WATER-QUALITY ASSESSMENT OF WHITE RIVER BETWEEN LAKE SEQUOYAH AND BEAVER RESERVOIR, WASHINGTON COUNTY, ARKANSAS

By J. E. Terry, E. E. Morris, and C. T. Bryant

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION TABLE

Multiply given units	By	To obtain desired units
cubic feet per second (ft^3/s)	0.6463	million gallons per day (Mgal/d)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
feet per second (ft/s)	0.6818	miles per hour (mi/h)
foot (ft)	0.3048	meter (m)
gallon (gal)	3.785	liter (L)
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
pound (lb)	0.454	kilogram (kg)
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)

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discharge (ft^3/s) x concentration (mg/L) x 5.3896 = total load of constituent (lb/d)

° Fahrenheit = 9/5(° C)+32 ° Celsius = 5/9(° F-32)

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ABSTRACT

A study was made of the White River between Lake Sequoyah and Beaver Lake to determine the quality of the river under existing conditions and how the effluent from the Fayetteville municipal wastewater-treatment plant, the only point source discharger of waste effluent to the river, affects this quality. A steady-state digital model was calibrated and used as a tool for simulating changes in nutrient loading. Under relatively low-flow conditions the White River downstream from the Fayetteville wastewater-treatment plant is dominated by the waste discharge. Because the treatment plant discharge is unsteady, a composite of two independent, synoptic data sets was used to calibrate the model in an effort to simulate "average" steady-state conditions.

Data collected during synoptic surveys downstream from the wastewater-treatment plant indicate that temperature, dissolved oxygen, dissolved solids, un-ionized ammonia, total phosphorus, and floating solids and depositable materials did not meet Arkansas stream standards.

Nutrient loadings downstream from the treatment plant result in dissolved-oxygen concentrations as low as 0.0 milligrams per liter. Biological surveys found low macroinvertebrate organism diversity and numerous dead fish.

Computed dissolved-oxygen deficits indicate that benthic demands are the most significant oxygen sinks in the river downstream from the wastewater-treatment plant. Benthic oxygen demands range from 2.8 to 11.0 grams per square meter per day.

Model projections indicate that for 7-day 10-year low-flow conditions and water temperatures of 29° Celsius, daily average dissolved-oxygen concentrations of 6.0 milligrams per liter can be maintained downstream from the wastewater-treatment plant if effluent concentrations of ultimate carbonaceous biochemical oxygen demand and ammonia nitrogen are 7.5 (5.0 5-day demand) and 2 milligrams per liter respectively. Model sensitivity analyses indicate that dissolved-oxygen concentrations were most sensitive to changes in stream temperature.

INTRODUCTION

Purpose and Scope

The upper White River, the receiving stream for Fayetteville's wastewater-treatment plant (WWTP) effluent, was selected by the Arkansas Department of Pollution Control and Ecology for an intensive water-quality study to determine the assimilative capacity of the river. This choice was based on Environmental Protection Agency Program Requirements Memorandum (PRM) 79-7 which sets forth policy and procedures for review of wastewater-treatment projects that involve advanced secondary treatment (AST) or advanced waste treatment (AWT). Environmental Protection Agency Region 6 guidelines indicate that a steady-state digital water quality model must be used to determine the assimilative capacity of a perennial stream into which an effluent greater than 3 cubic feet per second (ft^3/s) is discharged.

The study was conducted to assess the current effects of the Fayetteville WWTP upon the dissolved oxygen (DO) regime and biological community in the river. In addition, digital modeling techniques were to be used to determine the maximum effluent loadings to the river that would not reduce daily average river DO concentrations below the Arkansas standard (Arkansas Department of Pollution Control and Ecology, 1975) of 6 milligrams per liter (mg/L). The study was to be completed within a 9-month period.

Study-Area Description

The upper White River, at river mile 673.8, drains a 560 square-mile (mi^2) area (Sullavan, 1974) in northwest Arkansas (fig. 1) and flows generally northward into Beaver Reservoir. Annual precipitation is approximately 50 inches, and the average annual runoff for streams in the area is 1.1 cubic feet per square mile (Lamonds, 1972). The area is underlain by limestone, chert, and some beds of shale and sandstone (Lamonds, 1972).

The segment of river chosen for this study originates downstream from Lake Sequoyah (river-mile 684.8) and terminates at Beaver Reservoir (river-mile 673.8). Lake Sequoyah is a former water supply lake for the city of Fayetteville with a drainage area of 275 mi^2 (Sullavan, 1974). Principal tributaries in this segment are West Fork White River, drainage area 125 mi^2, and Richland Creek, drainage area 143 mi^2 (Sullavan, 1974).

The study area has moderate topographic relief characterized by gently rolling hills and stream valleys. The river has a gradient ranging from 4.2 feet per mile downstream from Lake Sequoyah to 6.9 feet per mile near Beaver Reservoir. It is characterized by numerous large pools separated by short, shallow riffles.

The area has a mixture of suburban-type residences and small farms. Agriculture in the area ranges from single family gardens to the commercial raising of cattle, hogs, chickens, soybeans, and feed grains. The river is a source of irrigation water for soybeans and feed grains.

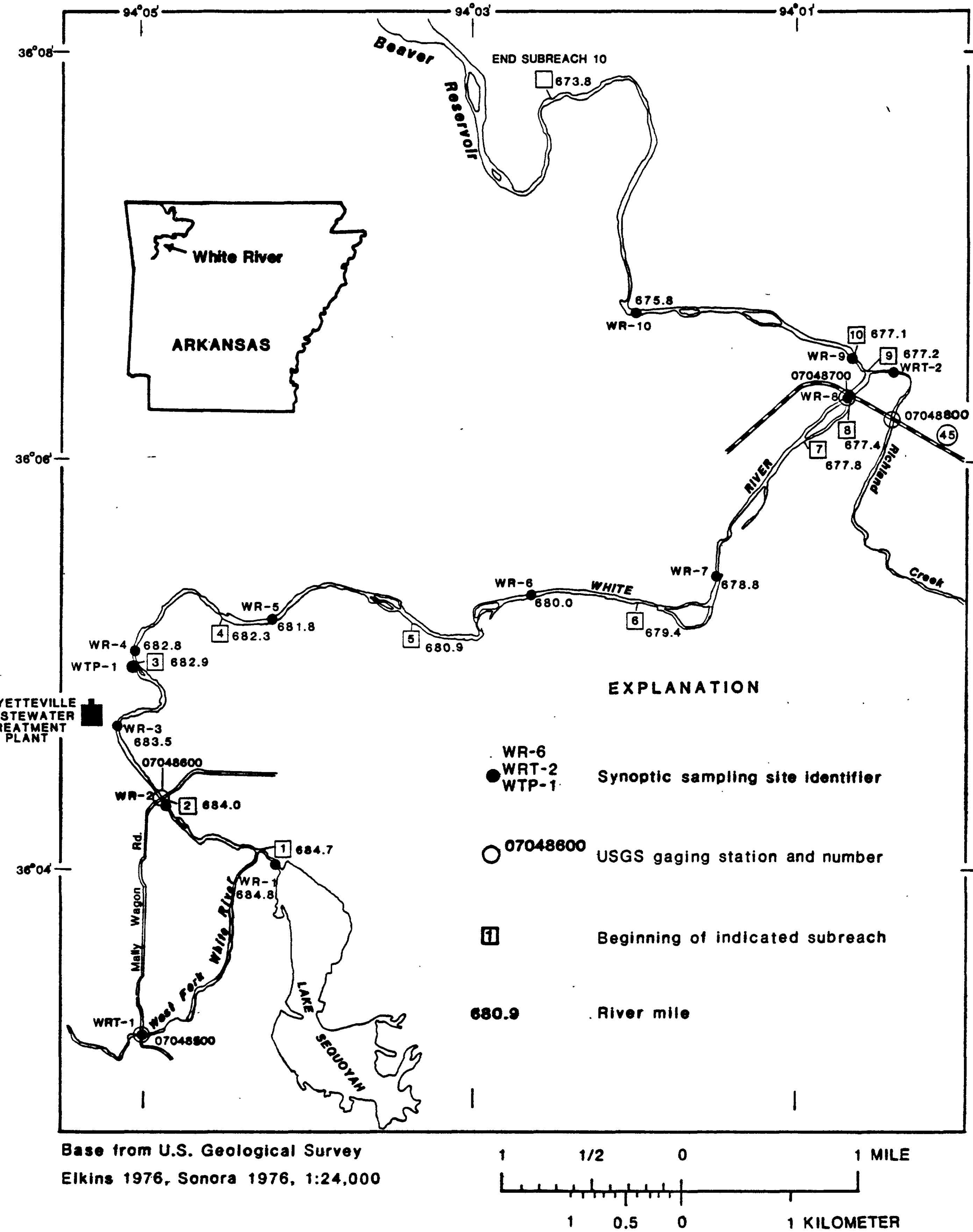


Figure 1.—Map showing upper White River basin sampling stations and subreach designations.

DATA COLLECTION

Two synoptic water samplings of White River were conducted in 1980. One sampling was made during September 24-25, 1980, the other during October 7-8, 1980. During each period of sampling, two grab water samples were collected at each of 13 sites (fig. 1). Each sampling site is located by an alphanumeric identifier. Sites designated with a WR-# are located on the main stem of the White River; those designated WRT-# are tributary sites; and the single site designated WTP-1 is the discharge pipe for the Fayetteville WWTP. Numbers following the dashes are consecutive for each type of site and are incremented in a downstream direction. Water temperature, DO concentration, pH, and specific conductance measurements were made each time water samples were collected. Additional temperature and DO measurements were obtained at night and near sunrise, both by individual measurements and by use of a continuous monitor. The water samples at 12 of the sampling sites were analyzed for fecal-coliform populations, nutrients, ultimate carbonaceous biochemical oxygen demand (CBODU), chlorophyll and content in phytoplankton, and suspended solids. Bed-material samples were collected at the 12 sites for determination of streambed oxygen demand. Samples from the Fayetteville WWTP were not analyzed for phytoplankton chlorophyll and or streambed oxygen demand. All samples were analyzed by the U.S. Geological Survey. Procedures described by Jennings and Bauer (1976), Greeson and others (1977), Skougstad and others (1979), Erdman, and Duncan (1979), Nolan and Johnson (1979), and Pickering (written commun., 1980) were used. A water-discharge measurement was made at each sampling site following the procedures of Buchanan and Somers (1969).

A comparative biological survey was conducted at two sites, one above and one below the Fayetteville WWTP, on October 7-8, 1980. Samples were collected to determine phytoplankton, benthic invertebrate, and fish population densities and taxonomic identification (Greeson and others, 1977).

In addition to the numerous cross-sectional areas determined during discharge measurements, the entire river segment was either waded or floated by boat to measure river widths and depths and pool-to-riffle ratios. The discharge measurements were used, along with releases of rhodamine WT dye, to determine time of travel and mean velocity on three river reaches, using methods described by Wilson (1968), Kilpatrick (1970), Yotsukura and Cobb (1972), and Bauer, Rathbun, and Lowham (1979). Effluent discharges during the sampling periods were determined by use of continuous flow charts provided by the Fayetteville WWTP.

SURFACE-WATER HYDROLOGY

The White River between river-mile 684.8, just downstream from Lake Sequoyah, to river-mile 673.8, near the headwaters of Beaver Reservoir, is a pool-and-riffle stream with channel slopes ranging from 6.9 to 4.2 to 6.9 feet per mile in a downstream direction. Under low-flow conditions the river is characterized by short riffles of varying width and long, deep pools.

During the sampling period September 24-25, 1980, discharges in the main stem of the White River increased from 0.91 ft^3/s at WR-1 to 22.4 ft^3/s at WR-10. During the October 7-8 sampling period discharge increased from 0.73 ft^3/s at WR-1 to 17 ft^3/s at WR-10 (table 1). For both periods, mean river depths varied from 1.3 to 4.8 feet through the reach of interest.

Under low-flow conditions, the flow characteristics of the White River downstream from the Fayetteville WWTP are dominated by the discharge from the treatment plant. For the two sampling periods, discharges at stations WR-3 and WTP-1 (table 2) indicate that, using daily averages, 65 to 90 percent of the river discharge downstream from the treatment plant is waste effluent.

The quantity of water discharged from the Fayetteville WWTP is not steady (fig. 2). Flows vary as much as 100 percent in a 24-hour period. Significant differences in discharges measured on the same day at river-sampling sites downstream from the treatment plant (table 2) are a reflection of changes in effluent flow from the plant.

Mean velocities for selected reaches of the river were estimated using dye tracers during both the September and October sampling periods. Travel times and mean velocities for these reaches are given in table 1. The measured velocities are small, ranging from 0.031 to 0.097 foot per second.

The 7-day 10-year low flows ($Q_{7/10}$) (modified from Hines, 1975) at stations 07048500, West Fork White River near Fayetteville; 07048600, White River near Fayetteville; and 07048800, Richland Creek at Goshen (fig. 1) are 0.3, 1.6, and 0.1 ft^3/s, respectively. Observed discharges in West Fork and the main stem of the White River upstream from the Fayetteville WWTP during the October sampling period (table 2) were less than the $Q_{7/10}$. Estimates of low-flow frequency for the White River are questionable because of the control of Lake Sequoyah and the continuous discharge from the Fayetteville WWTP.

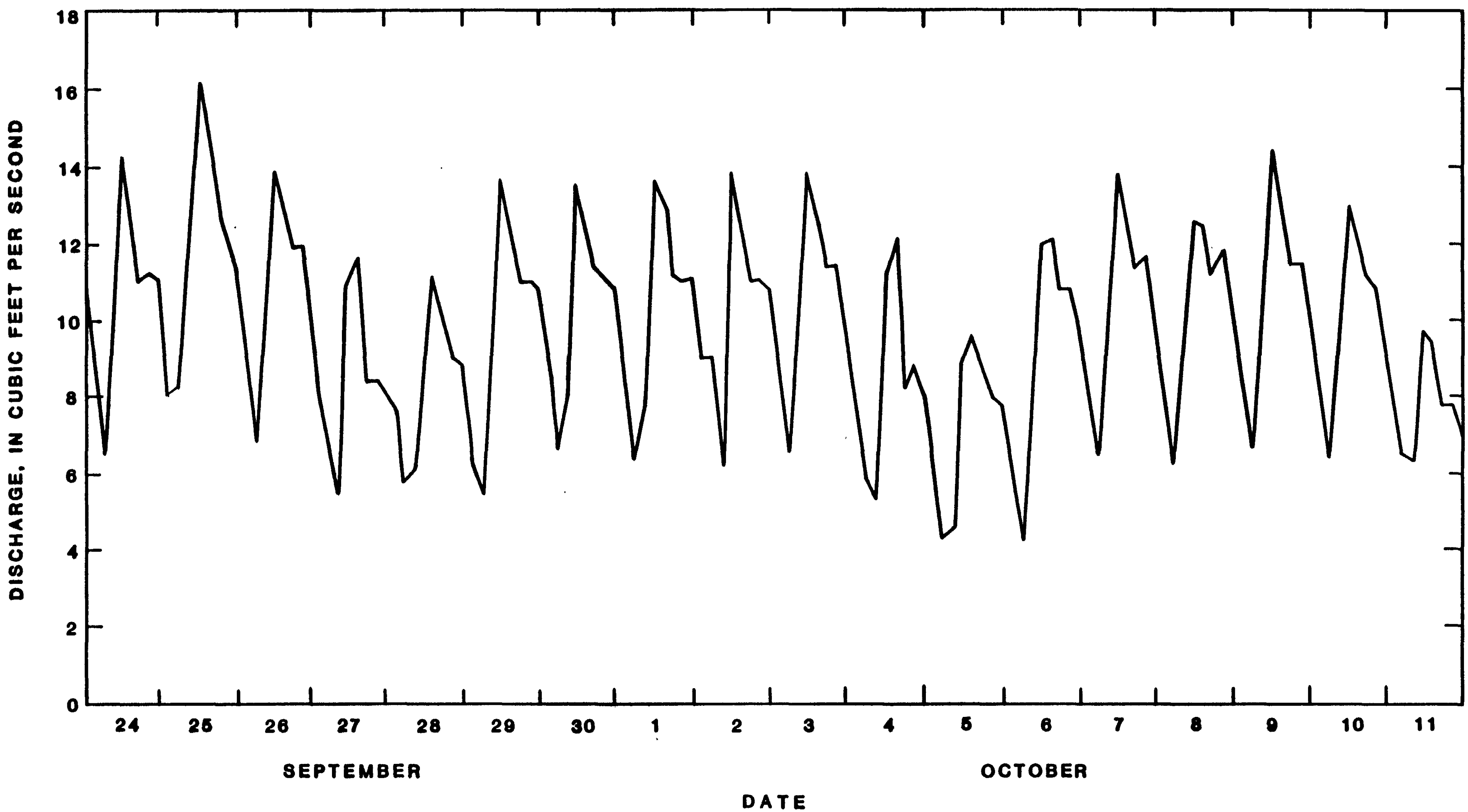


Figure 2.—Discharge hydrograph from the Fayetteville wastewater-treatment plant, from September 24 to October 11, 1980.

Table 1.--Measured traveltime and mean velocity for selected reaches of White River

Beginning mile	Ending mile	Discharge (ft^3/s)	Mean velocity (ft/s)	Travel time (h)
		September 1980		
684.80	684.00	5.4	0.031	37.6
682.91	681.78	15.6	.073	22.5
681.78	679.89	13.6	.087	32.3
678.83	677.86	13.1	.097	14.6
		October 1980		
681.78	679.96	10.4	0.073	36.6
679.96	678.86	11.1	.051	31.4

WATER QUALITY

Water-quality data collected in the study area during September 24-25 and October 7-8, 1980, are presented in table 2. Data collected at some sampling sites both upstream and downstream from the Fayetteville WWTP indicate that Arkansas water quality standards, (Arkansas Department of Pollution Control and Ecology, 1975) are not being met for the following constituents: temperature, DO, dissolved solids, total phosphorus, and the combined standard of solids, floating material, and deposits. In addition, the U.S. Environmental Protection Agency's criterion (1976) limits un-ionized ammonia (NH_3) to a maximum of 0.02 milligram per liter (mg/L) to prevent toxicity to freshwater aquatic life. This criterion was exceeded at all sampling sites downstream from the Fayetteville WWTP except site WR-7. The highest calculated unionized ammonia concentration was 0.095 mg/L as NH_3 (table 3, USEPA, 1976), at site WR-5.

Physical Characteristics

Physical water-quality characteristics measured during the study were suspended solids, water temperature, and specific conductance, along with visual observations of solids, floating material, and deposits.

Suspended Solids

Suspended solids generally can be related to stream turbidity. There are several sources of suspended solids in streams. 1) sediment washed off the watershed, 2) sediment scoured from the streambed, 3) particulate matter discharged by a WWTP, 4) and algal growth derived from dissolved nutrients in the water. Concentrations of suspended solids in a stream vary as new sources are added, as particles are deposited or resuspended, and as organic matter is produced and consumed. Turbidity, or light penetration, depends upon these concentrations and the type of suspended material. Suspended-solids concentrations on the river ranged from 1 mg/L at station WR-2 to 58 mg/L at station WR-4. Concentrations in the Fayetteville WWTP effluent ranged from 18 to 120 mg/L suspended solids. The State permit for the Fayetteville WWTP effluent states that suspended solids shall not exceed 30 mg/L as a maximum monthly average.

Water Temperature

Typically, surface-water temperature varies continually in response to changes in solar radiation and changing seasons. Temperature is highest in the late afternoon and lowest in the early morning. Seasonal temperature is highest in July, August, and September and lowest in December and January. High water temperatures lower the solubility of oxygen, increase the rates of oxygen-consuming reactions, and increase photosynthetic-oxygen production. Water temperature in the main stem of White River during the study period ranged from 13.5 to 26.0° C (table 3). Historical records show a maximum value of 30.5° C during July 1978 for site WR-2.

Table 2.--Chemical, physical, and bacteriological analyses, White River, tributary streams, and waste effluent

[Five digit numbers in parenthesis are storet parameter codes used for computer storage of data]

Site	River mile	Date of collection	Time of collection	Discharge (ft^3/s) (00061)	Specific conductance (µmhos/cm @ 25° C) (00095)	pH (00400)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)	Temperature (° C) (00010)	Ultimate carbonaceous biochemical oxygen demand (mg/L) (00320)	Base *e* deoxygenation rate for carbonaceous biochemical oxygen demand (day^{-1} @ 20° C) (82133)
WR-1	684.8	9-24-80	0940	0.91	206	7.0	3.2	36	21.0	17	0.046
		9-24-80	1620	.91	200	7.0	4.5	52	23.5	8.4	.004
		10- 7-80	0730	.73	198	7.1	3.7	38	17.5	22	.140
		10- 7-80	1740	.73	205	7.2	7.8	90	23.0	15	.313
WRT-1	684.7	9-24-80	1010	1.95	275	7.2	4.7	52	21.0	11	.219
		9-24-80	1650	4.21	280	7.3	6.4	74	23.0	4.8	.039
		10- 7-80	0750	.08	365	7.4	8.5	86	16.0	18	.189
		10- 7-80	1720	.08	360	7.3	9.3	102	20.5	7.1	.495
WR-2	684.0	9-24-80	1045	3.9	108	7.4	4.9	55	21.5	13	.087
		9-24-80	1730	6.96	124	7.2	5.6	64	23.0	5.6	-----
		10- 7-80	0810	.85	132	7.4	6.1	59	14.5	15	.562
		10- 7-80	1850	.85	129	7.5	6.4	69	19.0	15	.661
WR-3	683.5	9-24-80	1100	5.23	109	7.4	5.8	66	22.0	20	.123
		9-24-80	1755	8.29	90	7.3	7.4	86	23.5	15	.036
		10- 7-80	0830	1.06	103	7.4	8.5	84	15.5	21	.660
		10- 7-80	1600	1.08	105	7.4	10.4	116	21.0	13	.325
WTP-1	682.9	9-24-80	1137	14.3	600	7.3	8.4	101	25.5	100	.123
		9-24-80	1830	10.8	650	7.1	8.3	102	27.0	72	.060
		10- 7-80	0840	8.2	578	7.0	9.1	107	24.0	160	.100
		10- 7-80	1655	11.5	590	7.1	8.2	99	25.5	190	.171

Table 2.--Chemical, physical, and bacteriological analyses, White River, tributary streams, and waste effluent--Continued

Site	Date of collection	Time of collection	Streambed oxygen demand $(g/m^2)/d$ @ 21° C)	Total organic nitrogen (mg/L as N) (00605)	Total ammonia (mg/L as N) (00610)	Total nitrite (mg/L as N) (00615)	Total nitrate (mg/L as N) (00620)	Total orthophosphate (mg/L as P) (70507)	Total phosphorus (mg/L as P) (00665)
WR-1	9-24-80	0940	3.8	0.70	1.1	0.01	0.00	0.00	0.08
	9-24-80	1620	---	.60	1.1	.01	.01	.00	.07
	10- 7-80	0730	4.1	.92	.88	.01	.17	.11	.11
	10- 7-80	1740	---	1.9	.99	.02	.18	.02	.06
WRT-1	9-24-80	1010	---	1.1	.14	.01	.06	.02	.13
	9-24-80	1650	---	.88	.08	.00	.05	.03	.10
	10- 7-80	0750	---	2.6	.07	.00	.00	.21	.21
	10- 7-80	1720	---	1.2	.09	.00	.00	.00	.04
WR-2	9-24-80	1045	2.1	.69	.16	.01	.16	.00	.05
	9-24-80	1730	---	.69	.19	.02	.27	.00	.04
	10- 7-80	0810	4.5	.78	.22	.01	.20	.10	.21
	10- 7-80	1850	---	.41	.54	.02	.44	.06	.10
WR-3	9-24-80	1100	2.5	1.2	.03	.02	.03	.00	.16
	9-24-80	1755	---	.93	.01	.01	.12	.00	.09
	10- 7-80	0830	4.3	.99	.11	.01	.03	.00	.09
	10- 7-80	1600	---	1.2	.09	.01	.02	.00	.10
WTP-1	9-24-80	1137	---	5.1	4.4	.12	2.3	7.5	7.5
	9-24-80	1830	---	5.3	4.7	.19	1.5	6.4	7.7
	10- 7-80	0840	---	13.0	5.8	.04	4.3	8.5	14.0
	10- 7-80	1655	---	35.0	4.3	.18	2.2	10.0	19.0

Table 2.--Chemical, physical, and bacteriological analyses, White River, tributary streams, and waste effluent--Continued

Site	Date of collection	Time of collec-tion	Coliform, fecal[1] (colonies per 100 mL) (31625)	Suspended solids (residue at 105° C) (00530)	Chlorophyll *a*, phytoplankton, chroma-Fl (µg/L) (70953)	Chlorophyll *b*, phytoplankton chroma-Fl (µg/L) (70954)
WR-1	9-24-80	0940	K330	10	14.5	3.00
	9-24-80	1620	8	10	12.1	2.81
	10- 7-80	0730	K11	35	10.9	3.33
	10- 7-80	1740	K17	29	8.72	3.39
WRT-1	9-24-80	1010	K130	22	8.56	.870
	9-24-80	1650	240	26	10.9	1.90
	10- 7-80	0750	K78	13	21.8	8.06
	10- 7-80	1720	210	7	14.1	7.01
WR-2	9-24-80	1045	<100	6	3.97	.780
	9-24-80	1730	5	1	12.1	2.81
	10- 7-80	0810	<11	7	.540	.000
	10- 7-80	1850	10	9	.440	.000
WR-3	9-24-80	1100	2,900	14	24.6	7.95
	9-24-80	1755	<33	15	2.30	2.57
	10- 7-80	0830	280	30	13.0	.00
	10- 7-80	1600	K53	48	16.9	3.97
WTP-1	9-24-80	1137	<100	18	------	-----
	9-24-80	1830	<2	22	------	-----
	10- 7-80	0840	<11	38	------	-----
	10- 7-80	1655	K40	120	------	-----

See footnote at end of table.

Table 2.--Chemical, physical, and bacteriological analyses, White River, tributary streams, and waste effluent--Continued

Site	River mile	Date of collection	Time of collection	Discharge (ft^3/s) (00061)	Specific conductance (µmhos/cm at 25° C) (00095)	pH (00400)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)	Temperature (° C) (00010)	Ultimate carbonaceous biochemical oxygen demand (mg/L) (00320)	Base *e* deoxygenation rate for carbonadeous biochemical oxygen demand (day^{-1} @ 20° C) (82133)
WR-4	682.8	9-24-80	1120	14.1	560	7.2	5.9	70	25.0	52	0.007
		9-24-80	1810	17.8	470	7.2	4.5	55	26.0	24	.097
		10- 7-80	0913	11.7	520	7.0	4.9	56	22.0	51	.122
		10- 7-80	1700	9.29	550	7.0	3.9	45	23.5	120	.163
WR-5	681.8	9-24-80	1130	-----	525	7.3	2.5	29	23.0	31	.126
		9-24-80	1815	15.3	540	7.2	2.0	24	26.0	30	.052
		10- 7-80	0945	8.34	560	7.1	0.2	2	18.5	66	.213
		10- 7-80	1835	12.6	555	7.1	.0	0	22.5	44	.219
WR-6	680.0	9-24-80	1100	11.5	395	7.4	3.4	39	22.5	9.6	.107
		9-24-80	1745	15.6	415	7.3	5.3	62	23.5	18	.038
		10- 7-80	0925	11.1	275	7.2	1.0	10	17.0	11	.240
		10- 7-80	1815	9.74	328	7.2	1.7	19	20.5	8.5	.175
WR-7	678.8	9-24-80	1030	13.8	265	7.4	2.9	33	22.0	6.4	.157
		9-24-80	1715	12.4	260	7.3	7.4	86	23.5	7.3	.146
		10- 7-80	0900	12.9	272	7.3	2.0	21	17.0	13	.096
		10- 7-80	1718	10.6	265	7.3	6.4	71	21.0	6.2	.283
WR-8	677.4	9-24-80	0930	13.6	230	7.4	4.7	53	21.5	6.7	.101
		9-24-80	1615	12.7	225	7.3	7.4	86	23.5	6.2	.151
		10- 7-80	0820	12.0	420	7.4	1.2	12	17.0	19	.075
		10- 7-80	1820	12.0	342	7.4	6.3	68	20.0	6.2	.266

Table 2.--Chemical, physical, and bacteriological analyses, White River, tributary streams, and waste effluent--Continued

Site	Date of collection	Time of collection	Streambed oxygen demand $(g/m^2)/d$ @ 21° C)	Total organic nitrogen (mg/L as N) (00605)	Total ammonia (mg/L as N) (00610)	Total nitrite (mg/L as N) (00615)	Total nitrate (mg/L as N) (00620)	Total orthophosphate (mg/L as P) (70507)	Total phosphorus (mg/L as P) (00665)
WR-4	9-24-80	1120	3.7	4.7	4.9	0.13	1.5	6.9	7.9
	9-24-80	1810	---	2.6	4.1	.17	.83	3.9	5.6
	10- 7-80	0913	3.1	14.0	1.3	.07	2.9	7.5	12.0
	10- 7-80	1700	---	37.0	4.4	.13	1.7	9.1	17.0
WR-5	9-24-80	1130	6.0	2.1	4.2	.48	.82	7.7	8.8
	9-24-80	1815	---	2.4	6.8	.06	.02	7.7	8.7
	10- 7-80	0945	6.0	17.0	1.1	.01	.00	7.9	13.0
	10- 7-80	1835	---	12.0	6.1	.01	.00	8.3	12.0
WR-6	9-24-80	1100	3.5	1.2	3.0	.21	.79	5.9	7.2
	9-24-80	1745	---	1.4	2.4	.17	.67	4.5	6.1
	10- 7-80	0925	3.4	.80	2.8	.01	.00	2.8	4.3
	10- 7-80	1815	---	6.8	3.2	.02	.02	4.0	5.9
WR-7	9-24-80	1030	2.4	1.1	1.2	.14	.77	2.2	3.0
	9-24-80	1715	---	1.1	1.1	.14	.84	2.3	3.1
	10- 7-80	0900	2.8	.90	2.7	.05	.16	2.5	3.8
	10- 7-80	1718	---	1.9	2.2	.08	.29	2.3	3.6
WR-8	9-24-80	0930	1.8	1.3	.27	.15	1.3	1.7	2.2
	9-24-80	1615	---	1.0	.26	.15	1.2	1.6	2.1
	10- 7-80	0820	2.5	7.0	5.0	.03	.13	4.6	6.8
	10- 7-80	1820	---	6.0	3.6	.08	.41	3.3	4.8

Table 2.--Chemical, physical, and bacteriological analyses, White River, tributary, streams and waste effluent--Continued

Site	Date of collection	Time of collection	Coliform, fecal[1] (colonies per 100 mL) (31625)	Suspended solids (residue at 105° C) (00530)	Chlorophyll *a*, phytoplankton, chroma-Fl (µg/L) (70953)	Chlorophyll *b*, phytoplankton chroma-Fl (µg/L) (70954)
WR-4	9-24-80	1120	<100	4	0.680	0.000
	9-24-80	1810	1	6	1.67	.000
	10- 7-80	0913	<11	36	.000	.000
	10- 7-80	1700	>600	58	2.99	.000
WR-5	9-24-80	1130	K400,000	4	13.2	4.11
	9-24-80	1815	<2,000	2	3.23	.570
	10- 7-80	0945	2,400,000	5	6.06	2.85
	10- 7-80	1835	K9,200,000	5	9.09	3.36
WR-6	9-24-80	1100	K900	6	12.7	3.33
	9-24-80	1745	K160	6	22.5	.090
	10- 7-80	0925	K4,700	8	2.41	.880
	10- 7-80	1815	11,000	12	4.42	.000
WR-7	9-24-80	1030	K160	12	19.2	7.04
	9-24-80	1715	K33	12	23.0	5.58
	10- 7-80	0900	K2,900	12	6.54	1.32
	10- 7-80	1718	1,700	8	8.68	2.47
WR-8	9-24-80	0930	110	38	16.3	5.99
	9-24-80	1615	40	6	34.4	10.6
	10- 7-80	0820	K4,400	16	7.85	1.15
	10- 7-80	1820	K2,000	14	19.8	6.36

See footnote at end of table.

