron or manganese (Hem, 1985, p. 83 and 89). Dissolved iron in ground water is quickly oxidized to a more insoluble form when the ground water enters a stream. The characteristic yellow-orange deposits in streams receiving drainage from abandoned coal mines is a precipitate of oxidized iron. There are no coal mines, however, in the immediate Canaan Valley study area, although the Blackwater River is affected by abandoned-mine drainage in the reach downstream from the study area (Ward and Wilmouth, 1968).

The most likely explanation for the high concentrations of dissolved iron and manganese is that metals enter the streams in ground-water inflows to form complexes with organic matter derived from adjacent wetlands. Metal-organic complexes are common in streams with highly colored water (Hem, 1985, p. 83) and can exist in colloidal or particulate forms that are able to pass through a 0.45-μm-porosity membrane filter (Kennedy and others, 1974). The amount of dissolved iron or manganese in streamwater samples depends on the quantity of inflowing ground water, the concentrations of metals in the ground water, and the residence time of ground water in wetland soil. High concentrations of dissolved iron and manganese coincided with seasonal streamflow minima at the four mainstem monitoring sites (fig. 8), again implicating ground water as the source of the metals. The extent to which high concentrations of organic-complexed iron and manganese adversely affects stream organisms is unknown.

Pesticides

Water samples collected on August 19, 20, and 21, 1991, from all monitoring sites except Club Run, were analyzed for concentrations of 24 triazine herbicides and other nitrogen-containing compounds, 17 organochlorine compounds, 11 organophosphate insecticides, and 6 chlorophenoxy-acid herbicides (table 2). Of the 58 analytes, only 4--picloram, 2,4-dichlorophenoxyacetic acid (2,4-D), simazine, and lindane--were detected at concentrations above the minimum reporting levels given in table 2, and all of these were significantly lower than the maximum contaminant levels (MCL) established by the U.S. Environmental Protection Agency (1994) for drinking water. The State of West Virginia has not established separate limits for these four contaminants in rivers and streams.

Reportable concentrations of picloram were measured in samples from Mill Run (0.03 μg/L), at the Canaan Valley State Park mainstem site (0.04 μg/L), at the mainstem site on Timberline Road (0.03 μg/L), and in North Branch (0.02 μg/L). The MCL for picloram is 500 μg/L. Picloram (4-amino-3,5,6-trichloropicolinic acid) is a chlorophenoxy acid compound that is used as a broad-spectrum herbicide to control weeds growing along powerlines and highways (Kroehler, 1990). Picloram can persist in soil for long periods of time (up to 550 days) but is rapidly degraded by sunlight once it reaches a stream. Although picloram travels easily through soils to enter ground water, no reportable concentrations were found in a set of five ground-water samples collected from Canaan Valley wells and springs in July 1991 (Mark Kozar, U.S. Geological Survey, written commun., 1994).

A second chlorophenoxy acid herbicide, 2,4-D, was detected at a level of 0.02 μg/L in the mouth of Yoakum Run. The MCL for 2,4-D is 70 μg/L. The compound is used on wheat, corn, sorghum, and barley fields, and on pastures to kill broadleaf weeds (Kroehler, 1990). It degrades within weeks in soil, but can persist for days to months in water. A reportable concentration of 2,4-D (0.03 μg/L) also was found in one Canaan Valley well that was sampled in July 1991 (Mark Kozar, U.S. Geological Survey, written commun., 1994).

Reportable levels of simazine and lindane (0.4 μg/L and 0.001 μg/L, respectively) were measured in samples from the Blackwater River mainstem monitoring site near Davis, W. Va. Simazine (2-chloro-4,6-*bis*[ethylamino]-1,3,5-triazine) is a triazine herbicide used in pre-emergence applications on corn and sorghum fields and as an algaecide. The MCL for simazine is 4 μg/L. Lindane (1,2,3,4,5,6-hexachlorocyclohexane) is an organochlorine insecticide used in dips, sprays, and dusts for livestock and pets. The MCL for lindane

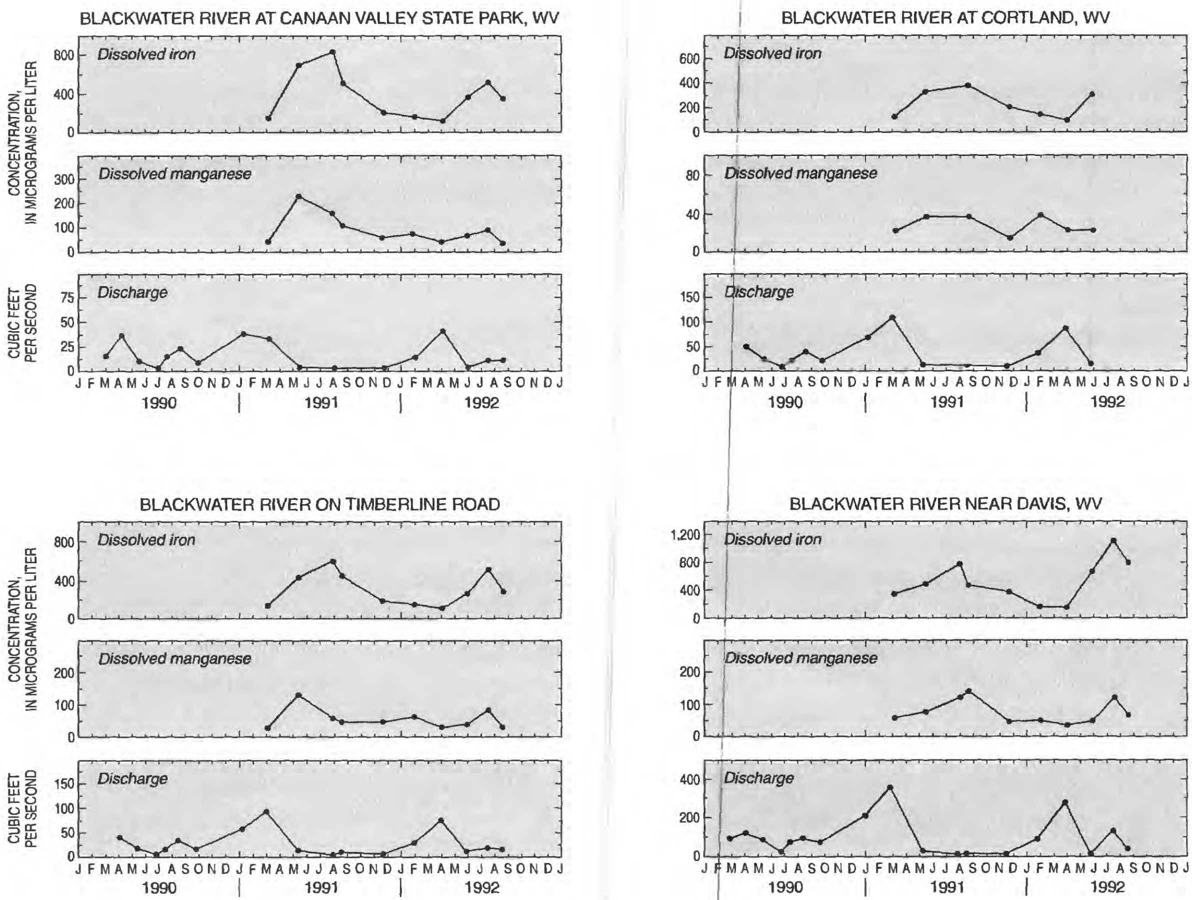


Figure 8. Data collected from March 1990 to August 1992 at the Blackwater River water-quality-monitoring sites for discharge, dissolved iron, and dissolved manganese.

is 0.2 μg/L. While simazine and lindane are relatively persistent in water (Kroehler, 1990), neither compound was detected at reportable levels in Canaan Valley wells and springs (Mark Kozar, U.S. Geological Survey, written commun., 1994).

PROCESSES AFFECTING DISSOLVED OXYGEN CONCENTRATIONS

The water-quality monitoring study evaluated the combined effects of many environmental processes on water quality in the Blackwater River. Effective management of water quality requires knowledge of the effects of individual processes and of the interactions among processes. Environmental processes thought to strongly affect DO concentrations in the Blackwater River were quantified and incorporated into a mathematical model. The model was calibrated and verified with data collected during midday hours from synoptic surveys conducted during low-flow periods in 1991 and 1992. The model was then used to simulate the effects of the 7-day, 10-year low flow (7Q10) on DO concentrations and carbonaceous biochemical oxygen demand (CBOD) in the upper Blackwater River.

Water-Quality Model Development

A description of a water-quality model for the Blackwater River, including methods of calibration, verification, and sensitivity testing, is presented. Assumptions and rationales used in developing the model, and model limitations, are discussed.

Model Description

QUAL2E (version 3.14; Brown and Barnwell, 1987) is a one-dimensional, steady-state, streamwater-quality model typically used for waste-allocation analysis and water-quality investigations (Mills and others, 1986). The model can simulate up to 15 water-quality constituents and properties and allows for multiple waste discharges, withdrawals, tributary flows, and incremental inflow and outflow along individual reaches. Details of the equations and formulations used in the model to simulate water-quality constituent reactions are described in a user's guide by Brown and Barnwell (1987). The following constituents and properties were modeled in this study:

- *Stream temperature,*
- *Total organic nitrogen,*
- *Total ammonia nitrogen,*
- *Total nitrite nitrogen,*
- *Total nitrate nitrogen,*
- *Dissolved oxygen,* and
- *Carbonaceous biochemical oxygen demand.*

Control pathways relating these constituents are shown in figure 9. The model was applied to simulate water quality during periods of low flow in a reach of the Blackwater River extending from near the headwaters (river mile 32, measured upstream from the confluence with the Cheat River) to a point upstream from Davis, W. Va. (river mile 13.6).

The stream reach chosen for study was divided conceptually into 11 subreaches, each with uniform hydraulic and local environmental characteristics. The 11 subreaches were further divided into 0.1-mi computational elements that formed the basis for the model's one-dimensional, advection-dispersion calculations. All computational elements in a subreach were considered to have the

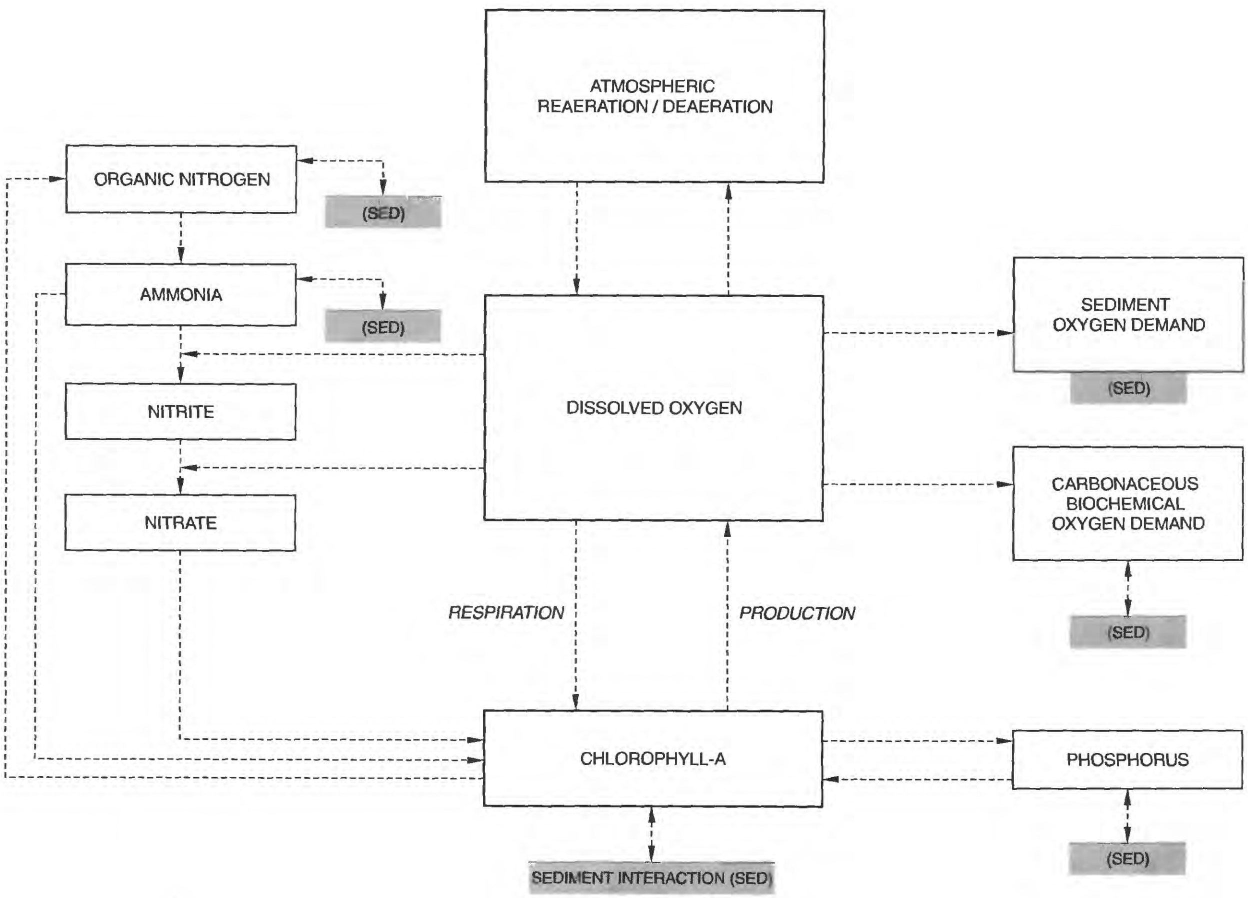


Figure 9. Water-quality constituents and processes evaluated by the model.

same hydrogeometric properties (for example, stream slope, roughness, width, depth) and ecological rate constants (for example, reaeration, biochemical oxygen demand, sediment oxygen demand). Locations of subreaches, sampling points for calibration and verification, tributary inflows, point-source discharges, and withdrawal are shown schematically in figure 10.

Methods of Calibration and Verification

Data used for model calibration and verification were collected during low-flow synoptic surveys conducted on July 30-August 1, 1991, July 14-17, 1992, and August 18-19, 1992. During each synoptic survey, 11 mainstem sites, 7 tributary inflows, 16 point discharges, and 1 withdrawal were sampled at least once during the period.

The model was calibrated using boundary conditions (flows and constituent concentrations for headwaters, tributaries, point discharges, and the single withdrawal) as measured during the August 1992 synoptic-survey data. Model coefficients and rate constants were measured whenever possible; coefficients that were not measured were set to median values obtained from published ranges (Bowie and others, 1985; Brown and Barnwell, 1987). These coefficients were adjusted when necessary, within published ranges, so that the model predictions of constituent concentrations and other system variables closely resembled the August 1992 survey measurements.

The calibrated model was verified using water-quality data collected from the other two synoptic surveys (July 1992 and July-August 1991). Rate constants and system coefficients were the same as for the calibrated model; boundary conditions and local meteorological variables were taken from the appropriate synoptic-survey data set. Model predicted values were compared to measured values for constituent concentrations to verify that the model adequately simulates environmental processes for the Blackwater River during low flows.

Field methods, laboratory analyses, and quality-assurance procedures

The sampling network for collection of model-calibration and model-verification data is shown in figure 11. Data collected for each synoptic survey monitoring site included discharge, barometric pressure, air temperature, water temperature, DO concentration, CBOD, specific conductance, and concentrations of total organic-nitrogen, total nitrite-nitrogen, total nitrate-nitrogen, and total ammonia-nitrogen. Sampling, analyses, and quality-assurance procedures were as described previously in this report. Additionally, estimates of the percentage of cloud cover and the percentage of shade at the stream surface were made at each monitoring site. All sites were sampled between the hours of 10:00 a.m. and 4:00 p.m. to reduce the effects of diel variability. Consequently, data used for model simulations are for midday conditions, when stream temperature and DO concentrations are at or near their daily maximum values.

Water samples were collected for 5-day and 20-day CBOD analyses. Measurements of 5-day CBOD were conducted by West Virginia Division of Parks and Recreation personnel using standard methods and quality-assurance procedures (American Public Health Association and others, 1989, p. 5-2). Water samples from 10 Canaan Valley streams and wastewater discharges were analyzed by a private laboratory in August 1992 for 5-day and 20-day CBOD. These data were used to estimate ultimate CBOD and CBOD-decay coefficients for the samples.

Diel variations in stream temperature, specific conductance, pH, and DO concentration were monitored at three mainstem sites in the valley during the July 1992 and the August 1992 synoptic surveys. Continuous-record gaging stations also were in operation at these sites (fig. 3). The three sites were: Canaan Valley State Park near Highway 32 (river mile 30.9), downstream from the Yoakum Run confluence near Cortland, W. Va. (river mile 24.3), and upstream from the Yellow Creek confluence near Davis, W. Va. (river mile 14.0). Stream temperature and DO concentration were recorded

MODEL SUBREACH NUMBER	RIVER MILES ABOVE MOUTH	BLACKWATER RIVER MAINSTEM SITE IDENTIFIER	REFERENCE DISTANCE IN RIVER MILES	TRIBUTARY STREAM SITE IDENTIFIER
1	32.0–30.7	C4 W C5 D5 C6	32 31.4, 31.8 31.3, 31.5 31.2 31.1, 31 30.9	*End of study reach modeled* (32) Confluence of Club Run, **T0** (31.8) Confluence of Mill Run, **T2** (31.5) Confluence of Coon Run (31)
2	30.7–28.7	D6 D9	30.4 30.0, 30 29	
3	28.7–26.7	C7 C9	28.6, 28.5 28.0, 28 27	Confluence of Freeland Run, **T8** (28.5)
4	26.7–24.7		26 25	
5	24.7–23.4	C10 C31	24.5, 24.4 24.3 24	Confluence of Yoakum Run, **T14** (24.4)
6	23.4–22.2		23	
7	22.2–20.5	C15	22 21.1, 21	Confluence of Sand Run, **T16** (22)
8	20.5–18.7	C17	20.4, 20.3 20 19	Confluence of North Branch, **T20** (20.3)
9	18.7–16.9		18 17	
10	16.9–15.2	C21	16.8, 16.7 16	Confluence of Little Blackwater River, **T22** (16.7)
11	15.2–13.6	C23	15 14.0, 14 13.6	*End of study reach modeled* (13.6)

BLACKWATER RIVER MAINSTEM

Figure 10. Model subreaches and river mile locations of tributary streams, sampling locations, water-withdrawal site, and point sources of water discharges. [**T22** = water-quality data collection site number 22 on a tributary stream; **C7** = water-quality data collection site number 7 on the upper Blackwater River; **W** = water-withdrawal site on the upper Blackwater River; **D6** = point source of water discharge on the upper Blackwater River.]

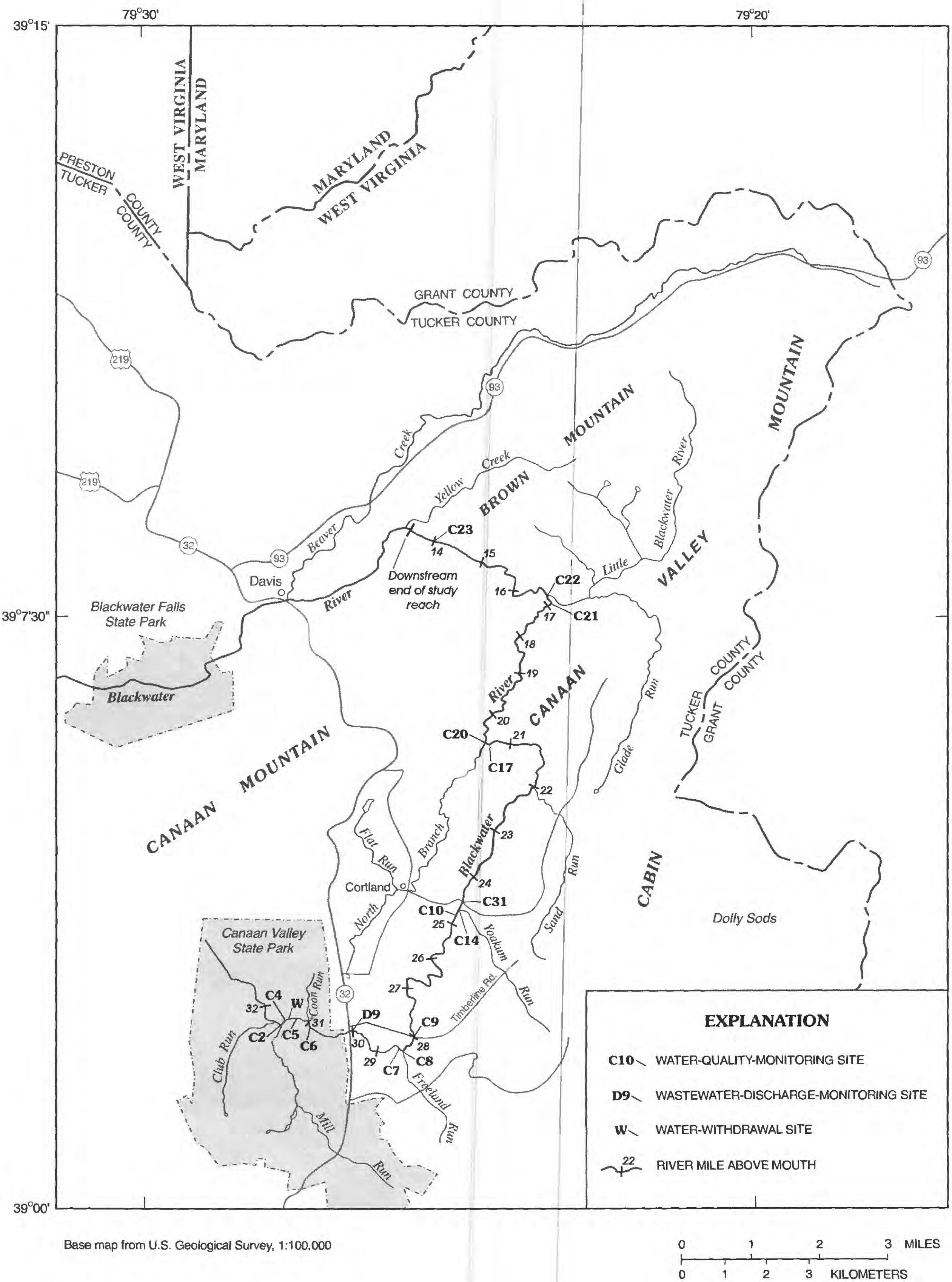


Figure 11. Locations of Canaan Valley wastewater-discharge sites and monitoring sites used for water-quality model calibration and verification.

at hourly intervals with a USGS minimonitor connected to an automated data recorder. The sensors were calibrated at the beginning of each synoptic-survey period according to the manufacturer's recommendations. Stage was also recorded at hourly intervals, and all data were stored on a 16-channel punched-paper tape. The tape was removed at the end of each survey period and the data transferred to computer files with a Mitron model MDTS-2 data translator. The data were then edited and transferred to permanent computer files for analysis. Continuous data were used to establish limits for diel variations throughout the study area. During the synoptic survey on August 18-19, 1992, the DO sensor at the Cortland monitoring site (mile 24.3) failed. Measurements of DO concentrations (Winkler titration) and barometric pressure were made manually every 4 hours, beginning at 6:00 p.m. on August 19 and continuing through 6:00 p.m. on August 20.

Hydraulics and discharge

Hydraulic characteristics for the Blackwater mainstem were determined and modeled using equations developed by Leopold and Maddock (1953). Typically, the hydrologic-model-calibration procedure begins with collection of time-of-travel data and calculation of average stream velocities at different discharges, so that individual relations can be developed between average velocities and discharges for each subreach. In this study, only one set of dye measurements was made, and time-of-travel data for upstream and downstream subreaches were combined and treated as if they represented measurements made at multiple discharges for the entire study reach.

According to Leopold and Maddock (1953, p. 14), variations of hydraulic characteristics in a downstream direction are related to flow duration, and characteristics of tributaries can be compared directly to the mainstem. In this study, discharge measurements made during the time-of-travel study indicated that flow durations were equivalent throughout the basin, and traveltime data collected on tributary streams were combined with data from the mainstem to develop regional (applicable to the entire basin) hydraulic-characteristic relations (Allen and others, 1994).

