U.S. Department of the Interior
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In cooperation with the
Kentucky Natural Resources and
Environmental Protection Cabinet

Modeling Hydrodynamics and Water Quality in Herrington Lake, Kentucky

Water-Resources Investigations Report 99-4281

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U.S. Department of the Interior
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By Angela S. Crain, Allison A. Shipp, *and* Thomas O. Mesko, U.S. Geological Survey, *and* G. Lynn Jarrett, University of Louisville

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Louisville, Kentucky
2000

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Charles G. Groat, Director

For additional information write to:

District Chief, Kentucky District
U.S. Geological Survey
Water Resources Division
9818 Bluegrass Parkway
Louisville, KY 40299–1906

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	2.54	centimeter
inch per year (in./yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
milligrams per square foot per day [$mg/(ft^2/d)$]	0.09290	milligrams per square meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square mile (mi^2)	2.590	square kilometer
ton	907.2	kilogram
ton per year (ton/yr)	907.2	kilogram per year

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

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

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Water year: The 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends.

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Abstract

Bathymetric, meteorologic, hydrologic, water-quality, and biological data collected in the Herrington Lake watershed were used to construct a laterally averaged, two-dimensional model (CE-QUAL-W2) of the reservoir that is capable of simulating hydrodynamics, temperature, and water-quality parameters. Input to the model based on 1996 conditions in the watershed and adjustments to kinetic-rate coefficients to constituents being simulated provided good agreement (root mean square error (RMSE) <20 percent) between measured and simulated water temperature, dissolved oxygen, and nitrate-nitrogen (NO_3-N), but only poor agreement (RMSE >20 percent) for soluble reactive phosphorus (SRP), ammonia-nitrogen (NH_3-N), and chlorophyll *a*.

The Herrington Lake model was used to evaluate the effectiveness of several possible management strategies for achieving the Total Maximum Daily Loads for phosphorus to Herrington Lake. Reductions in concentrations of SRP inputs to the reservoir were simulated for the Dix River, four tributaries, and two permitted wastewater-treatment sites to explore the effects of such reductions on the reservoir's water quality.

The results of several simulations in which SRP concentrations in all inflows were reduced from 30 to 80 percent, in 10-percent increments, were compared to the Herrington Lake model. Additional simulations included those in which inflow concentrations of SRP were reduced only for the Dix River and Clarks Run, the major inflows to Herrington Lake.

A comparison of the Carlson Trophic State Index (TSI) values calculated from the simulated SRP concentrations and simulated chlorophyll *a* concentrations were compared to evaluate the effectiveness of possible management strategies for the reservoir. Simulation results indicated that a 60-percent reduction in SRP concentrations from all the inflows would cause a decrease in the annual Carlson TSI for phosphorus value from 70 to 64; a similar decrease in the TSI value would result from a 60-percent reduction in SRP concentrations in only the Dix River and Clarks Run. Reductions in SRP concentrations in the inflows did not result in decreases in the Carlson TSI for chlorophyll *a*. This is probably a consequence of the model being unable to simulate concentrations of chlorophyll *a* as accurately as it does the concentrations of SRP. Thus, reductions in the Carlson TSI for SRP probably represent the effect of management strategies more accurately than the Carlson TSI for chlorophyll *a*.

INTRODUCTION

Herrington Lake is a reservoir on the Dix River in the Kentucky River Basin (fig. 1). As is true of many reservoirs throughout the southeastern United States (Kennedy and Walker, 1990), Herrington Lake is subject to excessive nutrient loading, which results in the deterioration of water-quality conditions, problematic algal blooms, and fish kills. The reservoir receives pollutants from point and nonpoint

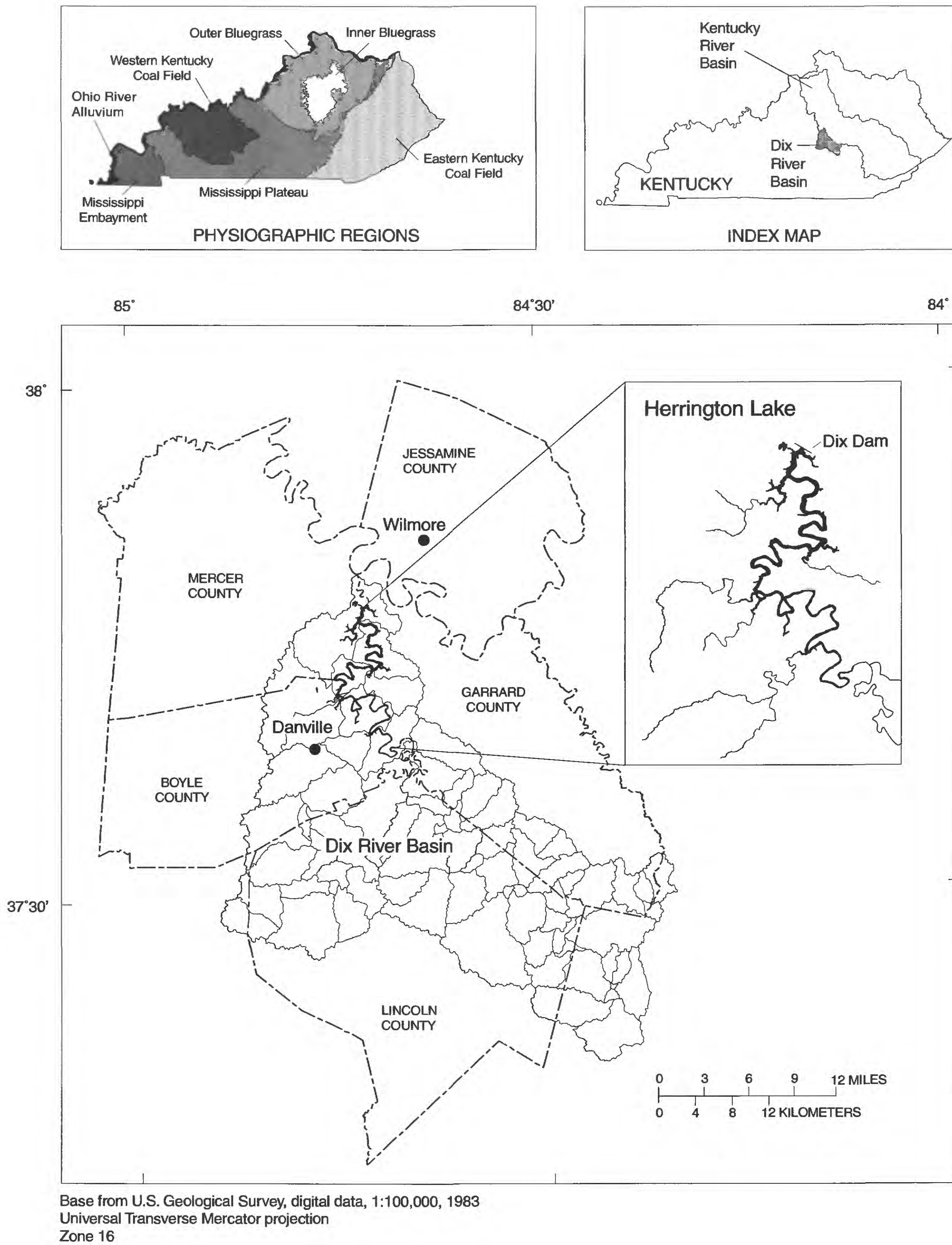


Figure 1. Location of study area, Herrington Lake, Kentucky.

sources along its length. The Dix River watershed has 24 permitted wastewater-discharge sites (David Leist, Kentucky Natural Resources and Environmental Protection Cabinet—Division of Water, written commun., 1998) (fig. 2 and table 1). Herrington Lake directly receives wastewater discharge from 6 of the 24 wastewater-discharge sites.

In response to the 1972 Clean Water Act passed by the United States Congress, the Commonwealth of Kentucky listed Herrington Lake in the 305(b) report to Congress as being one of six reservoirs in Kentucky not supporting its designated use as a warm-water aquatic habitat (Kentucky Natural Resources and Environmental Protection Cabinet, 1992a). Epilimnetic concentrations of dissolved oxygen (DO) of less than 5 mg/L were cited as a principal reason the reservoir did not support the intended use designation. This low level of DO is the primary contributing factor for reported fish kills. Dix River and Clarks Run, two major tributaries of the reservoir, were also cited in the 1998 305(b) report (Kentucky Natural Resources and Environmental Protection Cabinet, 1998). These two tributaries partially support their designated uses as "swimmable" and "fishable." The cited reasons for low levels of DO include: agricultural runoff, septic-tank leakage, urban/suburban storm-water runoff, and wastewater-treatment plant (WWTP) discharges.

Starting in 1992, the Commonwealth of Kentucky also listed Herrington Lake under section 303(d) of the Clean Water Act for not attaining water-quality standards for phosphorus (Kentucky Natural Resources and Environmental Protection Cabinet, 1992b). Each state is required to determine a Total Maximum Daily Load (TMDL) for water bodies listed under section 303(d). The goals of the TMDL program are to address concerns about specific pollutant loads to a water body and to ensure that the water body complies with water-quality standards. A TMDL determines the loading capacity of the water body for a single constituent that prevents the water body from exceeding water-quality standards. The equation for a TMDL as provided by the U.S. Environmental Protection Agency (USEPA) (U.S. Environmental Protection Agency, 1991) follows:

$$\text{TMDL} = \text{Loading capacity} = \text{Waste Load Allocation} + \text{Background} + \text{Nonpoint Source} + \text{Margin of Safety} \quad (1)$$

The calculation of the TMDL provides a basis for the State to develop an implementation plan for a specific water body in order to bring it into compliance with established standards. The loading capacity of a water body can be calculated in a number of ways. One way is to examine the simulated response of a water body to reductions in pollutant loading to determine when compliance with water-quality standards will be reached.

An index based on chlorophyll *a* concentrations for use in classifying the trophic state of water bodies was adopted by the Commonwealth of Kentucky for evaluating the trophic state of lakes and reservoirs throughout Kentucky. The Kentucky Natural Resources and Environmental Protection Cabinet—Division of Water (KDOW) evaluated the trophic state of Herrington Lake in 1973 and 1983 (Kentucky Natural Resources and Environmental Protection Cabinet, 1984). On the basis of this index, the reservoir was classified as eutrophic.

The U.S. Geological Survey (USGS), in cooperation with the Kentucky Natural Resources and Environmental Protection Cabinet—Division of Water, investigated the water quality of Herrington Lake. Specific objectives of this study were to: (1) estimate point source and nonpoint source nitrogen and phosphorus loads contributed to the reservoir by the selected tributaries and the nitrogen and phosphorus loads of the mainstem of the Dix River; (2) identify principal sources of phosphorus to the reservoir; (3) estimate the retention rate of nitrogen and phosphorus and determine the spatial and temporal distribution of nutrients, chlorophyll *a*, and phytoplankton communities within the reservoir; (4) determine the nutrient-assimilation capacity of the reservoir; and (5) evaluate the effect of alternative nutrient loading reductions on the water quality of Herrington Lake.

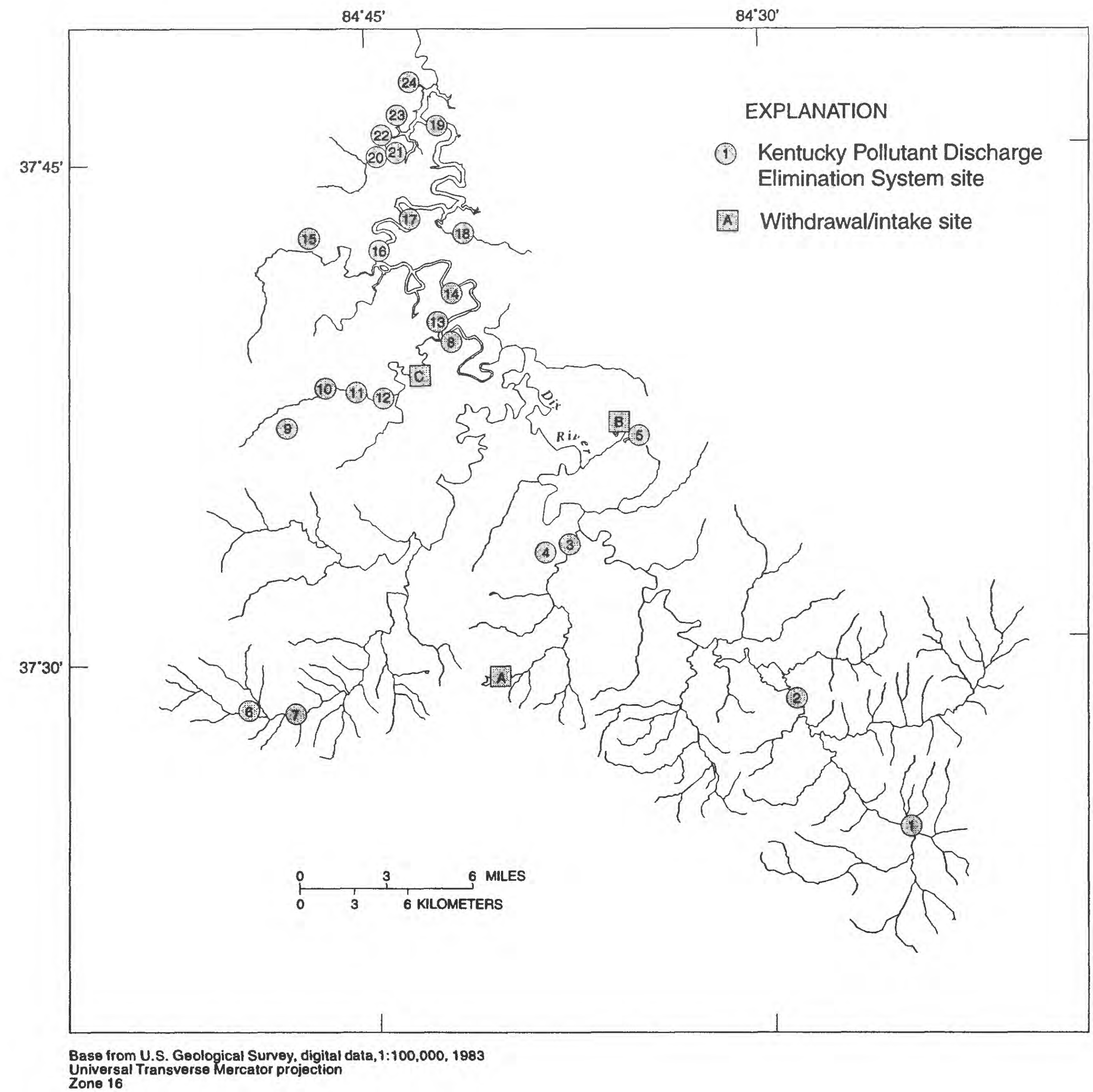


Figure 2. Location of State-permitted Kentucky Pollutant Discharge Elimination System sites, and location of water-withdrawal or intake sites, Dix River, Kentucky.

Table 1. State-permitted discharge limits for specific sites located in the Dix River watershed, Kentucky, and water-withdrawal or intake sites

[KDOW, Kentucky Division of Water; Mgal/d, million gallons per day; ---, no station number; MHP, Mobile Home Park; DHR, Department for Human Resources]

Map number/letter (figure 2)	Station name	KDOW station number	Permitted flow (Mgal/d)	Receiving stream
		Permitted discharge sites		
1	City of Brodhead	04033006	0.150	Dix River
2	City of Crab Orchard	04033008	.000	Dix River
3	City of Stanford	04033002	.800	Logan Creek
4	Baird Oil Company	04033001	.001	Logan Creek
5	City of Lancaster	04032003	1.000	White Oak Creek
6	Hustonville Elementary School	04032001	.006	Hanging Fork Creek
7	Hustonville Apartments	04032012	.003	Hanging Fork Creek
8	Herrington Haven Subdivision	04032006	.008	Dix River
9	Whirlpool Corporation	04031008	.000	Clarks Run
10	Phillips Lighting	04031007	.300	Clarks Run
11	Texaco Bulk Plant	04031005	.000	Clarks Run
12	City of Danville	04031010	4.800	Clarks Run
13	Horse Shoe Bend Subdivision	04030000	.012	Herrington Lake
14	Private Residence	04030010	.001	Herrington Lake
15	Greenview MHP	04030008	.004	Mocks Branch
16	Northpoint Training Center (formerly known as Kentucky DHR Youth Center)	04030006	.300	Herrington Lake
17	Paradise Camp Condos	04030012	.026	Herrington Lake
18	Robinson Elementary School	04031002	.006	McKecknie Creek
19	Chimney Rock Resort	04030005	.015	Herrington Lake
20	Village Inn Restaurant	04030004	.001	Cane Run
21	Burgin Elementary and High Schools	04030003	.008	Cane Run
22	Keystone Brush Company	04030002	.006	Cane Run
23	Private residence	04030000	.001	Cane Run
24	Kentucky Utilities Brown Power	04030001	.000	Herrington Lake
		Withdrawal/intake sites		
A	City of Stanford (reservoir intake)	04033004	.000	Neals Creek (Stanford Reservoir)
B	City of Lancaster (reservoir intake)	04032002	.000	Unnamed tributary to White Oak Creek (Lancaster Reservoir)
C	Danville Country Club (withdrawal)	---	.000	Clarks Run

This report describes the ambient physical, chemical, and biological characteristics of Herrington Lake and its major tributaries; the procedures used in the construction and sensitivity analysis of a numerical model of the reservoir; and the simulation of potential management strategies for the reservoir. The spatial and temporal distribution of chlorophyll *a* and phytoplankton are described in Crain (1998).

Description of Study Area

Herrington Lake is a warm, monomictic reservoir in the Inner Bluegrass physiographic region of Kentucky and is located in parts of Mercer, Garrard, and Boyle Counties (fig. 1). The reservoir was formed in the mid-1920's with the completion of the Dix Dam, and at the time of construction was the highest dam (270 ft) east of the Rocky Mountains. The reservoir is maintained and operated by the Kentucky Utilities Company for the primary purpose of hydropower generation. The two largest towns near the reservoir are Danville and Wilmore, Ky. Danville has a population of 12,420; Wilmore has a population of 4,215 (U.S. Bureau of the Census, 1991).

Herrington Lake has a surface area of 4.6 mi^2, a volume of 254,000 acre-ft, a length of 35 mi (at full pool), and mean and maximum depths of 78 ft and 250 ft, respectively (U.S. Environmental Protection Agency, 1977). The Dix River watershed (318 mi^2) comprises various land-use types, including approximately 70-percent agricultural, 25-percent forest, and 3-percent urban areas. Land-use data were compiled from 1:250,000-scale digital data (U.S. Geological Survey, 1986a) (fig. 3). The watershed is hilly in the headwaters, leading to gently rolling hills at the dam.

Acknowledgments

The authors acknowledge the cooperation, information, and assistance provided by Bradley C. Young, Kentucky Utilities Company, for furnishing discharge, pan evaporation, and precipitation data for Herrington Lake, Ky., the National Weather Service and the University of Kentucky Spindletop Research Farm for meteorological data, and Paul A. Bukaveckas, University of Louisville, Louisville, Ky., for providing guidance to the senior author while she was a graduate student at the University.

COLLECTION AND ANALYSIS OF DATA

Bathymetric, meteorologic, hydrologic, physical, water-quality, and biological data were collected and compiled from a variety of sources for this investigation. Water samples for chemical analysis were collected from selected tributaries, the main stem of the Dix River, and from Herrington Lake during 1995 and 1996 by the USGS. Biological samples were collected from Herrington Lake during 1995 and 1996 by the University of Louisville. Five inflow stations (Dix River, Clarks Run, Mocks Branch, McKecknie Creek, and Cane Run) were sampled (fig. 4) over a range of seasonal and hydrologic conditions. Five reservoir-sampling stations were selected to characterize the upstream (riverine), middle (transition), and downstream (lacustrine) sections of the reservoir. The reservoir-sampling stations included Chenault Bridge [S1 (in model segment 5)], the Water Tower [S2 (model segment 11)], Kennedy Bridge [S3 (model segment 16)], Ashes Creek [S4 (model segment 18)], and Dix River Dam [S5 (model segment 19)] (fig. 4). Chenault Bridge (S1), Water Tower (S2), Kennedy Bridge (S3), and Dix River Dam (S5) were within the mainstem of the reservoir; however, Ashes Creek (S4) was in an embayment. Detailed sampling and analytical methods are described below.

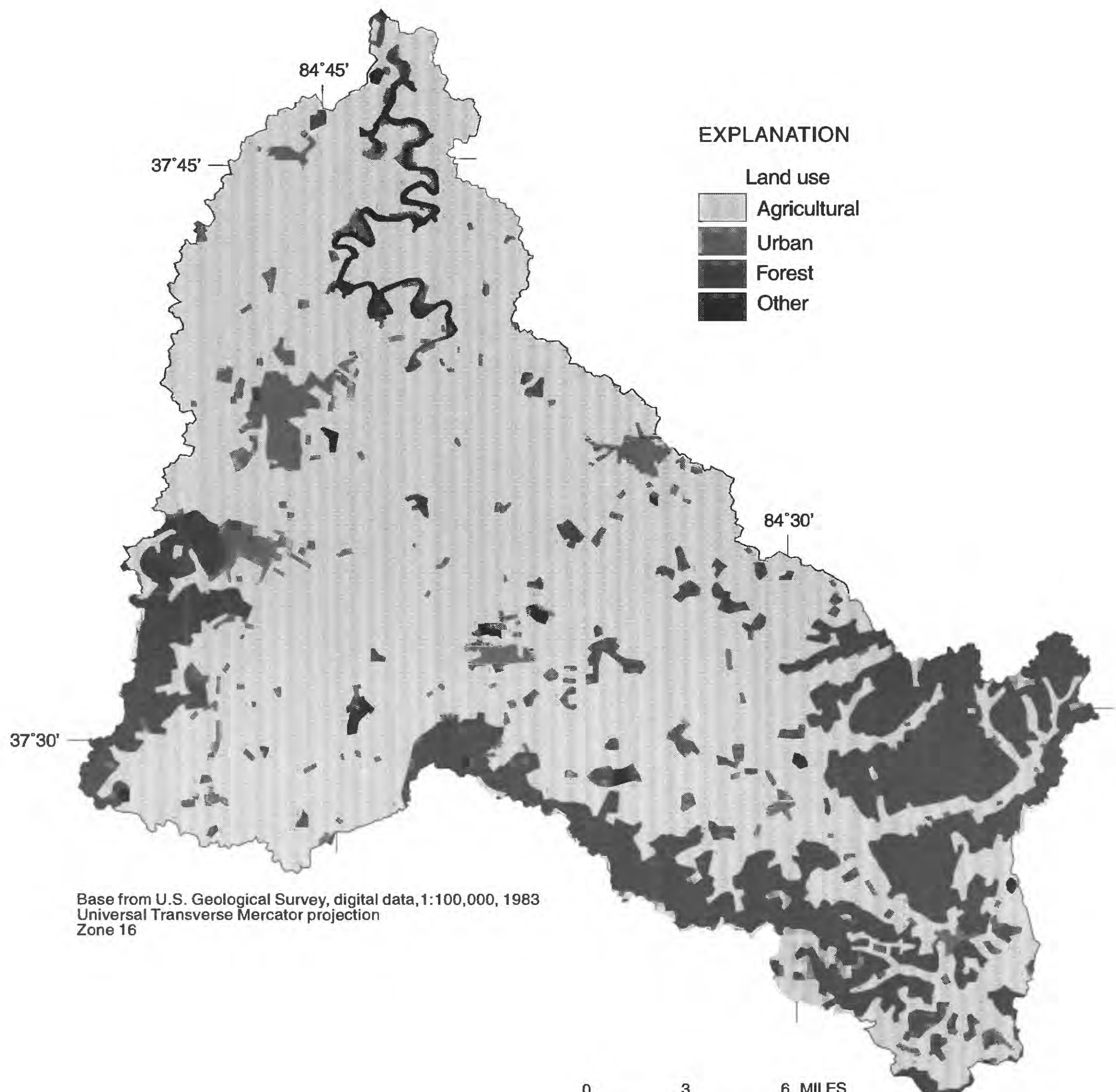
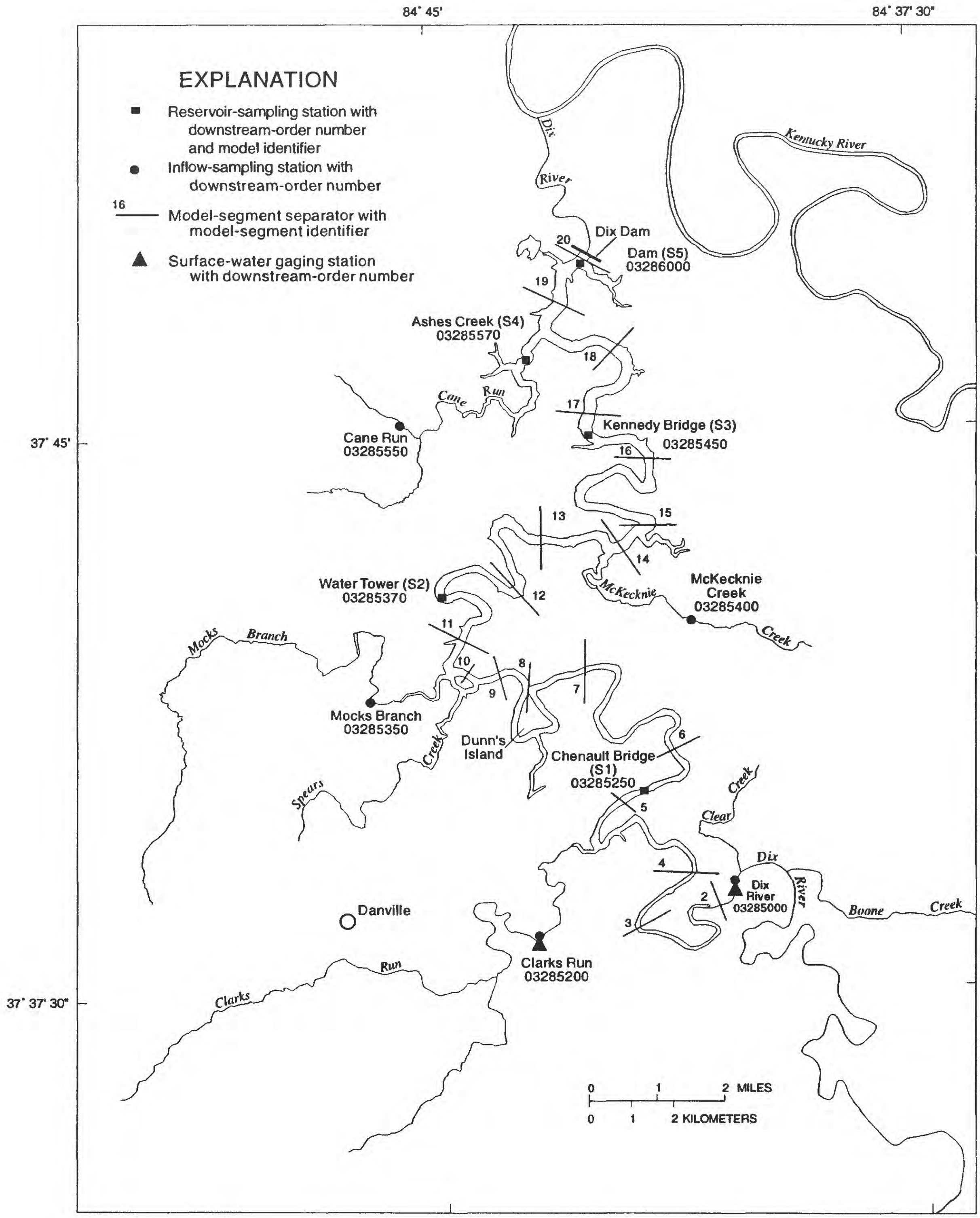


Figure 3. Generalized land use of Dix River Basin, Kentucky.



Base from U.S. Geological Survey, digital data, 1:100,000, 1983
Universal Transverse Mercator projection
Zone 16

Figure 4. Location of Herrington Lake, Kentucky, model segments, reservoir-sampling stations, and surface-water gaging and stream-inflow sampling stations.

Bathymetric Data

The USGS conducted a bathymetric survey of Herrington Lake in September 1994. Seventy transects were evaluated using a differential global-positioning system and a digital-recording acoustic fathometer with an analog strip chart backup using procedures recommended by the U.S. Army Corps of Engineers (COE) (U.S. Army Corps of Engineers, 1994). The digital data were compared for consistency with the analog strip chart and corrected as necessary. These data were provided to J.E. Edinger Associates, Inc., who prepared the file of input data for the reservoir bathymetry required by the CE-QUAL-W-2 model (Edward M. Buchak, J.E. Edinger and Associates, Inc., written commun., 1997).

Meteorologic Data

Regional meteorologic data were obtained from the National Weather Service (NWS). The University of Kentucky Spindletop Research Farm (located approximately 75 mi from Herrington Lake) provided hourly solar-radiation, air-temperature, dew-point, wind-speed, and wind-direction data. Hourly cloud-cover data were estimated by using a regression model that relates hourly cloud cover to hourly solar radiation collected by the NWS at Louisville, Kentucky. Precipitation data (fig. 5) and pan-evaporation data were collected at the Dix River Dam by the Kentucky Utilities Company.

Hydrologic Data

Discharge data were collected at USGS streamgaging stations on Clarks Run near Danville, Ky., and Dix River near Danville, Ky. (figs. 6 and 7) (McClain and others, 1996, 1997). Stream discharge was measured at 4- to 8-week intervals from February-November 1995 and January-September 1996 on selected tributaries of Herrington Lake, which include Cane Run, Mocks Branch, and McKecknie Creek. Daily mean discharge was estimated for these tributaries using drainage-area ratios based on the streamflow records at the Clarks Run station.

The amount of flow from subsurface-karst conduits into the reservoir is unknown, but may be significant. Thus, mass balance inputs may be over- or under-estimated because the assessment of flow from any such conduits was beyond the scope of this project. Discharge measured in streams was assumed to enter the reservoir with no losses or gains from the karst system.

Outflows and water-level data for the Dix River Dam were provided by Kentucky Utilities Power Company (Bradley C. Young, Kentucky Utilities Power Company, written commun., 1997). Data for several short periods during which measuring equipment malfunctioned were estimated.

Physical Water-Quality Characteristics

Water temperature and specific conductance were measured at 2- to 8-week intervals at the five selected inflows to Herrington Lake during February-November 1995 and January-September 1996, using a YSI Model S-C-T thermistor. For the five reservoir-sampling stations, water temperature, DO, pH, and specific conductance were measured at 1-ft depth intervals (surface to bottom) using a YSI 6000 water-quality meter. Light-attenuation profiles were measured using a Protomatic photometer equipped with upward and downward spherical sensors. Light profile readings were taken at 1.5-ft intervals from the surface to the lower boundary of the photic zone (1 percent of subsurface irradiance) to estimate coefficients of light attenuation. The attenuation coefficient (Kd) was calculated from the slope of the natural logarithm of down-welling irradiance against depth (Kirk, 1983).