Table 2.--Chemical, physical, and bacteriological analyses, White River, tributary streams, and waste effluent--Continued

Site	River mile	Date of collection	Time of collection	Discharge (ft^3/s) (00061)	Specific conductance (µmhos/cm at 25° C) (00095)	pH (00400)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)	Temperature (° C) (00010)	Ultimate carbonaceous biochemical oxygen demand (mg/L) (00320)	Base *e* deoxygenation rate for carbonaceous biochemical oxygen demand (day^{-1} @ 20° C) (82133)
WRT-2	677.2	9-24-80	0945	4.21	250	7.3	7.3	79	20.0	10.3	0.237
		9-24-80	1620	4.11	235	7.6	9.9	114	23.0	16	.047
		10- 7-80	0750	6.23	272	7.7	8.8	89	16.0	20	.140
		10- 7-80	1750	6.19	240	7.5	11.8	128	20.0	4.8	.441
WR-9	677.1	9-24-80	0950	20.0	230	7.5	4.7	53	21.5	4.7	.168
		9-24-80	1630	17.1	232	7.7	7.4	85	23.0	4.7	.157
		10- 7-80	0800	19.5	390	7.6	3.5	36	16.5	17	.122
		10- 7-80	1800	18.2	340	7.6	6.7	73	20.0	6.1	.291
WR-10	675.8	9-24-80	0900	22.4	265	7.4	4.7	53	22.0	4.6	.153
		9-24-80	1600	16.6	255	7.4	6.8	78	23.0	5.6	.118
		10- 7-80	0730	17.0	400	7.5	5.2	54	17.5	17	.092
		10- 7-80	1840	15.7	385	7.5	8.9	97	20.0	9	.257

Table 2.--Chemical, physical, and bacteriological analyses, White River, tributary streams, and waste effluent--Continued

Site	Date of collection	Time of collection	Stream-bed oxygen demand $(g/m^2)/d$ (@ 21° C)	Total organic nitrogen (mg/L as N) (00605)	Total ammonia (mg/L as N) (00610)	Total nitrite (mg/L as N) (00615)	Total nitrate (mg/L as N) (00620)	Total ortho-phos-phate (mg/L as P) (70507)	Total phos-phorus (mg/L as P) (00665)
WRT-2	9-24-80	0945	---	0.43	0.01	0.01	0.49	0.01	0.05
	9-24-80	1620	---	.79	.00	.01	.46	.01	.04
	10- 7-80	0750	---	1.2	.09	.02	1.6	.23	.23
	10- 7-80	1750	---	.76	.09	.02	1.4	.00	.07
WR-9	9-24-80	0950	1.9	1.1	.27	.13	1.2	1.5	2.0
	9-24-80	1630	---	1.1	.13	.09	1.0	1.1	1.6
	10- 7-80	0800	3.1	6.0	4.0	.04	.52	3.6	5.7
	10- 7-80	1800	---	.90	2.8	.08	.77	2.5	4.3
WR-10	9-24-80	0900	1.2	1.0	.49	.17	1.1	1.5	2.0
	9-24-80	1600	---	.90	.30	.14	1.1	1.4	1.7
	10- 7-80	0730	1.6	1.2	2.9	.11	.79	2.3	4.1
	10- 7-80	1840	---	1.6	3.2	.12	.88	2.9	4.8

Table 2.--Chemical, physical, and bacteriological analyses, White River, tributary streams, and waste effluent--Continued

Site	Date of collection	Time of collection	Coliform, fecal[1] (colonies per per 100 mL) (31625)	Suspended solids (residue at 105° C) (00530)	Chlorophyll *a*, phytoplankton, chroma-Fl (μg/L) (70953)	Chlorophyll *b*, phytoplankton chroma-Fl (μg/L) (70954)
WRT-2	9-24-80	0945	K67	16	5.19	1.26
	9-24-80	1620	K110	14	8.36	2.36
	10- 7-80	0750	K44	8	14.5	8.16
	10- 7-80	1750	33	7	25.9	13.4
WR-9	9-24-80	1950	K230	18	8.79	6.59
	9-24-80	1630	K33	9	20.4	5.78
	10- 7-80	0800	K3,200	18	15.9	7.21
	10- 7-80	1800	2,000	19	25.0	10.8
WR-10	9-24-80	0900	110	22	9.13	1.90
	9-24-80	1600	50	22	19.8	8.02
	10- 7-80	0730	930	38	19.2	7.93
	10- 7-80	1840	930	28	45.7	25.4

[1] Number preceded by a "K" indicates that plate count was outside ideal range.

Table 3.--Dissolved-oxygen and temperature data, White River, tributaries, and Fayetteville waste effluent

Site	Date (1980)	Time of collection (hour)	Temperature (° C) (00010)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)
WR-1	Sept. 24	0940	21.0	3.2	36
	Sept. 24	1620	23.5	4.5	52
	Oct. 2	1135	21.0	3.9	43
	Oct. 2	1650	21.0	5.2	58
	Oct. 2	1900	20.0	5.2	57
	Oct. 2	2250	21.0	5.8	64
	Oct. 3	0540	18.0	1.6	17
	Oct. 3	0710	17.0	1.4	14
	Oct. 3	1030	18.0	7.3	77
	Oct. 7	0730	17.5	3.7	39
	Oct. 7	1145	20.0	5.3	58
	Oct. 7	1740	23.0	7.8	90
	Oct. 7	1930	21.0	6.2	69
	Oct. 8	0640	18.0	3.9	41
	Oct. 8	0740	18.0	4.0	42
	Oct. 10	1400	23.0	4.9	56
	Oct. 11	1140	19.0	4.8	52
WRT-1	Sept. 24	1010	21.0	4.7	52
	Sept. 24	1650	23.0	6.4	74
	Oct. 2	1155	20.0	8.0	87
	Oct. 2	1710	21.0	8.6	96
	Oct. 2	1915	20.0	7.9	86
	Oct. 2	2310	19.5	7.9	85
	Oct. 3	0600	15.0	7.0	69
	Oct. 3	0725	15.5	6.0	60
	Oct. 3	1050	16.5	8.6	88
	Oct. 7	0750	16.0	8.5	86
	Oct. 7	1200	17.5	8.1	84
	Oct. 7	1720	20.5	9.3	102
	Oct. 7	2000	20.5	9.3	102
	Oct. 8	0650	17.0	8.6	89
	Oct. 8	0750	17.0	8.2	85
	Oct. 10	1345	21.5	6.7	75
	Oct. 11	1115	17.0	4.7	48
WR-2	Sept. 24	1045	21.5	4.9	55
	Sept. 24	1730	23.0	5.6	64
	Oct. 2	1210	20.5	5.8	64

Table 3.--Dissolved-oxygen and temperature data, White River, tributaries, and Fayetteville waste effluent--Continued

Site	Date (1980)	Time of collection (hour)	Temperature (° C) (00010)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)
WR-2	Oct. 2	1755	18.5	6.2	66
	Oct. 2	1925	18.0	6.0	63
	Oct. 2	2325	18.5	5.6	60
	Oct. 3	0610	15.0	5.7	56
	Oct. 3	0635	15.0	4.9	48
	Oct. 3	1100	17.0	7.3	75
	Oct. 7	0810	14.5	6.1	59
	Oct. 7	1540	23.5	7.0	81
	Oct. 7	1850	19.0	6.4	69
	Oct. 8	0640	16.0	6.0	61
	Oct. 8	0800	16.0	6.1	62
	Oct. 9	0810	14.5	6.1	59
	Oct. 9	1850	19.0	6.4	69
	Oct. 10	1355	23.5	7.2	84
	Oct. 11	1100	13.5	7.0	67
WR-3	Sept. 24	1100	22.0	5.8	66
	Sept. 24	1755	23.5	7.4	86
	Oct. 2	1255	20.0	6.6	72
	Oct. 2	1725	19.5	8.0	86
	Oct. 2	1940	18.0	8.2	86
	Oct. 2	2400	18.0	8.1	85
	Oct. 3	0640	17.0	7.2	74
	Oct. 3	0745	17.0	5.6	58
	Oct. 3	1040	17.0	7.6	78
	Oct. 7	0830	15.5	8.5	85
	Oct. 7	1215	18.5	9.5	101
	Oct. 7	1600	25.0	10.4	124
	Oct. 7	1800	20.5	10.2	112
	Oct. 7	2000	19.0	10.2	110
	Oct. 7	2200	18.0	9.9	104
	Oct. 7	2400	18.5	9.6	102
	Oct. 8	0200	18.0	9.4	99
	Oct. 8	0400	17.5	9.0	94
	Oct. 8	0600	17.5	8.8	92
	Oct. 8	0800	17.0	8.7	90
	Oct. 8	1000	16.5	8.9	91
	Oct. 8	1200	19.5	9.1	98
	Oct. 8	1400	23.0	9.1	105
	Oct. 8	1600	21.0	10.4	116
	Oct. 10	1315	20.0	8.6	93
	Oct. 11	1230	17.5	7.4	77

Table 3.--Dissolved-oxygen and temperature data, White River, tributaries, and Fayetteville waste effluent--Continued

Site	Date (1980)	Time of collection (hour)	Temperature (° C) (00010)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)
WTP-1	Sept. 24	1137	25.5	8.4	101
	Sept. 24	1830	27.0	8.3	102
	Oct. 2	1235	25.5	8.1	98
	Oct. 2	1735	25.0	9.2	110
	Oct. 2	1945	25.0	9.6	114
	Oct. 3	0010	24.5	9.2	109
	Oct. 3	0630	24.0	8.3	98
	Oct. 3	0755	24.5	9.2	109
	Oct. 3	1055	24.0	8.5	100
	Oct. 7	0840	24.0	9.1	107
	Oct. 7	1224	25.0	8.6	102
	Oct. 7	1655	25.5	8.2	99
	Oct. 7	2020	25.0	9.5	113
	Oct. 8	0750	24.0	9.4	111
	Oct. 8	0810	24.0	9.0	106
	Oct. 10	1240	24.5	8.6	102
	Oct. 10	1310	26.0	8.1	99
WR-4	Sept. 24	1120	25.0	5.9	70
	Sept. 24	1810	26.0	4.5	55
	Oct. 2	1245	25.0	2.6	31
	Oct. 2	1740	24.5	1.3	15
	Oct. 2	1950	22.5	2.3	26
	Oct. 3	0020	22.5	5.2	59
	Oct. 3	0645	21.0	3.1	34
	Oct. 3	0800	20.5	2.4	26
	Oct. 3	1100	22.5	4.8	55
	Oct. 7	0913	22.0	4.9	56
	Oct. 7	1219	25.0	6.0	71
	Oct. 7	1700	23.5	3.9	45
	Oct. 10	1300	26.5	3.5	43
	Oct. 10	1500	26.0	3.6	44
	Oct. 10	1700	25.0	4.3	51
	Oct. 10	1900	25.0	2.0	24
	Oct. 10	2100	24.0	4.8	56
	Oct. 10	2300	24.0	5.5	65
	Oct. 11	0100	24.0	5.6	66
	Oct. 11	0300	23.0	5.4	62
	Oct. 11	0500	22.5	5.4	62
	Oct. 11	0700	22.0	5.7	65

Table 3.--Dissolved-oxygen and temperature data, White River, tributaries, and Fayetteville waste effluent--Continued

Site	Date (1980)	Time of collection (hour)	Temperature (° C) (00010)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)
WR-4	Oct. 11	0900	22.0	5.7	65
	Oct. 11	1100	23.0	5.3	61
	Oct. 11	1240	25.0	5.7	68
	Oct. 11	1300	25.0	5.5	65
WR-5	Sept. 24	1130	23.0	2.5	29
	Sept. 24	1845	24.5	2.0	24
	Oct. 2	1415	22.0	0.2	2
	Oct. 2	1720	22.0	0.2	2
	Oct. 2	1750	21.5	0.0	0
	Oct. 3	0830	18.5	0.1	1
	Oct. 7	0945	18.5	0.2	2
	Oct. 7	1150	19.5	0.2	2
	Oct. 7	1530	22.0	0.1	1
	Oct. 7	1835	22.5	0.0	0
	Oct. 8	0815	19.0	0.1	1
	Oct. 10	1440	24.5	0.1	1
	Oct. 11	1040	13.0	0.1	1
WR-6	Sept. 24	1100	22.5	3.4	39
	Sept. 24	1745	23.5	5.3	62
	Sept. 24	1915	23.0	4.7	54
	Sept. 24	2325	22.5	3.4	39
	Sept. 25	0615	22.0	3.2	36
	Sept. 25	0800	22.5	3.2	37
	Oct. 2	1400	22.0	3.2	36
	Oct. 2	1740	21.0	3.1	34
	Oct. 2	1905	21.0	3.2	36
	Oct. 2	2300	19.5	2.7	29
	Oct. 3	0610	18.5	2.3	24
	Oct. 3	0815	18.5	2.3	24
	Oct. 3	1130	18.0	2.7	28
	Oct. 7	0925	17.0	1.0	10
	Oct. 7	1130	18.0	1.7	18
	Oct. 7	1515	21.0	1.7	19
	Oct. 7	1815	20.5	1.7	19
	Oct. 7	1950	19.5	0.9	10
	Oct. 8	0700	18.0	0.1	1
	Oct. 8	0830	18.0	0.2	2
	Oct. 10	1500	23.0	1.3	15
	Oct. 11	1030	18.0	0.2	2

Table 3.--Dissolved-oxygen and temperature data, White River, tributaries, and Fayetteville waste effluent--Continued

Site	Date (1980)	Time of collection (hour)	Temperature (° C) (00010)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)
WR-7	Sept. 24	1030	22.0	2.9	33
	Sept. 24	1715	23.5	7.4	86
	Oct. 6	1430	19.0	2.4	26
	Oct. 6	1630	19.5	2.6	28
	Oct. 6	1830	19.0	2.7	29
	Oct. 6	2030	18.5	2.5	27
	Oct. 6	2230	18.5	2.4	26
	Oct. 7	0030	18.5	2.3	24
	Oct. 7	0230	18.5	2.2	23
	Oct. 7	0430	18.0	2.2	23
	Oct. 7	0630	18.0	2.1	22
	Oct. 7	0830	17.5	2.2	23
	Oct. 7	0900	17.0	2.0	21
	Oct. 7	1000	21.0	6.4	71
	Oct. 7	1030	17.5	2.6	27
	Oct. 7	1230	18.5	3.1	33
	Oct. 7	1430	19.5	3.9	42
	Oct. 10	1515	22.0	1.8	20
	Oct. 11	1000	18.0	1.0	11
	Oct. 14	1500	17.5	3.7	39
WR-8	Sept. 22	1450	25.5	6.5	78
	Sept. 22	1632	26.0	6.8	83
	Sept. 24	0930	21.5	4.7	53
	Sept. 24	1615	23.5	7.4	86
	Sept. 24	2000	22.5	7.1	81
	Sept. 25	0015	22.5	5.4	62
	Sept. 26	0650	21.5	5.3	60
	Oct. 2	1335	19.5	3.2	35
	Oct. 2	1820	20.0	4.7	51
	Oct. 2	1950	20.0	5.0	54
	Oct. 2	2345	19.0	4.4	47
	Oct. 3	0655	18.5	3.5	37
	Oct. 3	0755	18.0	3.6	38
	Oct. 3	1215	18.0	4.1	43
	Oct. 7	0820	17.0	1.2	12
	Oct. 7	1112	17.0	2.0	21
	Oct. 7	1425	19.5	3.8	41
	Oct. 7	1820	20.0	6.3	68
	Oct. 7	1950	19.0	4.5	48
	Oct. 8	0640	18.0	3.0	32

Table 3.--Dissolved-oxygen and temperature data, White River, tributaries, and Fayetteville waste effluent--Continued

Site	Date (1980)	Time of Time of collection (hour)	Temperature (° C) (00010)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)
WR-8	Oct. 8	0815	18.0	3.0	32
	Oct. 10	1530	23.5	8.4	98
	Oct. 11	0900	18.0	3.9	41
	Oct. 14	1400	18.0	4.6	48
	Oct. 15	0900	17.0	3.4	35
	Oct. 15	1015	17.0	3.2	33
WRT-2	Sept. 22	1420	27.0	11.2	138
	Sept. 22	1630	27.0	10.2	126
	Sept. 24	0945	20.0	7.3	79
	Sept. 24	1620	23.0	9.9	114
	Sept. 24	1945	23.5	9.4	109
	Sept. 24	2350	22.0	7.9	90
	Sept. 25	0630	20.5	7.8	86
	Oct. 2	1320	20.0	11.0	120
	Oct. 2	1800	21.0	11.1	123
	Oct. 2	1930	20.5	10.8	119
	Oct. 2	2320	18.5	8.4	89
	Oct. 3	0630	16.0	8.2	83
	Oct. 3	0750	16.0	8.5	86
	Oct. 3	1145	16.5	10.7	109
	Oct. 7	0750	16.0	8.8	89
	Oct. 7	1050	16.0	9.8	99
	Oct. 7	1400	19.0	12.0	129
	Oct. 7	1750	20.0	11.8	128
	Oct. 7	1945	20.0	10.7	116
	Oct. 8	0635	17.0	8.3	86
	Oct. 8	0810	16.5	8.4	86
	Oct. 10	1535	21.5	11.2	126
	Oct. 11	0840	15.0	8.2	80
	Oct. 14	1430	18.0	10.6	112
	Oct. 15	0925	16.0	8.0	81
WR-9	Sept. 22	1507	26.0	8.5	104
	Sept. 22	1700	26.0	9.5	116
	Sept. 24	0950	21.5	4.7	53
	Sept. 24	1630	23.0	7.4	85
	Sept. 24	1950	23.0	7.6	87
	Sept. 24	2400	22.0	6.4	73
	Sept. 25	0640	21.0	6.0	67

Table 3.--Dissolved-oxygen and temperature data, White River, tributaries, and Fayetteville waste effluent--Continued

Site	Date (1980)	Time of collection (hour)	Temperature (° C) (00010)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)
WR-9	Oct. 2	1325	20.0	7.3	79
	Oct. 2	1810	20.0	7.2	78
	Oct. 2	1940	20.0	6.6	72
	Oct. 2	2330	19.0	6.0	64
	Oct. 3	0640	17.0	5.6	58
	Oct. 3	0740	17.0	5.9	61
	Oct. 3	1150	18.0	8.5	89
	Oct. 7	0800	16.5	3.5	36
	Oct. 7	1055	17.5	4.7	49
	Oct. 7	1410	19.5	5.7	62
	Oct. 7	1800	20.0	6.7	73
	Oct. 7	1940	19.5	6.4	69
	Oct. 8	0630	18.0	4.7	49
	Oct. 8	0800	17.5	4.3	45
	Oct. 10	1540	22.0	8.6	98
	Oct. 11	0830	17.0	5.5	57
	Oct. 14	1435	18.0	6.1	64
	Oct. 15	0930	16.5	4.8	49
WR-10	Sept. 22	1530	26.5	7.6	93
	Sept. 24	0900	22.0	4.7	53
	Sept. 24	1600	23.0	6.8	78
	Sept. 24	2015	23.0	6.6	76
	Sept. 25	0030	22.5	6.2	71
	Sept. 25	0700	21.0	6.2	69
	Oct. 2	1300	20.5	6.4	70
	Oct. 2	1500	21.0	6.7	74
	Oct. 2	1700	22.0	7.2	82
	Oct. 2	1900	21.0	7.0	78
	Oct. 2	2100	21.0	6.9	77
	Oct. 2	2300	20.0	6.3	68
	Oct. 3	0100	19.0	6.2	67
	Oct. 3	0300	18.0	6.1	64
	Oct. 3	0500	18.0	6.1	64
	Oct. 3	0700	17.0	6.1	63
	Oct. 3	0900	17.0	6.5	67
	Oct. 3	1100	18.0	7.3	77
	Oct. 3	1230	18.0	7.6	80
	Oct. 3	1300	18.0	8.0	84
	Oct. 7	0730	17.5	5.2	54

Table 3.--Dissolved-oxygen and temperature data, White River, tributaries, and Fayetteville waste effluent--Continued

Site	Date (1980)	Time of collection (hour)	Temperature (° C) (00010)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)
WR-10	Oct. 7	1040	17.5	5.8	60
	Oct. 7	1350	21.0	6.8	76
	Oct. 8	0655	18.5	5.6	60
	Oct. 8	0830	18.0	5.3	56
	Oct. 10	0730	17.5	5.2	54
	Oct. 10	1600	22.5	7.4	85
	Oct. 10	1840	20.0	8.9	97
	Oct. 10	2005	20.0	8.5	92
	Oct. 11	0810	18.0	6.7	71
	Oct. 14	1530	19.5	9.2	99
	Oct. 15	0815	17.5	6.1	64

Arkansas Water Quality Standards (Arkansas Department of Pollution Control and Ecology, 1975) state that "during any month of the year, heat shall not be added to any stream in excess of the amount that will elevate the temperature of the water more than 5° F (2.8° C)". Using this standard and the mean water temperature for site WR-3 (upstream from the Fayetteville WWTP) of 19.0° C (66.2° F) and the mean water temperature of 23.5° C (74.7° F) for site WR-4 (downstream from Fayetteville WWTP), it appears that the State temperature standard was not being met during the period of this study.

Specific Conductance and Dissolved Solids

Specific conductance is a measure of a water's ability to conduct an electric current and is, therefore, an indication, within wide limits, of the dissolved-solids concentration of the solution (Hem, 1970, p. 99). Measurements of specific conductance are expressed as micromhos per centimeter at 25° C. Hem (1970, p. 99) used a dissolved-solids-to-specific-conductance ratio of 0.54 as the lowest value present in natural water. Using the conservative 0.54 ratio at site WR-3, upstream from the WWTP, with a mean specific conductance of 102 micromhos per centimeter, yields a mean value of 55 mg/L for dissolved solids. Using the same ratio, site WR-5, with a mean specific conductance of 545 micromhos per centimeter, yields a mean value of 294 mg/L for dissolved solids. These calculations indicate that it is unlikely that total dissolved solids in the upper White River (Missouri state line to headwaters, including Beaver Reservoir), meet the Arkansas standard of 160 mg/L maximum concentration (Arkansas Department of Pollution Control and Ecology 1975). Specific conductance during the study ranged from 90 micromhos per centimeter at site WR-3 to 560 micromhos per centimeter at sites WR-4 and WR-5 (table 2).

Chemical Characteristics

Chemical water-quality characteristics measured during the study were pH, DO, CBODU, streambed oxygen demand, net photosynthetic dissolved-oxygen production, and nutrients.

pH

The pH of a solution refers to its hydrogen-ion activity and can range from 0 to 14 units. Water with pH values less than 7 units is acidic; water with pH values more than 7 units is alkaline. The pH of most natural water ranges from 6.0 to 8.5 units (Hem, 1970, p. 93). Where photosynthesis by aquatic organisms takes up dissolved carbon dioxide during the daylight hours, pH may fluctuate, and the maximum pH value may sometimes reach as high as 9.0 units (Hem, 1970, p. 93). The pH of the main stem of White River during the study ranged from 7.0 to 7.7 units (table 2). The pH of the Fayetteville WWTP effluent ranged from 7.0 to 7.3 units (table 2). Arkansas water-quality standards state that "the pH of water in the stream or lake must not fluctuate in excess of 1.0 pH unit, within the range of 6.0 to 9.0, over a period of 24 hours. The pH shall not be below 6.0 or above 9.0 due to wastes discharged to the receiving waters" (Arkansas Department of Pollution Control and Ecology, 1975).

Dissolved Oxygen

Dissolved oxygen is the most biologically important parameter in natural waters; it is essential to all biota that respire aerobically. Fish and other desirable clean-water organisms require sufficient DO concentrations to survive and propagate. Arkansas water-quality standards (Arkansas Department of Pollution Control and Ecology, 1975) require a minimum of 6.0 mg/L for the segment of White River in this study. This standard was established to insure conditions for the maintenance of a smallmouth-bass fishery.

The DO concentration of flowing water is highly variable. Oxygen in rivers is consumed by bacterial decomposition of suspended, dissolved, and deposited organic matter, oxidation of ammonia by nitrifying bacteria (nitrification), and the respiration of aquatic organisms. Oxygen is replenished in natural water primarily by reaeration, the diffusion of oxygen into the water from the atmosphere, and by photosynthesis.

Reaeration will not result in DO concentrations greater than saturation (the concentration of oxygen in the water that is in equilibrium with the oxygen concentration in the atmosphere). At sea level and a temperature of 10° C, water is saturated with oxygen when it contains about 11.3 mg/L. At 30° C, water is saturated with oxygen when it contains only about 7.7 mg/L.

During daylight hours, algae are both producers and consumer of oxygen. In some favorable river environments algal photosynthesis can raise DO concentrations much higher than the saturation value. Likely places for this condition are slow-moving rivers that have large pools and an abundant nutrient supply during summer. During such periods, algae can become a more important contributor of oxygen to the river than reaeration. At night, in the absence of sunlight, algae are only oxygen consumers. Where algal photosynthesis has resulted in supersaturated-oxygen concentrations, oxygen diffuses from the water, tending toward equilibrium. Because of the net oxygen production during the day, and losses to respiration and diffusion at night, the diel pattern is high DO concentrations during the day and low concentrations during the night. This diel pattern is characteristic of water with high algal productivity.

During summer months, when streamflow is low and water temperature is high, the DO concentration of a stream can be depleted by high organic loading. Such loading is common downstream from a WWTP with secondary or less treatment. A fish kill in the White River downstream from the Fayetteville WWTP was observed during the period of this study. A DO concentration of 0.0 mg/L was measured at site WR-5 on October 2 and 7, 1980 (table 3).

Dissolved-oxygen concentration of the White River was measured approximately four times during each 24-hour-sampling period; once during each collection of water-quality samples, once after darkness, and once near sunrise. In addition, a continuous temperature and DO concentration monitor was used at selected sampling sites while numerous additional temperature and DO measurements were being made at other sites. Dissolved-oxygen concentrations in the river ranged from a minimum of 0.0 mg/L (0 percent saturation) at site WR-5 on October 2 and 7, 1980, to a maximum of 10.4 mg/L (124 percent saturation) at site WR-3 at 1600 hours on October 7, 1980 (table 3). Mean daily DO profiles are shown in figure 3.

The DO concentration generally was lowest in the early morning hours at all of the White River sampling sites. This condition is due to cumulative nighttime respiration and the absence of production. Differences between nighttime and midday DO concentrations at several sites indicate that photosynthetic activity was significant during the study.

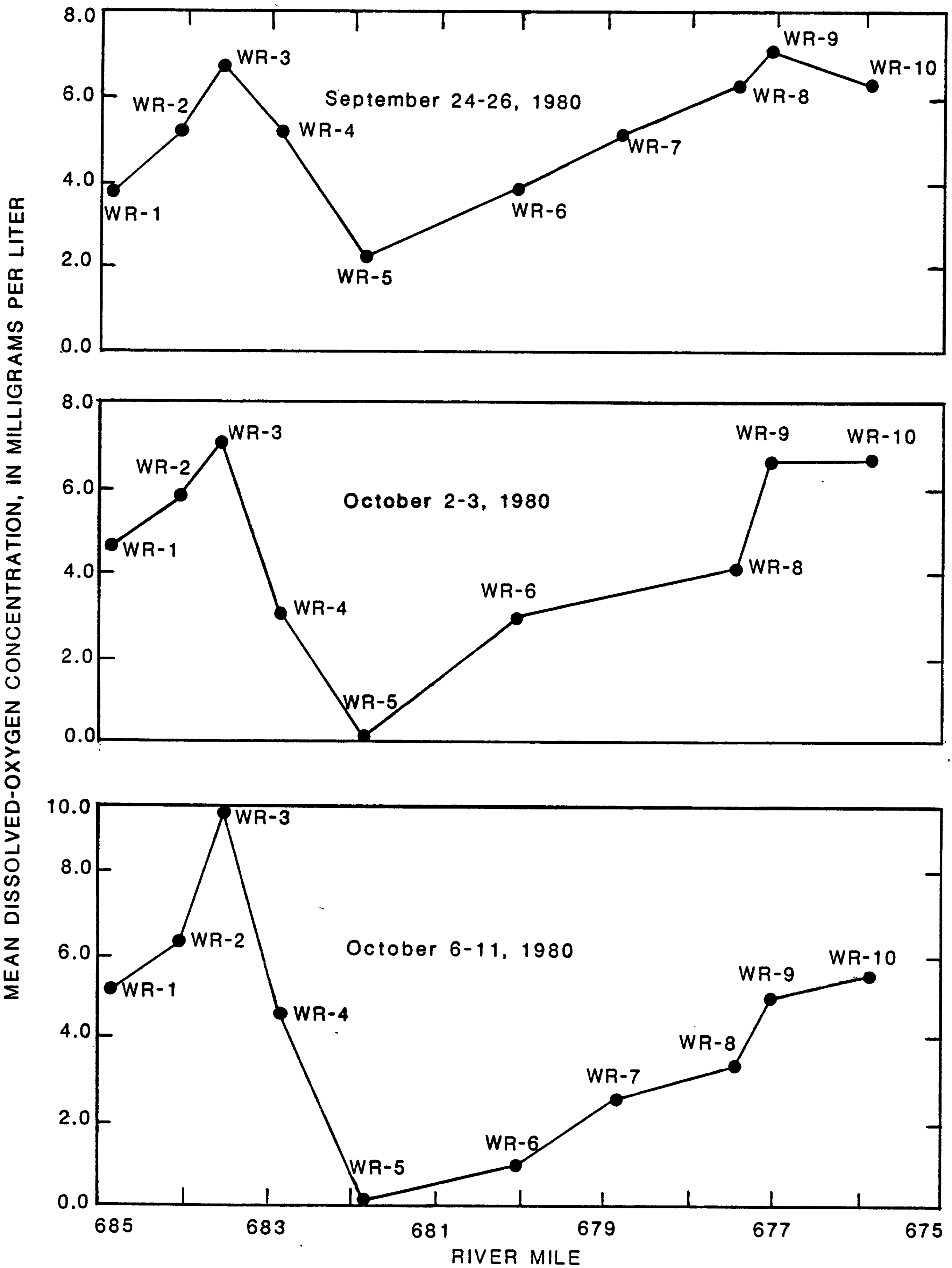


Figure 3.- Mean daily dissolved-oxygen profiles for sampling sites on the White River between Lake Sequoyah and Beaver Resevoir.

Carbonaceous Biochemical Oxygen Demand

Carbonaceous biochemical oxygen demand (CBOD) is a single stage reaction defining the quantity of oxygen used by organisms in the water column as they consume organic material. Demands can be defined for any period of time. The maximum quantity of DO required for the complete assimilation of carbonaceous material in a given parcel of water is defined as the "ultimate carbonaceous biochemical oxygen demand" (CBODU).

Water collected at each station during the September and October sampling periods was analyzed for CBOD according to methods described by Pickering (written commun., 1980). 2-chloro-6 (trichloromethyl) pyridine was introduced into each sample to inhibit nitrification. The observed decline in DO concentration in each sample was then assumed to be only due to the respiration of those organisms that consume carbonaceous material. Dissolved-oxygen concentrations in each sample were recorded initially and on day one of the test; thereafter concentrations were recorded every other day for a period of 20 days.

The single-stage decay of carbonaceous material can be defined by the first order kinetics model expressed in the following equation:

$$L_t = L_o e^{-kt},$$

where

t = time (in days),
e = base of natural logarithms,
L_t = concentration of CBOD remaining after t days, (mg/L),
L_o = initial concentration of CBOD at time 0, CBODU, (mg/L),
k = first-order CBOD decay rate, base e, (day^{-1}).

L_o and k are determined by defining a best-fit curve for the time-series DO data recorded during the laboratory CBODU tests. This fitting is accomplished using a computer program described by Jennings and Bauer (1976).

The fitting methods available in the program are:

1) the Thomas method (Thomas, 1950),
2) the least-squares method (Reed and Theriault, 1931), and
3) the nonlinear least-squares method (J. P. Bennett, written commun., 1974).