According to Leopold and Maddock (1953), relations among stream characteristics and discharge are of the form

$$v = kQ^m,$$
$$w = aQ^b, \textit{ and}$$
$$d = cQ^f,$$

where

v is the average stream velocity, in ft/s;
w is the average stream width, in ft;
d is the average stream depth, in ft;
Q is the quantity of flow, in ft^3/s;
k is the hydraulic geometry coefficient for velocity;
a is the hydraulic geometry coefficient for width;
c is the hydraulic geometry coefficient for depth;
m is the hydraulic geometry exponent for velocity;
b is the hydraulic geometry exponent for width; *and*
f is the hydraulic geometry exponent for depth.

The three equations are related to each other, such that the product of the hydraulic geometry coefficients (a * c * k) is 1, and the sum of the hydraulic geometry exponents (b + f + m) also is 1 (Leopold and Maddock, 1953, p. 9). These relations and data from a single dye study formed the basis for calculation of hydraulic coefficients used to model the mainstem Blackwater River.

Rhodamine dye was injected at two points on the Blackwater mainstem, at two points on the North Branch, and at one point on Yoakum Run during a low-flow period in July 1993. Traveltime was determined at several downstream locations for each injection, and traveltime data were used to calculate average velocities for the subreaches. Mean daily discharge at the Davis, W. Va., gage during the time-of-travel measurements ranged from 7.0 to 4.2 ft^3/s.

Mainstem hydraulics were affected by the presence of a beaver dam about 0.5 mi upstream from the mouth of Freeland Run. The resulting pool extended from river mile 29 upstream to river mile 31. Velocity through this subreach under the flow conditions of the dye study was 0.018 ft/s, compared to a velocity of 0.08 ft/s in the free-flowing section downstream. Maximum depth of the pool was about 5 ft, as compared with depths of 1 ft or less in parts of the river that were not affected by beaver dams. These data were not used to develop the regional hydraulic-characteristic relations, but were used to estimate the characteristics for the model subreach representing the beaver pool.

Traveltime data for free-flowing subreaches of the mainstem, North Branch, and Yoakum Run were combined in a regression equation relating average velocity to discharge for all open-channel subreaches. The following regional equation, with a correlation coefficient of 0.99, was obtained:

$$v = 0.059Q^{0.338}.$$

An equation describing the same relation for the mainstem beaver pool was obtained by extending a curve through a point with the appropriate average velocity and discharge (obtained from the time-of-travel study), while maintaining the slope of the regional curve (0.338, the hydraulic-geometry exponent for depth). The equation is

$$v = 0.017Q^{0.338}.$$

These two equations provided the hydraulic-geometry coefficients and exponents for velocity that were incorporated into the model (table 4).

Next, cross-section stream widths and discharges were measured to construct a regression equation relating average width to discharge. The resulting regional equation, with a correlation coefficient of 0.67, is

$$w = 14.997Q^{0.353}.$$

The distributions of the points used to construct the regional relation for width indicated localized subbasin differences that correlated with model subreaches. Regression curves for estimating width for subreaches were developed by constructing curves through appropriate width and discharge points while maintaining the slope of the regional curve (0.353, the hydraulic-geometry exponent for width).

Finally, hydraulic-depth equations were determined by solving the product-of-coefficients and summation-of-exponents equations (Leopold and Maddock, 1953, p. 9) for the hydraulic-geometry coefficients and exponents for depth (two equations and two unknowns). The coefficients and exponents for depth developed by this method (table 4) were used to model the hydraulic geometry of the Blackwater mainstem study reach.

Model boundary conditions for discharge were estimated using unit-discharge relationships, except for measured discharges at wastewater-treatment facilities and the single surface-water withdrawal location. Stream discharges measured during each synoptic survey were converted to unit discharges and averaged. The average unit discharge was then used to estimate steady-state discharges for each synoptic-survey data-collection period. The modeled steady-state discharges and measured discharges are compared in figure 12 for the calibration data set (August 1992) and the two verification data sets (July 1992 and July-August 1991). Modeled steady-state discharges for the July 1992 data set were lower upstream and higher downstream than the measured values for the period because flows were unsteady during the July 14-17, 1992, sampling period. Mean daily discharge at the Davis, W. Va., gage, just downstream from the study area, decreased from 141 to 63 ft^3/s during the July 1992 survey. Agreement between modeled and measured discharges was closer for the July 1991 data set, when discharges at the Davis gage decreased from 39 to 22 ft^3/s, and for the calibration data set (August 1992), when discharges decreased from 114 to 79 ft^3/s. Boundary conditions for the 7Q10 model simulation were estimated from a unit-discharge relation based on the 7Q10 of 4.99 ft^3/s for the Davis gage (Friel and others, 1989, p. 24).

Stream discharges, and the hydraulic coefficients and exponents for velocity, width, and depth are used in the model to represent the hydraulic characteristics for each subreach. Table 5 contains simulated depths, velocities, and other hydraulic characteristics for each model reach, with bound-

Table 4. Coefficients and exponents used to simulate hydraulic geometry of the Blackwater River, Canaan Valley, West Virginia

[ft = feet; ft/s = feet per second]

Model subreach	Hydraulic geometry coefficient for Velocity (ft/s)	Hydraulic geometry coefficient for Depth (ft)	Hydraulic geometry exponent for Velocity (ft/s)	Hydraulic geometry exponent for Depth (ft)
1	0.059	2.050	0.338	0.309
2	.017	4.316	.338	.309
3	.059	1.014	.338	.309
4	.059	1.014	.338	.309
5	.059	1.014	.338	.309
6	.059	1.014	.338	.309
7	.059	1.014	.338	.309
8	.059	.723	.338	.309
9	.059	.723	.338	.309
10	.059	.723	.338	.309
11	.059	.723	.338	.309

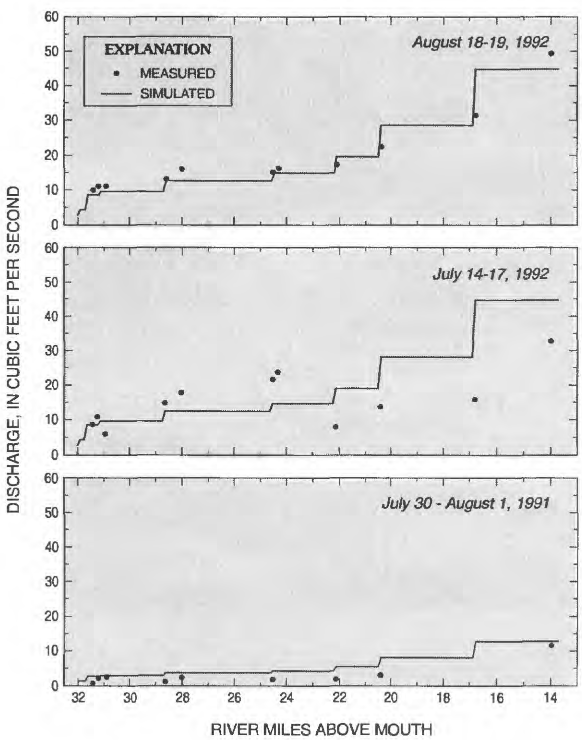


Figure 12. Comparison between calibration (August 18-19, 1992) and verification (July 14-17, 1992 and July 30 - August 1, 1991) data for discharge.

ary conditions and inflows set to values determined for the August 1992, July 1992, and July-August 1991 synoptic surveys. Simulated discharge at the downstream end of subreach 11 was about 44 ft^3/s for the July and August 1992 initial conditions, and about 13 ft^3/s for the 1991 initial conditions. The reduced simulated discharges for the 1991 conditions resulted in a reduction in depth and an increase in traveltimes for all reaches. In subreach 2 (the simulated beaver pool), predicted depths decreased by about 2 ft and traveltimes increased from 3.3 days to 5 days. Total traveltime through the 18.6-mi study reach was predicted as 9.6 days at the higher discharges of July 1992, compared to 13.2 days at the lower discharges of July-August 1991.

Transport of conservative constituents

Conservative constituents are not affected by metabolic processes, but are affected by physical processes, including point and nonpoint sources, traveltime, and dispersion. Accurate model predictions of concentrations for conservative constituents is an indication of accurate physical representation of the calibrated model. To simulate transport of a conservative constituent, the model must be able to simulate changes in stream volume accurately (Schmidt and others, 1989, p. 28).

Table 5. Simulated hydraulic characteristics for the upper Blackwater River in Canaan Valley, West Virginia, with boundary conditions and inflows based on August 1992, July 1992, and July-August 1991 survey data

[ft = feet; ft/s = feet per second; ft³/s = cubic feet per second; mi = miles]

Model subreach	Mean depth (ft)	Mean velocity (ft/s)	Mean discharge (ft^3/s)	Volume (ft^3)	Length (mi)	Traveltime (days)
			Model With August 18-19, 1992, Boundary Conditions			
1	3.75	0.12	7.44	432.59	1.3	0.71
2	8.69	.04	9.62	2,780.20	2.0	3.34
3	2.21	.14	12.38	946.16	2.0	.88
4	2.21	.14	12.52	953.80	2.0	.88
5	2.31	.15	14.38	679.26	1.3	.55
6	2.33	.15	14.72	636.96	1.2	.50
7	2.52	.16	18.96	1,066.36	1.7	.65
8	2.02	.18	27.72	1,451.72	1.8	.60
9	2.03	.18	28.22	1,470.06	1.8	.59
10	2.32	.21	43.47	1,846.15	1.7	.50
11	2.34	.21	44.42	1,764.48	1.6	.46
			Model With July 14-17, 1992, Boundary Conditions			
1	3.76	0.12	7.47	434.00	1.3	0.71
2	8.72	.04	9.72	2,799.40	2.0	3.34
3	2.21	.14	12.48	951.19	2.0	.88
4	2.22	.14	12.62	958.80	2.0	.88
5	2.32	.15	14.48	682.40	1.3	.55
6	2.33	.15	14.82	639.84	1.2	.50
7	2.52	.16	19.06	1,070.12	1.7	.65
8	2.02	.18	27.82	1,455.17	1.8	.60
9	2.03	.18	28.32	1,473.48	1.8	.59
10	2.32	.21	43.57	1,848.90	1.7	.50
11	2.34	.21	44.52	1,767.04	1.6	.46
			Model With July 30-August 1, 1991, Boundary Conditions			
1	2.57	0.08	2.19	192.37	1.3	1.07
2	5.95	.02	2.83	1,236.80	2.0	5.06
3	1.51	.09	3.64	420.62	2.0	1.35
4	1.52	.09	3.68	424.00	2.0	1.34
5	1.58	.10	4.24	302.55	1.3	.83
6	1.60	.10	4.34	283.80	1.2	.76
7	1.72	.11	5.59	475.33	1.7	.99
8	1.38	.12	8.19	647.71	1.8	.93
9	1.39	.12	8.34	655.92	1.8	.92
10	1.60	.14	12.86	824.28	1.7	.74
11	1.60	.14	13.14	787.84	1.6	.69

Specific conductance is a general indicator of the quantity of conservative ionic constituents. Boundary conditions for model calibration and verification were based on measured values for all inflows except from the headwaters and Coon Run; these were estimated from measurements made on Club Run and the upper section of Mill Run. Measured and predicted specific-conductance values are compared in figure 13 for the calibration data set (August 1992) and the two verification data sets (July 1992 and July-August 1991). Measured specific-conductance values were close to those predicted by the model for the August 1992 and the July-August 1991 data sets. Agreement between measured and simulated specific conductance was not as close for the July 1992 data set, when a large decrease in discharge during the survey period increased difficulty of accurate simulation of stream hydraulics. Predicted conductance values were lower than measured values during the July 1992 survey period, especially in the upstream half of the study reach. Most of the upstream half of the study area was measured early in the sampling period (July 14), while the study area farther downstream was measured on succeeding days (July 15-17) and at lower discharges. The model accurately reflects the expected increase in specific conductance at lower flows, as ground-water inflows come to dominate the chemistry of the stream.

Stream temperature

Many processes that affect DO concentrations in streams are dependent on streamwater temperature. Temperature values are predicted by the model and then used to correct the rate coefficients for these processes. A correction is made in each case, using empirical constants. This study used the default correction factors suggested by Brown and Barnwell (1987) for the QUAL2E model.

Stream temperature is predicted by computing a heat balance for each computational element in the network. The heat balance accounts for increases and decreases in temperature, including from headwaters and inflows, and from heat exchanges at the air-water interface. Model data input for temperature calculations include longitude and latitude of the basin, time of year, evaporation and dust-attenuation coefficients, wet-bulb and dry-bulb air temperatures, atmospheric pressure, cloud cover, and wind velocity. Values used for these data are presented in table 6. Evaporation coefficients for wind, AE = 0.00103 ft/(hour * inch-Hg), and BE = 0.00016 ft/(hour * inch-Hg * mi/hr), were selected from previously published values (Bowie and others, 1985). Atmospheric pressure and cloud cover were set to the means of values recorded during the appropriate synoptic survey. Humidity and wind speed were not measured during the synoptic surveys. Hourly records of wind speed for the U.S. Forest Service site at Bearden Knob were obtained for July and August 1992. Mean values for the period from 10:00 a.m. to 4:00 p.m. during the July and August 1992 synoptic surveys were computed and used as model data input. Hourly humidity and wind-velocity records for all three survey periods were obtained from the National Dry Deposition Network site at Parsons, W. Va., and used to approximate 10:00 a.m. to 4:00 p.m. humidity variations for all three survey periods, and wind velocity for the July-August 1991 survey (table 6).

Measured and predicted temperature for the three data sets are presented in figure 14. Predicted temperatures generally are too high by as much as 5°F, although the patterns of downstream increases and decreases in measured stream temperature are accurately simulated. The elevated water-temperature predictions are due to the inability of the model to account for shading of the stream surface by bank vegetation (Thomas Barnwell, U.S. Environmental Protection Agency, written commun., 1993). Although percentage of shade is a model data input, the model does not incorporate shading into the heat-balance computations. Sensitivity analyses (described below) indicate that the DO simulation is sensitive to water temperature, mainly through the effect of water temperature on oxygen solubility.

Nitrogenous biochemical oxygen demand

The water-quality model calculates decay of organic nitrogen to ammonia (NH_3), and the oxidation of ammonia to nitrite (NO_2^-) and nitrite to nitrate (NO_3^-). The model does not calculate denitrification, which is the anaerobic reduction of nitrate to ammonia or nitrogen gas (N_2). Algal bio-

Table 6. Geographic and local meteorological data used to simulate streamwater temperature of the upper Blackwater River, Canaan Valley, West Virginia

[ft = feet; ft/s = feet per second; °F = degrees Fahrenheit; in. Hg = inches of mercury]

Model subreach	Elevation (ft)	Dust attenuation coefficient	Cloudiness	Dry bulb temperature (°F)	Wet bulb temperature (°F)	Barometric pressure (in. Hg)	Wind velocity (ft/s)
1	3218	0.06	0.75	79.0	62.6	26.8	9.5
2	3213	.06	.75	76.0	60.8	26.8	9.5
3	3205	.06	.75	70.0	56.3	26.8	9.5
4	3186	.06	.75	76.0	60.8	26.8	9.5
5	3161	.06	.75	63.0	50.9	26.8	9.5
6	3154	.06	.75	66.0	53.6	26.8	9.5
7	3148	.06	.75	66.0	53.6	26.8	9.5
8	3142	.06	.75	64.0	50.9	26.8	9.5
9	3139	.06	.75	81.0	63.5	26.8	9.5
10	3135	.06	.75	81.0	63.5	26.8	9.5
11	3131	.06	.75	69.0	55.4	26.8	9.5

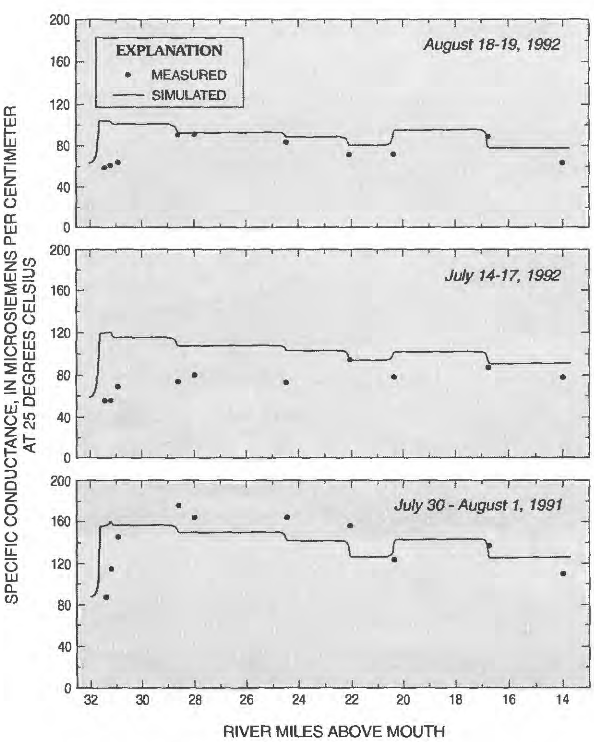


Figure 13. Comparison between calibration (August 18-19, 1992) and verification (July 14-17, 1992 and July 30 - August 1, 1991) data for specific conductance.

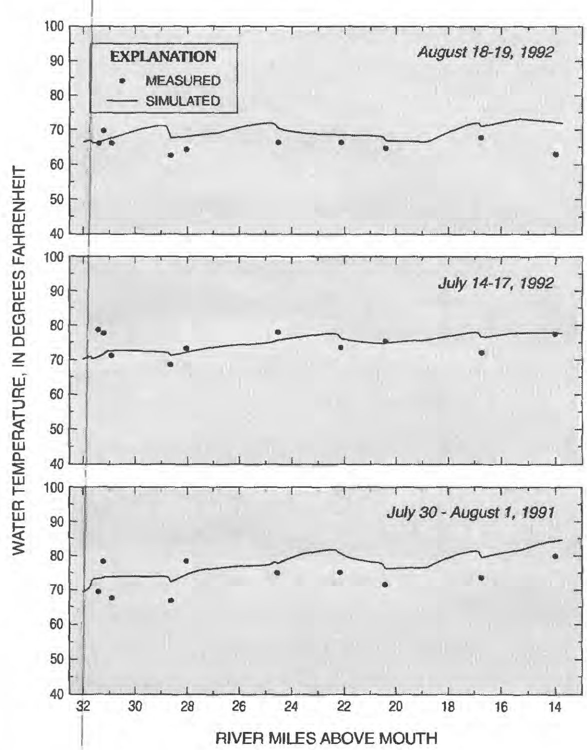


Figure 14. Comparison between calibration (August 18-19, 1992) and verification (July 14-17, 1992 and July 30 - August 1, 1991) data for stream temperature.

mass (expressed as chlorophyll-*a*) was set to zero µg/L for all inflows and initial conditions, because there were few phytoplankton algae in the study reach. Consequently, there could be no representation of nitrate uptake or ammonia uptake by phytoplankton algae, and nitrogen dynamics could not be explicitly affected in the model by photosynthetic processes as depicted in figure 9. There were, however, dense beds of benthic green algae and eelgrass in subreach one (miles 32.0 to 30.7). Algal beds were present in the middle subreaches (subreaches 3 through 8; miles 28.7 to 18.7), though not as dense as the algae and eelgrass in subreach 1.

Uptake of ammonia and sloughing of organic nitrogen by benthic algal beds were represented by setting some coefficients for nitrogen transformations to negative values (table 7). Subreaches 1, 3, 4, 5, and 6 were assigned negative coefficients for organic nitrogen settling to represent production and sloughing of organic nitrogen by algal beds (Van Benschoten and Walker, 1984). Subreaches 1, 3, and 4 also were assigned negative values for release of dissolved ammonia, thereby representing uptake by benthic algae and aquatic plants in these subreaches. Rates of oxidation of ammonia and nitrite were assumed to be slower in the subreach with the beaver pool (subreach 2) than in other model subreaches, because of the reduced turbulence and longer traveltime in the beaver pool. Also, the beaver pool was assumed to be an area of accumulation and active decomposition of organic matter and, therefore, a source of dissolved ammonia.

Considering the above assumptions and published ranges (Bowie and others, 1985; Brown and Barnwell, 1987) for the model coefficients for nitrogen transformations, a set of initial coefficients was selected that would enable prediction of observed conditions for the August 1992 synoptic survey. Wherever possible, values were either measured or inferred from related studies. Otherwise, coefficients were varied within published ranges to ensure closest agreement between model predictions and measured constituent concentrations. A listing of subreach-dependent coefficients is given in table 7.

Comparisons between measured and predicted values for total ammonia-nitrogen and total organic-nitrogen concentrations are shown in figures 15 and 16 for the calibration and verification data sets. Agreement between measured and predicted values was reasonably close given the extremely low concentrations of these constituents. Predicted ammonia-nitrogen concentrations were somewhat lower than measured concentrations for the August 1992 data set, and predicted concentrations were higher than measured concentrations for the other two data sets. These differences could be indicative of changes in the distribution or activity of the benthic algal beds.

All measured and predicted nitrite concentrations were lower than the minimum reporting level of 0.01 mg/L. Nitrate-nitrogen concentrations could not be calculated, because the river contains little, if any, phytoplankton, and the model makes no provision for benthic nitrate fluxes, as discussed above. Consequently, nitrate accumulates in the steady-state solution to concentrations as high as 0.26 mg/L, whereas measured concentrations usually were lower than 0.10 mg/L. Despite the inability of the model to predict nitrate-nitrogen concentrations, the contribution of the nitrogen cycle to the total biochemical oxygen demand was determined because the model accurately represented oxidation of ammonia-nitrogen and nitrite-nitrogen.

Dissolved oxygen and carbonaceous biochemical oxygen demand

One of the most significant indicators of water quality in any aquatic system is the concentration of dissolved oxygen. Oxygen is necessary for aquatic life, as well as being part of the mechanism of waste assimilation, as microorganisms use it to oxidize residual organic matter in effluent discharges. The dissolved oxygen concentration at any time or place in a stream is the net effect of oxygen-consuming processes (DO sinks) and oxygen-producing processes (DO sources) operating in the stream. Sinks for DO include the biochemical oxidation of carbonaceous and nitrogenous organic matter and the uptake of DO by bottom sediments. Sources for DO include atmospheric reaeration, photosynthesis, and DO present in the feeder streams. Model simulation of DO and CBOD is discussed below.

Table 7. Coefficients and rate constants used to simulate nitrogen transformations in the upper Blackwater River, Canaan Valley, West Virginia

[(mg/ft^2)/d = milligrams per square foot per day]

Model subreach	Organic-nitrogen hydrolysis (per day)	Organic-nitrogen settling (per day)	Ammonia-nitrogen oxidation (per day)	Benthic ammonia-nitrogen flux [(mg/ft^2)/d]	Nitrite-nitrogen oxidation (per day)
1	0.01	-0.20	0.20	-0.10	1.0
2	.01	0	.10	.10	.5
3	.01	-.10	.20	-.05	1.0
4	.01	-.10	.20	-.05	1.0
5	.01	-.05	.20	0	1.0
6	.01	-.05	.20	0	1.0
7	.01	0	.20	0	1.0
8	.01	0	.20	0	1.0
9	.01	0	.20	0	1.0
10	.01	0	.20	0	1.0
11	.01	0	.20	0	1.0

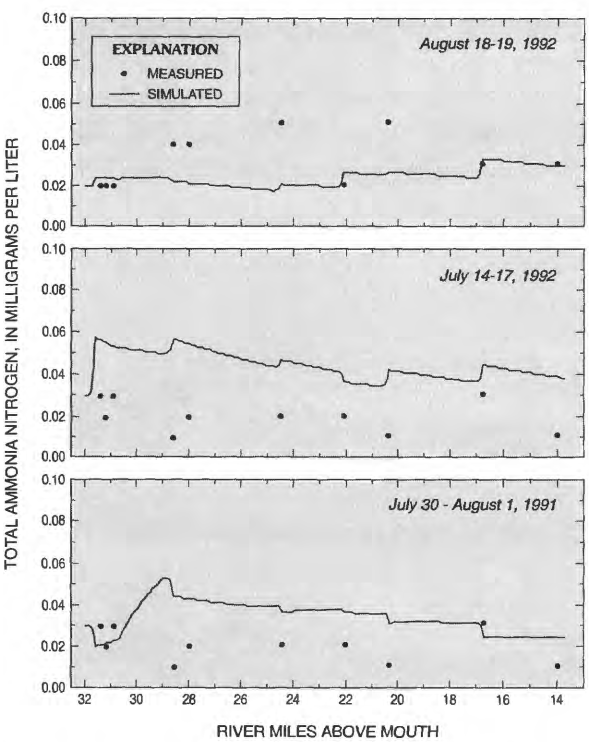


Figure 15. Comparison between calibration (August 18-19, 1992) and verification (July 14-17, 1992 and July 30 - August 1, 1991) data for ammonia nitrogen.