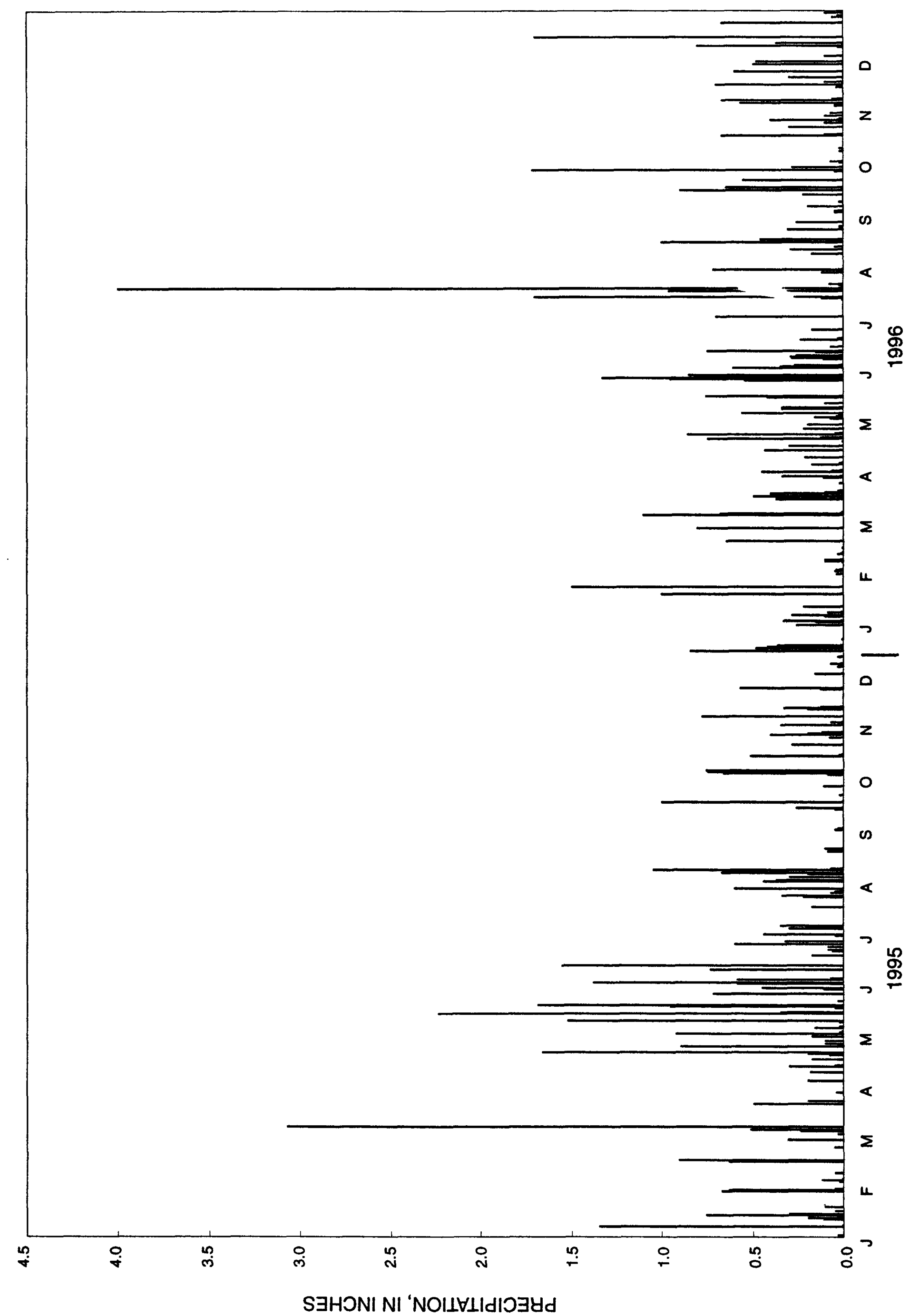


Figure 5. Precipitation at Dix Dam, Kentucky, 1995–96.

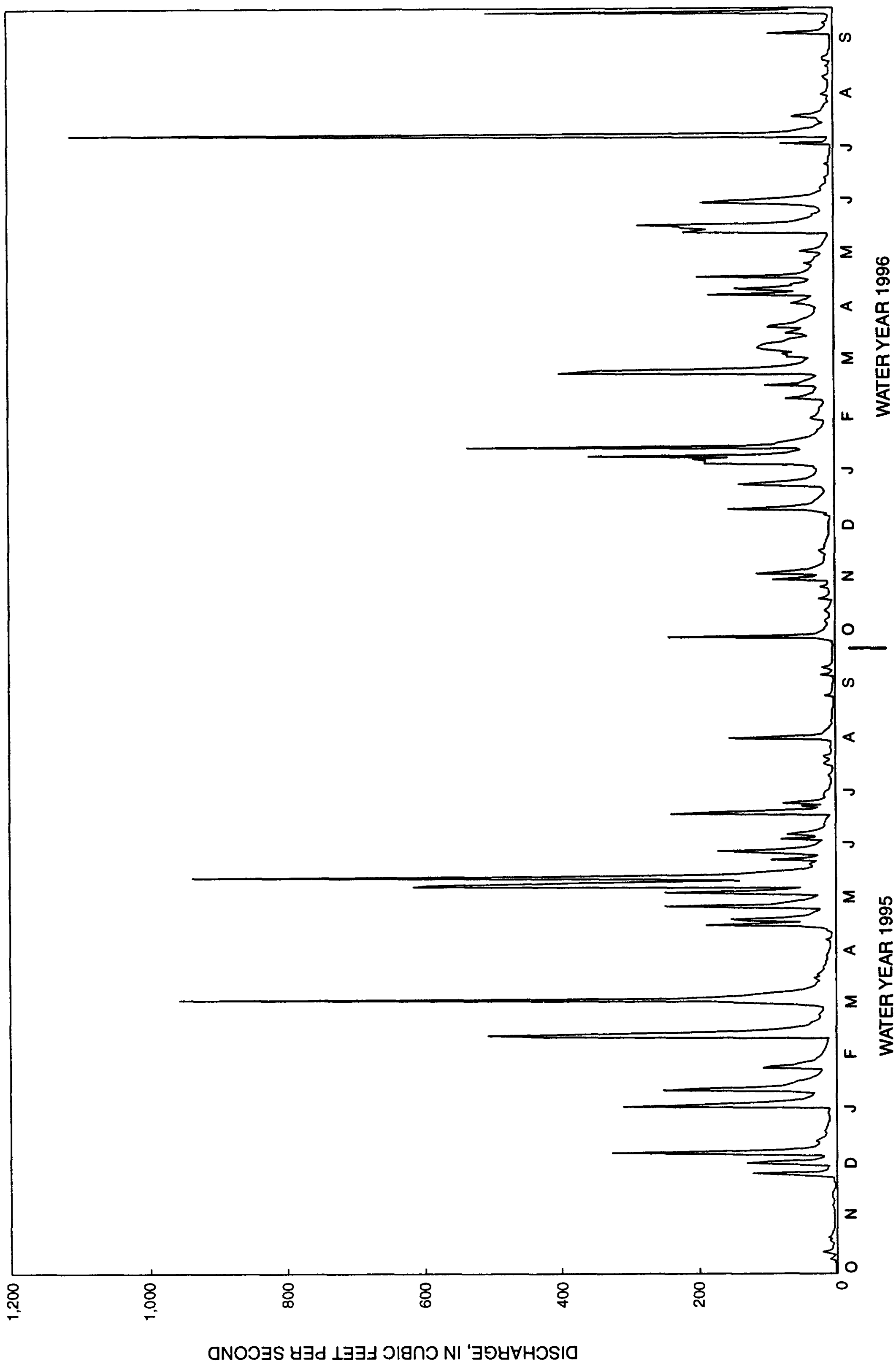


Figure 6. Daily mean discharge for Clarks Run near Danville, Kentucky, water years 1995-96.

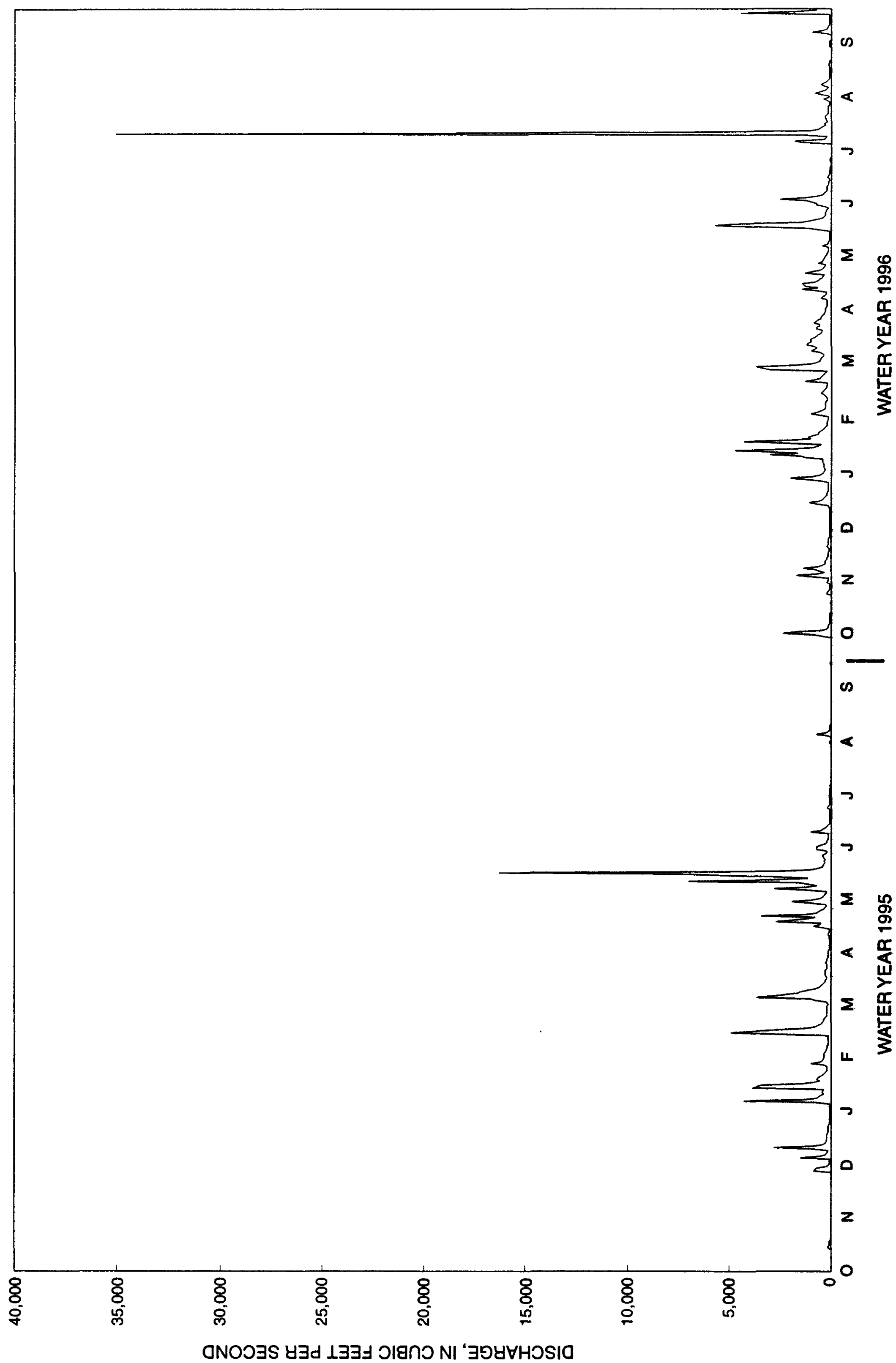


Figure 7. Daily mean discharge for Dix River near Danville, Kentucky, water years 1995-96.

Chemical and Biological Water-Quality Characteristics

Water samples were collected at 1- to 4-week intervals at five reservoir stations during March-October 1995 and 1996. In addition, a total of 22 water samples were collected at five inflow stations from February-November 1995 and January-September 1996. The samples were analyzed for chlorophyll *a*, total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate-nitrogen (NO_3-N), and ammonia-nitrogen (NH_4-N). Samples for chlorophyll *a* and light-attenuation profile data were not collected at the tributaries.

Nutrients

Samples were collected at depths of 2, 15, and 30 ft below the reservoir surface and 10 ft above the bottom at the reservoir-sampling stations using a 2.5-liter Kemmerer water sampler. Grab samples were collected from the Dix River, Clarks Run, Mocks Branch, Cane Run, and McKecknie Creek. Samples for analysis of nutrients were sent to the Kentucky State University laboratory. NH_4-N and NO_3-N concentrations were measured using an Orion 920A pH/ISE (ion-selective electrode) meter (American Public Health Association, 1992). SRP concentrations were analyzed on unfiltered samples using the manual ascorbic acid method (American Public Health Association, 1992). TP concentrations were analyzed by the digestion method followed by the manual ascorbic acid method (American Public Health Association, 1992).

Chlorophyll *a*

Samples for analysis of chlorophyll *a* were collected at three equally spaced depths between the surface and the 1-percent light level at the reservoir sampling stations using a 2.5-liter Kemmerer water sampler. Samples were stored on ice in 1-liter polyethylene bottles and processed within 1 to 2 hours of collection by filtration through 0.45 μm Gelman A/E glass fiber filters. The samples were analyzed for chlorophyll *a* at the University of Louisville Water Resources Laboratory. Crain (1998) provides a detailed description of the analytical procedure for determination of chlorophyll *a* concentrations.

Chlorophyll *a* concentrations, in micrograms per liter, were converted to milligrams per liter of algal biomass for the Herrington Lake model by use of two conversion factors. The first factor converts chlorophyll *a* to carbon. Literature values for the first factor range from 10 to 112 for total phytoplankton and from 14 to 67 for blue-green algae (Bowie and others, 1985). An average value of 19 was used based on measurements made from Herrington Lake phytoplankton samples. The second factor converts carbon to biomass. A value of 0.47 was taken from the literature for the second factor (Bowie and others, 1985).

Phytoplankton

Phytoplankton samples were collected at each reservoir station from three depths corresponding to those sampled for chlorophyll *a* analyses. Phytoplankton samples were processed using standard procedures (American Public Health Association, 1992). Phytoplankton taxa identifications were determined from Prescott (1978), Whitford and Schumacher (1984), Smith (1950), Desikachary (1959), and Dillard (1989). Enumeration of phytoplankton species followed standard procedures (American Public Health Association, 1992). A detailed description of phytoplankton identification and enumeration is provided by Crain (1998).

Carlson Trophic State Index

Chlorophyll *a* concentrations can be used to determine a trophic state index (TSI) (Carlson, 1977). The Carlson TSI equation for chlorophyll *a* is:

$$TSI(chla) = 10\left(6 - \frac{2.04 - 0.68(ln(chla))}{ln2}\right), \quad (2)$$

where

- *chla* is chlorophyll *a* concentrations in micrograms per liter, and
- *ln(chla)* is the natural logarithm of chlorophyll *a* concentrations in micrograms per liter.

Carlson also developed an equation for calculating a TSI using TP. The Carlson TSI equation for TP is:

$$TSI(TP) = 10\left(6 - \frac{ln\left(\frac{48}{TP}\right)}{ln2}\right), \quad (3)$$

where

- *TP* is the total phosphorus concentration in micrograms per liter, and
- $ln\left(\frac{48}{TP}\right)$ is the natural logarithm of a constant divided by the total phosphorus concentration in micrograms per liter.

Trophic-state classifications based on the Carlson TSI are oligotrophic (0-20), mesotrophic (31-50), eutrophic (51-69), and hypereutrophic (>69) (Carlson, 1977) for both the chlorophyll *a* and TP indexes.

KDOW uses a modified Carlson TSI in which log base 10 is used rather than the natural log to calculate the TSI values for the state's reservoirs. The modified Carlson TSI equations used were:

$$TSI(chla) = 30.6 + 22.6\ (log10\ chla), \quad (4)$$

where

- *chla* is chlorophyll *a* concentrations in micrograms per liter, and
- $log_{10}\ chla$ is the log base 10 of chlorophyll *a* concentrations in micrograms per liter; and

$$TSI\ (TP) = 4.2 + 33.2\ (log10\ TP), \quad (5)$$

where

- *TP* is the total phosphorus concentration in micrograms per liter, and
- $log_{10}\ TP$ is the log base 10 of the total phosphorus concentration in micrograms per liter.

Depth-composited samples collected by the KDOW from the euphotic zone at three sampling sites in Herrington Lake at the KDOW sampling sites from March 1 through September 30 at approximately 2-month intervals in 1973 and 1983 were analyzed for chlorophyll *a* and total phosphorus. A seasonal TSI value was calculated for each site and season, then averaged to determine a single TSI value for the reservoir for that year. Using the modified Carlson TSI, KDOW computed a TSI chlorophyll *a* value of 52 for 1973, and 56 for 1983 (Kentucky Natural Resources and Environmental Protection Cabinet, 1984).

AMBIENT CONDITIONS

Hydrology

Long-term average annual precipitation for the Dix River watershed ranges from 48 to 52 in. (U.S. Geological Survey, 1986b). Average annual runoff ranges from 18 to 20 in. The summer of 1995 was dryer than the summer of 1996 (fig. 5). The total cumulative rainfall for June-August 1995 was 12 in. During the same period in 1996, the total cumulative rainfall was about 15 in. The greatest total monthly cumulative rainfall occurred in May 1995.

The flow of Dix River and Clarks Run (figs. 6 and 7) were compared with the precipitation patterns. Clarks Run and Dix River contribute approximately 94 percent of the total surface flow to the reservoir. Mean annual discharge for Dix River in 1995 and 1996 was 442 and 591 ft^3/s, respectively. These results were compared to the historical data record (56 years) for Dix River and showed 1995 to be ranked 33rd out of the 56 annual values and 1996 to be ranked 11th. No-flow conditions were observed in McKecknie Creek once in February and once in April of 1996. Flow of less than 1 ft^3/s was measured at least once during 1995 at the other tributaries, primarily in late summer. The selected minor tributaries of Herrington Lake had a combined average flow of about 40 ft^3/s.

Physical Characteristics

Water temperature in the reservoir varied both spatially and seasonally (fig. 8). Temperature distributions indicate that, as the inflow reached the transitional zone of the reservoir, the cooler water sank below the epilimnion. In April, temperature differences at Chenault Bridge (S1), between the surface and bottom, did not exceed 9°F indicating water-column mixing; in June, however, the epilimnetic and hypolimnetic temperatures differed by more than 14°F (fig. 8). In contrast, temperature differences at Kennedy Bridge (S3) were never less than 17°F and were as much as 37°F. Temperature distributions from mid-reservoir to the dam were similar throughout 1995–96.

The water in Herrington Lake began to stratify in early April 1996 and remained stratified throughout the summer. Thermal stratification gradually weakened, and the reservoir underwent complete thermal mixing by mid-October 1996. During stratification, epilimnion and hypolimnion temperatures differed more than 30°F.

Water Quality

Marked seasonal and spatial patterns in concentrations of DO were evident in 1996 (fig. 9). Concentrations of DO less than 5 mg/L were typical at Chenault Bridge (S1) in 1996. A metalimnetic-oxygen minimum was measured in June 1996. A metalimnetic-oxygen minimum is produced by oxidizable material sinking into the metalimnion. Also contributing to the metalimnetic-oxygen minimum is the transport of allocthonous material and the decomposition of the material in the metalimnetic region. The potential origins of the oxidizable material are deposition from the overlying productive epilimnion and from watershed runoff entering the metalimnetic region. The denser water in the metalimnion reduces the sinking rate of the oxidizable material and allows more time for decomposition, thereby depleting oxygen levels in the metalimnion (Wetzel, 1983). Concentrations of DO near 0 mg/L were measured in the hypolimnion at Water Tower (S2) and Kennedy Bridge (S3) several times in 1996 (fig. 9). These low concentrations could be the result of increased demands from the hypolimnetic waters and bed sediments.

As a result of phytoplankton production, values of pH were elevated near the surface of Herrington Lake (fig. 10). The lower values of pH measured in the hypolimnion may be caused by the respiration and decomposition processes. Vertical differences in pH were associated with reservoir stratification. After thermal turnover in late October, the pH values remained uniform in the reservoir.

Specific conductance values in the upper reservoir were controlled by inflow from the Dix River and Clarks Run. Specific conductance in other parts of the reservoir was affected by in-reservoir processes such as stratification, algal productivity, and decomposition of organic material. Specific-conductance values were elevated in April and October, but were low in June. The elevated specific-conductance values were associated with minimal precipitation and little runoff. During stratification, a horizontal plume of high specific conductivity extended from Chenault Bridge (S1) to Kennedy Bridge (S3), indicating that this layer of water did not mix with adjacent water layers.

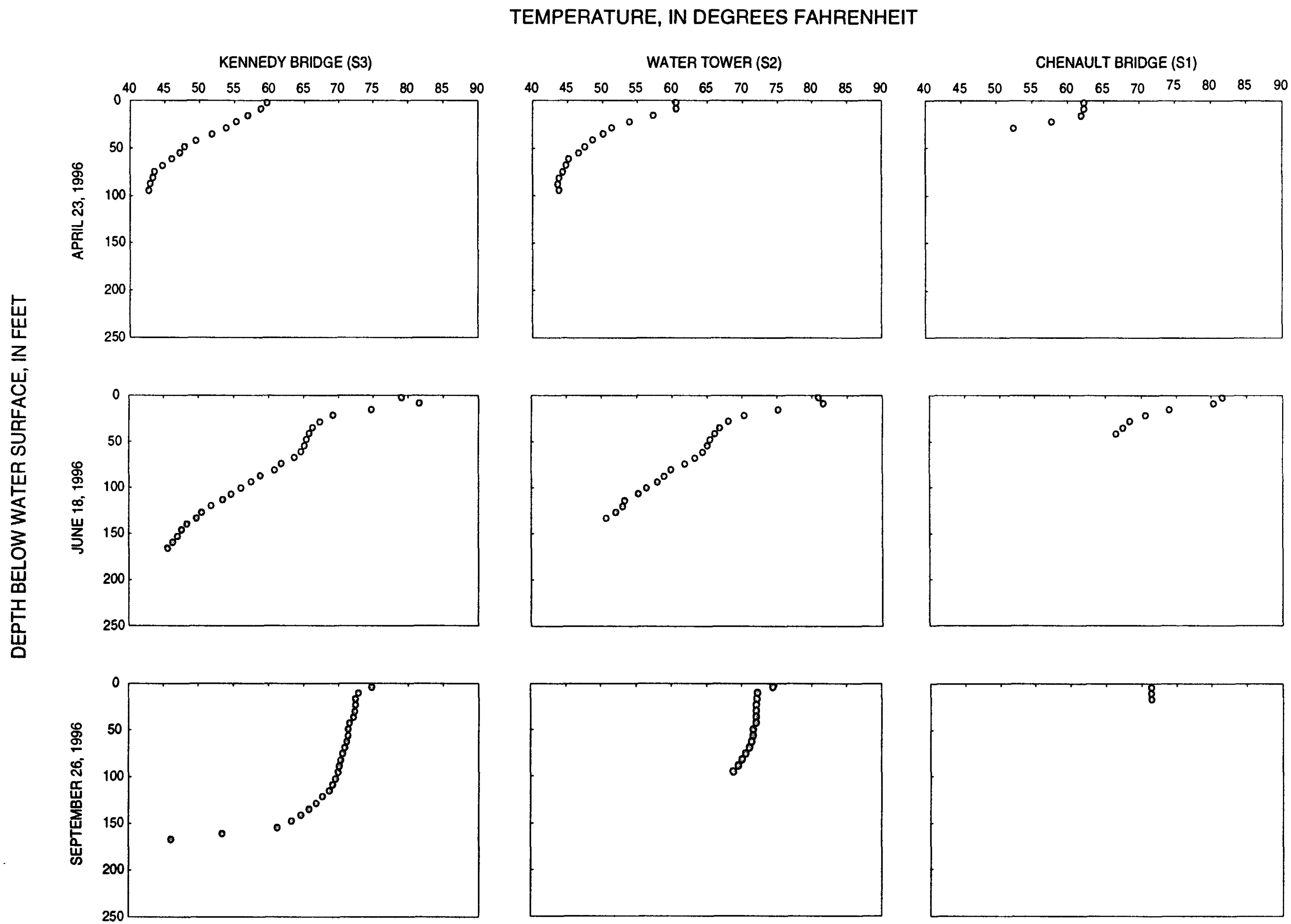


Figure 8. Observed vertical profiles of water temperature at three reservoir-sampling stations, Herrington Lake, Kentucky, April 23, June 18, and September 26, 1996.

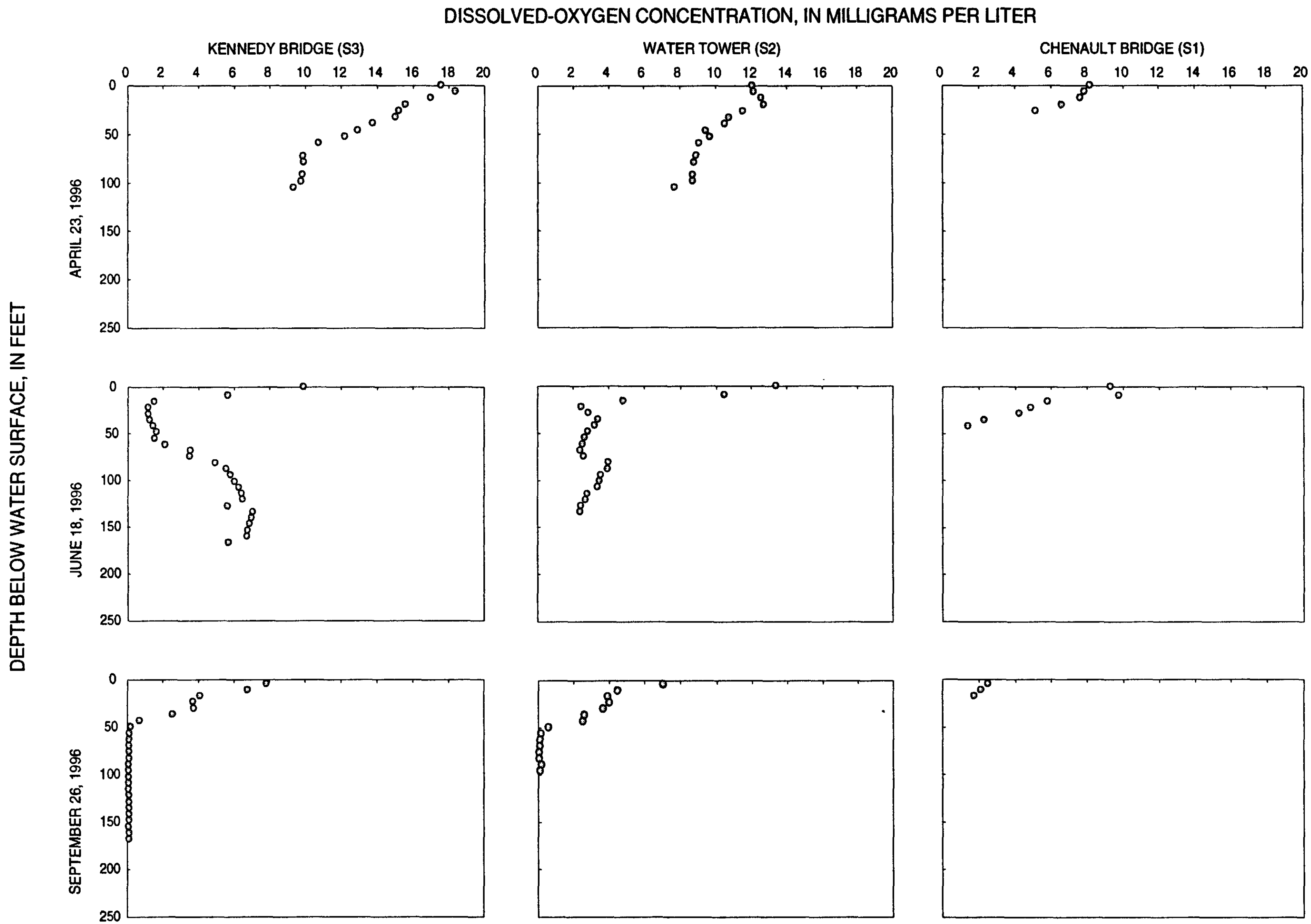


Figure 9. Observed vertical profiles of dissolved oxygen at three reservoir-sampling stations, Herrington Lake, Kentucky, April 23, June 18, and September 26, 1996.

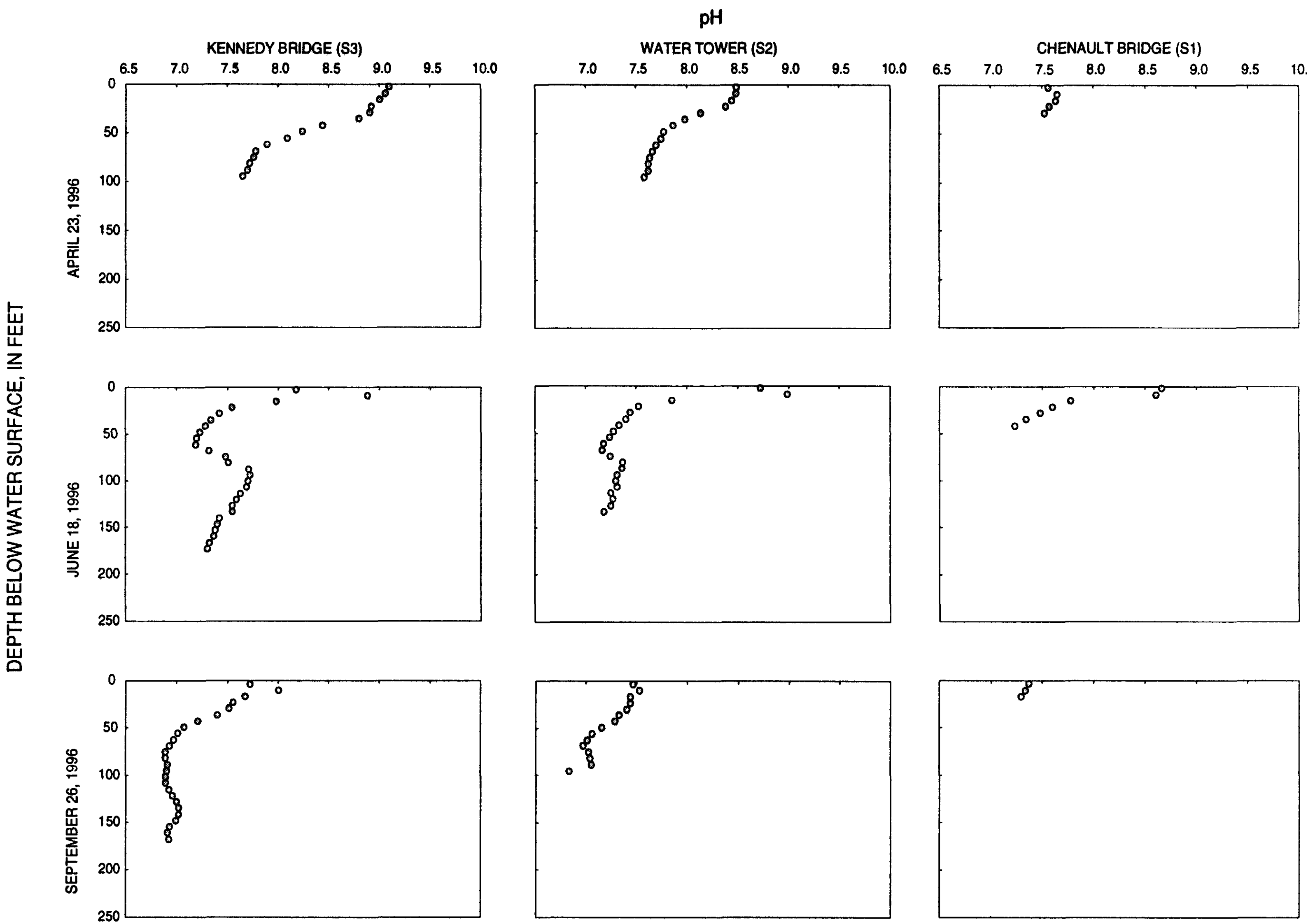


Figure 10. Observed vertical profiles of pH at three reservoir-sampling stations, Herrington Lake, Kentucky, April 23, June 18, and September 26, 1996.

Nitrogen and Phosphorus

Mean concentrations of nitrogen in the epilimnion show little spatial variability, but show substantial seasonal variability in 1996 (table 2). Concentrations of NO_3-N were an order of magnitude higher in March than in September. Epilimnetic NH_4-N concentrations ranged from <10 to 290 µg/L at all stations (table 2, fig. 11). However, the majority of NH_4-N concentrations were below the laboratory reporting level of 10 µg/L. The increased NH_4-N concentrations coincided with periods of low DO. Only small increased variations in NH_4-N were observed in June and August 1996.

Epilimnion and hypolimnion concentrations of phosphorus were more variable than concentrations of nitrogen in Herrington Lake (tables 2 and 3, figs. 11 and 12). There were no pronounced spatial patterns in the concentrations of phosphorus in the epilimnion (table 2, fig. 12). In general, concentrations of phosphorus tended to be higher in the mid to late summer than in the spring.

Elevated concentrations of phosphorus were associated with periods of heavy rainfall. The variation in concentrations of phosphorus in the tributaries associated with runoff were greater than the variation in concentrations of nitrogen. Similar spatial and seasonal patterns in the concentrations of NO_3-N were measured in the hypolimnion.