The nonlinear least-squares method requires that initial values of k and L_o be supplied by the user or by a presolution using the Thomas method or the least-squares method.

For each time-series data set analyzed, the fitting program was run twice; once utilizing the Thomas method followed by the nonlinear least-squares method, and once with the least-squares method followed by the nonlinear least-squares method, resulting in four attempts at fitting each data set. Estimates of L_o and k produced by the fitting procedure with the smallest computed root mean-square error were considered most accurate.

Values of L_o, or CBODU, at each sampling station are given in table 2. The reaction coefficients, k, determined in this manner represent deoxygenation rates, because deposition is not accounted for in the "bottle-time" tests. The deoxygenation rates determined for samples taken at each station are given in table 2. The present 5-day biochemical oxygen demand limit for the Fayetteville WWTP is 30 mg/L. Using a conversion factor of 1.5 (Velz, 1970, p. 145) gives an CBODU limit of 45 mg/L for the plant. CBODU concentrations for the

Fayetteville WWTP (site WTP-1) ranged from 72 mg/L on September 24, 1980, to 190 mg/L on October 7, 1980 (table 2). CBODU concentrations in White River ranged from 4.6 mg/L at site WR-10 to 120 mg/L at site WR-4, just downstream from the Fayetteville WWTP outfall.

Streambed Oxygen Demand

The streambed oxygen demand is a measure of the quantity of oxygen removed from overlying waters by processes occurring through a unit area of streambed in unit time. The demand from the streambed for oxygen is primarily due to the decay of natural organic detritus such as leaves and to the decay of settleable organics contributed by man from both point and nonpoint-sources.

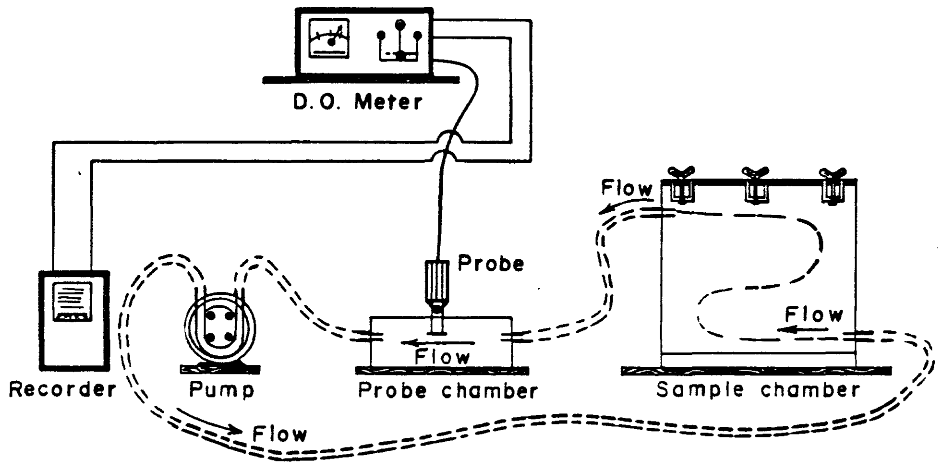
"Streambed oxygen demand," as used in this report, does not include the respiration of periphyton nor does it include the respiration of benthic invertebrates and bacteria attached to non-collectable substrates. These noncollectable substrates include submerged trees, aquatic macrophytes, bedrock outcrops, large gravel, and boulders. The term "benthic oxygen demand" (benthal demand) as used in this report, has a broader meaning than streambed oxygen demand and includes the bacterial and invertebrate oxygen demands from non-collectable substrates. Benthic demand is discussed further under the digital model calibration section.

Representative bed-material samples are collected by use of grab samplers or by use of a shovel. Approximately 20 pounds of the top 2 to 3 inches (50-80 millimeters) of bed material are collected in a large pan. The surface of the material is covered with plastic wrap. The sample is then chilled and transported to the laboratory for analysis. Analysis is begun within 24 hours of collection.

A respirometer, adapted from Nolan and Johnson (1979), is used in the determination of streambed oxygen demand in the laboratory. The respirometer (fig. 4) consists of a cylinder (1 foot in diameter) constructed from clear acrylic pipe with acrylic end plates, a dissolved-oxygen probe and container, a continuous recorder, a peristaltic pump, and polyethylene tubing.

The bed-material sample is placed on the bottom of the respirometer to a depth of 1 inch (25 millimeters). The surface area of the sample is 0.743 square foot (0.069 square meter). The inlet port is 1.18 inches (30 millimeters) above the sample surface, and the exit port is 3.54 inches (90 millimeters) below the lid of the respirometer. After a sample has been placed in the respirometer and the dissolved-oxygen probe has been calibrated, the respirometer is filled with 2.25 gallons (8.53 liters) of aerated, demineralized water, the peristaltic pump started, and the lid is placed on the respirometer forming an airtight container. The system is operated at room temperature (21° C ± 1° C) for 4-8 hours.

The first step in calculating the oxygen demand of the sample is to examine the DO versus time plot obtained from the continuous recorder. Initial DO (O_i) and final DO (O_f) (fig. 4) are determined from that part of the plot where oxygen consumption versus time is constant (fig.5). DO concentrations less than 2 mg/L are not used in rate determinations because of changing rates of oxygen demand by aquatic organisms during low DO periods. As a control, the analysis is also done without streambed material, using demineralized water, and the appropriate blank correction is made in the final calculation, shown in figure 4.



$$SOD = \left[\frac{[(O_i - O_f) - (B_i - B_f)]V}{SA} \right] \div \Delta t$$

where

SOD = Streambed oxygen demand (grams per square meter per day),
O_i = DO initial (milligrams per liter),
O_f = DO final (milligrams per liter),
B_i = blank DO initial (milligrams per liter),
B_f = blank DO final (milligrams per liter),
V = volume confined water (cubic meters)
SA = sample in area (square meters), and
Δt = $t_i - t_f$, change in time (days).

Figure 4.--Respirometer and calculations used for measuring streambed oxygen demand.

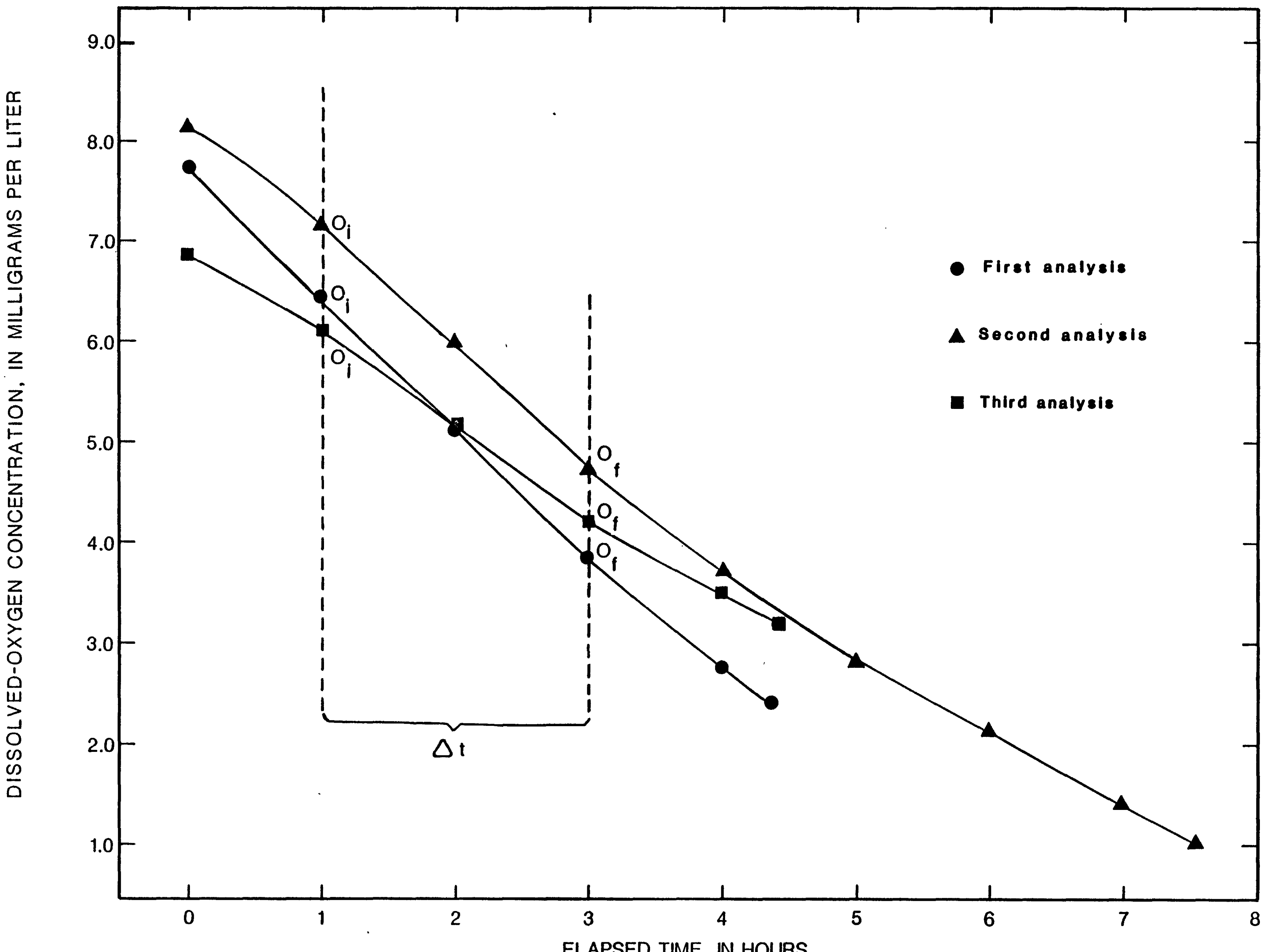


Figure 5.— Dissolved-oxygen curves resulting from three respirometer analyses of a White River bed-material sample collected on October 7, 1980.

Three replicate samples were analyzed when possible, and the mean value obtained is reported in table 2. Streambed oxygen demand values differ considerably between streams. Butts and Evans (1978) found that for several streams in Illinois, values ranged from 0.27 $(g/m^2)/d$ for a clean stream to 9.3 $(g/m^2)/d$ for a very polluted stream. Values for White River ranged ranged from 1.2 $(g/m^2)/d$ for site WR-10 to 6.0 $(g/m^2)/d$ at site WR-5.

Net Photosynthetic Dissolved-Oxygen Production

Net photosynthetic dissolved-oxygen production, defined as the difference between gross photosynthesis and algal respiration, is an integral component in the community metabolism of most streams. In this study the net DO production component was determined from an analysis of a diel series of DO and temperature measurements and chlorophyl *a* measurements made at each sampling site (table 3). A typical set of curves for such diel data is shown in figure 6. An approach developed by Odum (1956) was used to solve the oxygen-balance equation for each set of diel data collected. This analysis yields net daytime productivity, total nighttime respiration, and total 24-hour community metabolism.

The Odum methodology has been coded into a digital program and documented by Stephens and Jennings (1976). The program solves the oxygen-balance equation at a single station or as the difference between upstream and downstream stations. In this study, the single-station analysis was used. Problem solution is for the following oxygen balance equation:

$$X = P - R \pm D + \emptyset,$$

where

X = rate of change of dissolved oxygen per unit area,
P = rate of photosynthetic production per unit area,
R = rate of community respiration per unit area,
D = rate of gain or loss of oxygen through diffusion, and
$\emptyset$ = rate of accrual of oxygenated water.

In addition to the diel DO and temperature data, values for some additional parameters must be supplied to the program to solve the preceding equation. For these analyses, the additional parameters necessary are as follows:

1) oxygen diffusion coefficient

$$DIFC = k_2 \times 9.07/(BP/29.92),$$

where

$DIFC$ = diffusion coefficient, $(g/m^3)/h$
k_2 = reaeration coefficient, $hour^{-1}$, computed with the Velz predictive equation (Attachment A-2), and
9.07 = dissolved-oxygen saturation, mg/L, at 20° C, and
BP = barometric pressure, inches of mercury.

2) barometric pressure, inches of mercury,
3) stream depth, m, and
4) time of sunrise and sunset.

An example of printed results from the program is shown in figure 7. For further details concerning the derivation of net photosynthetic DO production, to this stage, the reader is referred to Stephens and Jennings (1976).

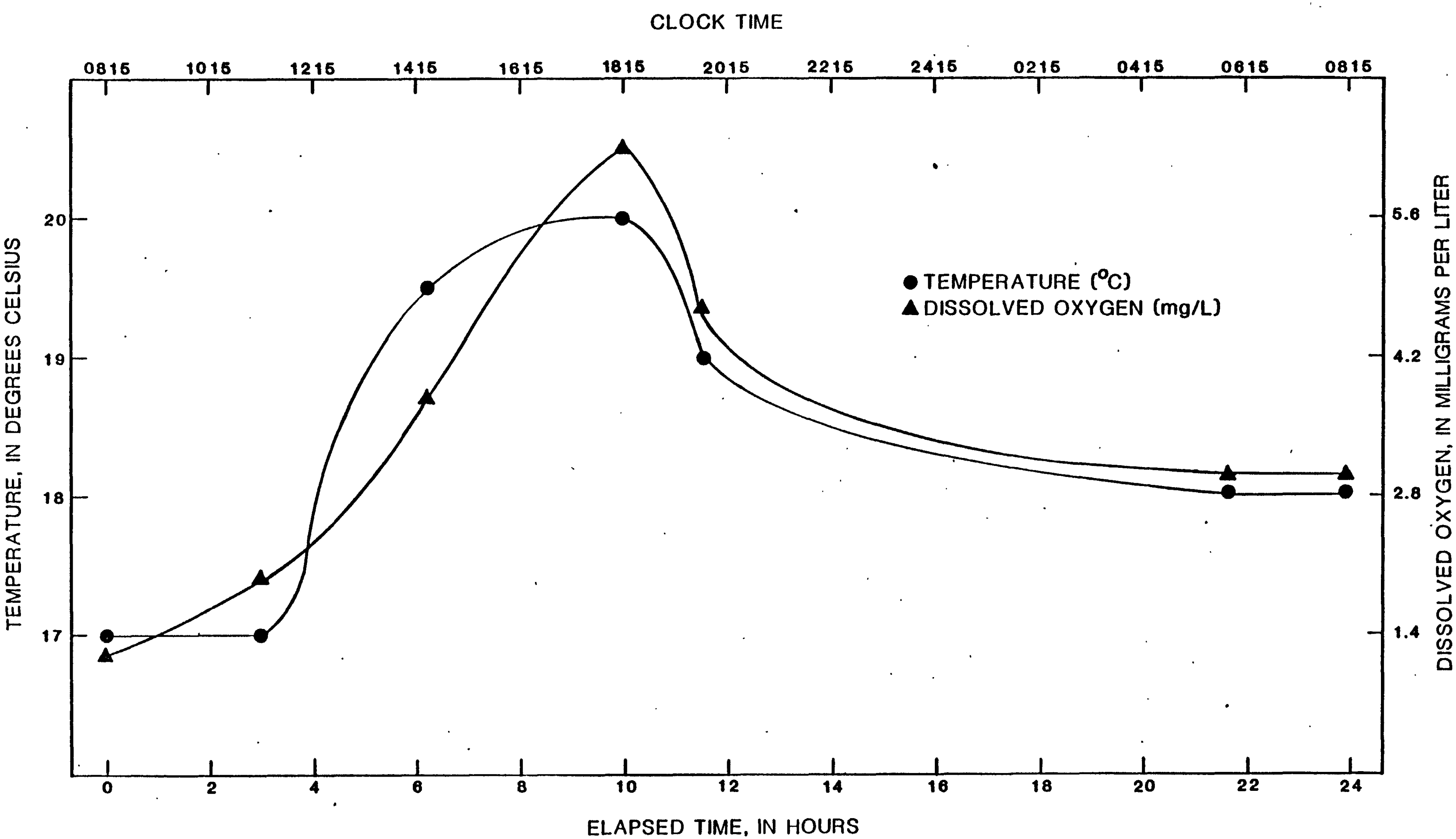


Figure 6.–Diel dissolved-oxygen and temperature curves for sampling site WR-8, October 7-8, 1980.

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                              OXYGEN METABOLISM

  STATION NUMBER 01: SUBREACH 6 WR7 10/6-10/7

NET DAYTIME PROD.   -3.893 GM O2/M3/DAY   -1.214 GM C /M3/DAY   -1.713 GM O2/M2/DAY   -0.534 GM C /M2/DAY
NIGHT RESPIRATION   -7.566 GM O2/M3/DAY   -2.361 GM C /M3/DAY   -3.329 GM O2/M2/DAY   -1.039 GM C /M2/DAY
*PRODUCTION DURING TIME PERIOD  715 TO 1845  HRS
                                       P/R RATIO      -0.5145