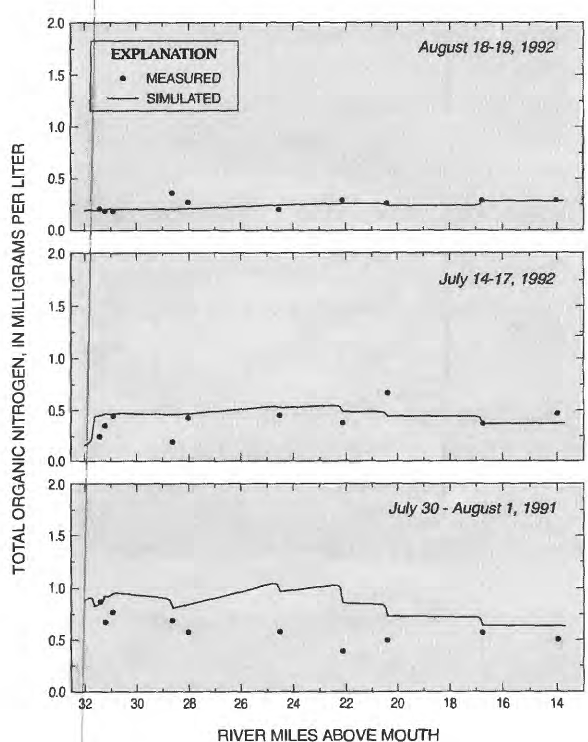


Figure 16. Comparison between calibration (August 18-19, 1992) and verification (July 14-17, 1992 and July 30 - August 1, 1991) data for total organic nitrogen.

The model calculates DO consumption resulting from CBOD, using a first-order decay equation. The decay coefficients (K_1) for CBOD were computed from analysis of 20-day CBOD performed on 10 water samples obtained from representative mainstem sites and wastewater discharges. The analysis resulted in time-series data that indicate the decay of DO. Two methods were used to fit the decay curves and to compute K_1-- a graphic method (Stamer and others, 1983) and a least-squares numerical method (Barnwell, 1980; Jennings and Bauer, 1976). There was close agreement between the results of the two methods (table 8). Decay coefficients ranged from 0.01 to 0.06 per day and were within published ranges for similar streams (Bowie and others, 1985).

The methods for computing K_1 described above are also used to estimate the ultimate CBOD, which is the amount of oxygen that would be consumed if all carbonaceous organic matter in the sample were oxidized. Model initial conditions for CBOD can be either ultimate CBOD or 5-day CBOD. A ratio of ultimate CBOD to 5-day CBOD is required by the model when 5-day CBOD is the selected model input. The ratio of 6:1 was used for both the calibration and verification data sets.

The model calculates nitrogenous biochemical oxygen demand (NBOD) with equations to describe the oxidation processes of ammonia to nitrite and nitrite to nitrate. The oxidation of ammonia nitrogen was estimated to require 3.43 mg of oxygen per mg of nitrogen, and that of nitrite nitrogen was estimated to require 1.14 mg of oxygen per mg of nitrogen. These estimates were obtained from previously published ranges (Brown and Barnwell, 1987). The model also calculates CBOD losses due to settling of carbonaceous organic matter. In this case, settling was assumed insignificant and all settling rate coefficients (K_3) were estimated as zero per day (table 9).

Reaeration-rate coefficients (K_2) were estimated for model input, based on mean stream velocity and depth, using the equation developed by O'Connor and Dobbins (1958). The value of K_2 increases with increasing mean stream velocity and decreases with increasing mean stream depth. Values computed for the August 1992 calibration data set ranged from 0.10 per day in subreach 2 (the beaver pool) to 2.0 per day in the downstream subreaches 9 and 10 (table 10). Values computed for the July 1992 verification data set were similar (0.10 to 2.17 per day) to those computed for the August 1992 calibration data set. Values computed for the July-August 1991 verification data set, however, ranged from 0.15 in subreach 2 (the beaver pool) to 3.27 in subreach 9. These dissimilar values resulted because discharges were lower and the river was more shallow when the July-August 1991 verification data set was collected, compared to discharges and river depths for the other two data sets (table 5).

Model calibration was completed by adjusting the rate coefficients for sediment oxygen demand (SOD) to predict measured DO concentrations for the August 1992 calibration data set. Negative coefficients were used to represent photosynthetic DO production by benthic algae and eelgrass beds (Park and Uchrin, 1990). The dense beds of benthic algae and aquatic plants in many of the upstream subreaches were hypothesized to be the main source of DO in the absence of phytoplankton. Both SOD and photosynthetic oxygen production would be proceeding simultaneously, since model simulation is limited to midday conditions. The SOD rate determined for each subreach represents the net result of these two processes.

The SOD-rate coefficients determined for the calibration and verification data sets are listed in table 9. Subreach 1 was adjusted to the largest negative value representing the greatest release of DO to the stream from the benthic algae and aquatic plants. Subreach 2 (the beaver pool) was adjusted to a positive SOD rate, representing a reduced light penetration and the resulting reduction in DO production from benthic algae. Subreaches 3 through 8 were adjusted to progressively smaller negative SOD rates, representing a decreasing amount of DO produced by benthic photosynthesis relative to the amount taken up by sediments. Subreach 9 was adjusted to a SOD rate of zero gm per ft^2 per day indicating that the oxygen-consuming and oxygen-producing processes were operating at equivalent rates. The two most downstream subreaches (10 and 11) were adjusted to positive SOD rates.

Table 8. Measured 5-day carbonaceous biochemical oxygen demand and calculated decay coefficients and ultimate biochemical oxygen demand for 10 Canaan Valley sampling sites, August 21, 1992

[K_1 = 5-day carbonaceous biochemical oxygen demand decay coefficient; mg/L = milligrams per liter; CVSP = Canaan Valley State Park; $CBOD_5$ = 5-day carbonaceous biochemical oxygen demand; $CBOD_U$ = ultimate carbonaceous biochemical oxygen demand; d = day]

			Calculated			
			Graphic method		Numerical method	
Site identifier	Site name	Measured $CBOD_5$ (mg/L)	K_1 per d	$CBOD_U$ (mg/L)	K_1 per d	$CBOD_U$ (mg/L)
C-6	Blackwater River at CVSP	1.8	0.05	10	0.042	11
C-9	Blackwater River on Timberline Rd.	1.9	.02	17	.021	18
C-23	Blackwater River near Davis, W. Va.	1.2	.01	26	.009	31
C-13	Yoakum Run at mouth	2.4	.06	13	.050	14
C-19	North Branch at Cortland, W. Va.	.9	.01	23	.010	24
C-28	Mill Run near headwaters	.3	.01	15	.016	11
D-5	Wastewater discharge no. 5	7.1	.03	82	.028	86
D-7	Wastewater discharge no. 7	16	.04	110	.040	108
D-12	Wastewater discharge no. 12	20	.04	630	.040	623
D-15	Wastewater discharge no. 15	6.0	.03	97	.029	101

Table 9. Coefficients and rate constants used to simulate carbonaceous biochemical oxygen demand and dissolved oxygen concentrations in the upper Blackwater River, Canaan Valley, West Virginia

[$(gm/ft^2)/d$ = grams per square foot per day]

	Biochemical oxygen demand		
Model subreach	Decay coefficient per day	Settling coefficient per day	Sediment oxygen demand rate [$(gm/ft^2)/d$]
1	0.04	0	-0.15
2	.04	0	.05
3	.02	0	-.1
4	.02	0	-.1
5	.01	0	-.05
6	.01	0	-.025
7	.01	0	-.01
8	.01	0	-.01
9	.01	0	0.0
10	.01	0	.01
11	.01	0	.05

Table 10. Calculated ranges of reaeration rate coefficients for the upper Blackwater River water-quality model with August 1992, July 1992, and July-August 1991 boundary conditions

Model subreach	Range of calculated reaeration rate coefficients[1] per day		
	August 1992	July 1992	July-August 1991
1	0.55-0.79	0.59-0.84	0.86-1.18
2	.10- .32	.10- .34	.15- .51
3	.86-1.51	.88-1.58	1.30-2.36
4	1.49-1.54	1.58-1.60	2.36-2.38
5	1.41-1.53	1.56-1.60	2.29-2.40
6	1.40-1.41	1.57-1.58	2.37-2.40
7	1.29-1.40	1.40-1.57	2.11-2.38
8	1.71-1.99	1.87-2.11	3.06-2.79
9	1.88-2.00	2.12-2.17	3.09-3.27
10	1.77-2.00	1.89-2.16	2.79-3.26
11	1.75-1.78	1.89-1.89	2.87-2.97

[1] K_2 calculated by water-quality model using the equation of O'Connor and Dobbins (1958) with boundary conditions set to those of the data set shown.

Predicted concentrations of DO are compared to measured concentrations for the calibration and verification data sets in figure 17. There was close agreement between predicted and measured DO concentrations for the August 1992 calibration data set. Model verification with the July 1992 data set predicted DO concentration near the upstream end of subreach 2 (the beaver pool, at mile 30.9) as 7.5 mg/L, whereas the measured value was 5.3 mg/L. Model verification with the lower flow conditions of the July-August 1991 data set compared to the flow conditions of the July 1992 verification data set predicted DO concentration near the downstream end of subreach 2 (the beaver pool) as 4.8 mg/L, whereas all measured DO concentrations were greater. These poor comparisons are due to the single-reach conceptual representation of the model for subreach 2 (the beaver pool). The model allows for only one set of hydraulic characteristics for each subreach, and indicates that all subreaches have similar lengths. Hydraulic characteristics of subreach 2 are actually a decrease in velocity, an increase in stream width, and an increase in stream depth, in the downstream direction, but the model representation is an average of these characteristics. For this reason, predicted concentrations lack accuracy, but the processes affecting DO concentrations are identified.

Carbonaceous biochemical oxygen demand was accurately predicted for the calibration data set as well as the two verification data sets, although the range of variation in the measured values for the July-August 1991 verification data set was greater than that predicted by the model (fig. 18). Measured CBOD concentrations were low in the August 1992 calibration data set (ranging from 0.2 to 0.9 mg/L) and the July-August 1991 verification data set (ranging from 1.1 to 3.5 mg/L). These low concentrations indicate low rates of treated-wastewater discharge in the valley during most of the months of July and August. Most facilities in the valley release treated wastewater into polishing ponds that discharge into a receiving stream by overflowing. During the summer low-flow period, water loss by evaporation from the polishing ponds frequently exceeds inputs, so there is very little discharge into the streams. Of the 15 active wastewater discharge in the valley, only 2 discharged during the July-August 1991 sampling period, only 6 discharged during the July 1992 sampling period, and only 7 discharged during the August 1992 sampling period. Only one of these was directly into the Blackwater mainstem; the rest were into tributaries that eventually emptied into the mainstem. The treatment-facility designs that include polishing ponds greatly reduce the effects of the discharges on the river and its tributaries during the warmer summer months.

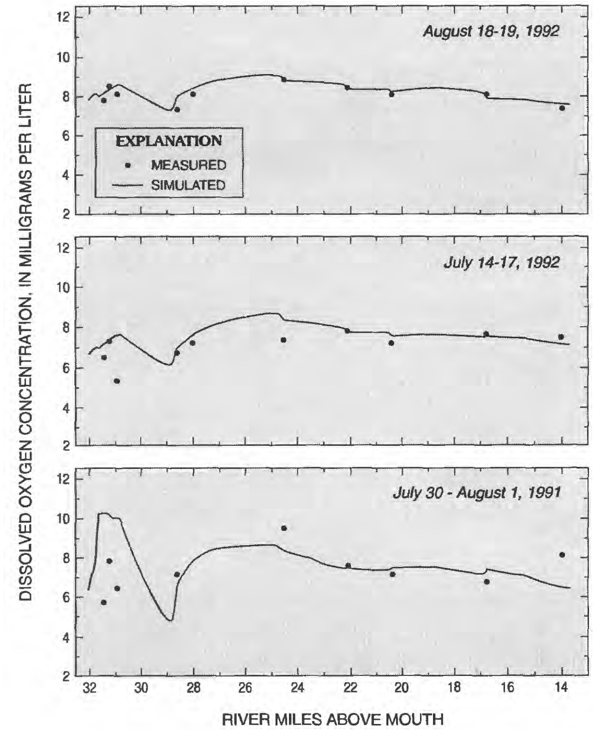


Figure 17. Comparison between calibration (August 18-19, 1992) and verification (July 14-17, 1992 and July 30 - August 1, 1991) data for dissolved oxygen.

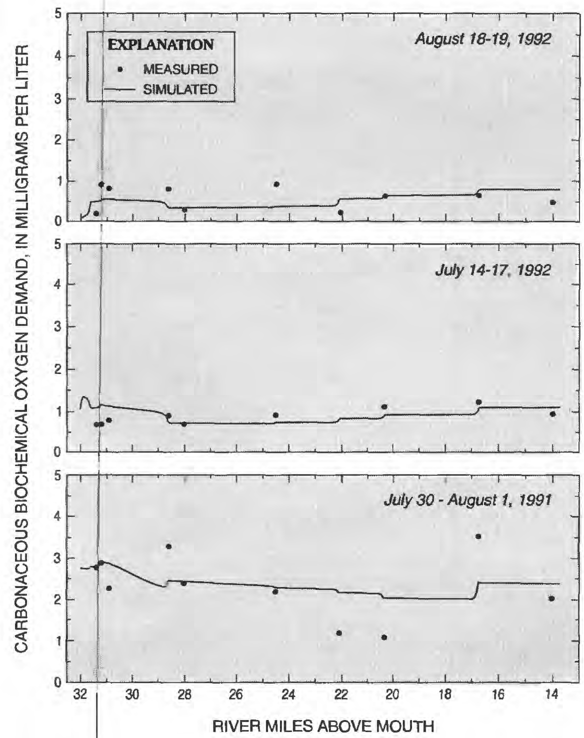


Figure 18. Comparison between calibration (August 18-19, 1992) and verification (July 14-17, 1992 and July 30 - August 1, 1991) data for carbonaceous biochemical oxygen demand.

Sensitivity Analysis

A sensitivity analysis was performed on the calibrated model (the August 1992 data set) by increasing all data input to the model individually by 5, 15, and 25 percent, and noting the effect of predicted DO concentrations at five locations on the Blackwater River. The stream locations selected for sensitivity analysis were the monitoring site in Canaan Valley State Park (river mile 30.9), the downstream end of the beaver pool in subreach two (river mile 28.8), the mainstem-monitoring site near Cortland, W. Va. (river mile 24.3), about 0.1 mi downstream from the mouth of North Branch (river mile 20.2), and the monitoring site upstream from Davis, W. Va. (river mile 14.0).

Relative sensitivities expressed as percent changes in DO concentrations resulting from a one percent increase in each input variable are listed in table 11 for the model. Only those input variables that produced a normalized change in DO concentration of 0.1 percent or more at any of the five locations are presented. In the upstream subreach (river mile 30.9) the DO simulation is most sensitive to input variables that act as forcing functions, such as the DO concentrations of tributary inflows and wastewater discharges (point-load DO concentrations), headwater DO concentrations, SOD rate, and atmospheric pressure. The simulation at this location also is sensitive to variables that affect the solubility of oxygen, such as atmospheric pressure, point-load temperature, and humidity (dry-bulb temperature and wet-bulb temperature).

At downstream locations, the importance of headwater DO concentrations is reduced and that of point-load DO concentrations is increased (table 11). In the beaver pool, for example, atmospheric pressure, point-load temperature, and DO concentration have the greatest effect on DO concentrations, followed by variables related to oxygen solubility. The magnitudes of the normalized sensitivity coefficients are the same for input-variable changes of 5, 15, and 25 percent, indicating that the sensitivity of the DO simulation is linear for that range of changes (Walker, 1982).

Table 11. Sensitivity analyses showing changes in dissolved oxygen concentrations in response to 5, 15, and 25 percent increases in model constants and coefficients for the calibration data set, August 1992

[Values are normalized and expressed as percentage of change in dissolved oxygen concentrations resulting from each 1 percent change in the input variable; numbers in parentheses indicate rankings of the four most sensitive constants or coefficients affecting dissolved oxygen, with (1) as the highest]

Input variable	River mile above mouth				
	30.9	28.8	24.3	20.2	14.0
5% Increase In:					
Dry-bulb temperature	0.001	-0.082	-0.091	-0.086	-0.157 (4)
Wet-bulb temperature	.002	-.183 (4)	-.197 (2)	-.183 (3)	-.337 (2)
Atmospheric pressure	.211 (2)	.539 (1)	.799 (1)	.690 (1)	1.011 (1)
Sediment oxygen demand rate	.085 (4)	-.040	.102 (4)	.020	-.036
Headwater dissolved oxygen concentration	.182 (3)	-.146	-.005	-.000	.000
Point-load temperature	.011	-.202 (3)	-.062	-.105 (4)	-.191 (3)
Point-load dissolved oxygen concentration	.533 (1)	.441 (2)	.140 (3)	.328 (2)	.090
15% Increase In:					
Dry-bulb temperature	.001	-.086	-.090	-.087	-.161 (4)
Wet-bulb temperature	.002	-.198 (3)	-.196 (2)	-.182 (3)	-.347 (2)
Atmospheric pressure	.211 (2)	.539 (1)	.801 (1)	.691 (1)	1.013 (1)
Sediment oxygen demand rate	.085 (4)	-.040	.102 (4)	.020	-.036
Headwater dissolved oxygen concentration	.182 (3)	.147 (4)	.005	.000	.000
Point-load temperature	.015	-.198 (3)	-.060	-.104 (4)	-.189 (3)
Point-load dissolved oxygen concentration	.533 (1)	.441 (2)	.140 (3)	.328 (2)	.090
25% Increase In:					
Dry-bulb temperature	.001	-.090	-.092	-.087	-.164 (4)
Wet-bulb temperature	.002	-.216 (3)	-.192 (2)	-.174 (3)	-.354 (2)
Atmospheric pressure	.211 (2)	.539 (1)	.802 (1)	.692 (1)	1.016 (1)
Sediment oxygen demand rate	.085 (4)	-.040	.102 (4)	.020	-.036
Headwater dissolved oxygen concentration	.182 (3)	-.147	.005	.000	.000
Point-load temperature	.020	-.195 (4)	-.058	-.102 (4)	-.184 (3)
Point-load dissolved oxygen concentration	.533 (1)	.441 (2)	.140 (3)	.328 (2)	.090

Model Limitations

Modifications to the model presented in this report will be required if the locations, numbers, or sizes of beaver pools, point-load discharges, or withdrawals change. Major changes in the density-distributions or types of benthic algae and other aquatic vegetation will require adjustment of model coefficients; changes in land use in the valley also could cause the model to be less representative of stream conditions.

The model developed in this study is applicable only when discharges are between the 7Q10 (4.99 ft^3/s at the Davis, W. Va. gage; 1.0 ft^3/s at the Cortland gage; and 0.5 ft^3/s at the Canaan Valley State Park gage) and the 50-percent flow duration (110 ft^3/s at the Davis, W. Va. gage; 24 ft^3/s at the Cortland gage; and 12 ft^3/s at the Canaan Valley State Park gage).

This study used SOD (sediment oxygen demand) as an indirect representation of photosynthetic DO production by benthic algae. In model subreaches that were known to contain dense populations of benthic algae and aquatic plants, the SOD-rate coefficients were adjusted to reflect the expected balance between benthic-oxygen production and benthic-oxygen consumption. Although this approach was successful at investigating processes affecting steady-state DO concentrations in the stream, the model is limited by the inability of the SOD to respond to changes in nutrient concentrations or solar radiation. More accurate predictions of modeled concentrations will require additional data for rates of benthic photosynthesis and respiration, and the effects of light and nutrient fluxes on these rates.

Model applications are limited to late summer (July through August), midday (10:00 a.m. to 4:00 p.m.), steady-discharge periods, because sampling for calibration and verification data was restricted to this time period. Continuous water-quality monitors were used at three mainstem sites [(Blackwater River at Canaan Valley State Park (mile 30.9), Blackwater River at Cortland (mile 24.3), and Blackwater River near Davis (mile 14.0)] during the July 1992 and the August 1992 synoptic surveys to determine the extent of the diel variations in stream temperature, pH, specific conductance, and DO concentrations. Results of the DO-concentration measurements for the three sites are shown in figures 19 and 20, together with steady-state DO concentrations predicted by the model. The predicted DO concentrations by the steady-state water-quality model are indicated by a dashed line superimposed over the monitor data for each monitoring site. The 6-hour midday periods (10:00 a.m. to 4:00 p.m.) in which all calibration data used in the model were collected are indicated by shading. Manual measurements of DO concentrations were made for part of the August 1992 survey period at the Cortland site (fig. 20) when the DO sensor at that monitor failed.

Diel changes in DO concentrations at the three continuous monitoring sites during the July 1992 synoptic survey are shown in figure 19. Daytime increases in DO concentrations occur when oxygen production by photosynthetic organisms proceeds at a higher rate than does oxygen consumption by all organisms. Maximum DO concentrations can exceed saturation concentrations. At night, only the oxygen-consuming processes are active, so DO concentrations usually decrease. At the upstream monitoring site (Blackwater River at Canaan Valley State Park), the predicted DO concentration is close to the measured value for each day of the 4-day synoptic survey, indicating the model accurately simulated conditions during that part of the day. Agreement was not as close for the other two monitoring sites. At the Cortland site, the maximum dissolved oxygen concentration was measured as 11.9 mg/L at 10:00 a.m. on July 17. This value was 147 percent of the saturation concentration of 8.1 mg/L for that combination of temperature and barometric pressure. The DO concentration predicted by the model was 8.3 mg/L, or only about 102 percent of saturation.

Diel changes in DO concentrations at the three continuous monitoring sites during the August 18-19, 1992, synoptic survey are shown in figure 20. Photosynthetic activity, as indicated by the magnitude of the diel DO cycle, was lowest at the monitoring site near Davis. Both the magni-

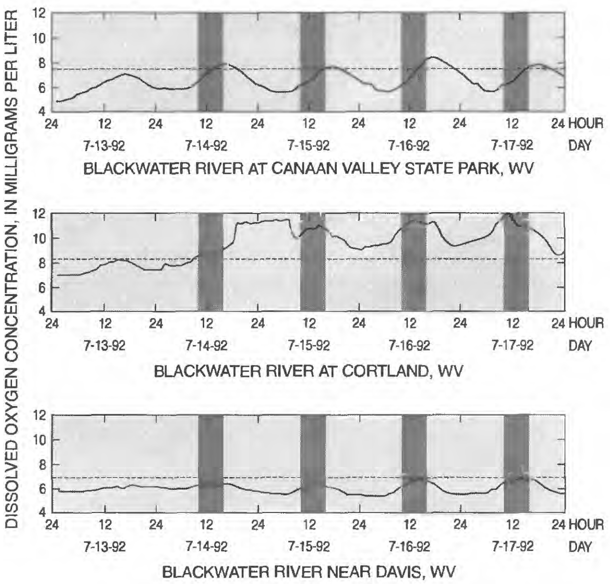


Figure 19. Changes in dissolved oxygen concentrations at three locations in the upper Blackwater River for the verification period July 13-17, 1992. [Solid lines are continuously-measured dissolved oxygen concentrations. Dashed lines are steady-state model predictions of dissolved oxygen concentrations. Darker shading indicates model calibration and verification time frame, 10:00 a.m. to 4:00 p.m.]