Chlorophyll *a* and Phytoplankton

Monthly average concentrations of chlorophyll *a* ranged from 2 to 35 µg/L and exhibited similar seasonal and spatial patterns in 1995 and 1996 (fig. 13). At the mid-reservoir station Kennedy Bridge (S3) and at the Dix River Dam (S5), the highest concentrations of chlorophyll *a* generally occurred in April. The decrease in May may be associated with spring runoff. Higher concentrations of chlorophyll *a* during the summer could be related to the decreased turbidity and adequate concentrations of nitrogen and phosphorus. Low concentrations of chlorophyll *a* in late summer could be associated with lower concentrations of NO_3-N. Previous studies have shown at certain times Herrington Lake is nitrogen limited (U.S. Environmental Protection Agency, 1977). In contrast to what was measured at the other reservoir stations, the highest concentration of chlorophyll *a* at Chenault Bridge (S1) were observed in late summer. The reason that Chenault Bridge (S1) shows the opposite pattern as downstream stations is unknown.

A total of 135 species of phytoplankton were found in Herrington Lake (Crain, 1998). The most abundant phytoplankton in Herrington Lake were blue-green algae (Cyanophyta) (table 4). During 1995 and 1996, the most abundant blue-green genera were *Aphanocapsa* and *Oscillatoria*. Both genera represented a combined relative abundance of more than 40 percent. The most widely distributed blue-green algae was the genera *Dactylococcopsis*. The genera *Stephanodiscus* represented the most abundant diatom (Bacillariophyta). The Chlorophyta was the most widely distributed taxa in the reservoir (table 4).

The 1995 and 1996 phytoplankton community included Cyanophytes, Chlorophytes, and Bacillariophytes at each sampling location in the reservoir (fig. 14). Distinct seasonal patterns in phytoplankton composition were evident in both sampling years. Bacillariophyte counts were extremely low in the summer, after spring peaks. Cyanophytes were abundant throughout the summer, particularly the coccoid-shaped, colonial forms.

Spatial variability in phytoplankton community composition was evident in both years. In 1995, the abundance of Chlorophytes was greater downstream [Kennedy Bridge (S3) and at the Dix River Dam (S5)] than at the upstream sampling station [Chenault Bridge (S1)]. The reverse was true, however, for Chlorophyte abundance in 1996. Chenault Bridge (S1) exhibited greater Bacillariphyte abundance than Kennedy Bridge (S3) or the Dix River Dam (S5) in 1995 and 1996. Cyanophytes were abundant throughout the three seasons at all three stations, particularly the coccoid-shaped, colonial forms.

Table 2. Statistical summary of selected chemical and biological constituents for epilimnetic (surface) samples collected during 1996 at Herrington Lake, Kentucky

[Spring, April to May; Summer, June to August; Fall, September to October; n, sample size; Min, minimum; Max, maximum; µg/L, micrograms per liter; N, nitrogen; <, less than; P, phosphorus]

Constituent	Spring				Summer				Fall			
	n	Min	Max	Mean	n	Min	Max	Mean	n	Min	Max	Mean
Chenault Bridge (S1)												
Nitrate-nitrogen dissolved (µg/L as N)	10	930	2,520	1,900	14	100	3,030	1,700	5	170	500	330
Ammonia-nitrogen dissolved (µg/L as N)	10	<10	100	20	14	<10	180	10	5	<10	<10	<10
Total phosphorus (µg/L as P)	8	110	310	200	14	80	1,180	390	5	130	620	260
Soluble reactive phosphorus (µg/L as P)	8	40	160	70	14	20	300	100	5	30	160	90
Chlorophyll *a* (photic-zone composite; µg/L)	21	<1	18	7	33	2	27	12	9	4	41	15
Water tower (S2)												
Nitrate-nitrogen dissolved (µg/L as N)	15	1,240	3,040	2,110	15	120	3,800	1,430	6	100	590	320
Ammonia-nitrogen dissolved (µg/L as N)	15	<10	<10	<10	15	<10	290	<10	6	<10	<10	<10
Total phosphorus (µg/L as P)	12	80	720	240	15	100	1,320	260	6	80	490	270
Soluble reactive phosphorus (µg/L as P25	15	10	210	90	15	50	240	140	6	20	90	60
Chlorophyll *a* (photic-zone composite; µg/L)	18	4	33	15	24	2	30	14	6	2	14	7
Dam (S5)												
Nitrate-nitrogen dissolved (µg/L as N)	15	1,370	2,800	2,130	16	350	4,070	1,450	6	150	670	350
Ammonia-nitrogen dissolved (µg/L as N)	15	<10	<10	<10	16	<10	240	40	6	<10	<10	<10
Total phosphorus (µg/L as P)	15	70	530	220	16	50	850	250	6	100	960	410
Soluble reactive phosphorus (µg/L as P)	15	20	360	90	16	30	390	90	6	40	90	70
Chlorophyll *a* (photic-zone composite; µg/L)	18	<1	35	11	20	7	35	14	6	2	10	5

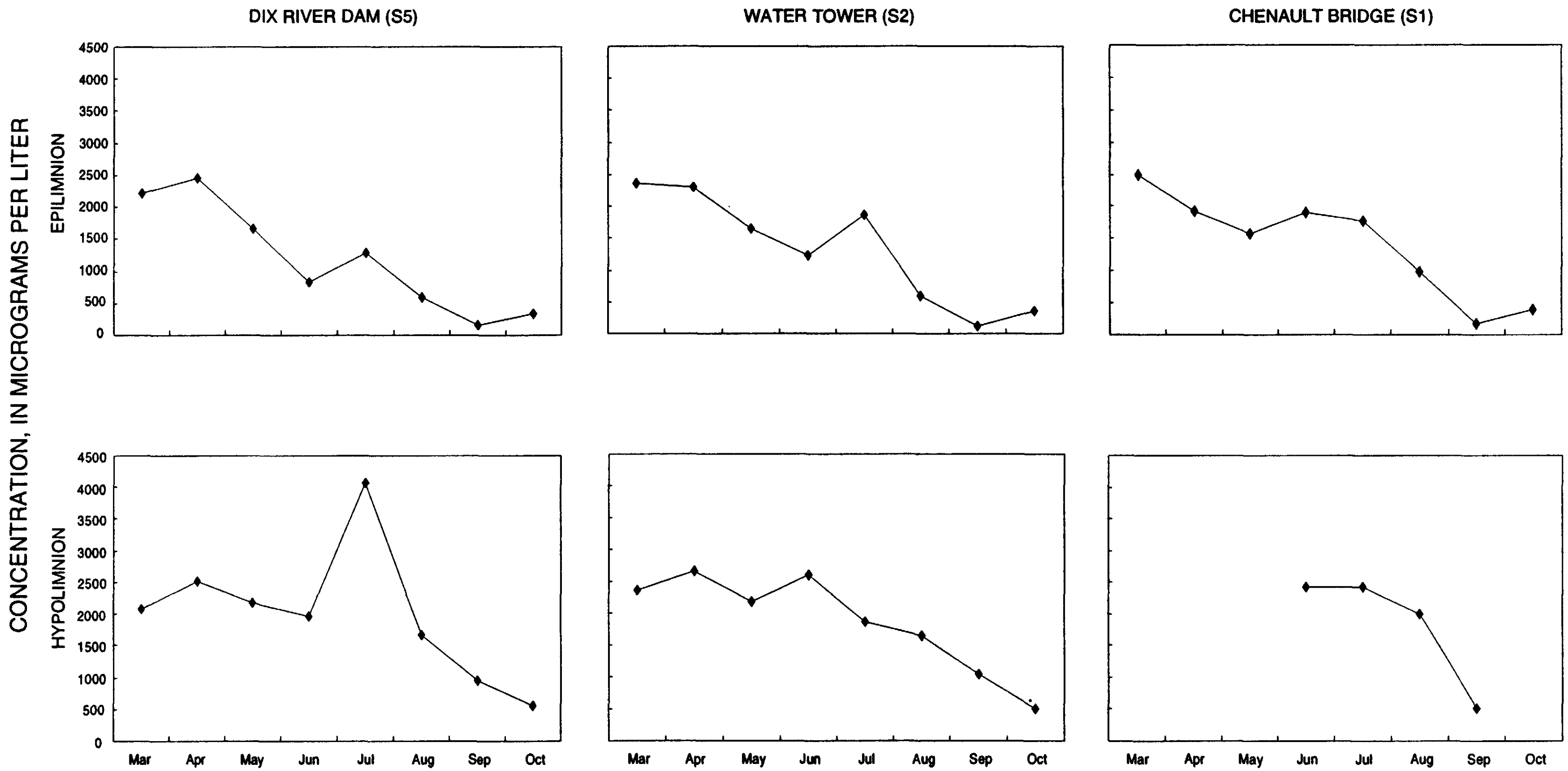


Figure 11. Average monthly nitrate-nitrogen (NO_3-N) in Herrington Lake epilimnetic and hypolimnetic samples for three reservoir-sampling stations, March-October 1996.

Table 3. Statistical summary of selected chemical constituents for hypolimnetic (near bottom) samples collected during 1996 at Herrington Lake, Kentucky

[Spring, April to May; Summer, June to August; Fall, September to October; n, sample size; Min, minimum; Max, maximum; µg/L, micrograms per liter; N, nitrogen; ---, no data; <, less than; P, phosphorus]

Constituent	Spring				Summer				Fall			
	n	Min	Max	Mean	n	Min	Max	Mean	n	Min	Max	Mean
Chenault Bridge (S1)												
Nitrate-nitrogen dissolved (µg/L as N)	---	---	---	---	3	1,540	2,470	2,150	2	500	2,400	1,460
Ammonia-nitrogen dissolved (µg/L as N)	---	---	---	---	3	<10	<10	<10	2	<10	<10	<10
Total phosphorus (µg/L as P)	---	---	---	---	3	180	1,180	610	2	270	310	290
Soluble reactive phosphorus (µg/L as P)	---	---	---	---	3	100	300	170	2	50	140	100
Water Tower (S2)												
Nitrate-nitrogen dissolved (µg/L as N)	10	1,700	3,000	2,400	10	1,200	3,800	2,000	4	400	1,500	700
Ammonia-nitrogen dissolved (µg/L as N)	10	<10	<10	<10	10	<10	250	30	4	<10	<10	<10
Total phosphorus (µg/L as P)	8	100	1,000	300	10	200	1,100	350	4	250	500	400
Soluble reactive phosphorus (µg/L as P)	10	50	700	150	10	100	200	180	4	50	150	100
Dam (S5)												
Nitrate-nitrogen dissolved (µg/L as N)	10	1,800	2,900	2,300	10	1,200	4,100	2,300	4	400	1,230	760
Ammonia-nitrogen dissolved (µg/L as N)	10	<10	<10	<10	10	<10	160	20	4	<10	<10	<10
Total phosphorus (µg/L as P)	8	90	520	260	10	80	1,530	390	4	160	650	360
Soluble reactive phosphorus (µg/L as P)	10	20	190	100	10	40	390	130	4	40	130	90

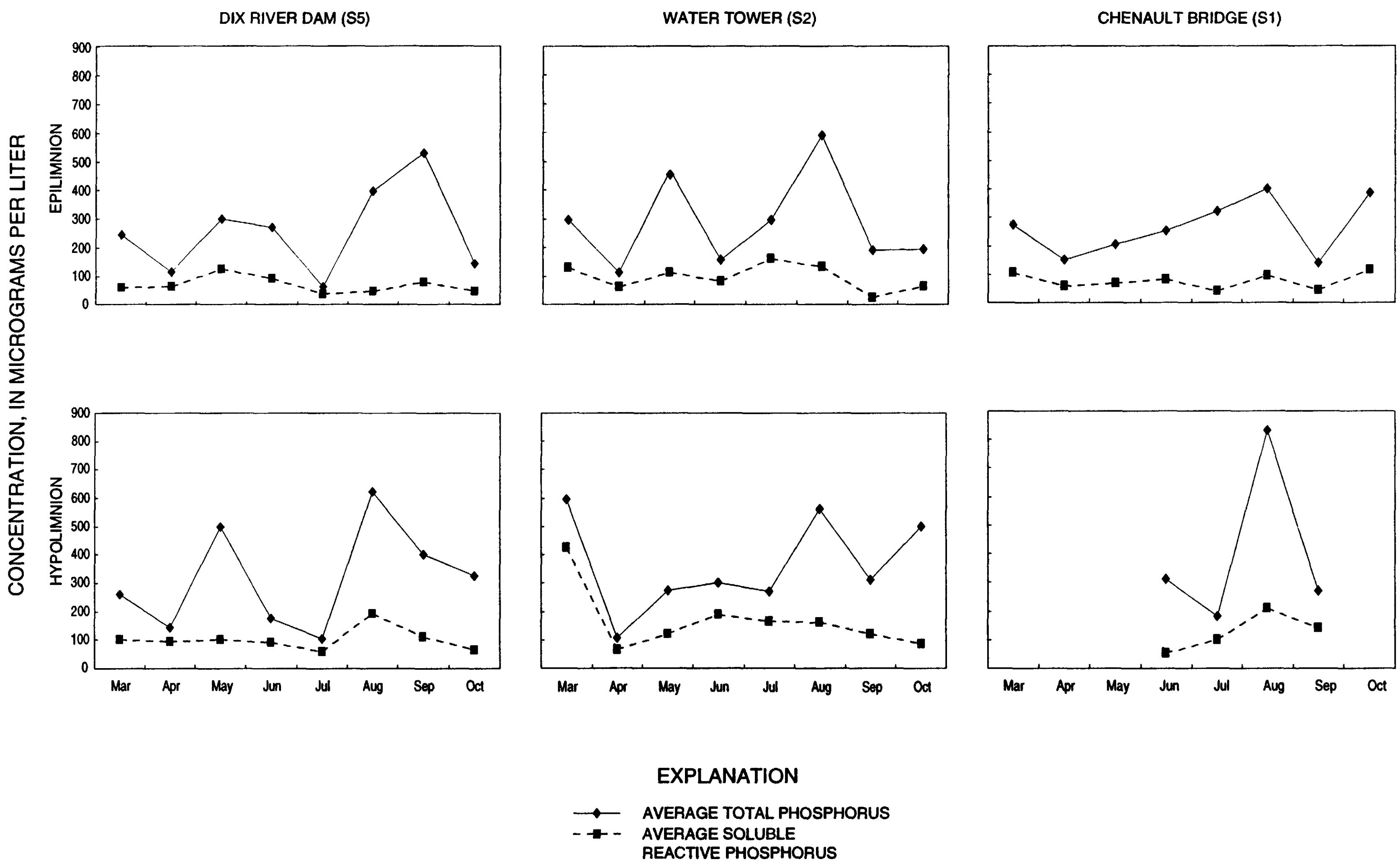


Figure 12. Average monthly total phosphorus and soluble reactive phosphorus in Herrington Lake epilimnetic and hypolimnetic samples for three reservoir-sampling stations, March-October 1996.

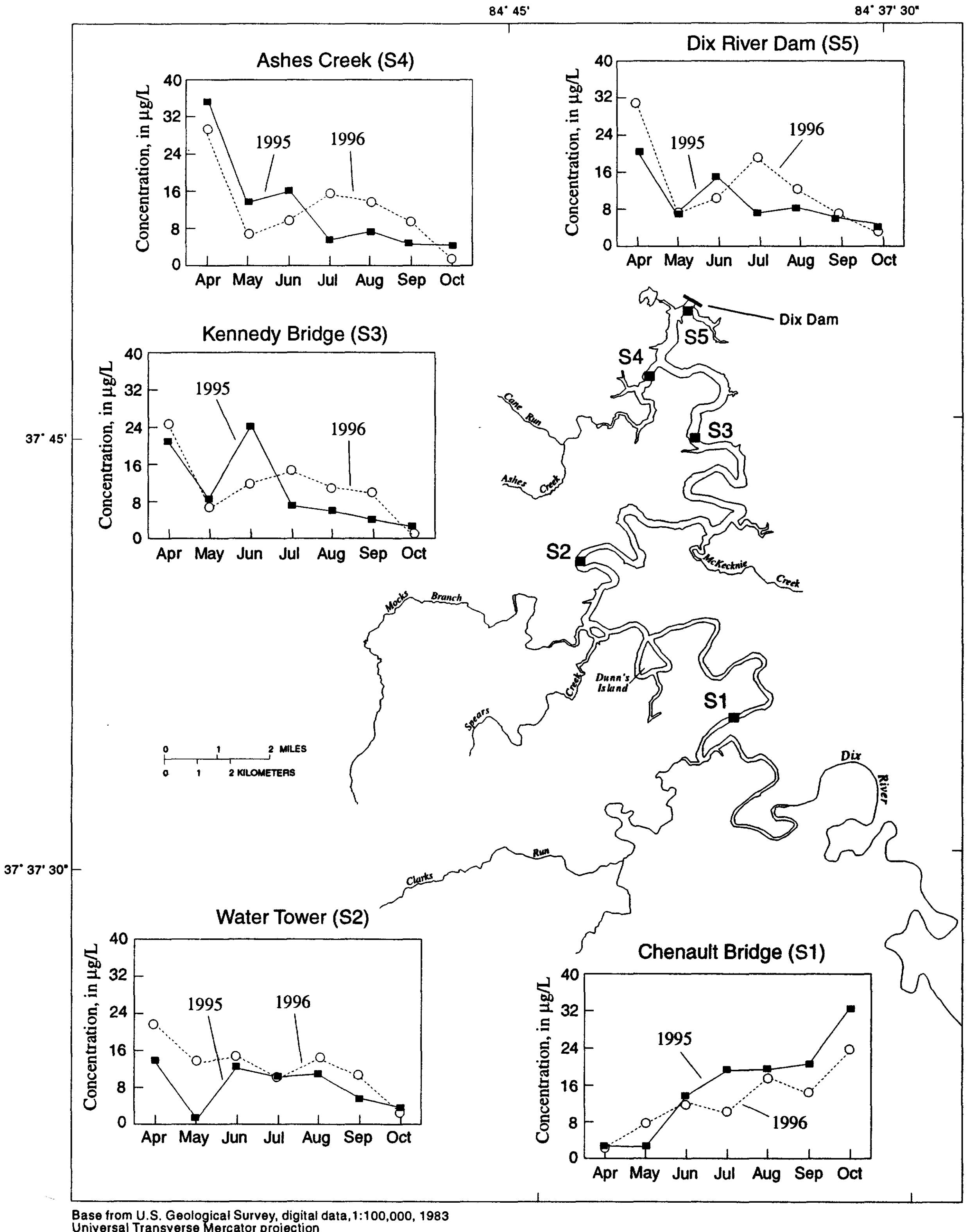


Figure 13. Average monthly chlorophyll *a* concentrations (in micrograms per liter (µg/L)) at five reservoir-sampling stations in Herrington Lake, Kentucky, April-October 1995-96.

Table 4. Dominant algae as a percentage of the total abundance and the percent of sample occurrences, Herrington Lake, Kentucky, 1995–96

[---, unidentifiable]

Group	Genus	Species	Variety	Relative abundance	Percentage of samples	Maximum relative abundance
			Most abundant taxa			
Cyanophyta	*Aphanocapsa*	*delicatissima*	*delicatissima*	0.189	0.48	0.757
Cyanophyta	*Oscillitoria*	*(planctonica)*	*(planctonica)*	.106	.59	.790
Cyanophyta	---	*species 2*	species 2	.095	.09	.564
Cyanophyta	*Gomphosphaerium*	*lacustris*	*compacta*	.080	.37	.814
Cyanophyta	*Aphanothece*	*nidulans*	*nidulans*	.055	.41	.692
Cyanophyta	---	*species 3*	*species 3*	.054	.09	.302
Cyanophyta	*Aphanocapsa*	*species*	*species*	.047	.07	.918
Cyanophyta	*Oscillitoria*	*(angustissima)*	*(angustissima)*	.033	.52	.333
Cyanophyta	*Merismopdeia*	*tennuissima*	*tennuissima*	.032	.37	.223
Chlorophyta	*Pandorina*	*morum*	*morum*	.027	.35	.616
Cyanophyta	*Synechoccous*	*elongatus*	*elongatus*	.023	.26	.409
Cyanophyta	*Oscillitoria*	*species 1*	*species 1*	.022	.15	.081
Cyanophyta	*Chroococcus*	*minimus*	*minimus*	.013	.33	.282
Cyanophyta	*Aphanocapsa*	*elachista*	*elachista*	.013	.28	.115
Bacillariophyta	*Stephanodiscus*	*hantzschii*	*tenuis*	.012	.24	.221
			Most widely distributed taxa			
Chlorophyta	*Ankistrodesmus*	*convolutus*	*convolutus*	.004	.63	.072
Chlorophyta	*Tetraedron*	*minimus*	*minimum*	.002	.63	.042
Chlorophyta	*Ankistrodesmus*	*falcatus*	*falcatus*	.001	.63	.011
Cyanophyta	*Dactylococcopsiis*	*irregularis*	*irregularis*	.005	.59	.129

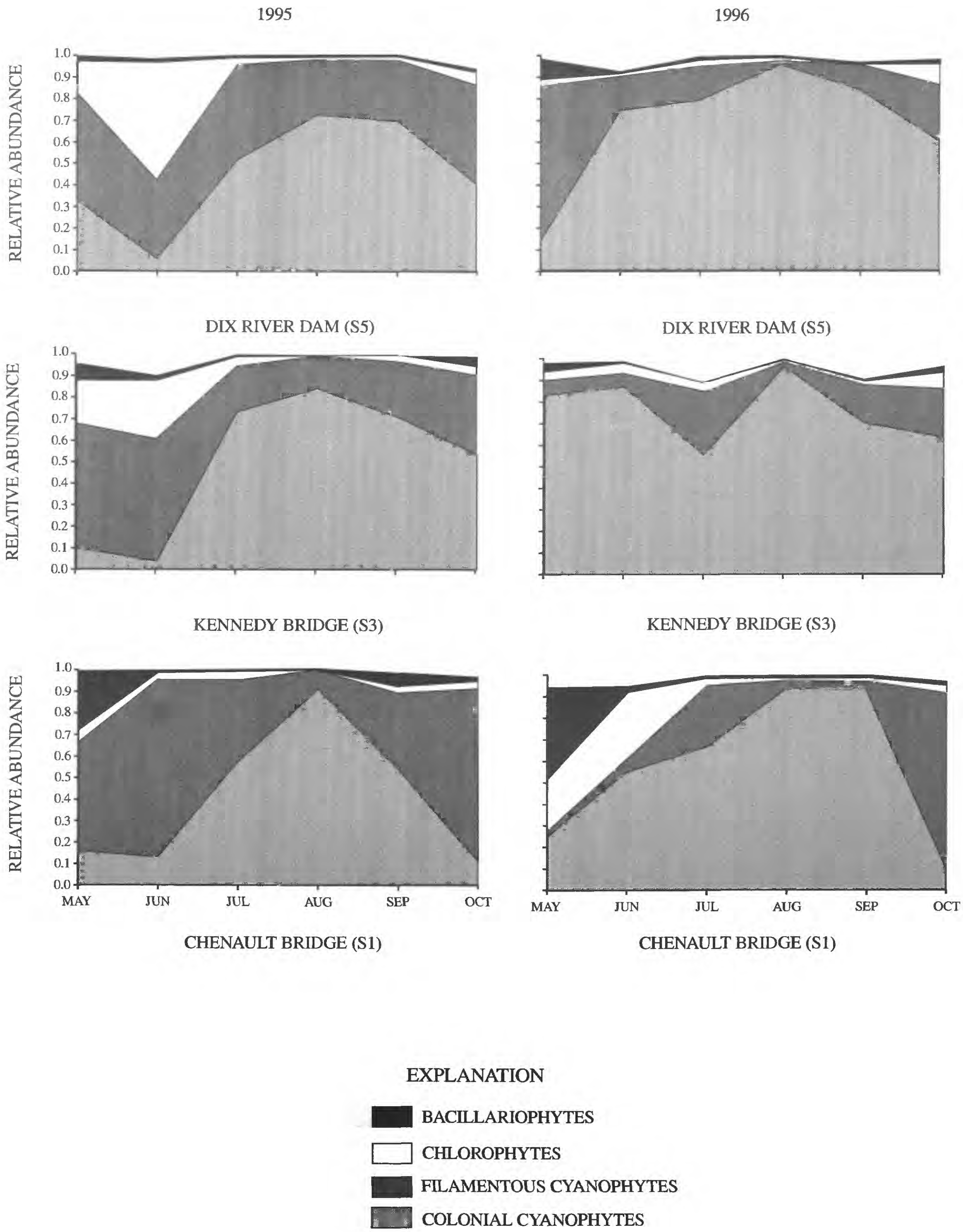


Figure 14. Monthly distribution of the relative abundance of major algal forms at three reservoir sampling stations in Herrington Lake, Kentucky, May - October 1995-96.

ESTIMATION OF NITROGEN AND PHOSPHORUS LOADS TO HERRINGTON LAKE

Daily NO_3-N and SRP loads and concentrations from the tributaries were estimated using the FLUX program (Walker, 1987). These estimates did not include air-shed input, ground-water input, or consider sediment as potential sources of NO_3-N and SRP loads.

Daily mean discharge and instantaneous concentrations of NO_3-N and SRP from each of the inflow tributaries were input into the FLUX program. The estimated mean daily discharge was used for Cane Run, Mocks Branch, and McKecknie Creek. One of three methods (International Joint Commission, regression-1, or regression-2) available in FLUX was used to estimate the load for each constituent at each station. The International Joint Commission method applies a flow-weighted mean concentration to the mean flow with a bias adjustment factor for situations where concentration varies with flow. The regression-1 method regresses the logarithm of concentration against the logarithm of mean daily discharge. The regression-2 method is similar except that it corrects for bias that can occur when regression slopes are high. For each method, the data can be stratified seasonally and by discharge (for example, a method can be applied separately to flows greater than or less than the average discharge) and the results of the individual strata aggregated to obtain the load. The method with the lowest estimated coefficient of variation was used to obtain estimates of mean daily NO_3-N and SRP loads and concentrations.

Annual loads of NO_3-N and SRP were estimated for five Herrington Lake tributaries by summing the daily loads estimated by using the FLUX program (table 5). The loads of NO_3-N and SRP from the Dix River accounted for 70 percent and 78 percent, respectively, of the total loads of those nutrients entering Herrington Lake. The second largest contributor of nutrient loads is Clarks Run, accounting for 18 percent of NO_3-N and 14 percent of SRP of the total loads of those nutrients entering the reservoir. In general, most nonpoint-source loading of water bodies occurs during periods of elevated flow, which results from surface runoff during storm events; nonpoint-source contributions are less during low-flow periods. Consequently during low-flow periods, point sources contribute more nutrient load, relative to the nonpoint source nutrient load (FTN Associates Limited, 1998).

Table 5. Estimated water year 1996 loads of nitrate-nitrogen and soluble reactive phosphorus contributed to Herrington Lake, Kentucky, by selected tributaries

[reg. 1, regression method 1; reg. 2, regression method 2; S, stratified flows; IJC, International Joint Commission]

Station	Drainage area (square miles)	FLUX method used for estimating nitrate-nitrogen loads[1]	Nitrate load as nitrogen (tons per year)	Coefficient of variation (in percent)	FLUX method used for estimating soluble reactive phosphorus loads[1]	Soluble reactive phosphorus load (tons per year)	Coefficient of variation (in percent)
Cane Run	3.2	reg. 1	22	9	reg. 1	2	17
Clarks Run	26.4	reg. 2, S	215	5	reg. 2, S	21	11
Dix River	318	IJC	824	9	reg. 1	117	52
McKecknie Creek	2.55	IJC, S	13	15	reg. 1	1	31
Mocks Branch	16.3	reg. 2, S	109	14	reg. 1	10	21

[1]Walker, 1987.

SIMULATION OF HYDRODYNAMICS, CONSTITUENT TRANSPORT, AND WATER QUALITY

The CE-QUAL-W2 model was used to simulate physical and water-quality conditions for Herrington Lake for the period January through September 1996. CE-QUAL-W2 is an unsteady-state, two-dimensional, laterally averaged hydrodynamic and water-quality model (Cole and Buchak, 1995). The structure of the model allows the simulation of up to 21 water-quality constituents, as well as water temperature, water density, and hydrodynamic properties. The model was used to simulate constituent transport during stratified and unstratified conditions, wind and temperature effects, and effects of nutrients on DO and phytoplankton production.

Model Description and Grid

The reservoir was divided into 20 longitudinal segments (figs. 4 and 15) based on bathymetric data collected for this study. Each segment was chosen to represent and identify potential hydraulic and (or) chemical/biological changes throughout the reservoir; each individual layer in a segment is a cell. All cells within a model segment have the same thickness (6.6 ft) and length, but the length of a cell varies by segment. Segment lengths range from a minimum of 2,960 ft in segments 8, 9, and 14 to a maximum of 15,420 ft in segment 6. Stream segments 1 and 20 are the upstream and downstream boundaries. Within each cell, conditions are considered to be homogeneous.

Boundary and Initial Conditions

The boundaries of the Herrington Lake model include the upstream boundary at the inflow of Dix River, the bottom of the reservoir, the water surface, the shoreline, the downstream boundary at Dix Dam, and the tributaries. Hydraulic and chemical boundary conditions are required by the CE-QUAL-W2 model.

Hydraulic Boundary Conditions

Daily inflow values for the Dix River were computed from the streamgage record at the station. The reservoir bottom was assumed to be an impermeable boundary with no subsurface-karst conduits discharging water into the reservoir within the model. Bottom heat exchange was assumed to be constant in space and time. Boundary conditions at the water surface include wind energy and surface heat exchange. The shoreline of the reservoir was designated as a no-flow boundary. During model simulation, the position of the shoreline changes because of the fluctuation in the reservoir water level. Outflow values from the dam were provided for two different gate elevations. Both gate releases were included as boundary conditions. The hydraulic boundary condition includes water temperature. Initial temperatures were assumed to be uniform at the start of the model simulation.

Additional hydraulic boundary conditions included selected permitted point-source inputs and tributaries. The selected permitted point-source inputs included Northpoint Training Center, formerly known as Kentucky DHR Youth Center in segment 10 and Chimney Rock Resort in segment 18. The largest permitted discharge directly into Herrington Lake was from the Northpoint Training Center (0.3 Mgal/d) (table 1). Clarks Run, Mocks Branch, McKecknie Creek, and Cane Run were the selected tributary inflow stations. Smaller tributaries into Herrington Lake (Clear Creek, Boone Creek, and Spears Creek) were not included in the model. The City of Danville's WWTP discharges into Clarks Run (4.8 Mgal/d) and, in turn, flows into Herrington Lake. The sampling station on Clarks Run is below the outfall of the City of Danville's WWTP and, therefore, includes the flow from the facility.

