ASSESSMENT OF LOW-FLOW WATER QUALITY IN RICHLAND CREEK, ILLINOIS

By W. O. Freeman and A. R. Schmidt

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

ILLUSTRATIONS

TABLES

FACTORS FOR CONVERTING INCH-POUND UNITS TO METRIC (INTERNATIONAL SYSTEM) UNITS

For the convenience of readers who may want to use metric (International System) units, the inch-pound units used in this report may be converted by using the following factors:

Multiply inch-pound units	By	To obtain metric units
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	0.09294	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
foot squared per second (ft^2/s)	0.09294	meter squared per second (m^2/s)
million gallons per day (Mgal/d)	0.04381 3,785	cubic meter per second (m^3/s) cubic meter per day (m^3/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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

$$°F = 9/5°C + 32$$

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ABSTRACT

Relations among several stream processes and concentrations of dissolved oxygen and other constituents were evaluated for a 30.1-mile reach of Richland Creek in southwestern Illinois, by comparing measured data with computer-simulated data. Measurements, made during periods of low flow, were used to calibrate and verify the QUAL-II one-dimensional, steady-state, water-quality model (Southeast Michigan Council of Governments' version). Equations for predicting reaeration rates were chosen from existing equations by comparing the predicted values with values that were measured using a steady-state, gas-tracer technique. Equations for predicting traveltimes were also developed from these measurements. Water samples were collected from the creek and known inflows during two 24-hour (diel) periods in July and August 1984. These samples were analyzed for up to 60 chemical constituents.

Diel dissolved oxygen concentrations in Richland Creek were as low as 0.1 mg/L (milligram per liter). During the two diel periods, the subreach of Richland Creek between RM (river mile) 29.0 and RM 23.0 had the lowest dissolved oxygen concentrations. Maximum diel dissolved oxygen concentrations throughout this subreach were seldom greater than the State's minimum standard of 5 mg/L. Model simulations indicated that sediment oxygen demand was the most important factor causing dissolved oxygen depletion in this critical subreach. Other factors such as biochemical oxygen demand and ammonia oxidation were overshadowed by the large sediment demands.

The maximum total iron concentration was 2,979 μg/L (micrograms per liter) compared to the State standard of 1,000 μg/L. The maximum manganese concentration was 1,046 μg/L compared to the State standard of 1,000 μg/L. The maximum copper concentration was 47 μg/L compared to the State standard of 20 μg/L. The maximum ammonia concentration for the two diel periods was 6.8 mg/L as nitrogen, and the pH and water temperature of the stream were such that the calculated un-ionized ammonia concentration exceeded the State general-use water-quality standard of 0.04 mg/L at four sites during the July diel study and at six sites during the August diel study.

Model simulations using hypothetical water-quality conditions indicated that a reduction of ammonia concentrations in wastewater treatment facility effluent would not greatly improve un-ionized ammonia concentrations in the creek. A simulation using a reduced sediment oxygen demand in the subreach of the creek between RM 30.0 and RM 27.1 improved dissolved oxygen concentrations, bringing them above the State minimum standard.

INTRODUCTION

The Richland Creek basin is in the St. Louis metropolitan area. Urban development can affect the water quality of nearby streams, making it necessary to carefully plan and implement good management practices for these basins. The population in the basin is increasing, from 55,388 in 1970 to 57,480 in 1980, an increase of about 3.6 percent (U.S. Census Bureau, 1980).

Previous water-quality studies have shown that dissolved oxygen and some other constituents did not comply with the State of Illinois general-use, water-quality standards (Illinois Environmental Protection Agency, 1976; Southwestern Illinois Metropolitan and Regional Planning Commission, 1978; and Freed and others, 1980). Water-quality monitoring studies of Richland Creek conducted by the IEPA (Illinois Environmental Protection Agency) show that between 1970 and 1976 dissolved oxygen concentrations were below the State minimum standard of 5.0 mg/L in 39 percent of the samples collected. A minimum concentration of 0.0 mg/L was measured at the Survey (U.S. Geological Survey) gaging station near Hecker (05595200) (Illinois Environmental Protection Agency, 1976). A similar study by Southwestern Illinois Metropolitan and Regional Planning Commission (1978) also identified low dissolved oxygen concentrations in subreaches of Richland Creek. These studies, as well as a study by Freed and others (1980), showed that other chemical constituents, including pH, iron, and manganese, also were in violation of the State general-use water-quality standards. This indicated that management practices were no longer adequate to maintain the stream quality.

Combined sewers, WWTFs (wastewater treatment facilities), industrial discharges, and several nonpoint sources such as runoff from coal mine tailings (gob piles), agricultural land, and feed lots are present in the basin. All of these have the potential to degrade the water quality of Richland Creek.

The IEPA has the primary responsibility for reviewing water-quality standards for streams and suggesting management plans and discharge limitations needed to achieve those standards. Data to define the chemical, physical, and biological interactions that control the water quality are needed to develop an understanding of stream processes. The best means to interpret this data and evaluate management alternatives is through the use of a computer water-quality model.

This report is the result of a cooperative effort by the Survey and the IEPA to describe the low-flow water quality of Richland Creek and to calibrate and verify a digital water-quality model for use by the IEPA in suggesting management plans for the basin. This report is the second in a series of reports that describe the low-flow water quality of Illinois streams (Freeman and others, 1986).

This report helps to fulfill some of the goals of the Federal-State cooperative program by providing the data needed to evaluate the quantity, quality, and use of Richland Creek. The physical, chemical, and biological characteristics described through this interpretive investigation provide the information necessary for the best use and management of these water resources.

Purpose and Scope

The purposes of this report are to present low-flow water-quality data for Richland Creek during the period of June through September 1984; to identify stream subreaches where State general-use, water-quality standards are not met; to describe environmental factors in those subreaches that contribute to the poor water quality; and to evaluate existing or modified management actions that affect water quality.

The scope of this investigation was to evaluate water quality during two periods of approximately steady-state, low-flow conditions. Chemical, physical, and biological measurements were made during low-flow periods in July and August 1984. These measurements were used to evaluate the average daily trends of constituent concentrations and to calibrate and verify the Southeast Michigan Council of Governments' version of the QUAL-II steady-state, water-quality model as described by the National Council of the Paper Industry for Air and Stream Improvement (1982). The model was used to simulate water-quality characteristics such as BOD (biochemical oxygen demand), SOD (sediment oxygen demand), and algal growth and respiration, along with the effects of the streamflow and channel characteristics on the dissolved oxygen, ammonia, nitrite plus nitrate, and phosphorus concentrations in the stream.

The model was used to identify environmental factors that cause water-quality standards in a subreach to be exceeded and thereby indicate possible actions to reduce the effects of those factors.

Study Area

Richland Creek drains 248 mi^2 (square miles) of Monroe, St. Clair, and Randolph Counties in southwestern Illinois (fig. 1). The creek flows 39.7 miles from its headwaters near O'Fallon, Illinois, to the Kaskaskia River. The study reach includes 30.1 river miles from a point near its headwaters (RM 38.1) downstream to Monroe County road LL (RM 8.0) (fig. 2). Table 1 lists the data-collection sites referred to in figure 2. The watershed of Richland Creek is predominantly agricultural except along the upper subreaches where the creek flows through two urban areas, Swansea (population 5,347) and Belleville (population 41,580) (U.S. Census Bureau, 1980).

The study reach drains 223 mi^2 and includes several tributaries and eight WWTFs. Nine of the tributaries were monitored. Three of these tributaries receive treated wastewater (table 2). There has been some mining in the basin; however, there were no active mining operations during this study and most of the old mine areas were well reclaimed. Runoff from some gob piles in the northern part of the basin may affect the upstream subreaches of Richland Creek.