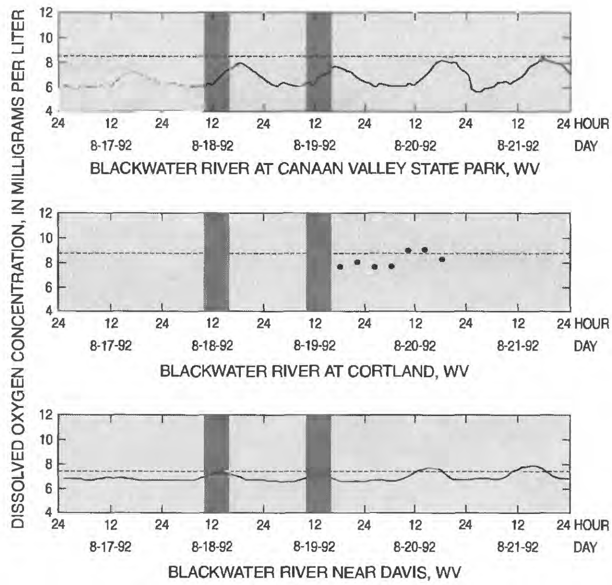


Figure 20. Changes in dissolved oxygen concentrations at three locations in the upper Blackwater River for the calibration period August 17-21, 1992. [Solid lines are continuously-measured dissolved oxygen concentrations. Dashed lines are steady-state model predictions of dissolved oxygen concentrations. Darker shading indicates model calibration and verification time frame, 10:00 a.m. to 4:00 p.m. Filled circles are manually-sampled dissolved oxygen concentrations.]

tude of the daily change in DO concentration and the maximum DO concentration were lower than at the other sites. Predictions for the midday peak DO concentrations were overestimated by about 0.5 mg/L with the model. Maximum DO concentrations predicted by the model exceeded those measured at both the Canaan Valley State Park and the Blackwater River near Davis monitoring sites (fig. 20). For both sites, the difference between the predicted DO concentration and the measured midday peak DO concentration was about 0.5 mg/L. Minimum DO concentrations predicted by the model are 1.0 to 2.5 mg/L higher than the minimum DO concentrations measured during the August 1992 survey period.

Simulation of Dissolved Oxygen in the Upper Blackwater River for the 7-Day, 10-Year Low Flow

The calibrated water-quality model was used to investigate processes affecting dissolved oxygen dynamics in the Canaan Valley study reach of the Blackwater River for the 7-day, 10-year low flow (7Q10). Estimated boundary conditions for discharge were based on unit discharge relations and a published 7Q10 value of 4.99 ft^3/s for the USGS gaging station at Davis, W. Va. (Friel and others, 1989). Initial conditions for DO and CBOD concentrations, concentrations of all nitrogen species, water temperatures, and local meteorological conditions were taken from the July 30-August 1, 1991, data set, during which discharges were about six times larger than the 7Q10.

Simulated hydraulic characteristics for the 7Q10 model are presented in table 12. Traveltime for the 18.4-mi study reach was 27.28 days; traveltime through the 2.0-mi beaver pool in subreach 2 was 9.68 days. Simulated depths for most of the study reach were less than 1 ft; the beaver pool had a simulated depth of 3.29 ft. These traveltimes and depths are consistent with those measured during the time-of-travel study conducted in July 1993 and used to develop hydraulic coefficients for the model. Flows at the Davis gage during the period of the time-of-travel study ranged from 7.1 to 4.2 ft^3/s, bracketing the published 7Q10.

Table 12. Simulated hydraulic characteristics for the upper Blackwater River, Canaan Valley, West Virginia, with inflows set to the 7-day, 10-year low flows

[ft = feet; ft^3 = cubic feet; ft/s = feet per second; ft^3/s = cubic feet per second; mi = miles; d = days)]

Model subreach	Mean depth (ft)	Mean velocity (ft/s)	Mean discharge (ft^3/s)	Volume (ft^3)	Length (mi)	Traveltime (d)
1	1.47	0.04	0.35	57.39	1.3	1.97
2	3.29	.01	.42	347.60	2.0	9.68
3	.86	.05	.57	123.00	2.0	2.51
4	.86	.05	.58	124.20	2.0	2.50
5	.90	.05	.68	90.19	1.3	1.54
6	.91	.05	.70	84.84	1.2	1.40
7	.99	.06	.94	145.31	1.7	1.80
8	.81	.07	1.42	202.95	1.8	1.65
9	.81	.07	1.45	205.74	1.8	1.64
10	.93	.08	2.30	263.11	1.7	1.34
11	.94	.08	2.35	251.68	1.6	1.25

Model predictions for discharge, DO concentrations, and CBOD concentrations are shown in figure 21. The model predicts discharges to be less than 1 ft^3/s in reaches 1 through 7 (miles 32.0 through 20.5), and to increase to a maximum of 2.4 ft^3/s by the end of the study reach. Dissolved oxygen concentrations are predicted to be supersaturated in subreach 1. The maximum deficit (2.4 mg/L) is predicted in subreach 2 (the beaver pool, miles 30.7 to 28.7). Maximum and minimum dissolved oxygen concentrations occurring in subreach 1 and 2 are discussed in detail below. Dissolved oxygen concentrations increase rapidly in subreach 3, partly because of the contribution from benthic photosynthesis and partly because the shallow stream has a high rate of reaeration. In subreach 5, DO concentrations begin to decrease, eventually reaching 6.05 mg/L at the downstream end of the study reach. This concentration is close to the State water-quality limit of 6.0 mg/L for the Blackwater River upstream from Davis, W. Va. Carbonaceous biochemical oxygen demand increases by less than 0.5 mg/L with the inflows from Freeland Run (mile 28.5) and the Little Blackwater River (mile 16.7). Concentrations of CBOD were high in both tributaries in the July 30-August 1, 1991, synoptic survey. The rate of decay of CBOD generally decreases in the downstream direction.

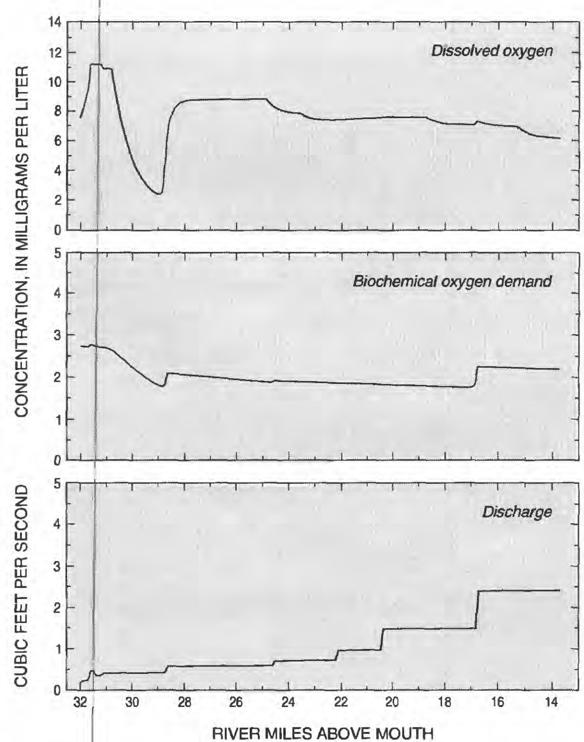


Figure 21. Water-quality model simulations of discharge, dissolved oxygen concentration, and biochemical oxygen demand at the 7-day, 10-year low flows in the upper Blackwater River.

Maximum DO concentrations are predicted in subreach 1. Measurements of DO concentrations that exceed the saturation concentration are not uncommon during low flows in the Blackwater River (see fig. 6 and the results of the monitoring study described previously). In most cases, the DO supersaturation probably is due to photosynthetic activity by benthic algae and other aquatic plants. Numerous investigations have shown that benthic algae and aquatic plants in lakes, rivers, and streams can increase the DO content of the water to supersaturated concentrations (Ondok and others, 1984; Carpenter and Lodge, 1986; Carter and others, 1991). In subreach 1, there is little turbulence at low flows to promote degassing and stream depths are low. Photosynthesis produces DO supersaturation during the morning hours and the warming of the highly colored streamwater further reduces the saturation concentration during the afternoon. The model does not accurately account for these processes. Therefore, predicted concentrations for supersaturation are not accurate, but the maximum dissolved oxygen concentration will occur in this subreach. Note that the water-quality assessment previously discussed in this report indicated DO concentrations below the State water-quality limit at the Canaan Valley State Park mainstem site, but those assessments were at discharges greater than the 7Q10.

Minimum DO concentrations are predicted in subreach 2 (the beaver pool). Model calibration and verification indicated traveltime through this subreach was between 3 and 5 days (table 5), and traveltime increased to about 10 days for this simulation (table 12). As discharge decreases, traveltime through subreach 2 increases, allowing CBOD and SOD processes more time to affect DO concentrations. As previously discussed in this report, hydraulic characteristics of subreach 2 actually decrease in velocity, increase in stream width, and increase in stream depth in the downstream direction, but model representation is an average of these characteristics. Therefore, predicted concentrations of DO are not accurate, but the minimum dissolved oxygen concentration will occur in this subreach.

Simulated discharge is consistent with the expected 7Q10 discharges (fig. 21). The 0.12 ft^3/s withdrawal at river mile 31.3 represents a 25-percent reduction in discharge at that point. The magnitude of the withdrawal is based on an estimated value of 0.08 Mgal/d and includes the drinking-water supply for the Park Lodge and irrigation water for the Park golf course.

SUMMARY AND CONCLUSIONS

Water quality was assessed for the Blackwater River and several of its tributaries in Canaan Valley, a large, montane valley in northeastern Tucker County, W. Va. Results were determined from measurements of discharge and 29 water-quality properties and constituents, collected at eight monitoring sites at intervals of 1 to 2 months from March 1990 through August 1992. Processes affecting dissolved oxygen (DO) were investigated by (1) collecting data for three synoptic surveys, (2) applying a steady-state, one-dimensional water-quality model, and (3) simulating water quality for the 7-day, 10-year low flow.

Most streams in Canaan Valley can be described as having a dilute calcium magnesium bicarbonate-type water. Streamwater typically was soft and low in alkalinity and dissolved solids. The highest median values for specific conductance, hardness, alkalinity, and concentrations of dissolved calcium, magnesium, sodium, potassium, alkalinity, sulfate, chloride, and dissolved solids were recorded at monitoring sites on Mill Run and North Branch, which are tributaries that receive inflows of ground water from limestone aquifers. Lowest median values for these characteristics were recorded for Club Run and Yoakum Run, two tributaries that are fed mainly by ground water from sandstones and shales. Ionic concentration values and other water-quality properties were generally intermediate for monitoring sites on the Blackwater mainstem. Maximum values for specific conductance, hardness, alkalinity, and dissolved solids occurred during low-flow periods when streamflow was at or near base flow.

Nitrogen and phosphorus were present at low concentrations in Canaan Valley streams. Concentrations of nitrate-nitrogen, nitrite-nitrogen, and un-ionized ammonia-nitrogen were always lower than State water-quality limits. Precipitation could supply a significant fraction of the nitrate-nitrogen used by stream biota. The mean concentration of nitrate-nitrogen in precipitation was at least eight times that of streamwater during the study period. Concentrations of dissolved nitrite-nitrogen plus nitrate-nitrogen and dissolved orthophosphorus were highest during periods of high streamflow. Particulate forms of nitrogen were more abundant during summer low-flow periods and probably represent organic production within the streams.

Dissolved oxygen concentrations usually were below the saturation concentrations at the Blackwater mainstem monitoring site in Canaan Valley State Park and usually were at or above saturation at all other sites. Five measurements of DO concentration at the Park site were below the State limit of 6.0 mg/L. Diel fluctuations in DO concentrations and low reaeration, rather than problems with wastewater discharges, probably account for most of the low DO-concentration measurements. At discharges near those of the 7-day, 10-year low flow, the Canaan Valley State Park mainstem site can have supersaturated DO concentrations due to photosynthetic activity by benthic algae and other aquatic plants.

Fecal coliform bacteria episodically exceeded the State limit of 200 colonies per 100 mL in Canaan Valley streams. Maximum counts during the warmest months of the year often were in the thousands of colonies per 100 mL. Fecal coliform and fecal streptococcus bacteria probably originate from nonpoint sources, including wildlife and domestic animals. Transport of fecal bacteria into the streams during summer months probably occurs sporadically following localized rainstorms on the watershed.

Concentrations of dissolved iron and manganese were high in Canaan Valley streams. Dissolved iron concentrations were higher than the State limit of 500 µg/L at seven of the eight monitoring sites. Maximum concentrations of dissolved iron ranged from 380 µg/L at the mainstem monitoring site near Cortland, W. Va., to 1,100 µg/L at the site near Davis, W. Va. Concentrations of dissolved manganese frequently exceeded the recommended maximum of 50 µg/L for public water supplies. The most likely explanation for the high concentrations of dissolved iron and manganese is that the metals entering the streams in ground water are forming complexes with organic matter derived from adjacent wetlands.

Contamination from pesticide applications was not evident in Canaan Valley streams. Of 58 pesticides and other organic contaminants analyzed in August 1991 at seven water-quality-monitoring sites, only four--the herbicides picloram, 2,4-D, and simazine, and the insecticide lindane--were detectable, and all of these were at concentrations significantly lower than the MCL's.

The dominant environmental processes affecting DO concentrations for low-flow periods in Canaan Valley streams are reaeration and processes related to stream turbulence. Dissolved oxygen concentrations are most sensitive to processes affecting the rate of reaeration. The rate of reaeration is affected by processes that determine dissolved oxygen solubility (the interaction among atmospheric pressure, water temperature, humidity, and cloud cover) and processes that determine stream turbulence (the interaction among stream depth, width, velocity, and roughness).

Additional processes play significant roles in determining DO concentrations in the headwaters and beaver pools. In the headwaters, photosynthetic DO production by benthic algae can result in supersaturated DO concentrations. This process is affected by light availability (dependent upon stream depth and the presence of light absorbing organic constituents) and plant nutrients (dependent upon discharges from wastewater treatment plants and overland runoff). In beaver pools, DO consumption from SOD and CBOD can result in dissolved oxygen deficits. This process is affected by sedimentation of organic particles (dependent upon reduced velocity and increased traveltime).

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Table 3. Summaries of water-quality data collected at eight Canaan Valley monitoring sites, March 1990 to August 1992

[ft^3/s = cubic feet per second; µS/cm = microsiemens per centimeter at 25 degrees Celsius; °C = degrees Celsius; mg/L = milligrams per liter; µg/L = micrograms per liter; cols/100 mL = colonies per 100 milliliters]

Monitoring site	Streamflow, instantaneous (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature, water (°C)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percentage of saturation)	Coliform fecal, 0.7 UM-MF (cols/100 mL)
Club Run near headwaters - 390059079283401							
Median	0.08	59	6.3	16.0	7.6	85	44
Maximum	.25	81	7.1	21.0	10.3	100	310
Minimum	.02	32	5.9	4.0	5.5	66	1
Number of samples	11	11	11	11	11	11	11
Mill Run at Canaan Valley State Park, W. Va. - 390136079273301							
Median	2.1	134	7.2	17.0	10.0	97	73
Maximum	7.6	203	8.7	29.0	11.9	157	1,300
Minimum	.44	102	6.5	0.0	6.3	72	3
Number of samples	17	17	17	17	17	17	17
Blackwater River at Canaan Valley State Park, W. Va. - 03065050							
Median	11	63	6.7	14.0	8.1	84	105
Maximum	41	118	7.0	26.0	11.3	110	1,000
Minimum	1.9	49	5.9	0.0	5.3	63	2
Number of samples	17	18	18	18	18	18	18
Blackwater River on Timberline Road - 390211079253601							
Median	18	90	7.2	16.5	9.6	101	120
Maximum	94	165	8.6	26.0	13.1	182	1,800
Minimum	2.3	66	6.2	0.0	7.0	81	1
Number of samples	17	17	17	17	17	17	17

Table 3. Summaries of water-quality data collected at eight Canaan Valley monitoring sites, March 1990 to August 1992

[ft^3/s = cubic feet per second; µS/cm = microsiemens per centimeter at 25 degrees Celsius; °C = degrees Celsius; mg/L = milligrams per liter; µg/L = micrograms per liter; cols/100 mL = colonies per 100 milliliters]

Monitoring site	Streamflow, instantaneous (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature, water (°C)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percentage of saturation)	Coliform fecal, 0.7 UM-MF (cols/ 100 mL)
Club Run near headwaters - 390059079283401							
Median	0.08	59	6.3	16.0	7.6	85	44
Maximum	.25	81	7.1	21.0	10.3	100	310
Minimum	.02	32	5.9	4.0	5.5	66	1
Number of samples	11	11	11	11	11	11	11
Mill Run at Canaan Valley State Park, W. Va. - 390136079273301							
Median	2.1	134	7.2	17.0	10.0	97	73
Maximum	7.6	203	8.7	29.0	11.9	157	1,300
Minimum	.44	102	6.5	0.0	6.3	72	3
Number of samples	17	17	17	17	17	17	17
Blackwater River at Canaan Valley State Park, W. Va. - 03065050							
Median	11	63	6.7	14.0	8.1	84	105
Maximum	41	118	7.0	26.0	11.3	110	1,000
Minimum	1.9	49	5.9	0.0	5.3	63	2
Number of samples	17	18	18	18	18	18	18
Blackwater River on Timberline Road - 390211079253601							
Median	18	90	7.2	16.5	9.6	101	120
Maximum	94	165	8.6	26.0	13.1	182	1,800
Minimum	2.3	66	6.2	0.0	7.0	81	1
Number of samples	17	17	17	17	17	17	17

Table 3. Summaries of water-quality data collected at eight Canaan Valley monitoring sites, March 1990 to August 1992--*continued*

[ft^3/s = cubic feet per second; µS/cm = microsiemens per centimeter at 25 degrees Celsius; °C = degrees Celsius; mg/L = milligrams per liter; µg/L = micrograms per liter; cols/100 mL = colonies per 100 milliliters]

Monitoring site	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Solids, residue at 180 °C, dissolved (mg/L)	Nitrogen, NO_2+NO_3, total (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)
Club Run near headwaters - 390059079283401							
Median	4.9	5.4	0.1	34	0.20	0.27	0.02
Maximum	6.7	8.5	.1	50	.40	.40	.03
Minimum	3.8	.20	.1	17	.10	.10	.01
Number of samples	11	11	7	11	11	11	11
Mill Run at Canaan Valley State Park, W. Va. - 390136079273301							
Median	7.9	7.1	.1	83	.11	.10	.05
Maximum	18	15	.2	146	.41	.41	.08
Minimum	3.4	4.5	.1	59	.05	.05	.01
Number of samples	17	17	11	17	17	17	17
Blackwater River at Canaan Valley State Park, W. Va. - 03065050							
Median	6.0	3.0	.1	48	.10	.10	.04
Maximum	14	5.6	.2	97	.33	.34	.08
Minimum	3.6	1.9	.1	29	.05	.05	.01
Number of samples	18	18	12	18	18	18	18
Blackwater River on Timberline Road - 390211079253601							
Median	6.8	3.0	.1	57	.13	.20	.02
Maximum	12	5.5	.2	98	.50	.40	.11
Minimum	4.3	2.2	.1	37	.06	.06	.01
Number of samples	17	17	12	17	17	17	17

Table 3. Summaries of water-quality data collected at eight Canaan Valley monitoring sites, March 1990 to August 1992--*continued*

[ft^3/s = cubic feet per second; µS/cm = microsiemens per centimeter at 25 degrees Celsius; °C = degrees Celsius; mg/L = milligrams per liter; µg/L = micrograms per liter; cols/100 mL = colonies per 100 milliliters]

Monitoring site	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, organic, total (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Carbon, organic, dissolved (mg/L as C)
Club Run near headwaters - 390059079283401							
Median	0.02	0.34	0.01	0.01	310	47	2.6
Maximum	.03	.68	.05	.01	690	110	4.2
Minimum	.01	.17	.01	.01	100	21	2.2
Number of samples	11	6	11	11	6	6	5
Mill Run at Canaan Valley State Park, W. Va. - 390136079273301							
Median	.04	.48	.03	.01	340	92	6.9
Maximum	.08	.97	.09	.02	910	440	9.6
Minimum	.01	.16	.01	.01	140	26	4.3
Number of samples	17	17	17	17	9	9	7
Blackwater River at Canaan Valley State Park, W. Va. - 03065050							
Median	.03	.38	.03	.01	355	69	6.2
Maximum	.06	.68	.08	.01	820	230	8.6
Minimum	.01	.18	.01	.01	110	35	4.6
Number of samples	18	15	18	18	10	10	6
Blackwater River on Timberline Road - 390211079253601							
Median	.02	.36	.02	.01	260	45	5.4
Maximum	.07	.76	.06	.01	580	130	7.4
Minimum	.01	.18	.01	.01	94	26	4.7
Number of samples	17	15	17	17	10	10	6

Table 3. Summaries of water-quality data collected at eight Canaan Valley monitoring sites, March 1990 to August 1992--*continued*

[ft^3/s = cubic feet per second; µS/cm = microsiemens per centimeter at 25 degrees Celsius; °C = degrees Celsius; mg/L = milligrams per liter; µg/L = micrograms per liter; cols/100 mL = colonies per 100 milliliters]

Monitoring site	Streamflow, instantaneous (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature, water (°C)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percentage of saturation)	Coliform, fecal, 0.7 UM-MF (cols/ 100 mL)
Yoakum Run at mouth - 390346079244801							
Median	1.9	57	7.2	17.8	8.1	99	96
Maximum	11	110	7.8	25.0	12.2	105	3,200
Minimum	.11	45	5.8	1.0	6.7	89	1
Number of samples	16	16	16	16	16	16	16
Blackwater River at Cortland, W. Va. - 03065200							
Median	22	80	7.6	11.8	9.9	102	12
Maximum	105	134	8.0	23.5	12.8	117	1,400
Minimum	6.3	55	6.3	0.0	7.7	90	1
Number of samples	14	14	14	14	14	14	14
North Branch at Cortland, W. Va. - 390400079253301							
Median	10	121	7.2	15.0	9.5	98	93
Maximum	27	216	7.5	21.5	11.6	116	2,200
Minimum	1	83	6.0	1.0	8.0	85	4
Number of samples	17	17	17	17	17	17	17
Blackwater River near Davis, W. Va. - 03065400							
Median	82	67	7.1	14.3	8.5	96	45
Maximum	360	124	7.5	26.5	13.4	112	2,900
Minimum	12	47	6.5	0.0	6.8	80	3
Number of samples	18	18	18	18	18	18	18

Table 3. Summaries of water-quality data collected at eight Canaan Valley monitoring sites, March 1990 to August 1992--*continued*

[ft^3/s = cubic feet per second; μS/cm = microsiemens per centimeter at 25 degrees Celsius; °C = degrees Celsius; mg/L = milligrams per liter; μg/L = micrograms per liter; cols/100 mL = colonies per 100 milliliters]

Monitoring site	Strepto-cocci, fecal, KF agar (cols/ 100 mL)	Hard-ness, total (mg/L as $CaCO_3$)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Bicar-bonate, dis-solved (mg/L as HCO_3	Alka-linity, total, field (mg/L as $CaCO_3$)
Yoakum Run at mouth - 390346079244801								
Median	31	23	7.6	1.1	1.4	0.6	20	16
Maximum	3,300	47	16	1.6	3.5	1.2	41	34
Minimum	2	19	6.1	.76	.8	.5	13	11
Number of samples	13	16	16	16	16	16	13	13
Blackwater River at Cortland, W. Va. - 03065200								
Median	12	34	12	.98	1.7	.45	30	25
Maximum	1,700	59	21	1.6	3.7	1.0	61	50
Minimum	1	22	7.6	.74	1.3	.30	15	12
Number of samples	14	13	13	14	14	14	14	14
North Branch at Cortland, W. Va. - 390400079253301								
Median	69	47	16	1.6	2.9	.5	41	34
Maximum	2,500	100	35	3.1	5.6	1.6	101	83
Minimum	5	34	12	1.0	1.9	.4	28	23
Number of samples	14	17	17	17	17	17	14	14
Blackwater River near Davis, W. Va. - 03065400								
Median	13	29	10	1.0	1.3	.4	22	18
Maximum	3,100	54	19	1.7	3.0	.9	56	46
Minimum	1	19	6.4	.7	.9	.2	11	9
Number of samples	15	18	18	18	18	18	15	15

Table 3. Summaries of water-quality data collected at eight Canaan Valley monitoring sites, March 1990 to August 1992--*continued*

[ft^3/s = cubic feet per second; µS/cm = microsiemens per centimeter at 25 degrees Celsius; °C = degrees Celsius; mg/L = milligrams per liter; µg/L = micrograms per liter; cols/100 mL = colonies per 100 milliliters]