Chemical Boundary Conditions

Time series for constituents to be simulated in the CE-QUAL-W2 model are required at all inflow boundaries. The chemical boundary conditions included in the Herrington Lake model are suspended sediment, total dissolved solids, dissolved organic matter, algae, particulate organic matter (detritus), PO_4 (orthophosphorus), NH_4-N, NO_3-N,

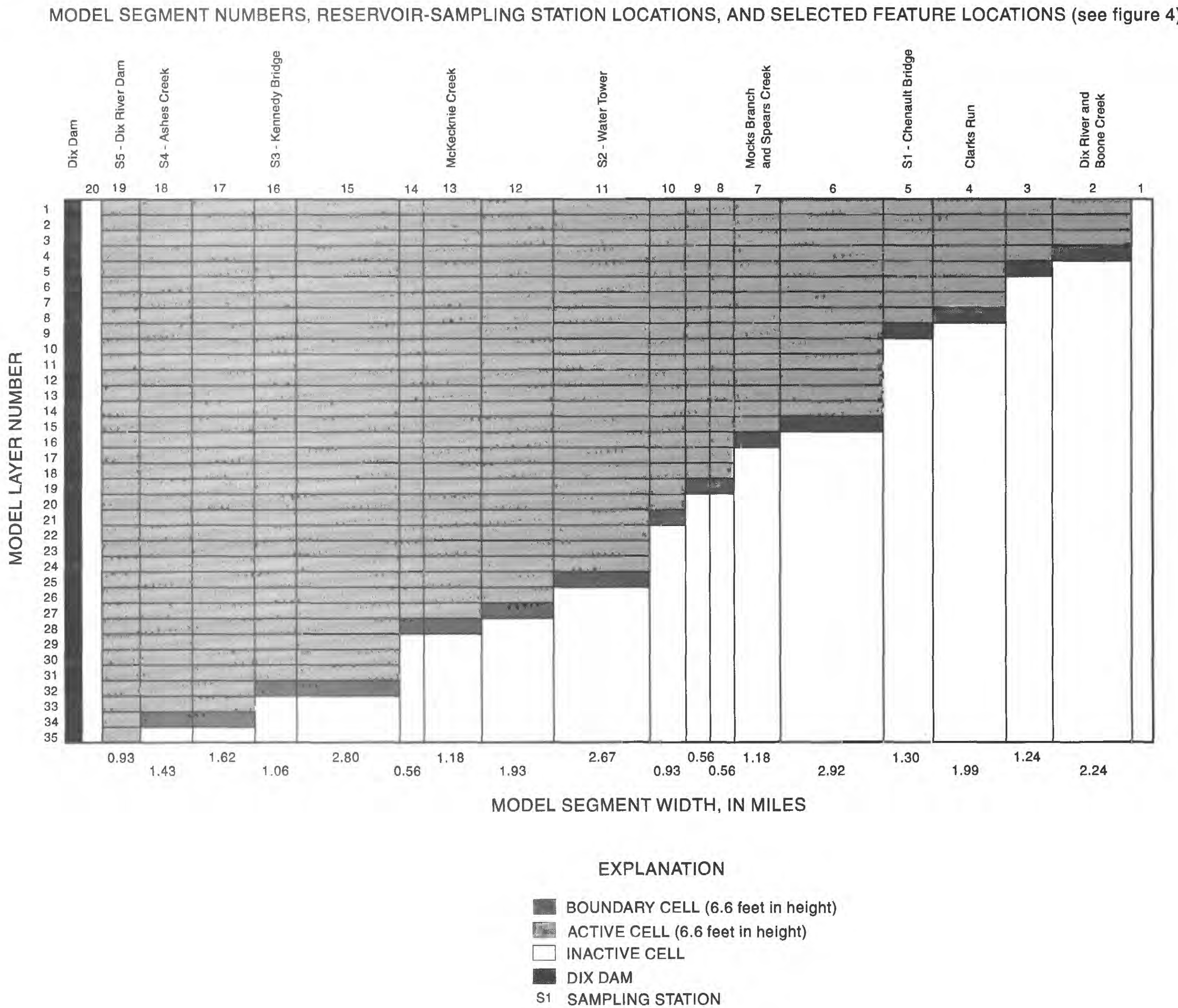


Figure 15. Two-dimensional grid used to represent Herrington Lake in CE-QUAL-W2.

DO, total inorganic carbon, alkalinity, and iron. The Dix River and selected tributary input values for PO_4 and NO_3-N were available from the data collected for this study. Values of SRP collected for this study were used to approximate PO_4. In most situations encountered, these two forms of phosphorus are virtually equivalent (Chapra, 1997). Daily concentrations of NO_3-N and SRP for the Dix River and the tributaries were estimated with the FLUX program as previously described in this report. Time series for the other constituents were not available, and therefore, were estimated. Data were generated to exhibit typical seasonal patterns and relations to discharge. The estimated values were compared to available data from streams in nearby watersheds to determine if the estimated values were realistic. These estimated values were within the range of available data collected in nearby watersheds. The same estimated data were used for the Dix River and each of the selected tributary inputs; an example input data set (the Dix River) is given in Appendix 1. Monthly values of NO_3-N, SRP, and NH_4-N were available for the Northpoint Training Center and Chimney Rock Resort point-source discharges; values for other constituents were not available and also were estimated. Point-source time-series data were input only monthly. The model assumed that inputs from these discharges were constant during any given month.

Model Parameters and Other Variables

Most chemical kinetic-rate coefficients required by the CE-QUAL-W2 model are difficult to measure directly. Consequently, these coefficients for the Herrington Lake simulation were selected from values published in the literature (Appendix 2). Some coefficients were adjusted within the range shown within the literature to improve the model fit. The coefficients used do not vary spatially or seasonally. The values used are given in Appendix 2, which also includes the model code variable, the parameter, and the computational purpose of the parameter.

Model Fit

Water-quality data collected from January to September 1996 were used to assess the "fit" of the CE-QUAL-W2 model to Herrington Lake. Data for evaluation of the model performance optimally would be collected weekly or even more frequently. For the Herrington Lake model, however, only data were collected at 2- to 8-week intervals. These water-quality data are presented in Appendix 3.

The root mean square error (RMSE) was used as a measure of model fit. The RMSE statistic is a measure of the differences between the observed and simulated;

$$RMSE = \sqrt{\frac{[\Sigma(y_i - \hat{y}_i)^2]}{n}} \quad , \qquad (6)$$

where

y_i observed value,

$\hat{y}_i$ simulated value, and

n the number of paired values.

An RMSE of <20 percent was achieved for concentrations of temperature, DO, and NO_3-N. The RMSE for SRP, NH_4-N, and algae was greater than 20 percent.

Hydrology

Observed and simulated water levels are shown in figure 16. Generally, the RMSE between measured and simulated water levels was less than 20 percent. Overall, the water balance between the inflow and outflow was approximately 2.4 percent after adjustments for withdrawals and pan evaporation. The error can be attributed to seepage under and around the dam, which has an estimated range of 9.9 to 20 ft^3/s. Daily outflow data at two withdrawal structures for the Dix River Dam are provided in Appendix 4. The estimated hydraulic residence time in Herrington Lake for 1996 was 344 days.

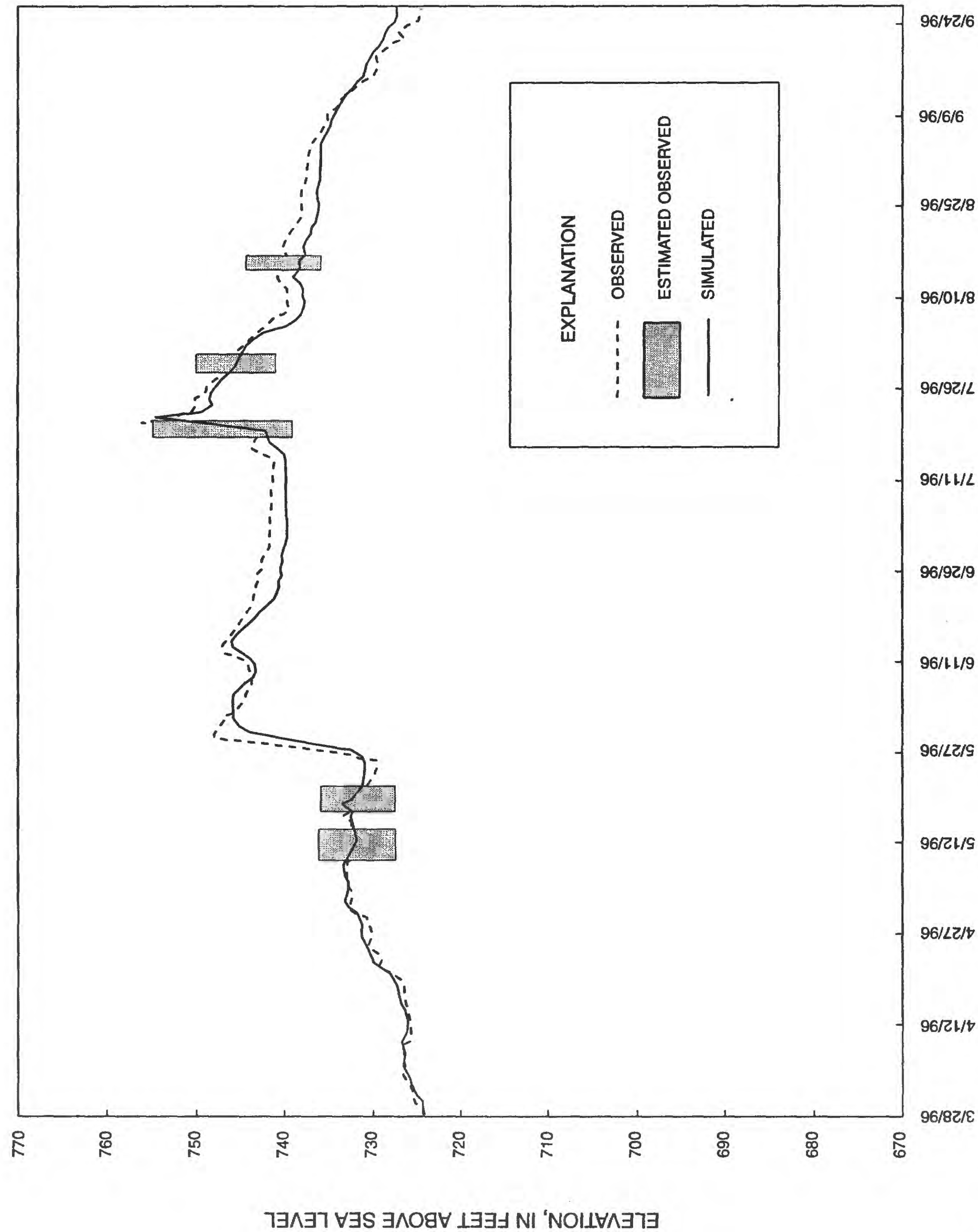


Figure 16. Observed and simulated water levels at Herrington Lake, Kentucky, March 28-September 24, 1996.

Temperature

Observed and simulated data are shown for selected dates in 1996 for three sampling stations in the reservoir (fig. 17). Differences between the observed and simulated temperatures were greatest near the reservoir bottom, where observed temperatures tended to decrease faster than did the model-simulated temperatures. In April, a reasonably good fit between the observed and simulated temperature distributions was indicated at Water Tower (S2) and Kennedy Bridge (S3). However, at Chenault Bridge (S1), the simulated temperatures at deeper depths were cooler than the observed temperatures. In June, the model underestimates the temperature at deeper depths at the two downstream stations and overestimates the temperature at Chenault Bridge (S1). In September, the simulated temperatures are typically warmer than the observed temperatures at all stations and depths. Overall, the model tended to better simulate temperature distributions during the spring and fall and at stations closer to the Dix River Dam (S5).

Dissolved Oxygen

Observed and simulated DO concentrations are shown for selected dates in 1996 (fig. 18). In April, the model underestimated DO concentrations at Kennedy Bridge (S3) and Water Tower (S2). In June, at Chenault Bridge (S1), the model simulation showed good agreement with the observed DO data; however, observed and simulated DO concentrations were in poor agreement at Water Tower (S2) and Kennedy Bridge (S3). Generally, the poor agreement occurred at mid-depths and at deeper depths. The model did a poor job of reproducing the metalimnetic-oxygen minimum observed at Water Tower (S2) and Kennedy Bridge (S3) sampling stations. This phenomena was overpredicted at Water Tower (S2) and underpredicted at Kennedy Bridge (S3). Poor agreement between the observed and simulated DO concentrations at mid-depths also occurred at Water Tower (S2) in September. The model also failed to predict the low DO concentrations observed at Chenault Bridge (S1) in September. The model did predict the near anoxic conditions in the hypolimnion at Water Tower (S2) and Kennedy Bridge (S3) sampling stations.

Nitrogen and Phosphorus

Generally, simulated epilimnetic and hypolimnetic NO_3-N concentrations showed good agreement with the observed NO_3-N (fig. 19). Model simulated epilimnetic values of NO_3-N at the downstream stations were not as good as the upstream station, especially from August through September 1996, although none of the simulated values during this period were particularly good. Simulated hypolimnetic values of NO_3-N were in good agreement at reservoir-sampling stations from March through June 1996, and not as good from July to September.

The model underestimated the concentrations of epilimnetic SRP in June at the Dix River Dam (S5) (fig. 20). By early July, however, epilimnetic concentrations of SRP were in good agreement at that station. Simulated epilimnetic concentrations of SRP at the upstream station were in good agreement from March through September 1996. Simulated hypolimnetic concentrations of SRP were also in good agreement at the three reservoir-sampling stations from March through September 1996.

Nutrient-mass balances computed for Herrington Lake indicate a SRP retention rate of approximately 67 percent and a nitrogen retention rate of 31 percent. On the basis of the results of the CE-QUAL-W2 model simulations, most of the SRP settles out in the upper-half (13 mi) of the reservoir.

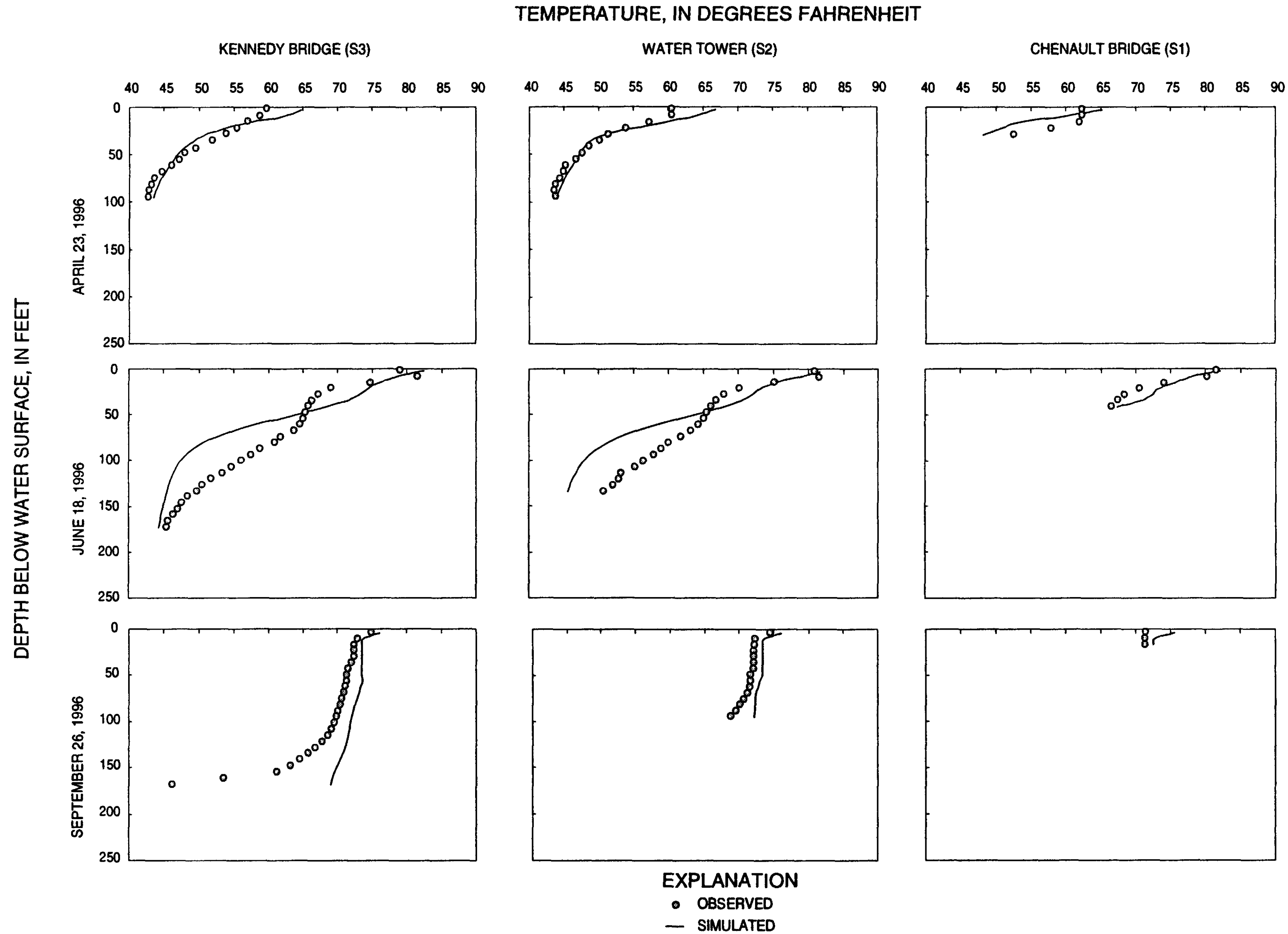


Figure 17. Observed and simulated vertical profiles of water temperature at three reservoir-sampling stations, Herrington Lake, Kentucky, April 23, June 18, and September 26, 1996.

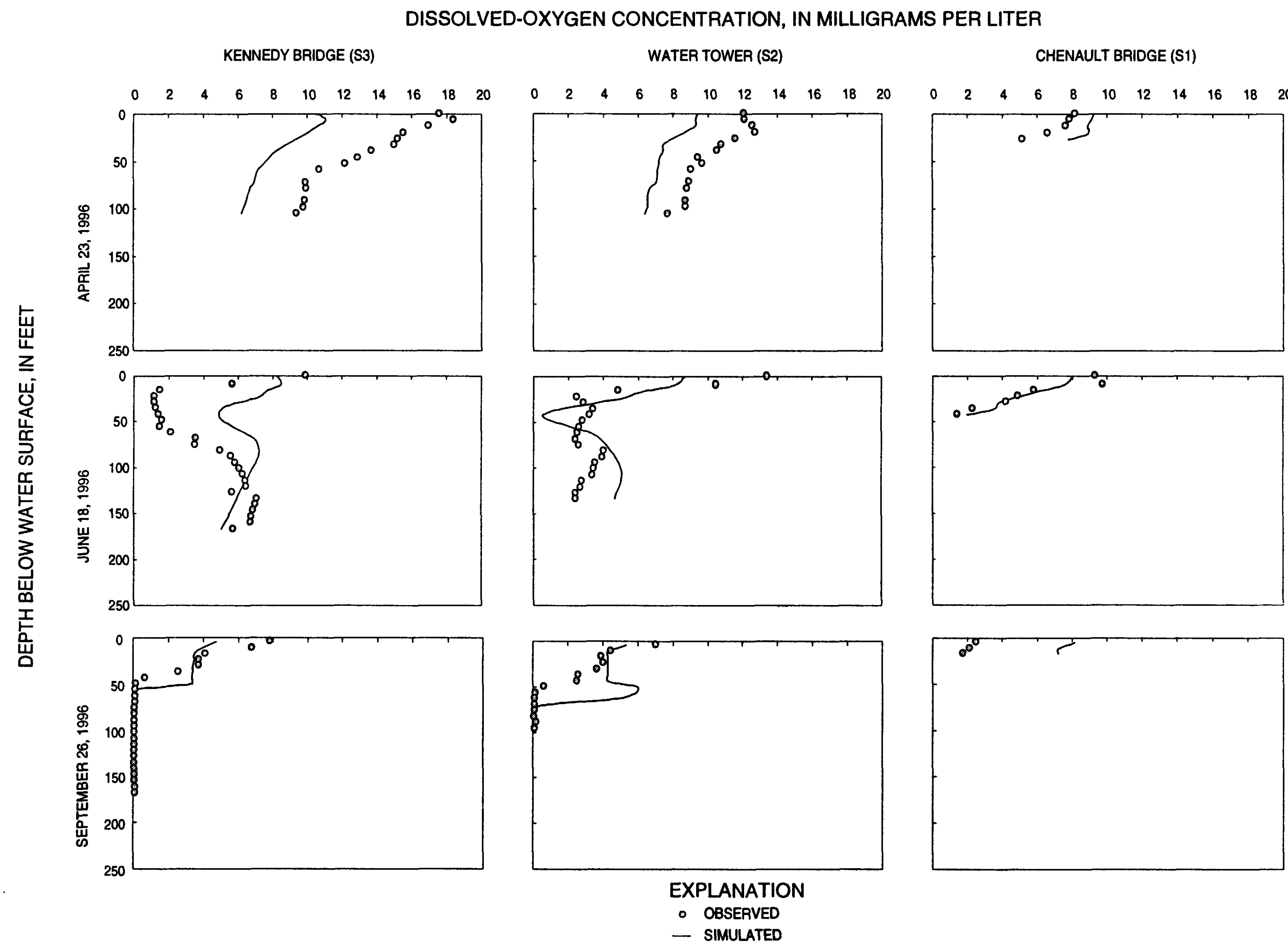


Figure 18. Observed and simulated vertical profiles of dissolved oxygen at three reservoir-sampling stations, Herrington Lake, Kentucky, April 23, June 18, and September 26, 1996.

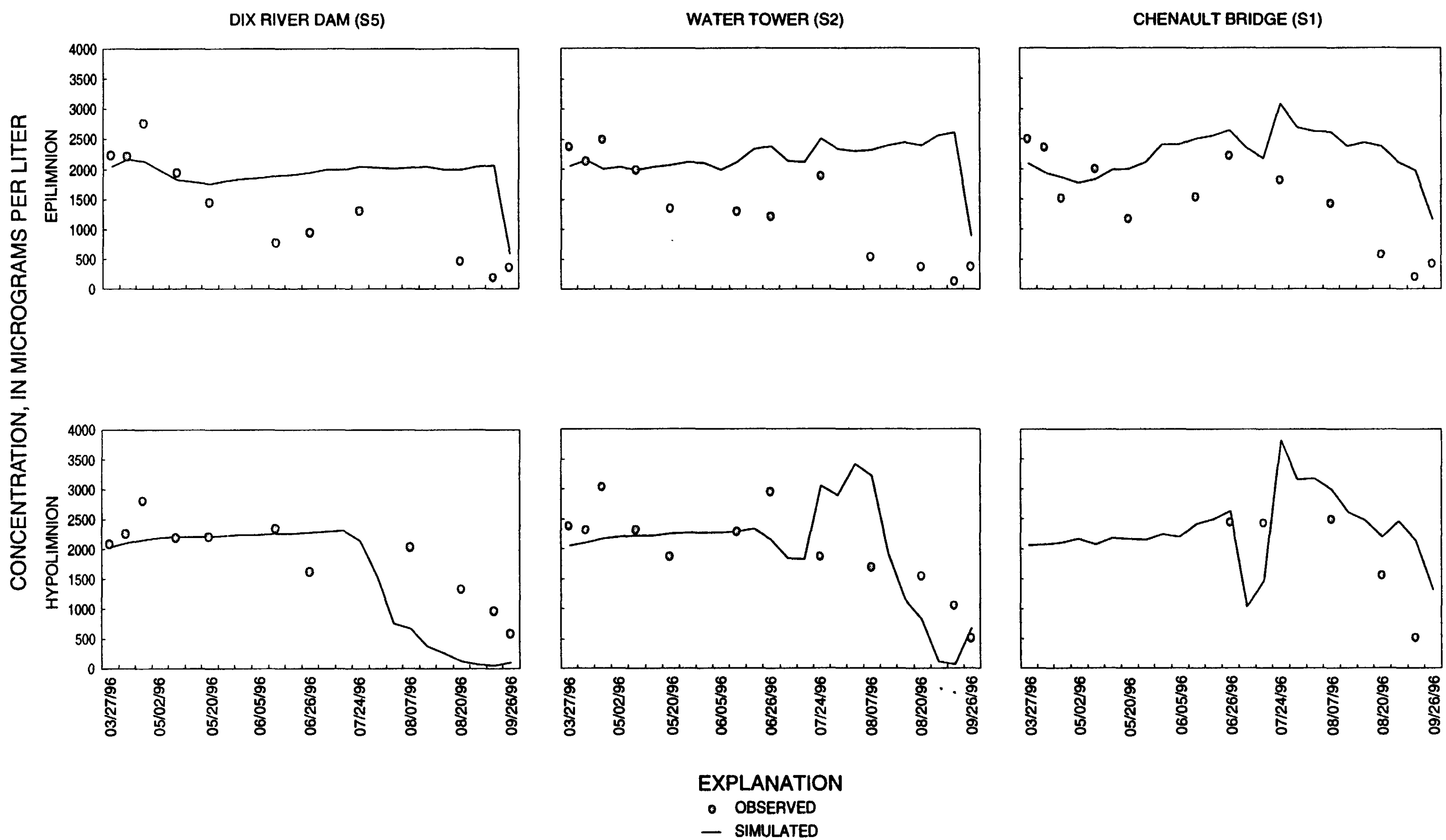


Figure 19. Observed and simulated nitrate-nitrogen in Herrington Lake epilimnetic and hypolimnetic samples for three reservoir-sampling stations, March-September 1996.

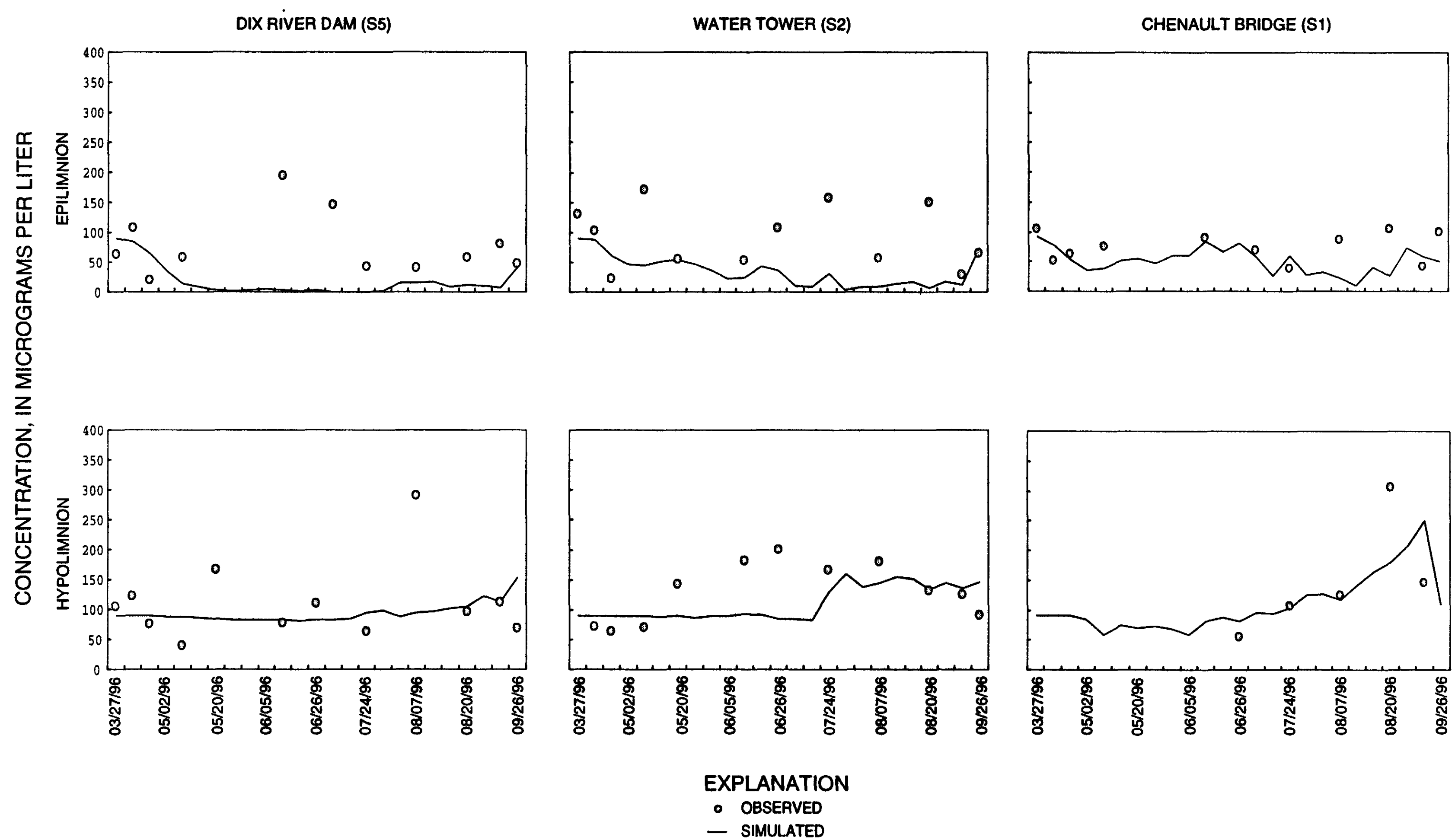


Figure 20. Observed and simulated soluble reactive phosphorus in Herrington Lake epilimnetic and hypolimnetic samples for three reservoir-sampling stations, March-September 1996.

Chlorophyll *a*

CE-QUAL-W2 does not simulate chlorophyll *a* directly; rather, the model simulates algal biomass. Algal biomass was converted to chlorophyll *a* using the conversion factors discussed in the section on chlorophyll *a* under chemical and biological water-quality characteristics. Observed and simulated chlorophyll *a* data are shown for selected dates in 1996 for three sampling stations in the reservoir (fig. 21). During the spring at the upstream stations, simulated chlorophyll a concentrations were in good agreement. Beginning in June, however, the model overestimates concentrations of chlorophyll *a* at those stations. Concentrations of chlorophyll *a* at the dam were overestimated by the model from March through September 1996. Overall, there was poor agreement between the observed and simulated chlorophyll *a* concentrations.

Simulating chlorophyll *a* concentrations is very difficult for many reasons. Phytoplankton are not uniformly distributed throughout the reservoir, thus, obtaining a representative sample can be difficult. Additionally, the CE-QUAL-W2 model simulates phytoplankton as a single assemblage, so that no distinctions are made between the different species of phytoplankton present. As was previously discussed in the section on chlorophyll *a* and phytoplankton, there was considerable seasonal and spatial variability in phytoplankton. An average factor was used to convert algal biomass simulated by CE-QUAL-W2 to chlorophyll *a* for this study; in actuality, however, the factor varies with the type of phytoplankton and the season. This unknown variability can potentially introduce a considerable amount of error into the estimation of the concentrations of chlorophyll *a*.

Sensitivity Analysis

A sensitivity analysis of a model allows one to evaluate the response of the model to variations in input values. If a change in an input value or model parameter causes significant changes in output values (i.e., constituent concentrations), the model is said to be sensitive to that input. In practice, a sensitivity analysis is conducted by changing (increasing or decreasing) the magnitude of a specified input value or parameter within reasonable limits while keeping all other parameters unchanged. All input values and model parameters used in the Herrington Lake model were not evaluated because of the large number of inputs and parameters. Simulations to evaluate model sensitivity were done for each of the model parameter changes described below. The model output for each of these simulations was compared to the original model output.

Algal growth rate (AG), saturation light intensity (ASAT), algal mortality rate (AM), algal settling rate (AS), and the algal-half saturation constant for phosphorus (AHSP) were varied by ±50 percent of the original value to determine the sensitivity of the concentrations of chlorophyll *a* to these parameters. Model simulations of chlorophyll *a* concentrations were sensitive to AG, but were less sensitive to ASAT and AHSP. Increasing AG resulted in increases in chlorophyll *a* concentrations throughout the epilimnion, especially during the summer. The model was not sensitive to changes in AM and AS. The wind-sheltering coefficient (WSC) and the oxygen stoichiometric equivalent for algal growth (O2AG) were varied by ±50 percent of the original value to determine the sensitivity of the concentrations of DO to these parameters. Vertical dissolved-oxygen concentrations were not sensitive to the wind-sheltering coefficient (WSC), which directly affects reaeration. Model simulations of DO concentrations were most sensitive to AG and O2AG. Simulated temperatures were not sensitive to changes in the light extinction coefficient (EXH2O), the adsorption of solar radiation coefficient (BETA), or WSC.