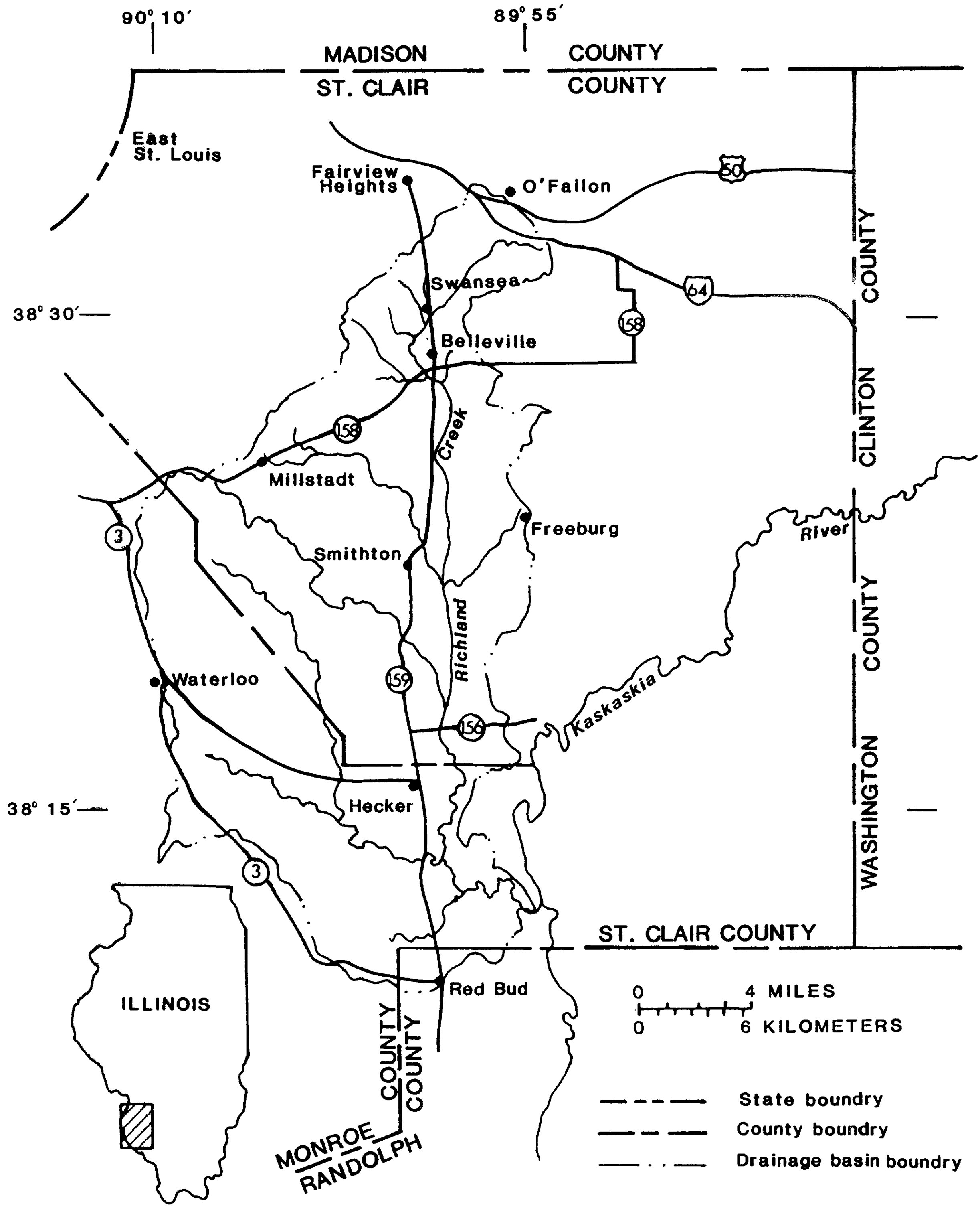

Figure 1.--Location of the Richland Creek basin in southwestern Illinois.

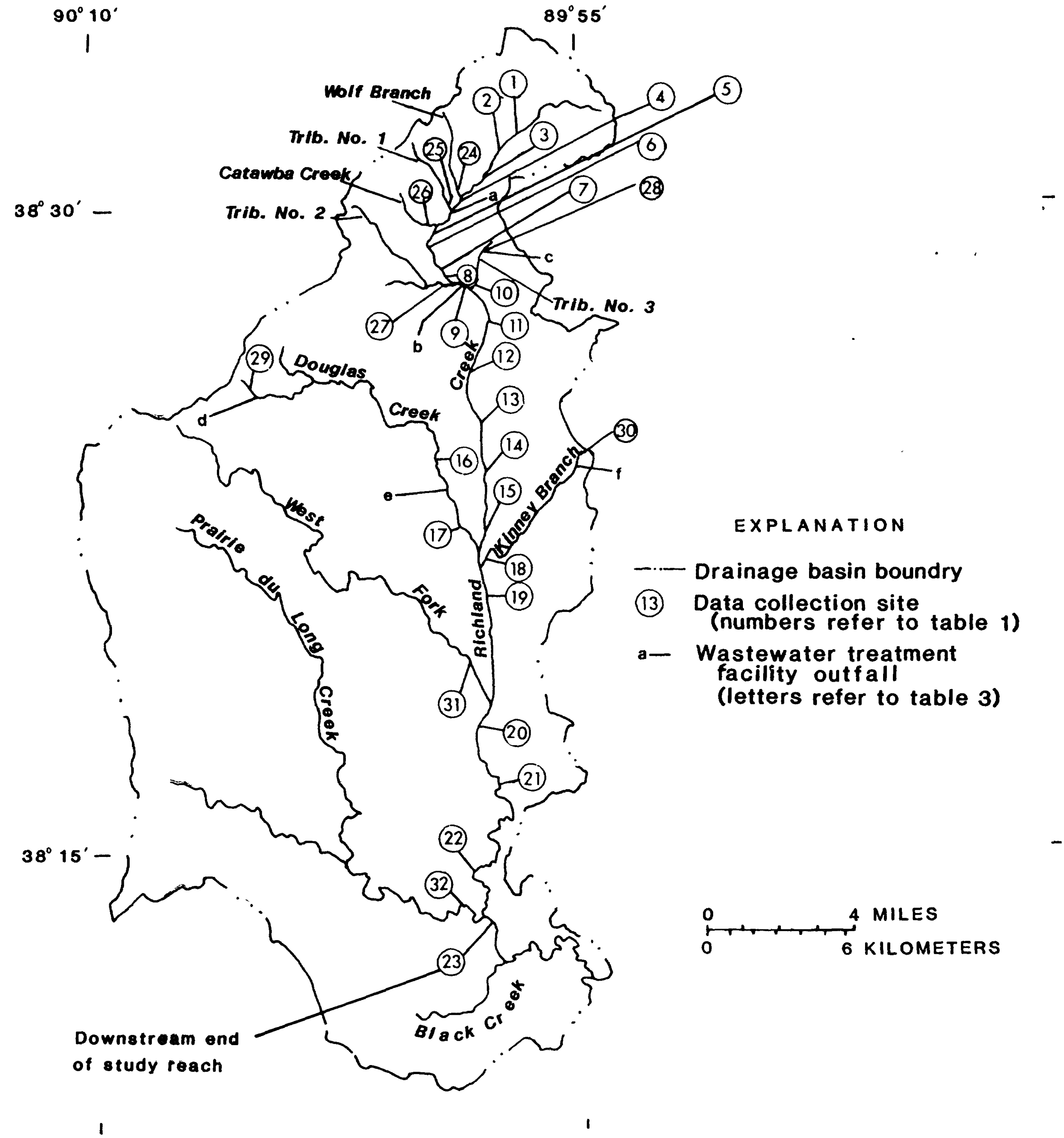

Figure 2.--Richland Creek basin showing the locations of the data-collection sites and the wastewater treatment facility outfalls.

Table 1.--Data-collection sites

[Site numbers correspond to those in figure 2 of this report]

Site No.	Station No.	River mile above mouth	Station name and location
1	05595025	38.10	Richland Creek at Township Line Road near O'Fallon Lat: 38°34'05" Long: 89°55'46"
2	05595035	36.40	Richland Creek at Hartman Lane near Belleville Lat: 38°33'31" Long: 89°56'50"
3	05595045	34.70	Richland Creek at Old Collinsville Road at Belleville Lat: 38°32'26" Long: 89°57'51"
4	05595050	33.80	Richland Creek at Route 161 at Belleville Lat: 38°32'00" Long: 89°58'31"
5	05595075	32.60	Richland Creek at Route 159 at Belleville Lat: 38°31'18" Long: 89°59'02"
6	05595090	31.70	Richland Creek at West Main Street at Belleville Lat: 38°30'48" Long: 89°59'35"
7	05595095	31.30	Richland Creek at Monroe Street at Belleville Lat: 38°30'31" Long: 89°59'24"
8	05595100	30.70	Richland Creek at Belleville Lat: 38°30'09" Long: 89°59'03"
9	05595110	29.40	Richland Creek at Route 15 at Belleville Lat: 38°29'35" Long: 89°57'59"
10	05595119	[1]28.60	Richland Creek Tributary No. 3 at County Highway 4 near Belleville Lat: 38°29'14" Long: 89°57'26"
11	05595123	28.00	Richland Creek near Belleville Lat: 38°28'30" Long: 89°57'54"
12	05595127	27.10	Richland Creek at Schleuter-Germain Road near Belleville Lat: 38°27'49" Long: 89°58'14"

Table 1.--Data-collection sites--Continued

Site No.	Station No.	River mile above mouth	Station name and location
13	05595133	25.50	Richland Creek at Schreimer Road near Smithton Lat: 38°26'30" Long: 89°57'53"
14	05595139	24.30	Richland Creek at Douglas Road near Smithton Lat: 38°25'28" Long: 89°57'52"
15	05595145	22.70	Richland Creek at Press Road at Smithton Lat: 38°24'11" Long: 89°58'07"
16	05595160	[1]22.40	Douglas Creek at Route 159 at Smithton Lat: 38°25'16" Long: 89°59'00"
17	05595163	[1]22.40	Douglas Creek at Press Road at Smithton Lat: 38°24'11" Long: 89°58'31"
18	05595173	[1]22.00	Kinney Branch at Brenner Road near Smithton Lat: 38°23'49" Long: 89°57'39"
19	05595178	21.20	Richland Creek at Robinson School Road near Smithton Lat: 38°22'51" Long: 89°57'55"
20	05595200	17.20	Richland Creek near Hecker Lat: 38°19'26" Long: 89°58'15"
21	05595203	14.80	Richland Creek at Nike Road near Hecker Lat: 38°18'14" Long: 89°57'30"
22	05595207	10.80	Richland Creek at M Road near Hecker Lat: 38°16'30" Long: 89°58'15"
23	05595219	8.00	Richland Creek at LL Road near Red Bud Lat: 38°15'07" Long: 89°57'33"
24	05595055	[1]33.50	Wolf Branch at Route 161 at Swansea Lat: 38°32'01" Long: 89°58'49"
25	05595070	[1]33.00	Richland Creek Tributary No. 1 at Southern Railroad at Swansea Lat: 38°31'32" Long: 89°58'55"
26	05595080	[1]32.40	Catawba Creek at Belleville Lat: 38°31'15" Long: 89°59'17"

Table 1.--Data-collection sites--Continued

Site No.	Station No.	River mile above mouth	Station name and location
27	05595105	[1]30.40	Richland Creek Tributary No. 2 at Routes 15 and 159 at Belleville Lat: 38°29'55" Long: 89°58'56"
28	05595115	[1]28.60	Richland Creek Tributary No. 3 above wastewater treatment facility at Belleville Lat: 38°30'38" Long: 89°57'23"
29	05595149	[1]22.40	Douglas Creek Tributary above Millstadt wastewater treatment facility at Millstadt Lat: 38°27'20" Long: 90°05'12"
30	05595167	[1]22.00	Kinney Branch above Freeburg West wastewater treatment facility at Freeburg Lat: 38°25'22" Long: 89°55'39"
31	05595195	[1]18.10	West Fork Richland Creek at Skaer Road near Hecker Lat: 38°21'11" Long: 89°58'52"
32	05595216	[1]8.70	Prairie du Long Creek at Route 159 near Red Bud Lat: 38°15'35" Long: 89°59'46"

[1] River miles indicate the location of the mouth of the tributary above the mouth of Richland Creek.