Monitoring site	Sulfate, dis- solved (mg/L as SO_4)	Chloride, dis- solved (mg/L as Cl)	Fluoride dis- solved (mg/L as F)	Solids, residue at 180 °C, dis- solved (mg/L)	Nitrogen, NO_2+NO_3, total (mg/L as N)	Nitrogen, NO_2+NO_3, dis- solved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)
Yoakum Run at mouth - 390346079244801							
Median	5.9	1.4	0.10	37	0.22	0.23	0.04
Maximum	8.5	3.2	.20	75	.44	.48	.25
Minimum	4.0	.8	.10	24	.10	.09	.01
Number of samples	15	15	11	15	16	16	16
Blackwater River at Cortland, W. Va. - 03065200							
Median	6.1	2.8	.1	50	.12	.20	.02
Maximum	12	5.0	.2	90	.67	.45	.06
Minimum	4.5	1.4	.1	27	.05	.05	.01
Number of samples	14	14	9	14	14	14	14
North Branch at Cortland, W. Va. - 390400079253301							
Median	7.3	4.8	.1	66	.30	.30	.03
Maximum	15	11	.1	126	.60	.60	.09
Minimum	6.3	3.0	.1	44	.20	.20	.01
Number of samples	17	17	12	17	17	17	17
Blackwater River near Davis, W. Va. - 03065400							
Median	5.8	1.9	.1	48	.11	.11	.03
Maximum	9.2	3.5	.2	78	.30	.30	.05
Minimum	3.9	.7	.1	24	.05	.05	.01
Number of samples	18	18	12	18	18	18	18

Table 3. Summaries of water-quality data collected at eight Canaan Valley monitoring sites, March 1990 to August 1992--*continued*

[ft^3/s = cubic feet per second; µS/cm = microsiemens per centimeter at 25 degrees Celsius; °C = degrees Celsius; mg/L = milligrams per liter; µg/L = micrograms per liter; cols/100 mL = colonies per 100 milliliters]

Monitoring site	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, organic, total (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Carbon, organic, dissolved (mg/L as C)
Yoakum Run at mouth - 390346079244801							
Median	0.03	0.38	0.03	0.01	495	46	4.9
Maximum	.24	.73	.06	.04	920	71	7.5
Minimum	.01	.19	.01	.01	90	22	7.2
Number of samples	16	15	16	16	10	10	5
Blackwater River at Cortland, W. Va. - 390351079244901							
Median	.02	.28	.02	.01	200	22	5.2
Maximum	.05	.88	.05	.01	380	38	7.3
Minimum	.01	.16	.01	.01	89	14	4.8
Number of samples	14	12	14	14	7	7	5
North Branch at Cortland, W. Va. - 390400079253301							
Median	.03	.28	.02	.01	210	52	3.0
Maximum	.07	1.2	.08	.02	560	160	4.8
Minimum	.01	.16	.01	.01	76	29	2.8
Number of samples	17	12	17	17	10	10	6
Blackwater River near Davis, W. Va. - 390824079251201							
Median	.02	.30	.02	.01	475	63	5.5
Maximum	.05	1.0	.05	.01	1,100	140	7.3
Minimum	.01	.20	.01	.01	140	34	4.3
Number of samples	18	16	18	18	10	10	6

APPENDIXES

Appendix A.—Computer-model output listing the input calibration data set, August 1992

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 * * * QUAL-2E  STREAM QUALITY ROUTING MODEL * * *
       Version 3.14  January 1992

  $$$ (PROBLEM TITLES) $$$

 CARD TYPE                              QUAL-2E PROGRAM TITLES
 TITLE01              BLACKWATER MAINSTEM MODEL WITH 8/18-19/92 DATA
 TITLE02              File: CAL.INP      Date: 06-28-94
 TITLE03  YES         CONSERVATIVE MINERAL I      SK   IN uScm
 TITLE04   NO         CONSERVATIVE MINERAL II     Cl   IN mg/L
 TITLE05   NO         CONSERVATIVE MINERAL III    SiO2 IN mg/L
 TITLE06  YES         TEMPERATURE
 TITLE07  YES         5-DAY BIOCHEMICAL OXYGEN DEMAND
 TITLE08  YES         ALGAE AS CHL-A IN UG/L
 TITLE09   NO         PHOSPHORUS CYCLE AS P IN MG/L
 TITLE10                (ORGANIC-P, DISSOLVED-P)
 TITLE11  YES         NITROGEN CYCLE AS N IN MG/L
 TITLE12                (ORGANIC-N, AMMONIA-N, NITRITE-N, NITRATE-N)
 TITLE13  YES         DISSOLVED OXYGEN IN MG/L
 TITLE14   NO         FECAL COLIFORMS IN NO./100 ML
 TITLE15   NO         ARBITRARY NON-CONSERVATIVE
 ENDTITLE

  $$$ DATA TYPE 1 (CONTROL DATA) $$$

 CARD TYPE                                     CARD TYPE
 LIST DATA INPUT              0.00000                                     0.00000
 WRITE OPTIONAL SUMMARY       0.00000                                     0.00000
 NO FLOW AUGMENTATION         0.00000                                     0.00000
 STEADY STATE                 0.00000                                     0.00000
 NO TRAPEZOIDAL X-SECTIONS    0.00000                                     0.00000
 PRINT LCD/SOLAR DATA         0.00000                                     0.00000
 PLOT DO AND BOD              0.00000                                     0.00000
 FIXED DNSTM COND (YES=1)=    0.00000      5D-ULT BOD CONV K COEF   =     0.03600
 INPUT METRIC (YES=1)    =    0.00000      OUTPUT METRIC (YES=1)    =     0.00000
 NUMBER OF REACHES       =   11.00000      NUMBER OF JUNCTIONS      =     0.00000
 NUM OF HEADWATERS       =    1.00000      NUMBER OF POINT LOADS    =    12.00000
 TIME STEP (HOURS)       =    0.00000      LNTH  COMP  ELEMENT (DX)=      0.10000
 MAXIMUM ITERATIONS      =   30.00000      TIME INC. FOR RPT2 (HRS)=      0.00000
 LATITUDE OF BASIN (DEG) =   39.05000      LONGITUDE OF BASIN (DEG)=     79.40000
 STANDARD MERIDIAN (DEG) =   75.00000      DAY OF YEAR START TIME   =   235.00000
 EVAP. COEFF. (AE)       =    0.00103      EVAP. COEFF. (BE)        =     0.00016
 ELEV. OF BASIN (ELEV)   =3167.00000       DUST ATTENUATION COEF.   =     0.06000
 ENDATA1                      0.00000                                     0.00000

  $$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN OXIDATION CONSTANTS) $$$

 CARD TYPE                                      CARD TYPE
 O UPTAKE BY NH3 OXID(MG O/MG N)=    3.4300     O UPTAKE BY NO2 OXID(MG O/MG N)=    1.1400
 O PROD  BY ALGAE (MG O/MG A)   =    1.6000     O UPTAKE BY ALGAE (MG O/MG A)  =    2.0000
 N CONTENT OF ALGAE (MG N/MG A) =    0.0850     P CONTENT OF ALGAE (MG P/MG A) =    0.0140
 ALG MAX SPEC GROWTH RATE(1/DAY)=    2.5000     ALGAE RESPIRATION RATE (1/DAY) =    0.0500
 N HALF SATURATION CONST (MG/L) =    0.2000     P HALF SATURATION CONST  (MG/L)=    0.0400
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LIN ALG SHADE CO (1/FT-UGCHA/L=)     0.0008          NLIN SHADE(1/FT-(UGCHA/L)**2/3)=    0.0000
LIGHT FUNCTION OPTION (LFNOPT) =     2.0000          LIGHT SAT'N COEF (BTU/FT2-MIN) =    0.0900
DAILY AVERAGING OPTION (LAVOPT)=     1.0000          TOTAL DAILY SOLAR RADTN (INT)  =    0.9200
NUMBER OF DAYLIGHT HOURS (DLH) =    14.0000          TOTAL DAILY SOLR RAD (BTU/FT-2)= 1500.0000
ALGY GROWTH CALC OPTION(LGROPT)=     2.0000          ALGAL PREF FOR NH3-N (PREFN)   =    0.9000
ALG/TEMP SOLR RAD FACTOR(TFACT)=     0.4400          NITRIFICATION INHIBITION COEF  =   10.0000
ENDATA1A                             0.0000                                              0.0000

 $$$ DATA TYPE 1B (TEMPERATURE CORRECTION CONSTANTS FOR RATE COEFFICIENTS) $$$

CARD TYPE      RATE CODE      THETA VALUE
THETA( 1)       BOD DECA         1.047     DFLT
THETA( 2)       BOD SETT         1.024     DFLT
THETA( 3)       OXY TRAN         1.024     DFLT
THETA( 4)       SOD RATE         1.060     DFLT
THETA( 5)       ORGN DEC         1.047     DFLT
THETA( 6)       ORGN SET         1.024     DFLT
THETA( 7)       NH3 DECA         1.083     DFLT
THETA( 8)       NH3 SRCE         1.074     DFLT
THETA( 9)       NO2 DECA         1.047     DFLT
THETA(10)       PORG DEC         1.047     DFLT
THETA(11)       PORG SET         1.024     DFLT
THETA(12)       DISP SRC         1.074     DFLT
THETA(13)       ALG GROW         1.047     DFLT
THETA(14)       ALG RESP         1.047     DFLT
THETA(15)       ALG SETT         1.024     DFLT
THETA(16)       COLI DEC         1.047     DFLT
THETA(17)       ANC DECA         1.000     DFLT
THETA(18)       ANC SETT         1.024     DFLT
THETA(19)       ANC SRCE         1.000     DFLT
ENDATA1B


 $$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$

CARD TYPE          REACH ORDER AND IDENT                R. MI/KM               R. MI/KM
STREAM REACH     1.0  RCH=RCH 01           FROM          18.4     TO            17.1
STREAM REACH     2.0  RCH=RCH 02           FROM          17.1     TO            15.1
STREAM REACH     3.0  RCH=RCH 03           FROM          15.1     TO            13.1
STREAM REACH     4.0  RCH=RCH 04           FROM          13.1     TO            11.1
STREAM REACH     5.0  RCH=RCH 05           FROM          11.1     TO             9.8
STREAM REACH     6.0  RCH=RCH 06           FROM           9.8     TO             8.6
STREAM REACH     7.0  RCH=RCH 07           FROM           8.6     TO             6.9
STREAM REACH     8.0  RCH=RCH 08           FROM           6.9     TO             5.1
STREAM REACH     9.0  RCH=RCH 09           FROM           5.1     TO             3.3
STREAM REACH    10.0  RCH=RCH 10           FROM           3.3     TO             1.6
STREAM REACH    11.0  RCH=RCH 11           FROM           1.6     TO             0.0
ENDATA2          0.0                                      0.0                    0.0

 $$$ DATA TYPE 3 (TARGET LEVEL DO AND FLOW AUGMENTATION SOURCES) $$$

CARD TYPE                  REACH  AVAIL HDWS TARGET     ORDER OF AVAIL SOURCES
ENDATA3                     0.        0.       0.0   0.   0.   0.   0.   0.   0.
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Appendix A.—Computer-model output listing the input calibration data set, August 1992--Continued

$$$ DATA TYPE 4 (COMPUTATIONAL REACH FLAG FIELD) $$$

CARD TYPE	REACH	ELEMENTS/REACH	COMPUTATIONAL FLAGS
FLAG FIELD	1.	13.	1.6.2.2.6.2.7.2.6.6.2.2.2.0.0.0.0.0.0.0.
FLAG FIELD	2.	20.	2.2.6.2.2.2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD	3.	20.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD	4.	20.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD	5.	13.	2.2.6.2.2.2.2.2.2.2.2.2.2.0.0.0.0.0.0.0.
FLAG FIELD	6.	12.	2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.0.0.0.0.0.
FLAG FIELD	7.	17.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.
FLAG FIELD	8.	18.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.
FLAG FIELD	9.	18.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.
FLAG FIELD	10.	17.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.
FLAG FIELD	11.	16.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.5.0.0.0.0.
ENDATA4	0.	0.	0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.

$$$ DATA TYPE 5 (HYDRAULIC DATA FOR DETERMINING VELOCITY AND DEPTH) $$$

CARD TYPE	REACH	COEF-DSPN	COEFQV	EXPOQV	COEFQH	EXPOQH	CMANN
HYDRAULICS	1.	500.00	0.059	0.338	2.050	0.309	0.034
HYDRAULICS	2.	500.00	0.017	0.338	4.316	0.309	0.020
HYDRAULICS	3.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	4.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	5.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	6.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	7.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	8.	500.00	0.059	0.338	0.723	0.309	0.034
HYDRAULICS	9.	500.00	0.059	0.338	0.723	0.309	0.034
HYDRAULICS	10.	500.00	0.059	0.338	0.723	0.309	0.034
HYDRAULICS	11.	500.00	0.059	0.338	0.723	0.309	0.037
ENDATA5	0.	0.00	0.000	0.000	0.000	0.000	0.000

$$$ DATA TYPE 5A (STEADY STATE TEMPERATURE AND CLIMATOLOGY DATA) $$$

CARD TYPE	REACH	ELEVATION	DUST COEF	CLOUD COVER	DRY BULB TEMP	WET BULB TEMP	ATM PRESSURE	WIND	SOLAR RAD ATTENUATION
TEMP/LCD	1.	3218.00	0.06	0.75	79.00	62.60	26.80	9.50	1.00
TEMP/LCD	2.	3213.00	0.06	0.75	76.00	60.80	26.80	9.50	1.00
TEMP/LCD	3.	3205.00	0.06	0.75	70.00	56.30	26.80	9.50	1.00
TEMP/LCD	4.	3186.00	0.06	0.75	76.00	60.80	26.80	9.50	1.00
TEMP/LCD	5.	3161.00	0.06	0.75	63.00	50.90	26.80	9.50	1.00
TEMP/LCD	6.	3154.00	0.06	0.75	66.00	53.60	26.80	9.50	1.00
TEMP/LCD	7.	3148.00	0.06	0.75	66.00	53.60	26.80	9.50	1.00
TEMP/LCD	8.	3142.00	0.06	0.75	64.00	50.90	26.80	9.50	1.00
TEMP/LCD	9.	3139.00	0.06	0.75	81.00	63.50	26.80	9.50	1.00
TEMP/LCD	10.	3135.00	0.06	0.75	81.00	63.50	26.80	9.50	1.00
TEMP/LCD	11.	3131.00	0.06	0.75	69.00	55.40	26.80	9.50	1.00
ENDATA5A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix A.—Computer-model output listing the input calibration data set, August 1992—Continued

$$$ DATA TYPE 6 (REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION) $$$

CARD TYPE	REACH	K1	K3	SOD RATE	K2OPT	K2	COEQK2 OR TSIV COEF OR FOR OPT 8	EXPQK2 SLOPE FOR OPT 8
REACT COEF	1.	0.04	0.00	-0.150	3.	3.00	0.000	0.00000
REACT COEF	2.	0.04	0.00	0.050	3.	3.00	0.000	0.00000
REACT COEF	3.	0.02	0.00	-0.100	3.	3.00	0.000	0.00000
REACT COEF	4.	0.02	0.00	-0.100	3.	3.00	0.000	0.00000
REACT COEF	5.	0.01	0.00	-0.050	3.	3.00	0.000	0.00000
REACT COEF	6.	0.01	0.00	-0.025	3.	3.00	0.000	0.00000
REACT COEF	7.	0.01	0.00	-0.010	3.	3.00	0.000	0.00000
REACT COEF	8.	0.01	0.00	-0.010	3.	3.00	0.000	0.00000
REACT COEF	9.	0.01	0.00	0.000	3.	3.00	0.000	0.00000
REACT COEF	10.	0.01	0.00	0.010	3.	3.00	0.000	0.00000
REACT COEF	11.	0.01	0.00	0.050	3.	3.00	0.000	0.00000
ENDATA6	0.	0.00	0.00	0.000	0.	0.00	0.000	0.00000

$$$ DATA TYPE 6A (NITROGEN AND PHOSPHORUS CONSTANTS) $$$

CARD TYPE	REACH	CKNH2	SETNH2	CKNH3	SNH3	CKNO2	CKPORG	SETPORG	SPO4
N AND P COEF	1.	0.01	-0.20	0.20	-0.10	1.00	0.10	-0.10	-0.10
N AND P COEF	2.	0.01	0.00	0.10	0.10	0.50	0.10	0.00	0.05
N AND P COEF	3.	0.01	-0.10	0.20	-0.05	1.00	0.10	-0.05	-0.10
N AND P COEF	4.	0.01	-0.10	0.20	-0.05	1.00	0.10	-0.05	-0.10
N AND P COEF	5.	0.01	-0.05	0.20	0.00	1.00	0.10	-0.01	-0.05
N AND P COEF	6.	0.01	-0.05	0.20	0.00	1.00	0.10	-0.01	-0.05
N AND P COEF	7.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	8.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	9.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	10.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	11.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
ENDATA6A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 6B (ALGAE/OTHER COEFFICIENTS) $$$

CARD TYPE	REACH	ALPHAO	ALGSET	EXCOEF	CK5 CKCOLI	CKANC	SETANC	SRCANC
ALG/OTHER COEF	1.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	2.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	3.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	4.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	5.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	6.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	7.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	8.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	9.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	10.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	11.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ENDATA6B	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix A.—Computer-model output listing the input calibration data set, August 1992—Continued

$$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$

CARD TYPE	REACH	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INITIAL COND-1	1.	66.00	7.80	0.20	59.00	2.10	3.00	0.00	110.00
INITIAL COND-1	2.	66.00	7.30	0.80	64.00	2.20	2.90	0.00	150.00
INITIAL COND-1	3.	63.00	8.10	0.30	90.00	2.90	3.10	0.00	190.00
INITIAL COND-1	4.	64.00	8.10	0.30	90.00	2.50	3.40	0.00	190.00
INITIAL COND-1	5.	66.00	8.80	0.90	82.00	2.30	2.90	0.00	47.00
INITIAL COND-1	6.	66.00	8.80	0.90	70.00	2.30	3.00	0.00	47.00
INITIAL COND-1	7.	66.00	8.40	0.20	70.00	2.30	3.00	0.00	50.00
INITIAL COND-1	8.	64.00	8.00	0.60	70.00	2.30	3.00	0.00	73.00
INITIAL COND-1	9.	67.00	8.00	0.60	86.00	2.60	3.00	0.00	120.00
INITIAL COND-1	10.	67.00	8.00	0.60	86.00	2.60	3.00	0.00	120.00
INITIAL COND-1	11.	65.00	7.30	0.40	61.00	1.60	3.10	0.00	130.00
ENDATA7	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INITIAL COND-2	1.	0.00	0.20	0.02	0.01	0.05	0.01	0.01
INITIAL COND-2	2.	0.00	0.36	0.04	0.01	0.08	0.01	0.02
INITIAL COND-2	3.	0.00	0.26	0.04	0.01	0.13	0.01	0.03
INITIAL COND-2	4.	0.00	0.26	0.04	0.01	0.13	0.01	0.03
INITIAL COND-2	5.	0.00	0.19	0.01	0.01	0.08	0.01	0.01
INITIAL COND-2	6.	0.00	0.19	0.01	0.01	0.08	0.01	0.01
INITIAL COND-2	7.	0.00	0.28	0.02	0.01	0.06	0.01	0.02
INITIAL COND-2	8.	0.00	0.25	0.05	0.01	0.08	0.01	0.01
INITIAL COND-2	9.	0.00	0.27	0.03	0.01	0.09	0.02	0.02
INITIAL COND-2	10.	0.00	0.27	0.03	0.01	0.09	0.02	0.02
INITIAL COND-2	11.	0.00	0.27	0.03	0.01	0.15	0.01	0.01
ENDATA7A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 8 (INCREMENTAL INFLOW CONDITIONS) $$$

CARD TYPE	REACH	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INCR INFLOW-1	1.	0.000	54.00	6.00	0.00	89.00	4.20	3.00	0.00	50.00
INCR INFLOW-1	2.	0.000	52.00	6.00	0.00	89.00	4.20	3.00	0.00	50.00
INCR INFLOW-1	3.	0.000	48.00	5.00	0.00	127.00	4.20	3.40	0.00	50.00
INCR INFLOW-1	4.	0.000	54.00	5.00	0.00	127.00	4.20	3.40	0.00	50.00
INCR INFLOW-1	5.	0.000	57.00	1.00	0.00	105.00	3.60	2.70	0.00	50.00
INCR INFLOW-1	6.	0.000	55.00	1.00	0.00	105.00	3.60	2.70	0.00	50.00
INCR INFLOW-1	7.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	50.00
INCR INFLOW-1	8.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	50.00
INCR INFLOW-1	9.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	50.00
INCR INFLOW-1	10.	0.000	54.00	1.00	0.00	117.00	3.10	2.30	0.00	50.00
INCR INFLOW-1	11.	0.000	54.00	1.00	0.00	117.00	3.10	2.30	0.00	50.00
ENDATA8	0.	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix A.—Computer-model output listing the input calibration data set, August 1992—Continued

$$$ DATA TYPE 8A (INCREMENTAL INFLOW CONDITIONS FOR CHLOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INCR INFLOW-2	1.	0.00	0.48	0.04	0.01	0.03	0.03	0.02
INCR INFLOW-2	2.	0.00	0.48	0.04	0.01	0.03	0.03	0.02
INCR INFLOW-2	3.	0.00	0.38	0.02	0.00	0.13	0.02	0.02
INCR INFLOW-2	4.	0.00	0.38	0.02	0.00	0.13	0.02	0.02
INCR INFLOW-2	5.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	6.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	7.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	8.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	9.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	10.	0.00	0.30	0.01	0.00	0.02	0.00	0.01
INCR INFLOW-2	11.	0.00	0.30	0.01	0.00	0.02	0.00	0.01
ENDATA8A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$

CARD TYPE	JUNCTION ORDER AND IDENT	UPSTRM	JUNCTION	TRIB
ENDATA9	0.	0.	0.	0.

$$$ DATA TYPE 10 (HEADWATER SOURCES) $$$

CARD TYPE	HDWTR ORDER	NAME	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
HEADWTR-1	1.	BLKWTR (EST)	2.60	66.00	7.60	0.10	64.00	2.10	3.10
ENDATA10	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 10A (HEADWATER CONDITIONS FOR CHLOROPHYLL, NITROGEN, PHOSPHORUS,
COLIFORM AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE	HDWTR ORDER	ANC	COLI	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
HEADWTR-2	1.	0.00	14.00	0.00	0.18	0.02	0.01	0.05	0.01	0.01
ENDATA10A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 11 (POINT SOURCE / POINT SOURCE CHARACTERISTICS) $$$

CARD TYPE	POINT LOAD ORDER	NAME	EFF	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
POINTLD-1	1.	CLB RN (EST)	0.00	1.70	66.00	7.80	0.20	64.00	2.10	3.10
POINTLD-1	2.	MILL RUN C2	0.00	4.30	64.00	7.50	0.90	147.00	4.50	2.50
POINTLD-1	3.	CVSP WTP W1	0.00	-0.12	66.00	7.80	0.20	59.00	2.10	3.00
POINTLD-1	4.	CVSP LDG D5	0.00	0.04	70.00	5.10	4.50	300.00	20.00	0.50
POINTLD-1	5.	COON R (EST)	0.00	1.10	66.00	8.50	0.90	64.00	2.10	3.10
POINTLD-1	6.	RSCHMIDT D6	0.00	0.00	70.00	0.00	0.00	0.00	0.00	0.00
POINTLD-1	7.	BLKWT CTR D9	0.00	0.00	70.00	0.00	0.00	0.00	0.00	0.00
POINTLD-1	8.	FRELND R C8	0.00	2.90	57.00	9.20	0.00	69.00	0.80	4.00

Appendix A.—Computer-model output listing the input calibration data set, August 1992—Continued

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POINTLD-1      9.  YOAKUM R C14         0.00     2.20    65.00     7.50     0.50    61.00     2.00     3.50
POINTLD-1     10.  SAND RUN C16         0.00     4.50    68.00     7.40     1.10    51.00     2.00     3.50
POINTLD-1     11.  N BRANCH C20         0.00     9.00    64.00     7.80     0.80   124.00     4.50     3.00
POINTLD-1     12.  L BLKWTR C22         0.00    16.20    67.00     7.20     1.00    43.00     0.10     3.40
ENDATA11       0.                       0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 $$$ DATA TYPE 11A (POINT SOURCE CHARACTERISTICS - CHLOROPHYLL A, NITROGEN, PHOSPHORUS,
                   COLIFORMS AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