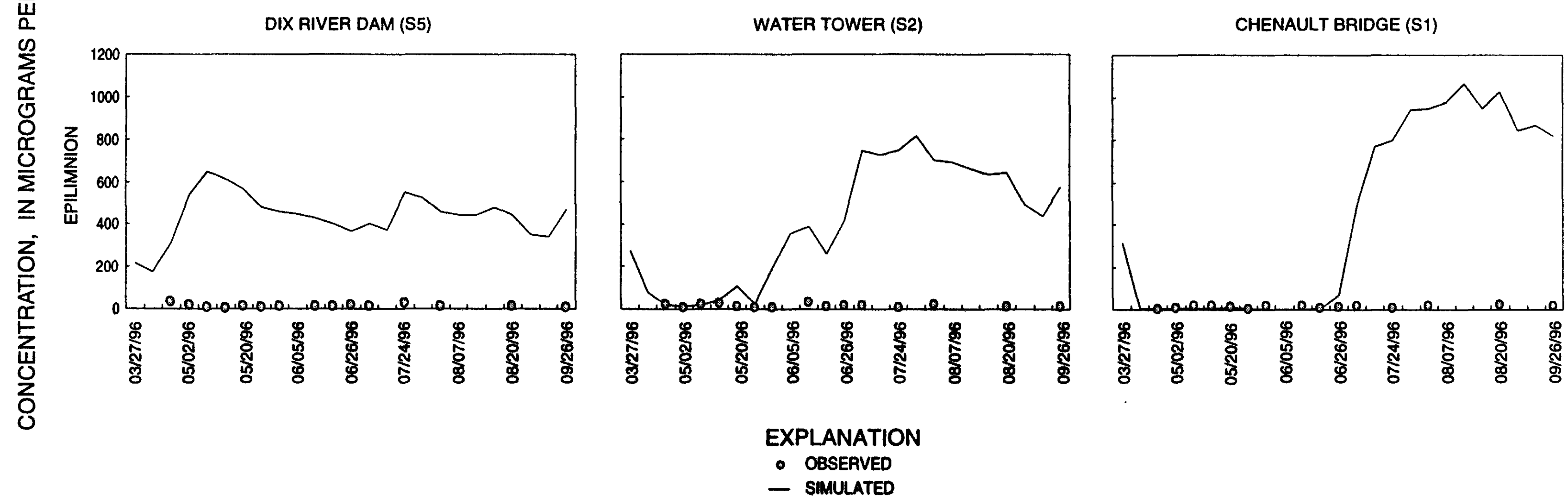


Figure 21. Observed and simulated chlorophyll *a* in Herrington Lake epilimnetic samples for three reservoir-sampling stations, March-September 1996.

Limitations of CE-QUAL-W2 Model for Herrington Lake

It is important to note that models are not reality, but are simply an approximation of what the individual modeler believes is reality. Because natural systems are complex, modelers must take into account the assumptions and limitations of the model and have the ability to understand the interactions taking place in the system. Some of the model limitations include the model representation for various chemical and physical processes and the quality of the data input into the model.

The scope and cost considerations of the study prevented data being collected at optimal intervals (weekly) for the model or all needed data being measured. This limitation was addressed by using the FLUX program to estimate selected constituent concentrations and loads between the 4- to 8-week sampling intervals and estimating other data from available data in other watersheds. The large amount of estimated data used for this study affect the model's predictive capabilities. Collection of additional data at a more frequent sampling interval would enable refinement of the model, and, consequently, should result in better model predictions. In addition, because of several problems apparent in the nutrient data, the quality of the nutrient analyses for this study were poor. Results of a blind sample program for NO_3-N indicated unacceptable results for the two samples analyzed as part of the program. Results of the blind samples for SRP were satisfactory; however, it was not uncommon for concentrations of SRP to exceed those of TP in 1995. Results in 1996 were better.

The CE-QUAL-W2 model water-quality algorithms include several important processes that control phytoplankton production and nutrient cycling; however, these algorithms contain many generalizations and assumptions. For example, only a single compartment is available to represent all phytoplankton species. All phytoplankton species are combined and simulated with one set of growth and mortality parameters and one carbon to chlorophyll *a* ratio. Most of the kinetic-rate coefficients and phytoplankton growth parameters used in the model are assumed to be constant. Variations in the simulation of phytoplankton growth, such as phytoplankton growth in response to seasonal changes in light or fluctuations in nutrient concentrations are not incorporated into the Herrington Lake model, which makes it difficult to model the seasonal growth of phytoplankton.

The Herrington Lake model does not simulate algal biomass, and, consequently, chlorophyll *a* concentrations very well. The model consistently overestimates the amount of algal biomass present in the reservoir. This is a major limitation of the model. The poor simulation of algal biomass could be the result of the poor quality of the nutrient data being input to the model, or the result of so much of the daily input being estimated, or the limitations in model algorithms previously described.

The model does not rigorously simulate sediment oxygen demand. As a result, DO concentrations in the reservoir after turnover may be overestimated. This is because the model does not account for DO depletion resulting from oxidation and reduction reactions.

According to Cole and Buchak (1995), in some situations no amount of model parameter adjustment will result in an adequately calibrated model; they conclude, however, such a model can still be useful. Despite the limitations of this version of the Herrington Lake model, it is able to simulate the general characteristics and dynamics of water quality in the reservoir. Consequently, the model can be used to show how different management options can affect water quality.

PHOSPHORUS REDUCTIONS NEEDED TO ATTAIN SELECTED TROPHIC STATE INDEXES

The Herrington Lake model was used to evaluate the effectiveness of several potential management strategies for achieving the TMDL of phosphorus for the reservoir. These strategies included various reductions in the concentration of SRP inputs to the reservoir from the Dix River, four tributaries, and two point sources included in the model. KDOW defined the period June 1-August 15 to be critical since this is when concentrations of DO of less than 5 mg/L are most likely to occur; when DO drops below 5 mg/L, fish kills can occur. The effects of SRP reduction on this critical period were emphasized in the simulations. Results of the simulations for the periods immediately prior to and following the critical period also were evaluated. The results of the simulation of the potential management strategies are presented in this section.

Partitioning Loads

Daily mean discharge and concentrations of SRP for the Dix River and four tributaries included in the model are shown in table 6 for selected periods. Multiplying the average concentration times the average discharge for a period does not yield the average load of a constituent for that period unless the concentration is constant. If concentrations tend to increase with streamflow, an average load computed in this fashion will underestimate the true load. If concentrations tend to decrease with streamflow, an average load computed in this fashion will overestimate the true load. For this study, daily loads were computed with the FLUX program. The daily loads for the period of interest were then averaged to obtain the load for a period (table 7).

A TMDL (for a specified constituent) is calculated from the equation provided by the USEPA, equation 1. This equation requires that a determination be made of the sources and relative contribution of the sources of the contaminant. There is one primary point source of nutrients near Herrington Lake, the Danville WWTP on Clarks Run. Records for the point-source-discharge contributions were available from reporting and permitting data provided by KDOW. Average concentrations of SRP and discharge for the Danville WWTP and the two point sources discharging directly to Herrington Lake are presented in table 8. For the TMDL calculation, the point-source loads for a period of interest were calculated by averaging the individual loads computed for that period from the reported concentrations of phosphorus measured in the effluent and the discharge measurements for Northpoint Training Center, Chimney Rock Resort, and Danville WWTP. SRP loads from the Danville WWTP ranged from 0.3 to 2 tons per period of interest (table 9).

During low-flow conditions, Clarks Run contributes one-third of the total surface flow and about one-third of the total SRP load to the reservoir. The sampling station on Clarks Run was below the Danville WWTP; therefore, the Clarks Run load includes that from both the Danville WWTP load and the nonpoint-source contributed load upstream from the plant. Two additional minor point sources into the reservoir included in the load determinations are the Northpoint Training Center and the Chimney Rock Resort. Both of these sources discharge directly into the reservoir.

For the purpose of the TMDL calculation, the total SRP loads obtained from the FLUX program included total nonpoint-source loads, plus known point-source loads, plus estimated background loads. Background loads were estimated with data from a watershed of similar size with little or no anthropogenic effects. Tributary nonpoint-source loads can be estimated by subtracting the estimated background load and any point-source load from the total SRP load. For example, the load estimate at Clarks Run include contributions from the Danville WWTP, nonpoint sources, and background sources. To estimate the nonpoint-source contribution, the Danville WWTP load and the background load were subtracted from the load calculated by the FLUX program for Clarks Run. Total nonpoint-source loads are defined to be the sum of nonpoint-source loads and background loads.

Dix River, the major inflow to Herrington Lake, is affected by nonpoint sources of nutrients but also has point sources located along its length (fig. 2). However, the sampling location in the Dix River is below all of the point sources. The upstream point sources were not considered individually in the determination of point-source loads. No attempt was made to separate the point- and nonpoint-source contributions upstream of the sampling point in the Dix River. In determining the other point-source and nonpoint-source contributions to Herrington Lake, the Dix River is treated as a separate case and both types of load contributions are considered together.

Table 6. Daily mean discharge and concentrations of soluble reactive phosphorus input to the Herrington Lake model for selected tributaries and selected periods in 1996

[Q, discharge; ft^3/s, cubic foot per second; SRP, soluble reactive phosphorus; μg/L, micrograms per liter]

Period	Dix River Q (ft^3/s)	Dix River SRP (μg/L)	Clarks Run Q (ft^3/s)	Clarks Run SRP (μg/L)	Mocks Branch Q (ft^3/s)	Mocks Branch SRP (μg/L)	McKecknie Creek Q (ft^3/s)	McKecknie Creek SRP (μg/L)	Cane Run Q (ft^3/s)	Cane Run SRP (μg/L)	Background SRP (μg/L)
January 1 - February 29	773	289	66	381	26	297	4	505	13	355	77
March 1 - May 31	793	202	68	401	25	378	4	454	13	430	77
June 1 - August 15	911	42	49	348	9	326	1	700	13	165	77
August 16 - September 28	226	45	23	336	19	293	3	508	4	254	77

Table 7. Average loads of soluble reactive phosphorus input to the Herrington Lake model for selected tributaries and selected periods in 1996

[Daily loads from the FLUX program were averaged to obtain the loads of soluble reactive phosphorus]

Period	Tons per period					
	Dix River	Clarks Run	Mocks Branch	McKecknie Creek	Cane Run	Background
January 1 - February 29	17	4	2	0.2	0.5	0.01
March 1 - May 31	13	4	2	.2	.5	.01
June 1 - August 15	24	2	2	.1	.2	.01
August 16 - September 28	7	2	.7	.1	.2	.02

Table 8. Daily mean discharge and concentration of soluble reactive phosphorus input to the Herrington Lake model for Northpoint Training Center, Chimney Rock Resort, and Danville Wastewater-Treatment Plant during selected periods in 1996

[ft^3/s, cubic foot per second; SRP, soluble reactive phosphorus; μg/L, micrograms per liter; WWTP, wastewater-treatment plant; *, 1995–97 data; soluble reactive phosphorus concentrations were obtained by multiplying the measured total phosphorus concentrations by 0.7]

Period	Northpoint Training Center discharge (ft^3/s)	Northpoint Training Center SRP (μg/L)	Chimney Rock Resort discharge (ft^3/s)	Chimney Rock Resort SRP (μg/L)	Danville WWTP discharge* (ft^3/s)	Danville WWTP SRP* (μg/L)
January 1 - February 29	0.3	15	0.004	150	4.0	469
March 1 - May 31	.3	20	.004	200	7.6	1,050
June 1 - August 15	.3	10	.004	100	4.9	1,190
August 16 - September 28	.3	15	.004	150	1.9	2,060

Table 9. Average loads of soluble reactive phosphorus input to the Herrington Lake model for Northpoint Training Center, Chimney Rock Resort, and the Danville Wastewater-Treatment Plant during selected periods in 1996

Period	Tons per period		
	Northpoint Training Center	Chimney Rock Resort	Danville Wastewater-Treatment Plant
January 1 - February 29	0.001	0.0001	0.3
March 1 - May 31	.0006	.0002	2
June 1 - August 15	.0005	.0001	1
August 16 - September 28	.0007	.0001	.5

Current background phosphorus concentrations would ideally be determined by sampling a pristine watershed in an environmental setting similar to that of Herrington Lake. No pristine watersheds exist in the area surrounding Herrington Lake. An alternative is to sample a watershed with minimal human disturbance; such a watershed can be described as least affected. As a part of the Kentucky Watershed Management Plan (Kentucky Natural Resources and Environmental Cabinet, 1997), the Commonwealth of Kentucky assessed reference-reach site data. The results of the reference-reach assessment provided an indication of the possible background nutrient load to Herrington Lake for the period simulated by the CE-QUAL-W2 model. Background SRP loads for the Herrington Lake Basin were estimated using available data from a representative least-affected watershed, that of Crooked Creek in the adjacent Salt River Basin. In an intensive study conducted from 1991 through 1993, the background TP concentration for Crooked Creek was determined to be 0.11 mg/L (FTN Associates Limited, 1998). For this study, a background SRP concentration of 0.077 mg/L was obtained by multiplying the background TP concentration from Crooked Creek by 0.70 because this factor typically represents that portion of TP that is SRP. The background loading from each inflow was obtained by summing the product of the background concentration times the daily discharge for each tributary times a unit conversion factor. The background load for each tributary and the Dix River were summed to compute the total background load for the reservoir.

Estimated point source, nonpoint source, and background loads for Herrington Lake are given in table 10. Loads from Dix River are listed separately in table 10. The largest contributor of phosphorus to Herrington Lake is the Dix River. Background loads were estimated to be less than 1 percent of the load into Herrington Lake. Estimated point source loads (excluding those on Dix River) ranged from 1 to 9 percent.

Table 10. Average loads of soluble reactive phosphorus and percent total loads for nonpoint and point sources of Herrington Lake, Kentucky, in 1996

[<, less than; Dix River, total inflow into Herrington Lake including input from point and nonpoint sources; Total nonpoint sources, sum of soluble reactive phosphorus loads from Clarks Run, Mocks, McKecknie, Cane Run, and background; Nonpoint sources, sum of soluble reactive phosphorus loads from Clarks Run, Mocks, McKecknie, and Cane Run; Point sources, sum of soluble phosphorus loads from Danville Wastewater-Treatment Plant, Chimney Rock Resort, and Northpoint Training Center; Background, based on average phosphorus measurements in Crooked Creek located in Salt River Basin (least disturbed)]

	Loads of soluble reactive phosphorus, in tons per period					Total loads, in percent			
Period	Point sources	Dix River	Nonpoint sources	Background	Total nonpoint sources	Point sources	Dix River	Nonpoint sources	Background
January 1 - February 29	0.3	17	6	0.01	6	1	73	26	<1
March 1 - May 31	2	13	6	.01	6	9	62	29	<1
June 1 - August 15	1	24	3	.01	3	3	86	11	<1
August 16 - September 28	.5	7	3	.002	3	5	67	28	<1

Reservoir Response to Phosphorus Reductions

The effects of phosphorus reductions in the reservoir were determined by changes in the Carlson TSI values for chlorophyll *a* and SRP. The KDOW calculated a Carlson TSI for chlorophyll *a* for Herrington Lake of 56 in 1983. Simulated concentrations of chlorophyll *a* and SRP obtained from the model for 1996 were used to calculate an average reservoir TSI for chlorophyll *a* of 77 and a TSI for phosphorus of 70.

Simulations were also run in which the SRP concentrations were reduced for only the Dix River and Clarks Run. For these simulations, concentrations of SRP in the Dix River and Clarks Run were reduced simultaneously while all other input concentrations were unchanged. The Carlson TSI was computed for three locations along the main stem of the reservoir: Chenault Bridge (S1), Water Tower (S2), and Kennedy Bridge (S3) (fig. 4). In a series of simulations, the input concentrations of SRP were reduced by a specified percentage—from 30 to 80 percent, in increments of 10 percent. The effects on the reservoir of simulated reductions in SRP input concentrations were determined by comparing TSI values calculated from the concentrations of SRP and chlorophyll *a* simulated by the model and the concentrations simulated in the phosphorus-reduction model runs. The Carlson TSI values in tables 11-14 were not calculated from the single average concentration for the period of interest, rather individual Carlson TSI's were calculated and then averaged to obtain a Carlson TSI value for each period of interest. Therefore, a Carlson TSI value calculated from a seasonal mean concentration estimated from figures 22-25 will not result in the same Carlson TSI value as listed in tables 11-14.

Carlson Trophic State Index for Phosphorus

Average simulated concentrations of SRP in Herrington Lake are reduced as a result of reductions in all SRP inputs (fig. 22). The greatest reductions are indicated for Chenault Bridge (S1) during the August 16-September 28 period. Chenault Bridge (S1) is the station closest to the Dix River and Clarks Run. Since these two inflows are the largest contributors of phosphorus to the reservoir, it is expected that the largest immediate reduction of phosphorus would be observed at Chenault Bridge (S1). Reductions are also indicated at stations further downstream although the magnitude of the predicted reduction is less. The Carlson TSI for SRP resulting from the simulated alternative reductions in SRP inputs from all sources is given in tables 11 and 12. There are reductions in the Carlson TSI for SRP reflecting the decreased SRP concentrations predicted to occur in the Herrington Lake as a result of decreased inputs.

The magnitude of the reduction in simulated concentrations of SRP in Herrington Lake when only the SRP inputs for the Dix River and Clarks Run are reduced is similar to that obtained when SRP from all of the inputs is reduced (fig. 23). This is not surprising since most of the SRP entering Herrington Lake is from these two sources. The spatial and seasonal patterns of simulated SRP concentrations corresponding to reductions in SRP in only the Dix River and Clarks Run are nearly identical to those obtained from reductions in SRP from all sources. SRP reductions in only the Dix River and Clarks Run result in Carlson TSI for SRP values that differ little from those obtained when the reductions were applied to all inflows.

The Carlson TSI for SRP computed for all of the management strategies considered in this study would still result in Herrington Lake being considered eutrophic. Reductions of SRP inputs of 30 percent or more, however, would result in a classification of eutrophic rather than hypereutrophic. The largest reductions in the Carlson TSI for SRP were predicted to occur at Chenault Bridge (S1).

Table 11. Model-predicted average seasonal Carlson Trophic State Index values for soluble reactive phosphorus (SRP) computed for simulated alternative reductions in phosphorus inputs to Herrington Lake, Kentucky, in 1996

[SRP, soluble reactive phosphorus; %, percent]

Reservoir segment (figure 4)	March 1 – May 31							June 1 – August 15							August 16 – September 28						
	Reduction in SRP input, in percent							Reduction in SRP input, in percent							Reduction in SRP input, in percent						
	Base	30%	40%	50%	60%	70%	80%	Base	30%	40%	50%	60%	70%	80%	Base	30%	40%	50%	60%	70%	80%
								SRP reductions in all sources													
Chenault Bridge (S1)	65	62	62	61	60	59	57	67	63	62	60	58	55	52	74	68	66	63	59	55	50
Water Tower (S2)	68	68	68	67	67	67	67	70	68	67	66	66	64	63	74	71	70	68	67	65	64
Kennedy Bridge (S3)	68	68	68	68	68	68	68	70	68	68	67	66	66	65	76	73	72	71	69	68	66
								SRP reductions in only Dix River and Clarks Run													
Chenault Bridge (S1)	65	62	62	61	60	59	57	67	63	62	60	58	56	53	74	68	66	63	60	56	50
Water Tower (S2)	68	68	68	67	67	67	67	70	68	68	67	66	65	64	74	71	70	69	67	66	64
Kennedy Bridge (S3)	68	68	68	68	68	67	68	70	68	68	67	67	66	65	76	73	72	71	69	68	66

Table 12. Model-predicted average annual Carlson Trophic State Index values for soluble reactive phosphorus (SRP) computed for simulated alternative reductions in phosphorus inputs to Herrington Lake, Kentucky, in 1996

[%, percent; SRP, soluble reactive phosphorus]

Reservoir segment (figure 4)	Annual						
	Base	30%	40%	50%	60%	70%	80%
	SRP reductions in all sources						
Chenault Bridge (S1)	69	65	63	61	59	56	53
Water Tower (S2)	71	69	68	67	66	66	65
Kennedy Bridge (S3)	71	70	69	68	68	67	66
	SRP reductions in only Dix River and Clarks Run						
Chenault Bridge (S1)	69	65	63	61	59	56	53
Water Tower (S2)	71	69	68	68	67	66	65
Kennedy Bridge (S3)	71	70	69	68	68	67	66

Table 13. Model-predicted average seasonal Carlson Trophic State Index values for chlorophyll *a* computed for simulated alternative reductions in phosphorus inputs to Herrington Lake, Kentucky, in 1996

[SRP, soluble reactive phosphorus; %, percent]

Reservoir segment (figure 4)	March 1 – May 31: Reduction in SRP input, in percent							June 1 – August 15: Reduction in SRP input, in percent							August 16 – September 28: Reduction in SRP input, in percent						
	Base	30%	40%	50%	60%	70%	80%	Base	30%	40%	50%	60%	70%	80%	Base	30%	40%	50%	60%	70%	80%
SRP reductions in all sources																					
Chenault Bridge (S1)	57	57	57	57	57	57	57	75	74	74	73	73	72	72	94	92	92	91	90	89	88
Water Tower (S2)	69	69	69	69	69	69	69	80	79	78	78	78	77	77	84	83	83	82	82	81	81
Kennedy Bridge (S3)	76	76	75	75	75	75	75	82	81	81	80	80	80	80	80	79	79	79	78	78	78
SRP reductions in only Dix River and Clarks Run																					
Chenault Bridge (S1)	57	57	57	57	57	57	57	75	74	74	73	73	72	72	94	93	92	91	90	89	88
Water Tower (S2)	69	69	69	69	69	69	69	80	79	78	78	78	78	77	84	83	83	82	82	82	81
Kennedy Bridge (S3)	76	76	75	75	75	75	75	82	81	81	80	80	80	80	80	80	79	79	79	78	78

Table 14. Model-predicted average annual Carlson Trophic State Index values for chlorophyll *a* computed for simulated alternative reductions in phosphorus inputs to Herrington Lake, Kentucky, in 1996

[%, percent; SRP, soluble reactive phosphorus]

Reservoir segment (figure 4)	Annual						
	Base	30%	40%	50%	60%	70%	80%
SRP reductions in all sources							
Chenault Bridge (S1)	75	74	74	74	73	73	72
Water Tower (S2)	78	77	77	76	76	76	75
Kennedy Bridge (S3)	79	79	78	78	78	78	78
SRP reductions in only Dix River and Clarks Run							
Chenault Bridge (S1)	75	75	74	74	74	73	72
Water Tower (S2)	78	77	77	77	76	76	76
Kennedy Bridge (S3)	79	79	78	78	78	78	78

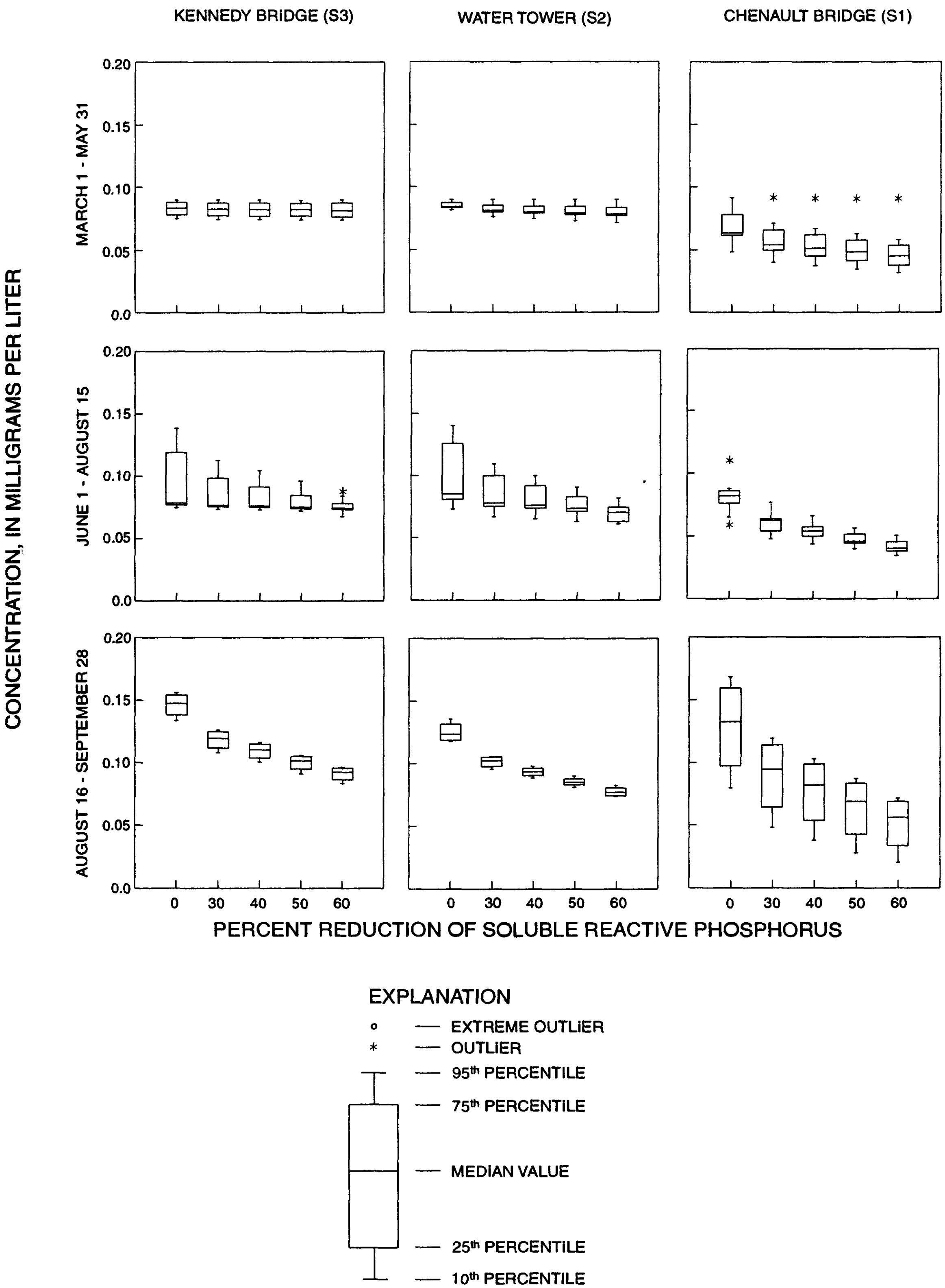


Figure 22. Distribution of simulated soluble reactive phosphorus concentrations at Kennedy Bridge (S3), Water Tower (S2), and Chenault Bridge (S1) in the Herrington Lake model for input soluble reactive phosphorus reductions from all sources for March 1–May 31, June 1–August 15, and August 16–September 28, 1996.

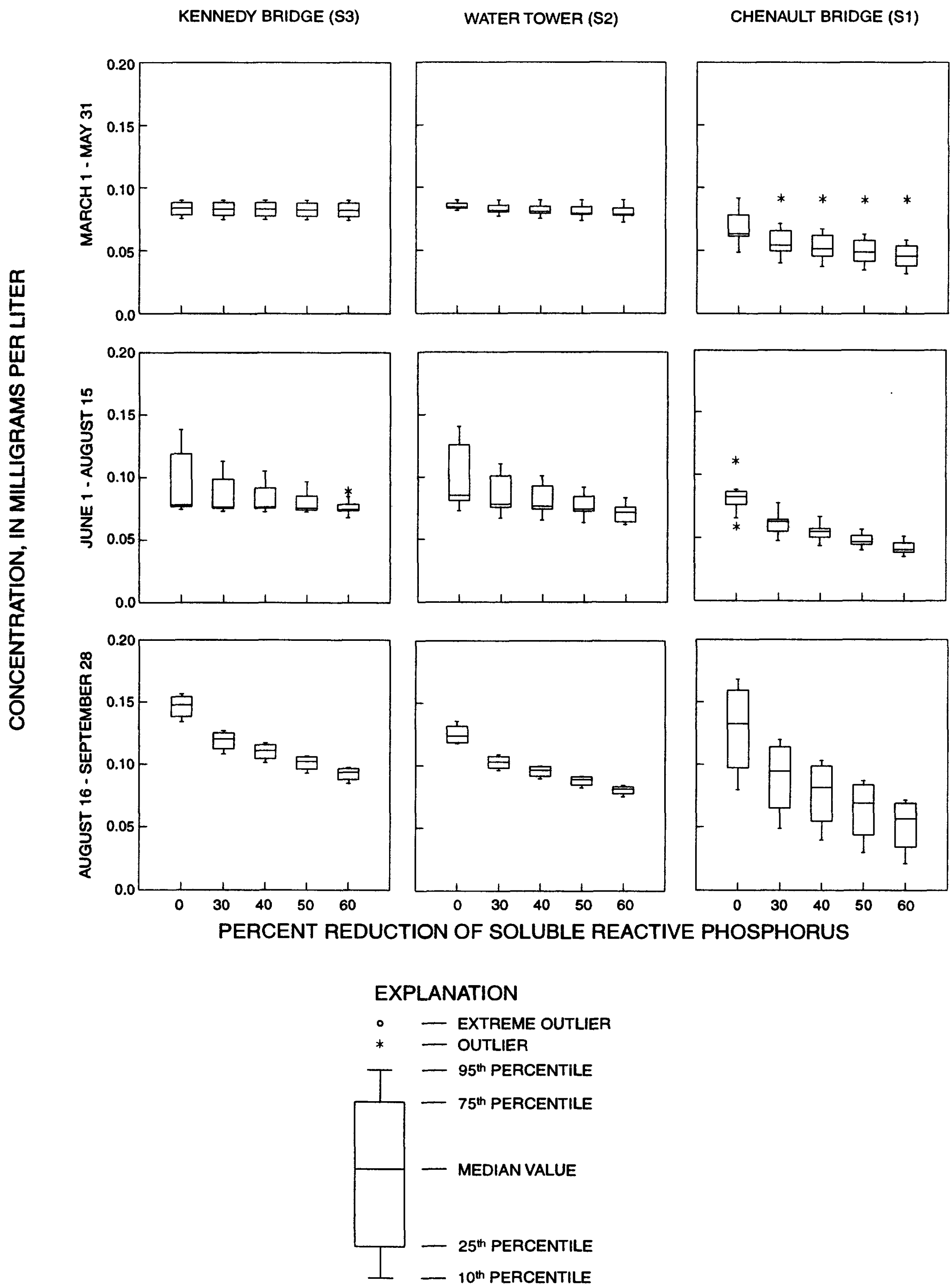


Figure 23. Distribution of simulated soluble reactive phosphorus concentrations at Kennedy Bridge (S3), Water Tower (S2), and Chenault Bridge (S1) in the Herrington Lake model for input soluble reactive phosphorus reductions from Dix River and Clarks Run for March 1–May 31, June 1–August 15, and August 16–September 28, 1996.

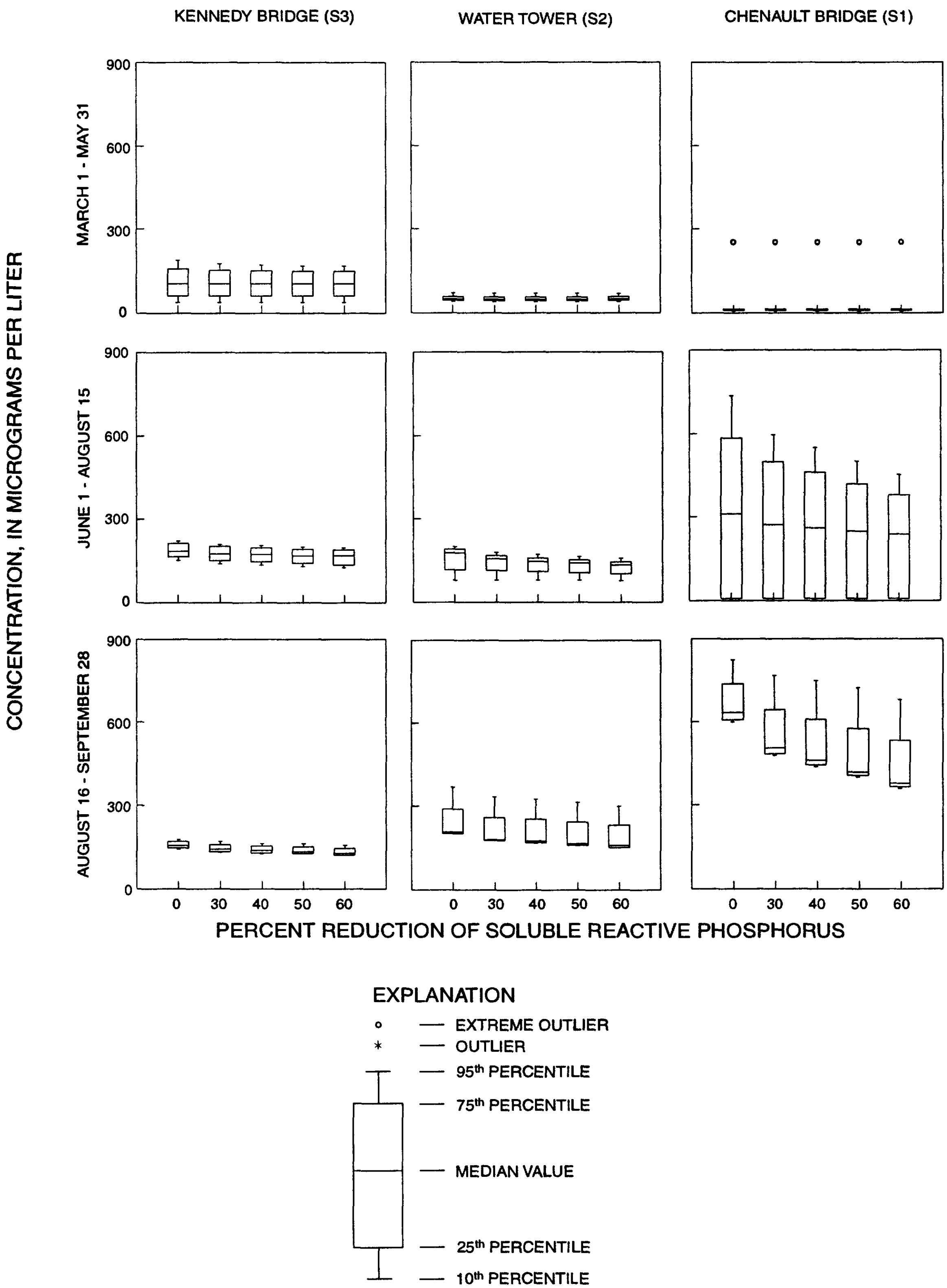


Figure 24. Distribution of simulated chlorophyll *a* concentrations at Kennedy Bridge (S3), Water Tower (S2), and Chenault Bridge (S1) in the Herrington Lake model for input soluble reactive phosphorus reductions from all sources for March 1–May 31, June 1–August 15, and August 16–September 28, 1996.