24 HOUR COMMUNITY METABOLISM=    -5.042 GM O2/M2/DAY
(DIFFERENCE BETWEEN NET DAILY PRODUCTION AND NIGHT RESPIRATION)
```

Figure 7. -Computer printout of results of Odum single station method for determining community metabolism at site WR-7.

Using, as an example, the results of the Odum analysis (fig. 7) and observed chlorophyll *a* concentrations (table 2) for station WR-7, the following procedure was used to derive values for net photosynthetic DO production at each station.

Equalities:

1) *Net daytime oxygen production = gross photosynthesis + [daytime benthal demand + daytime BOD + daytime respiration of periphyton + daytime respiration of phytoplankton].*

2) *Night respiration = nighttime benthal demand + nighttime BOD + nighttime respiration of periphyton + nighttime respiration of phytoplankton.*

3) *24-hour community metabolism = net daytime production + nighttime respiration.*

4) *Algal respiration = -0.025 (chlorophyll a concentration),* (Shindala, 1972).

Assumptions:

1) *Daytime benthal demand and BOD = nighttime benthal demand and BOD.*

2) *Daytime algal respiration = nighttime algal respiration.*

3) *Periphyton respiration = phytoplankton respiration;* in the absence of good periphyton data.

Computations:

Chlorophyll a = 7.61 ug/L, therefore, by equality 4 *phytoplankton respiration = -0.025 (7.61 ug/L) = -0.190 (g/m³)/d* of oxygen.

By assumption 3, then *periphyton respiration = -0.190 $(g/m^3)/d$.*

By equality 2, *nighttime benthal demand + nighttime BOD = night respiration - nighttime respiration of periphyton - nighttime respiration of phytoplankton*

$= -7.566-(-0.190/2)-(-0.190/2)$

$= -7.376\ (g/m^3)/d.$

Define: *"Net DO production" = gross photosynthesis + daytime respiration of periphyton + daytime respiration of phytoplankton + nighttime respiration of periphyton + nighttime respiration of phytoplankton.*

By equality 1, *net DO production = net daytime production - [daytime benthal demand + daytime BOD] + nighttime respiration of periphyton + nighttime respiration of phytoplankton.*

Therefore, using assumptions 1 and 2,

$$\text{net DO production} = -3.893-(-7.376) + (-0.190/2) + (-0.190/2)$$
$$= 3.29\ (g/m^3)/d, \text{ and}$$
$$= 3.29\ (mg/L)/d.$$

The results of the preceding derivation for each station where sufficient data were collected are given in table 4.

Nutrients

Plants, including algae, require carbon, nitrogen, phosphorus, and potassium, as well as trace amounts of other elements to grow (Hynes, 1970). Potassium, a common constituent in river water, seldom limits plant growth. Forms of nitrogen dissolved in water include bound organic, ionized ammonia

Table 4.--Net photosynthetic dissolved-oxygen production derived from community-metabolism analysis of instream-diel dissolved-oxygen and temperature measurements

[Temperature measurements are shown in table 3]

Sampling station	Date (1980)	Net photosynthetic dissolved-oxygen production (mg/L)
WR-1	Oct. 7, 8	7.4
WR-2	Oct. 7, 8	0.0
WR-3	Oct. 7, 8	2.0
WR-5	Oct. 7, 8	.4
WR-6	Oct. 7, 8	4.0
WR-7	Oct. 6, 7	3.3
WR-8	Oct. 7, 8	7.4
WR-9	Oct. 7, 8	4.1
WR-10	Oct. 10, 11	1.8

(NH_4^+), un-ionized ammonia (NH_3), nitrite, and nitrate. Of these forms, nitrate is the most readily available for plant growth and is the predominant form present in streams, except, when there is a man-made source of ammonia present or under reducing conditions when denitrification occurs. Forms of phosphorus in water include orthophosphate and the bound phosphate in soluble or particulate form. Dissolved forms of nitrate and phosphate are rapidly taken up by plants. Consequently, their concentrations in natural water are usually low.

Nutrient enrichment may encourage blooms of nuisance algae. Such blooms are common in lakes (Wetzel, 1975, p. 659) but are seldom seen in rivers. A principal reason for the absence of blooms in rivers is an unfavorable environment for planktonic algae because of river currents. Many algae present in rivers are not truly planktonic but are members of the periphyton (attached) community that have become dislodged because of river currents or overgrowth. The following genera of algae classed as truly planktonic by Hynes (1970, p.99) were present in significant numbers in the White River: pennate diatom, *Fragilaria;* centric diatoms, *Melosira* and *Cyclotella;* green algae, *Scenedesmus* and *Ankistrodesmus;* blue-green algae, *Anacystis;* flagellates, *Euglena* and *Trachelomonas*. An algal bloom was observed in the river on several days in late September and early October, 1980. A phytoplankton sample taken during a bloom on October 8, 1980, at site WR-5 had a cell density of 1,400,000 cells per milliliter; *Oscillatoria,* a filamentous blue-green alga, was the dominant genus. These blooms, along with the presence of several truly planktonic algae, indicate that the river reach of the study biologically behaves more like a lake than a river.

The main source of nitrogen and phosphorus in the White River study segment is the Fayetteville WWTP (site WTP-1). For the four samples taken at site WTP-1 during this study, water discharge was 286 percent greater than the flow of the receiving stream (White River at site WR-3). The four effluent samples had the following average concentrations: total organic nitrogen as nitrogen (organic-N), 14.6 mg/L; total ammonia as nitrogen (ammonia-N), 4.8 mg/L; total nitrite as nitrogen (NO_2-N), 0.13 mg/L; total nitrate as nitrogen (NO_3-N), 2.6 mg/L; and total orthophosphate as phosphorus (PO_4-P), 8.1 mg/L.

Nutrient concentrations in the river varied widely during the study (table 2). The concentration of organic-N in the river ranged from 0.41 mg/L at site WR-2 upstream from the Fayetteville WWTP to 37 mg/L at site WR-4, immediately downstream from the treatment-plant outfall. Ammonia-N concentrations ranged from 0.01 mg/L at site WR-3 to 6.8 mg/L at site WR-5. NO_2-N concentrations ranged from 0.00 mg/L at site WRT-1 to 0.48 mg/L at site WR-5. NO3-N concentrations ranged from 0.00 mg/L at site WR-1 (downstream from Lake Sequoyah) and site WRT-1 (West Fork White River) to 2.9 mg/L at site WR-4. PO_4-P was not detected in at least one sample for each of the four stations upstream from the Fayetteville WWTP. The highest concentration present downstream was 9.1 mg/L at site WR-4.

The concentration of all nutrients except nitrate showed a general decline downstream. This trend is caused by several factors working simultaneously in the stream. Organic-N is decomposed by bacterial action and hydrolysis to form ammonia-N. Ammonia-N is oxidized to NO_2-N mainly through the action of bacteria belonging to the genus *Nitrosomonas*. The resulting NO_2-N is quickly oxidized to NO_3-N by bacteria of the genus *Nitrobacter*. The resulting NO_3-N is the form of nitrogen most used by algae and higher plants. NO_3-N production was proceeding in the rivr at a higher rate than plant uptake, resulting in increasing NO_3-N concentrations downstream.

Lesser reactions in the nitrogen cycle of a river include microbial fixation of molecular nitrogen in water and bottom sediments and microbial reduction of NO_3-N and NO_2-N to ammonia-N, and to the gaseous products nitrous oxide and molecular nitrogen.

PO_4-P concentrations showed a typical decline downstream from the Fayetteville WWTP. Several factors affect instream concentrations of PO_4-P. Algae and, to a lesser extent, bacteria (Hynes, 1970, p. 46) and aquatic macrophytes (Wetzel, 1975, p. 227) remove PO_4-P from solution for growth. Bacterial action on organically-bound phosphorus releases PO_4-P to the stream. Phosphorus is continually removed from and added to the streambed by a series of complex processes, generally with a net loss to the streambed. During a storm, however, high river velocities may scour the riverbed and resuspend a large amount of phosphorus and carry it downstream.

Biological Characteristics

The stream biological community was selectively sampled for phytoplankton, benthic invertebrates, fish, and fecal coliform bacteria. To document changes in the biological community of White River resulting from the effluent discharge from the Fayetteville WWTP, particular attention was given to site WR-3 (upstream from the Fayetteville WWTP) and site WR-5 (downstream from the Fayetteville WWTP).

Phytoplankton

Phytoplankton are an assemblage of microscopic plants that drift passively with the currents of rivers and lakes. The species composition and abundance of phytoplankton are significantly affected by water quality. As a result, for water-quality assessments, phytoplankton are good indicators of general water quality.

Phytoplankton populations can directly affect the pH, DO concentration, concentrations of certain inorganic constituents (particularly nutrients), turbidity, and color of surface water. Phytoplankton cause problems in domestic water supplies when their concentrations reach nuisance levels. Some of the problems caused by nuisance organisms are blooms, taste, odor, clogging of sand filters, and toxicity (Palmer, 1959).

There are no applicable water-quality standards for phytoplankton in water used for recreation. However, esthetic considerations by users may limit recreational use when algal blooms are present. In addition to imparting turbidity and color, algal blooms have been known to impart grassy, moldy, or fishy odors to water and produce substances toxic to livestock and man (Palmer, 1959).

Seven genera of algae known to produce objectionable odors (Palmer, 1959) were identified from samples taken from sites WR-3 and WR-5, table 5; the genera *Scenedesmus*, *Chlamydomonas*, *Cyclotella*, *Fragilaria*, and *Anacystis* (the latter also capable of toxin production) from site WR-3 and the genera *Chlamydomonas*, *Fragilaria*, *Anacystis*, *Oscillatoria*, and *Euglena* from site WR-5.

Nine genera of algae commonly present in organically enriched areas were present in samples from sites WR-3 and WR-5 (Palmer, 1959, 1968), table 5. Site WR-3 included the genera *Ankistrodesmus*, *Scenedesmus*, *Chlamydomonas*, *Melosira*, *Nitzchia*, and *Anacystis*. Site WR-5 included the genera *Chlamydomonas*, *Melosira*, *Gomphonema*, *Nitzschia*, *Anacystis*, *Oscillatoria*, and *Euglena*.

Table 5.--Phytoplankton genera and densities of White River upstream and downstream from Fayetteville wastewater-treatment plant

[Phytoplankton density in cells per milliliter]

Scientific name	Common name	Station WR-3, White River upstream from treatment plant, October 7, 1980 (RM 683.5)	Station WR-5, White River downtream from treatment plant, October 8, 1980 (RM 681.8)
CHLOROPHYTA	Green algae		
.CHLOROPHYCEAE			
..CHLOROCOCCALES			
...OOCYSTACEAE			
....*ANKISTRODESMUS*		160	-----
....*TETRAEDRON*		160	-----
....*WESTELLA*		660	-----
...SCENEDESMACEAE			
....*SCENEDESMUS*		3,800	-----
....*TETRASTRUM*		660	-----
..VOLVOCALES			
...CHLAMYDOMONADACEAE			
....*CHLAMYDOMONAS*		330	290
CRYSOPHYTA			
.BACILLARIOPHYCEAE	Diatoms		
..CENTRALES	Centric		
...COSCINODISCACEAE			
....*CYCLOTELLA*		5,400	-----
....*MELOSIRA*		15,000	1,500
..PENNALES	Pennate		
...ACHNANTHACEAE			
....*ACHNANTHES*		160	-----
...FRAGILARIACEAE			
....*FRAGILARIA*		160	590
...GOMPHONEMATACEAE			
....*GOMPHONEMA*		------	880
...NITZSCHIACEAE			
....*NITZSCHIA*		490	290
CYANOPHYTA	Blue-green algae		
.CYANOPHYCEAE			
..CHROOCOCCALES	Coccoid		
...CHROOCOCCACEAE			
....*AGMENELLUM*		------	4,700
....*ANACYSTIS*		42,000	590
..HORMOGONALES	Filamentous		
...OSCILLATORIACEAE			

Table 5.--Phytoplankton genera and densities of White River upstream and downstream from Fayetteville wastewater-treatment plant--Continued

Scientific name	Common name	Station WR-3, White River upstream from treatment plant, October 7, 1980 (RM 683.5)	Station WR-5, White River downtream from treatment plant, October 8, 1980 (RM 681.8)
....*OSCILLATORIA*		------	1,400,000
...NOSTOCACEAE			
....*ANABAENOPSIS*		2,300	------
EUGLENOPHYTA	Euglenoids		
.EUGLENOPHYCEAE			
..EUGLENALES			
...EUGLENACEAE			
....*EUGLENA*		------	10,000
....*TRACHELOMONAS*		330	------
	Total	71,610	1,418,840

Palmer's (1968) algal-pollution index was calculated using the preceding genera from each site. This index was developed for use in rating water samples for organic pollution. A score of 20 or more for a sample is taken as evidence of high organic pollution, whereas a score of 15 to 19 is taken as probable evidence of high organic pollution. Site WR-3 had a score of 16, and site WR-5 had a score of 24.

Possible sources of the waste at site WR-3 are pastureland, feedlots, and disposal of sludge from the Fayetteville WWTP. The principal source of organic wastes at site WR-5 is the Fayetteville WWTP.

In summary, phytoplankton species and densities at sites upstream and downstream from the Fayetteville WWTP are indicative of organically enriched streams. However, the high phytoplankton density (1,400,000 cells per milliliter) at site WR-5 as compared with site WR-3 (72,000 cells per milliliter) and the high numbers of *Oscillatoria* and *Euglena* at site WR-5 indicate much higher enrichment at station WR-5. Furthermore, the calculation of Shannon's diversity index (Shannon and Weaver, 1949) for phytoplankton genera at the two sites results in an index of 1.9 for site WR-3 and an index of 0.1 for site WR-5. Diversity indices less than 1 indicate large concentrations of only a few species and usually are indicative of organic pollution.

Benthic Invertebrates

The benthic invertebrate classification includes those invertebrates that live on, in, or near the substratum of rivers, streams, or lakes during some period of their life cycle. Much work has been done using benthic invertebrates to assess water quality.

Because chemical studies give information on physical-chemical conditions only at the time of sampling, and because pollution surveys frequently cannot be made during the period of the most critical conditions, additional methods are needed that can be used throughout the year for determining the extent and severity of brief critical or limiting, environmental factors. The qualitative and quantitative composition of an aquatic population is determined by recurring critical conditions, even though of short duration, as well as the more stable or long-term environmental factors. Therefore, the complex of organisms that develops in a given area is, in turn, indicative of environmental conditions that have occurred during its development (Gaufin, 1976). Possible exceptions to this rule are some of the adult forms of the orders Coleoptera and Hemiptera. These organisms are atmospheric-air breathers; they may enter or leave the water at will and are generally not good indicators of water quality.

Benthic-invertebrate samples were collected from the biological-assessment stations (sites WR-3 and WR-5) by use of a hand net for a period of 15 minutes. Each site was sampled throughout 225 feet of river length. Both sites were large pools approximately 75 feet in width and 3.5 feet in depth. Site WR-3 had 10 feet of riffle, whereas site WR-5 had no riffles in the sampled reach. The organisms identified and the numbers found at each site are given in table 6.

A comparison of site WR-3 (upstream from the Fayetteville WWTP) with site WR-5 (downstream from the Fayetteville WWTP) reveals both similarities and differences between the benthic-invertebrate populations. Shannon's diversity index, an often used comparative tool, was 2.3 at the genus level for all organisms for site WR-3, whereas site WR-5 had a value of 2.6.

Table 6.--Benthic invertebrate identification, to genera, upstream and downstream from Fayetteville wastewater-treatment plant

[15-minute search by hand net; organisms per sample]

Scientific name	Common name	Station WR-3, White River upstream from treatment plant, October 7, 1980 (RM 683.5)	Station WR-5, White River downstream from treatment plant, October 8, 1980 (RM 681.8)
ANNELIDA			
.HIRUDINEA	Leeches		
..RHYNCHOBDELLIDA			
...GLOSSIPHONIIDAE			
....UNKNOWN GENUS		--	1
.OLIGOCHAETA	Aquatic earthworms		
..PLESIOPORA			
...TUBIFICIDAE			
....*BRANCHIURA*		--	2
ARTHROPODA	Arthropods		
.CRUSTACEA			
..AMPHIPODA	Scuds		
...TALITRIDAE			
....*HYALLELA*		1	--
..DECAPODA	Decapods		
...ASTACIDAE	Crayfish		
....UNKNOWN GENUS		--	1
.INSECTA			
..COLEOPTERA	Beetles		
...GYRINIDAE	Whirligig beetles		
....*GYRINUS*		--	1
...HALIPLIDAE	Crawling water beetle		
....*PELTODYTES*		--	1
...HYDROPHILIDAE	Water-scavenger		
....*BEROSUS*		--	1
..DIPTERA			
...CHIRONOMIDAE	Midges		
....*CHIRONOMUS*		--	52
....*GLYPTOTENDIPES*		--	8
....*POLYPEDILUM*		3	--
..EPHEMEROPTERA	Mayflies		
...BAETIDAE			
....*BAETIS*		2	--
...SIPHLONURIDAE			
....*ISONYCHIA*		32	--
..HEMIPTERA	True bugs		
...CORIXIDAE	Water boatmen		
....*TRICHOCORIXA*		--	35
...UNKNOWN			

Table 6.--Benthic invertebrate identification, to genera, upstream and downstream from Fayetteville wastewater-treatment plant--Continued

Scientific name	Common name	Station WR-3, White River upstream from treatment plant, October 7, 1980 (RM 683.5)	Station WR-5, White River downstream from treatment plant, October 8, 1980 (RM 681.8)
....UNKNOWN GENUS		--	1
..MEGALOPTERA	Megalopterans		
...CORYDALIDAE			
....*CORYDALUS*	Dobsonflies	2	--
..ODONATA	Dragonflies		
...AESHNIDAE			
....*BASIAESCHNA*		--	2
...AGRIIDAE	(Calopterygidae)		
....*HETAERINA*		2	--
...COENAGRIIDAE			
....*ENALLAGMA*		--	3
...LIBELLULIDAE			
....*MICRATHYRIA*		--	5
....*PERITHEMIS*		--	7
....*PLATHEMIS*		--	1
..TRICHOPTERA	Caddis flies		
...HYDROPSYCHIDAE			
....*CHEUMATOPSYCHE*		5	--
....*HYDROPSYCHE*	(Split genus 1979)	1	--
MOLLUSCA	Molluscs		
.GASTROPODA	Snails		
..BASOMMATOPHORA			
...PHYSIDAE	Pond snails		
....*PHYSA*		--	5

Using the index for genera of the class Insecta gives a value of 2.1 for the upstream station and 2.3 for the downstream station. Accepted without further analysis, this index shows the downstream station to be more diverse and, presumably, cleaner than the upstream station. In reality, however, the three dominant genera at site WR-3 (*Baetis*, *Cheumatopsyche*, and *Polypedilum*) are all listed by Hart and Fuller (1974) as being tolerant of biochemical oxygen demand greater than 5.9 mg/L but not tolerant of DO concentrations less than 4 mg/L. Of the three dominant genera at site WR-5 (*Chironomus*, *Glyptotendipes*, and *Trichocorixa*), the first two are of the family Chironomidae that has representatives tolerant of many chemical extremes including high biochemical oxygen demand and low DO concentrations. The Chironomids possess a hemoglobinlike blood pigment which aids in oxygen uptake under stressful conditions. The third dominant genera at site WR-5 are the *Trichocorixa* (water boatmen) which are atmospheric-air breathers and are therefore not affected by low DO concentrations in the stream.

A comparison of the dominant genera present at WR-3 and WR-5 indicates that, in contradiction to Shannons diversity index, site WR-3 is indeed cleaner than WR-5. Although several organisms at site WR-3 were tolerant of organic enrichment, they were not tolerant of low DO concentrations. This intolerance of low DO concentrations was especially true of the mayflies, caddis flies, and dobsonflies present at the site. Site WR-5 contained numerous organisms tolerant of organic enrichment, but a better indicator of overall water quality at the site was the presence of numerous organisms that were atmospheric-air breathers or had otherwise adapted to a low DO environment. Among these organisms were members of the following families: Tubificidae, Astacidae, Gyrinidae, Haliplidae, Hydrophilidae, Chironomidae, Corixidae, and Physidae. The presence of the order Odonata at site WR-5 during periods of apparent zero DO should be noted. These organisms were all taken very near the stream edge in a dense growth of aquatic macrophytes. These areas tend to isolate themselves from the main riverflow and may produce enough oxygen to prevent the death of river fauna during periods of low DO (Whitton, 1975). In summary, the benthic community indicates a degradation in water quality downstream from the effluent of the Fayetteville WWTP.