              POINT
CARD TYPE      LOAD     ANC      COLI     CHL-A    ORG-N    NH3-N    NO2-N    N03-N    ORG-P    DIS-P
              ORDER
POINTLD-2       1.     0.00     10.00     0.00     0.20     0.02     0.01     0.05     0.01     0.01
POINTLD-2       2.     0.00    400.00     0.00     0.17     0.03     0.01     0.12     0.01     0.01
POINTLD-2       3.     0.00    110.00     0.00     0.20     0.02     0.01     0.05     0.01     0.01
POINTLD-2       4.     0.00     31.00     0.00     0.72     0.28     0.02     0.04     0.30     1.70
POINTLD-2       5.     0.00    100.00     0.00     0.18     0.02     0.01     0.05     0.01     0.02
POINTLD-2       6.     0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
POINTLD-2       7.     0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
POINTLD-2       8.     0.00    490.00     0.00     0.20     0.02     0.01     0.28     0.01     0.01
POINTLD-2       9.     0.00    130.00     0.00     0.26     0.04     0.01     0.18     0.05     0.01
POINTLD-2      10.     0.00     28.00     0.00     0.25     0.05     0.01     0.08     0.01     0.01
POINTLD-2      11.     0.00    260.00     0.00     0.17     0.03     0.01     0.16     0.01     0.02
POINTLD-2      12.     0.00    180.00     0.00     0.35     0.05     0.01     0.05     0.01     0.01
ENDATA11A       0.     0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 $$$ DATA TYPE 12 (DAM CHARACTERISTICS) $$$

                       DAM   RCH   ELE   ADAM     BDAM     FDAM     HDAM
ENDATA12                0.    0.    0.   0.00     0.00     0.00     0.00

 $$$ DATA TYPE 13 (DOWNSTREAM BOUNDARY CONDITIONS-1) $$$

    CARD TYPE              TEMP       D.O.      BOD       CM-1      CM-2      CM-3       ANC       COLI
DOWNSTREAM BOUNDARY-1      DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED
ENDATA13

 $$$ DATA TYPE 13A (DOWNSTREAM BOUNDARY CONDITIONS-2) $$$
    CARD TYPE              CHL-A     ORG-N     NH3-N     NO2-N     NH3-N     ORG-P     DIS-P

ENDATA13A                  DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED
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Appendix B.—Computer-model output listing the input verification data set, July 1992

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* * * QUAL-2E  STREAM QUALITY ROUTING MODEL * * *
      Version 3.14  January 1992

 $$$ (PROBLEM TITLES) $$$

CARD TYPE                             QUAL-2E PROGRAM TITLES
TITLE01             BLACKWATER MAINSTEM MODEL WITH 7/14-17/92 DATA
TITLE02             File: VER1.INP      Date: 06-22-94
TITLE03  YES        CONSERVATIVE MINERAL I     SK   IN uScm
TITLE04  YES        CONSERVATIVE MINERAL II    Cl   IN mg/L
TITLE05  YES        CONSERVATIVE MINERAL III   SiO2 IN mg/L
TITLE06  YES        TEMPERATURE
TITLE07  YES        5-DAY BIOCHEMICAL OXYGEN DEMAND
TITLE08  YES        ALGAE AS CHL-A IN UG/L
TITLE09  YES        PHOSPHORUS CYCLE AS P IN MG/L
TITLE10               (ORGANIC-P, DISSOLVED-P)
TITLE11  YES        NITROGEN CYCLE AS N IN MG/L
TITLE12               (ORGANIC-N, AMMONIA-N, NITRITE-N, NITRATE-N)
TITLE13  YES        DISSOLVED OXYGEN IN MG/L
TITLE14  YES        FECAL COLIFORMS IN NO./100 ML
TITLE15   NO        ARBITRARY NON-CONSERVATIVE
ENDTITLE

 $$$ DATA TYPE 1 (CONTROL DATA) $$$

CARD TYPE                                   CARD TYPE
LIST DATA INPUT             0.00000                                     0.00000
WRITE OPTIONAL SUMMARY      0.00000                                     0.00000
NO FLOW AUGMENTATION        0.00000                                     0.00000
STEADY STATE                0.00000                                     0.00000
NO TRAPEZOIDAL X-SECTIONS   0.00000                                     0.00000
PRINT LCD/SOLAR DATA        0.00000                                     0.00000
PLOT DO AND BOD             0.00000                                     0.00000
FIXED DNSTM COND (YES=1)=   0.00000         5D-ULT BOD CONV K COEF  =   0.04000
INPUT METRIC (YES=1)    =   0.00000         OUTPUT METRIC (YES=1)   =   0.00000
NUMBER OF REACHES       =  11.00000         NUMBER OF JUNCTIONS     =   0.00000
NUM OF HEADWATERS       =   1.00000         NUMBER OF POINT LOADS   =  12.00000
TIME STEP (HOURS)       =   0.00000         LNTH  COMP  ELEMENT (DX)=   0.10000
MAXIMUM ITERATIONS      =  30.00000         TIME INC. FOR RPT2 (HRS)=   0.00000
LATITUDE OF BASIN (DEG) =  39.05000         LONGITUDE OF BASIN (DEG)=  79.40000
STANDARD MERIDIAN (DEG) =  75.00000         DAY OF YEAR START TIME  = 195.00000
EVAP. COEFF. (AE)       =   0.00103         EVAP. COEFF. (BE)       =   0.00016
ELEV. OF BASIN (ELEV)   =3167.00000         DUST ATTENUATION COEF.  =   0.06000
ENDATA1                     0.00000                                     0.00000

 $$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN OXIDATION CONSTANTS) $$$

CARD TYPE                                          CARD TYPE
O UPTAKE BY NH3 OXID(MG O/MG N)=     3.4300        O UPTAKE BY NO2 OXID(MG O/MG N)=     1.1400
O PROD  BY ALGAE (MG O/MG A)   =     1.6000        O UPTAKE BY ALGAE (MG O/MG A)  =     2.0000
N CONTENT OF ALGAE (MG N/MG A) =     0.0850        P CONTENT OF ALGAE (MG P/MG A) =     0.0140
ALG MAX SPEC GROWTH RATE(1/DAY)=     2.5000        ALGAE RESPIRATION RATE (1/DAY) =     0.0500
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Appendix B.—Computer-model output listing the input verification data set, July 1992--Continued

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N HALF SATURATION CONST (MG/L) =      0.2000       P HALF SATURATION CONST  (MG/L)=     0.0400
LIN ALG SHADE CO (1/FT-UGCHA/L=)      0.0008       NLIN SHADE(1/FT-(UGCHA/L)**2/3)=     0.0000
LIGHT FUNCTION OPTION (LFNOPT) =      2.0000       LIGHT SAT'N COEF (BTU/FT2-MIN) =     0.0900
DAILY AVERAGING OPTION (LAVOPT)=      1.0000       TOTAL DAILY SOLAR RADTN (INT)  =     0.9200
NUMBER OF DAYLIGHT HOURS (DLH) =     14.0000       TOTAL DAILY SOLR RAD (BTU/FT-2)=  1500.0000
ALGY GROWTH CALC OPTION(LGROPT)=      2.0000       ALGAL PREF FOR NH3-N (PREFN)   =     0.9000
ALG/TEMP SOLR RAD FACTOR(TFACT)=      0.4400       NITRIFICATION INHIBITION COEF  =    10.0000
ENDATA1A                              0.0000                                            0.0000

 $$$ DATA TYPE 1B (TEMPERATURE CORRECTION CONSTANTS FOR RATE COEFFICIENTS) $$$

CARD TYPE      RATE CODE      THETA VALUE
THETA( 1)       BOD DECA         1.047      DFLT
THETA( 2)       BOD SETT         1.024      DFLT
THETA( 3)       OXY TRAN         1.024      DFLT
THETA( 4)       SOD RATE         1.060      DFLT
THETA( 5)       ORGN DEC         1.047      DFLT
THETA( 6)       ORGN SET         1.024      DFLT
THETA( 7)       NH3 DECA         1.083      DFLT
THETA( 8)       NH3 SRCE         1.074      DFLT
THETA( 9)       NO2 DECA         1.047      DFLT
THETA(10)       PORG DEC         1.047      DFLT
THETA(11)       PORG SET         1.024      DFLT
THETA(12)       DISP SRC         1.074      DFLT
THETA(13)       ALG GROW         1.047      DFLT
THETA(14)       ALG RESP         1.047      DFLT
THETA(15)       ALG SETT         1.024      DFLT
THETA(16)       COLI DEC         1.047      DFLT
THETA(17)       ANC DECA         1.000      DFLT
THETA(18)       ANC SETT         1.024      DFLT
THETA(19)       ANC SRCE         1.000      DFLT
ENDATA1B

 $$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$

CARD TYPE           REACH ORDER AND IDENT                R. MI/KM           R. MI/KM
STREAM REACH     1.0  RCH=RCH 01            FROM           18.4      TO        17.1
STREAM REACH     2.0  RCH=RCH 02            FROM           17.1      TO        15.1
STREAM REACH     3.0  RCH=RCH 03            FROM           15.1      TO        13.1
STREAM REACH     4.0  RCH=RCH 04            FROM           13.1      TO        11.1
STREAM REACH     5.0  RCH=RCH 05            FROM           11.1      TO         9.8
STREAM REACH     6.0  RCH=RCH 06            FROM            9.8      TO         8.6
STREAM REACH     7.0  RCH=RCH 07            FROM            8.6      TO         6.9
STREAM REACH     8.0  RCH=RCH 08            FROM            6.9      TO         5.1
STREAM REACH     9.0  RCH=RCH 09            FROM            5.1      TO         3.3
STREAM REACH    10.0  RCH=RCH 10            FROM            3.3      TO         1.6
STREAM REACH    11.0  RCH=RCH 11            FROM            1.6      TO         0.0
ENDATA2          0.0                                        0.0                 0.0
```

Appendix B.—Computer-model output listing the input verification data set, July 1992--Continued

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 $$$ DATA TYPE 3 (TARGET LEVEL DO AND FLOW AUGMENTATION SOURCES) $$$

CARD TYPE                  REACH  AVAIL HDWS TARGET     ORDER OF AVAIL SOURCES
ENDATA3                     0.         0.       0.0  0.   0.   0.   0.   0.   0.

 $$$ DATA TYPE 4 (COMPUTATIONAL REACH FLAG FIELD) $$$

CARD TYPE         REACH ELEMENTS/REACH             COMPUTATIONAL FLAGS
FLAG FIELD         1.        13.         1.6.2.2.6.2.7.2.6.6.2.2.2.0.0.0.0.0.0.0.
FLAG FIELD         2.        20.         2.2.6.2.2.2.2.6.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD         3.        20.         2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD         4.        20.         2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD         5.        13.         2.2.6.2.2.2.2.2.2.2.2.2.2.0.0.0.0.0.0.0.
FLAG FIELD         6.        12.         2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.0.0.0.0.0.
FLAG FIELD         7.        17.         2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.
FLAG FIELD         8.        18.         2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.
FLAG FIELD         9.        18.         2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.
FLAG FIELD        10.        17.         2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.
FLAG FIELD        11.        16.         2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.5.0.0.0.0.
ENDATA4            0.         0.         0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.

 $$$ DATA TYPE 5 (HYDRAULIC DATA FOR DETERMINING VELOCITY AND DEPTH) $$$

CARD TYPE         REACH  COEF-DSPN  COEFQV    EXPOQV    COEFQH   EXPOQH     CMANN
HYDRAULICS         1.    500.00     0.059     0.338     2.050     0.309     0.034
HYDRAULICS         2.    500.00     0.017     0.338     4.316     0.309     0.034
HYDRAULICS         3.    500.00     0.059     0.338     1.014     0.309     0.043
HYDRAULICS         4.    500.00     0.059     0.338     1.014     0.309     0.043
HYDRAULICS         5.    500.00     0.059     0.338     1.014     0.309     0.043
HYDRAULICS         6.    500.00     0.059     0.338     1.014     0.309     0.043
HYDRAULICS         7.    500.00     0.059     0.338     1.014     0.309     0.043
HYDRAULICS         8.    500.00     0.059     0.338     0.723     0.309     0.034
HYDRAULICS         9.    500.00     0.059     0.338     0.723     0.309     0.034
HYDRAULICS        10.    500.00     0.059     0.338     0.723     0.309     0.034
HYDRAULICS        11.    500.00     0.059     0.338     0.723     0.309     0.037
ENDATA5            0.      0.00     0.000     0.000     0.000     0.000     0.000

 $$$ DATA TYPE 5A (STEADY STATE TEMPERATURE AND CLIMATOLOGY DATA) $$$

CARD TYPE                             DUST     CLOUD    DRY BULB  WET BULB    ATM                SOLAR RAD
                 REACH   ELEVATION    COEF     COVER      TEMP      TEMP     PRESSURE     WIND   ATTENUATION
TEMP/LCD           1.     3218.00     0.06      0.75     82.40     65.30     26.60     11.00       1.00
TEMP/LCD           2.     3213.00     0.06      0.75     71.60     57.20     26.60     11.00       1.00
TEMP/LCD           3.     3205.00     0.06      0.75     77.00     60.80     26.60     11.00       1.00
TEMP/LCD           4.     3186.00     0.06      0.75     77.00     60.80     26.60     11.00       1.00
TEMP/LCD           5.     3161.00     0.06      0.75     81.50     64.40     26.60     11.00       1.00
TEMP/LCD           6.     3154.00     0.06      0.75     81.50     64.40     26.60     11.00       1.00
TEMP/LCD           7.     3148.00     0.06      0.75     71.60     57.20     26.60     11.00       1.00
TEMP/LCD           8.     3142.00     0.06      0.75     77.90     61.70     26.60     11.00       1.00
TEMP/LCD           9.     3139.00     0.06      0.75     82.40     65.30     26.60     11.00       1.00
TEMP/LCD          10.     3135.00     0.06      0.75     82.40     65.30     26.60     11.00       1.00
TEMP/LCD          11.     3131.00     0.06      0.75     78.80     62.60     26.60     11.00       1.00
ENDATA5A           0.        0.00     0.00      0.00      0.00      0.00      0.00      0.00       0.00
```

$$$ DATA TYPE 6 (REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION) $$$

CARD TYPE	REACH	K1	K3	SOD RATE	K2OPT	K2	COEQK2 TSIV COEF FOR OPT 8	OR OR	EXPQK2 SLOPE FOR OPT 8
REACT COEF	1.	0.04	0.00	-0.150	3.	3.00	0.000		0.00000
REACT COEF	2.	0.04	0.00	0.050	3.	3.00	0.000		0.00000
REACT COEF	3.	0.02	0.00	-0.100	3.	3.00	0.000		0.00000
REACT COEF	4.	0.02	0.00	-0.100	3.	3.00	0.000		0.00000
REACT COEF	5.	0.01	0.00	-0.050	3.	3.00	0.000		0.00000
REACT COEF	6.	0.01	0.00	-0.025	3.	3.00	0.000		0.00000
REACT COEF	7.	0.01	0.00	-0.010	3.	3.00	0.000		0.00000
REACT COEF	8.	0.01	0.00	-0.010	3.	3.00	0.000		0.00000
REACT COEF	9.	0.01	0.00	0.000	3.	3.00	0.000		0.00000
REACT COEF	10.	0.01	0.00	0.010	3.	3.00	0.000		0.00000
REACT COEF	11.	0.01	0.00	0.050	3.	3.00	0.000		0.00000
ENDATA6	0.	0.00	0.00	0.000	0.	0.00	0.000		0.00000

$$$ DATA TYPE 6A (NITROGEN AND PHOSPHORUS CONSTANTS) $$$

CARD TYPE	REACH	CKNH2	SETNH2	CKNH3	SNH3	CKNO2	CKPORG	SETPORG	SPO4
N AND P COEF	1.	0.01	-0.20	0.20	-0.10	1.00	0.10	-0.10	-0.10
N AND P COEF	2.	0.01	0.00	0.10	0.00	0.50	0.10	0.00	0.05
N AND P COEF	3.	0.01	-0.10	0.20	-0.05	1.00	0.10	-0.05	-0.10
N AND P COEF	4.	0.01	-0.10	0.20	-0.05	1.00	0.10	-0.05	-0.10
N AND P COEF	5.	0.01	-0.05	0.20	0.00	1.00	0.10	-0.01	-0.05
N AND P COEF	6.	0.01	-0.05	0.20	0.00	1.00	0.10	-0.01	-0.05
N AND P COEF	7.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	8.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	9.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	10.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	11.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
ENDATA6A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 6B (ALGAE/OTHER COEFFICIENTS) $$$

CARD TYPE	REACH	ALPHAO	ALGSET	EXCOEF	CK5 CKCOLI	CKANC	SETANC	SRCANC
ALG/OTHER COEF	1.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	2.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	3.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	4.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	5.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	6.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	7.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	8.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	9.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	10.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	11.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ENDATA6B	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix B.—Computer-model output listing the input verification data set, July 1992--Continued

$$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$

CARD TYPE	REACH	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INITIAL COND-1	1.	79.00	6.50	0.70	56.00	2.60	2.80	0.00	260.00
INITIAL COND-1	2.	69.00	6.70	0.90	73.00	0.40	4.10	0.00	1700.00
INITIAL COND-1	3.	73.00	7.20	0.70	79.00	3.10	3.00	0.00	410.00
INITIAL COND-1	4.	73.00	7.20	0.70	79.00	3.10	3.00	0.00	410.00
INITIAL COND-1	5.	78.00	7.30	0.90	72.00	2.90	2.80	0.00	190.00
INITIAL COND-1	6.	78.00	7.30	0.90	72.00	2.90	2.80	0.00	190.00
INITIAL COND-1	7.	73.00	7.70	0.70	93.00	1.10	2.00	0.00	50.00
INITIAL COND-1	8.	75.00	7.10	1.10	76.00	2.40	2.40	0.00	32.00
INITIAL COND-1	9.	72.00	6.90	1.20	85.00	3.00	2.60	0.00	130.00
INITIAL COND-1	10.	72.00	6.90	1.20	85.00	3.00	2.60	0.00	130.00
INITIAL COND-1	11.	77.00	7.30	0.90	75.00	0.70	3.00	0.00	70.00
ENDATA7	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INITIAL COND-2	1.	0.00	0.25	0.05	0.01	0.05	0.01	0.01
INITIAL COND-2	2.	0.00	0.20	0.02	0.01	0.41	0.01	0.05
INITIAL COND-2	3.	0.00	0.43	0.07	0.01	0.08	0.02	0.02
INITIAL COND-2	4.	0.00	0.43	0.07	0.01	0.08	0.02	0.02
INITIAL COND-2	5.	0.00	0.45	0.05	0.01	0.10	0.01	0.04
INITIAL COND-2	6.	0.00	0.45	0.05	0.01	0.10	0.01	0.04
INITIAL COND-2	7.	0.00	0.37	0.03	0.01	0.12	0.01	0.02
INITIAL COND-2	8.	0.00	0.66	0.04	0.01	0.09	0.02	0.03
INITIAL COND-2	9.	0.00	0.36	0.04	0.01	0.09	0.01	0.01
INITIAL COND-2	10.	0.00	0.36	0.04	0.01	0.09	0.01	0.01
INITIAL COND-2	11.	0.00	0.45	0.05	0.01	0.10	0.01	0.01
ENDATA7A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 8 (INCREMENTAL INFLOW CONDITIONS) $$$

CARD TYPE	REACH	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INCR INFLOW-1	1.	0.000	54.00	6.00	0.00	89.00	4.20	3.00	0.00	50.00
INCR INFLOW-1	2.	0.000	52.00	6.00	0.00	89.00	4.20	3.00	0.00	50.00
INCR INFLOW-1	3.	0.000	48.00	5.00	0.00	127.00	4.20	3.40	0.00	50.00
INCR INFLOW-1	4.	0.000	54.00	5.00	0.00	127.00	4.20	3.40	0.00	50.00
INCR INFLOW-1	5.	0.000	57.00	1.00	0.00	105.00	3.60	2.70	0.00	50.00
INCR INFLOW-1	6.	0.000	55.00	1.00	0.00	105.00	3.60	2.70	0.00	50.00
INCR INFLOW-1	7.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	50.00
INCR INFLOW-1	8.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	50.00
INCR INFLOW-1	9.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	50.00
INCR INFLOW-1	10.	0.000	54.00	1.00	0.00	117.00	3.10	2.30	0.00	50.00
INCR INFLOW-1	11.	0.000	54.00	1.00	0.00	117.00	3.10	2.30	0.00	50.00
ENDATA8	0.	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix B.—Computer-model output listing the input verification data set, July 1992--Continued

$$$ DATA TYPE 8A (INCREMENTAL INFLOW CONDITIONS FOR CHLOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INCR INFLOW-2	1.	0.00	0.48	0.04	0.01	0.03	0.03	0.02
INCR INFLOW-2	2.	0.00	0.48	0.04	0.01	0.03	0.03	0.02
INCR INFLOW-2	3.	0.00	0.38	0.02	0.00	0.13	0.02	0.02
INCR INFLOW-2	4.	0.00	0.38	0.02	0.00	0.13	0.02	0.02
INCR INFLOW-2	5.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	6.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	7.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	8.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	9.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	10.	0.00	0.30	0.01	0.00	0.02	0.00	0.01
INCR INFLOW-2	11.	0.00	0.30	0.01	0.00	0.02	0.00	0.01
ENDATA8A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$

CARD TYPE	JUNCTION ORDER AND IDENT	UPSTRM	JUNCTION	TRIB
ENDATA9	0.	0.	0.	0.

$$$ DATA TYPE 10 (HEADWATER SOURCES) $$$

CARD TYPE	HDWTR ORDER	NAME	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
HEADWTR-1	1.	BLKWTR (EST)	2.60	70.00	6.40	1.00	59.00	6.00	2.50
ENDATA10	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 10A (HEADWATER CONDITIONS FOR CHLOROPHYLL, NITROGEN, PHOSPHORUS,
COLIFORM AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE	HDWTR ORDER	ANC	COLI	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
HEADWTR-2	1.	0.00	200.00	0.00	0.17	0.03	0.01	0.19	0.01	0.01
ENDATA10A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 11 (POINT SOURCE / POINT SOURCE CHARACTERISTICS) $$$

CARD TYPE	POINT LOAD ORDER	NAME	EFF	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
POINTLD-1	1.	CLB RN (EST)	0.00	1.70	70.00	6.40	2.00	59.00	6.00	2.50
POINTLD-1	2.	MILL RUN C2	0.00	4.30	69.00	6.50	0.80	185.00	11.00	2.60
POINTLD-1	3.	CVSP WTP W1	0.00	-0.12	78.00	6.50	0.70	56.00	2.60	2.80
POINTLD-1	4.	CVSP LDG D5	0.00	0.14	73.00	6.50	8.70	312.00	20.00	1.70
POINTLD-1	5.	COON R (EST)	0.00	1.10	78.00	7.30	0.70	56.00	2.40	2.90
POINTLD-1	6.	RSCHMIDT D6	0.00	0.00	70.00	0.00	0.00	0.00	0.00	0.00
POINTLD-1	7.	BLKWT CTR D9	0.00	0.00	70.00	0.00	0.00	0.00	0.00	0.00
POINTLD-1	8.	FRELND R C8	0.00	2.90	67.00	8.20	0.10	86.00	3.20	2.90

Appendix B.—Computer-model output listing the input verification data set, July 1992--Continued

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POINTLD-1      9.  YOAKUM R C14          0.00     2.20    77.00     6.70     0.90    73.00     1.00     2.90
POINTLD-1     10.  SAND RUN C16          0.00     4.50    72.00     7.00     1.10    60.00     0.30     2.50
POINTLD-1     11.  N BRANCH C20          0.00     9.00    75.00     7.00     1.10   117.00     5.00     2.90
POINTLD-1     12.  L BLKWTR C22          0.00    16.20    73.00     7.50     1.40    67.00     0.30     3.60
ENDATA11       0.                        0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 $$$ DATA TYPE 11A (POINT SOURCE CHARACTERISTICS - CHLOROPHYLL A, NITROGEN, PHOSPHORUS,
                   COLIFORMS AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

              POINT
CARD TYPE      LOAD     ANC      COLI     CHL-A     ORG-N     NH3-N     NO2-N     N03-N     ORG-P     DIS-P
              ORDER
POINTLD-2       1.     0.00    200.00     0.00      0.17      0.03      0.01      0.19      0.01      0.01
POINTLD-2       2.     0.00    640.00     0.00      0.71      0.09      0.02      0.15      0.02      0.03
POINTLD-2       3.     0.00    260.00     0.00      0.25      0.05      0.01      0.05      0.01      0.01
POINTLD-2       4.     0.00     97.00     0.00      1.20      0.06      0.01      0.05      0.07      0.87
POINTLD-2       5.     0.00    320.00     0.00      0.35      0.05      0.01      0.06      0.03      0.01
POINTLD-2       6.     0.00      0.00     0.00      0.00      0.00      0.00      0.00      0.00      0.00
POINTLD-2       7.     0.00      0.00     0.00      0.00      0.00      0.00      0.00      0.00      0.00
POINTLD-2       8.     0.00   1000.00     0.00      0.42      0.08      0.01      0.06      0.01      0.04
POINTLD-2       9.     0.00    280.00     0.00      0.43      0.07      0.01      0.21      0.01      0.02
POINTLD-2      10.     0.00    110.00     0.00      0.28      0.02      0.01      0.08      0.01      0.02
POINTLD-2      11.     0.00    310.00     0.00      0.34      0.06      0.01      0.18      0.01      0.03
POINTLD-2      12.     0.00    180.00     0.00      0.24      0.06      0.02      0.34      0.04      0.01
ENDATA11A       0.     0.00      0.00     0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 12 (DAM CHARACTERISTICS) $$$