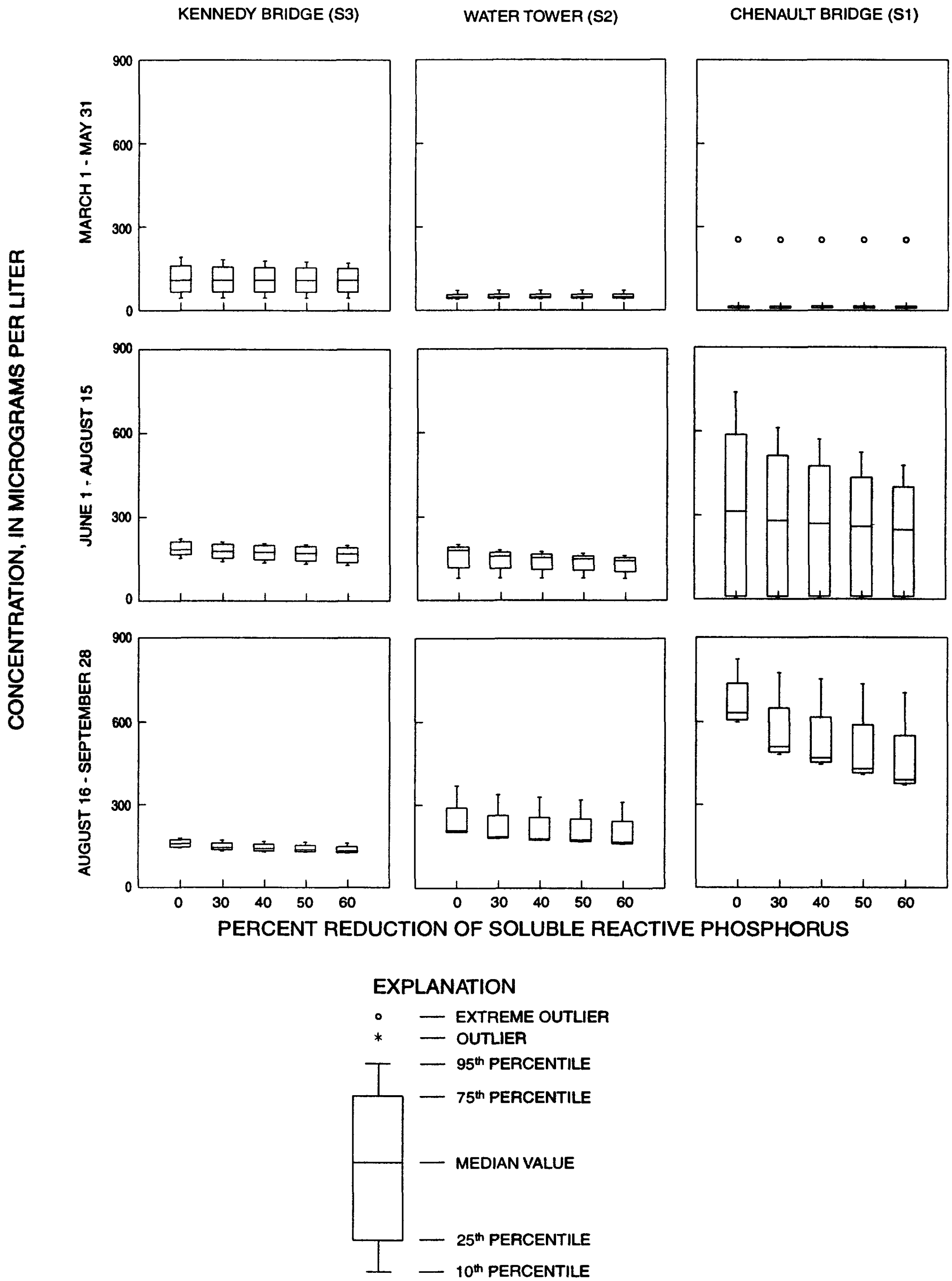


Figure 25. Distribution of simulated chlorophyll *a* concentrations at Kennedy Bridge (S3), Water Tower (S2), and Chenault Bridge (S1) in the Herrington Lake model for input soluble reactive phosphorus reductions from Dix River and Clarks Run for March 1–May 31, June 1–August 15, and August 16–September 28, 1996.

Carlson Trophic State Index for Chlorophyll *a*

Average simulated concentrations of chlorophyll *a* in Herrington Lake are also reduced as a result of reductions in all SRP inputs (fig. 24). The greatest reductions are indicated for Chenault Bridge (S1) during the August 16-September 28 period. As previously mentioned, Chenault Bridge (S1) is the station closest to the Dix River and Clarks Run and reductions in SRP from these sources would be expected to result in the most immediate reductions in chlorophyll *a* concentrations at this station. Reductions are also indicated at stations further downstream although the magnitude of the predicted reduction is less. The Carlson TSI for chlorophyll *a* resulting from the simulated alternative reductions in SRP inputs from all sources is given in tables 13 and 14.

The Carlson TSI for chlorophyll *a* computed for all of the management strategies considered in this study would result in Herrington Lake being considered as hypereutrophic. On average though, the Herrington Lake model greatly overestimates chlorophyll *a* concentrations. Consequently, the Carlson TSI for chlorophyll *a* values shown in tables 13 and 14 are probably greatly overestimated. The Carlson TSI for chlorophyll *a* computed from data collected during 1996 would result in the reservoir being considered eutrophic but not hypereutrophic. Unlike the Carlson TSI for SRP, there is little reduction in the Carlson TSI for chlorophyll *a*, even for simulations where SRP inputs were reduced by 80 percent. However, because simulation of chlorophyll *a* in the Herrington Lake model is poor, the reduction that would occur in the Carlson TSI values if SRP inputs to Herrington Lake were reduced is probably underestimated. Reductions in the Carlson TSI for chlorophyll *a* may also be underestimated because of the way the model simulates phosphorus cycling. Phosphorus stored in bed sediment serves as an available source of phosphorus to the overlying water. Because of this additional source and the short time period simulated in the Herrington Lake model, limiting concentrations of phosphorus may not be achieved. Over time, however, as this stored phosphorus is removed from the reservoir, phosphorus should become limiting and the effects of the reduced SRP loads to the reservoir on the Carlson TSI for chlorophyll *a* should become apparent.

As with SRP, the magnitude of the reduction in simulated concentrations of chlorophyll *a* in Herrington Lake when only the SRP inputs for the Dix River and Clarks Run are reduced is similar to that obtained when SRP from all inputs is reduced (fig. 25). Again, this is not surprising since most of the SRP entering Herrington Lake is from these two sources. The spatial and seasonal patterns of simulated chlorophyll *a* concentrations corresponding to reductions in SRP in only the Dix River and Clarks Run are nearly identical to those obtained from reductions in SRP from all sources. SRP reductions in only the Dix River and Clarks Run result in Carlson TSI for chlorophyll *a* values that differ little from those obtained when the reductions were applied to all inflows (tables 13 and 14).

SUMMARY AND CONCLUSIONS

Herrington Lake, Kentucky, which is impounded from the Dix River by the Dix Dam, covers a surface area of 4.6 mi^2 and is approximately 35 mi long. Major inflows to the reservoir are the Dix River and Clarks Run. Stream-discharge and water-quality data collected at these inflows and at the minor tributaries (Mocks Branch, Cane Run, and McKecknie Creek) and data from two permitted-discharge sites were used as input to a water-quality model for the reservoir. Samples collected from the Dix River and the four tributaries were analyzed for nutrients and physical properties. Samples collected in the reservoir were analyzed for algae, nutrients, chlorophyll *a*, and physical properties.

During a 2-year (1995–96) study of Herrington Lake to assess nutrient loading, ambient water-quality conditions varied both spatially and seasonally. The spatial gradients in the reservoir reflect the combined effect of reservoir morphology and flow into it. Interannual variability in nutrient concentrations and chlorophyll *a* were affected by the hydrology of the reservoir. During July–October 1995, tributary flow into the reservoir was below average because of low precipitation levels, which in turn resulted in lower concentrations of nutrients and chlorophyll *a* throughout the reservoir. In July 1996, runoff from a rainstorm caused elevated nutrient levels throughout the reservoir; the nutrient concentrations remained elevated for the duration of the summer. Although discharge affected nutrient concentrations, chlorophyll *a* levels were not affected during the summer of 1996. Chlorophyll *a* levels at Chenault Bridge (S1) remained high in the summer for both years despite the significant differences in discharge and precipitation; however, this does not eliminate the role discharge plays in phytoplankton dynamics.

Loads of nitrate-nitrogen (NO_3-N) and soluble reactive phosphorus (SRP) were determined over a range of seasonal and hydrologic conditions. Results indicated that most of the nitrogen and phosphorus entering the reservoir originated from the Dix River and Clarks Run. Combined loads from both tributaries were estimated to contribute about 92 percent of the SRP load into Herrington Lake. Dix River, the major inflow, is affected not only by nonpoint sources of nutrients but also by point sources located along its length. When determining point-source and nonpoint-source contributions of the nutrients to Herrington Lake, the Dix River was treated as a separate case and both types of load contributions are grouped together. Point-source total-load percentages other than those in the Dix River ranged seasonally from 1 to 9 percent. Total-load percentages from nonpoint sources ranged from 11 to 29 percent. A nutrient-mass balance indicated that Herrington Lake has a retention rate of 67 percent per year for phosphorus and a nitrogen retention rate of 31 percent per year.

A two-dimensional, laterally averaged water-quality model (CE-QUAL-W2) was used to simulate physical and water-quality constituents for Herrington Lake for the period January through September 1996. The model was used to simulate constituent transport during stratified and unstratified conditions, wind and temperature effects, and effects of nutrients on DO and phytoplankton production. The model simulated temperature, DO, and nitrate-nitrogen reasonably well (root mean square error (RMSE) <20 percent). However, simulations of soluble reactive phosphorus, ammonia-nitrogen, and chlorophyll *a* were poor (RMSE >20 percent). The Herrington Lake model was used to evaluate the effect of alternative nutrient-loading reductions on the water-quality of Herrington Lake. These alternative nutrient loading reductions are represented by simulations in which input SRP concentrations were reduced at the Dix River, the four tributaries, and two permitted wastewater-treatment sites. The effects on phosphorus and chlorophyll *a* concentrations in the reservoir as a result were evaluated. Input SRP concentrations were reduced from 30 and 80 percent (in 10-percent increments).

The simulated SRP concentrations and Carlson Trophic State Index (TSI) values calculated from those concentrations were compared to evaluate the effectiveness of potential management strategies. SRP input concentration reductions of 60 percent resulted in a decrease of the annual TSI for phosphorus from 70 to 64. Reductions of 60 percent in only the Dix River and Clarks Run yielded similar results. Model simulations indicate that water quality in Herrington Lake may be improved through reductions in input SRP concentrations. There was little reduction in the Carlson TSI for chlorophyll *a* as a result of even 80-percent reductions of input concentrations of SRP; however, simulated concentrations of chlorophyll *a* are poor and the predicted reduction probably underestimated. Refinements of the model so that it would better simulate chlorophyll *a* more accurately would improve the Carlson TSI values calculated for chlorophyll *a* and phosphorus.

REFERENCES CITED

American Public Health Association, 1992, Standard methods for the examination of water and wastewater (19th ed.): Washington, D.C., American Public Health Association, 1,268 p.

Bowie, G.L., Mills, W.B., Porcella, D.B., Campbell, C.L., Pagenkopf, J.R., Rupp, G.L., Johnson, K.M., Chan, P.W.H., Gherini, S.A., and Chamberlin, C.E., 1985, Rates, constants, and kinetics formulations in surface water quality modeling: U.S. Environmental Protection Agency, EPA/600/3-85/040, 455 p.

Carlson, R.E., 1977, A trophic state index for lakes: Limnological Oceanography, v. 22, no. 2, p. 361-369.

Chapra, S.S., 1997, Surface water-quality modeling: New York, McGraw-Hill, 884 p.

Cole, T.M., and Buchak, E.M., 1995, CE-QUAL-W2—A two dimensional, laterally averaged, hydrodynamic and water quality model, version 2.0: Vicksburg, Miss., U.S. Army Corps of Engineers [variously paged].

Crain, A.S., 1998, Hydrologic constraints on phytoplankton production and nutrient assimilation capacity in a eutrophic Kentucky reservoir: Louisville, Ky., University of Louisville, M.S. thesis, 40 p., 11 figs.

Desikachary, T.V., 1959, *Cyanophyta*: New York, Academic Press, 686 p.

Dillard, G.E., 1989, Freshwater algae of the southeastern United States: Berlin, J. Cramer [various parts].

FTN Associates Limited, 1998, Taylorsville Lake water quality model study: Little Rock, Ark., [variously paged] (prepared for U.S. Army Corps of Engineers, Louisville District).

Giorgino, M.J., and Bales, J.D., 1997, Rhodiss Lake, North Carolina—Analysis of ambient conditions and simulation of hydrodynamics, constituent transport, and water-quality characteristics, 1993-94: U.S. Geological Survey Water-Resources Investigations Report 97-4131, 62 p.

Kennedy, R.H., and Walker, W.W., 1990, Reservoir nutrient dynamics, *in* Thornton, K.W., Kimmel, B.L., and Payne, F.E., eds., Reservoir Limnology—Ecological perspectives: New York, Wiley, p. 109-132.

Kentucky Natural Resources and Environmental Protection Cabinet, 1984, 1984 Kentucky report to Congress on water quality section (305b): Frankfort, Ky., Division of Water [variously paged].

_____1992a, 1992 Kentucky report to Congress on water quality section (305b): Frankfort, Ky., Division of Water [variously paged].

_____1992b, 303(d) List of Waters for Kentucky: Frankfort, Ky,. Division of Water [variously paged].

_____1997, Kentucky Watershed Management Plan, accessed November 23, 1999, at URL http://water.nr.state.ky.us/dow/watrshd.htm.

_____1998, 1998 Kentucky report to Congress on water quality section (305b): Frankfort, Ky., Division of Water [variously paged].

Kirk, J.T.O., 1983, Light and photosynthesis in aquatic ecosystems: Cambridge, England, Cambridge University Press, 401 p.

McClain, D.L., Byrd, F.D., and Brown, A.C., 1996, Water resources data, Kentucky, water year 1995: U.S. Geological Survey Water-Data Report KY-95-1, 272 p.

_____1997, Water resources data, Kentucky, water year 1996: U.S. Geological Survey Water-Data Report KY-96-1, 286 p.

Prescott, G.W., 1978, How to know the freshwater algae: Dubuque, Iowa, W.C. Brown Company, 293 p.

Smith, G.M., 1950, The freshwater algae of the United States (2d ed.): New York, McGraw-Hill, 719 p.

U.S. Army Corps of Engineers, 1994, Hydrographic Surveying: Washington, D.C., EM 1110-2-1003 [variously paged].

U.S. Bureau of the Census, 1991, 1990 Census of population and housing, summary population and housing characteristics, Kentucky: U.S. Department of Commerce, 1990 CPH-1-19, 370 p.

U.S. Environmental Protection Agency, 1977, National eutrophication survey—Herrington Lake—Boyle, Garrard, and Mercer Counties, Kentucky: U.S. Environmental Protection Agency Working Paper no. 353, 21 p.

_____1991, Guidance for water quality-based decisions—The TMDL process: U.S. Environmental Protection Agency 440/4-91-001, 72 p.

U.S. Geological Survey, 1986a, Land use and land cover digital data from 1:250,000 and 1:100,000 scale maps: National Mapping Program Technical Instructions Data Users Guide 4, 36 p.

_____1986b, National Water Summary, 1985—Hydrologic events and surface-water resources: U.S. Geological Survey Water-Supply Paper 2300, 506 p.

Walker, W.W., Jr., 1987, Empirical methods for predicting eutrophication in impoundments—Report 4, Phase III—Application manual: Vicksburg, Miss., U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report E-81-9 [variously paged].

Wetzel, R.G., 1983, Limnology: Orlando, Fla., Saunders College Publishing, Harcourt Brace College Publishers, 767 p.

Whitford, L.A., and Schumacher, G.J., 1984, A manual of fresh-water algae: Raleigh, N.C., Sparks Press, 337 p.

APPENDIXES

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	$N0_3$-N	02	TIC	ALK	FE
0	4.67	97.33	3.05	7.19	0	0.17	0.119	0.04	1.146	7.77	13.59	10.12	0.07
1	14.9	187.64	6.99	17.19	.01	.41	.119	.02	1.158	14.39	14.91	24.48	.22
2	27.78	253.58	11.67	24.72	.02	.66	.12	.05	1.478	10.92	20.5	23.81	.39
3	19.48	216.56	8.57	19.87	.01	.53	.12	.01	1.493	7.14	8.85	10.78	.28
4	15.25	190.18	7.07	17.41	.01	.44	.12	.01	1.508	15.71	15.93	12.75	.23
5	13.89	178.81	6.53	15.99	.01	.38	.12	.04	1.207	12.42	3	19.27	.21
6	12.04	162.36	5.95	14.78	.01	.34	.121	.05	1.22	16.22	8.8	19.3	.19
7	10.11	145.85	5.27	12.97	.01	.27	.121	.03	1.232	14.15	20.57	50.46	.16
8	12.15	164.58	5.96	14.87	.01	.34	.121	.04	1.245	13.22	22.8	22.51	.19
9	11.14	155.07	5.54	13.84	.01	.31	.122	.01	1.258	13.57	7.39	35.21	.17
10	10.8	152.66	5.5	13.73	.01	.29	.122	.01	1.271	10.91	29.87	20.44	.17
11	11.98	161.69	5.93	14.53	.01	.34	.122	.03	1.284	12.38	11.31	42.74	.19
12	12.76	165.88	6.11	15.12	.01	.34	.123	.02	1.298	9.44	9.47	24.23	.19
13	14.09	178.98	6.63	16.24	.01	.38	.123	.05	1.311	11.44	24.96	36.78	.21
14	21.89	233.2	9.79	21.46	.01	.59	.123	.01	1.673	11.61	8.1	10.37	.34
15	23.6	245.71	10.24	22.37	.02	.62	.124	.01	1.69	9.78	12.54	33.78	.36
16	28.01	260.31	11.97	25.38	.02	.67	.131	.01	1.608	9.13	13.81	33.92	.4
17	23.99	246.92	10.68	22.63	.02	.62	.139	.01	1.531	9.32	30.02	24.22	.37
18	32.72	298.18	13.19	28.94	.02	.74	.147	.02	1.457	11.66	19.7	9.46	.48
19	25.9	248.79	10.95	23.4	.02	.64	.144	.02	1.487	13.14	16.62	22.74	.38
20	19.18	214.58	8.37	19.56	.01	.53	.142	.02	1.517	14.68	19.17	14.98	.28
21	15.65	194.84	7.31	17.68	.01	.45	.139	.01	1.549	15.74	21.1	34.04	.23
22	14.52	185.42	6.91	16.91	.01	.4	.137	.02	1.581	17.48	9.15	26.66	.22
23	31.39	270.74	12.47	26.98	.02	.69	.135	0	1.613	17.26	5.36	10.81	.44
24	27.52	253.28	11.48	24.5	.02	.65	.132	.04	1.647	17.39	15.13	30.52	.39

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	NO_3-N	02	TIC	ALK	FE
25	19.65	216.93	8.64	19.94	0.01	0.53	0.13	0	1.681	15.19	17	33.19	0.29
26	20.64	225.69	9.06	20.9	.01	.55	.128	.01	1.715	10.9	22.06	35.47	.31
27	19.49	216.69	8.61	19.9	.01	.53	.126	.04	1.751	14.01	13.82	30.04	.29
28	16.33	198.54	7.62	17.97	.01	.47	.124	.02	1.787	17.68	7.52	29.35	.24
29	14.64	186.04	6.92	17.01	.01	.41	.122	.02	1.824	12.91	13.25	16.22	.22
30	13.26	171.33	6.34	15.52	.01	.36	.12	.02	1.474	10.71	11.61	32.86	.2
31	11.05	153.59	5.53	13.8	.01	.3	.118	.01	1.505	16.12	17.87	20.25	.17
32	8.85	134.1	4.78	11.69	.01	.25	.116	.04	1.536	10.74	21.98	19.11	.13
33	7.79	126.32	4.5	10.82	.01	.23	.114	.02	1.567	11.79	15.91	.44	.11
34	9.65	142.09	5.17	12.69	.01	.27	.112	.04	1.6	10.49	11.79	27.22	.15
35	9.52	141.62	5.16	12.67	.01	.27	.11	.03	1.633	14.45	19.03	39.4	.15
36	9.47	140.68	5.11	12.56	.01	.26	.108	.03	1.666	16.89	23.7	28.01	.14
37	9.25	140.17	5.04	12.3	.01	.26	.106	.03	1.701	15.44	13.91	23.98	.14
38	10.68	151.85	5.49	13.48	.01	.29	.104	.05	1.736	13.25	29.32	42.82	.17
39	19.9	220.32	8.7	20.32	.01	.54	.103	.05	2.237	12.53	14.24	9.86	.3
40	17.01	203.37	7.8	18.55	.01	.47	.107	.02	2.213	9.24	9.89	31.49	.24
41	14.33	180.76	6.65	16.34	.01	.38	.112	.02	1.735	14.81	8.59	31.8	.21
42	11.72	158.21	5.84	14.34	.01	.32	.117	.04	1.716	14.35	15.49	16.35	.18
43	10.3	146.17	5.28	13.06	.01	.28	.123	.01	1.698	9.22	12.05	21.15	.16
44	9.5	140.87	5.11	12.63	.01	.26	.128	.04	1.68	12.6	11.68	32.7	.14
45	9.2	138.8	4.95	12.26	.01	.26	.134	.01	1.663	11.73	3.55	14.57	.14
46	8.56	133.27	4.75	11.55	.01	.24	.14	.04	1.645	9.72	7.73	20.47	.13
47	7.09	119.12	4.28	10.05	.01	.2	.146	.02	1.628	11.2	1.5	22.22	.09
48	6.04	111.33	3.82	8.89	.01	.19	.153	.04	1.611	11.73	23.69	35.82	.08
49	5.95	109.94	3.67	8.86	.01	.18	.16	.03	1.594	13.61	15.78	16.35	.08
50	11.39	156.85	5.74	14.23	.01	.32	.167	.05	1.577	12.8	13.58	23.96	.18
51	14.39	182.2	6.81	16.66	.01	.4	.175	.04	1.561	14.48	14.51	20.85	.21

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	$N0_3$-N	02	TIC	ALK	FE
52	12.78	166.12	6.18	15.19	0.01	0.34	0.182	0.04	1.544	13.35	17.45	15.97	0.2
53	11.05	154.38	5.54	13.83	.01	.31	.191	.04	1.528	15.42	3.79	28.66	.17
54	10.07	144.02	5.22	12.85	.01	.27	.199	.04	1.512	14.51	11.37	4.43	.15
55	8.15	130.17	4.59	11.2	.01	.24	.208	.03	1.496	11.31	19.85	26.88	.12
56	7.3	120.77	4.35	10.32	.01	.21	.218	.03	1.48	10.52	11.55	28.37	.1
57	8.09	129.76	4.56	11.17	.01	.24	.228	.03	1.465	9.12	4.87	18.87	.12
58	21.16	231.65	9.42	21.32	.01	.58	.238	.02	1.83	8.34	7.9	39.23	.32
59	18.31	210.41	8.21	19.4	.01	.51	.229	.02	1.821	12.59	25.04	35.17	.27
60	14.8	186.19	6.94	17.11	.01	.41	.22	.02	1.811	9.16	5.68	24.6	.22
61	13.24	170.36	6.26	15.5	.01	.36	.211	.01	1.427	7.23	10.01	21.47	.2
62	10.94	153.45	5.51	13.76	.01	.29	.203	.04	1.42	13.96	15.17	19.59	.17
63	9.12	136.54	4.83	11.87	.01	.25	.195	.04	1.412	14.26	13.57	28.42	.14
64	8.41	132.1	4.68	11.4	.01	.24	.187	.04	1.405	7.87	13.34	23.56	.13
65	29.05	260.76	12.21	25.69	.02	.67	.18	.04	1.765	10.71	7.73	24.03	.41
66	29.79	264.02	12.31	25.81	.02	.67	.172	.05	1.766	15.19	14.62	28.34	.42
67	27.15	250.14	11.2	23.59	.02	.65	.165	.02	1.766	17.81	9.45	27.19	.38
68	19.85	219.31	8.69	20.25	.01	.54	.159	.01	1.767	9.63	14.44	30.84	.29
69	17.29	205.22	7.84	18.68	.01	.49	.152	.05	1.768	11.63	20.67	37.76	.24
70	15.39	190.27	7.11	17.44	.01	.44	.146	.03	1.768	9.91	18.27	22.47	.23
71	14.39	182.02	6.8	16.57	.01	.39	.14	.04	1.401	11.53	7.74	25.14	.21
72	13.17	169.23	6.24	15.33	.01	.36	.134	.02	1.402	9.83	9.89	2.32	.2
73	11.35	156.19	5.7	14.11	.01	.31	.129	.04	1.402	7.39	18.96	26.76	.18
74	14.24	179.93	6.65	16.32	.01	.38	.124	.02	1.403	8.58	11.06	21.25	.21
75	14.94	189.25	7.03	17.27	.01	.42	.119	.04	1.772	11.5	16.8	37.64	.22
76	20.45	222.51	8.86	20.72	.01	.54	.114	.02	1.772	15.85	14.26	24.58	.3
77	17.42	206.55	7.86	18.74	.01	.5	.109	.03	1.773	11.64	21.03	28.79	.24
78	18.95	211.56	8.36	19.49	.01	.52	.105	.01	1.774	8.82	8.56	42.93	.28

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	NO_3-N	02	TIC	ALK	FE
79	20.76	229.95	9.31	21.02	0.01	0.57	0.101	0.01	1.774	10.68	12.22	13.17	0.32
80	20.68	229.19	9.08	20.94	.01	.56	.096	.03	1.775	8.44	4.53	25.65	.31
81	20.06	220.65	8.79	20.36	.01	.54	.093	.03	1.775	13.91	17.37	21.73	.3
82	20.58	223.45	8.9	20.8	.01	.54	.089	.02	1.776	13.1	9.66	23.49	.3
83	18.67	211.29	8.23	19.44	.01	.52	.085	.05	1.777	12.86	5.6	19.7	.27
84	17.1	204.89	7.83	18.6	.01	.48	.082	0	1.777	8.83	13.35	17.58	.24
85	15.5	191.79	7.21	17.54	.01	.44	.078	.01	1.778	12.5	12.73	13.62	.23
86	14.19	179.53	6.63	16.24	.01	.38	.075	.03	1.409	17.18	13.32	27.45	.21
87	13.47	173.6	6.38	15.64	.01	.37	.072	.05	1.409	11.6	14.19	31.86	.2
88	17.49	209.35	7.95	19.14	.01	.5	.069	.03	1.78	9.23	18.06	11.8	.25
89	16.87	203.29	7.74	18.55	.01	.47	.066	0	1.781	12.32	10.17	34.15	.24
90	14.86	187.51	6.99	17.12	.01	.41	.064	.03	1.781	11.84	16.17	28.15	.22
91	15.97	195.44	7.34	17.7	.01	.45	.061	.01	1.782	15.02	32.32	12.04	.23
92	19.22	215.8	8.41	19.63	.01	.53	.059	.03	1.783	12.3	16.33	26.59	.28
93	16.28	198.49	7.6	17.9	.01	.47	.056	.05	1.783	13.7	14.34	29.54	.24
94	14.49	183.7	6.9	16.86	.01	.4	.054	.02	1.413	9.87	13.62	12.86	.21
95	14.33	181.92	6.77	16.44	.01	.39	.052	.02	1.414	11.36	7.51	20.66	.21
96	13.55	174.29	6.41	15.79	.01	.37	.05	.05	1.414	11.3	14.56	28.2	.2
97	11.6	157.92	5.83	14.32	.01	.32	.048	.05	1.415	8.36	7.29	41.56	.18
98	10.56	149.56	5.43	13.25	.01	.28	.046	.04	1.415	7.38	16.95	24.7	.16
99	9.87	143.86	5.21	12.75	.01	.27	.044	0	1.416	14.99	14.26	35.28	.15
100	8.95	134.67	4.81	11.75	.01	.25	.042	.05	1.416	9.84	9.73	23.46	.13
101	7.37	121.88	4.41	10.44	.01	.22	.04	.01	1.417	13.26	18.84	18.96	.1
102	6.87	118.49	4.26	10	.01	.2	.037	.01	1.398	8.86	15.63	34.6	.09
103	6.01	110.53	3.81	8.89	.01	.18	.034	.03	1.38	10.34	11.69	17.4	.08
104	6.55	117.6	4.04	9.53	.01	.2	.032	.01	1.362	10.37	7	38.25	.09
105	7.3	120.7	4.35	10.29	.01	.21	.029	.02	1.344	9.82	22.55	34.4	.1

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	$N0_3$-N	02	TIC	ALK	FE
106	14.43	183.03	6.82	16.83	0.01	0.4	0.027	0.01	1.326	9.69	27.89	23.91	0.21
107	12.15	164.79	5.98	14.98	.01	.34	.025	.04	1.309	10.86	12.2	31.79	.19
108	9.24	140.15	5.02	12.28	.01	.26	.023	.04	1.292	11.9	19.15	41.03	.14
109	7.8	126.77	4.54	10.89	.01	.24	.021	.04	1.275	9.87	9.62	17.6	.12
110	18.01	209.4	8.02	19.22	.01	.51	.02	0	1.588	12.89	16.93	17.48	.26
111	23	236.47	10.04	21.94	.01	.61	.018	.03	1.568	3.88	11.2	25.41	.35
112	16.14	198.01	7.51	17.85	.01	.46	.017	.05	1.547	12.58	14.25	33.62	.24
113	21.4	232.43	9.76	21.46	.01	.59	.015	.01	1.527	10.63	22.42	24.92	.33
114	22.85	235.84	10.02	21.67	.01	.6	.014	.04	1.507	14	21.95	23.91	.35
115	18.24	210.14	8.18	19.32	.01	.51	.015	0	1.517	9.59	5.5	26.89	.27
116	16.09	197.26	7.43	17.7	.01	.46	.015	.04	1.528	9.63	22.71	18.45	.23
117	15.13	189.55	7.04	17.35	.01	.44	.015	.04	1.539	7.88	31.54	17.13	.22
118	12.62	165.22	6.08	15.02	.01	.34	.016	.02	1.228	10.88	1.96	7.13	.19
119	11.44	157.31	5.81	14.25	.01	.32	.016	.02	1.237	12.07	18.65	27.15	.18
120	21.94	234.41	10.01	21.62	.01	.59	.017	.04	1.573	13.33	17.53	34.07	.34
121	19.84	218.69	8.69	20.15	.01	.54	.017	.05	1.584	10.1	10.47	9.39	.29
122	15.42	190.66	7.17	17.45	.01	.44	.017	.03	1.595	14.77	6.63	28.56	.23
123	13.79	176.83	6.47	15.88	.01	.37	.018	0	1.272	11.6	4.48	18.11	.2
124	11.19	155.08	5.57	13.89	.01	.31	.018	0	1.282	15.85	10.06	31.72	.17
125	9.67	143.04	5.2	12.7	.01	.27	.019	.02	1.291	8.21	23.85	45.51	.15
126	16.13	197.57	7.5	17.7	.01	.46	.019	.04	1.641	9.92	8.97	17.99	.24
127	13.03	167.22	6.22	15.26	.01	.34	.02	.04	1.309	8.97	12.84	38.91	.2
128	13.18	169.47	6.25	15.41	.01	.36	.021	.03	1.319	7.53	4.06	20.67	.2
129	11.39	156.74	5.72	14.17	.01	.32	.021	0	1.328	8.35	15.88	23.36	.18
130	9.11	136.14	4.82	11.84	.01	.25	.022	.03	1.338	12.08	24.61	37.15	.14
131	7.17	120.39	4.31	10.26	.01	.21	.022	.02	1.347	8.24	17.96	20.53	.1
132	6.8	118.29	4.24	9.98	.01	.2	.023	.04	1.357	14.9	11.29	8.47	.09