Table 2.--Drainage areas and average flows for Richland Creek tributaries

[dashes indicate no data]

Tributary name	Drainage area at the mouth (square miles)	Tributary contains treated wastewater from these facilities	Average flow near the mouth during the diel studies (cubic feet per second)	
			July diel	August diel
Wolf Branch	1.74	None	0.00	0.00
Tributary No. 1	1.59	None	.07	.01
Catawba Creek	1.88	None	.13	.04
Tributary No. 2	7.22	None	--	.13
Tributary No. 3	3.85	Belleville Area 3	.22	.15
Douglas Creek	20.6	Millstadt and Smithton	.41	.27
Kinney Branch	5.26	Freeburg West	.06	.09
West Fork Richland Creek	26.9	None	.05	.03
Prairie du Long Creek	79.7	None	4.89	2.57

There is one continuous-record stream-gaging station on Richland Creek that is operated by the Survey. This station, Richland Creek near Hecker (05595200), was used as an index of flow for this study. The average discharge at this site computed from 15 years of record is 104 ft^3/s (cubic feet per second) (Stahl and others, 1985). The average discharges (computed from the stage-discharge relation) at this station during the two 24-hour (diel) studies of July 23-24 and August 6-7, 1984, were 10.1 and 16.5 ft^3/s, respectively. The 7-day, 10-year low flow for this station reported by Singh and Stall (1973) is 3.8 ft^3/s. The 7-day, 10-year low flow calculated from station data through 1984 is 5.10 ft^3/s. Thus, the streamflows during the diel studies were near critical low-flow conditions. Streamflow upstream of site 3 was intermittent, and there was essentially no flow during the August diel study. During these low-flow periods, there is very little flow upstream of the Swansea WWTF, and throughout most of the study reach, the streamflow is composed primarily of treated wastewater.

Acknowledgments

The authors wish to acknowledge the assistance of the IEPA personnel in helping organize and execute this study, especially during the diel-data collections. Acknowledgment is also given to the local wastewater treatment facilities for providing access for sampling and for providing us with their discharge data during the diel periods.

DATA COLLECTION AND DESCRIPTION

Data requirements for assessing stream quality include traveltimes, reaeration-rate coefficients, stream discharges, BODs, and various chemical-constituent concentrations. Channel and streamflow characteristics, atmospheric reaeration rates, and chemical-quality measurements were made on Richland Creek during low-flow periods from June through September 1984. Traveltimes and reaeration-rate coefficients were determined at various flow rates throughout the study period. Two diel studies at different low-flow conditions were performed in July and August 1984. Chlorophyll-a concentrations, BODs, and the chemical constituent concentrations were determined from samples collected at 38 sites during the diel studies. These sites included 6 WWTF outfalls, 13 tributary sites, and 19 sites on Richland Creek (fig. 2). Field measurements of pH, specific conductance, dissolved oxygen, stage, and air and water temperatures were also made at these sites.

Eight WWTFs discharge to Richland Creek or its tributaries within the study reach. Two of these eight WWTFs were not monitored (Hector and Tamarak Country Club and Estates) because the WWTFs discharge an insignificant volume of effluent compared to the volume of streamflow at the point of discharge. Table 3 lists the treatment processes and outfall locations of the six WWTFs monitored. The Belleville Area 1 and Swansea WWTFs are the most significant contributors to streamflow in the basin.

Table 3.--Wastewater treatment facility characteristics

[All wastewater treatment facility design information from R. Hite, Illinois Environmental Protection Agency, written commun., 1984]

Map symbols[1]	Wastewater treatment facility name	Secondary treatment[2]	Tertiary treatment[2]	Nitrification[2]	Treatment-plant discharge (cubic feet per second)			Location of outfall[3]
					Design discharge	Average discharge during diel study		
						July	August	
a	Swansea wastewater treatment facility	Activated sludge	Polishing pond	None	1.55	0.96	0.86	RC / 33.20
b	Belleville Area 1 wastewater treatment facility	Activated sludge	High-rate filters	None	12.38	7.71	6.81	RC / 30.00
c	Belleville Area 3 wastewater treatment facility	Activated sludge	High-rate filters	None	.62	.20	.20	Trib. No. 3 / 28.60
d	Millstadt wastewater treatment facility	Activated sludge	High-rate filters	None	.77	.32	.28	Douglas Ck. / 22.40
e	Smithton wastewater treatment facility	Lagoon	High-rate filters	None	.37	.39	.39	Douglas Ck. / 22.40
f	Freeburg West treatment facility	Activated sludge	High-rate filters	None	.62	.15	.14	Kinney Br. / 22.00

1 Map symbols correspond to those in figure 2 of this report.

2 Explanation of treatment processes are discussed by Clark and others (1977).

3 The format for this column is as follows: stream name or symbol / river mile
River miles are from the mouth of Richland Creek (RC).
River miles for tributaries are the location of the mouth of the tributary from the mouth of Richland Creek.

Streamflow and Channel Characteristics

Stream discharge was measured several times at 52 different sites throughout the study period. Reference points were established and stage-discharge relations were developed at the 19 creek sites sampled during the diel studies, using the methods described by Rantz and others (1982). Discharge was measured once during each diel study at each sampling site. Discharge at the times of sampling was estimated using these low-flow stage-discharge relations. Discharges from the WWTFs were determined from the flow charts maintained by the WWTF; for those WWTFs without daily discharge records, average monthly data that they provide to the IEPA were used.

Channel cross-sectional area and width measurements were made as a part of the discharge measurements using the methods described by Rantz and others (1982). The locations of the measuring sites were chosen to provide the best measurement of discharge. Average channel depth was calculated by dividing cross-sectional area by the top width.

Traveltimes and Reaeration-Rate Coefficients

Traveltime refers to the period of time it takes for water or waterborne materials to move from one point to another in a stream (Hubbard and others, 1982). Reaeration rate refers to the rate at which oxygen is absorbed from the atmosphere by the stream (Rathbun and Grant, 1978). Measurement of traveltimes and reaeration rates were not made for subreaches upstream of RM 34.7, because stream discharge was too low to provide accurate results. The remaining 26.7 miles were divided into 24 subreaches based on estimates of traveltimes and reaeration rates, and on accessibility. Selection of the subreaches used in the traveltime and reaeration-rate studies was also based on the criterion that the product of the propane desorption rate and traveltime equal one. This minimizes the errors introduced in the gas tracer technique described by Yotsukura and others (1983). Traveltime and reaeration rate measurements were made throughout the study period. At least one measurement was made for each subreach.

The technique used in measuring reaeration rates is based on the constant relation between the rate at which a tracer gas desorbs from water and the rate at which oxygen is absorbed from or desorbed to the atmosphere by the water. This relation has been shown using laboratory tank tests, and the technique has been used to measure rates of gas loss over stream reaches (Rathbun and Grant, 1978).

Traveltimes and reaeration-rate coefficients of Richland Creek were measured simultaneously using a steady-state version of the gas-tracer technique (Yotsukura and others, 1983). Traveltimes were determined using rhodamine-WT fluorescent dye by timing its movement through a subreach. The reaeration rates were determined using propane gas that was steadily injected through porous diffuser plates for approximately the entire traveltime of the subreach being measured. Freeman and others (1986) describe in detail the methods used for injection and analysis of reaeration rates and traveltimes. All rate coefficients in this report are calculated using natural logarithms (base e).

Sediment Oxygen Demand Measurements

Measurements of SOD in Richland Creek were made at several locations during the study period. These measurements were made by using a steel box of known volume that is open only to the streambed. This box was placed in contact with the streambed so that the water inside could not recirculate with the streamflow. A dissolved oxygen probe with stirrer was secured inside the box. A volume of water equal to about three volumes of the box was filtered through a 10-micrometer filter and then poured through a gravity feed system into a valve in the top of the box. This flushed the water inside the box out through another valve and replaced a large part of that water with water that had been filtered to remove some of the phytoplankton and other material that might affect the dissolved oxygen concentration. The remaining oxygen demand of the water in the box was assumed to be negligible. The valves were then closed to seal the box and periodic measurements of the dissolved oxygen inside the box were recorded over a period of 4 to 6 hours. This time-series data was used to calculate the SOD.

The amount of oxygen consumed within the box was plotted as a function of time. There is an initial high rate of demand that is caused by demand from sediments disturbed when the box was positioned or by the oxygen levels in the filtered water coming to equilibrium with the rest of the system. The linear portion of the plot following this initial high demand represents the SOD of the sample area. The slope of this linear portion is used with the following equation to calculate the SOD (Butts, 1974):

$$SOD = (1,440\ SV) / A \qquad (1)$$

where SOD is the sediment oxygen demand, in milligrams per square foot per day;

S is the slope (as described above), in milligrams per liter per minute;

V is the volume of the box, in liters;

A is the area of the open side of the box, in square feet; and

1,440 is a constant to convert minutes to days.

Water-Quality Characteristics

Effluent samples from the WWTFs were collected for 4 days prior to each diel study. A 24-hour composite sample of effluent was collected from two of the WWTFs (Swansea and Belleville Area 1), and daily discrete samples of effluent were collected from the remaining four WWTFs. These samples were used to identify any variations in effluent quality that might affect the stream quality during the diel studies. Four discrete samples of effluent (each 6 hours apart) were collected from each WWTF during each diel study.

During the diel studies, water samples were collected every 4 hours from the 19 creek sites and from 4 sites on the tributaries that received treated wastewater (sites 1 to 23). Tributaries that did not receive treated wastewater (sites 24 to 32) were assumed to have a fairly constant water quality during low-flow periods (table 1). Sites 24 to 32 were sampled twice during each diel study; once in the early morning (0200-0600 hours) and again in the late afternoon (1400-1800 hours) in order to measure chemical-constituent concentrations and to estimate the range of daily variations in the dissolved oxygen concentrations. Water-quality field measurements of specific conductance, dissolved oxygen concentration, pH, and water temperature were made using hand-held four-parameter monitors. These measurements, along with air temperature and stream stage, were made every 2 to 4 hours at all creek sites and at the sites on tributaries that received treated wastewater. Field measurements were also made during the two visits to the other tributary sites and on each visit to the WWTF outfalls.