                         DAM    RCH    ELE     ADAM      BDAM      FDAM      HDAM
ENDATA12                  0.     0.     0.     0.00      0.00      0.00      0.00

 $$$ DATA TYPE 13 (DOWNSTREAM BOUNDARY CONDITIONS-1) $$$
     CARD TYPE               TEMP       D.O.       BOD        CM-1       CM-2       CM-3       ANC       COLI

DOWNSTREAM BOUNDARY-1        DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED
ENDATA13

 $$$ DATA TYPE 13A (DOWNSTREAM BOUNDARY CONDITIONS-2) $$$

     CARD TYPE               CHL-A      ORG-N      NH3-N      NO2-N      NH3-N      ORG-P      DIS-P
ENDATA13A                    DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED
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Appendix C.—Computer-model output listing the input verification data set, July-August 1991

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* * * QUAL-2E  STREAM QUALITY ROUTING MODEL * * *
         Version 3.14  January 1992

 $$$ (PROBLEM TITLES) $$$

CARD TYPE                         QUAL-2E PROGRAM TITLES
TITLE01             BLACKWATER MAINSTEM MODEL WITH 7/30-8/1/91 DATA
TITLE02             File: VER2.INP      Date: 06-22-94
TITLE03  YES        CONSERVATIVE MINERAL I     SK   IN uScm
TITLE04  YES        CONSERVATIVE MINERAL II    Cl   IN mg/L
TITLE05  YES        CONSERVATIVE MINERAL III   SiO2 IN mg/L
TITLE06  YES        TEMPERATURE
TITLE07  YES        5-DAY BIOCHEMICAL OXYGEN DEMAND
TITLE08  YES        ALGAE AS CHL-A IN UG/L
TITLE09  YES        PHOSPHORUS CYCLE AS P IN MG/L
TITLE10               (ORGANIC-P, DISSOLVED-P)
TITLE11  YES        NITROGEN CYCLE AS N IN MG/L
TITLE12               (ORGANIC-N, AMMONIA-N, NITRITE-N, NITRATE-N)
TITLE13  YES        DISSOLVED OXYGEN IN MG/L
TITLE14  YES        FECAL COLIFORMS IN NO./100 ML
TITLE15   NO        ARBITRARY NON-CONSERVATIVE
ENDTITLE

 $$$ DATA TYPE 1 (CONTROL DATA) $$$

CARD TYPE                                CARD TYPE
LIST DATA INPUT            0.00000                                   0.00000
WRITE OPTIONAL SUMMARY     0.00000                                   0.00000
NO FLOW AUGMENTATION       0.00000                                   0.00000
STEADY STATE               0.00000                                   0.00000
NO TRAPEZOIDAL X-SECTIONS  0.00000                                   0.00000
PRINT LCD/SOLAR DATA       0.00000                                   0.00000
PLOT DO AND BOD            0.00000                                   0.00000
FIXED DNSTM COND (YES=1)=  0.00000       5D-ULT BOD CONV K COEF  =   0.04000
INPUT METRIC (YES=1)    =  0.00000       OUTPUT METRIC (YES=1)   =   0.00000
NUMBER OF REACHES       = 11.00000       NUMBER OF JUNCTIONS     =   0.00000
NUM OF HEADWATERS       =  1.00000       NUMBER OF POINT LOADS   =  12.00000
TIME STEP (HOURS)       =  0.00000       LNTH  COMP  ELEMENT (DX)=   0.10000
MAXIMUM ITERATIONS      = 30.00000       TIME INC. FOR RPT2 (HRS)=   0.00000
LATITUDE OF BASIN (DEG) = 39.05000       LONGITUDE OF BASIN (DEG)=  79.40000
STANDARD MERIDIAN (DEG) = 75.00000       DAY OF YEAR START TIME  = 211.00000
EVAP. COEFF. (AE)       =  0.00103       EVAP. COEFF. (BE)       =   0.00016
ELEV. OF BASIN (ELEV)   =3167.00000      DUST ATTENUATION COEF.  =   0.06000
ENDATA1                    0.00000                                   0.00000

 $$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN OXIDATION CONSTANTS) $$$

CARD TYPE                                     CARD TYPE
O UPTAKE BY NH3 OXID(MG O/MG N)=    3.4300    O UPTAKE BY NO2 OXID(MG O/MG N)=    1.1400
O PROD  BY ALGAE (MG O/MG A)   =    1.6000    O UPTAKE BY ALGAE (MG O/MG A)  =    2.0000
N CONTENT OF ALGAE (MG N/MG A) =    0.0850    P CONTENT OF ALGAE (MG P/MG A) =    0.0140
ALG MAX SPEC GROWTH RATE(1/DAY)=    2.5000    ALGAE RESPIRATION RATE (1/DAY) =    0.0500
N HALF SATURATION CONST (MG/L) =    0.2000    P HALF SATURATION CONST  (MG/L)=    0.0400
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Appendix C.—Computer-model output listing the input verification data set, July-August 1991--Continued

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LIN ALG SHADE CO (1/FT-UGCHA/L=)     0.0008        NLIN SHADE(1/FT-(UGCHA/L)**2/3)=    0.0000
LIGHT FUNCTION OPTION (LFNOPT) =     2.0000        LIGHT SAT'N COEF (BTU/FT2-MIN) =    0.0900
DAILY AVERAGING OPTION (LAVOPT)=     1.0000        TOTAL DAILY SOLAR RADTN (INT)  =    0.9200
NUMBER OF DAYLIGHT HOURS (DLH) =    14.0000        TOTAL DAILY SOLR RAD (BTU/FT-2)= 1500.0000
ALGY GROWTH CALC OPTION(LGROPT)=     2.0000        ALGAL PREF FOR NH3-N (PREFN)   =    0.9000
ALG/TEMP SOLR RAD FACTOR(TFACT)=     0.4400        NITRIFICATION INHIBITION COEF  =   10.0000
ENDATA1A                             0.0000                                            0.0000

 $$$ DATA TYPE 1B (TEMPERATURE CORRECTION CONSTANTS FOR RATE COEFFICIENTS) $$$

CARD TYPE     RATE CODE     THETA VALUE
THETA( 1)      BOD DECA        1.047     DFLT
THETA( 2)      BOD SETT        1.024     DFLT
THETA( 3)      OXY TRAN        1.024     DFLT
THETA( 4)      SOD RATE        1.060     DFLT
THETA( 5)      ORGN DEC        1.047     DFLT
THETA( 6)      ORGN SET        1.024     DFLT
THETA( 7)      NH3 DECA        1.083     DFLT
THETA( 8)      NH3 SRCE        1.074     DFLT
THETA( 9)      NO2 DECA        1.047     DFLT
THETA(10)      PORG DEC        1.047     DFLT
THETA(11)      PORG SET        1.024     DFLT
THETA(12)      DISP SRC        1.074     DFLT
THETA(13)      ALG GROW        1.047     DFLT
THETA(14)      ALG RESP        1.047     DFLT
THETA(15)      ALG SETT        1.024     DFLT
THETA(16)      COLI DEC        1.047     DFLT
THETA(17)      ANC DECA        1.000     DFLT
THETA(18)      ANC SETT        1.024     DFLT
THETA(19)      ANC SRCE        1.000     DFLT
ENDATA1B

 $$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$

CARD TYPE          REACH ORDER AND IDENT              R. MI/KM              R. MI/KM
STREAM REACH     1.0  RCH=RCH 01           FROM        18.4     TO          17.1
STREAM REACH     2.0  RCH=RCH 02           FROM        17.1     TO          15.1
STREAM REACH     3.0  RCH=RCH 03           FROM        15.1     TO          13.1
STREAM REACH     4.0  RCH=RCH 04           FROM        13.1     TO          11.1
STREAM REACH     5.0  RCH=RCH 05           FROM        11.1     TO           9.8
STREAM REACH     6.0  RCH=RCH 06           FROM         9.8     TO           8.6
STREAM REACH     7.0  RCH=RCH 07           FROM         8.6     TO           6.9
STREAM REACH     8.0  RCH=RCH 08           FROM         6.9     TO           5.1
STREAM REACH     9.0  RCH=RCH 09           FROM         5.1     TO           3.3
STREAM REACH    10.0  RCH=RCH 10           FROM         3.3     TO           1.6
STREAM REACH    11.0  RCH=RCH 11           FROM         1.6     TO           0.0
ENDATA2          0.0                                    0.0                  0.0