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	NO_3-N	02	TIC	ALK	FE
133	5.77	105.93	3.37	8.52	0.01	0.18	0.023	0.02	1.366	11.31	10.22	14.9	0.07
134	4.61	96.75	3.03	7.03	0	.16	.024	.01	1.376	10.19	20.83	26.4	.06
135	5.88	108.12	3.67	8.82	.01	.18	.025	.05	1.386	9.56	16.6	21.41	.08
136	13.2	170.17	6.26	15.43	.01	.36	.025	.03	1.396	8.11	15.15	34.32	.2
137	7.97	129.55	4.55	11.1	.01	.24	.026	.01	1.406	10.53	12.03	19.47	.12
138	5.63	103.71	3.35	8.31	.01	.18	.027	.01	1.416	10.37	17.51	39.1	.07
139	4.15	91.14	2.94	6.46	0	.15	.027	.05	1.426	16.97	8.84	45.85	.06
140	3.88	84.67	2.78	5.93	0	.14	.028	.02	1.436	11.4	22.1	26.27	.05
141	3.37	76.39	2.5	5.23	0	.13	.029	.04	1.447	10.99	10.07	36.06	.04
142	3.04	71.36	2.26	5.02	0	.12	.03	.03	1.457	10.53	15.2	31.48	.03
143	2.62	65.78	1.97	4.72	0	.1	.031	.01	1.467	8.98	12.97	27.67	.03
144	2.6	65.1	1.97	4.67	0	.1	.031	.01	1.478	10.06	11.32	28.05	.03
145	2.07	60.47	1.64	3.99	0	.08	.032	.03	1.489	8.77	20.7	32	.02
146	21.07	231.41	9.42	21.22	.01	.58	.033	.03	1.893	12.29	24.02	22.82	.32
147	30.74	265.28	12.35	25.85	.02	.68	.034	.02	1.906	11.53	12.34	18.98	.42
148	33.24	299.28	13.58	29.31	.02	.79	.035	.05	1.92	6.78	12.28	35.03	.51
149	31.92	287.16	12.89	28.04	.02	.73	.036	.05	1.947	7.06	10.62	16.27	.48
150	23.17	239.32	10.12	22.27	.01	.61	.037	.04	1.974	11.27	22.14	17.74	.36
151	16.47	199.91	7.66	18.25	.01	.47	.038	.01	2.001	10.13	8.91	28.51	.24
152	13.77	175.88	6.44	15.83	.01	.37	.039	.02	1.607	10.61	11.94	27.89	.2
153	10.79	152.13	5.49	13.71	.01	.29	.04	.03	1.63	12.37	26.31	32.65	.17
154	10.66	151.27	5.48	13.34	.01	.29	.041	.03	1.652	13.18	11.06	21.07	.17
155	10.31	146.91	5.31	13.18	.01	.28	.042	.03	1.675	9.96	17.36	17.24	.16
156	8.24	130.64	4.59	11.2	.01	.24	.043	.01	1.699	6.94	18.56	22.25	.12
157	6.04	112.3	3.83	9.01	.01	.19	.044	.04	1.722	9.53	14.79	37.1	.08
158	5.07	100.69	3.15	7.69	0	.17	.045	.02	1.746	8.4	9.94	20.3	.07
159	11.92	161.49	5.9	14.52	.01	.33	.047	.01	1.77	12.42	7.48	18.87	.19

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	NO_3-N	02	TIC	ALK	FE
160	17.11	204.99	7.84	18.68	0.01	0.49	0.048	0.03	2.266	10.15	17.16	28.44	0.24
161	17.05	204.36	7.8	18.56	.01	.48	.049	0	2.298	6.68	22.62	24.54	.24
162	20.91	230.61	9.38	21.14	.01	.58	.051	.03	2.33	10.35	19.18	38.29	.32
163	27.91	258	11.9	24.83	.02	.66	.052	.04	2.362	11.95	13.84	23.36	.4
164	20.85	230.51	9.31	21.1	.01	.57	.053	.02	2.395	12.21	8.15	18.78	.32
165	16.43	198.66	7.65	18.03	.01	.47	.055	.01	2.429	5.98	13.19	34.65	.24
166	13.29	171.39	6.36	15.54	.01	.37	.056	.05	1.95	13.21	16.83	38.11	.2
167	10.16	145.87	5.28	13	.01	.27	.058	.03	1.977	8.68	14.92	18.2	.16
168	7.48	125.24	4.48	10.55	.01	.22	.059	0	2.005	11.22	19.93	5.39	.11
169	5.88	108.09	3.49	8.61	.01	.18	.061	.01	2.033	10.94	10.37	17.14	.08
170	7.34	121.81	4.39	10.38	.01	.22	.062	.02	2.061	9.63	16.82	33.94	.1
171	6.68	117.85	4.17	9.82	.01	.2	.064	.02	2.09	7.53	9.65	11.17	.09
172	4.88	97.91	3.11	7.31	0	.17	.066	.04	2.119	10.82	26.81	29.24	.07
173	4.05	89.81	2.88	6.29	0	.14	.068	.02	2.148	11.68	8.82	17.41	.06
174	3.42	78.46	2.54	5.26	0	.13	.069	.03	2.178	8.34	21.14	30.63	.05
175	3.19	73.14	2.33	5.1	0	.12	.071	.03	2.209	7.14	10.62	18.97	.04
176	6.28	115.04	3.94	9.25	.01	.19	.073	.03	2.239	8.88	27.07	25.65	.08
177	4.26	93.06	2.94	6.81	0	.15	.075	.05	2.271	9.06	7.24	12.76	.06
178	3.77	82.98	2.71	5.83	0	.14	.077	.03	2.302	5.97	12.92	16.99	.05
179	2.97	70.72	2.25	4.95	0	.11	.079	.02	2.334	10.5	18.42	16.97	.03
180	2.47	64.91	1.85	4.29	0	.09	.081	.01	2.367	9.78	14.6	23.1	.02
181	1.98	56	1.57	3.74	0	.07	.084	.05	2.4	7.25	15.12	21.16	.02
182	1.3	46.75	1.21	2.95	0	.06	.086	.01	2.433	10.37	14.43	30.25	.01
183	1.13	40.44	.88	2.28	0	.05	.088	.02	2.467	6.01	7.28	31.42	.01
184	1.21	44.96	1.19	2.74	0	.06	.091	.02	2.501	10.03	11.4	12.5	.01
185	2.17	62.46	1.67	4.01	0	.08	.093	.02	2.536	8.78	9.98	14.17	.02
186	2.51	65.01	1.94	4.41	0	.1	.095	.04	2.571	9.42	20.17	20.1	.03

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	NO_3-N	02	TIC	ALK	FE
187	1.76	50.55	1.35	3.29	0	0.06	0.098	0	2.607	7.9	12.26	39.1	0.02
188	.94	31.79	.83	2.09	0	.04	.101	0	2.644	9.53	14.69	11.71	.01
189	.79	25.84	.65	1.59	0	.03	.103	.04	2.68	9.05	17.4	21.37	.01
190	.65	18.15	.37	1.48	0	.02	.106	0	2.718	7.11	10.08	32.81	.01
191	.52	12.87	.24	1.15	0	.01	.109	0	2.755	6.58	22.61	36.11	0
192	.38	12.53	.17	1.13	0	.01	.112	.01	2.794	9.6	22.37	21.4	0
193	.34	9.34	.12	.53	0	0	.115	0	2.833	8.04	15.97	18.15	0
194	.28	8.14	.11	.3	0	0	.118	.03	2.872	7.81	14.68	8.79	0
195	.22	6.99	.09	.22	0	0	.121	0	2.912	8.6	21.42	29.42	0
196	23.21	242.66	10.14	22.29	.01	.61	.124	0	3.728	7.16	20.83	19.77	.36
197	24.43	247.66	10.68	22.86	.02	.63	.128	0	3.78	11.88	19.11	35.38	.37
198	10.61	150.37	5.43	13.32	.01	.29	.131	.04	3.035	12.72	12.95	33.82	.16
199	6.25	114.49	3.93	9.24	.01	.19	.135	.03	3.078	8.01	14.76	37.34	.08
200	27.86	257.98	11.9	24.74	.02	.66	.138	0	3.94	4.68	14.71	22.9	.39
201	37.55	302	14.54	34.62	.02	.98	.142	.04	3.995	8.24	21.57	24.69	.56
202	35.15	301.77	13.63	33.01	.02	.87	.146	.05	4.05	11.83	14.97	39.77	.53
203	20.59	224.41	9.01	20.89	.01	.55	.15	.03	4.107	4.85	6.95	13.17	.31
204	15.62	193.94	7.26	17.57	.01	.45	.153	.04	4.033	8.16	29.99	27.06	.23
205	12.91	166.78	6.18	15.26	.01	.34	.157	.04	3.137	11.59	12.5	29.82	.2
206	10.1	145.67	5.25	12.95	.01	.27	.161	.05	3.08	8.11	17.15	33.71	.15
207	10.6	149.97	5.43	13.31	.01	.29	.164	0	3.025	7.99	18.72	23.96	.16
208	7.43	124.9	4.48	10.54	.01	.22	.168	.02	2.97	10.53	22.8	31.77	.11
209	6.42	115.88	3.96	9.41	.01	.19	.172	0	2.917	8.3	13.3	33.97	.09
210	8.87	134.3	4.79	11.71	.01	.25	.176	.04	2.864	6.83	15.16	31.98	.13
211	9.14	137.28	4.87	11.99	.01	.26	.18	.01	2.812	10.13	18.45	20.71	.14
212	6.98	118.62	4.28	10.02	.01	.2	.185	.04	2.762	10.51	13.65	19.52	.09
213	5.73	105.74	3.37	8.45	.01	.18	.189	.03	2.712	9.84	8.65	31.16	.07

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	NO_3-N	02	TIC	ALK	FE
214	4.58	96.68	3.02	6.94	0	0.16	0.193	0.01	2.663	7.39	14.34	10.2	0.06
215	4.08	89.85	2.88	6.38	0	.15	.198	.03	2.615	9.61	19.09	24.79	.06
216	5.45	102.31	3.3	8.18	0	.17	.203	.04	2.568	12.26	29.33	17.82	.07
217	3.93	86.01	2.8	6.1	0	.14	.207	.03	2.522	7.71	12.52	21.39	.05
218	3.28	73.48	2.34	5.16	0	.12	.212	.01	2.477	8.42	15.12	26.31	.04
219	2.96	67.32	2.07	4.89	0	.11	.217	.02	2.432	9.06	14.38	24.83	.03
220	2.5	64.95	1.87	4.36	0	.1	.222	.01	2.388	7.88	15.79	38.53	.03
221	11.29	155.89	5.69	14.07	.01	.31	.227	.04	2.345	9.95	12.1	17.67	.17
222	4.77	97.66	3.09	7.2	0	.17	.233	.05	2.303	9.75	9.6	37.3	.07
223	3.44	78.62	2.55	5.28	0	.13	.238	.02	2.261	5.03	12.19	33.1	.05
224	13.45	171.75	6.38	15.63	.01	.37	.244	0	2.221	8.56	16.93	49.3	.2
225	17.44	207.46	7.87	18.99	.01	.5	.25	.03	2.753	5.82	21.97	30.66	.25
226	10.09	145.15	5.25	12.91	.01	.27	.255	.02	2.141	7.22	3.67	21.21	.15
227	5.86	107	3.46	8.61	.01	.18	.261	.01	2.103	8.32	22.49	23.31	.08
228	4.09	90.86	2.88	6.39	0	.15	.268	.03	2.065	9.58	14.26	19.47	.06
229	11.9	160.77	5.89	14.51	.01	.33	.274	.04	2.028	6.07	9.14	23.06	.19
230	13.81	178.78	6.51	15.95	.01	.37	.28	.03	1.991	11	13.1	19.63	.2
231	7.42	123.48	4.45	10.48	.01	.22	.287	.03	1.955	9.11	22.84	33.59	.11
232	4.25	92.2	2.94	6.66	0	.15	.294	.03	1.92	8.94	9.15	5.55	.06
233	3.56	78.98	2.56	5.38	0	.13	.3	.02	1.886	7.22	3.64	26.11	.05
234	3.75	81.45	2.69	5.6	0	.14	.307	.04	1.852	10.37	19.29	31.25	.05
235	3.41	77.48	2.52	5.25	0	.13	.315	.05	1.818	9.98	13.02	32.57	.04
236	2.89	65.95	2.02	4.83	0	.11	.322	.01	1.786	7.39	24.1	29.95	.03
237	2.46	64.6	1.83	4.24	0	.09	.33	.03	1.753	7.05	30.44	34.67	.02
238	1.95	54.51	1.57	3.72	0	.06	.337	.02	1.722	9.16	17.87	31.08	.02
239	1.2	42.87	1.12	2.66	0	.05	.345	.04	1.691	8.21	15.69	15.34	.01
240	3.36	73.77	2.41	5.17	0	.12	.353	.03	1.66	6.24	13.5	17.85	.04

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	NO_3-N	02	TIC	ALK	FE
241	3.86	83.56	2.73	5.87	0	0.14	0.362	0.01	1.63	6.16	21.63	8.54	0.05
242	2.51	65.04	1.96	4.5	0	.1	.37	.04	1.601	7.93	24.12	13.83	.03
243	1.34	48.74	1.28	3.12	0	.06	.379	.03	1.572	11.08	9.94	31.39	.01
244	1.18	40.53	1.02	2.59	0	.05	.388	.04	1.544	7.08	18.87	11.92	.01
245	.81	28.44	.7	1.79	0	.03	.397	.01	1.516	5.78	13.98	19.08	.01
246	.7	24.08	.49	1.58	0	.03	.406	.01	1.489	7.67	9.67	4.05	.01
247	.97	34.32	.84	2.1	0	.04	.416	.04	1.462	9.27	13.21	29.1	.01
248	.79	26.3	.68	1.66	0	.03	.425	0	1.436	8.16	8.95	8.16	.01
249	.69	23.42	.49	1.55	0	.02	.435	.05	1.41	10.16	9.11	30.68	.01
250	.62	13.57	.28	1.32	0	.02	.446	.03	1.384	9.59	13.07	41.18	0
251	.55	13.34	.27	1.22	0	.02	.456	.04	1.359	10.17	17.91	15.24	0
252	1.99	56.06	1.58	3.8	0	.07	.467	.02	1.335	13.2	14.63	34.61	.02
253	2.4	63.69	1.76	4.24	0	.09	.478	.05	1.311	8.3	11	30.62	.02
254	1.2	40.72	1.08	2.62	0	.05	.489	.05	1.287	9.79	30.85	25.97	.01
255	1.78	53.44	1.51	3.66	0	.06	.5	.03	1.264	12.85	12.52	22.75	.02
256	.94	30.56	.8	1.92	0	.04	.512	.01	1.241	7.23	17.24	27.55	.01
257	.65	21.2	.49	1.51	0	.02	.524	.02	1.219	5.8	25.28	33.51	.01
258	.37	9.87	.14	.68	0	.01	.537	.04	1.197	7.63	14.89	17.05	0
259	8.84	134	4.76	11.66	.01	.25	.549	.04	1.176	6.63	11.38	28.18	.13
260	19.22	216.42	8.49	19.77	.01	.53	.562	.03	1.457	10.09	20.37	18.12	.28
261	13.07	169.03	6.23	15.27	.01	.35	.575	.01	1.134	10.02	3.66	26.85	.2
262	7.11	119.16	4.28	10.11	.01	.2	.589	.03	1.113	8.22	14.84	30.21	.09
263	4.55	96.05	2.97	6.88	0	.16	.603	.03	1.093	10.27	21.14	28.54	.06
264	3.86	83.37	2.71	5.84	0	.14	.617	.02	1.073	7.42	11.81	30.96	.05
265	3.36	75.68	2.43	5.19	0	.13	.631	.03	1.054	11.82	8.85	25.46	.04
266	3.1	72.53	2.33	5.09	0	.12	.646	.02	1.035	10.51	2.77	19.19	.03
267	2.9	66.05	2.04	4.86	0	.11	.661	.01	1.016	7.55	7.3	23.95	.03

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	$N0_3$-N	02	TIC	ALK	FE
268	2.28	63.6	1.7	4.06	0	0.08	0.677	0.04	0.998	7.23	13.91	26.01	0.02
269	1.76	51.17	1.49	3.31	0	.06	.693	.05	.98	10	15.7	23.56	.02
270	1.8	54.08	1.52	3.7	0	.06	.709	.03	.963	6.36	20.17	43.72	.02
271	31.56	278.61	12.74	28.04	.02	.69	.725	0	.945	7.24	17.12	31.51	.47
272	.07	5.06	.02	.12	.01	.28	.725	.03	1.193	6.78	17.1	23.49	0
273	1.23	46.42	1.21	2.75	0	.04	.725	.01	1.193	11.33	9	29.04	.01
274	1.01	40.16	.85	2.11	.02	.31	.725	.04	.945	11.45	9.51	20.17	.01
275	1.34	49.2	1.34	3.24	.02	.3	.725	.01	.945	9.42	23.83	20.03	.02
276	11.84	158.62	5.87	14.36	.01	.15	.725	.02	.945	6.49	26.84	14.53	.18
277	27.49	241.58	11.37	24.2	.01	.12	.725	.05	.945	7.04	12.84	39.76	.39
278	18.07	200.05	8.05	19.3	.01	.23	.725	.02	.945	9.73	18.23	41.01	.26
279	13.14	166.69	6.23	15.31	.01	.73	.725	.03	.945	7.92	15.72	21.73	.2
280	9.25	140.25	5.07	12.37	.01	.37	.725	.02	.945	13.8	23.97	29.44	.14
281	8.37	132.03	4.67	11.33	.01	.05	.725	.05	.945	11.93	16.74	19.11	.13
282	7.8	126.49	4.53	10.87	.01	.52	.725	.02	.945	12.37	10.4	22.84	.11
283	7.23	120.53	4.31	10.29	.01	.28	.725	.04	.945	9.15	20.55	31.09	.1
284	6.13	113.57	3.9	9.16	0	.28	.725	.01	.945	8.4	7.35	21.65	.08
285	6.2	114.18	3.93	9.16	.01	.21	.725	.02	.945	9.79	8	15.58	.08
286	6.12	112.92	3.83	9.13	.01	.26	.725	.04	.945	12.12	11.25	25.66	.08
287	6.13	113.12	3.87	9.15	.01	.09	.725	0	.945	8.05	22.19	22.77	.08
288	5.34	101.9	3.24	7.97	.01	.2	.725	0	.945	8.37	20.65	23.37	.07
289	5.41	102.04	3.3	8.08	.03	.81	.725	0	.945	9.35	6.08	32.22	.07
290	3.94	89.3	2.82	6.2	0	.7	.725	.02	.945	6.89	10.34	30.47	.05
291	3.99	89.51	2.88	6.27	.01	.45	.725	0	.945	9.92	15.89	20.29	.06
292	5.27	101.24	3.18	7.81	.01	.36	.725	.04	.945	6.32	13.73	10.81	.07
293	6.4	115.8	3.95	9.39	.01	.6	.725	.02	.945	9.57	4.24	19	.09
294	5.26	101.09	3.16	7.74	.03	.54	.725	.01	.945	12.6	5.43	17.61	.07

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	NO_3-N	02	TIC	ALK	FE
295	3.92	85.97	2.79	6.06	0.01	0.26	0.725	0.03	0.945	9.55	12.67	38.54	0.05
296	3.74	80.76	2.64	5.48	.02	.51	.725	.03	.945	11	10.94	35.72	.05
297	3.65	80.43	2.63	5.45	0	.2	.725	.03	.945	13.5	5.45	28.92	.05
298	2.03	56.33	1.63	3.93	.04	.18	.725	.04	.945	13.41	8.52	13.85	.02
299	10.63	150.46	5.45	13.32	.01	.44	.725	.02	.945	10.87	10.49	38.96	.16
300	8.51	132.73	4.72	11.49	.03	.09	.725	.04	.945	11.43	7.99	15.19	.13
301	5.88	108.1	3.53	8.68	.02	.25	.725	.01	.945	10.66	7.06	35.33	.08
302	5.18	100.87	3.16	7.73	.03	.05	.725	.02	.945	10.1	22.21	25.4	.07
303	5.31	101.54	3.18	7.91	.01	.4	.725	.03	.945	12.23	6.96	30.06	.07
304	4.5	94.34	2.97	6.83	0	.22	.725	.03	.945	11.09	14.63	21.13	.06
305	6.57	117.65	4.12	9.54	0	.53	.725	.03	.945	7.58	14.49	15.47	.09
306	9.2	138.46	4.92	12.19	.02	.55	.725	.02	.945	12.69	15.41	36.56	.14
307	7.12	119.68	4.28	10.18	.03	.3	.725	.03	.945	13.01	11.48	34.63	.1
308	5.96	110.51	3.73	8.87	.01	.52	.725	.04	.945	10	10.67	25.33	.08
309	6.49	116.85	4	9.5	.02	.53	.725	.03	.945	16.73	17.06	14.83	.09
310	21.9	225.07	9.86	21.59	.03	.64	.725	.03	.945	6.12	7.68	22.46	.34
311	18.14	200.9	8.14	19.31	.04	.06	.725	.01	.945	13.4	16.47	26.18	.26
312	14	172.03	6.58	16.02	.02	.35	.725	.02	1.193	10.92	6.55	33.98	.21
313	12.45	163.13	6.01	14.99	.01	.41	.725	.04	1.193	12.07	15.32	14.33	.19
314	21.28	221.77	9.44	21.33	.02	.43	.725	.02	1.193	13.08	20.12	27.71	.33
315	18.8	204.85	8.25	19.44	.04	.77	.725	.03	.945	12.27	18.29	20.73	.27
316	15.37	183.94	7.11	17.43	.02	.34	.725	.02	.945	14.59	14.49	17.67	.23
317	14.04	172.27	6.6	16.06	.04	.23	.725	.02	.945	8.38	22.47	28.75	.21
318	12.73	164.59	6.1	15.12	0	.11	.725	.02	.945	9.2	7.36	49.97	.19
319	10.52	149.3	5.42	13.21	.03	.55	.725	.04	.945	13.35	16.3	15.35	.16
320	9.44	140.61	5.08	12.42	.03	.38	.725	0	.945	8.71	12.63	20.18	.14
321	8.77	133.93	4.76	11.64	.03	.19	.725	.04	.945	11.06	15.91	24.26	.13

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	NO_3-N	02	TIC	ALK	FE
322	7.85	129.1	4.55	10.96	0.04	0.31	0.725	0.02	1.193	16.75	12.81	4.78	0.12
323	7.8	126.61	4.54	10.87	.01	.14	.725	.02	1.193	7.09	13.47	25.8	.11
324	7.41	122.78	4.43	10.45	.03	.35	.725	.01	1.193	12.38	1.79	31.74	.1
325	7.14	119.95	4.3	10.24	.01	.26	.725	.02	1.193	8.33	20.74	23.99	.1
326	6.74	118.26	4.23	9.94	.02	:2	.725	.04	1.193	12.23	12.54	17.46	.09
327	10.31	146.26	5.3	13.14	.03	.39	.725	0	1.193	9.85	28.63	28.99	.16
328	8.71	133.35	4.76	11.6	0	.16	.725	.03	.945	13.97	17.06	39.17	.13
329	8.52	132.98	4.72	11.52	.02	.42	.725	.01	1.193	11.15	8.96	45.07	.13
330	8.26	130.99	4.62	11.21	.04	.23	.725	.04	1.193	9.43	16.75	19.57	.12
331	8.46	132.52	4.71	11.41	.02	.07	.725	.04	1.193	10.15	17.78	43.69	.13
332	7.83	128.28	4.55	10.93	.02	.07	.725	.01	1.193	13.04	17.66	25.95	.12
333	7.56	126.03	4.5	10.55	.01	.37	.725	.04	.945	8.7	10.39	10.38	.11
334	7.34	121.36	4.36	10.36	.03	.02	.725	.04	1.193	7.8	18.92	25.89	.1
335	6.46	116.26	3.97	9.42	.02	.13	.725	.01	1.193	9.58	18.09	16.02	.09
336	5.7	104.69	3.36	8.43	0	.19	.725	.03	1.193	12.79	20.01	20.5	.07
337	5.5	103.56	3.32	8.24	.04	.39	.725	.03	1.193	7.32	14	27.78	.07
338	5.59	103.61	3.32	8.29	.02	.16	.725	.02	1.193	11.24	10.47	18.14	.07
339	5.79	106.44	3.39	8.53	.01	.36	.725	.03	.945	9.87	16.78	16.8	.08
340	4.62	97.24	3.04	7.15	.01	.4	.725	.04	.945	14.06	6.83	20.86	.07
341	4.13	91	2.91	6.45	.04	.39	.725	.03	.945	12.74	13.38	29.08	.06
342	4.85	97.79	3.11	7.21	.03	.12	.725	.03	.945	11.65	5.08	25.96	.07
343	5.03	100.31	3.15	7.46	.02	.11	.725	.02	.945	17.23	20.11	29.99	.07
344	5	99.09	3.15	7.39	.04	.3	.725	.05	.945	11.18	11.53	35.39	.07
345	4.17	91.63	2.94	6.52	.01	.01	.725	.03	.945	8.64	22.72	11.79	.06
346	3.6	80.27	2.57	5.42	.04	.18	.725	.03	.945	8.77	15.2	37.94	.05
347	3.87	83.91	2.74	5.91	.03	.28	.725	.02	1.193	10.83	14.68	17.27	.05
348	3.89	84.78	2.78	6.01	.01	.44	.725	.01	.945	13.86	14.72	34.95	.05

Appendix 1. CE-QUAL-W2 input file for Dix River, January 1, 1996 to December 31, 1996—*Continued*

[JDAY, julian day; SS, suspended solids; TDS, total dissolved solids; LDOM, labile dissolved organic matter; RDOM, refractive dissolved organic matter; DETRIT, detritus; SRP, soluble reactive phosphorus; NH_4-N, ammonia-nitrogen; NO_3-N, nitrate-nitrogen; O2, dissolved oxygen; TIC, total inorganic carbon; ALK, alkalinity; FE, iron; concentrations in milligrams per liter]

JDAY	SS	TDS	LDOM	RDOM	ALGAE	DETRIT	SRP	NH_4-N	$N0_3$-N	02	TIC	ALK	FE
349	7.66	126.07	4.5	10.67	0.01	0.31	0.725	0.04	0.945	9.34	10.74	32.85	0.11
350	5.82	106.77	3.46	8.57	.02	.23	.725	.05	.945	13.73	19.16	14.94	.08
351	16.68	192.21	7.73	18.37	.02	.5	.725	.03	1.193	11.64	24.67	27.35	.24
352	25.84	236.13	10.77	23.04	0	.06	.725	.05	1.193	14.07	12.33	27.61	.38
353	21.4	222.47	9.68	21.39	.02	.15	.725	.03	1.193	15.68	13.55	45.8	.33
354	17.95	198.77	7.95	19.21	.01	.23	.725	.03	1.193	17.49	5.32	28.23	.25
355	15.5	187.14	7.23	17.55	.02	.31	.725	.04	.945	13.13	4.33	8.88	.23
356	14.06	172.9	6.62	16.1	0	.34	.725	.05	.945	16.99	38.53	22.92	.21
357	12.78	165.11	6.16	15.14	.01	.38	.725	.02	.945	17.07	20.5	20.65	.19
358	11.23	155.51	5.61	13.89	.03	.16	.725	.03	1.193	16.11	12.81	19.65	.17
359	10.37	147.93	5.34	13.21	.03	.29	.725	.01	1.193	13.45	17.74	21.32	.16
360	9.77	143.27	5.2	12.72	0	.1	.725	0	1.193	9.7	25	18.37	.15
361	9.15	138.22	4.9	12.04	.02	.39	.725	.04	1.193	11.42	9.68	11.64	.14
362	9.01	135.09	4.82	11.83	.01	.64	.725	.01	.945	8.09	17.24	20.9	.13
363	8.33	131.31	4.67	11.26	.01	.23	.725	.01	.945	14.87	18.06	22.27	.12
364	8.32	131.26	4.66	11.23	.01	.07	.725	.04	.945	11.75	16.68	27.12	.12

Appendix 2. Chemical kinetic-rate coefficients and hydraulic and thermal parameters specified as model input, Herrington Lake, Kentucky, 1996

[m, meter; m^3(m/g), cubic meter per meter per gram; --, not applicable; *, dimensionless parameter, m/d, meter per day; watts/m^2, watts per square meter; °C, degrees Celsius; SOD, streambed oxygen demand; BOD, biological oxygen demand; g/m, gram per meter; mg/L, milligram per liter; gO_2m^2/d, grams of oxygen per square meter per day; >, greater than; $m^{0.5}$/s, meter to the half power per second; m^2/s, square meter per second]

Parameter abbreviation	Parameter	Computational purpose	Value in Herrington Lake model	Values from [1]Cole and Buchak, 1995	Values from Giorgino and Baies, 1997
EXH20	Light-extinction coefficient for pure water (m^{-1})	Amount of solar radiation absorbed in the surface layer	0.49	0.18 - 4.0	0.5
EXSS	Light-extinction coefficient for suspended solids (m^3(m/g))	Amount of solar radiation absorbed by total suspended material	.10	.10	--
EXOM	Light-extinction coefficient for organic solids (m^3(m/g))	Amount of solar radiation absorbed by organic material	.27	.17	.2
BETA	Fraction of incident solar radiation absorbed at water surface	Amount of solar radiation absorbed in the surface layer	*.45	*.45	*.3
SSS	Suspended solids settling rate (m/d)	Settling rates and sediment accumulation on reservoir bottom	1.30	.86 - 860	2.0
AG	Algal growth rate (d^{-1})	Maximum gross algal-production rate, uncorrected for respiration, mortality, excretion, or settling; temperature dependent	1.56	1.1	1.9
AM	Algal mortality rate (d^{-1})	Maximum algal-mortality rate; temperature dependent	.01	.01 - .03	.09
AE	Algal excretion rate (d^{-1})	Maximum algal-photorespiration rate, which becomes labile dissolved organic matter	.005	.014 - .44	.005
AR	Algal dark-respiration rate (d^{-1})	Maximum algal dark-respiration rate	.01	.01 - 92	.005
AS	Algal settling rate (m/d)	Representative settling velocity for algal assemblages	.14	.0 - 30	.10
ASAT	Saturation light intensity (watts/m^2)	Saturation light intensity at maximum algal-photosynthesis rate	150	150	150
APOM	Fraction of algal biomass lost by mortality to detritus	Detritus and dissolved organic-matter concentrations; remaining biomass becomes labile dissolved organic matter	*.8	*.8	*.8
ATI	Lower temperature for algal growth (°C)	Algal-growth rate as a function of water temperature	10	10	10
AKI	Fraction of algal growth at lower temperature	Algal-growth rate as a function of water temperature	*.1	*.1	*.1

Appendix 2. Chemical kinetic-rate coefficients and hydraulic and thermal parameters specified as model input, Herrington Lake, Kentucky, 1996—*Continued*

[m, meter; m^3(m/g), cubic meter per meter per gram; --, not applicable; *, dimensionless parameter, m/d, meter per day; watts/m^2, watts per square meter; °C, degrees Celsius; SOD, streambed oxygen demand; BOD, biological oxygen demand; g/m, gram per meter; mg/L, milligram per liter; gO_2m^2/d, grams of oxygen per square meter per day; >, greater than; $m^{0.5}$/s, meter to the half power per second; m^2/s, square meter per second]