Water and effluent samples were immediately chilled with ice, transported to the IEPA laboratory within 8 hours of being collected, and analyzed using IEPA laboratory methods (1986). Each water sample was analyzed to determine the concentrations of total organic plus ammonia nitrogen (total kjeldahl nitrogen), dissolved ammonia nitrogen, dissolved nitrite plus nitrate nitrogen, and dissolved and total phosphorus. Ultimate carbonaceous BOD and the decay rate were determined for each sample, and total (nitrogenous plus carbonaceous) BOD was also determined for selected samples. Ultimate carbonaceous BOD refers to the total amount of dissolved oxygen used by heterotrophic microbes to oxidize all of the biologically oxidizable carbonaceous material in a specified volume. It is expressed as milligrams dissolved oxygen consumed per liter of sample. The decay rate is the rate at which the oxygen is consumed.

Ultimate carbonaceous BOD and the decay rate were determined using the methods described by Stamer and others (1983). This method involves incubating the samples in the dark at 20°C and periodically determining the amount of dissolved oxygen consumed. The ultimate carbonaceous BOD and the decay rate are then calculated from this time-series data by using a nonlinear least squares method. A small amount of nitrapyrin was added to most of the BOD samples to inhibit nitrification. One sample from each site was analyzed without nitrapyrin to measure the total (nitrogenous plus carbonaceous) BOD. Total BOD simply refers to the dissolved oxygen depletion due to oxidation of all of the biologically oxidizable material. Residual chlorine concentrations were measured in all BOD samples, and appropriate amounts of sodium sulfite were added to neutralize the chlorine residual. All BOD samples were then seeded using 1 milliliter of raw sewage obtained from the Champaign, Illinois, Sewage Treatment Works in order to introduce microbe populations that may have been killed by the chlorine. The BOD contribution from the seed was negligible.

Two of the samples, collected in the early morning and late afternoon from each site, and one sample from the WWTF effluents were analyzed for chlorophyll-a concentration. One sample from each site was analyzed for 53 other constituents: turbidity; chemical oxygen demand; total alkalinity;

total acidity; total suspended solids; volatile suspended solids; total ammonia nitrogen; total nitrite plus nitrate nitrogen; cyanide; hardness; chloride; sulfate; fluoride; arsenic; phenol; total dissolved solids; mercury; and total and dissolved calcium, magnesium, sodium, potassium, lead, manganese, nickel, silver, barium, boron, beryllium, cadmium, strontium, vanadium, zinc, chromium, copper, and iron. All water-quality results are available for inspection at the Survey's Illinois District office.

ASSESSMENT OF LOW-FLOW WATER QUALITY

Diel Water Quality

The Illinois Pollution Control Board establishes the water-quality standards for the State of Illinois. The general-use, water-quality standards, which apply to Richland Creek and its tributaries, are intended to "protect the State's water for aquatic life, agricultural use, primary and secondary contact use, and most industrial uses and to ensure the aesthetic quality of the State's aquatic environment" (Illinois Pollution Control Board, 1984). Stream concentration limits for some constituents are established to indicate levels at which these constituents would affect the intended uses of streams. Aside from these specific constituent concentrations identified, the State water-quality regulations state that "any substance toxic to aquatic life shall not exceed one-tenth of its 96-hour median tolerance limit for native fish or essential fish food organisms." This 96-hr LC50 (96-hour median lethal tolerance limit) is the concentration at which 50 percent of the test organisms die within 96 hours. Measurement of 96-hr LC50 levels was beyond the scope of this project. For this report, we will deal primarily with the specific constituent concentration standards as stated in the Illinois water pollution regulations (Illinois Pollution Control Board, 1984).

The results of the water-quality analyses on the samples collected at the 19 creek sites and the 13 tributary sites on July 23-24 and on August 6-7, 1984, are presented in tables 10 and 11 at the end of this report. These results and their relation to applicable water-quality standards are discussed here.

The State standard for dissolved oxygen concentrations declares that during at least 16 hours of any 24-hour period the concentration must be at least 6.0 mg/L, and the concentration may never be less than 5.0 mg/L (Illinois Pollution Control Board, 1984). Dissolved oxygen concentrations can be affected by BOD, SOD, reaeration, plant growth and respiration, and other factors. There is probably no place in the creek where dissolved oxygen concentrations are not affected by one or more of these factors. The QUAL-II water-quality model was used to determine which of these factors had the largest impact on dissolved oxygen concentrations in several subreaches of the creek. A second method was used to identify those sites where the effect of plant respiration would cause dissolved oxygen concentrations to fall below the State minimum standard regardless of the effect from other factors. This method required the assumption that the diel fluctuation in dissolved oxygen concentration was caused by plant photosynthesis and respiration. In this method, the magnitude of the change in dissolved oxygen concentration between the time-weighted average concentration and minimum concentration measured at a site (representing the dissolved oxygen depletion attributed to plant activity) was compared to the magnitude of the calculated change between the dissolved oxygen saturation concentration and the State minimum standard of 5.0 mg/L (representing the dissolved oxygen depletion necessary for the State standard to be exceeded) (S. C. McCutcheon, U.S. Geological Survey, written commun., 1984). The dissolved oxygen saturation concentration for each site was determined from the average water temperature at that site using the following equation (Thomann, 1972):

$$Cs = 14.652 - 0.41022\ T + 0.007991\ T^2 - 0.000077774\ T^3 \qquad (2)$$

where Cs is the oxygen saturation concentration at standard pressure (29.92 inches of mercury), in milligrams per liter, and

T is the water temperature, in degrees Celsius.

If the magnitude of the measured change in dissolved oxygen concentration (depletion due to plant activity) is larger than the magnitude of the calculated change, plant activity was considered a major factor in dissolved oxygen depletion and the State minimum standard would probably have been violated regardless of the effects of other factors such as BOD and SOD.

The measured dissolved oxygen concentrations in Richland Creek ranged from 0.1 to 10.3 mg/L during the July diel study and from 1.0 to 14.4 mg/L during the August diel study. Time-weighted average dissolved oxygen concentrations during the July diel study fell below 6.0 mg/L at all sites except 6, 7, 8, 16, and 17, and some measured dissolved oxygen concentrations fell below the State minimum standard of 5.0 mg/L at all sites except 6, 7, and 8. The lowest dissolved oxygen concentrations measured during the July diel study were between sites 9 and 14 (RM 29.4 to RM 24.3). During the August diel study, time-weighted average dissolved oxygen concentrations fell below 6.0 mg/L at all sites except 6, 7, 8, 9, 16, and 17, and measured dissolved oxygen concentrations fell below 5.0 mg/L at all sites except 6, 8, and 9. The lowest dissolved oxygen concentrations measured during the August diel study were between sites 11 and 19 (RM 28.0 to RM 21.2). This indicates a downstream shift in the critical region in terms of dissolved oxygen. The only location where plant activity appeared to be the primary cause of the dissolved oxygen concentration going below 5.0 mg/L was site 19 during the August diel study.

The State general-use, water-quality standards specify that pH should be between 6.5 and 9.0 except for natural causes (Illinois Pollution Control Board, 1984). Measured pH values in Richland Creek ranged from 6.0 to 8.7 during the July diel study and from 5.2 to 8.5 during the August diel study. The pH dropped below the State standard at site 3 during the July diel study and at sites 11 and 12 during the August diel study.

The State general-use, water-quality standard for total ammonia nitrogen and un-ionized ammonia nitrogen specifies that the total ammonia nitrogen concentration must be less than or equal to 15.0 mg/L. If the total ammonia nitrogen concentration is between 1.5 and 15.0 mg/L, the un-ionized ammonia nitrogen concentration must be less than or equal to 0.04 mg/L. Total ammonia nitrogen concentrations less than 1.5 mg/L are considered lawful regardless of the corresponding un-ionized ammonia nitrogen concentrations (Illinois Pollution Control Board, 1984). Total (unfiltered) ammonia nitrogen concentrations were determined from one sample at each site. The total ammonia nitrogen concentrations in Richland Creek ranged from 0.10 to 3.32 mg/L and from 0.10 to 6.76 mg/L during the July and August diel studies, respectively. The un-ionized ammonia nitrogen concentrations were calculated using measured pH and water temperatures with these equations (Illinois Pollution Control Board, 1984):

$$u = \frac{N}{(0.94412(1 + 10^{x}) + 0.0559)} \quad (3)$$

$$x = 0.09018 + \frac{2729.92}{(T + 273.16)} - pH \quad (4)$$

where u is the concentration of un-ionized ammonia nitrogen, in milligrams per liter;

N is the concentration of ammonia nitrogen, in milligrams per liter; and

T is the water temperature, in degrees Celsius.

The results of these calculations indicated that sites 13, 14, 15, and 20 were not in compliance with the State standard for un-ionized ammonia nitrogen during the July diel study and that sites 12, 14, 15, 19, 20, and 21 were not in compliance during the August diel study.

Dissolved phosphorus and dissolved nitrite plus nitrate nitrogen concentrations were determined from samples collected from Richland Creek. There are no State standards that apply to these constituents; however, these constituents are of concern as nutrients for algal growth. The concentrations of inorganic phosphorus and inorganic nitrogen needed to promote algal growth are 0.01 and 0.3 mg/L, respectively (Sawyer, 1952; Muller, 1953). These constituents are present in Richland Creek in large enough concentrations to promote algal growth at all sites except sites 5, 17, and 18 during the July diel study and sites 4, 5, 12, 13, 14, 17, and 18 during the August diel study.

Total iron concentrations ranged from 210 to 2,796 µg/L during the July diel study and from 238 to 2,979 µg/L during the August diel study. These concentrations exceeded the State standard of 1,000 µg/L throughout much of the creek.