 $$$ DATA TYPE 3 (TARGET LEVEL DO AND FLOW AUGMENTATION SOURCES) $$$

CARD TYPE                  REACH  AVAIL HDWS TARGET    ORDER OF AVAIL SOURCES
ENDATA3                     0.         0.       0.0   0.   0.   0.   0.   0.   0.
```

Appendix C.—Computer-model output listing the input verification data set, July-August 1991—Continued

$$$ DATA TYPE 4 (COMPUTATIONAL REACH FLAG FIELD) $$$

CARD TYPE	REACH	ELEMENTS/REACH	COMPUTATIONAL FLAGS
FLAG FIELD	1.	13.	1.6.2.2.6.2.7.2.6.6.2.2.2.0.0.0.0.0.0.0.
FLAG FIELD	2.	20.	2.2.6.2.2.2.2.6.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD	3.	20.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD	4.	20.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD	5.	13.	2.2.6.2.2.2.2.2.2.2.2.2.2.0.0.0.0.0.0.0.
FLAG FIELD	6.	12.	2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.0.0.0.0.0.
FLAG FIELD	7.	17.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.
FLAG FIELD	8.	18.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.
FLAG FIELD	9.	18.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.
FLAG FIELD	10.	17.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.
FLAG FIELD	11.	16.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.5.0.0.0.0.
ENDATA4	0.	0.	0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.

$$$ DATA TYPE 5 (HYDRAULIC DATA FOR DETERMINING VELOCITY AND DEPTH) $$$

CARD TYPE	REACH	COEF-DSPN	COEFQV	EXPOQV	COEFQH	EXPOQH	CMANN
HYDRAULICS	1.	500.00	0.059	0.338	2.050	0.309	0.034
HYDRAULICS	2.	500.00	0.017	0.338	4.316	0.309	0.034
HYDRAULICS	3.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	4.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	5.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	6.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	7.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	8.	500.00	0.059	0.338	0.723	0.309	0.034
HYDRAULICS	9.	500.00	0.059	0.338	0.723	0.309	0.034
HYDRAULICS	10.	500.00	0.059	0.338	0.723	0.309	0.034
HYDRAULICS	11.	500.00	0.059	0.338	0.723	0.309	0.037
ENDATA5	0.	0.00	0.000	0.000	0.000	0.000	0.000

$$$ DATA TYPE 5A (STEADY STATE TEMPERATURE AND CLIMATOLOGY DATA) $$$

CARD TYPE	REACH	ELEVATION	DUST COEF	CLOUD COVER	DRY BULB TEMP	WET BULB TEMP	ATM PRESSURE	WIND	SOLAR RAD ATTENUATION
TEMP/LCD	1.	3218.00	0.06	0.75	74.30	59.00	26.80	8.80	1.00
TEMP/LCD	2.	3213.00	0.06	0.75	73.40	59.00	26.80	8.80	1.00
TEMP/LCD	3.	3205.00	0.06	0.75	78.80	62.60	26.80	8.80	1.00
TEMP/LCD	4.	3186.00	0.06	0.75	78.80	62.60	26.80	8.80	1.00
TEMP/LCD	5.	3161.00	0.06	0.75	86.00	68.00	26.80	8.80	1.00
TEMP/LCD	6.	3154.00	0.06	0.75	86.00	68.00	26.80	8.80	1.00
TEMP/LCD	7.	3148.00	0.06	0.75	77.00	61.70	26.80	8.80	1.00
TEMP/LCD	8.	3142.00	0.06	0.75	77.00	61.70	26.80	8.80	1.00
TEMP/LCD	9.	3139.00	0.06	0.75	86.00	68.00	26.80	8.80	1.00
TEMP/LCD	10.	3135.00	0.06	0.75	86.00	68.00	26.80	8.80	1.00
TEMP/LCD	11.	3131.00	0.06	0.75	89.60	71.60	26.80	8.80	1.00
ENDATA5A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix C.—Computer-model output listing the input verification data set, July-August 1991—Continued

$$$ DATA TYPE 6 (REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION) $$$

CARD TYPE	REACH	K1	K3	SOD RATE	K2OPT	K2	COEQK2 TSIV COEF FOR OPT 8	OR OR	EXPQK2 SLOPE FOR OPT 8
REACT COEF	1.	0.04	0.00	-0.150	3.	3.00	0.000		0.00000
REACT COEF	2.	0.04	0.00	0.050	3.	3.00	0.000		0.00000
REACT COEF	3.	0.02	0.00	-0.100	3.	3.00	0.000		0.00000
REACT COEF	4.	0.02	0.00	-0.100	3.	3.00	0.000		0.00000
REACT COEF	5.	0.01	0.00	-0.050	3.	3.00	0.000		0.00000
REACT COEF	6.	0.01	0.00	-0.025	3.	3.00	0.000		0.00000
REACT COEF	7.	0.01	0.00	-0.010	3.	3.00	0.000		0.00000
REACT COEF	8.	0.01	0.00	-0.010	3.	3.00	0.000		0.00000
REACT COEF	9.	0.01	0.00	0.000	3.	3.00	0.000		0.00000
REACT COEF	10.	0.01	0.00	0.010	3.	3.00	0.000		0.00000
REACT COEF	11.	0.01	0.00	0.050	3.	3.00	0.000		0.00000
ENDATA6	0.	0.00	0.00	0.000	0.	0.00	0.000		0.00000

$$$ DATA TYPE 6A (NITROGEN AND PHOSPHORUS CONSTANTS) $$$

CARD TYPE	REACH	CKNH2	SETNH2	CKNH3	SNH3	CKNO2	CKPORG	SETPORG	SPO4
N AND P COEF	1.	0.01	-0.20	0.20	-0.10	1.00	0.10	-0.10	-0.10
N AND P COEF	2.	0.01	0.00	0.10	0.10	0.50	0.10	0.00	0.05
N AND P COEF	3.	0.01	-0.10	0.20	-0.05	1.00	0.10	-0.05	-0.10
N AND P COEF	4.	0.01	-0.10	0.20	-0.05	1.00	0.10	-0.05	-0.10
N AND P COEF	5.	0.01	-0.05	0.20	0.00	1.00	0.10	-0.01	-0.05
N AND P COEF	6.	0.01	-0.05	0.20	0.00	1.00	0.10	-0.01	-0.05
N AND P COEF	7.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	8.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	9.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	10.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	11.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
ENDATA6A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 6B (ALGAE/OTHER COEFFICIENTS) $$$

CARD TYPE	REACH	ALPHAO	ALGSET	EXCOEF	CK5 CKCOLI	CKANC	SETANC	SRCANC
ALG/OTHER COEF	1.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	2.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	3.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	4.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	5.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	6.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	7.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	8.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	9.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	10.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	11.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ENDATA6B	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix C.—Computer-model output listing the input verification data set, July-August 1991--Continued

$$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$

CARD TYPE	REACH	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INITIAL COND-1	1.	70.00	5.80	2.80	89.00	4.00	3.40	0.00	350.00
INITIAL COND-1	2.	67.00	7.20	3.30	177.00	6.80	3.30	0.00	1600.00
INITIAL COND-1	3.	79.00	13.10	2.40	165.00	5.40	3.30	0.00	420.00
INITIAL COND-1	4.	79.00	11.30	2.30	165.00	5.40	3.30	0.00	420.00
INITIAL COND-1	5.	75.00	9.50	2.20	165.00	6.00	2.00	0.00	20.00
INITIAL COND-1	6.	75.00	8.60	1.70	165.00	6.00	2.00	0.00	20.00
INITIAL COND-1	7.	75.00	7.60	1.20	156.00	4.60	1.90	0.00	80.00
INITIAL COND-1	8.	72.00	7.10	1.10	123.00	3.10	1.20	0.00	97.00
INITIAL COND-1	9.	73.00	6.70	3.50	136.00	3.70	1.50	0.00	200.00
INITIAL COND-1	10.	73.00	6.70	3.50	136.00	3.70	1.50	0.00	200.00
INITIAL COND-1	11.	80.00	7.00	2.80	108.00	2.60	2.30	0.00	7.00
ENDATA7	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INITIAL COND-2	1.	0.00	0.87	0.03	0.01	0.05	0.03	0.02
INITIAL COND-2	2.	0.00	0.69	0.01	0.01	0.05	0.03	0.02
INITIAL COND-2	3.	0.00	0.58	0.02	0.01	0.06	0.03	0.03
INITIAL COND-2	4.	0.00	0.58	0.02	0.01	0.06	0.03	0.03
INITIAL COND-2	5.	0.00	0.58	0.02	0.01	0.05	0.00	0.03
INITIAL COND-2	6.	0.00	0.58	0.02	0.01	0.05	0.00	0.02
INITIAL COND-2	7.	0.00	0.38	0.02	0.01	0.05	0.02	0.01
INITIAL COND-2	8.	0.00	0.48	0.01	0.01	0.05	0.02	0.01
INITIAL COND-2	9.	0.00	0.57	0.03	0.01	0.05	0.03	0.01
INITIAL COND-2	10.	0.00	0.57	0.03	0.01	0.05	0.03	0.01
INITIAL COND-2	11.	0.00	0.49	0.01	0.01	0.05	0.01	0.01
ENDATA7A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 8 (INCREMENTAL INFLOW CONDITIONS) $$$

CARD TYPE	REACH	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INCR INFLOW-1	1.	0.000	54.00	6.00	0.00	89.00	4.20	3.00	0.00	0.00
INCR INFLOW-1	2.	0.000	52.00	6.00	0.00	89.00	4.20	3.00	0.00	0.00
INCR INFLOW-1	3.	0.000	48.00	5.00	0.00	127.00	4.20	3.40	0.00	0.00
INCR INFLOW-1	4.	0.000	54.00	5.00	0.00	127.00	4.20	3.40	0.00	0.00
INCR INFLOW-1	5.	0.000	57.00	1.00	0.00	105.00	3.60	2.70	0.00	0.00
INCR INFLOW-1	6.	0.000	55.00	1.00	0.00	105.00	3.60	2.70	0.00	0.00
INCR INFLOW-1	7.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	0.00
INCR INFLOW-1	8.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	0.00
INCR INFLOW-1	9.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	0.00
INCR INFLOW-1	10.	0.000	54.00	1.00	0.00	117.00	3.10	2.30	0.00	0.00
INCR INFLOW-1	11.	0.000	54.00	1.00	0.00	117.00	3.10	2.30	0.00	0.00
ENDATA8	0.	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix C.—Computer-model output listing the input verification data set, July-August 1991--Continued

$$$ DATA TYPE 8A (INCREMENTAL INFLOW CONDITIONS FOR CHLOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INCR INFLOW-2	1.	0.00	0.48	0.04	0.01	0.03	0.03	0.02
INCR INFLOW-2	2.	0.00	0.48	0.04	0.01	0.03	0.03	0.02
INCR INFLOW-2	3.	0.00	0.38	0.02	0.00	0.13	0.02	0.02
INCR INFLOW-2	4.	0.00	0.38	0.02	0.00	0.13	0.02	0.02
INCR INFLOW-2	5.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	6.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	7.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	8.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	9.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	10.	0.00	0.30	0.01	0.00	0.02	0.00	0.01
INCR INFLOW-2	11.	0.00	0.30	0.01	0.00	0.02	0.00	0.01
ENDATA8A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$

CARD TYPE	JUNCTION ORDER AND IDENT	UPSTRM	JUNCTION	TRIB
ENDATA9	0.	0.	0.	0.

$$$ DATA TYPE 10 (HEADWATER SOURCES) $$$

CARD TYPE	HDWTR ORDER	NAME	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
HEADWTR-1	1.	BLKWTR (EST)	0.77	69.00	5.80	2.80	89.00	4.00	3.40
ENDATA10	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 10A (HEADWATER CONDITIONS FOR CHLOROPHYLL, NITROGEN, PHOSPHORUS,
COLIFORM AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE	HDWTR ORDER	ANC	COLI	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
HEADWTR-2	1.	0.00	350.00	0.00	0.87	0.03	0.01	0.05	0.03	0.02
ENDATA10A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 11 (POINT SOURCE / POINT SOURCE CHARACTERISTICS) $$$

CARD TYPE	POINT LOAD ORDER	NAME	EFF	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
POINTLD-1	1.	CLB RN (EST)	0.00	0.51	69.00	7.00	2.80	89.00	4.00	3.40
POINTLD-1	2.	MILL RUN C2	0.00	1.27	77.00	13.10	2.90	230.00	12.00	3.50
POINTLD-1	3.	CVSP WTP W1	0.00	-0.12	70.00	5.80	2.80	89.00	4.00	3.40
POINTLD-1	4.	CVSP LDG D5	0.00	0.08	75.00	7.10	7.40	340.00	22.00	2.20
POINTLD-1	5.	COON R (EST)	0.00	0.32	79.00	7.90	2.90	116.00	4.90	3.30
POINTLD-1	6.	RSCHMIDT D6	0.00	0.00	70.00	0.00	0.00	0.00	0.00	0.00
POINTLD-1	7.	BLKWT CTR D9	0.00	0.00	70.00	0.00	0.00	0.00	0.00	0.00
POINTLD-1	8.	FRELND R C8	0.00	0.85	64.00	8.90	3.00	131.00	0.50	2.50
POINTLD-1	9.	YOAKUM R C14	0.00	0.66	72.00	8.20	2.10	93.00	2.50	3.50
POINTLD-1	10.	SAND RUN C16	0.00	1.33	79.00	7.80	1.90	72.00	0.40	0.30

Appendix C.—Computer-model output listing the input verification data set, July-August 1991—Continued

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POINTLD-1     11.  N BRANCH C20        0.00     2.67    73.00     7.70     1.80   178.00     6.00     2.30
POINTLD-1     12.  L BLKWTR C22        0.00     4.80    75.00     8.00     3.10    91.00     0.30     3.60
ENDATA11       0.                      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 $$$ DATA TYPE 11A (POINT SOURCE CHARACTERISTICS - CHLOROPHYLL A, NITROGEN, PHOSPHORUS,
                   COLIFORMS AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

              POINT
CARD TYPE     LOAD     ANC      COLI     CHL-A    ORG-N    NH3-N    NO2-N    N03-N    ORG-P    DIS-P
              ORDER
POINTLD-2      1.     0.00    350.00     0.00     0.87     0.03     0.01     0.05     0.03     0.02
POINTLD-2      2.     0.00    480.00     0.00     0.69     0.01     0.01     0.08     0.03     0.02
POINTLD-2      3.     0.00    350.00     0.00     0.87     0.03     0.01     0.05     0.03     0.02
POINTLD-2      4.     0.00    900.00     0.00     2.60     0.05     0.03     0.11     0.60     1.40
POINTLD-2      5.     0.00    450.00     0.00     0.68     0.02     0.01     0.05     0.02     0.02
POINTLD-2      6.     0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
POINTLD-2      7.     0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
POINTLD-2      8.     0.00    250.00     0.00     0.48     0.02     0.01     0.16     0.01     0.01
POINTLD-2      9.     0.00     67.00     0.00     0.48     0.02     0.01     0.13     0.01     0.04
POINTLD-2     10.     0.00     97.00     0.00     0.27     0.03     0.01     0.08     0.01     0.02
POINTLD-2     11.     0.00    260.00     0.00     0.48     0.02     0.01     0.05     0.02     0.01
POINTLD-2     12.     0.00    210.00     0.00     0.50     0.01     0.01     0.05     0.01     0.03
ENDATA11A      0.     0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 $$$ DATA TYPE 12 (DAM CHARACTERISTICS) $$$

                      DAM   RCH   ELE    ADAM     BDAM     FDAM     HDAM
ENDATA12                0.    0.    0.    0.00     0.00     0.00     0.00

 $$$ DATA TYPE 13 (DOWNSTREAM BOUNDARY CONDITIONS-1) $$$
     CARD TYPE              TEMP       D.O.      BOD      CM-1      CM-2      CM-3      ANC      COLI

DOWNSTREAM BOUNDARY-1       DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED
ENDATA13

 $$$ DATA TYPE 13A (DOWNSTREAM BOUNDARY CONDITIONS-2) $$$

     CARD TYPE              CHL-A     ORG-N     NH3-N     NO2-N     NH3-N     ORG-P     DIS-P
ENDATA13A                   DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED
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Appendix D.—Computer-model output listing the simulation data set for the 7-day, 10-year low flow

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 * * * QUAL-2E  STREAM QUALITY ROUTING MODEL * * *
           Version 3.14  January 1992

 $$$ (PROBLEM TITLES) $$$

CARD TYPE                          QUAL-2E PROGRAM TITLES
TITLE01              BLKWTR MNSTM LO-FLOW VERIF MDL WITH 7Q10 FLOWS
TITLE02              File: VER2.710      Date: 06-29-94
TITLE03  YES         CONSERVATIVE MINERAL I     SK   IN uScm
TITLE04  YES         CONSERVATIVE MINERAL II    Cl   IN mg/L
TITLE05  YES         CONSERVATIVE MINERAL III   SiO2 IN mg/L
TITLE06  YES         TEMPERATURE
TITLE07  YES         5-DAY BIOCHEMICAL OXYGEN DEMAND
TITLE08  YES         ALGAE AS CHL-A IN UG/L
TITLE09  YES         PHOSPHORUS CYCLE AS P IN MG/L
TITLE10                (ORGANIC-P, DISSOLVED-P)
TITLE11  YES         NITROGEN CYCLE AS N IN MG/L
TITLE12                (ORGANIC-N, AMMONIA-N, NITRITE-N, NITRATE-N)
TITLE13  YES         DISSOLVED OXYGEN IN MG/L
TITLE14  YES         FECAL COLIFORMS IN NO./100 ML
TITLE15   NO         ARBITRARY NON-CONSERVATIVE
ENDTITLE

 $$$ DATA TYPE 1 (CONTROL DATA) $$$

CARD TYPE                                  CARD TYPE
LIST DATA INPUT             0.00000                                   0.00000
WRITE OPTIONAL SUMMARY      0.00000                                   0.00000
NO FLOW AUGMENTATION        0.00000                                   0.00000
STEADY STATE                0.00000                                   0.00000
NO TRAPEZOIDAL X-SECTIONS   0.00000                                   0.00000
PRINT LCD/SOLAR DATA        0.00000                                   0.00000
PLOT DO AND BOD             0.00000                                   0.00000
FIXED DNSTM COND (YES=1)=   0.00000        5D-ULT BOD CONV K COEF  =  0.03600
INPUT METRIC (YES=1)    =   0.00000        OUTPUT METRIC (YES=1)   =  0.00000
NUMBER OF REACHES       =  11.00000        NUMBER OF JUNCTIONS     =  0.00000
NUM OF HEADWATERS       =   1.00000        NUMBER OF POINT LOADS   = 12.00000
TIME STEP (HOURS)       =   0.00000        LNTH  COMP  ELEMENT (DX)=  0.10000
MAXIMUM ITERATIONS      =  30.00000        TIME INC. FOR RPT2 (HRS)=  0.00000
LATITUDE OF BASIN (DEG) =  39.05000        LONGITUDE OF BASIN (DEG)= 79.40000
STANDARD MERIDIAN (DEG) =  75.00000        DAY OF YEAR START TIME  = 211.00000
EVAP. COEFF. (AE)       =   0.00103        EVAP. COEFF. (BE)       =  0.00016
ELEV. OF BASIN (ELEV)   =3167.00000        DUST ATTENUATION COEF.  =  0.06000
ENDATA1                     0.00000                                   0.00000

 $$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN OXIDATION CONSTANTS) $$$

CARD TYPE                                    CARD TYPE
O UPTAKE BY NH3 OXID(MG O/MG N)=    3.4300   O UPTAKE BY NO2 OXID(MG O/MG N)=   1.1400
O PROD  BY ALGAE (MG O/MG A)   =    1.6000   O UPTAKE BY ALGAE (MG O/MG A)  =   2.0000
N CONTENT OF ALGAE (MG N/MG A) =    0.0850   P CONTENT OF ALGAE (MG P/MG A) =   0.0140
ALG MAX SPEC GROWTH RATE(1/DAY)=    2.5000   ALGAE RESPIRATION RATE (1/DAY) =   0.0500
N HALF SATURATION CONST (MG/L) =    0.2000   P HALF SATURATION CONST  (MG/L)=   0.0400
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Appendix D.—Computer-model output listing the simulation data set for the 7-day, 10-year low flow--Continued

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LIN ALG SHADE CO (1/FT-UGCHA/L=)     0.0008        NLIN SHADE(1/FT-(UGCHA/L)**2/3)=    0.0000
LIGHT FUNCTION OPTION (LFNOPT) =     2.0000        LIGHT SAT'N COEF (BTU/FT2-MIN) =    0.0900
DAILY AVERAGING OPTION (LAVOPT)=     1.0000        TOTAL DAILY SOLAR RADTN (INT)  =    0.9200
NUMBER OF DAYLIGHT HOURS (DLH) =    14.0000        TOTAL DAILY SOLR RAD (BTU/FT-2)= 1500.0000
ALGY GROWTH CALC OPTION(LGROPT)=     2.0000        ALGAL PREF FOR NH3-N (PREFN)   =    0.9000
ALG/TEMP SOLR RAD FACTOR(TFACT)=     0.4400        NITRIFICATION INHIBITION COEF  =   10.0000
ENDATA1A                             0.0000                                            0.0000

 $$$ DATA TYPE 1B (TEMPERATURE CORRECTION CONSTANTS FOR RATE COEFFICIENTS) $$$

CARD TYPE     RATE CODE     THETA VALUE
THETA( 1)      BOD DECA        1.047     DFLT
THETA( 2)      BOD SETT        1.024     DFLT
THETA( 3)      OXY TRAN        1.024     DFLT
THETA( 4)      SOD RATE        1.060     DFLT
THETA( 5)      ORGN DEC        1.047     DFLT
THETA( 6)      ORGN SET        1.024     DFLT
THETA( 7)      NH3 DECA        1.083     DFLT
THETA( 8)      NH3 SRCE        1.074     DFLT
THETA( 9)      NO2 DECA        1.047     DFLT
THETA(10)      PORG DEC        1.047     DFLT
THETA(11)      PORG SET        1.024     DFLT
THETA(12)      DISP SRC        1.074     DFLT
THETA(13)      ALG GROW        1.047     DFLT
THETA(14)      ALG RESP        1.047     DFLT
THETA(15)      ALG SETT        1.024     DFLT
THETA(16)      COLI DEC        1.047     DFLT
THETA(17)      ANC DECA        1.000     DFLT
THETA(18)      ANC SETT        1.024     DFLT
THETA(19)      ANC SRCE        1.000     DFLT
ENDATA1B

 $$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$

CARD TYPE           REACH ORDER AND IDENT             R. MI/KM           R. MI/KM
STREAM REACH     1.0  RCH=RCH 01         FROM        18.4     TO       17.1
STREAM REACH     2.0  RCH=RCH 02         FROM        17.1     TO       15.1
STREAM REACH     3.0  RCH=RCH 03         FROM        15.1     TO       13.1
STREAM REACH     4.0  RCH=RCH 04         FROM        13.1     TO       11.1
STREAM REACH     5.0  RCH=RCH 05         FROM        11.1     TO        9.8
STREAM REACH     6.0  RCH=RCH 06         FROM         9.8     TO        8.6
STREAM REACH     7.0  RCH=RCH 07         FROM         8.6     TO        6.9
STREAM REACH     8.0  RCH=RCH 08         FROM         6.9     TO        5.1
STREAM REACH     9.0  RCH=RCH 09         FROM         5.1     TO        3.3
STREAM REACH    10.0  RCH=RCH 10         FROM         3.3     TO        1.6
STREAM REACH    11.0  RCH=RCH 11         FROM         1.6     TO        0.0
ENDATA2          0.0                                  0.0                0.0

 $$$ DATA TYPE 3 (TARGET LEVEL DO AND FLOW AUGMENTATION SOURCES) $$$
CARD TYPE                 REACH  AVAIL HDWS TARGET    ORDER OF AVAIL SOURCES

ENDATA3                    0.        0.        0.0  0.   0.   0.   0.   0.   0.
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Appendix D.—Computer-model output listing the simulation data set for the 7-day, 10-year low flow--Continued

$$$ DATA TYPE 4 (COMPUTATIONAL REACH FLAG FIELD) $$$

CARD TYPE	REACH	ELEMENTS/REACH	COMPUTATIONAL FLAGS
FLAG FIELD	1.	13.	1.6.2.2.6.2.7.2.6.6.2.2.2.0.0.0.0.0.0.0.
FLAG FIELD	2.	20.	2.2.6.2.2.2.2.6.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD	3.	20.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD	4.	20.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD	5.	13.	2.2.6.2.2.2.2.2.2.2.2.2.2.0.0.0.0.0.0.0.
FLAG FIELD	6.	12.	2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.0.0.0.0.0.
FLAG FIELD	7.	17.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.
FLAG FIELD	8.	18.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.
FLAG FIELD	9.	18.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.
FLAG FIELD	10.	17.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.0.
FLAG FIELD	11.	16.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.5.0.0.0.0.
ENDATA4	0.	0.	0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.

$$$ DATA TYPE 5 (HYDRAULIC DATA FOR DETERMINING VELOCITY AND DEPTH) $$$

CARD TYPE	REACH	COEF-DSPN	COEFQV	EXPOQV	COEFQH	EXPOQH	CMANN
HYDRAULICS	1.	500.00	0.059	0.338	2.050	0.309	0.034
HYDRAULICS	2.	500.00	0.017	0.338	4.316	0.309	0.034
HYDRAULICS	3.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	4.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	5.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	6.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	7.	500.00	0.059	0.338	1.014	0.309	0.043
HYDRAULICS	8.	500.00	0.059	0.338	0.723	0.309	0.034
HYDRAULICS	9.	500.00	0.059	0.338	0.723	0.309	0.034
HYDRAULICS	10.	500.00	0.059	0.338	0.723	0.309	0.034
HYDRAULICS	11.	500.00	0.059	0.338	0.723	0.309	0.037
ENDATA5	0.	0.00	0.000	0.000	0.000	0.000	0.000

$$$ DATA TYPE 5A (STEADY STATE TEMPERATURE AND CLIMATOLOGY DATA) $$$

CARD TYPE	REACH	ELEVATION	DUST COEF	CLOUD COVER	DRY BULB TEMP	WET BULB TEMP	ATM PRESSURE	WIND	SOLAR RAD ATTENUATION
TEMP/LCD	1.	3218.00	0.06	0.75	74.30	59.00	26.80	8.80	1.00
TEMP/LCD	2.	3213.00	0.06	0.75	73.40	59.00	26.80	8.80	1.00
TEMP/LCD	3.	3205.00	0.06	0.75	78.80	62.60	26.80	8.80	1.00
TEMP/LCD	4.	3186.00	0.06	0.75	78.80	62.60	26.80	8.80	1.00
TEMP/LCD	5.	3161.00	0.06	0.75	86.00	68.00	26.80	8.80	1.00
TEMP/LCD	6.	3154.00	0.06	0.75	86.00	68.00	26.80	8.80	1.00
TEMP/LCD	7.	3148.00	0.06	0.75	77.00	61.70	26.80	8.80	1.00
TEMP/LCD	8.	3142.00	0.06	0.75	77.00	61.70	26.80	8.80	1.00
TEMP/LCD	9.	3139.00	0.06	0.75	86.00	68.00	26.80	8.80	1.00
TEMP/LCD	10.	3135.00	0.06	0.75	86.00	68.00	26.80	8.80	1.00
TEMP/LCD	11.	3131.00	0.06	0.75	89.60	71.60	26.80	8.80	1.00
ENDATA5A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix D.—Computer-model output listing the simulation data set for the 7-day, 10-year low flow--Continued

$$$ DATA TYPE 6 (REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION) $$$

CARD TYPE	REACH	K1	K3	SOD RATE	K2OPT	K2	COEQK2 TSIV COEF FOR OPT 8	OR OR	EXPQK2 SLOPE FOR OPT 8
REACT COEF	1.	0.04	0.00	-0.150	3.	3.00	0.000		0.00000
REACT COEF	2.	0.04	0.00	0.050	3.	3.00	0.000		0.00000
REACT COEF	3.	0.02	0.00	-0.100	3.	3.00	0.000		0.00000
REACT COEF	4.	0.02	0.00	-0.100	3.	3.00	0.000		0.00000
REACT COEF	5.	0.01	0.00	-0.050	3.	3.00	0.000		0.00000
REACT COEF	6.	0.01	0.00	-0.025	3.	3.00	0.000		0.00000
REACT COEF	7.	0.01	0.00	-0.010	3.	3.00	0.000		0.00000
REACT COEF	8.	0.01	0.00	-0.010	3.	3.00	0.000		0.00000
REACT COEF	9.	0.01	0.00	0.000	3.	3.00	0.000		0.00000
REACT COEF	10.	0.01	0.00	0.010	3.	3.00	0.000		0.00000
REACT COEF	11.	0.01	0.00	0.050	3.	3.00	0.000		0.00000
ENDATA6	0.	0.00	0.00	0.000	0.	0.00	0.000		0.00000

$$$ DATA TYPE 6A (NITROGEN AND PHOSPHORUS CONSTANTS) $$$

CARD TYPE	REACH	CKNH2	SETNH2	CKNH3	SNH3	CKNO2	CKPORG	SETPORG	SPO4
N AND P COEF	1.	0.01	-0.20	0.20	-0.10	1.00	0.10	-0.10	-0.10
N AND P COEF	2.	0.01	0.00	0.10	0.10	0.50	0.10	0.00	0.05
N AND P COEF	3.	0.01	-0.10	0.20	-0.05	1.00	0.10	-0.05	-0.10
N AND P COEF	4.	0.01	-0.10	0.20	-0.05	1.00	0.10	-0.05	-0.10
N AND P COEF	5.	0.01	-0.05	0.20	0.00	1.00	0.10	-0.01	-0.05
N AND P COEF	6.	0.01	-0.05	0.20	0.00	1.00	0.10	-0.01	-0.05
N AND P COEF	7.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	8.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	9.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	10.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
N AND P COEF	11.	0.01	0.00	0.20	0.00	1.00	0.10	0.00	0.00
ENDATA6A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 6B (ALGAE/OTHER COEFFICIENTS) $$$

CARD TYPE	REACH	ALPHAO	ALGSET	EXCOEF	CK5 CKCOLI	CKANC	SETANC	SRCANC
ALG/OTHER COEF	1.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	2.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	3.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	4.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	5.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	6.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	7.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	8.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	9.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	10.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ALG/OTHER COEF	11.	15.00	0.60	0.04	0.40	0.00	0.00	0.00
ENDATA6B	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix D.—Computer-model output listing the simulation data set for the 7-day, 10-year low flow--Continued

$$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$

CARD TYPE	REACH	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INITIAL COND-1	1.	70.00	5.80	2.80	89.00	4.00	3.40	0.00	350.00
INITIAL COND-1	2.	67.00	7.20	3.30	177.00	6.80	3.30	0.00	1600.00
INITIAL COND-1	3.	79.00	13.10	2.40	165.00	5.40	3.30	0.00	420.00
INITIAL COND-1	4.	79.00	11.30	2.30	165.00	5.40	3.30	0.00	420.00
INITIAL COND-1	5.	75.00	9.50	2.20	165.00	6.00	2.00	0.00	20.00
INITIAL COND-1	6.	75.00	8.60	1.70	165.00	6.00	2.00	0.00	20.00
INITIAL COND-1	7.	75.00	7.60	1.20	156.00	4.60	1.90	0.00	80.00
INITIAL COND-1	8.	72.00	7.10	1.10	123.00	3.10	1.20	0.00	97.00
INITIAL COND-1	9.	73.00	6.70	3.50	136.00	3.70	1.50	0.00	200.00
INITIAL COND-1	10.	73.00	6.70	3.50	136.00	3.70	1.50	0.00	200.00
INITIAL COND-1	11.	80.00	7.00	2.80	108.00	2.60	2.30	0.00	7.00
ENDATA7	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INITIAL COND-2	1.	0.00	0.87	0.03	0.01	0.05	0.03	0.02
INITIAL COND-2	2.	0.00	0.69	0.01	0.01	0.05	0.03	0.02
INITIAL COND-2	3.	0.00	0.58	0.02	0.01	0.06	0.03	0.03
INITIAL COND-2	4.	0.00	0.58	0.02	0.01	0.06	0.03	0.03
INITIAL COND-2	5.	0.00	0.58	0.02	0.01	0.05	0.00	0.03
INITIAL COND-2	6.	0.00	0.58	0.02	0.01	0.05	0.00	0.02
INITIAL COND-2	7.	0.00	0.38	0.02	0.01	0.05	0.02	0.01
INITIAL COND-2	8.	0.00	0.48	0.01	0.01	0.05	0.02	0.01
INITIAL COND-2	9.	0.00	0.57	0.03	0.01	0.05	0.03	0.01
INITIAL COND-2	10.	0.00	0.57	0.03	0.01	0.05	0.03	0.01
INITIAL COND-2	11.	0.00	0.49	0.01	0.01	0.05	0.01	0.01
ENDATA7A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 8 (INCREMENTAL INFLOW CONDITIONS) $$$

CARD TYPE	REACH	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INCR INFLOW-1	1.	0.000	54.00	6.00	0.00	89.00	4.20	3.00	0.00	0.00
INCR INFLOW-1	2.	0.000	52.00	6.00	0.00	89.00	4.20	3.00	0.00	0.00
INCR INFLOW-1	3.	0.000	48.00	5.00	0.00	127.00	4.20	3.40	0.00	0.00
INCR INFLOW-1	4.	0.000	54.00	5.00	0.00	127.00	4.20	3.40	0.00	0.00
INCR INFLOW-1	5.	0.000	57.00	1.00	0.00	105.00	3.60	2.70	0.00	0.00
INCR INFLOW-1	6.	0.000	55.00	1.00	0.00	105.00	3.60	2.70	0.00	0.00
INCR INFLOW-1	7.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	0.00
INCR INFLOW-1	8.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	0.00
INCR INFLOW-1	9.	0.000	54.00	1.00	0.00	105.00	3.60	2.70	0.00	0.00
INCR INFLOW-1	10.	0.000	54.00	1.00	0.00	117.00	3.10	2.30	0.00	0.00
INCR INFLOW-1	11.	0.000	54.00	1.00	0.00	117.00	3.10	2.30	0.00	0.00
ENDATA8	0.	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 8A (INCREMENTAL INFLOW CONDITIONS FOR CHLOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INCR INFLOW-2	1.	0.00	0.48	0.04	0.01	0.03	0.03	0.02
INCR INFLOW-2	2.	0.00	0.48	0.04	0.01	0.03	0.03	0.02
INCR INFLOW-2	3.	0.00	0.38	0.02	0.00	0.13	0.02	0.02

Appendix D.—Computer-model output listing the simulation data set for the 7-day, 10-year low flow--Continued

INCR INFLOW-2	4.	0.00	0.38	0.02	0.00	0.13	0.02	0.02
INCR INFLOW-2	5.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	6.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	7.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	8.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	9.	0.00	0.29	0.02	0.01	0.11	0.02	0.01
INCR INFLOW-2	10.	0.00	0.30	0.01	0.00	0.02	0.00	0.01
INCR INFLOW-2	11.	0.00	0.30	0.01	0.00	0.02	0.00	0.01
ENDATA8A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$

CARD TYPE	JUNCTION ORDER AND IDENT	UPSTRM	JUNCTION	TRIB
ENDATA9	0.	0.	0.	0.

$$$ DATA TYPE 10 (HEADWATER SOURCES) $$$

CARD TYPE	HDWTR ORDER	NAME	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
HEADWTR-1	1.	BLKWTR (EST)	0.14	69.00	6.00	2.80	89.00	4.00	3.40
ENDATA10	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 10A (HEADWATER CONDITIONS FOR CHLOROPHYLL, NITROGEN, PHOSPHORUS, COLIFORM AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE	HDWTR ORDER	ANC	COLI	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
HEADWTR-2	1.	0.00	350.00	0.00	0.87	0.03	0.01	0.05	0.03	0.02
ENDATA10A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 11 (POINT SOURCE / POINT SOURCE CHARACTERISTICS) $$$

CARD TYPE	POINT LOAD ORDER	NAME	EFF	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
POINTLD-1	1.	CLB RN (EST)	0.00	0.09	69.00	7.00	2.80	89.00	4.00	3.40
POINTLD-1	2.	MILL RUN C2	0.00	0.24	77.00	13.10	2.90	230.00	12.00	3.50
POINTLD-1	3.	CVSP WTP W1	0.00	-0.12	70.00	5.80	2.80	89.00	4.00	0.34
POINTLD-1	4.	CVSP LDG D5	0.00	0.00	75.00	7.10	7.40	340.00	22.00	2.20
POINTLD-1	5.	COON R (EST)	0.00	0.06	79.00	7.90	2.90	116.00	4.90	3.30
POINTLD-1	6.	RSCHMIDT D6	0.00	0.00	70.00	0.00	0.00	0.00	0.00	0.00
POINTLD-1	7.	BLKWT CTR D9	0.00	0.00	70.00	0.00	0.00	0.00	0.00	0.00
POINTLD-1	8.	FRELND R C8	0.00	0.16	64.00	8.90	3.00	131.00	0.50	2.50
POINTLD-1	9.	YOAKUM R C14	0.00	0.12	72.00	8.20	2.10	93.00	2.50	3.50
POINTLD-1	10.	SAND RUN C16	0.00	0.25	79.00	7.80	1.90	72.00	0.40	0.30
POINTLD-1	11.	N BRANCH C20	0.00	0.50	73.00	7.70	1.80	178.00	6.00	2.30
POINTLD-1	12.	L BLKWTR C22	0.00	0.90	75.00	8.00	3.10	91.00	0.30	3.60
ENDATA11	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix D.—Computer-model output listing the simulation data set for the 7-day, 10-year low flow--Continued

$$$ DATA TYPE 11A (POINT SOURCE CHARACTERISTICS - CHLOROPHYLL A, NITROGEN, PHOSPHORUS, COLIFORMS AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE	POINT LOAD ORDER	ANC	COLI	CHL-A	ORG-N	NH3-N	NO2-N	N03-N	ORG-P	DIS-P
POINTLD-2	1.	0.00	350.00	0.00	0.87	0.03	0.01	0.05	0.03	0.02
POINTLD-2	2.	0.00	480.00	0.00	0.69	0.01	0.01	0.08	0.03	0.02
POINTLD-2	3.	0.00	350.00	0.00	0.87	0.03	0.01	0.05	0.03	0.02
POINTLD-2	4.	0.00	900.00	0.00	2.60	0.05	0.03	0.11	0.60	1.40
POINTLD-2	5.	0.00	450.00	0.00	0.68	0.02	0.01	0.05	0.02	0.02
POINTLD-2	6.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
POINTLD-2	7.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
POINTLD-2	8.	0.00	250.00	0.00	0.48	0.02	0.01	0.16	0.01	0.01
POINTLD-2	9.	0.00	67.00	0.00	0.48	0.02	0.01	0.13	0.00	0.04
POINTLD-2	10.	0.00	97.00	0.00	0.27	0.03	0.01	0.08	0.00	0.02
POINTLD-2	11.	0.00	260.00	0.00	0.48	0.02	0.01	0.05	0.02	0.01
POINTLD-2	12.	0.00	210.00	0.00	0.50	0.01	0.01	0.05	0.00	0.03
ENDATA11A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 12 (DAM CHARACTERISTICS) $$$

	DAM	RCH	ELE	ADAM	BDAM	FDAM	HDAM
ENDATA12	0.	0.	0.	0.00	0.00	0.00	0.00

$$$ DATA TYPE 13 (DOWNSTREAM BOUNDARY CONDITIONS-1) $$$

CARD TYPE	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI

DOWNSTREAM BOUNDARY-1 DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED
ENDATA13

$$$ DATA TYPE 13A (DOWNSTREAM BOUNDARY CONDITIONS-2) $$$

CARD TYPE	CHL-A	ORG-N	NH3-N	NO2-N	NH3-N	ORG-P	DIS-P

ENDATA13A DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED

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