Fish

Fish were collected at the two biological-assessment sites (sites WR-3 and WR-5) on October 7-8, 1980. Fish genera and densities are given in table 7. The fish were collected by setting block nets at both ends of a 225-foot river reach and then seining toward the block nets. The seining was carried out for a 45-minute period. The fish were then collected, counted, identified, and an estimate was made of the weight of each fish. Because fish have the ability to swim away from unfavorable river conditions and then return upon subsequent river recovery, they are probably poor indicators of water quality. However, the contrast of the 43 live fish collected at site WR-3 with the 3 live and 16 dead fish collected at site WR-5 is sufficient evidence of a degradation of water quality downstream from the Fayetteville WWTP.

Table 7.--Fish genera and densities upstream and downstream from Fayetteville wastewater-treatment plant

[225 feet of river length sampled for each station by use of block nets and seine for a 45-minute period]

Scientific name	Common name	Station WR-3, White River upstream from treatment plant, October 7, 1980 (RM 683.5)		Station WR-5, White River downstream from treatment plant, October 8, 1980 (RM 681.8)	
		Number of individuals	Weight per individual (lb)	Number of individuals	Weight per individual (lb)
CHORDATA					
.OSTEICHTHYES					
..CLUPEIFORMES					
...CLUPEIDAE					
....*DOROSOMA CEPEDIANUM*	Gizzard shad	10	0.06	-----	-----
..CYPRINIFORMES					
...CYPRINIDAE					
....*CYPRINUS CARPIO*	Carp	1	3.00	-----	-----
....*CYPRINUS CARPIO*	do.	2	2.00	-----	-----
....UNKNOWN GENUS	Minnow	22	.03	2	0.03
...CATOSTOMIDAE					
....UNKNOWN GENUS	Sucker	2	3.00	-----	-----
..PERCIFORMES					
...CENTRARCHIDAE					
....*LEPOMIS MEGALOTIS*	Longear sunfish	2	.20	1(struggling)	.20
....*LEPOMIS MEGALOTIS*	do.			15(dead)	.20
....*MICROPTERUS SALMOIDES*	Largemouth bass	1	.50	-----	-----
..SEMIONOTIFORMES					
...LEPISOSTEIDAE					
....*LEPISOSTEUS OSSEUS*	Longnose gar	1	6.00	-----	-----
....*LEPISOSTEUS OSSEUS*	do.	2	2.00	-----	-----
..SILURIFORMES					
...ICTALURIDAE					
....*ICTALURUS PUNCTATUS*	Channel catfish			1(dead)	1.00

Fecal Coliform

The coliform bacteria are normal inhabitants of the large intestine of man and animals and have been used in water-quality assessments as indicators of fecal wastes. Recently, because some coliform bacteria can originate from nonfecal sources, an elevated temperature test was standardized (Greeson and others, 1977) to distinguish fecal coliform bacteria from those of other environmental sources.

Arkansas water-quality standards for a class A water (Arkansas Department of Pollution Control and Ecology, 1975), such as White River, for use as a source for public water supply or body contact recreation state that "based on a minimum of not less than five samples taken throughout not more than a 30-day period, the fecal coliform content shall not exceed a log mean of 200 per 100 milliters, nor shall more than 10 percent of samples during any 30-day period exceed 400 per 100 milliliters".

Four samples were collected at each of 13 sites during September and October 1980. Results are presented in table 2. Because of an equipment mal function at the Fayetteville WWTP during part of this period, a large variation in colony counts was observed in the river downstream from the WWTP effluent. The lowest observed count was one colony per 100 milliliters at site WR-4 immediately downstream from the Fayetteville WWTP, when the plant chlorinators were operating. The highest count was an estimated 9,200,000 colonies per 100 milliliters at site WR-5. Upstream from the WWTP, an increase in fecal coliform density was observed between site WR-2 and WR-3. Several cattle were observed watering in this reach and are a possible source of the increased counts. The large variations in fecal-coliform densities made it impossible to model the bacteria.

DIGITAL MODEL

To adequately appraise the "quality" of any environmental system for a given set of conditions and for a specific period of time, the investigator must know the criteria by which the "quality" of that system is judged. He must then, during this specific period of time, be able to collect sufficient quantities of appropriate data to evaluate the quality of that system according to the given criteria. This task can be time consuming and laborious, depending upon the size and complexity of the system being investigated. However, once the "quality" criteria for the system have been established for a given set of conditions, the course of action generally is clear and the task can be completed efficiently and accurately. In addition to defining the "quality" of the system, the investigator can probably identify the impacting processes.

In many instances, however, the primary need is to predict the effect of changing process impacts upon the quality of the system. This prediction is a much more complex task. The investigator must not only adequately appraise the existing quality of the system, he must also simulate the kinetics of the impacting processes. It is imperative to know:

1) The rates at which system processes change in form or magnitude;
2) the extent and nature of the coupling of these processes; and
3) how these changing processes affect the magnitude of those parameters by which the quality of the system is judged.

The most practical way to simulate such a system is with a mathematical model in which the most important processes of the system are represented numerically. This representation includes a description of system parameters, process reaction kinetics, and the coupling of related processes. Except for those systems that are very simple and uncomplicated, the only way to efficiently manage such a model is with a digital computer. The digital model has therefore become a very common tool in the environmental science field, as well as other scientific fields in which it is necessary to simulate complex, dynamic systems.

According to existing water-quality standards, the key criterion for determining the "quality" of a stream system is the instream concentration of DO. Various physical and biochemical components simultaneously impact the DO profile in a stream, resulting in both diel and spatial variations in DO concentration. Some of the components help replenish the DO, whereas others are consumers. Determining the assimilative capacity of a stream entails defining how large the oxygen-demanding processes can be before DO concentrations fall below standard.

Digital models are quite commonly used in assessing the capacity of streams to assimilate municipal and/or industrial wasteloads. Guidelines were released in March, 1980 by the Environmental Protection Agency, Region 6, for justifying advanced secondary treatment or advanced waste treatment of municipal sewage. Any perennial stream into which an effluent greater than 3 ft^3/s is to be discharged must be analyzed for assimilative capacity by using a calibrated and verified, steady-state digital water-quality model of the Streeter and Phelps (1925) variety. The White River, which receives an average discharge of 11.2 ft^3/s from the Fayetteville WWTP, falls within this criterion.

Description

A modified version of a one-dimensional, steady-state stream water-quality model, described by Bauer and others (1979), was used in this study. The model requires that flow rates and associated inflow constituents from all tributaries and waste discharges be constant. The model is based primarily on the Streeter-Phelps (1925) oxygen-sag equation.

Problem solution is achieved by dividing each reach of a modeled stream system into a number of subreaches. These subreaches generally are defined by the locations of waste or tributary inflow points. In addition to the inflow of waste or tributary sources at the head of each subreach, linear runoff (nonpoint flow) may be specified along any subreach. All constituents being modeled are assumed to be instantaneously and completely mixed within any stream cross section. The model can be used to simulate and predict concentrations of DO, CBOD, nitrogen forms, total and fecal coliform bacteria, PO_4-P and various conservative substances. Output from the model includes tabulations of those concentrations at user-defined fixed-distance intervals and profile plots of concentration versus river mile.

The basic model was modified by the authors of this report to correct some problems in the code and to provide the capability of simulating a more varied set of conditions for any given receiving stream. The primary modifications include the following:

1) The addition of a new subroutine to compute reaeration coefficients for each subreach by any one of eight predictive equations.
2) The addition of a temperature-correction factor for net photosynthetic DO production (gross photosynthesis minus algal respiration), as described by Krenkel and Novotny (1980, p. 397).
3) The imposition of an upper limit of saturation upon projected DO concentrations when projecting the assimilative capacity of a potential receiving stream, the "dependable" DO concentration in the stream should not be greater than saturation. When such conditions occur it is because of the projected effects of net photosynthetic production. Modifications have been made in the model so that, under such circumstances, only that part of photosynthetically produced DO needed to maintain saturation is retained in the water column; the "excess" is assumed lost to the atmosphere. However, if additional or larger demands are placed upon instream DO causing increased deficits, then what had been "excess photosynthesis" is available to maintain saturation until it is depleted.
4) The correction of DO mass-balance computations at point-source inflow locations. The problem that existed caused significant errors in DO concentrations at the beginning of a subreach where the point-source discharge was a significant part of the downstream flow and where the temperature of the point-source discharge was significantly different from the water temperature in the subreach. Further discussion of this problem may be found in attachment A, section IV.

To further increase the efficiency and utility of the model, several other minor modifications were made, including some changes in card input and printed output. A complete discussion of significant model modifications is included in Appendix A.

Calibration

The values of some of the components needed to describe the quality of a stream system numerically and the rates at which these components change in the system can be determined directly; the values of others must be determined by trial and error. Model calibration is the process by which these trial-and-error determinations are made. Calibration is considered successful when plausible values have been determined for all components and rate coefficients, and a sufficient similarity had been achieved between model results and observed data.

In this study, the variable constituents that are predictable include the following:

1) dissolved oxygen,
2) carbonaceous biochemical oxygen demand
3) nitrogen forms (organic-N, ammonia-N, NO_2-N NO_3-N), and
4) orthophosphate-P.

Those constituents and processes that directly impact the quality of the system, as defined by the instream concentration of DO, are:

1) carbonaceous biochemical oxygen demand,
2) nitrogen transformations,
3) benthic oxygen demand,
4) net photosynthesis, and
5) reaeration.

The values of the benthic oxygen demand and of the following rate coefficients are determined in the calibration process:

KR = Average CBOD decay rate for a subreach, day^{-1} (base *e*). Expressed as an average subreach instream rate coefficient.

KD = Average CBOD deoxygenation rate for a subreach, day^{-1} (base *e*). Expressed as an average subreach instream rate coefficient.

KØRG = Average organic-N forward-reaction coefficient for subreach, day^{-1} (base *e*). Expressed as an average subreach instream rate coefficient.

KNH3 = Average ammonia-N forward-reaction coefficient for a subreach, day^{-1} (base *e*). Expressed as an average subreach instream rate coefficient.

KNØ2 = Average NO_2-N forward-reaction coefficient for a subreach, day^{-1}. Expressed as an average subreach instream rate coefficient.

KNØ3 = Average NO_3-N decay rate for a subreach, day^{-1} (base *e*). Expressed as an average subreach instream rate coefficient.

SKØRG = Average organic-N decay rate for a subreach, day^{-1} (base *e*). Expressed as an average subreach instream rate coefficient.

SKNH3 = Average ammonia-N decay rate for a subreach, day^{-1} (base *e*). Expressed as an average subreach instream rate coefficient.

SKNØ2 = Average NO_2-N decay rate for a subreach, day^{-1} (base *e*). Expressed as an average subreach instream rate coefficient.

KPØ41 = Coefficient for stream bottom-deposit uptake rate in orthophosphate-P equation, day^{-1}. Expressed an an average subreach instream rate coefficient.

Some explanation of the dual-decay rates for CBOD, organic-N, ammonia-N, and NO_2-N is necessary.

CBOD is removed from the water column at a rate defined by *KR*. Part of this removal is due to decay and part may be the result of deposition. Actual decay of the material proceeds at a rate defined by *KD* such that $KD \leq KR$. If all removal is due to decay, then $KD = KR$. The nitrogen-cycle transformation is a coupled biologically mediated-sequential reaction involving the decay of organic-N to ammonia-N through NO_2-N to NO_3-N. The forward reaction of each nitrogen form to the next sequential nitrogen form and the associated concentration coupling is determined by the forward-reaction coefficient. These forward reactions--the transformation of one nitrogen form to another--generally are the most significant reactions. However, there are other possible reactions. These include the deposition of organic-N, plant utilization of ammonia-N, reduction of NO_3-N and NO_3-N to ammonia-N, and the escape as gas of unionized ammonia-N and molecular nitrogen. The rates at which these reactions occur are included in the decay-rate coefficients.

The decay rates describe the total rate of removal of the nitrogen forms from the water; whereas, the forward-reaction coefficients describe the rate at which one form of nitrogen decays sequentially forward to the next form. Therefore, each decay rate should always be greater than, or equal to, its associated forward-reaction coefficient. The rate at which nitrate is utilized is described by the nitrate-N-decay rate, which includes reduction of nitrate-N to ammonia-N and, primarily, plant utilization of nitrate-N.

Two independent synoptic data sets were collected; one set in September and one in October 1980, as discussed in the data-collection section. It was intended that these two data sets be used to calibrate and verify the White River model. During both synoptic-sampling periods, morning and afternoon samples were collected and analyzed. The average of these two analyses was considered most representative of average conditions the day of collection. In the following discussions, "October data set" will mean the average of data collected on October 7, 1980, and "September data set" will mean the average of data collected on September 24, 1980.

The river reach to be modeled was divided into 10 subreaches, as shown in figure 1. The beginning of each subreach is based upon a point-source inflow or a distinct change in channel geometry.

Attempted Simulation

After all the data were analyzed and compiled, efforts were begun to calibrate the model using the October data set. Discrepancies in discharge mass balances could not be explained by natural gains and losses along the channel. There were also abrupt changes in the slope of observed constituent profiles at points where they could not be reasonably explained by either point- or nonpoint-source inflow. These conditions were exhibited in a reach of the river downstream from the Fayetteville WWTP. There seemed to be a real possibility that in these reaches both discharge and constituent transport were unsteady.

During the October sampling period, flows in the White River upstream from the Fayetteville WWTP were less than the estimated 7-day 10-year low flow and were steady. Downstream from the plant, as much as 90 percent of the flow in the river is waste discharge (table 2). Therefore, the most logical explanation for the apparent unsteady flow and constituent transport conditions in the reaches downstream from the plant seemed to be variable flows and constituent concentrations being discharged from the plant. The synoptic data collected for the effluent (table 2) indicates some variation between morning and afternoon samplings and between sampling periods. Additional discharge data obtained from the Fayetteville WWTP (fig. 2) indicate more than a 100 percent variation in flow during some 24-hour periods. Additional continuous data on effluent constituent concentrations were not available.

The concept of "steady-state" conditions in a stream implies that, the discharge and water quality measured at a particular point along the stream would not vary significantly with time. When this basic assumption is violated, "real" steady-state conditions do not exist. When standard steady-state data-collection techniques are used under such circumstances, many varying "parcels" of water may be sampled. These "parcels" cannot be properly simulated with a steady-state model.

Under present conditions, the White River downstream from the Fayetteville WWTP probably never experiences steady-state conditions, especially during low-flow periods. For all of the preceding reasons, it was impossible to calibrate a steady-state model of the White River using the October data set and verify it with the September data set or vice versa.

The upper White River is a very unusual and complex system. The best way to model the system would be to collect enough continuous data to calibrate and verify an unsteady-flow and constituent-transport model. However, this was not feasible, because of a shortage of both time and funds. The next best course of action would be to have enough synoptic data to define "average" conditions throughout the complete range in flow and constituent concentrations for the Fayetteville WWTP effluent and then use these data to calibrate a steady-state model for "average" conditions. Unfortunately, there are not enough synoptic data available to cover the entire range of effluent constituent concentrations and flows. However, the data that were collected during the September and October, 1980 sampling periods reflect some variation in both quantity and quality of the effluent. It was therefore decided that these data would be averaged and used to calibrate a steady-state model. This procedure was considered by the authors to be the best analysis possible within the given time-frame.

Alternate Simulation

Averaging the September and October data sets seemed to "smooth out" many of the discrepancies that existed in each one. Model calibration for conditions described by this "average" data set was successful. The results are contained in Attachment B.

Velocities computed using measured discharges and observed "average" channel geometry did not agree with velocities determined from time-of-travel data. This discrepancy indicated that the observed "average" subreach channel geometry was not representative of the subreach in which it was observed. Significant errors in channel geometry can cause substantial errors in computed reaeration coefficients and the model application of benthic oxygen demands.

The average of time-of-travel data collected during the September and October sampling periods (table 1) was used to "fit" subreach channel geometry so that computed and observed mean velocities would be equal. Computed mean velocities are given in table 8. In the fitting process, average cross-sectional areas were modified to adjust computed velocities. Observed width-to-depth ratios were maintained as follows:

$$W_o D_o = A_o,$$
$$D_o = A_o/W_o,$$
$$A_o/W_o = A_f/W_f,$$
$$W_f = A_f W_o/A_o, \text{ and}$$
$$D_f = A_f/W_f,$$

where,

W_o, W_f = observed and fitted mean channel width,
D_o, D_f = observed and fitted mean channel depth, and
A_o, A_f = observed and fitted mean cross-sectional area.

Attachment B-6 shows the mean channel geometry for each subreach derived in this manner.

Reaeration coefficients for each subreach were computed by a predictive equation developed by Hirsch (1980), from previous work by Velz (1970). This equation is described in Attachment A. Mean velocities in the White River were very slow (table 1). Under such conditions, most reaeration equations that are dependent upon mean velocity tend to under predict the reaeration coefficient. For this reason, the Velz equation, which uses only channel depth as an independent variable, was chosen. The computed reaeration coefficients are shown in Attachment B-7.

Values for net photosynthetic dissolved-oxygen production were derived for each sampling station where diel-DO and temperature measurements were made (table 4). Values for each subreach were then computed by interpolation using a distance-weighting procedure. These interpolated values, temperature corrected to 20° C, are shown in Attachment B-6.

Table 12.--Distributed average dissolved-oxygen deficits, by subreach, for simulations that include projected changes in CBOD5 and ammonia nitrogen concentrations from the Fayetteville wastewater-treatment plant

[Deficits in milligrams per liter]

Flow and tempera-ture con-ditions	Sub-reach no.	Ben-thal def-icit	CBOD5=30 mg/L Ammonia=No change: CBOD def-icit	Ammo-nia def-icit	Ni-trite def-icit	Net photo-syn-thetic deficit	CBOD5=20 mg/L Ammonia=10 mg/L: CBOD def-icit	Ammo-nia-def-icit	Ni-trite def-icit	Net photo-syn-thetic deficit	CBOD5=10 mg/L Ammonia=10 mg/L: CBOD def-icit	Ammo-nia def-icit	Ni-trite def-icit	Net phot syn thet defic
Initial river	1	4.443	0.134	0.041	0.014	-1.617	0.134	0.041	0.014	-1.617	0.134	0.041	0.014	-1.617
discharge =	2	.539	.140	.004	.001	-.470	.140	.004	.001	-.470	.140	.004	.001	-.470
7-day 10-	3	.510	.318	.036	.005	-.112	.215	.085	.006	-.112	.110	.085	.006	-.112
year low	4	.384	.422	.125	.039	-.194	.285	.191	.063	-.195	.148	.191	.063	-.195
flow.	5	.369	.343	.155	.060	-.418	.233	.154	.064	-.418	.121	.154	.064	-.418
	6	.397	.220	.072	.026	-.658	.148	.037	.015	-.568	.077	.037	.015	-.568
Water tempera-	7	.198	.160	.068	.016	-.466	.110	.019	.006	-.333	.060	.219	.006	-.280
ture = 29° C.	8	.572	.840	.378	.114	-1.905	.570	.064	.026	-1.230	.295	.064	.026	-.958
	9	.220	.110	.040	.006	-.357	.080	.005	.001	-.301	.040	.005	.001	-.265
	10	.475	.288	.344	.110	-.982	.202	.010	.004	-.691	.105	.010	.004	-.595
Initial river	1	3.047	.113	.035	.011	-.964	.113	.035	.011	-.964	.113	.035	.011	-.964
discharge =	2	.380	.131	.011	.003	-.288	.120	.011	.003	-.288	.131	.011	.003	-.288
7-day 10-	3	.294	.220	.016	.002	-.056	.150	.039	.002	-.056	.080	.039	.002	-.056
year low	4	.216	.300	.046	.014	-.095	.204	.089	.024	-.095	.106	.089	.024	-.095
flow	5	.207	.262	.074	.026	-.204	.178	.113	.043	-.204	.090	.113	.043	-.204
	6	.224	.181	.064	.021	-.323	.123	.078	.028	-.323	.064	.078	.028	-.323
Water tempera-	7	.108	.132	.068	.014	-.374	.090	.072	.017	-.374	.050	.072	.017	-.325
ture = 19° C.	8	.316	.725	.324	.097	-1.693	.490	.286	.100	-1.287	.255	.286	.100	-.962
	9	.121	.100	.030	.005	-.170	.070	.023	.024	-.170	.030	.023	.004	-.170
	10	.264	.300	.284	.080	-.473	.206	.078	.027	-.473	.109	.087	.027	-.461

Flow and tempera-ture con-ditions	Sub-reach no.	CBOD5=10 mg/L Ammonia= 5 mg/L: CBOD def-icit	Ammo-nia def-icit	Ni-trite def-icit	Net photo syn-thetic deficit	CBOD5=10 mg/L Ammonia= 3 mg/L: CBOD def-icit	Ammo-nia def-icit	Ni-trite def-icit	Net photo syn-thetic deficit	CBOD5=5 mg/L Ammonia=2 mg/L: CBOD def-icit	Ammo-nia def-icit	Ni-trite def-icit	Net photo syn-thetic deficit
Initial river	1	0.134	0.041	0.014	-1.617	0.134	0.041	0.014	-1.617	0.134	0.041	0.014	[illegible]
discharge =	2	.140	.004	.001	-.470	.140	.004	.001	-.470	.140	.004	.001	[illegible]
7-day 10-	3	.110	.042	.005	-.112	.110	.025	.004	-.112	.060	.017	.004	[illegible]
year low	4	.148	.096	.035	-.194	.148	.057	.023	-.195	.080	.038	.018	[illegible]
flow.	5	.121	.077	.032	-.417	.121	.046	.019	-.418	.065	.031	.013	[illegible]
	6	.077	.021	.007	-.520	.077	.011	.005	-.508	.040	.008	.003	[illegible]
Water tempera-	7	.060	.018	.003	-.268	.060	.006	.002	-.263	.030	.004	.001	[illegible]
ture = 29° C.	8	.295	.032	.012	-.913	.295	.020	.008	-.896	.165	.013	.006	[illegible]
	9	.040	.002	.000	-.262	.040	.001	.000	-.261	.020	.001	.000	[illegible]
	10	.105	.006	.002	-.588	.105	.003	.001	-.585	.058	.002	.001	[illegible]
Initial river	1	.113	.035	.011	-.964	.113	.035	.011	-.964	.113	.035	.011	[illegible]
discharge =	2	.131	.011	.003	-.288	.131	.011	.003	-.288	.131	.011	.003	[illegible]
7-day 10-	3	.080	.020	.002	-.056	.080	.012	.002	-.056	.040	.008	.002	[illegible]
year low	4	.106	.045	.015	-.095	.106	.027	.011	-.095	.060	.018	.010	[illegible]
flow	5	.090	.056	.022	-.204	.090	.034	.014	-.204	.050	.023	.010	[illegible]
	6	.064	.039	.014	-.323	.064	.024	.008	-.322	.036	.016	.006	[illegible]
Water tempera-	7	.050	.036	.008	-.224	.050	.022	.005	-.182	.030	.014	.004	[illegible]
ture = 19° C.	8	.255	.143	.050	-.768	.255	.086	.030	-.692	.140	.058	.020	[illegible]
	9	.030	.012	.002	-.169	.030	.007	.001	-.164	.020	.005	.001	[illegible]
	10	.109	.039	.014	-.425	.109	.023	.008	-.393	.060	.016	.005	[illegible]

82-406

Table 11.--White River model simulation summary

Initial river conditions: Discharge (ft³/s)	Initial river conditions: Dissolved oxygen (mg/L)	Fayetteville treatment-plant effluent: Discharge (ft³/s)	Fayetteville: Dissolved oxygen (mg/L)	Fayetteville: CBOD5 (mg/L)	Fayetteville: Total ORG-N (mg/L)	Fayetteville: Total NH3-N (mg/L)	Fayetteville: Total NO2-N (mg/L)	Fayetteville: Total NO3-N (mg/L)	Fayetteville: Total PO4-P (mg/L)	Water temperature (° C)	Minimum downstream dissolved-oxygen concentration and location: Mg/L	Minimum downstream DO location: River mile	Projected concentrations and loadings to Beaver Lake: Discharge (ft³/s)	Projected: Dissolved oxygen (mg/L)	CBOD5 Mg/L	CBOD5 Lb/d	Total ORG-N Mg/L	Total ORG-N Lb/d	Total NH3-N Mg/L	Total NH3-N Lb/d	Total NO2-N Mg/L	Total NO2-N Lb/d	Total NO3-N Mg/L	Total NO3-N Lb/d	Total PO4-P Mg/L	Total PO4-P Lb/d
1.37	3.8	11.2	7.8	30	15	4.1	0.13	2.6	8.1	29	4.6	681.2	12.97	7.5	5.0	352	0.02	1.4	.09	6.3	.02	1.4	.63	44.0	0.62	43.0
1.37	3.8	11.2	7.8	20	-----	10.0	.13	2.6	8.1	29	4.7	681.4	12.97	7.5	3.4	239	.01	.7	.02	1.4	.00	.0	.63	44.0	.62	43.0
1.37	3.8	11.2	7.8	10	-----	10.0	.13	2.6	8.1	29	5.2	681.4	12.97	7.5	1.8	126	.01	.7	.02	1.4	.00	.0	.63	44.0	.62	43.0
1.37	3.8	11.2	7.8	10	-----	5.0	.13	2.6	8.1	29	5.7	681.6	12.97	7.5	1.8	126	.01	.7	.01	.7	.00	.0	.32	22.4	.62	43.0
1.37	3.8	11.2	7.8	10	-----	3.0	.13	2.6	8.1	29	5.9	681.6	12.97	7.5	1.8	126	.01	.7	.01	.7	.00	.0	.20	14.0	.62	43.0
1.37	3.8	11.2	7.8	5	-----	2.0	.13	2.6	1.0	29	6.2	682.0	12.97	7.5	1.0	69.0	.01	.7	.01	.7	.00	.0	.14	9.8	.08	5.3
1.37	4.5	11.2	9.2	30	15	4.1	.13	2.6	8.1	19	6.4	680.9	12.97	7.6	9.4	655	.84	58.7	1.5	105	.23	16.1	1.7	121	2.5	175
1.37	4.5	11.2	9.2	20	-----	10.0	.13	2.6	8.1	19	6.7	680.9	12.97	8.8	6.4	446	.03	2.1	.68	47.5	.12	8.4	1.9	135	2.5	175
1.37	4.5	11.2	9.2	10	-----	10.0	.13	2.6	8.1	19	7.2	680.9	12.97	9.2	3.4	236	.03	2.1	.68	47.5	.12	8.4	1.9	135	2.5	175
1.37	4.5	11.2	9.2	10	-----	5.0	.13	2.6	8.1	19	7.5	681.0	12.97	9.2	3.4	236	.03	2.1	.34	23.8	.06	4.2	1.0	72.0	2.5	175
1.37	4.5	11.2	9.2	10	-----	3.0	.13	2.6	8.1	19	7.6	681.0	12.97	9.2	3.4	236	.03	2.1	.21	14.7	.04	2.8	.67	46.8	2.5	175
1.37	4.5	11.2	9.2	5	-----	2.0	.13	2.6	1.0	19	8.0	681.2	12.97	9.2	1.9	131	.03	2.1	.14	9.8	.02	1.4	.49	34.3	.31	21.7
1.37	3.8	[a]5.6	7.8	5	-----	2.0	.13	2.6	8.1	29	6.2	682.3	7.37	7.5	.29	11.6	.01	.7	.00	.00	.00	.0	.04	2.8	.08	3.2
b2.37	[c]3.8	11.2	7.8	10	-----	10.0	.13	2.6	8.1	29	5.3	681.4	13.97	7.5	2.0	153	.02	1.5	.03	2.3	.01	.8	.68	51.2	.68	51.2
b2.37	[d]7.8	11.2	7.8	10	-----	10.0	.13	2.6	8.1	29	5.3	681.4	13.97	7.5	2.0	153	.02	1.5	.03	2.3	.01	.8	.68	51.2	.68	51.2
e5.37	[c]3.8	11.2	7.8	10	-----	10.0	.13	2.6	8.1	29	5.4	681.2	16.97	7.5	2.7	248	.09	8.2	.08	7.3	.01	.9	.81	74.1	.84	76.6
e5.37	[d]7.8	11.2	7.8	10	-----	10.0	.13	2.6	8.1	29	5.4	681.2	16.97	7.5	2.7	248	.09	8.2	.08	7.3	.01	.9	.81	74.1	.84	76.6
b2.37	[c]3.8	11.2	7.8	5	-----	2.0	.13	2.6	8.1	29	6.2	681.9	13.97	7.5	1.2	89.4	.02	1.5	.01	.8	.00	.0	.15	11.3	.68	51.2
b2.37	[d]7.8	11.2	7.8	5	-----	2.0	.13	2.6	8.1	29	6.2	681.9	13.97	7.5	1.2	89.4	.02	1.5	.01	.8	.00	.0	.15	11.3	.68	51.2
e5.37	[c]3.8	11.2	7.8	5	-----	2.0	.13	2.6	8.1	29	6.2	681.7	16.97	7.5	1.8	164	.09	8.2	.02	1.8	.00	.0	.19	17.4	.84	76.6
e5.37	[d]7.8	11.2	7.8	5	-----	2.0	.13	2.6	8.1	29	6.2	681.7	16.97	7.5	1.8	164	.09	8.2	.02	1.8	.00	.0	.19	17.4	.84	76.6
1.37	3.8	[e]15.2	7.8	6.5	.26	1.7	.10	1.9	6.0	29	6.2	681.7	16.97	7.5	1.8	166	.17	15.5	.04	3.7	.01	.9	.22	20.1	.84	76.6

Reflects 50-percent reduction in flow from wastewater-treatment plant.
Reflects 1-cubic-foot-per-second-flow augmentation from Lake Sequoyah.
Reflects observed percent saturation of Lake Sequoyah discharge.

[d] Reflects saturation of Lake Sequoyah discharge.
[e] Reflects 4-cubic-foot-per-second-flow augmentation from Lake Sequoyah.

Table 8.--Traveltime and mean velocity as simulated during model calibration for "average" conditions

Sub-reach no.	Beginning mile	Ending mile	Discharge (ft^3/s)	Mean velocity (ft/s)	Travel time (h)
1	684.7	684.0	3.1	0.023	44.6
2	684.0	682.9	3.9	.020	79.9
3	682.9	682.3	13.2	.080	11.0
4	682.3	680.9	12.1	.081	25.2
5	680.9	679.4	12.0	.076	29.0
6	679.4	677.8	12.4	.087	26.9
7	677.8	677.4	12.4	.111	5.28
8	677.4	677.2	12.6	.020	14.9
9	677.2	677.1	18.7	.204	.72
10	677.1	673.8	17.9	.050	96.72

Values for benthic demand in each subreach were determined by calibration. These benthic demands, at 20° C, are shown in Attachment B-6. Calibrated benthic demands are not comparable to the measured streambed oxygen demands (table 2). The calibrated benthic demands represent the respiration of organisms living in and attached to the streambed sediments, as well as those that are attached to any other substrate in the stream. Other substrates may include bedrock outcrops, aquatic macrophytes, logs and trees, and large rocks and boulders. Respiration of fish is also "lumped" into this component. The measured streambed oxygen demand is then, by definition, only a part of the total benthic demand. Even in a stream where the only substrate from which a demand is being exerted is the bottom sediments, the benthic demand and the measured streambed oxygen demand may not be comparable because of the spacial variability; the first represents a "subreach average", the latter is the result of a "point sample."

Attachment B-7 shows final values for all rate coefficients. In several subreaches, the removal rates are higher than deoxygenation rates for carbonaceous material and decay rates for nitrogenous substances are higher than the forward-reaction coefficients. These relationships indicate that under existing conditions there is significant stream-bottom uptake and deposition of nutrients occurring, which contributes to the high benthic demands observed.

The "goodness of fit" reached for the predicted variable components during calibration is illustrated by plots of computed and observed data versus stream distance (Attachments B-11 through B-17). A reasonable similarity between computed- and observed-concentration profiles was attained for each component.

Table 9 shows the average DO deficits caused in each subreach. Under existing conditions, the most significant DO sink in each subreach is the benthic demand. It also seems apparent that net photosynthetic production in each subreach is an important source of DO.

Projections

Simulations were made for the following projected effluent concentrations from the Fayetteville WWTP:

1) CBOD5 = 30 mg/L, DO = saturation.
2) CBOD5 = 20 mg/L, ORG-N = 0.0 mg/L, NH3-N = 10 mg/L, DO = saturation.
3) CBOD5 = 10 mg/L, ORG-N = 0.0 mg/L, NH3-N = 10 mg/L, DO = saturation.
4) CBOD5 = 10 mg/L, ORG-N = 0.0 mg/L, NH3-N = 5 mg/L, DO = saturation.
5) CBOD5 = 10 mg/L, ORG-N = 0.0 mg/L, NH3-N = 3 mg/L, DO = saturation.
6) CBOD5 = 5 mg/L, ORG-N = 0.0 mg/L, NH3-N = 2 mg/L, DO = saturation.

Table 9.--Average dissolved-oxygen deficits, by subreach, for existing conditions as simulated in model calibration

[In milligrams per liter]

Subreach no.	Net photo-synthetic deficit	Benthal deficit	CBOD deficit	Ammonia deficit	Nitrite deficit
1	-0.647	2.073	0.065	0.014	0.004
2	-.168	.224	.070	.007	.001
3	-.075	1.616	.772	.022	.002
4	-.104	1.038	.526	.049	.016
5	-.216	1.065	.242	.068	.025
6	-.315	1.393	.100	.044	.016
7	-.360	.469	.070	.044	.010
8	-1.848	1.428	.360	.183	.060
9	-.110	.365	.040	.008	.001
10	-.342	.305	.130	.055	.016

All of the preceding projections are the result of secondary or further sewage effluent treatment. Under such conditions, the instream CBOD removal rate is equal to the instream deoxygenation rate. It is necessary, however, to redefine the instream deoxygenation rates in terms of the projected changes in CBOD loading to the river. Because the Fayetteville WWTP is the primary source of CBOD loading in the White River downstream from its point of entry, it is assumed that any change in the instream deoxygenation rates in these reaches is related to the projected deoxygenation rate for the WWTP effluent.

When the treatment of sewage wastes is secondary or better, the ratio of CBODU/CBOD5 in the effluent is assumed to be 1.5 (Velz, 1970, p. 145). Given the value of CBOD5, the value of CBODU can be readily computed by:

$$CBODU = 1.5(CBOD5),$$

then substituting these values into the following equation

$$CBOD5 = CBODU(1-e^{-kt}),$$

where,

$$t = 5 \text{ days},$$

yields a new value for the CBOD rate, k , in the treatment-plant effluent.

$$CBOD5 = 1.5(CBOD5) - 1.5(CBOD5)(e^{-5k})$$

$$1 = 1.5 - 1.5(e^{-5k})$$

$$0.33 = e^{-5k}$$

$$-1.11 = -5k$$

$$k = 0.22 \text{ day}^{-1}$$

Because of the assumption that $CBODU = 1.5(CBOD5)$, this coefficient would be applicable to all of the effluent projections.

The carbonaceous deoxygenation coefficient for the WWTP effluent under existing conditions is 0.11 day^{-1} (table 2). In their discussion of carbonaceous deoxygenation coefficients, O'Connor and Mueller (1980) state that; "In general, the coefficient of the river water is usually less than the coefficient of an undiluted sample. The coefficient depends on the nature of wastewater and river water, the age of the sample and the dilution . . . Furthermore, the coefficient tends to decrease in downstream direction indicating the more readily oxidizable substances, the availability of foods and the progressive resistance to oxidation of the more stable end products." Model calibration indicates that for existing conditions a part of this premise is violated in the White River under conditions of low river-flow and minimal dilution. Deoxygenation coefficients for the river are significantly higher than for the Fayetteville WWTP effluent (table 2). However, the river coefficients generally decrease downstream after peaking approximately 2.0 miles downstream from the WWTP. This condition indicates that only after reaching subreach 4 has the effluent oxidized sufficiently to meet the condition $CBODU = 1.5(CBOD5)$.

The ratio of new rate coefficient to old rate coefficient for the treatment plant, *0.22/0.11* in this case, is often used as a multiplier to obtain new projected CBOD instream decay rate coefficients. However, to do this would perpetuate the condition of higher rate coefficients in the river than in the effluent. Velz and Gannon (1962) define a coefficient β which describes a boundary effect of absorption by biological slimes attached to a solid bottom. A factor, m, was defined as the reciprocal of the ratio *0.22/0.11* plus β such that;

$$m = (1/2.0) + \beta$$

where,

$$\beta = 0.08$$

The factor m was then used as a multiplier, such that;

$$\textit{new instream rate coefficient} = m \times (\textit{old instream rate coefficient}),$$

to obtain projected instream CBOD decay rate coefficients for each subreach downstream from the WWTP. Such a procedure for reducing instream rate coefficients is somewhat arbitrary. However, after treatment, the deoxygenation rate coefficient should decrease with decreasing CBOD concentration. Such relationships have been noted by other investigators such as Kittrell and Kochtitzky (1947) on the Holston River in Wisconsin.

With the advanced treatment process, it is assumed that no deposition of carbonaceous material would occur and $KD = KR$. The product of the observed instream deoxygenation rates (KD in Attachment B-7) and m yields projected instream CBOD decay rates for the effluent projections analyzed. Table 10 contains the CBOD decay rates that were used in all the projections.

There are no projected organic-N concentrations in the WWTP discharge for effluent projections 2, 3, 4, 5, and 6. Therefore, the observed forward-reaction coefficient and decay rate in subreach 3 are assumed valid in all downstream subreaches. Table 10 contains all the organic-N forward-reaction coefficients and decay rates used in the simulations for effluent projections 2, 3, 4, 5, and 6. Because there was no reduction in organic-N in effluent projection 1, the simulation for this condition uses organic-N forward-reaction coefficients and decay rates equal to those derived in calibration (Attachment B-7).

Because little or no deposition of organic matter would occur with any of the proposed effluent projections, benthic demands would become smaller and smaller and eventually stabilize at lower levels than those observed. There is not a direct relation for determining the magnitude of these reductions. It was assumed that for existing conditions the benthic demand determined through calibration for subreach 2 is representative of background conditions upstream from the WWTP and that the calibrated benthic demand in subreach 10 is representative of "recovered" conditions downstream from the WWTP. Therefore, an average of these two values was used for benthic demand in each subreach downstream from the WWTP for every simulated projection made. These values are shown in table 10.

Table 10.--Modified components and rate coefficients for simulated effluent projections

Sub-reach no.	CBOD *KD* (day^{-1})	CBOD *KR* (day^{-1})	ORG-N *KORG* (day^{-1})	ORG-N *SKORG* (day^{-1})	Benthic demand $(g/m^2)/d$
1	0.03	0.03	0.02	0.20	6.3
2	.03	.03	.02	.15	.7
3	.08	.08	.02	.02	1.75
4	.13	.13	.02	.02	1.75
5	.12	.12	.02	.02	1.75
6	.11	.11	.02	.02	1.75
7	.10	.10	.02	.02	1.75
8	.10	.10	.02	.02	1.75
9	.12	.12	.02	.02	1.75
10	.10	.10	.02	.02	1.75

Simulations for effluent projections 1 through 6 were made for 7-day 10-year low-flow conditions with water temperatures of 29° C to reflect summer time low-flow conditions and with water temperatures of 19° C to reflect fall low-flow conditions. The results of these simulations are shown in table 11. Average DO deficits caused by oxygen sinks in each subreach are shown in table 12. Deficits resulting from the benthic demands are the most significant. At water temperatures of 29° C, the only simulation in which DO concentration downstream from the WWTP does not fall below 6.0 mg/L is for effluent projection number 6. At water temperatures of 19° C, for effluent projections 2, 3, 4, 5, and 6, downstream DO concentrations are 6.0 mg/L or greater.

Ten additional simulations were made reflecting either a modification in the quantity of flow from the Fayetteville WWTP or initial river-flow augmentation from Lake Sequoyah. Each of these simulations was made for water temperatures of 29° C.