The concentration of total iron from the measured inflows was used in conjunction with the discharge measured at these point sources to determine dilution factors and calculate corresponding stream concentrations. These calculated concentrations assumed that the headwaters and point sources were the only contributing factors to stream concentrations and that iron was a conservative constituent. Calculated concentrations were compared with measured stream concentrations to determine if the point sources could account for the total iron concentrations present.

Figure 3 shows the calculated and measured concentrations of total iron. These results show that the calculated concentrations underestimate the measured concentrations for much of the study reach. This indicates that the point-source inflows are not the major factor controlling the total iron concentration and that other factors (such as sediment interactions) may be important.

Manganese concentrations in Richland Creek ranged from 140 to 1,024 µg/L and from 108 to 1,046 µg/L for the July and August diel studies, respectively. The State water-quality standard of 1,000 µg/L was exceeded only at site 22 during both the July and August diel studies. Figure 4 shows the concentrations calculated from the point sources and the measured concentrations. It is apparent from these results that the contributions from the point sources are not the primary factor controlling stream concentrations. The calculated concentrations consistently underestimate the measured concentrations, especially in the downstream subreaches.

Copper concentrations ranged from less than 5 to 30 µg/L and from less than 5 to 47 µg/L during the July and August diel studies, respectively. These concentrations exceeded the State water-quality standard of 20 µg/L at site 4 during the July diel study and at sites 1, 3, and 5 during the August diel study. Figure 5 shows the calculated and measured copper concentrations. These results show that the calculated and measured concentrations are comparable, indicating that the point sources are very likely a major factor in controlling the concentration of copper in the stream. Note that measured concentrations of zero in figure 5 actually indicate levels below the analytical detection limit of 5 µg/L.

Boron concentrations, determined from samples collected during the diel studies, were relatively high for natural waters, but they did not exceed the State standard of 1,000 µg/L. Figure 6 shows that the point sources were the primary factor causing these high boron concentrations. The measured boron concentrations in Catawba Creek (site 26), which discharges to Richland Creek at RM 32.4, were 1,811 and 2,431 µg/L during the July and August diel studies, respectively. The measured concentration in Richland Creek Tributary No. 2 (site 27, RM 30.4) during the August diel study was 1,079 µg/L. These concentrations did exceed the State standard.

Sulfate concentrations were also high, although concentrations determined from samples collected from Richland Creek did not exceed the State water-quality standard (500 mg/L). The measured sulfate concentration at Richland Creek Tributary No. 2 (site 27) during the August diel study was 1,430 mg/L, which does exceeds the State standard. Figure 7 indicates that these constituent concentrations are not entirely controlled by point-source inflows. The August results of these mass balance calculations suggest that the point sources may play a role, while the July results suggest just the opposite. It is most likely that sulfate deposited in the sediments from runoff from gob piles in the basin are the major contributor to these sulfate concentrations; however, these results are inconclusive.

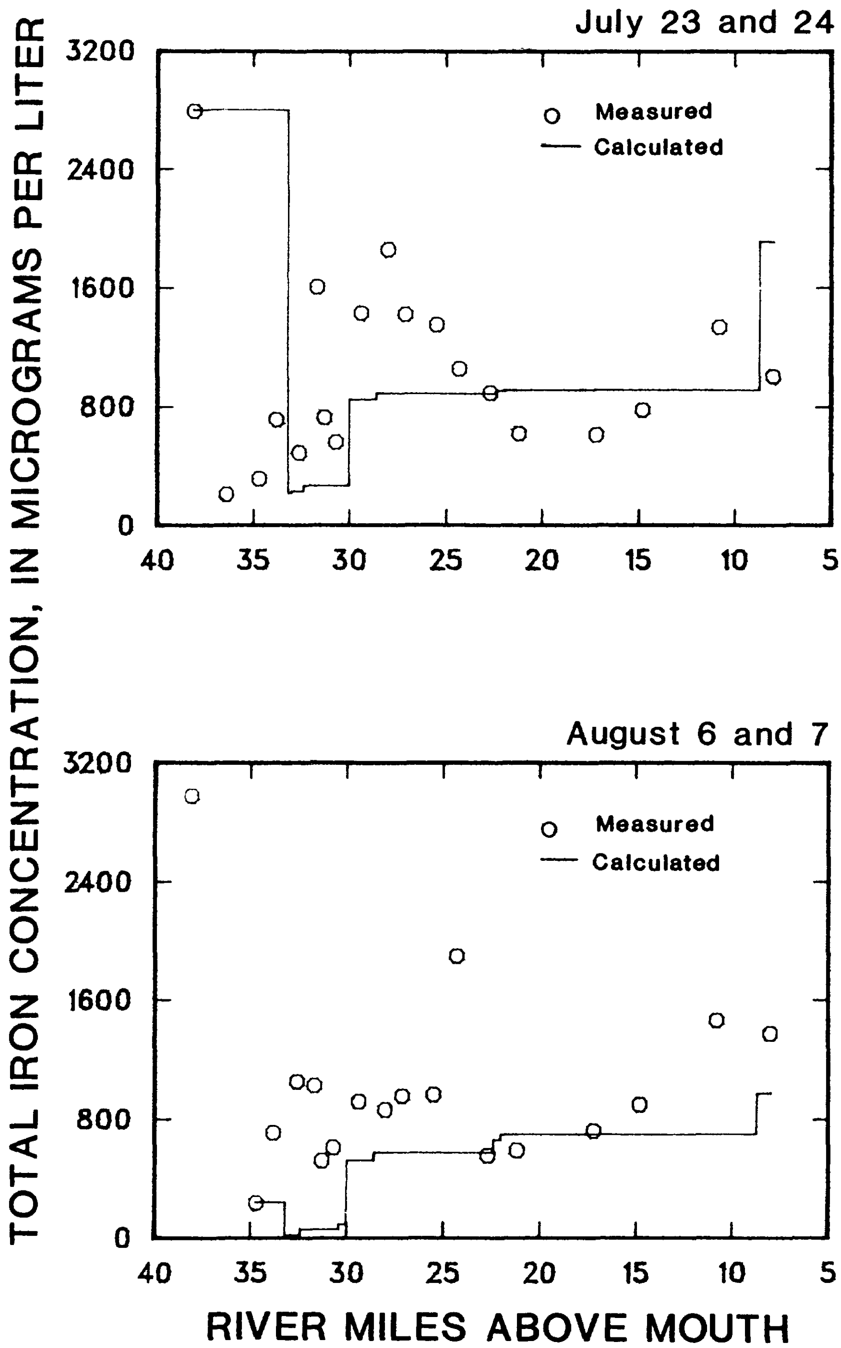

Figure 3.--Profiles of measured and calculated total iron concentrations in Richland Creek for the July and August diel studies.

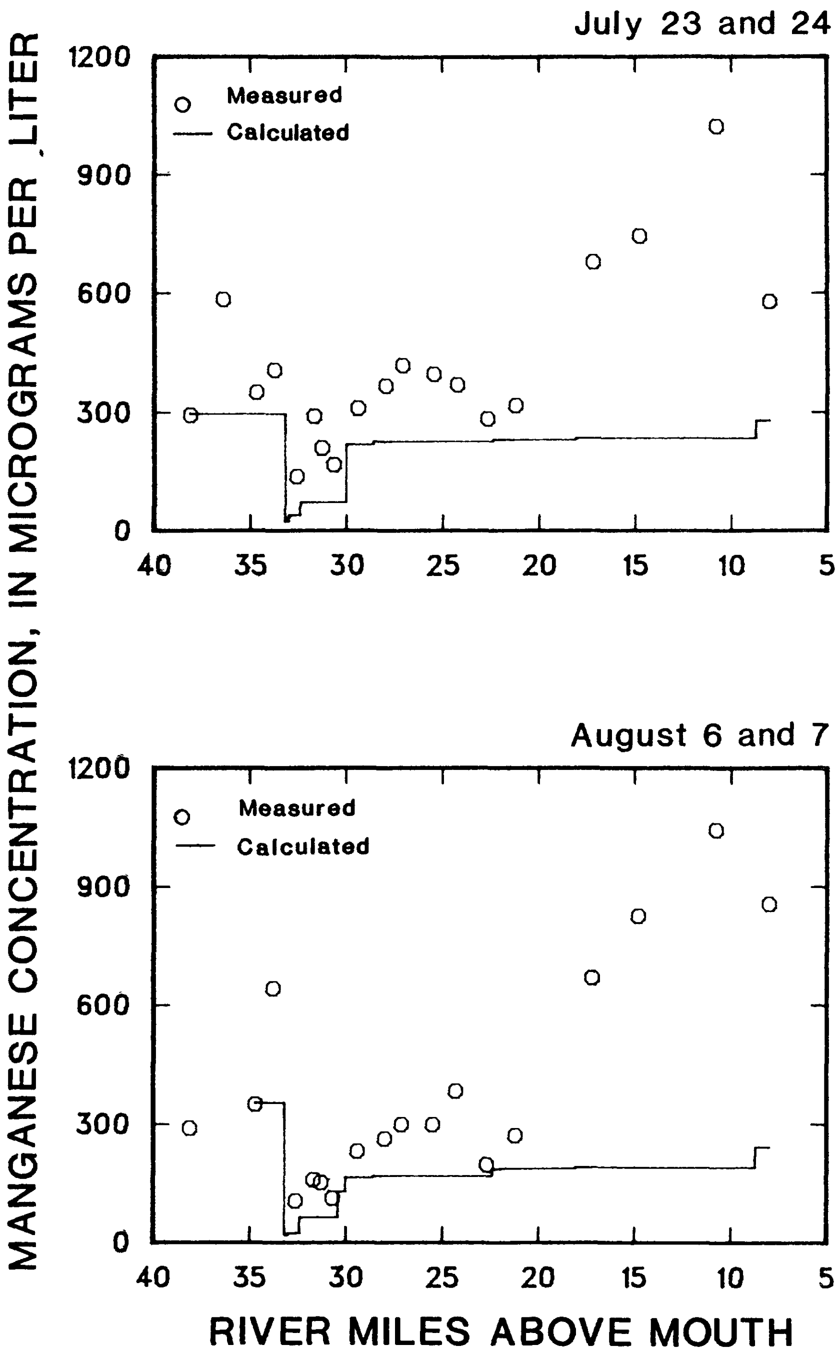

Figure 4.--Profiles of measured and calculated manganese concentrations in Richland Creek for the July and August diel studies.