Parameter abbreviation	Parameter	Computational purpose	Value in Herrington Lake model	Values from [1]Cole and Buchak, 1995	Values from Giorgino and Bales, 1997
AT2	Lower temperature for maximum algal growth (°C)	Algal-growth rate as a function of water temperature	30	30	22
AK2	Fraction of maximum growth at lower temperature	Algal-growth rate as a function of water temperature	*.99	*.99	*.99
AT3	Upper temperature for maximum algal growth (°C)	Algal-growth rate as a function of water temperature	35	35	22.5
AK3	Fraction of maximum growth at upper temperature	Algal-growth rate as a function of water temperature	*.99	*.99	*.95
AT4	Upper temperature for algal growth (°C)	Algal-growth rate as a function of water temperature	40	40	35
AK4	Fraction of algal growth at upper temperature	Algal-growth rate as a function of water temperature	*.1	*.1	*.1
LDOMDK	Labile dissolved organic-matter-decay rate (d^{-1})	Dissolved-oxygen loss and production of inorganic carbon, ammonium, and phosphate from algal decay; temperature dependent	.02	.01 - .63	.04
LRDDK	Labile to refractory decay rate (d^{-1})	Transfer of labile to refractory dissolved organic matter	.001	.001	.005
RDOMDK	Maximum refractory dissolved organic-matter-decay rate (d^{-1})	Dissolved-oxygen loss and production of inorganic carbon, ammonium, and phosphate from decay of refractory dissolved organic matter; temperature dependent	.001	.001	.001
LPOMDK	Detritus decay rate (d^{-1})	Dissolved-oxygen loss and production of inorganic carbon, ammonium, and phosphate from decay particulate-organic matter; temperature dependent	.04	.001 - .111	.002
POMS	Detritus settling velocity (m/d)	Loss of particulate organic matter to bottom sediment	.35	.001 - 20.0	2.5
OMT1	Lower temperature for organic matter decay (°C)	Organic-matter decay as a function of temperature	4.0	4.0	5.0
OMK1	Fraction of organic matter decay at lower temperature	Organic-matter decay as a function of temperature	*.1	*.1	*.05

Appendix 2. Chemical kinetic-rate coefficients and hydraulic and thermal parameters specified as model input, Herrington Lake, Kentucky, 1996—*Continued*

[m, meter; $m^3(m/g)$, cubic meter per meter per gram; --, not applicable; *, dimensionless parameter, m/d, meter per day; watts/m^2, watts per square meter; °C, degrees Celsius; SOD, streambed oxygen demand; BOD, biological oxygen demand; g/m, gram per meter; mg/L, milligram per liter; gO_2m^2/d, grams of oxygen per square meter per day; >, greater than; $m^{0.5}/s$, meter to the half power per second; m^2/s, square meter per second]

Parameter abbreviation	Parameter	Computational purpose	Value in Herrington Lake model	Values from [1]Cole and Buchak, 1995	Values from Giorgino and Baies, 1997
OMT2	Lower temperature for maximum organic matter decay (°C)	Organic-matter decay as a function of temperature	20.0	20.0	25.0
OMK2	Fraction of maximum organic matter decay at lower temperature	Organic-matter decay as a function of temperature	*.99	*.99	*.95
SDK	Sediment decay rate (d^{-1})	Decay rate of organic matter in bed sediments	.06	.06	.015
FSOD	Fraction of SOD	Sediment oxygen-demand function	.8	.9	--
SOD	Sediment oxygen demand by 20 segments (gO_2m^2/d)	Factor for assessing sediment oxygen demand at various strata and computational segments	.1 - .6	.1 - 5.8	.0
KBOD	5-day chemical oxygen-demand-decay rate (d^{-1})	Effects of BOD loading on dissolved oxygen	.25	.25	.15
TBOD	BOD temperature-rate coefficient	Adjusts 5-day BOD decay rate at 20°C to ambient temperature	*1.047	*1.047	*1.0147
RBOD	Ratio of 5-day BOD to ultimate BOD	Effects of BOD loading on dissolved oxygen	*1.85	*1.85	*1.20
PO4R	Release rate of phosphorus from bottom sediments	Phosphorus balance; computed as a fraction of the sediment oxygen demand	*.015	*0 - .30	*.005
PARTP	Phosphorus partitioning coefficient	Describes sorption of phosphorus onto suspended solids	.02	1.2	3.0
AHSP	Algal half-saturation constant for phosphorus (g/m)	The phosphorus concentration at which the uptake rate is one-half the maximum uptake rate; upper concentration at which algal growth is proportional to phosphorus concentration	.005	.001 - 1.520	.005
NH4R	Release rate of ammonia from bottom sediments	Nitrogen balance; computed as a fraction of the sediment oxygen demand	*.08	*0 - .4	*.003
NH4DK	Ammonia-decay rate (d^{-1})	Rate at which ammonia is oxidized to nitrate	.12	.09 - 1.30	.20
AHSN	Algal half-saturation constant for ammonia	Nitrogen concentration at which the algal uptake rate is one-half the maximum uptake rate	*.044	*.006 - 4.34	*.014

Appendix 2. Chemical kinetic-rate coefficients and hydraulic and thermal parameters specified as model input, Herrington Lake, Kentucky, 1996—*Continued*

[m, meter; m^3(m/g), cubic meter per meter per gram; --, not applicable; *, dimensionless parameter, m/d, meter per day; watts/m^2, watts per square meter; °C, degrees Celsius; SOD, streambed oxygen demand; BOD, biological oxygen demand; g/m, gram per meter; mg/L, milligram per liter; gO_2m^2/d, grams of oxygen per square meter per day; >, greater than; $m^{0.5}$/s, meter to the half power per second; m^2/s, square meter per second]

Parameter abbreviation	Parameter	Computational purpose	Value in Herrington Lake model	Values from [1]Cole and Buchak, 1995	Values from Giorgino and Bales, 1997
PARTN	Ammonia partitioning coefficient for sorption onto suspended solids	A function of conversion of ammonia to nitrate or sorption to suspended solids	1.0	1.0	--
NH4T1	Lower temperature for ammonia decay (°C)	Ammonia nitrification as a function of temperature	5.0	5.0	5.0
NH4K1	Fraction of nitrification at lower temperature	Ammonia nitrification as a function of temperature	*.1	*.1	*.10
NH4T2	Lower temperature for maximum ammonia decay (°C)	Ammonia nitrification as a function of temperature	20.0	20.0	25.0
NH4K2	Fraction of maximum nitrification at lower temperature	Ammonia nitrification as a function of temperature	*.99	*.99	*.99
NO3DK	Nitrate decay rate (d^{-1})	Rate at which nitrate is denitrified; temperature dependent	.202	.05 - .15	.15
NO3T1	Lower temperature for nitrate decay (°C)	Denitrification as a function of temperature	5.0	5.0	5.0
NO3K1	Fraction of denitrification at lower temperature	Denitrification as a function of temperature	*.1	*.1	*.10
NO3T2	Lower temperature for maximum nitrate decay (°C)	Denitrification as a function of temperature	20.0	20.0	25.0
NO3K2	Fraction of maximum denitrification at lower temperature	Denitrification as a function of temperature	*.99	*.99	*.99
CO2R	Sediment carbon-dioxide-release rate; fraction of sediment oxygen demand	Rate at which CO_2 is released from sediments	.10	.10	--
FER	Iron-release rate from bottom sediments	Iron balance; computed as fraction of sediment oxygen demand	*.5	*.3 - .5	*1.0
FES	Iron settling velocity (m/d)	Particulate iron-settling velocity under anoxic conditions	2.0	.5 - 2.0	2.0
O2NH4	Oxygen stoichiometric equivalent for ammonia decay	Relates oxygen consumption to ammonia decay	*4.57	*4.57	*4.0
O2OM	Oxygen stoichiometric equivalent for organic-matter decay	Relates oxygen consumption to decay of organic matter	*1.4	*1.4	*1.5

Appendix 2. Chemical kinetic-rate coefficients and hydraulic and thermal parameters specified as model input, Herrington Lake, Kentucky, 1996—*Continued*

[m, meter; m^3(m/g), cubic meter per meter per gram; --, not applicable; *, dimensionless parameter, m/d, meter per day; watts/m^2, watts per square meter; °C, degrees Celsius; SOD, streambed oxygen demand; BOD, biological oxygen demand; g/m, gram per meter; mg/L, milligram per liter; gO_2m^2/d, grams of oxygen per square meter per day; >, greater than; $m^{0.5}$/s, meter to the half power per second; m^2/s, square meter per second]

Parameter abbreviation	Parameter	Computational purpose	Value in Herrington Lake model	Values from [1]Cole and Buchak, 1995	Values from Giorgino and Baies, 1997
O2AR	Oxygen stoichiometric equivalent for dark respiration	Relates oxygen consumption to algae dark respiration	*1.4	*1.4	*0.9
O2AG	Oxygen stoichiometric equivalent for algal growth	Relates oxygen production to algal growth	*1.4	*1.4	*3.0
BIOP	Stoichiometric equivalent between organic matter and phosphorus	Relates phosphorus release to decay of organic matter	*.011	*.011	*.009
BION	Stoichiometric equivalent between organic matter and nitrogen	Relates nitrogen release to decay of organic matter	*.08	*.08	*.08
BIOC	Stoichiometric equivalent between organic matter and carbon	Relates carbon release to decay of organic matter	*.45	*.45	--
O2LIM	Dissolved-oxygen limit (mg/L)	Dissolved-oxygen concentration below which anaerobic processes, such as nitrification and sediment-nutrient releases occur	.2	>.0	.10
CEHZY	Chezy resistance coefficient ($m^{0.5}$/s)	Represents turbulent exchange of energy at reservoir bottom	72	70	70
CBHE	Coefficient of sediment-water heat exchange (watts/m^2/°C)	Computes heat exchange between reservoir bottom and overlying water	7.0×10^{-8}	7.0×10^{-8}	8×10^{-7}
WSC	Wind sheltering coefficient	Reduces measured wind speed to effective wind speed at water surface	.85 - .95	0 - 1.0	.7 - .9
AX	Longitudinal eddy viscosity (m^2/s)	Represents laterally averaged longitudinal turbulent transport of momentum	1.0	1.0	1.0
DX	Longitudinal eddy diffusivity (m^2/s)	Represents laterally averaged longitudinal turbulent transport of mass and heat	1.0	1.0	1.0

[1]Defined appropriate initial start-up value.

Appendix 3. Discharge and nutrient concentrations for selected tributaries entering Herrington Lake, Kentucky, October 25, 1995–September 28, 1996

[NO_3-N, nitrate-nitrogen; NH_4-N, ammonia-nitrogen; TP, total phosphorus; SRP, soluble reactive phosphorus; ft^3/s, cubic foot per second; micrograms per liter, µg/L; for NH_4-N, the detection limit is less than 10 µg/L]

Tributary name	Station number	Date	Discharge (ft^3/s)	NO_3-N (µg/L)	NH_4-N (µg/L)	TP (µg/L)	SRP (µg/L)
Cane Run	03285550	10/25/1995	0.3	1,653.3	<10.0	361.1	296.6
Cane Run	03285550	11/01/1995	.6	1,626.7	<10.0	320.8	277.2
Cane Run	03285550	11/07/1995	14.6	3,663.3	<10.0	660.3	501.6
Cane Run	03285550	01/16/1996	20.0	3,946.7	113.3	311.1	270.3
Cane Run	03285550	01/19/1996	88.3	5,426.7	<10.0	718.8	331.3
Cane Run	03285550	02/09/1996	8.0	5,213.3	<10.0	323.7	258.9
Cane Run	03285550	02/28/1996	19.7	4,146.7	<10.0	393.6	.0
Cane Run	03285550	03/06/1996	108.0	4,000.0	<10.0	995.9	388.6
Cane Run	03285550	04/11/1996	6.4	4,773.3	<10.0	250.5	198.1
Cane Run	03285550	04/24/1996	35.2	4,390.0	<10.0	473.6	166.8
Cane Run	03285550	05/28/1996	91.0	5,456.7	<10.0	96.9	46.9
Cane Run	03285550	07/22/1996	22.5	6,426.7	<10.0	354.4	170.1
Cane Run	03285550	09/28/1996	155.0	2,760.0	<10.0	1,048	767.7
Clarks Run	03285200	10/25/1995	6.5	12,000.0	<10.0	1266.7	1123.3
Clarks Run	03285200	11/01/1995	7.9	9,556.7	<10.0	1,052.7	991.4
Clarks Run	03285200	11/07/1995	90.0	3,250.0	<10.0	854.1	395.6
Clarks Run	03285200	01/16/1996	187.0	3,100.0	296.0	324.1	222.2
Clarks Run	03285200	01/19/1996	357.0	3,666.7	247.3	482.1	282.9
Clarks Run	03285200	02/09/1996	35.0	5,220.0	<10.0	316.3	216.2
Clarks Run	03285200	02/28/1996	101.0	3,476.7	<10.0	457	194.8
Clarks Run	03285200	03/06/1996	401.0	2,850.0	<10.0	755.8	586.5
Clarks Run	03285200	04/11/1996	27.0	6,296.7	<10.0	397.1	348.4
Clarks Run	03285200	04/24/1996	85.0	3,820.0	<10.0	239.5	84.3
Clarks Run	03285200	05/28/1996	221.0	4,233.3	<10.0	375	305.9
Clarks Run	03285200	07/22/1996	64.0	7,706.7	301.3	274.6	252.7
Clarks Run	03285200	09/28/1996	505.0	2,910.0	<10.0	982.5	596.9
Dix River	03285000	10/25/1995	28.0	1,413.3	<10.0	198.8	142.7
Dix River	03285000	11/01/1995	76.0	935.6	<10.0	169.8	120.0
Dix River	03285000	11/07/1995	1020.0	819.7	<10.0	109.7	86.7
Dix River	03285000	01/16/1996	1460.0	1,690.0	110.0	961.6	109.7
Dix River	03285000	01/19/1996	4,710.0	1,456.7	<10.0	173	156.6

Appendix 3. Discharge and nutrient concentrations for selected tributaries entering Herrington Lake, Kentucky, October 25, 1995–September 28, 1996—*Continued*

[NO_3-N, nitrate-nitrogen; NH_4-N, ammonia-nitrogen; TP, total phosphorus; SRP, soluble reactive phosphorus; ft^3/s, cubic foot per second; micrograms per liter, µg/L; for NH_4-N, the detection limit is less than 10 µg/L]

Tributary name	Station number	Date	Discharge (ft^3/s)	NO_3-N (µg/L)	NH_4-N (µg/L)	TP (µg/L)	SRP (µg/L)
Dix River	03285000	02/09/1996	1,000.0	2,236.7	<10.0	229.8	85.9
Dix River	03285000	02/28/1996	1,290.0	1,830.0	<10.0	280.2	207.1
Dix River	03285000	03/06/1996	3,040.0	1,765.0	<10.0	1,182	179.0
Dix River	03285000	04/11/1996	223.0	1,416.7	<10.0	63.7	26.7
Dix River	03285000	04/24/1996	1,420.0	1,506.7	<10.0	111.4	12.5
Dix River	03285000	05/28/1996	5,670.0	1,920.0	<10.0	0	.0
Dix River	03285000	07/22/1996	1,060.0	4,106.7	<10.0	166.2	126.5
Dix River	03285000	09/28/1996	4,400.0	1,193.3	<10.0	1631	766.3
McKecknie Creek	03285400	11/07/1995	1.4	1,666.7	<10.0	1,004	670.5
McKecknie Creek	03285400	01/16/1996	8.6	2,250.0	156.3	224.6	167.9
McKecknie Creek	03285400	01/19/1996	11.3	4,240.0	<10.0	338.5	298.4
McKecknie Creek	03285400	02/28/1996	1.2	1,833.3	<10.0	646.8	126.9
McKecknie Creek	03285400	03/06/1996	10.4	2,100.0	<10.0	489.7	173.6
McKecknie Creek	03285400	04/11/1996	2.6	.0	.0	0	.0
McKecknie Creek	03285400	04/24/1996	1.9	2,260.0	<10.0	150.2	80.0
McKecknie Creek	03285400	05/28/1996	14.3	4,420.0	<10.0	338.2	40.7
McKecknie Creek	03285400	07/22/1996	.7	8,013.3	<10.0	279.5	238.8
McKecknie Creek	03285400	09/28/1996	22.3	2,416.7	<10.0	650.6	389.2
Mocks Branch	03285350	10/25/1995	.3	208.7	<10.0	339.3	240.7
Mocks Branch	03285350	11/01/1995	.7	1,077.0	<10.0	262.6	196.3
Mocks Branch	03285350	11/07/1995	34.3	1,703.3	<10.0	408.3	261.8
Mocks Branch	03285350	01/16/1996	35.7	3,373.3	170.0	427.1	216.2
Mocks Branch	03285350	01/19/1996	148.0	4,373.3	<10.0	733.5	363.8
Mocks Branch	03285350	02/09/1996	12.0	3,506.7	<10.0	287.2	203.7
Mocks Branch	03285350	02/28/1996	31.9	2,376.7	<10.0	822.1	278.0
Mocks Branch	03285350	03/06/1996	158.0	2,670.0	<10.0	1,005.7	439.6
Mocks Branch	03285350	04/11/1996	7.4	2,923.3	<10.0	167	106.5
Mocks Branch	03285350	04/24/1996	54.6	4,103.3	<10.0	245.5	12.5
Mocks Branch	03285350	05/28/1996	127.0	4,580.0	<10.0	244.3	106.7
Mocks Branch	03285350	07/22/1996	52.0	5,926.7	<10.0	316	299.1
Mocks Branch	03285350	09/28/1996	175.0	2,733.3	<10.0	1,197.7	610.8

Appendix 4. Average discharge outflows in 1996 at two withdrawal structures at the Dix River Dam

[These data were input into CE-QUAL-W2; --, recording equipment malfunction]

Date	Discharge (gate elevations at 532 feet above sea level)	Discharge (gate elevations at 584 feet above sea level)
01/01/1996	13.468	5.772
01/02/1996	13.468	5.772
01/03/1996	18.529	7.941
01/04/1996	18.375	7.875
01/05/1996	10.423	4.467
01/06/1996	.203	.087
01/07/1996	6.398	2.742
01/08/1996	2.17	.93
01/09/1996	9.807	4.203
01/10/1996	19.299	8.271
01/11/1996	19.25	8.25
01/12/1996	19.145	8.205
01/13/1996	19.04	8.16
01/14/1996	7.483	3.207
01/15/1996	1.855	.795
01/16/1996	8.463	3.627
01/17/1996	13.111	5.619
01/18/1996	13.363	5.726
01/19/1996	19.404	8.316
01/20/1996	19.817	8.493
01/21/1996	20.076	8.604
01/22/1996	20.489	8.781
01/23/1996	20.125	8.625
01/24/1996	19.712	8.448
01/25/1996	22.344	9.576
01/26/1996	28.952	12.408
01/27/1996	29.155	12.495
01/28/1996	29.211	12.519
01/29/1996	29.155	12.495
01/30/1996	29.106	12.474
01/31/1996	30.191	12.939
02/01/1996	27.405	11.745
02/02/1996	30.135	12.915
02/03/1996	30.191	12.939
02/04/1996	29.932	12.828
02/05/1996	29.624	12.696
02/06/1996	29.624	12.696
02/07/1996	29.155	12.495
02/08/1996	28.952	12.408
02/09/1996	28.742	12.318
02/10/1996	28.28	12.12
02/11/1996	8.26	3.54
02/12/1996	19.145	8.205
02/13/1996	28.231	12.099
02/14/1996	28.434	12.186
02/15/1996	28.385	12.165
02/16/1996	27.916	11.964
02/17/1996	2.324	.996
02/18/1996	1.19	.51
02/19/1996	8.099	3.471
02/20/1996	8.568	3.672
02/21/1996	2.268	.972
02/22/1996	6.244	2.676
02/23/1996	8.463	3.627
02/24/1996	10.22	4.38
02/25/1996	--	--
02/26/1996	7.175	3.075
02/27/1996	11.095	4.755
02/28/1996	20.335	8.715
02/29/1996	25.802	11.058
03/01/1996	.616	.264
03/02/1996	--	--

Appendix 4. Average discharge outflows in 1996 at two withdrawal structures at the Dix River Dam—*Continued*

[These data were input into CE-QUAL-W2; --, recording equipment malfunction]

Date	Discharge (gate elevations at 532 feet above sea level)	Discharge (gate elevations at 584 feet above sea level)	Date	Discharge (gate elevations at 532 feet above sea level)	Discharge (gate elevations at 584 feet above sea level)
03/03/1996	3.304	1.416	04/04/1996	3.766	1.614
03/04/1996	20.279	8.691	04/05/1996	17.647	7.563
03/05/1996	12.593	5.397	04/06/1996	4.389	1.881
03/06/1996	19.922	8.538	04/07/1996	4.13	1.77
03/07/1996	28.588	12.252	04/08/1996	7.28	3.12
03/08/1996	27.972	11.988	04/09/1996	21.777	9.333
03/09/1996	27.818	11.922	04/10/1996	7.532	3.228
03/10/1996	28.077	12.033	04/11/1996	3.409	1.461
03/11/1996	28.28	12.12	04/12/1996	--	--
03/12/1996	28.231	12.099	04/13/1996	--	--
03/13/1996	28.077	12.033	04/14/1996	--	--
03/14/1996	27.916	11.964	04/15/1996	2.373	1.017
03/15/1996	27.762	11.898	04/16/1996	7.532	3.228
03/16/1996	27.559	11.811	04/17/1996	.105	.045
03/17/1996	27.503	11.787	04/18/1996	--	--
03/18/1996	27.349	11.721	04/19/1996	--	--
03/19/1996	27.195	11.655	04/20/1996	--	--
03/20/1996	27.146	11.634	04/21/1996	--	--
03/21/1996	27.195	11.655	04/22/1996	20.797	8.913
03/22/1996	27.195	11.655	04/23/1996	26.992	11.568
03/23/1996	20.594	8.826	04/24/1996	12.95	5.55
03/24/1996	--	--	04/25/1996	7.791	3.339
03/25/1996	19.971	8.559	04/26/1996	20.384	8.736
03/26/1996	27.349	11.721	04/27/1996	10.066	4.314
03/27/1996	14.35	6.15	04/28/1996	--	--
03/28/1996	18.319	7.851	04/29/1996	8.309	3.561
03/29/1996	14.504	6.216	04/30/1996	--	--
03/30/1996	--	--	05/01/1996	21.315	9.135
03/31/1996	--	--	05/02/1996	13.573	5.817
04/01/1996	17.031	7.299	05/03/1996	19.817	8.493
04/02/1996	9.548	4.092	05/04/1996	--	--
04/03/1996	7.175	3.075	05/05/1996	--	--

Appendix 4. Average discharge outflows in 1996 at two withdrawal structures at the Dix River Dam—*Continued*

[These data were input into CE-QUAL-W2; --, recording equipment malfunction]

Date	Discharge (gate elevations at 532 feet above sea level)	Discharge (gate elevations at 584 feet above sea level)	Date	Discharge (gate elevations at 532 feet above sea level)	Discharge (gate elevations at 584 feet above sea level)
05/06/1996	11.718	5.022	06/07/1996	38.279	1.823
05/07/1996	10.164	4.356	06/08/1996	14.528	1.648
05/08/1996	21.105	9.045	06/09/1996	15.312	1.458
05/09/1996	28.952	12.408	06/10/1996	14.385	1.269
05/10/1996	11.305	4.845	06/11/1996	13.279	1.067
05/11/1996	--	--	06/12/1996	31.059	1.513
05/12/1996	--	--	06/13/1996	21.007	9.003
05/13/1996	--	--	06/14/1996	37.145	8.683
05/14/1996	--	--	06/15/1996	35.715	8.018
05/15/1996	--	--	06/16/1996	33.088	7.272
05/16/1996	--	--	06/17/1996	28.703	6.512
05/17/1996	13.986	5.994	06/18/1996	20.069	3.823
05/18/1996	19.349	3.015	06/19/1996	35.801	3.58
05/19/1996	22.562	3.377	06/20/1996	27.619	2.367
05/20/1996	18.72	2	06/21/1996	18.368	1.574
05/21/1996	6.12	1.08	06/22/1996	--	--
05/22/1996	9.027	1.146	06/23/1996	6.762	2.898
05/23/1996	.882	.706	06/24/1996	6.293	2.697
05/24/1996	.558	.382	06/25/1996	--	--
05/25/1996	.12	.02	06/26/1996	10.066	4.314
05/26/1996	.2	.1	06/27/1996	--	--
05/27/1996	--	.005	06/28/1996	8.673	3.717
05/28/1996	.01	.094	06/29/1996	7.329	3.141
05/29/1996	.023	.198	06/30/1996	--	--
05/30/1996	1.665	.257	07/01/1996	.875	.375
05/31/1996	2.361	.231	07/02/1996	--	--
06/01/1996	9.75	.292	07/03/1996	--	--
06/02/1996	10.487	.18	07/04/1996	--	--
06/03/1996	10.984	.168	07/05/1996	--	--
06/04/1996	12.285	5.265	07/06/1996	--	--
06/05/1996	28.123	2.411	07/07/1996	--	--
06/06/1996	40.251	2.433	07/08/1996	--	--

Appendix 4. Average discharge outflows in 1996 at two withdrawal structures at the Dix River Dam—*Continued*

[These data were input into CE-QUAL-W2; --, recording equipment malfunction]

Date	Discharge (gate elevations at 532 feet above sea level)	Discharge (gate elevations at 584 feet above sea level)	Date	Discharge (gate elevations at 532 feet above sea level)	Discharge (gate elevations at 584 feet above sea level)
07/09/1996	--	--	08/10/1996	0.045	0.01
07/10/1996	--	--	08/11/1996	.05	.05
07/11/1996	--	--	08/12/1996	.143	.072
07/12/1996	--	--	08/13/1996	.137	.066
07/13/1996	--	--	08/14/1996	24.08	4.885
07/14/1996	--	--	08/15/1996	12.887	2.699
07/15/1996	9.527	4.083	08/16/1996	30.188	5.308
07/16/1996	7.16	2.166	08/17/1996	.111	.042
07/17/1996	15.942	3.854	08/18/1996	.104	.036
07/18/1996	27.404	5.593	08/19/1996	26.372	3.478
07/19/1996	162.562	.57	08/20/1996	10.164	4.356
07/20/1996	610.566	62.489	08/21/1996	7.532	3.228
07/21/1996	262.303	43.717	08/22/1996	12.334	5.286
07/22/1996	1.56	.134	08/23/1996	9.289	3.981
07/23/1996	1.114	2.387	08/24/1996	--	--
07/24/1996	18.788	8.052	08/25/1996	--	--
07/25/1996	26.608	7.653	08/26/1996	--	--
07/26/1996	24.334	6.999	08/27/1996	--	--
07/27/1996	27.609	6.317	08/28/1996	5.782	2.478
07/28/1996	26.292	5.672	08/29/1996	7.637	3.273
07/29/1996	22.164	5.028	08/30/1996	--	--
07/30/1996	11.605	2.124	08/31/1996	--	--
07/31/1996	20.116	2.73	09/01/1996	--	--
08/01/1996	27.823	3.112	09/02/1996	--	--
08/02/1996	20.692	8.868	09/03/1996	--	--
08/03/1996	51.897	4.236	09/04/1996	7.378	3.162
08/04/1996	47.33	3.864	09/05/1996	8.827	3.783
08/05/1996	53.684	3.486	09/06/1996	10.528	4.512
08/06/1996	30.273	3.177	09/07/1996	6.916	2.964
08/07/1996	23.533	2.831	09/08/1996	7.378	3.162
08/08/1996	11.9	1.641	09/09/1996	10.423	4.467
08/09/1996	.033	.012	09/10/1996	12.95	5.55

Appendix 4. Average discharge outflows in 1996 at two withdrawal structures at the Dix River Dam—*Continued*

[These data were input into CE-QUAL-W2; --, recording equipment malfunction]

Date	Discharge (gate elevations at 532 feet above sea level)	Discharge (gate elevations at 584 feet above sea level)	Date	Discharge (gate elevations at 532 feet above sea level)	Discharge (gate elevations at 584 feet above sea level)
09/11/1996	7.483	3.207	10/13/1996	--	--
09/12/1996	15.582	6.678	10/14/1996	--	--
09/13/1996	17.388	7.452	10/15/1996	8.512	3.648
09/14/1996	19.558	8.382	10/16/1996	7.637	3.273
09/15/1996	18.627	7.983	10/17/1996	--	--
09/16/1996	19.404	8.316	10/18/1996	--	--
09/17/1996	17.962	7.698	10/19/1996	--	--
09/18/1996	18.683	8.007	10/20/1996	--	--
09/19/1996	18.165	7.785	10/21/1996	--	--
09/20/1996	17.444	7.476	10/22/1996	--	--
09/21/1996	16.408	7.032	10/23/1996	--	--
09/22/1996	--	--	10/24/1996	--	--
09/23/1996	17.857	7.653	10/25/1996	5.215	2.235
09/24/1996	17.962	7.698	10/26/1996	--	--
09/25/1996	--	--	10/27/1996	--	--
09/26/1996	4.9	2.1	10/28/1996	--	--
09/27/1996	3.507	1.503	10/29/1996	--	--
09/28/1996	16.359	7.011	10/30/1996	--	--
09/29/1996	28.952	12.408	10/31/1996	--	--
09/30/1996	28.798	12.342	11/01/1996	11.718	5.022
10/01/1996	24.773	10.617	11/02/1996	18.375	7.875
10/02/1996	19.04	8.16	11/03/1996	18.375	7.875
10/03/1996	17.234	7.386	11/04/1996	16.772	7.188
10/04/1996	17.962	7.698	11/05/1996	6.706	2.874
10/05/1996	7.483	3.207	11/06/1996	--	--
10/06/1996	--	--	11/07/1996	5.215	2.235
10/07/1996	11.97	5.13	11/08/1996	--	--
10/08/1996	12.334	5.286	11/09/1996	--	--
10/09/1996	9.751	4.179	11/10/1996	--	--
10/10/1996	--	--	11/11/1996	--	--
10/11/1996	--	--	11/12/1996	--	--
10/12/1996	--	--	11/13/1996	--	--

Appendix 4. Average discharge outflows in 1996 at two withdrawal structures at the Dix River Dam—*Continued*

[These data were input into CE-QUAL-W2; --, recording equipment malfunction]

Date	Discharge (gate elevations at 532 feet above sea level)	Discharge (gate elevations at 584 feet above sea level)	Date	Discharge (gate elevations at 532 feet above sea level)	Discharge (gate elevations at 584 feet above sea level)
11/14/1996	--	--	12/08/1996	--	--
11/15/1996	--	--	12/09/1996	18.27	7.83
11/16/1996	--	--	12/10/1996	--	--
11/17/1996	--	--	12/11/1996	18.116	7.764
11/18/1996	--	--	12/12/1996	18.473	7.917
11/19/1996	--	--	12/13/1996	18.837	8.073
11/20/1996	--	--	12/14/1996	17.493	7.497
11/21/1996	--	--	12/15/1996	--	--
11/22/1996	--	--	12/16/1996	13.265	5.685
11/23/1996	--	--	12/17/1996	20.748	8.892
11/24/1996	--	--	12/18/1996	29.211	12.519
11/25/1996	--	--	12/19/1996	29.316	12.564
11/26/1996	--	--	12/20/1996	29.155	12.495
11/27/1996	--	--	12/21/1996	29.001	12.429
11/28/1996	--	--	12/22/1996	26.628	11.412
11/29/1996	--	--	12/23/1996	19.509	8.361
11/30/1996	--	--	12/24/1996	20.02	8.58
12/01/1996	28.49	12.21	12/25/1996	29.155	12.495
12/02/1996	28.693	12.297	12/26/1996	24.773	10.617
12/03/1996	28.539	12.231	12/27/1996	20.076	8.604
12/04/1996	28.798	12.342	12/28/1996	20.02	8.58
12/05/1996	28.952	12.408	12/29/1996	19.922	8.538
12/06/1996	27.454	11.766	12/30/1996	22.603	9.687
12/07/1996	18.578	7.962	12/31/1996	16.618	7.122

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