Using the effluent concentrations of projection 6, an additional simulation was run in which a 50-percent reduction in flow from the Fayetteville WWTP was assumed. Although this procedure caused a reduced wasteload, it also reduced velocities and increased instream-reaction times. Consequently, the minimum DO concentration in the downstream-profile was unchanged (table 11). However, because of the increased reaction times, all nutrient concentrations and loadings to Beaver Reservoir were reduced (table 11). Table 13 gives the average DO deficits caused in each subreach for these additional simulations. Differences between deficits for effluent projection 6 at water temperatures of 29° C in table 12 and those in table 13 are because of instream constituent-loading differences and changes in reaction times.

Assuming the same treatment level at the Fayetteville WWTP as reflected in effluent projection 6, an augmentation of 4 ft^3/s was imposed at the effluent discharge point. Constituent concentrations reflect a discharge-weighted average of those concentrations in effluent projection 6 and those observed in the Lake Sequoyah discharge. DO was assumed saturated. There was no perceptible change in the minimum downstream DO concentration. Because of increased velocities and decreased reaction times, all nutrient concentrations and loadings to Beaver Reservoir increased (table 11).

Initial river-flow augmentations of 1 ft/s and 4 ft^3/s from Lake Sequoyah were simulated. Initial DO concentrations in the river were simulated as saturated and as containing the same percent saturation as was observed. Effluent projections 3 and 6 were simulated under these conditions. The minimum downstream DO concentrations were not significantly different from those simulated for the basic effluent projections 3 and 6. However, because of increased velocities and decreased reaction times, all nutrient concentrations and loadings to Beaver Lake increased (table 11).

Concentrations of 8.1 mg/L orthophosphate-P were observed in the Fayetteville WWTP effluent. Simulations indicated that reducing this concentration to 1.0 mg/L would reduce the orthophosphate-P loading to Beaver Lake from 43 pounds per day to 5.3 pounds per day (table 11).

Table 13.--Distributed average dissolved-oxygen deficits, by subreach, for those simulations with modified river or effluent discharges

[Deficits in milligrams per liter]

Flow and temperature conditions	Subreach number	Benthal deficit	CBOD5 = 10 milligrams per liter, Ammonia = 10 milligrams per liter: CBOD deficit	Ammonia deficit	Nitrite deficit	Net photosynthetic deficit	CBOD5 = 5 milligrams per liter, Ammonia = 2 milligrams per liter: CBOD deficit	Ammonia deficit	Nitrite deficit	Net photosynthetic deficit
Initial river discharge	1	3.564	0.114	0.047	0.016	-1.297	0.114	0.047	0.016	-1.297
= 7-day 10-year low	2	.445	.133	.009	.003	-.387	.133	.009	.003	-.387
flow + 1 ft^3/s augmen-	3	.481	.107	.074	.005	-.106	.060	.015	.004	-.106
tation from Lake Se-	4	.360	.141	.167	.055	-.183	.082	.034	.016	-.183
quoyah with dissolved	5	.345	.118	.142	.059	-.391	.067	.028	.012	-.391
oxygen at observed	6	.373	.076	.039	.016	-.525	.043	.008	.003	-.437
concentration or at	7	.185	.060	.022	.006	-.269	.030	.004	.001	-.223
saturation.	8	.534	.295	.075	.030	-.932	.170	.015	.006	-.724
	9	.205	.040	.006	.001	-.251	.020	.001	.000	-.229
Water temperature 29° C.	10	.445	.108	.013	.005	-.570	.063	.003	.001	-.511
Initial river discharge	1	2.147	.070	.039	.012	-.782	.070	.039	.012	-.781
= 7-day 10-year low	2	.277	.094	.017	.003	-.241	.094	.010	.003	-.241
flow + 4 ft^3/s augmen-	3	.409	.090	.052	.004	-.090	.060	.011	.003	-.090
tation from Lake Se-	4	.303	.124	.118	.038	-.154	.082	.024	.013	-.154
quoyah with dissolved	5	.290	.106	.113	.047	-.329	.070	.024	.010	-.329
oxygen at observed	6	.314	.071	.042	.017	-.466	.048	.009	.003	-.387
concentration or at	7	.153	.050	.028	.008	-.242	.033	.006	.002	-.196
saturation.	8	.446	.285	.101	.038	-.868	.185	.022	.008	-.662
	9	.171	.040	.008	.002	-.218	.020	.002	.000	-.198
Water temperature 29° C.	10	.372	.111	.021	.008	-.512	.074	.005	.002	-.453

Table 13.--Distributed average dissolved-oxygen deficits, by subreach, for those simulations with modified river or effluent discharges--Continued

[Deficits in milligrams per liter]

Flow and temperature conditions	Subreach number	Benthal deficit	CBOD5 = 10 milligrams per liter, Ammonia = 10 milligrams per liter: CBOD deficit	Ammonia deficit	Nitrite deficit	Net photosynthetic deficit	CBOD5 = 5 milligrams per liter, Ammonia = 2 milligrams per liter: CBOD deficit	Ammonia deficit	Nitrite deficit	Net photosynthetic deficit
Initial river discharge	1	4.443	--	--	--	--	0.013	0.041	0.014	-1.617
= 7-day 10-year low	2	.539	--	--	--	--	.140	.004	.001	-.470
flow.	3	.776	--	--	--	--	.092	.023	.006	-.171
Water temperature = 29° C.	4	.611	--	--	--	--	.120	.051	.022	-.310
Discharge from waste-	5	.590	--	--	--	--	.076	.025	.011	-.669
water treatment plant	6	.628	--	--	--	--	.044	.001	.001	-.674
reduced 50 percent,	7	.337	--	--	--	--	.030	.000	.000	-.369
dissolved oxygen at	8	.937	--	--	--	--	.155	.001	.000	-1.094
saturation.	9	.364	--	--	--	--	.020	.000	.000	-.386
	10	.772	--	--	--	--	.043	.000	.000	-.816
Initial river discharge	1	4.443	--	--	--	--	.134	.041	.014	-1.617
= 7-day 10-year low	2	.539	--	--	--	--	.140	.004	.001	-.470
flow.	3	.409	--	--	--	--	.060	.012	.002	-.090
Water temperature = 29° C.	4	.302	--	--	--	--	.084	.028	.013	-.154
Discharge from waste-	5	.290	--	--	--	--	.071	.027	.011	-.329
water treatment plant	6	.314	--	--	--	--	.049	.010	.004	-.417
increased by 4 ft^3/s	7	.153	--	--	--	--	.038	.007	.002	-.197
from Lake Sequoyah,	8	.446	--	--	--	--	.185	.026	.010	-.670
with dissolved oxygen	9	.171	--	--	--	--	.030	.002	.000	-.199
at saturation.	10	.372	--	--	--	--	.074	.007	.002	-.456

Sensitivity Analysis

The "worst natural conditions" simulated in this study are 7-day 10-year low flows at water temperatures of 29° C. Under these conditions, only the simulation for effluent projection 6 (CBOD5=5.0 mg/L, Organic-N mg/L, ammonia-N mg/L, DO=saturation) produced minimum DO concentrations downstream from the Fayetteville WWTP greater than 6.0 mg/L. Sensitivity analyses were made for this simulation to evaluate the effect upon the DO concentration profile of controlled changes in various impacting components and rate coefficients. The types of changes imposed include a plus or minus 20-percent change in the following:

1) mean river depths,
2) mean river velocities,
3) reaeration rate coefficients
4) benthic demands,
5) net photosynthetic production,
6) instream CBOD deoxygenation rate and removal rate coefficients,
7) organic-N forward-reaction rate and decay rate coefficients,
8) ammonia-N forward-reaction rate coefficient,
9) ammonia-N decay rate coefficient,
10) NO2-N forward-reaction rate and decay rate coefficients,

Fayetteville wastewater-treatment plant;

11) DO concentration,
12) CBOD concentration,
13) ammonia-N concentration,

and a plus or minus 2.0° C change in:

14) stream-water temperature.

The effect of each of these changes was determined independently with a separate model run, making a total of 30 sensitivity runs. The resulting DO profiles for each plus and minus change have been plotted and define a DO sensitivity band for each component or rate coefficient (figs. 8 through 21).

According to 1980 Environmental Protection Agency criteria for justifying AST/AWT effluent limits, the value of any component or rate coefficient may need further evaluation if its DO sensitivity-band width is greater than 1.0 mg/L. Of all the components and rate coefficients evaluated, DO concentrations were most sensitive to changes in water temperature (fig. 21). The maximum band width for DO is 0.63 mg/L and is not considered significant. No reevaluation of any components or rate coefficients was done as a result of these sensitivity analyses.

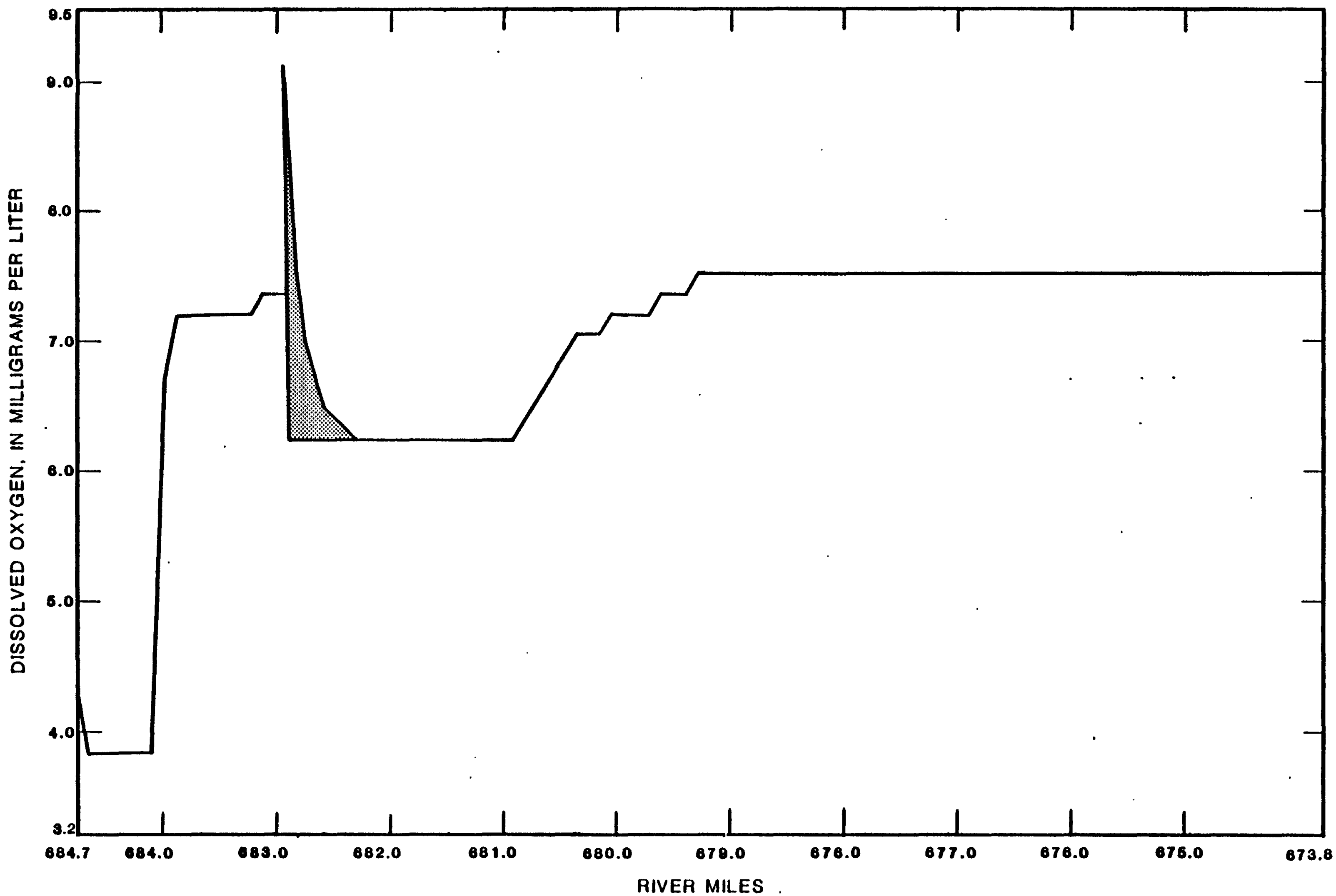

Figure 8.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in the dissolved-oxygen concentration of the effluent from the Fayetteville wastewater-treatment plant; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7 milligrams per liter dissolved oxygen.

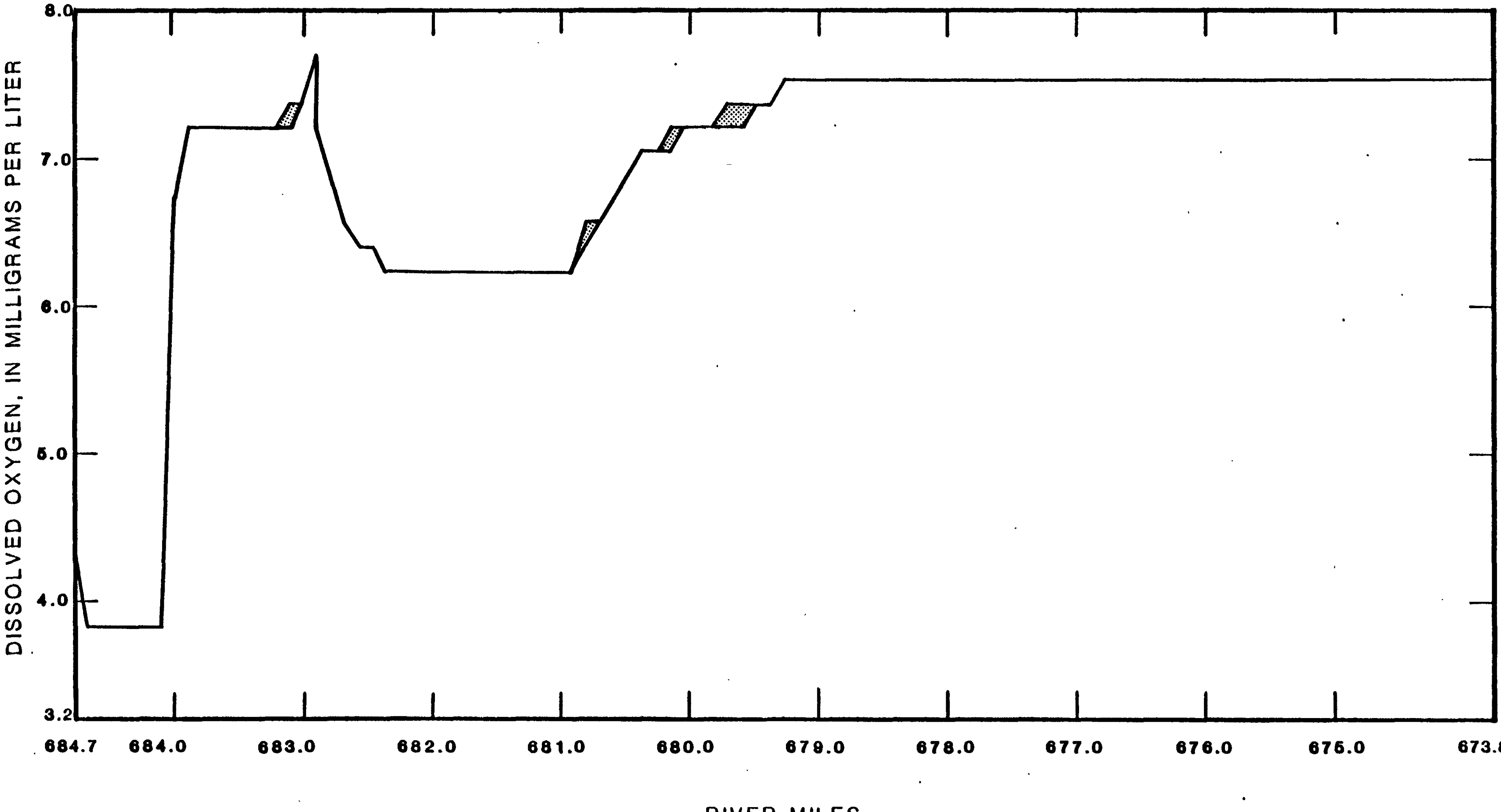

Figure 9.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in the ammonia decay rate coefficient; water temperature is 29°C, river discharge is equal to the 7-day 10-year flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

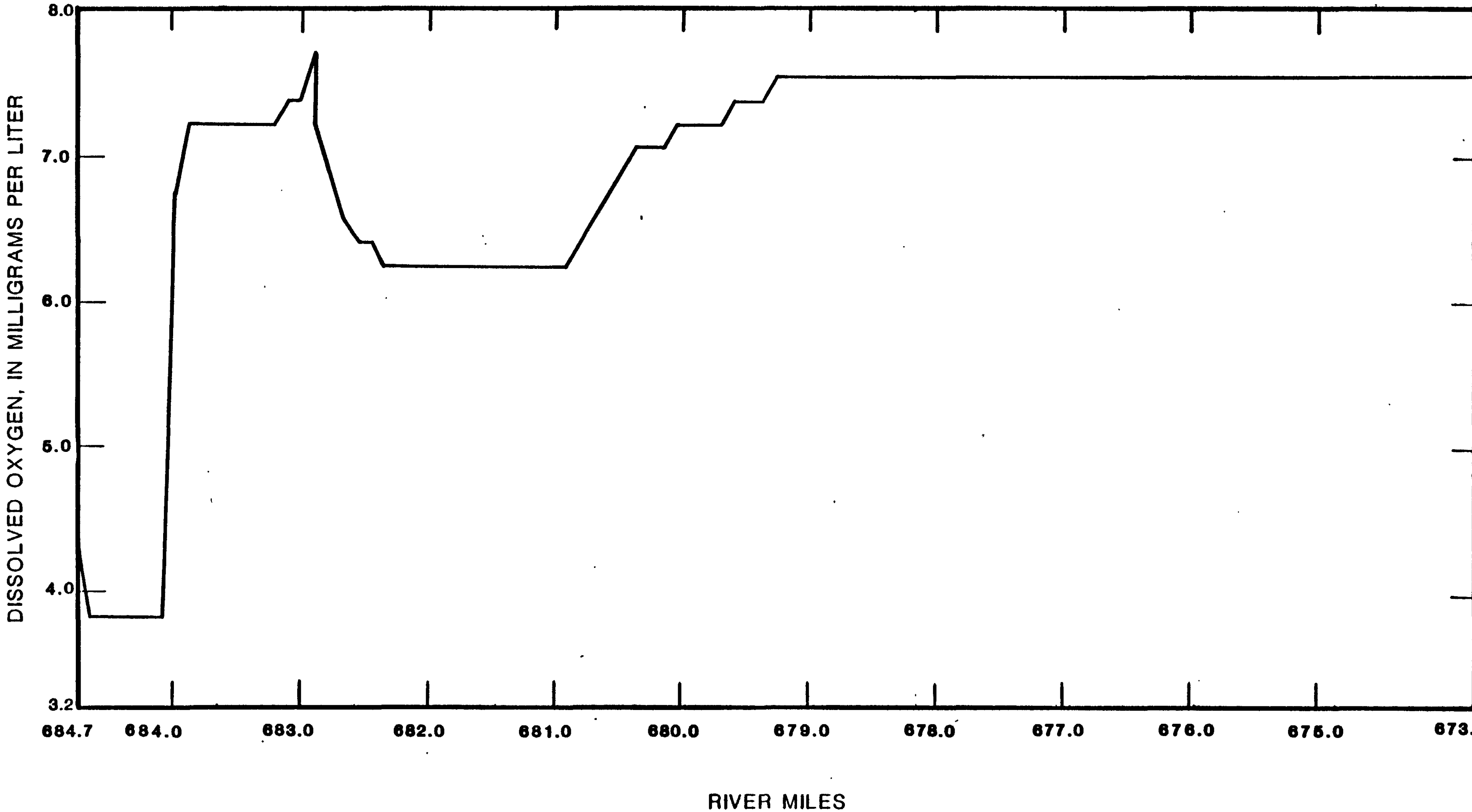

Figure 10.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in the organic nitrogen forward-reaction rate and decay rate coefficients; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

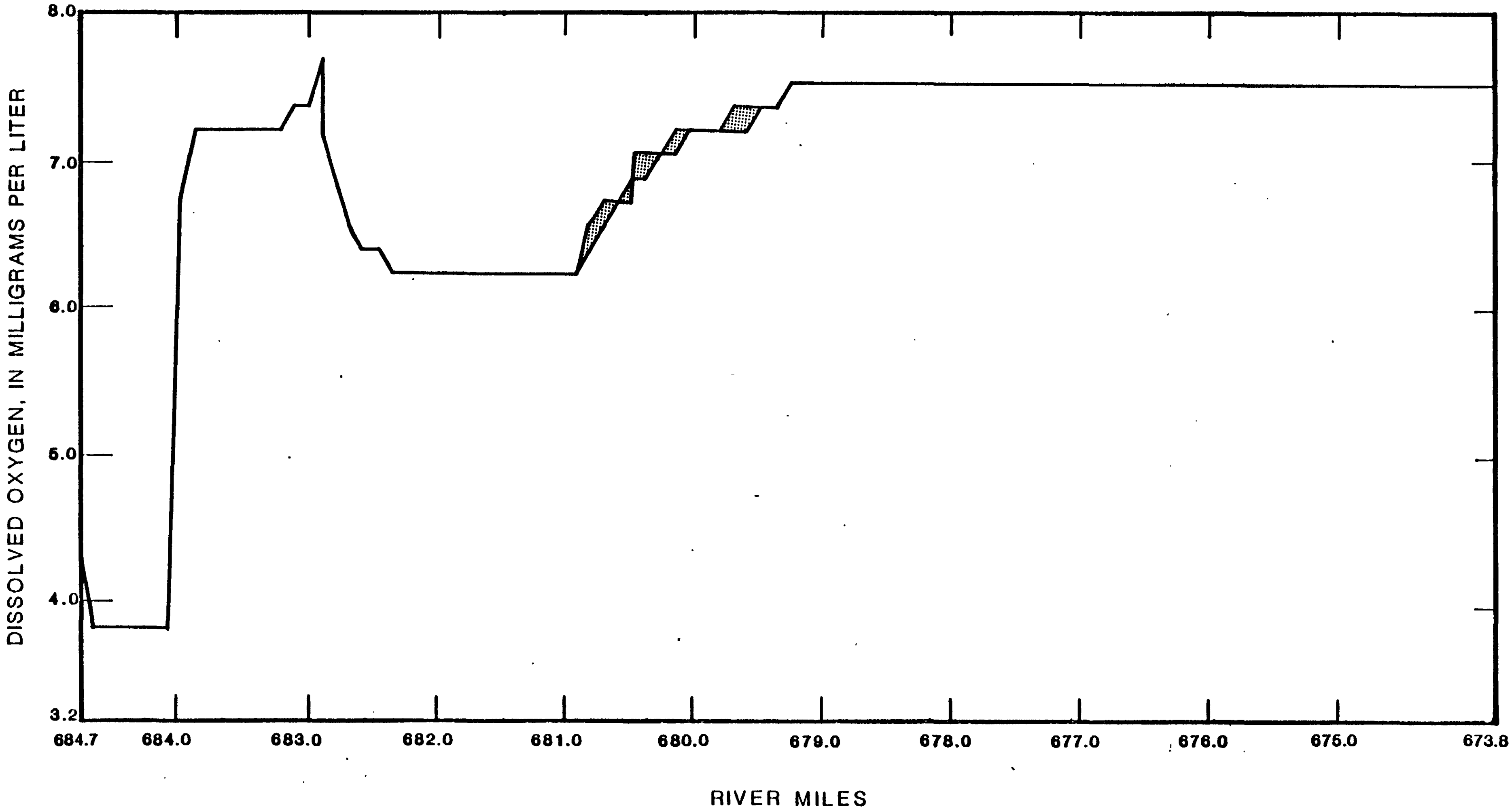

Figure 11.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in the ammonia concentrations from the Fayetteville wastewater-treatment plant; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

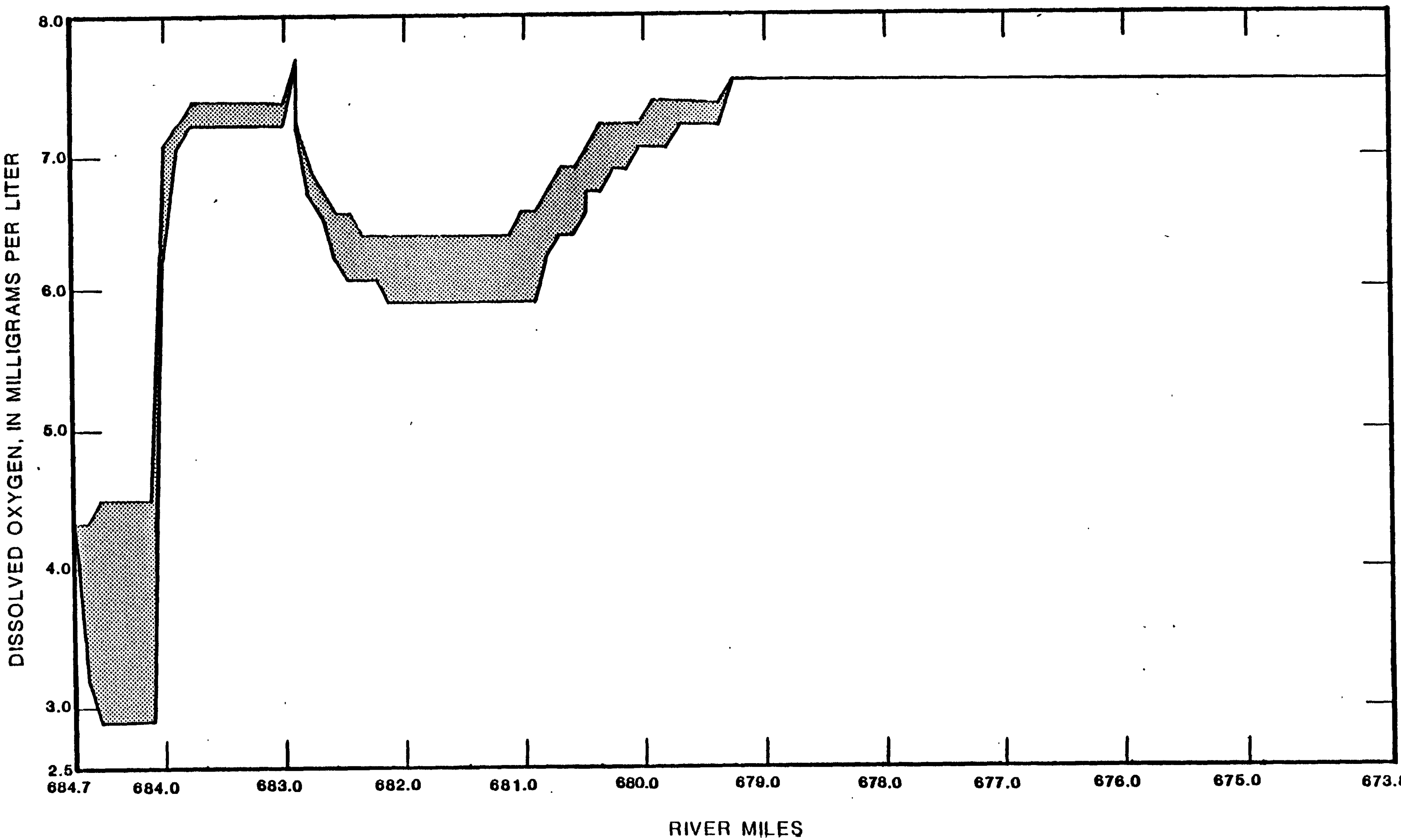

Figure 12.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in the reaeration rate coefficients; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

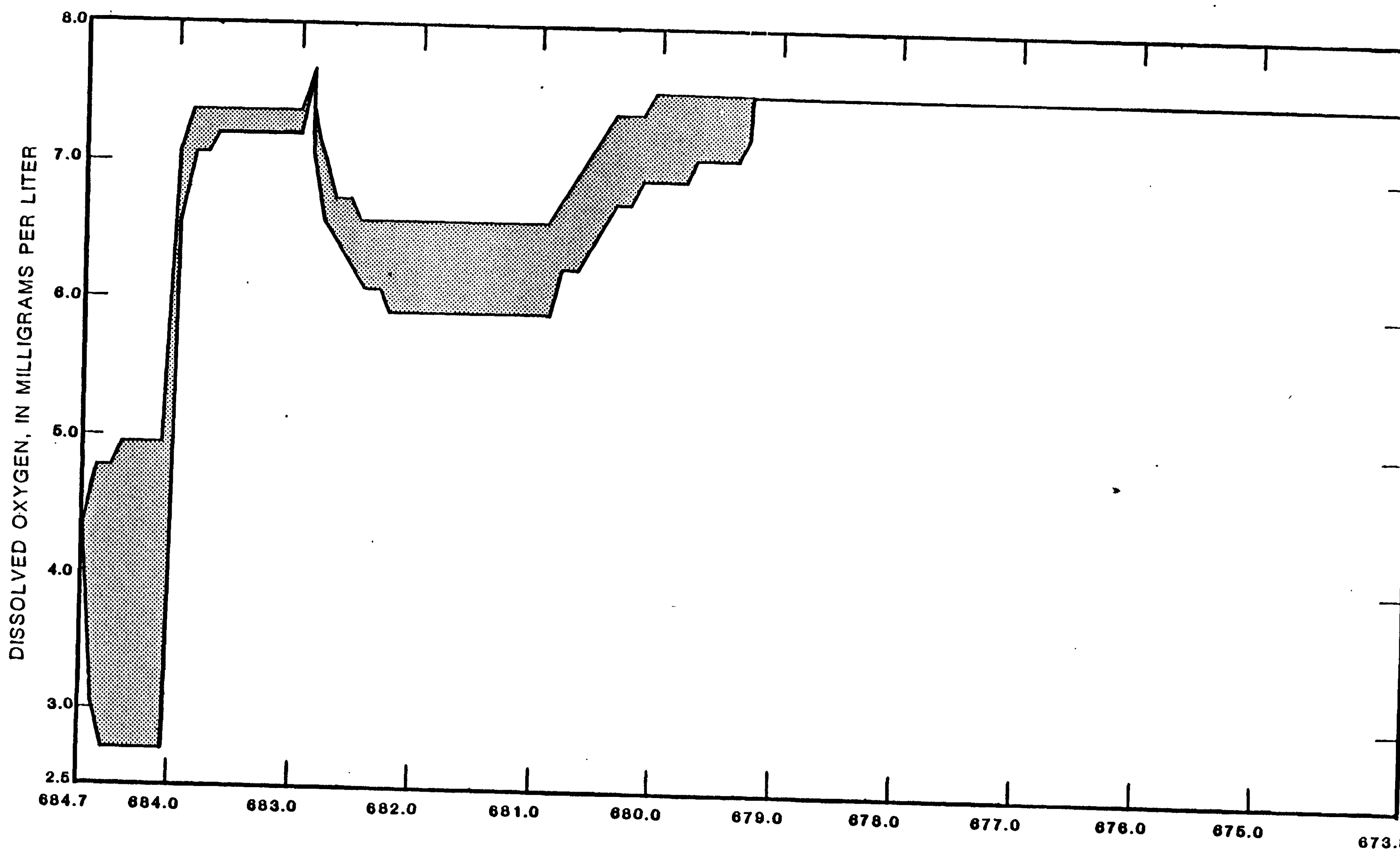

Figure 13.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in the benthic demand; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

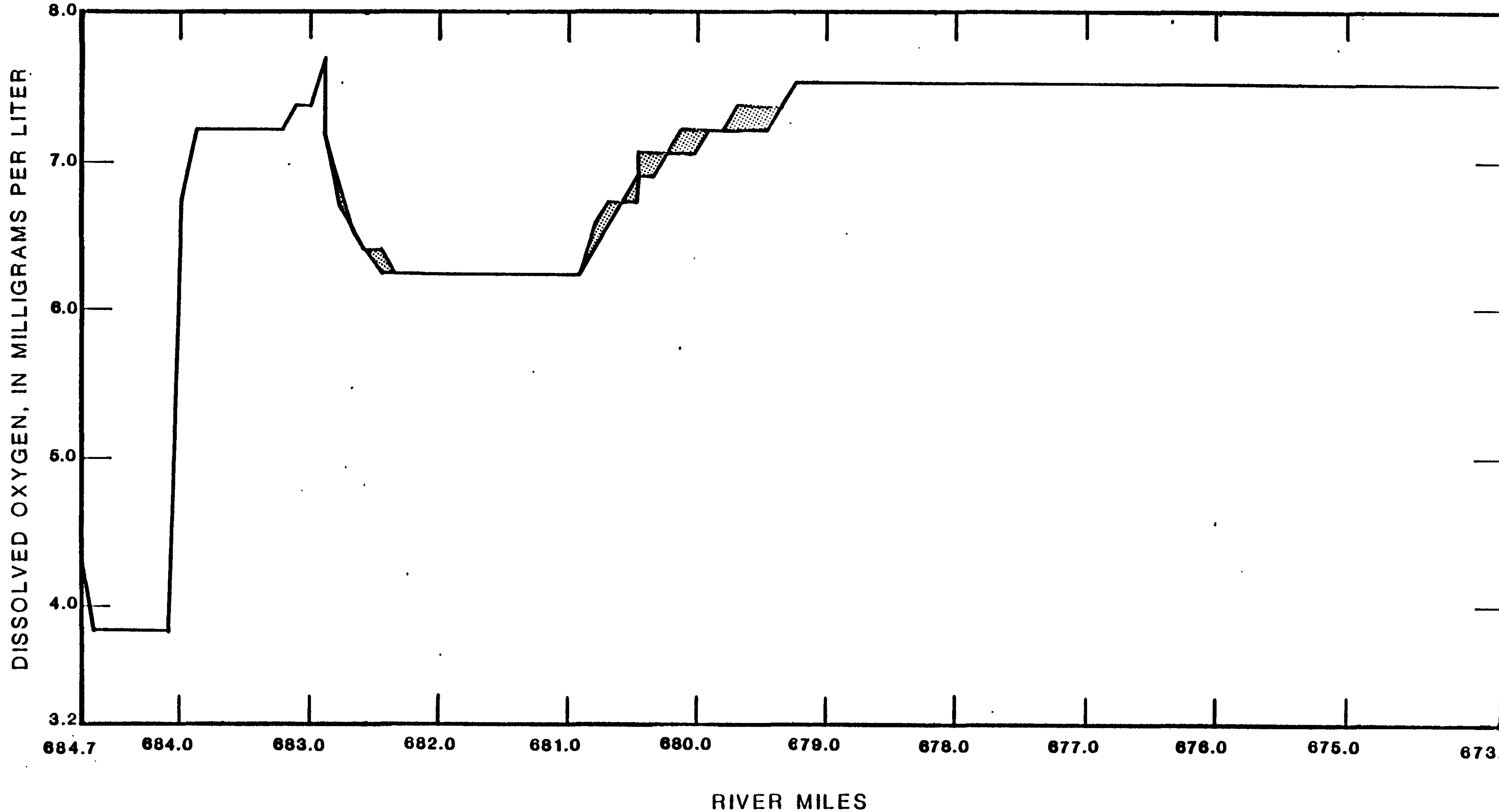

Figure 14.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in the ultimate carbonaceous biochemical oxygen demand from the Fayetteville wastewater-treatment plant; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

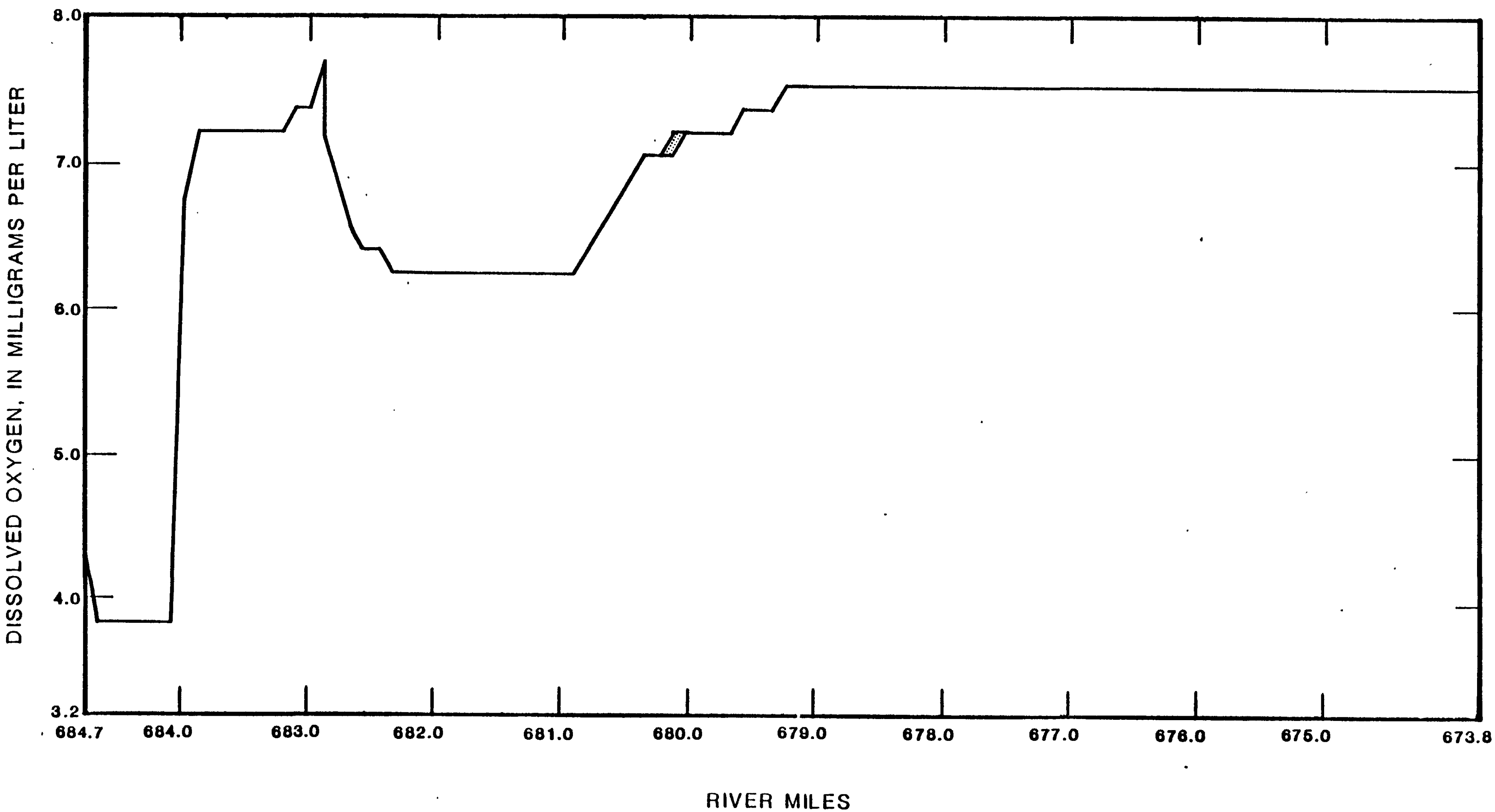

Figure 15.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in the nitrite forward-reaction rate and decay rate coefficients; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

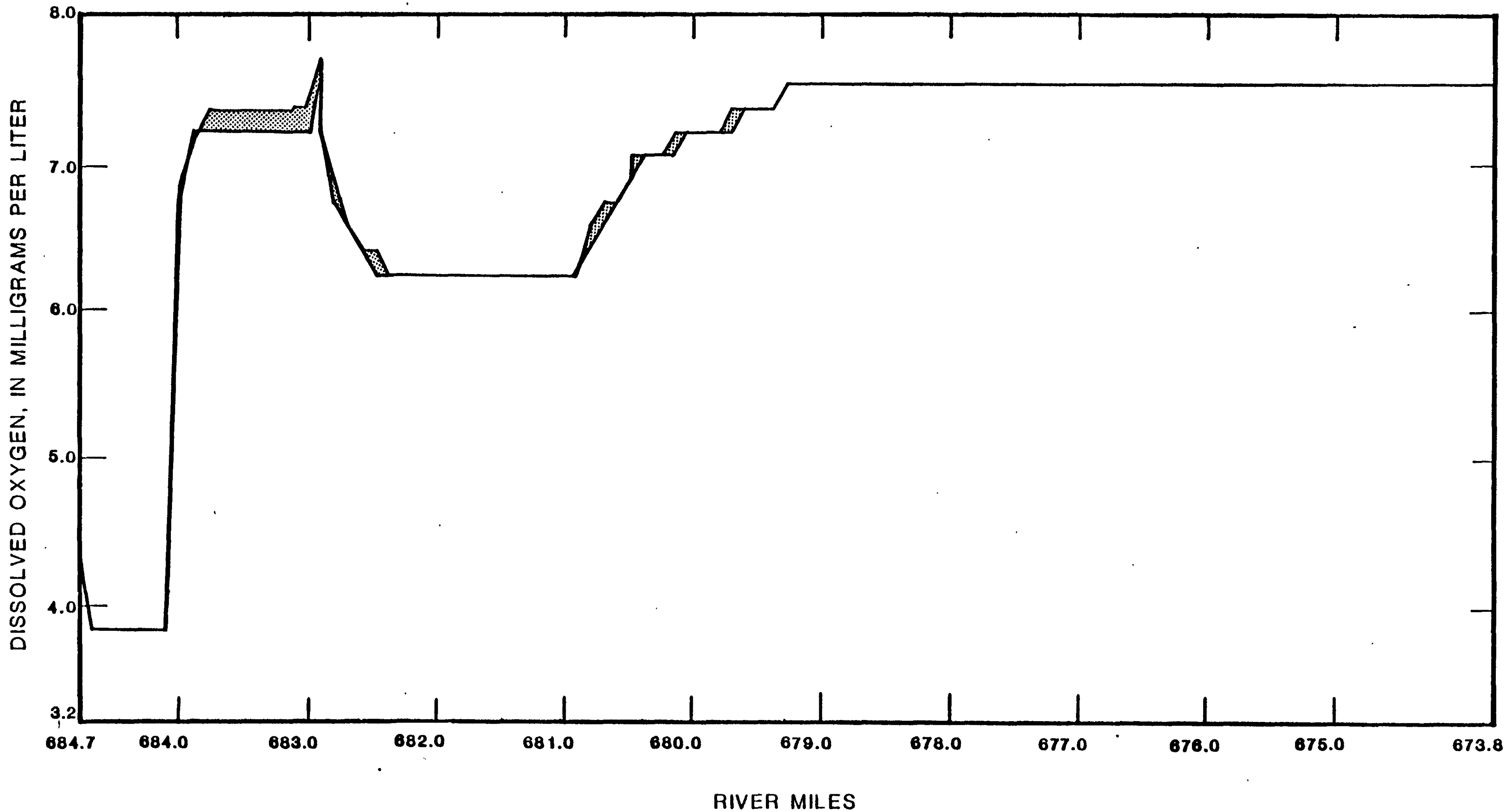

Figure 16.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in the carbonaceous deoxygenation rate and removal rate coefficients; water temperature charge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milli-per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams grams per liter dissolved oxygen.

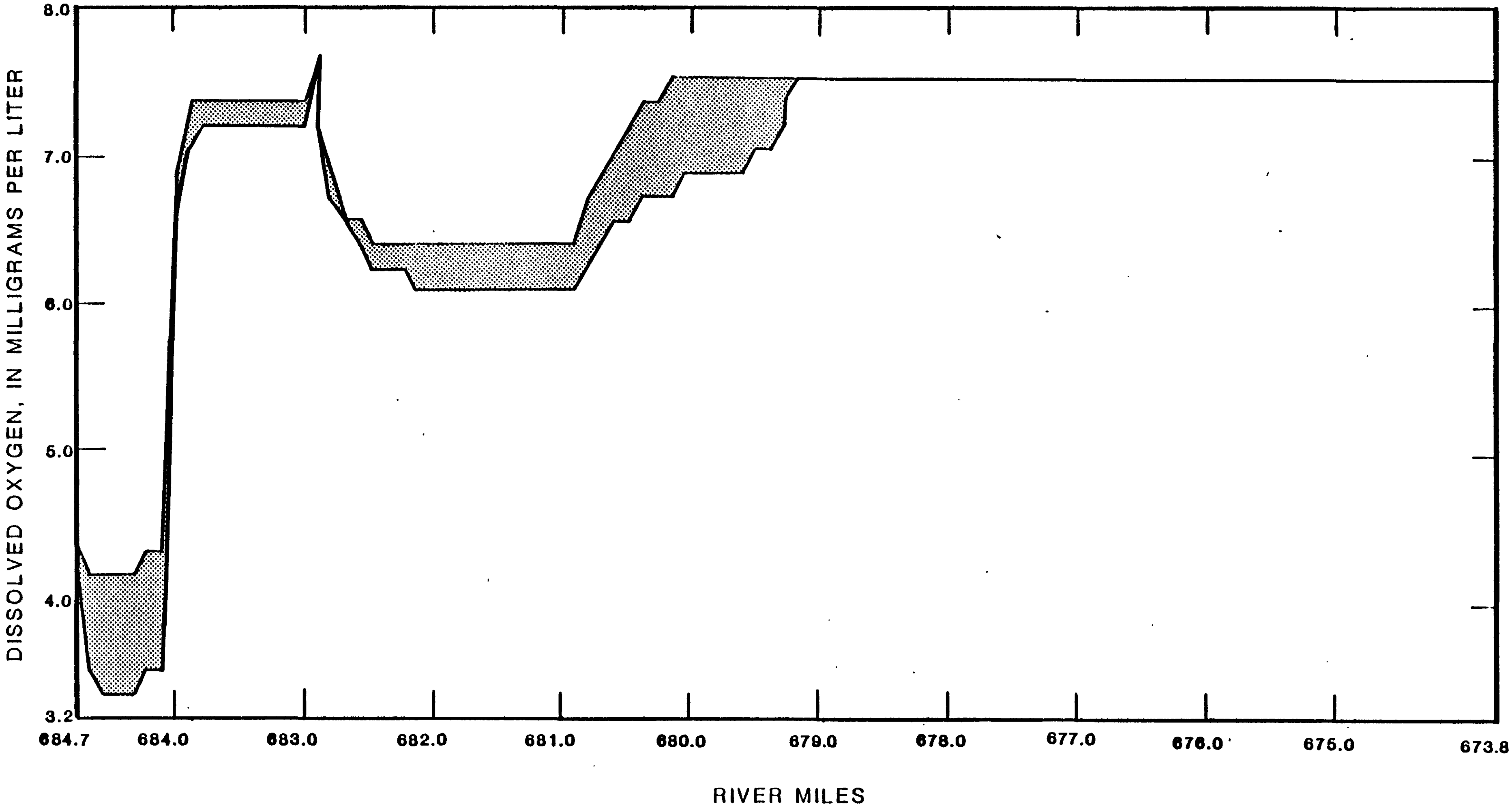

Figure 17.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in net photosynthetic production; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

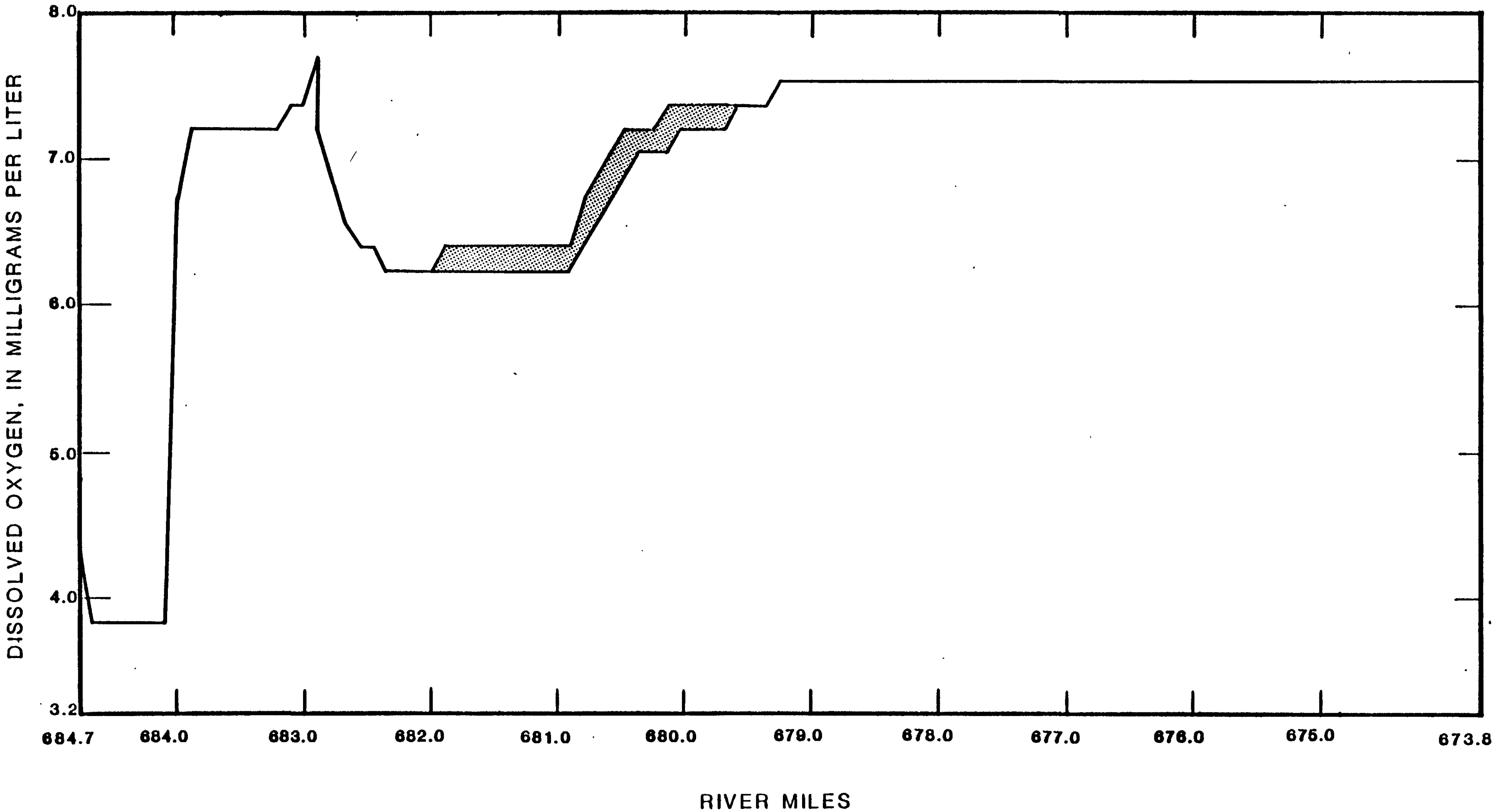

Figure 18.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in the ammonia forward-reaction rate coefficient; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

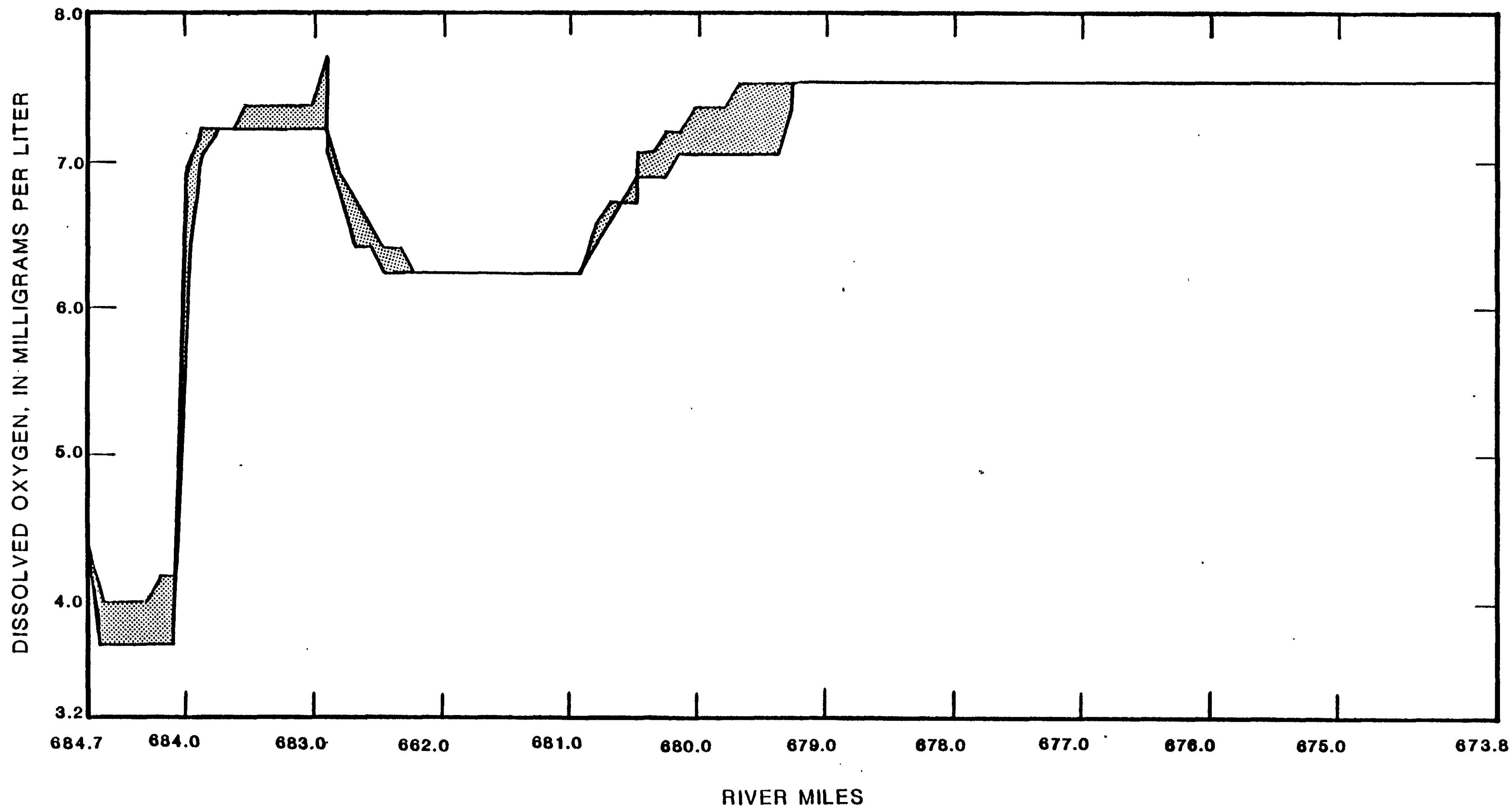

Figure 19.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in mean river depths; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

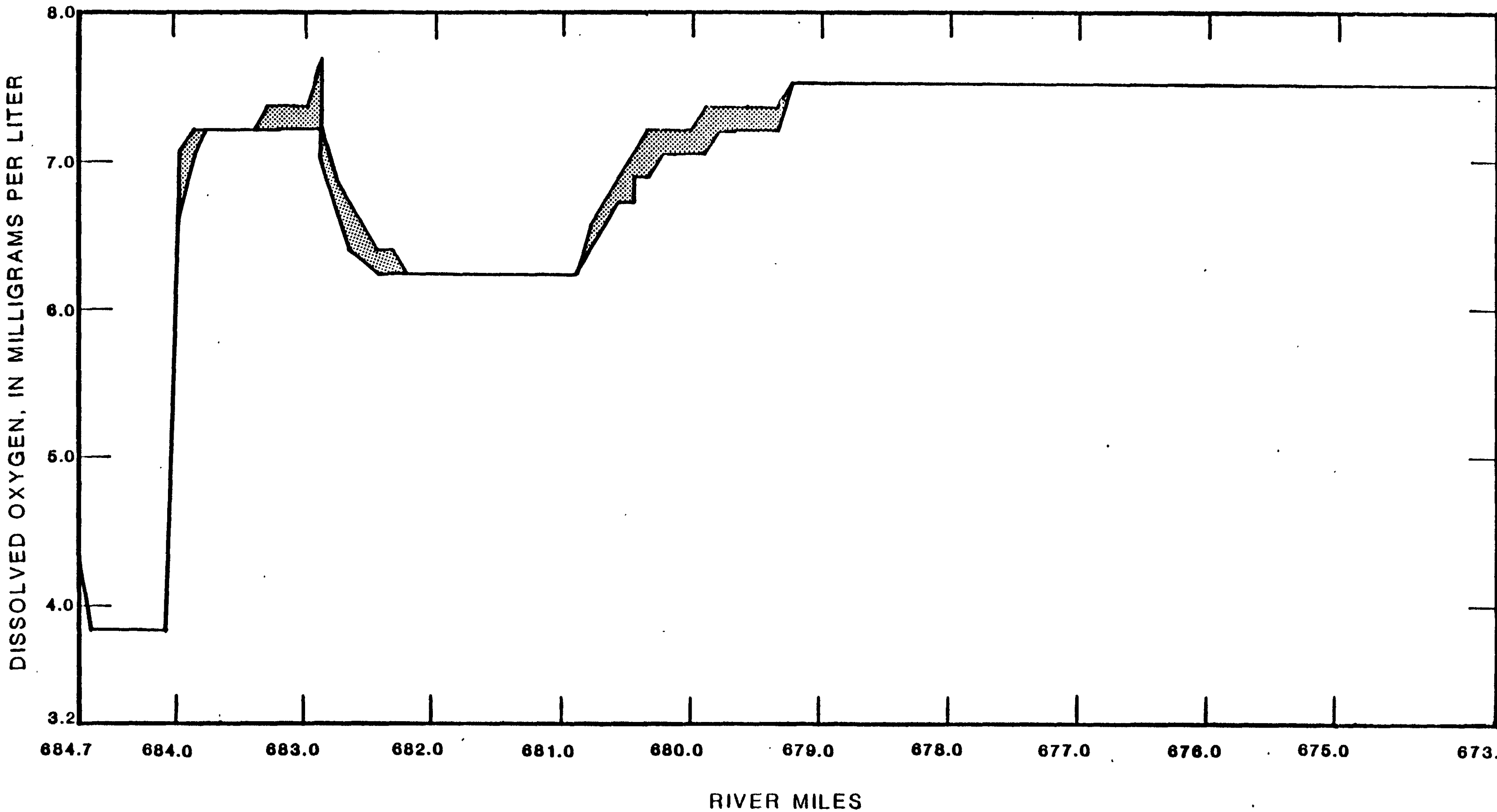

Figure 20.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 20-percent change in mean river velocity; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

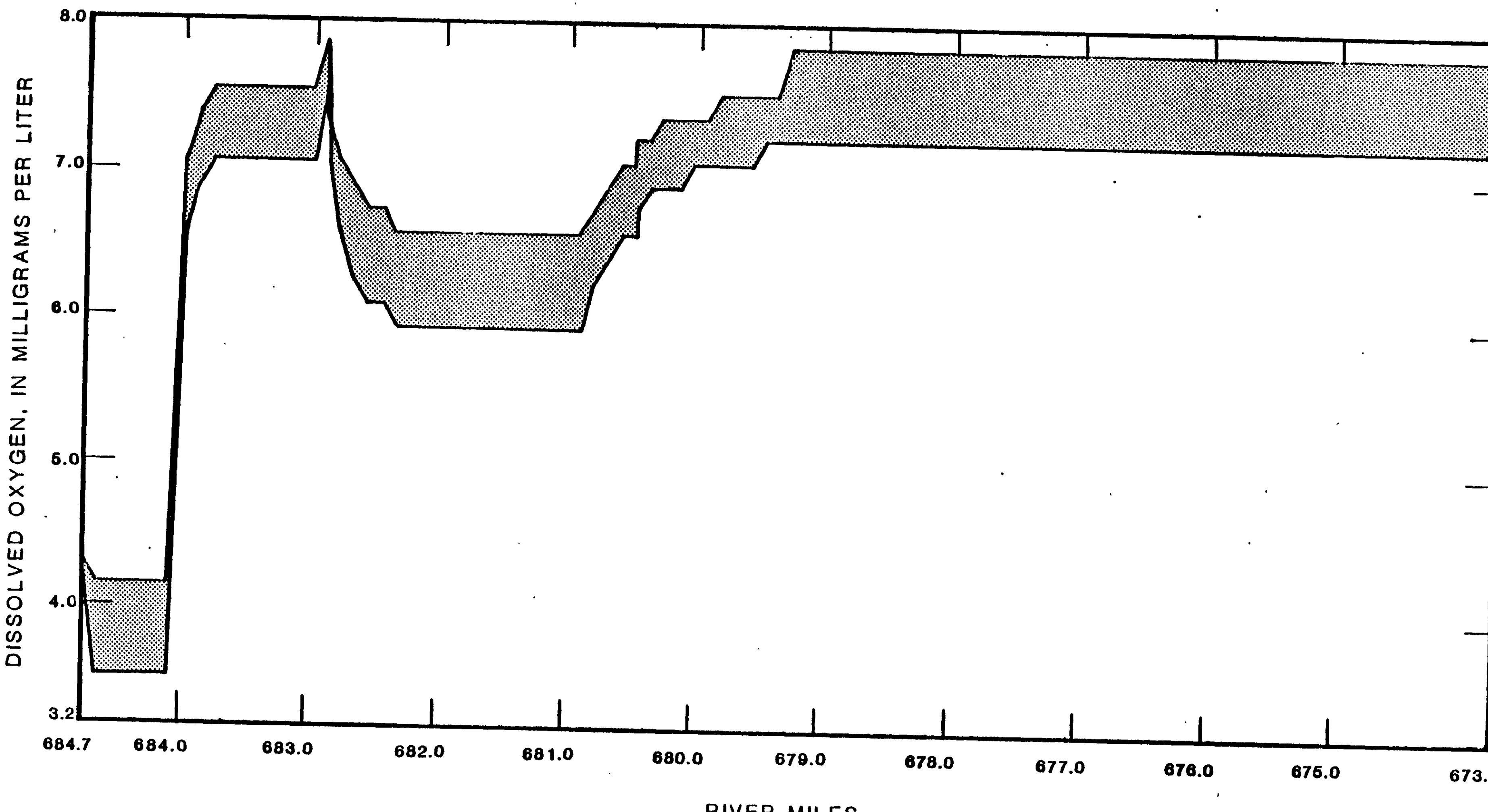

Figure 21.--Band reflecting the sensitivity of instream dissolved-oxygen concentrations to a plus or minus 2.0-degree-celsius change in water temperature; water temperature is 29°C, river discharge is equal to the 7-day 10-year low flow, and the wasteload projection for the Fayetteville wastewater-treatment plant is 5 milligrams per liter 5-day biochemical oxygen demand, 2 milligrams per liter ammonia, and 7.8 milligrams per liter dissolved oxygen.

CONCLUSIONS

Under existing conditions, the White River does not meet Arkansas water-quality standards (Arkansas Department of Pollution Control and Ecology, 1975) for several parameters: water temperature, DO, dissolved solids, un-ionized ammonia, total phosphorus, and floating solids and depositable material. Conditions are at their worst during periods of high water temperature and low river flows. Under these conditions, as much as 90 percent of the flow in the river downstream from the Fayetteville WWTP is effluent discharge. High temperatures and high concentrations of nutrients in the effluent cause a sag in the DO profile downstream. At times, minimum DO concentrations reach zero at sampling station WR-5, 1.1 miles downstream from the Fayetteville WWTP.

The largest DO sink in the White River between Lake Sequoyah and Beaver Reservoir is the benthic demand. This demand seems to be supported largely by deposited organic material from the Fayetteville WWTP effluent. Observed CBODU concentrations in the WWTP effluent were as high as 190 mg/L.

High nitrogen and phosphorus loads discharged by the treatment plant stimulate the growth of phytoplankton blooms which increase river turbidity and also contribute to the benthic demand. However, net photosynthetic production by the algae is also a significant source of DO.

Under low-flow conditions, reaeration in the river is slow. Instream reaeration coefficients range from $0.40\ day^{-1}$ to $4.24\ day^{-1}$. Mean velocities are so slow that turbulence becomes relatively insignificant in defining the reaeration coefficients.

According to digital-model projections, the assimilative capacity of the White River is such that daily-average DO concentrations will not remain at or above the Arkansas standard (Arkansas Department of Pollution Control and Ecology, 1975) of 6.0 mg/L unless concentrations of CBOD5, organic-N, and ammonia-N are reduced to 5.0, 0.0, and 2.0 mg/L, respectively. This is also assuming that the effluent will be saturated with DO and that downstream benthic demands in the river will be reduced significantly because of the decreased organic loading from the plant. No flow augmentation or effluent retention combinations were found that will offer any relief to the Fayetteville WWTP from these treatment levels. The lack of assimilative capacity and of effective alternative solutions is due in part to the high effluent to receiving stream discharge ratio and in part to the downstream river geometry.

Unsteady conditions prevailed on the river due to variations in discharge and effluent quality from the Fayetteville WWTP during the collection of data used to calibrate the model. For this reason, the accuracy of these projections is less than ideal. The collection of supportive data for model verification or calibration of an unsteady model would be advantageous.

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ATTACHMENT A

MODEL MODIFICATIONS

MODEL MODIFICATIONS

Several modifications have been made to the original one-dimensional, steady-state stream water-quality model as described by Bauer, Jennings, and Miller (1979). Most of the changes have been noted in the digital model description section. The discussions presented here clarify some of the reasons for the modifications and provide some of the necessary details about them:

I. A new subroutine, K2, which computes reaeration coefficients by the user's choice of any one of eight predictive equations has been added to the model. Lawrence H. Smith, U.S. Geological Survey, Nevada District, has done some similar work (oral commun., 1980). The following equaitons are included:

1. Bennett and Rathbun (1972)

$$k_2 = 8.76u^{0.607}h^{-1.689}(2.303)(1.0241)^{T-20},$$

2. Velz "Rational method," Hirsch (1980)

$$k_2 = \frac{-ln[1-2((m \times 1.42 \times 1.1^{T-20}/60)/\pi(30.48 \times h)^2)^{.5}] \times 1440}{m}$$

$$m = \begin{cases} 2.279 + 0.721 \times h, \text{ if } h < 2.26 \\ 13.94 \times ln(h) - 7.45, \text{ if } h \geq 2.26 \end{cases}$$

3. Langbein and Durum (1967)

$$k_2 = 7.6u \times h^{-1.33}(1.0241)^{T-20}$$

4. Padden and Gloyna (1971)

$$k_2 = 6.86u^{0.703}h^{-1.054}(1.0241)^{T-20}$$

5. Bansal (1973)

$$k_2 = 4.67^{0.6}h^{-1.4}(1.0241)^{T-20}$$

6. Parkhurst and Pomeroy (1972)

$$k_2 = 48.36\left(1 + \frac{0.17 \times u^2}{g \times h}\right)(u \times s)^{.375}h^{-1}(1.0241)^{T-20}$$

7. Tsivoglou and Wallace (1972)

$$k_2 = 4133(u)(s)(1.0241)^{T-20}$$

8. O'Connor and Dobbins (1958)

$$k_2 = (127(dif \times u)^{.5}/h^{1.5})(2.303)(1.0241)^{T-20}$$

where for each of the above equations

h = mean stream depth,
u = mean stream velocity,
s = stream slope,
dif = diffusion coefficient,
m = mixing interval, and
T = stream temperature.

Each equation yields a valid estimate of reaeration coefficient for a particular type stream, depending upon its hydraulic and geometric properties. Choice of the "best" equation for a particular stream can be made during calibration of the model. A thorough knowledge of stream geometry and velocities is needed.

II. Most of the reactions in a stream system that affect the oxygen balance are temperature dependent. The relationships are expressed in the following form:

$$k_T = k_{20} R^{(T-20)},$$

where

k_T = reaction rate at temperature T,
k_{20} = reaction rate at temperature 20° C, and
R = thermal factor.

With the exception of "net photosynthetic DO production" (photosynthesis minus respiration), and the optional user supplied reaeration coefficient all the reactions that affect the oxygen balance are temperature corrected in the model as described by Bauer and others (1979),

A modification has been made so that net-photosynthetic-production values entered to the model are standardized to 20° C. The values are then converted to stream temperature using the above relationship and a R factor of 1.08 (Krenkel and Novotny, 1980). This modification is especially helpful when making projections for various water temperatures.

III. When water temperature increases, all reactions that affect the oxygen balance in a stream increase, including the net quantity of oxygen produced by photosynthesis. At the same time, the capacity of the water to retain DO, or the saturation level of the water, decreases. Under such conditions, much of the oxygen produced by photosynthesis may not be retained in the water column. When saturation levels are reached, "excess" oxygen produced begins to be lost to the atmosphere.

The model, as described by Bauer and others (1979) allows computed DO concentrations to increase above saturation, which is a natural occurrance due to net photosynthetic DO production. Computed saturation levels under such conditions have been observed to be 150-200 percent. Modifications have been made to the model so that DO concentrations do not exceed saturation. That part of photosynthetically produced DO that would cause supersaturation is treated as "excess" and is assumed lost to the atmosphere. This procedure makes it possible to maintain "reasonable" computed DO concentrations without reducing valid net photosynthetic production values.

IV. In the model, mass-balance computations are made for each constituent at all locations of point-source inflow. In the version described by Bauer and others (1979) the concentrations used in the mass-balance computation for DO were derived from computed deficits and saturation concentrations. The saturation concentrations for the point source were determined using the water temperature for the mainstem subreach rather than for the point source. This error caused significant errors in the resulting mass balance when the point-source discharge was a significant part of the downstream flow and where the temperature of the point-source discharge was significantly different from the water temperature in the subreach. Modifications have been made so that DO mass balances are computed using actual concentrations, negating the necessity of a computation based upon temperature-dependent saturation values.

V. Some of the required card input to the model, as described by Bauer and others (1979), was for "printout purposes only" and was not necessary for program execution. The printed data tables resulting from this card input were not complete and only of marginal value to the user. All the data contained in these tables are available elsewhere in the model printout. In order to avoid unnecessary input preparation and to delete the printing of incomplete, duplicate information, modifications were made so that card input types 7, K, and 8 are no longer necessary.

Modifications I, IV, and V have been reviewed and accepted by the Deterministic Models Group at the U.S. Geological Survey Gulf Coast Hydroscience Center in Bay St. Louis, Mississippi. These modifications have now been made to the official version of the model which they support (Marshall E. Jennings, oral commun., 1981). Recent modifications II and III have not yet been reviewed by the Group (1981).

ATTACHMENT B

WHITE RIVER MODEL CALIBRATION