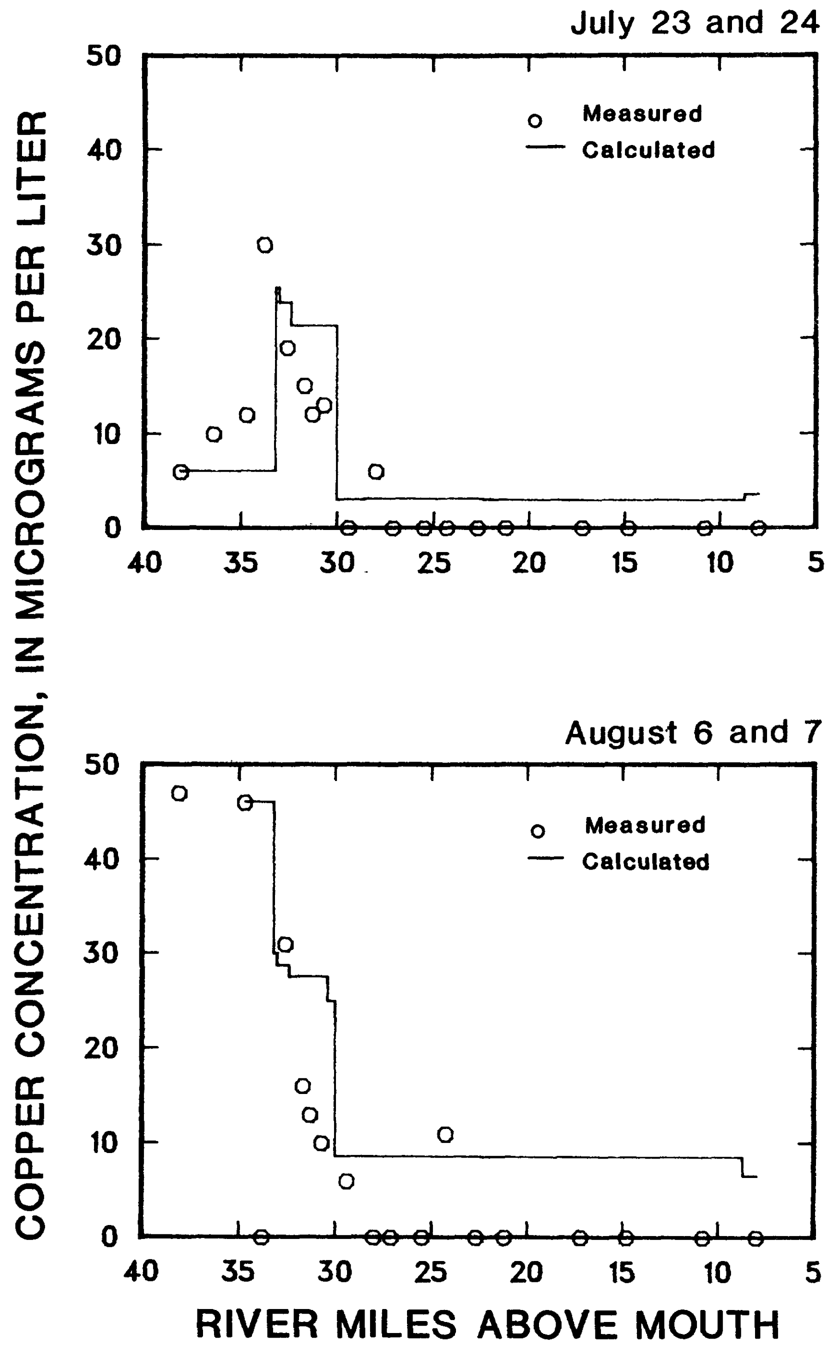

Figure 5.--Profiles of measured and calculated copper concentrations in Richland Creek for the July and August diel studies.

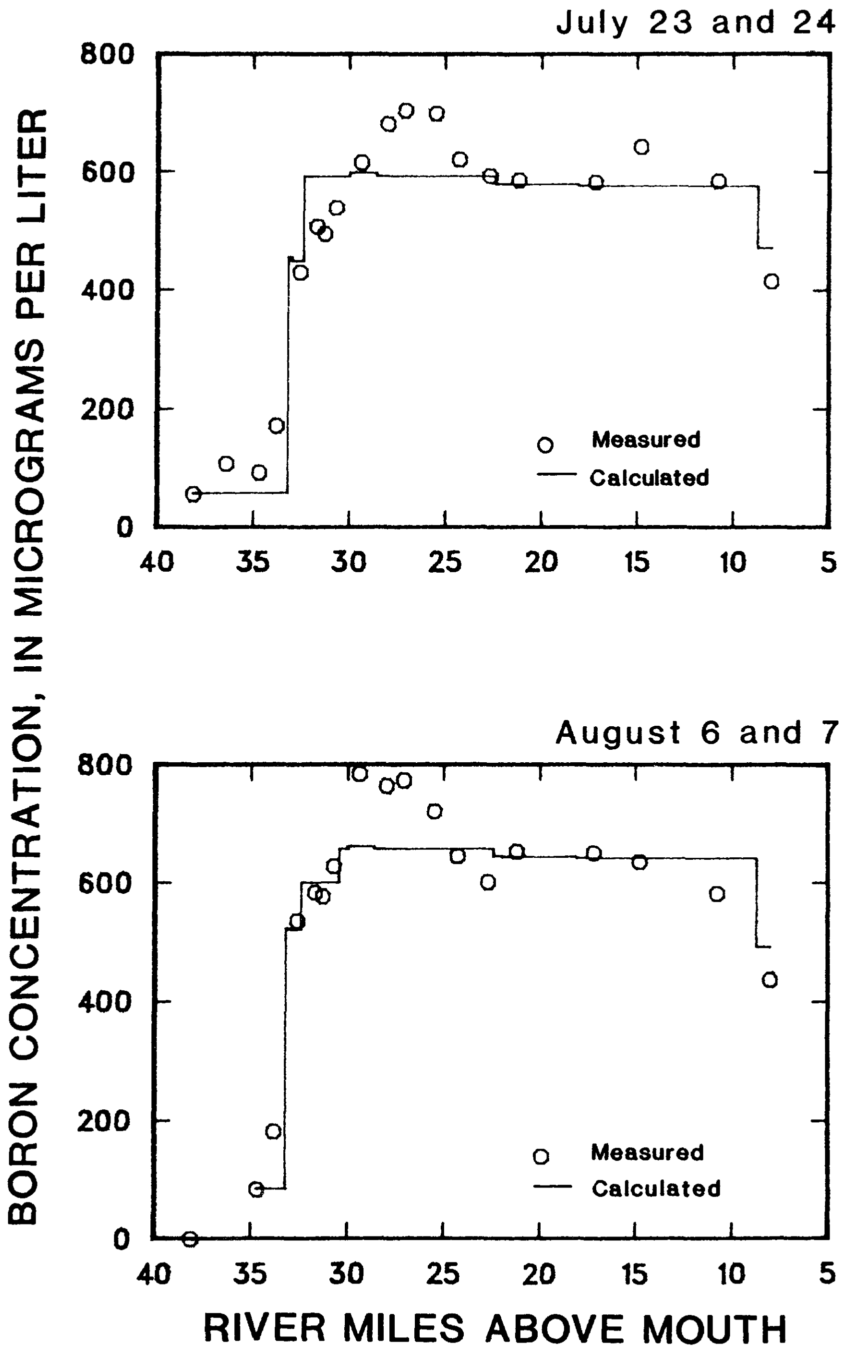

Figure 6.--Profiles of measured and calculated boron concentrations in Richland Creek for the July and August diel studies.

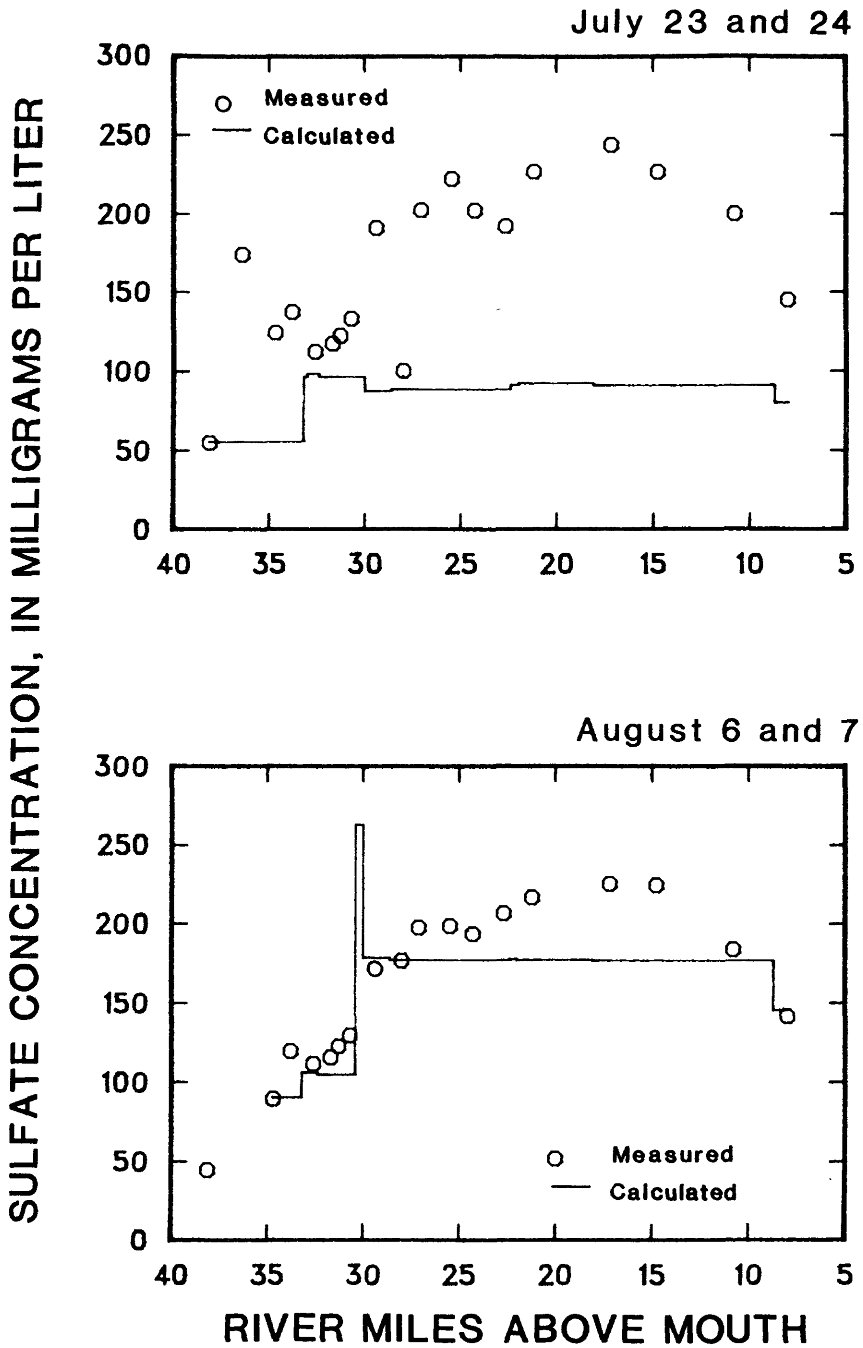

Figure 7.--Profiles of measured and calculated sulfate concentrations in Richland Creek for the July and August diel studies.

Total dissolved solids concentrations in Richland Creek did not exceed the State standard of 1,000 mg/L. However, tne concentration in Richland Creek Tributary No. 2 during the August diel study was 2,510 mg/L, which does exceed the State standard. Figure 8 indicates that the point-source inflows contribute significantly to the total dissolved solids concentrations in Richland Creek.

The State water-quality standard for silver (5 µg/L) was equaled at site 23 once during the August diel study. All other measurements for silver indicated that concentrations were below the analytical detection limit.

All other constituents that were measured during the two diel studies were within the limits specified by the applicable State general-use water-quality standards.

Water-Quality Modeling

The QUAL-II, one-dimensional, steady-state, water-quality model (National Council of the Paper Industry for Air and Stream Improvement, 1982) was used because it is capable of modeling up to 13 water-quality constituents, including algae (modeled as chlorophyll-a). For this study, the QUAL-II model was used to evaluate nine water-quality characteristics: dissolved oxygen, ultimate carbonaceous BOD, SOD, algae as chlorophyll-a, ammonia, nitrite, nitrate, phosphorus, and specific conductance. Figure 9 shows the constituents and their interactions in the QUAL-II model.

Water samples were analyzed for nitrite plus nitrate nitrogen to avoid the problem of possible concentration changes due to oxidation during transport to the laboratory. To compensate for this in the model, a high nitrite-oxidation rate was used so that nitrite plus nitrate nitrogen was simulated rather than the separate constituents.

The QUAL-II model assumes that stream discharge at any point approximates steady-state flow conditions. Average flow variations during the July and August diel studies were 45.2 and 48.0 percent, respectively. This variability was considered high. During low-flow periods in Richland Creek, the streamflow is comprised primarily of treated wastewater, and the discharges from the WWTFs were highly variable during these diel studies. This, coupled with the small quantities of flow and the inaccuracies of the stage-discharge relations, could account for the large variability in stream discharge. For the purpose of this study, it was necessary to assume that the variation in flow was small enough to satisfy the QUAL-II model's assumption of steady-state flow conditions.

The upstream 3.4 miles of Richland Creek were not modeled because the flow was intermittent and rate coefficients could not be determined. The remaining 26.7-mile reach of Richland Creek is represented by a series of subreaches in the QUAL-II model. These subreaches are referred to as model subreaches in this report. Model subreaches were further subdivided into computational elements that define the shortest length of the creek that the QUAL-II model considers for its calculations. The mathematical basis for QUAL-II is given in the model user's guide (National Council of the Paper Industry for Air and Stream Improvement, 1982).

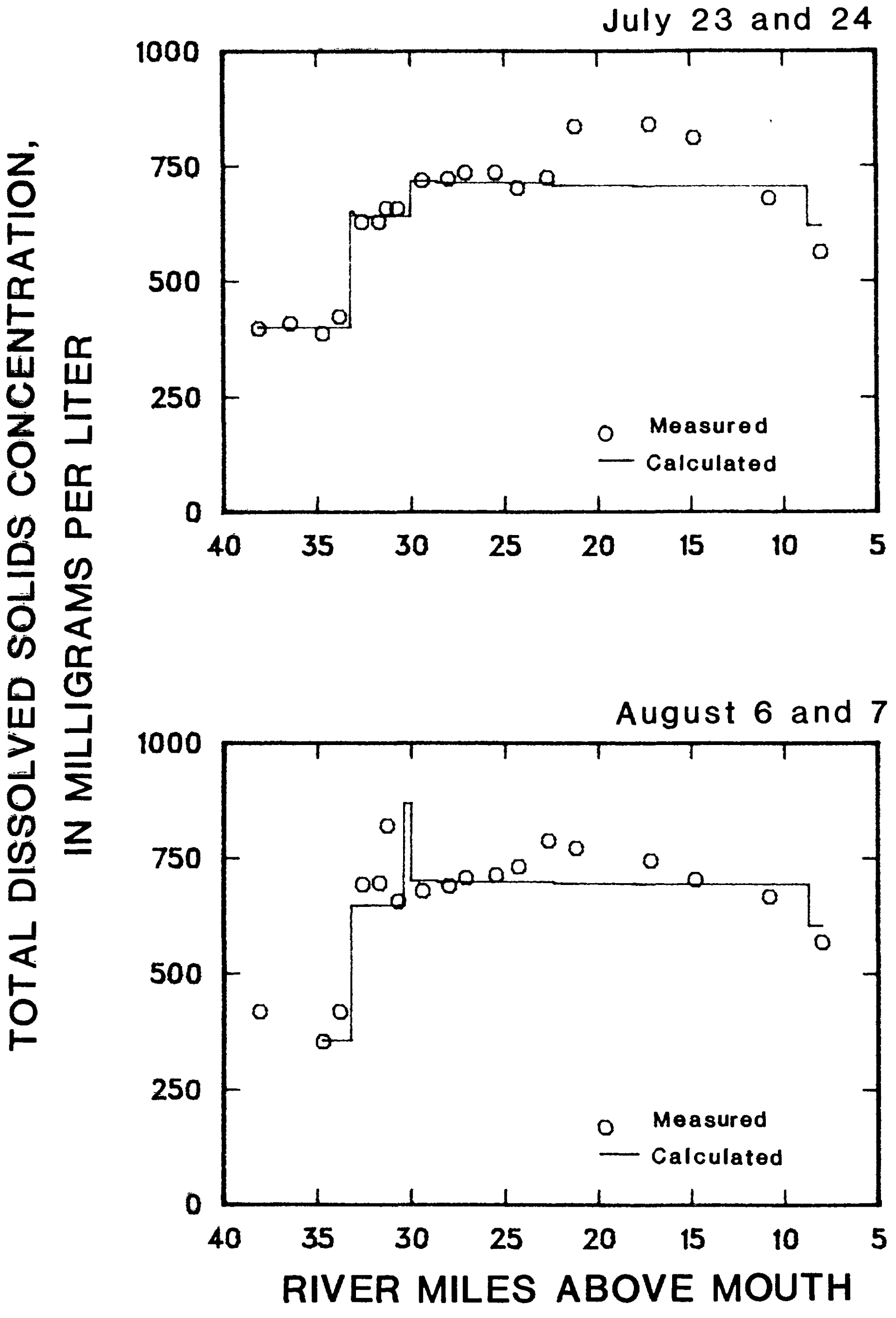

Figure 8.--Profiles of measured and calculated total dissolved solids concentrations in Richland Creek for the July and August diel studies.