```
                STEADY STATE WATER QUALITY MODEL
                 GULF COAST HYDROSCIENCE CENTER
                    U. S. GEOLOGICAL SURVEY
                       (ARKANSAS VERSION)
              DATE OF LAST REVISION, DECEMBER  1980

     WHITE RIVER CALIBRATION (COMBINED DATA SETS)

       NITRIFICATION CYCLE INCLUDED IN MODEL

       NUMBER OF SUBREACHES FOR THIS PROBLEM =   10

           PRINTING INTERVAL (MILES) =   0.100
          STARTING DISTANCE (MILES) =  684.700
INITIAL CBOD CONC (MG/L) AT STARTING DISTANCE =   16.00
INITIAL ORGANIC NITROGEN CONC (MG/L) AT STARTING DISTANCE =   1.000
INITIAL AMMONIUM NITROGEN CONC (MG/L) AT STARTING DISTANCE =   1.000
INITIAL NITRITE NITROGEN CONC (MG/L) AT STARTING DISTANCE =   0.010
INITIAL NITRATE NITROGEN CONC (MG/L) AT STARTING DISTANCE =   0.0
INITIAL DO CONC (MG/L) AT STARTING DISTANCE =   4.600
INITIAL PHOSPHATE CONC (MG/L) AT STARTING DISTANCE =   0.030
INITIAL TOT. COLIF. CONC (COL/100ML) AT STARTING DISTANCE =       0.
INITIAL FEC. COLIF. CONC (COL/100ML) AT STARTING DISTANCE =       0.
    STREAMFLOW (CFS) AT STARTING DISTANCE =     0.820
```

WHITE RIVER CALIBRATION (COMBINED DATA SETS)

S U B R E A C H   L I N E A R   R U N O F F   D A T A

SUBREACH	Q	CBOD	ORGANIC	AMMONIA	NITRITE	NITRATE	DO	PO4
	(CFS)	(MG/L)	(MG/L)	(MG/L)	(MG/L)	(MG/L)	(MG/L)	(MG/L)
1	0.74	12.0	1.3	0.4	0.0	0.0	7.0	0.1
2	0.78	15.0	0.9	0.2	0.0	0.2	7.4	0.0
3	-1.92	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	-1.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	-0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.40	8.2	1.2	1.8	0.1	0.5	2.4	2.3
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.20	9.5	3.8	2.3	0.1	0.8	3.7	2.8
9	0.92	8.1	2.3	1.3	0.1	0.9	5.9	2.2
10	-0.80	0.0	0.0	0.0	0.0	0.0	0.0	0.0

REACH DESCRIPTION DATA (MAJOR TRIBUTARIES AND MAIN STEM)

SUBREACH	CODE	NAME	BEGIN (MILE)	END (MILE)
1	B	WEST FORK	684.70	684.00
2	B		684.00	682.90
3	C	FAYETTEVILLE WWTP	682.90	682.30
4	C		682.30	680.90
5	C		680.90	679.40
6	C		679.40	677.80
7	C		677.80	677.40
8	B		677.40	677.20
9	B	RICHLAND CREEK	677.20	677.10
10	A		677.10	673.80

KEY: CODE

A ROCKY BOTTOM-POOL RIFFLE-LIGHT VEGETATION
B ROCKY BOTTOM-POOL RIFFLE-MEDIUM VEGETATION
C ROCKY BOTTOM-POOL RIFFLE-HEAVY VEGETATION
D ROCKY BOTTOM-CHANNEL CONTROL-LIGHT VEGETATION
E ROCKY BOTTOM-CHANNEL CONTROL-MEDIUM VEGETATION
F ROCKY BOTTOM-CHANNEL CONTROL-HEAVY VEGETATION
G MUD BOTTOM-POOL RIFFLE-LIGHT VEGETATION
H MUD BOTTOM-POOL RIFFLE-MEDIUM VEGETATION
I MUD BOTTOM-POOL RIFFLE-HEAVY VEGETATION
J MUD BOTTOM-CHANNEL CONTROL-LIGHT VEGETATION
K MUD BOTTOM-CHANNEL CONTROL-MEDIUM VEGETATION
L MUD BOTTOM-CHANNEL CONTROL-HEAVY VEGETATION

WHITE RIVER CALIBRATION (COMBINED DATA SETS)

INPUT PARAMETERS

CONCENTRATIONS(MG/L) OF --

SUBREACH	CARB BOD	ORG-N	NH3-N	NO2-N	NO3-N	DISSOLVED OXYGEN	PO4	TOT.COLIF.	FEC.COLIF.
1	10.00	1.40	0.10	0.0	0.03	8.20	0.06	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	130.00	15.00	4.80	0.13	2.60	8.90	8.10	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	13.00	0.80	0.05	0.02	0.99	9.90	0.06	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DIRECT DISCHARGES(LB/DAY) OF --

SUBREACH	CARBONACEOUS ULT. BOD	ORGANIC NITROGEN	AMMONIA NITROGEN	NITRITE NITROGEN	NITRATE NITROGEN	PHOSPHATE
1	0.0	0.0	0.0	0.0	0.0	0.
2	0.0	0.0	0.0	0.0	0.0	0.
3	0.0	0.0	0.0	0.0	0.0	0.
4	0.0	0.0	0.0	0.0	0.0	0.
5	0.0	0.0	0.0	0.0	0.0	0.
6	0.0	0.0	0.0	0.0	0.0	0.
7	0.0	0.0	0.0	0.0	0.0	0.
8	0.0	0.0	0.0	0.0	0.0	0.
9	0.0	0.0	0.0	0.0	0.0	0.
10	0.0	0.0	0.0	0.0	0.0	0.

WHITE RIVER CALIBRATION (COMBINED DATA SETS)

SUBREACH	NET PHOTOSYNTHETIC DO PRODUCTION (MG/L/DAY @ 20 DEG C)	BENTHIC DO DEMAND (G/SQ M/DAY @ 20 DEG C)
1	3.790	6.300
2	0.840	0.700
3	0.850	7.800
4	1.530	7.800
5	3.150	8.500
6	5.790	11.000
7	8.010	7.800
8	7.380	8.200
9	5.400	8.000
10	3.170	2.800

G E O M E T R Y

SUBREACH	FLOW CHANGE (CFS)	AREA (SQFT)	DEPTH (FT)	SLOPE	TEMP (DEG.CENT)	END MI (MI)
1	1.58	122.	1.75	0.0013000	18.00	684.00
2	0.0	176.	2.10	0.0013000	18.00	682.90
3	11.20	172.	1.31	0.0013000	24.00	682.30
4	0.0	155.	1.68	0.0008000	20.00	680.90
5	0.0	160.	1.82	0.0011000	19.00	679.40
6	0.0	140.	1.45	0.0011000	18.00	677.80
7	0.0	110.	2.52	0.0013000	18.00	677.40
8	0.0	639.	4.85	0.0013000	18.00	677.20
9	5.18	75.	1.50	0.0013000	18.00	677.10
10	0.0	366.	3.30	0.0013000	19.00	673.80

WHITE RIVER CALIBRATION (COMBINED DATA SETS)

R E A C T I O N   C O E F F I C I E N T S (/DAY @ 20 DEG C)

SUBREACH	KR	KD	KORG	SKORG	KNH3	SKNH3	KNO2	SKNO2	KNO3	KCOLF	KCOLT	KPO41	KPO42
1	0.03	0.03	0.02	0.20	0.07	0.30	2.50	2.50	0.30	0.0	0.0	0.02	0.0
2	0.03	0.03	0.02	0.15	0.05	0.30	0.20	0.20	0.30	0.0	0.0	0.02	0.0
3	1.25	0.14	0.02	0.02	0.02	0.02	0.20	0.20	4.00	0.0	0.0	0.02	0.0
4	0.70	0.22	0.13	0.55	0.05	0.05	1.50	1.50	0.70	0.0	0.0	0.10	0.0
5	0.70	0.21	0.06	0.95	0.09	0.75	2.50	2.50	0.65	0.0	0.0	0.35	0.0
6	0.25	0.19	0.05	0.10	0.15	0.70	2.50	2.50	0.05	0.0	0.0	0.45	0.0
7	0.18	0.18	0.05	0.10	0.25	0.55	2.00	2.00	0.05	0.0	0.0	0.02	0.0
8	0.18	0.18	0.10	0.10	0.20	0.25	2.00	2.00	0.05	0.0	0.0	0.02	0.0
9	0.21	0.21	0.15	0.15	0.15	0.15	0.75	0.75	0.05	0.0	0.0	0.02	0.0
10	0.18	0.18	0.20	0.20	0.15	0.15	1.00	1.00	0.02	0.0	0.0	0.02	0.0

TEMPERATURE CORRECTED REACTION COEFFICIENTS (/DAY)

SUBREACH	KR	KD	KORG	SKORG	KNH3	SKNH3	KNO2	SKNO2	KNO3	KA	KPO41	KPO42
1	0.03	0.03	0.02	0.17	0.06	0.25	2.10	2.10	0.25	2.27	0.02	0.0
2	0.03	0.03	0.02	0.13	0.04	0.25	0.17	0.17	0.25	1.83	0.02	0.0
3	1.50	0.17	0.03	0.03	0.03	0.03	0.28	0.28	5.65	4.24	0.03	0.0
4	0.70	0.22	0.13	0.55	0.05	0.05	1.50	1.50	0.70	2.62	0.10	0.0
5	0.67	0.20	0.06	0.87	0.08	0.69	2.29	2.29	0.60	2.27	0.32	0.0
6	0.23	0.17	0.04	0.08	0.13	0.59	2.10	2.10	0.04	2.83	0.38	0.0
7	0.16	0.16	0.04	0.08	0.21	0.46	1.68	1.68	0.04	1.27	0.02	0.0
8	0.16	0.16	0.08	0.08	0.17	0.21	1.68	1.68	0.04	0.40	0.02	0.0
9	0.19	0.19	0.13	0.13	0.13	0.13	0.63	0.63	0.04	2.72	0.02	0.0
10	0.17	0.17	0.18	0.18	0.14	0.14	0.92	0.92	0.02	0.78	0.02	0.0

WHITE RIVER CALIBRATION (COMBINED DATA SETS)

SUBRFACH	REAERATION COEFFICIENT DERIVATION
1	KA COMPUTED BY VELZ EQUATION
2	KA COMPUTED BY VELZ EQUATION
3	KA COMPUTED BY VELZ EQUATION
4	KA COMPUTED BY VELZ EQUATION
5	KA COMPUTED BY VELZ EQUATION
6	KA COMPUTED BY VELZ EQUATION
7	KA COMPUTED BY VELZ EQUATION
8	KA COMPUTED BY VELZ EQUATION
9	KA COMPUTED BY VELZ EQUATION
10	KA COMPUTED BY VELZ EQUATION

WHITE RIVER CALIBRATION (COMBINED DATA SETS)

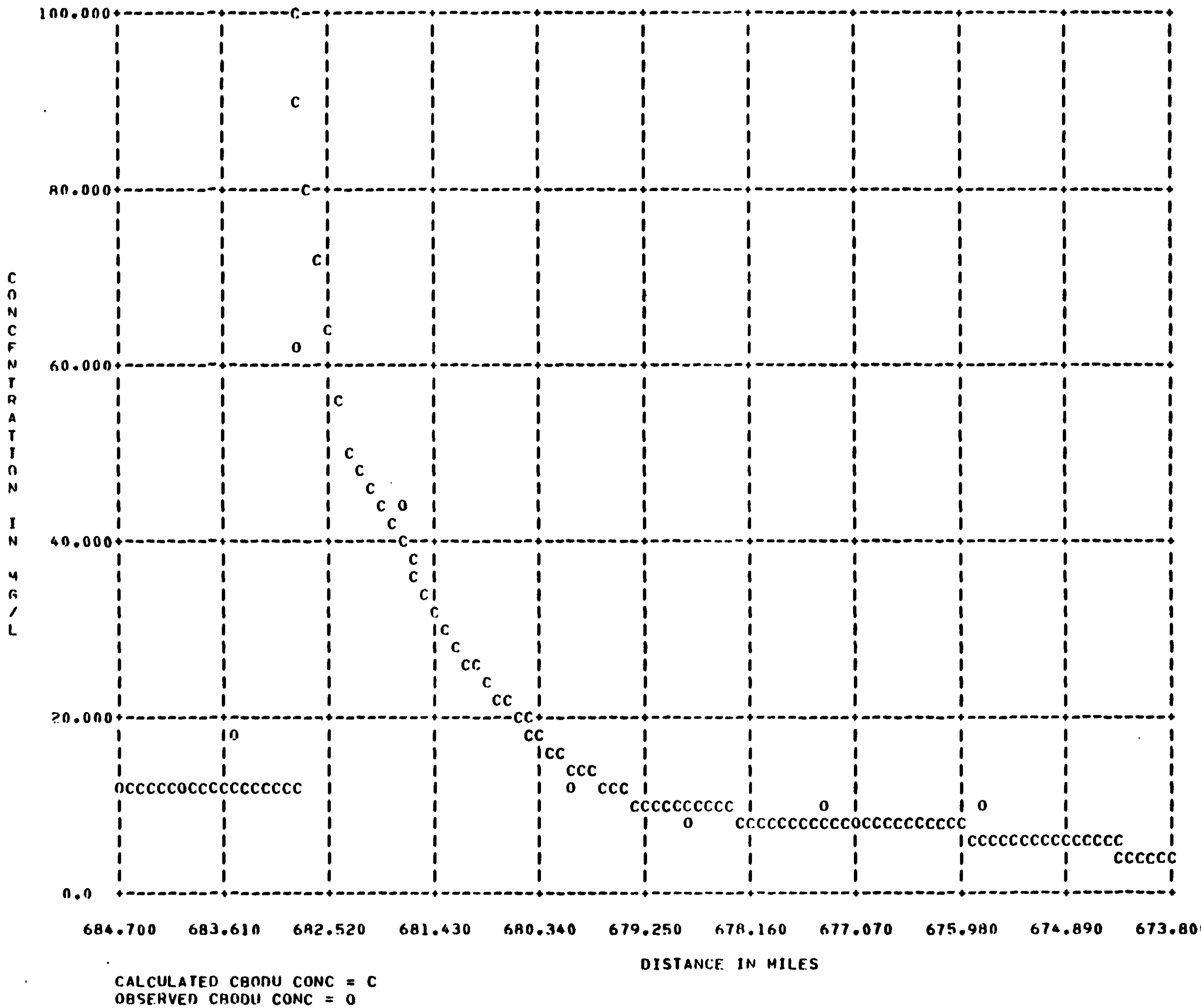
SUBREACH	DO SATURATION (MG/L)
1	9.442
2	9.442
3	8.390
4	9.067
5	9.251
6	9.442
7	9.442
8	9.442
9	9.442
10	9.251

WHITE RIVER CALIBRATION (COMBINED DATA SETS)

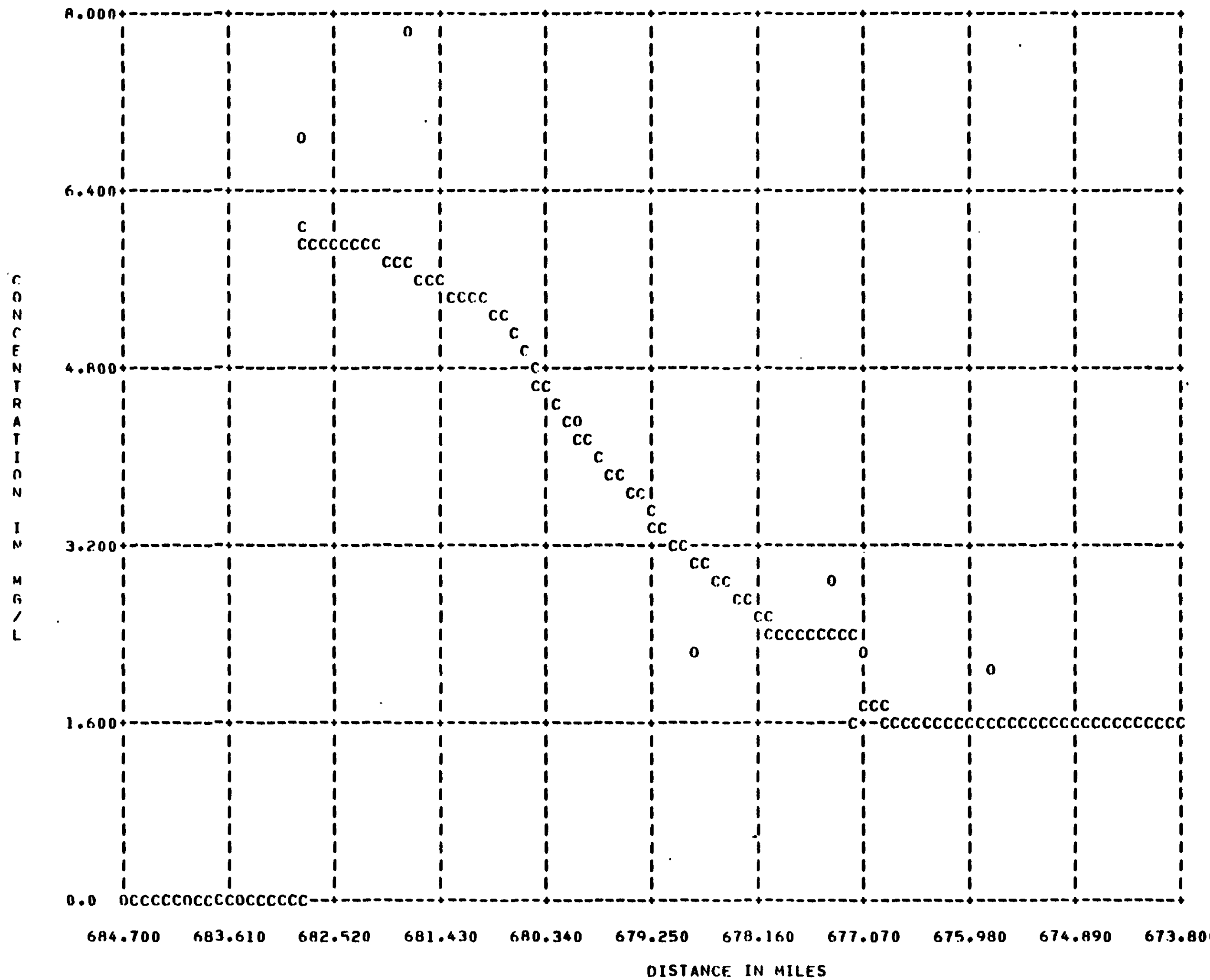
O B S E R V E D   M E A S U R E M E N T S

DISTANCE (MI)	DO CONC (MG/L)	CBODU (MG/L)	NBODU (MG/L)	ORG-N (MG/L)	NH3-N (MG/L)	NO2-N (MG/L)	NO3-N (MG/L)	TOTAL COLIFORM	FECAL COLIFORM	PO4 (MG/L)
684.70	6.97	12.00	0.0	1.26	0.41	0.0	0.02	0.	0.	0.05
684.00	6.10	12.00	0.0	0.64	0.28	0.02	0.27	0.	0.	0.04
683.50	8.80	17.00	0.0	1.10	0.06	0.01	0.05	0.	0.	0.0
682.80	4.20	62.00	0.0	14.60	3.70	0.12	1.70	0.	0.	6.80
681.80	0.10	43.00	0.0	8.40	4.60	0.14	0.21	0.	0.	7.90
680.00	1.80	12.00	0.0	2.60	2.80	0.10	0.37	0.	0.	4.30
678.80	2.40	8.20	0.0	1.20	1.80	0.10	0.52	0.	0.	2.30
677.40	3.70	9.50	0.0	3.80	0.23	0.10	0.76	0.	0.	2.80
677.10	5.90	8.10	0.0	2.30	1.30	0.08	0.87	0.	0.	2.20
675.80	6.90	9.00	0.0	1.20	1.70	0.14	0.97	0.	0.	2.00

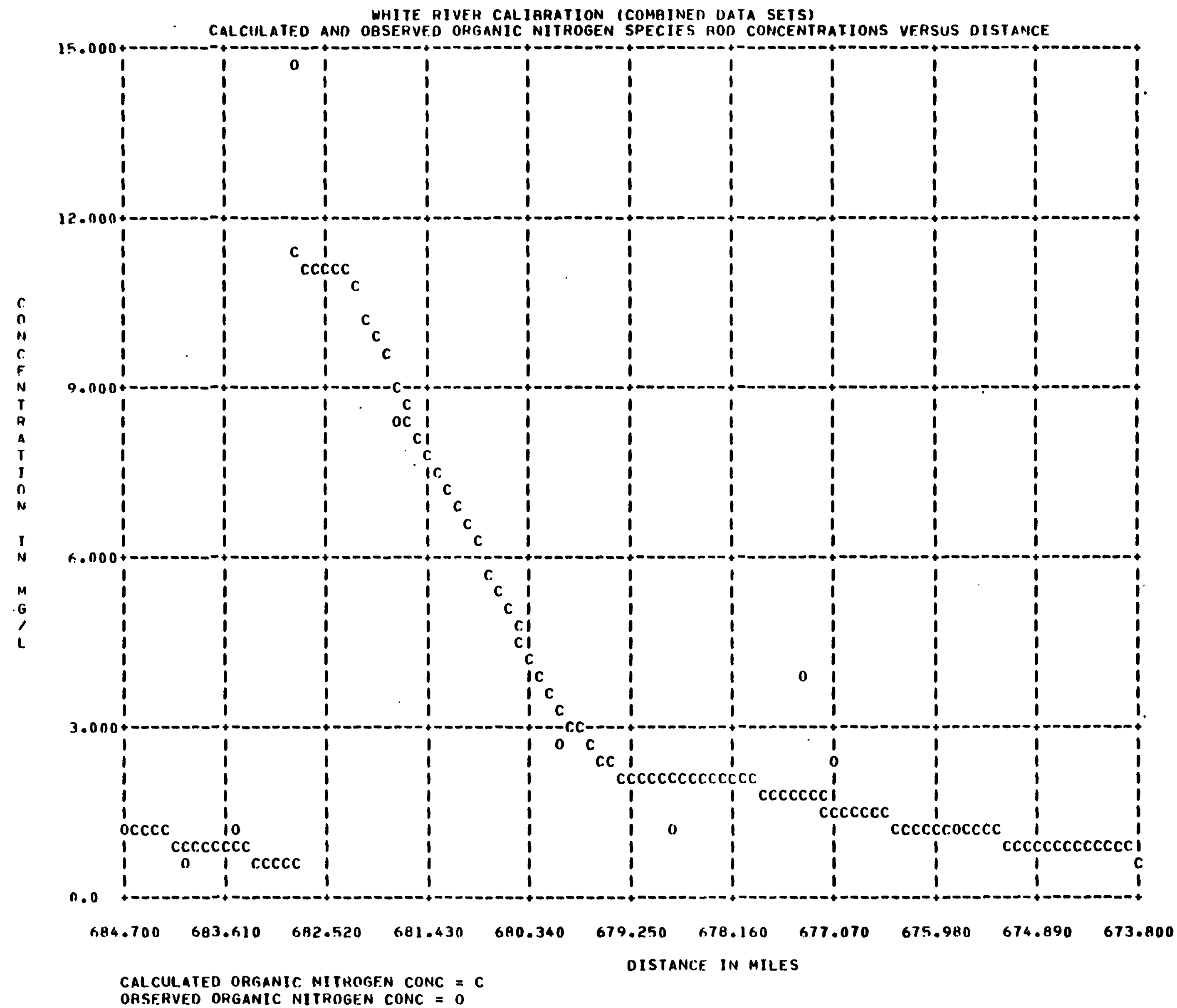
WHITE RIVER CALIBRATION (COMBINED DATA SETS)
CALCULATED AND OBSERVED CBOD CONCENTRATIONS VERSUS DISTANCE



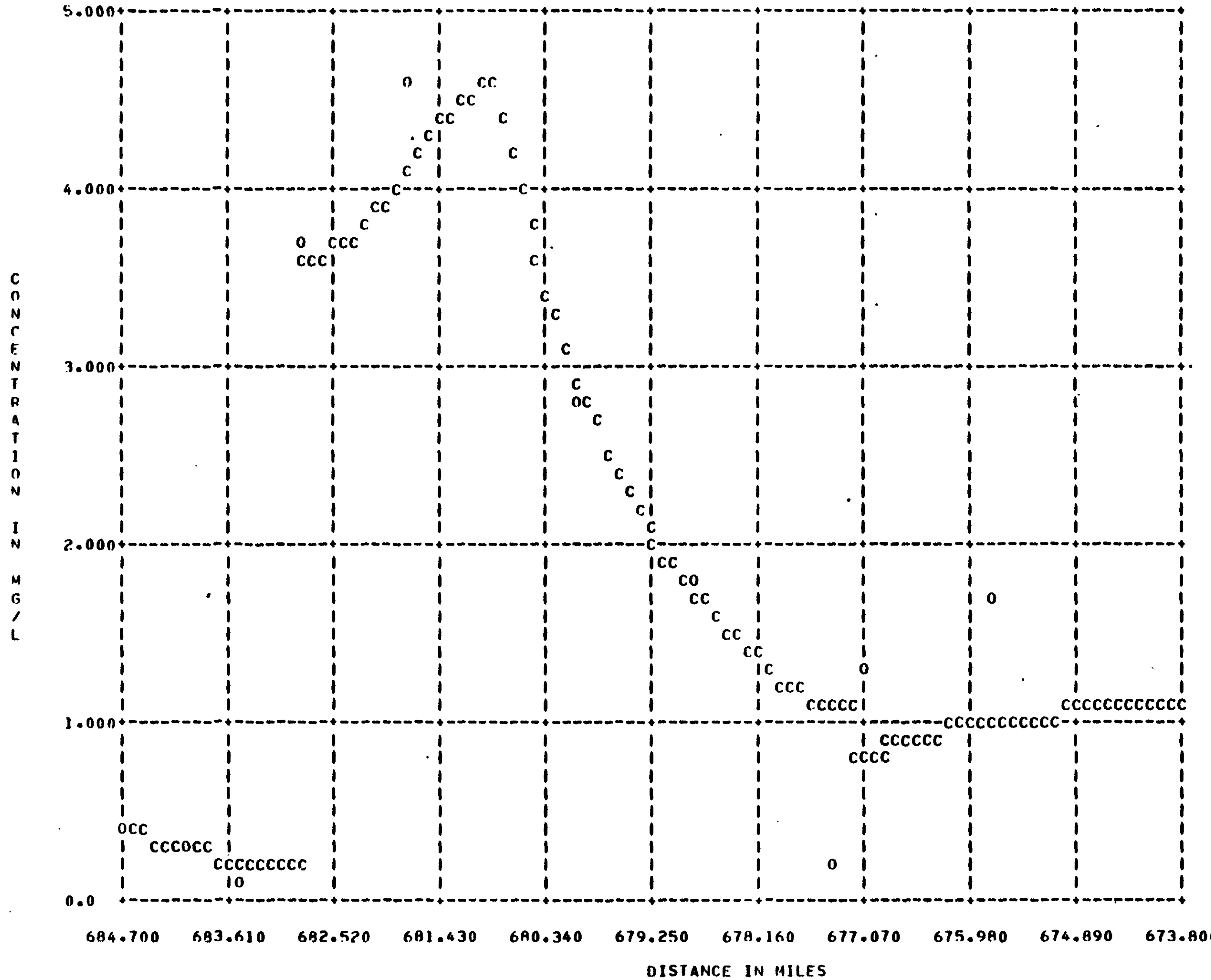
WHITE RIVER CALIBRATION (COMBINED DATA SETS)
CALCULATED AND OBSERVED PO4 CONCENTRATIONS VERSUS DISTANCE



CALCULATED PO4 CONC = C
OBSERVED PO4 CONC = O

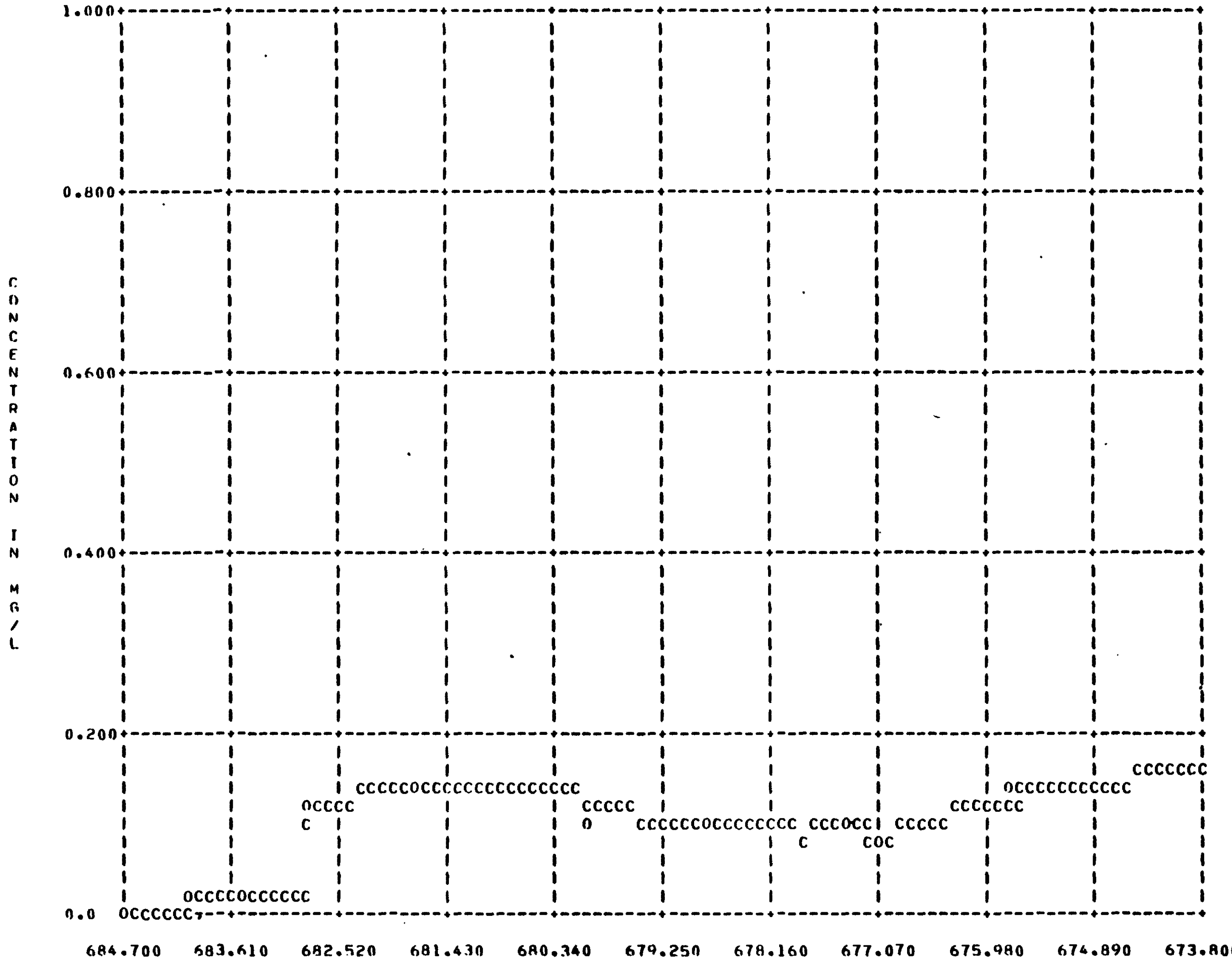

WHITE RIVER CALIBRATION (COMBINED DATA SETS)
CALCULATED AND OBSERVED ORGANIC NITROGEN SPECIES ROD CONCENTRATIONS VERSUS DISTANCE
CONCENTRATION IN MG/L
15.000
12.000
9.000
6.000
3.000
0.0
684.700
683.610
682.520
681.430
680.340
679.250
678.160
677.070
675.980
674.890
673.800
DISTANCE IN MILES
CALCULATED ORGANIC NITROGEN CONC = C
OBSERVED ORGANIC NITROGEN CONC = O

WHITE RIVER CALIBRATION (COMBINED DATA SETS)
CALCULATED AND OBSERVED AMMONIA NITROGEN SPECIES BOD CONCENTRATIONS VERSUS DISTANCE



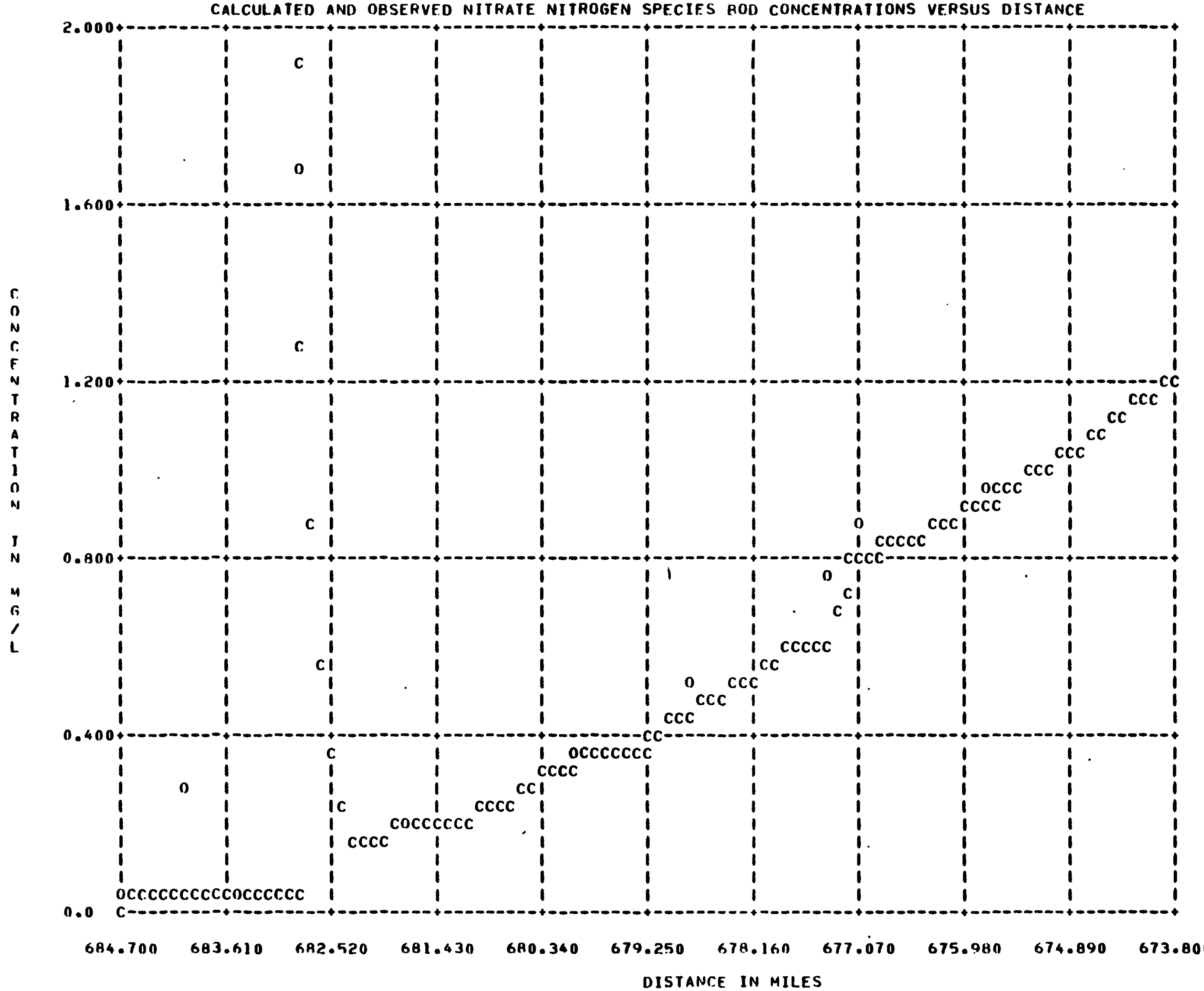
CALCULATED AMMONIA NITROGEN CONC = C
OBSERVED AMMONIA NITROGEN CONC = O

WHITE RIVER CALIBRATION (COMBINED DATA SETS)
CALCULATED AND OBSERVED NITRITE NITROGEN SPECIES BOD CONCENTRATIONS VERSUS DISTANCE



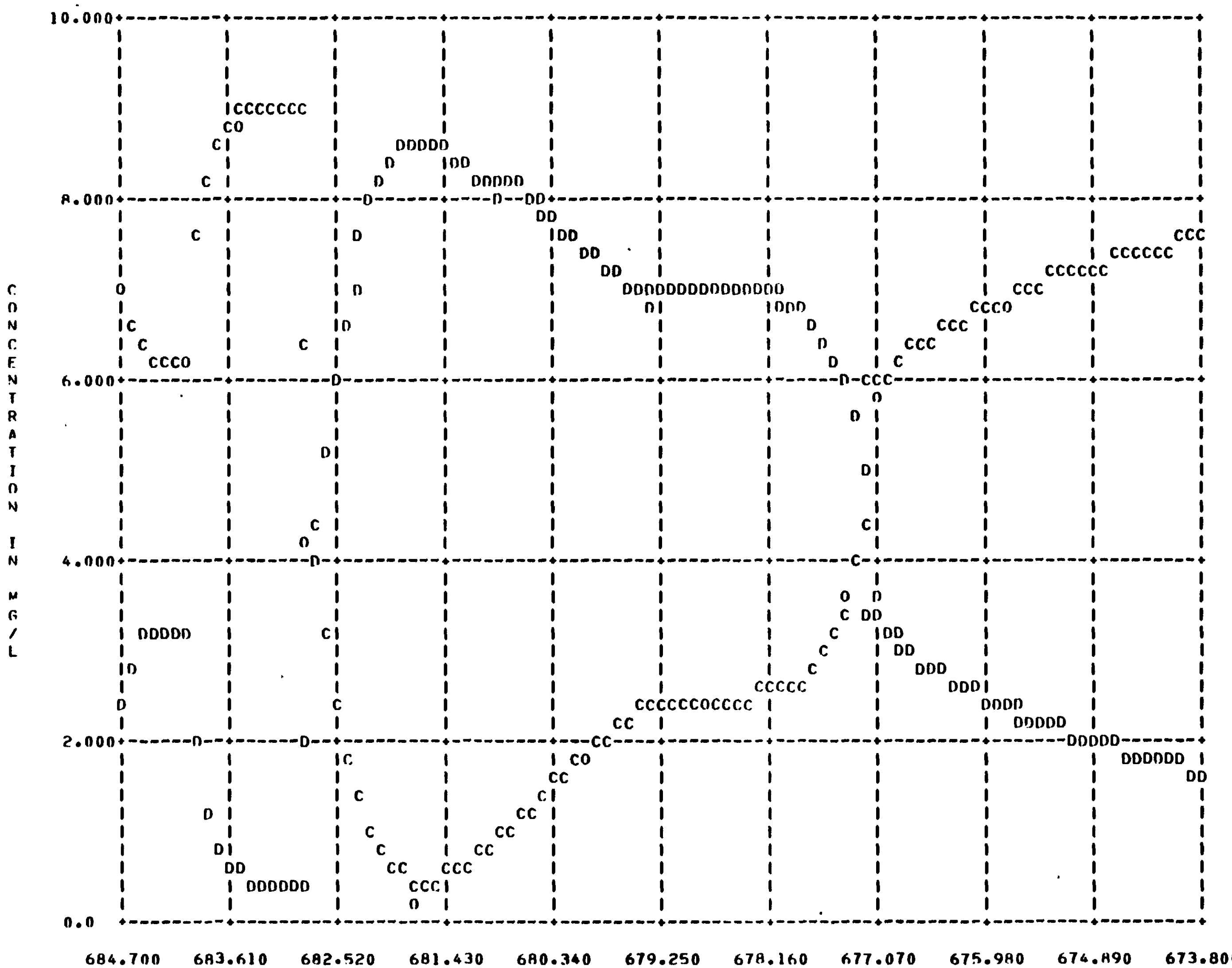
CALCULATED NITRITE NITROGEN CONC = C
OBSERVED NITRITE NITROGEN CONC = O

WHITE RIVER CALIBRATION (COMBINED DATA SETS)
CALCULATED AND OBSERVED NITRATE NITROGEN SPECIES BOD CONCENTRATIONS VERSUS DISTANCE



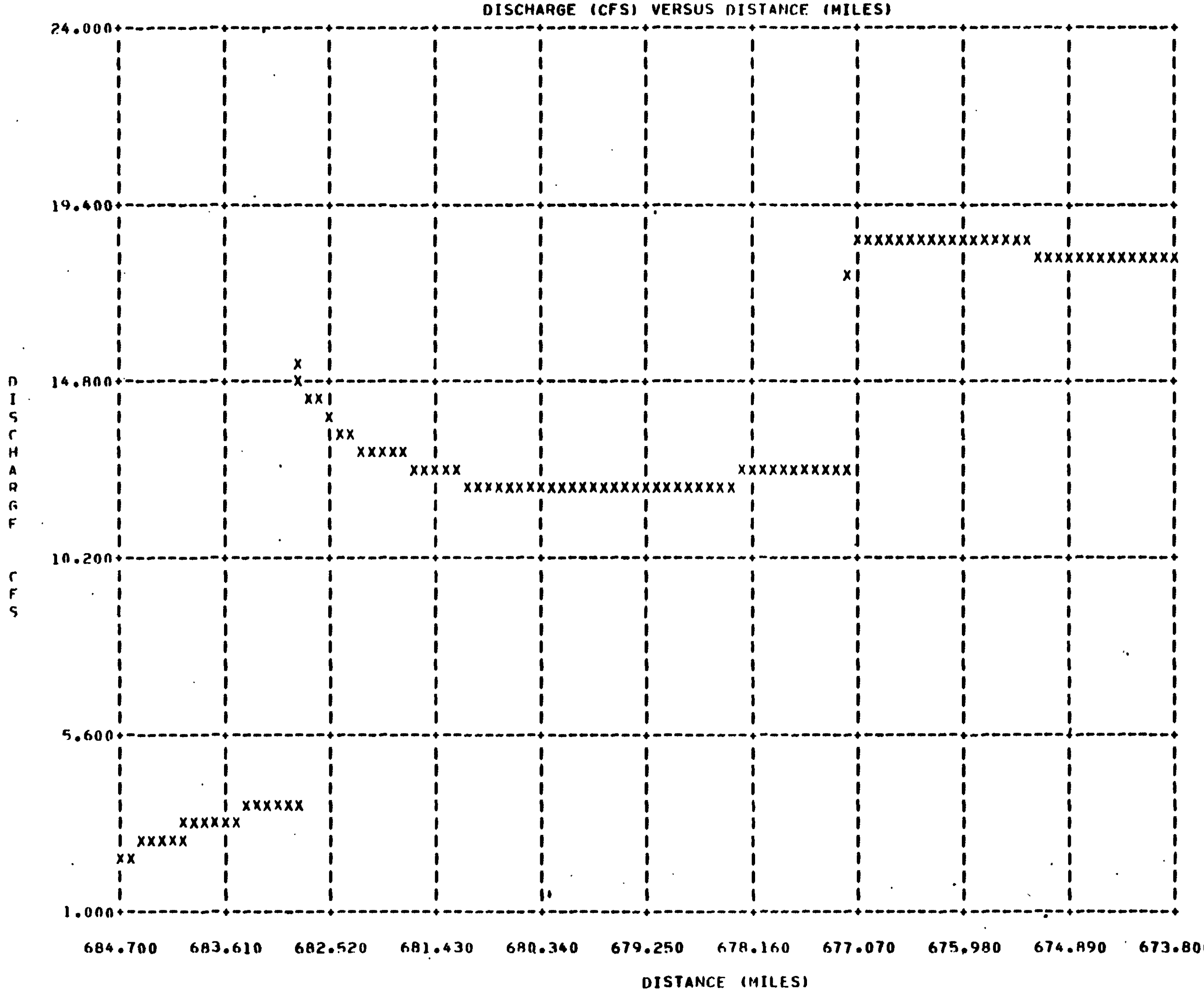
CALCULATED NITRATE NITROGEN CONC = C
OBSERVED NITRATE NITROGEN CONC = O

WHITE RIVER CALIBRATION (COMBINED DATA SETS)
CALCULATED AND OBSERVED DO CONCENTRATIONS AND DO DEFICIT VERSUS DISTANCE



CALCULATED DO CONC = C
OBSERVED DO CONC = O
DO DEFICIT = D

WHITE RIVER CALIBRATION (COMBINED DATA SETS)
DISCHARGE (CFS) VERSUS DISTANCE (MILES)



WHITE RIVER CALIBRATION (COMBINED DATA SETS)
DEPTH (FEET) VERSUS DISTANCE (MILES)