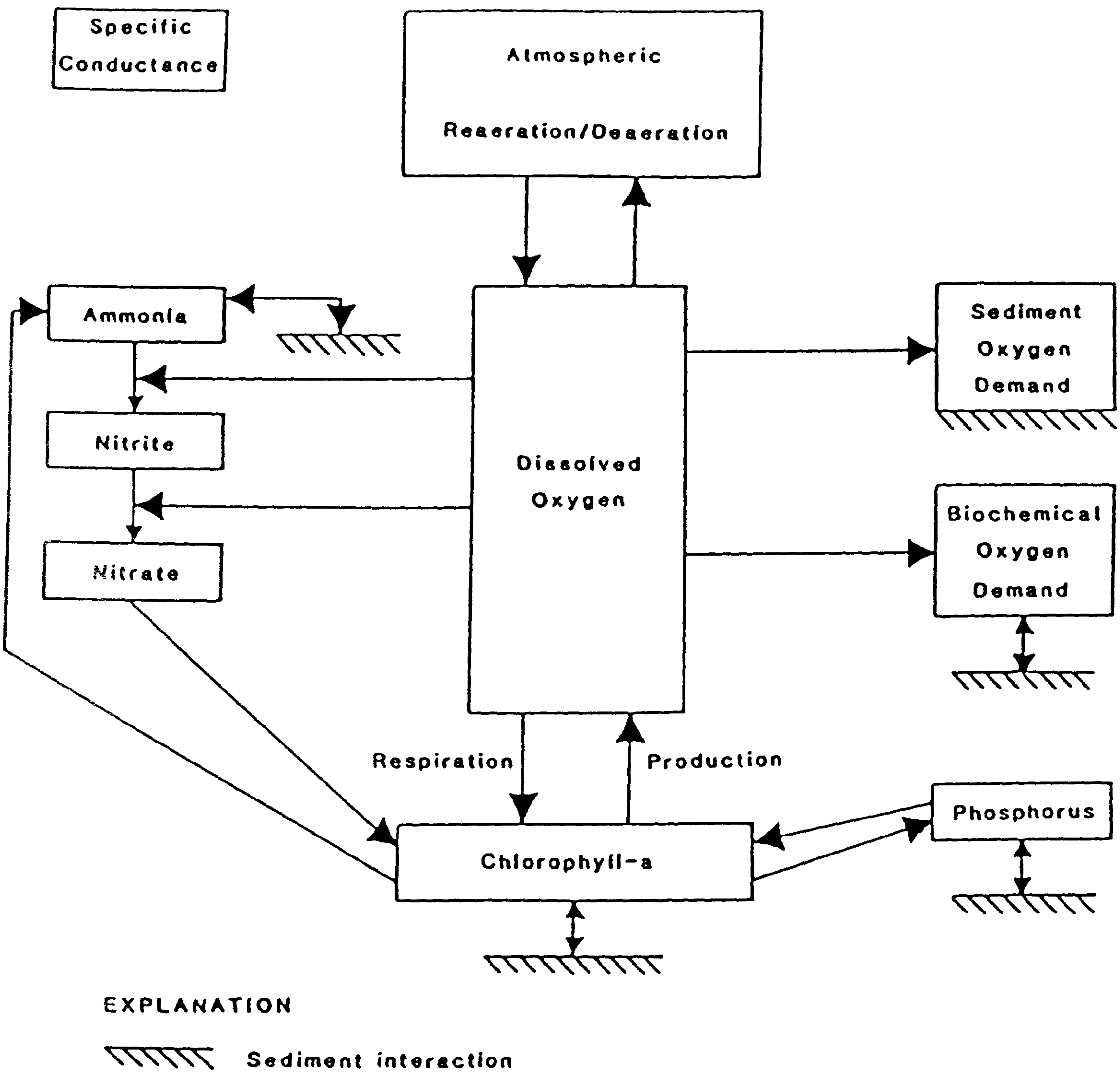

Figure 9.--Constituents and interactions evaluated with the QUAL-II model.

The 26.7-mile reach was divided into 25 model subreaches with 11 point sources. The computational element length was specified as 0.1 mile. A schematic of the creek as it was modeled is shown in figure 10.

Computing Model Requirements from Field Data

Data from the July diel study were used to calibrate the QUAL-II model and data from the August diel study were used to verify the model by validating the choice of calibration coefficients under different hydrologic and waste-load conditions.

Traveltime and reaeration-rate coefficient measurements were made at different stream discharges. Stream discharge at the index station near Hecker (05595200) ranged from 11 to 100 ft^3/s during these measurements.

An equation that relates traveltime, in terms of velocity, to the streamflow characteristics was developed to predict traveltimes for the diel-study conditions. The best equation incorporating data from all subreaches of the creek was

$$V = 0.0801(Q)^{0.5991} \qquad (5)$$

where V is the average subreach velocity, in feet per second, and
Q is the average discharge in the subreach, in cubic feet per second.

The multiple correlation coefficient of the equation-estimated traveltimes, when compared with the measured traveltimes, is 0.84. The relation has an associated standard error of +49.8 to -33.3 percent.

The reaeration-rate coefficients were measured during periods of flow that were different from those of the diel studies. The coefficients and their corresponding hydraulic characteristics were used with 17 reaeration-rate predictive equations (O'Connor and Dobbins, 1958; Churchill and others, 1962 (2 equations); Krenkel and Orlob, 1963; Owens and others, 1964; Langbein and Durum, 1967; Cadwallader and McDonnell, 1969; Thackston and Krenkel, 1969; Velz, 1970; Padden and Gloyna, 1971; Bennett and Rathbun, 1972 (2 equations); Lau, 1972; Parkhurst and Pomeroy, 1972; Tsivoglou and Wallace, 1972; Bansal, 1973; and Tsivoglou and Neal, 1976) to determine which could best predict the reaeration-rate coefficients for Richland Creek.

Two equations were chosen to predict the reaeration-rate coefficients for Richland Creek. The equation developed by Krenkel and Orlob (1963) was used for subreaches with average stream depths of less than 1.15 feet. This equation,

$$K_2 = 11.0(VS)^{0.408} \; H^{-0.660} \qquad (6)$$

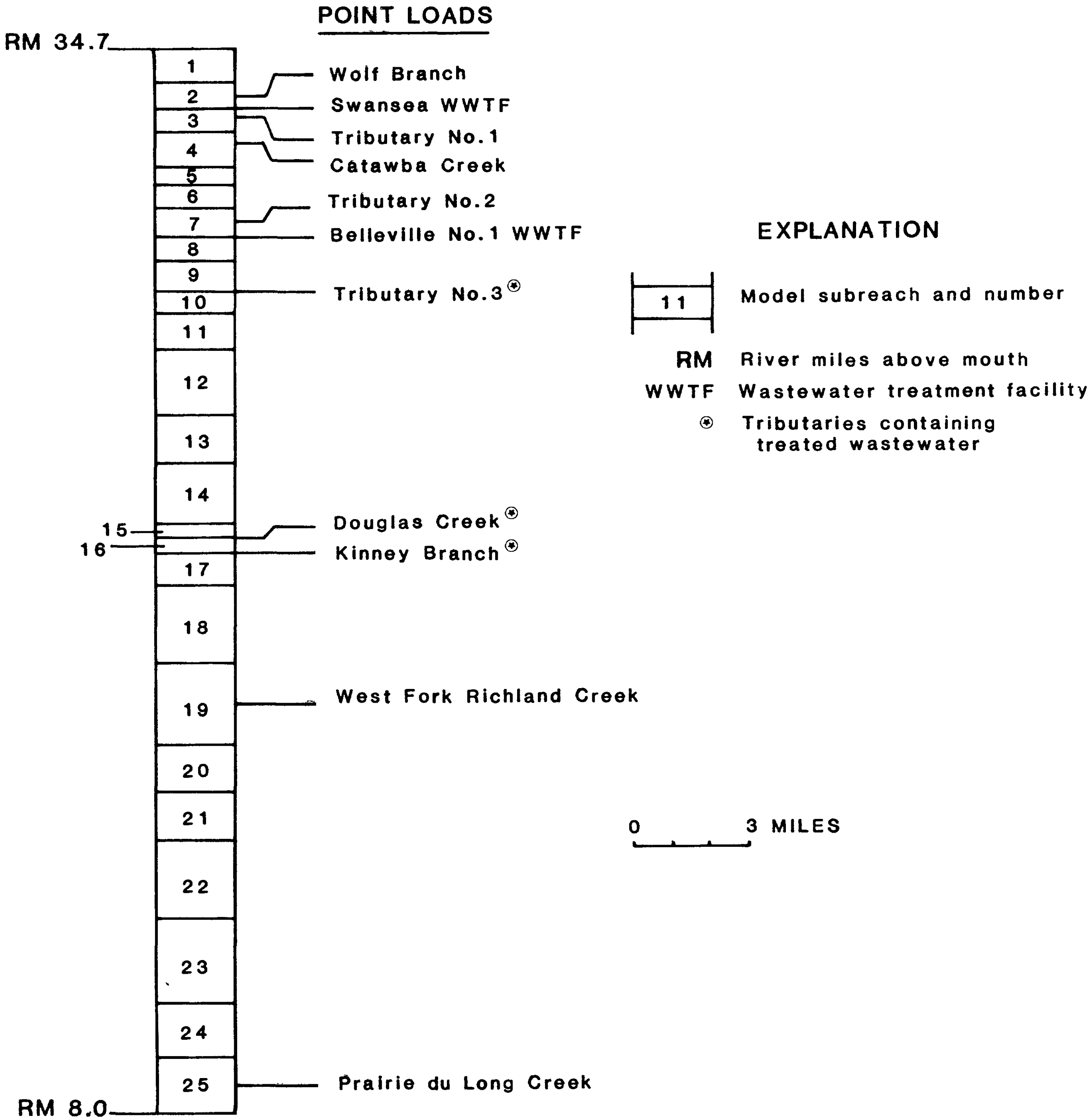

Figure 10.--The modeled river system.

where K_2 is the reaeration-rate coefficient at 20°C, in reciprocal days,
V is the average subreach velocity, in feet per second,
S is the bed slope of the subreach, and
H is the average subreach depth, in feet,

when compared with the measured values, has a multiple correlation coefficient of 0.59 that proved significant at the 78 percent confidence level. The standard error of estimate with this equation is ±0.82 reciprocal days.

The other equation, used for subreaches with average stream depths of 1.15 feet or greater, was developed by Padden and Gloyna (1971). This equation is

$$K_2 = 0.322\ V^{0.703}\ H^{-1.054} \qquad (7)$$

where all the variables are as defined in equation 6. When compared with the measured values, this equation has a multiple correlation coefficient of 0.32 that proved significant at the 61 percent confidence level. The standard error of estimate with this equation is ±2.81 reciprocal days.

Average cross-sectional area, surface width, depth, and discharge for each subreach were determined from an average of the values measured at the two sites that define the subreach boundaries. As discussed previously, the surface width and cross-sectional area were measured at each site, and the average depth was calculated from the width and cross-sectional area measurements assuming a rectangular channel.

Calibration, Verification, and Sensitivity

The QUAL-II model was used to simulate environmental processes and water quality of Richland Creek. The processes and their interactions (fig. 9) are defined in the model by several rate constants and coefficients. These constants and coefficients were specified in the model to best describe the processes in Richland Creek. Model calibration was accomplished by using calculated and measured values for the coefficients, when available, and adjusting the other coefficients within ranges described by Bowie and others (1985) and by the Qual-II user's manual (National Council of the Paper Industry for Air and Stream Improvement, 1982) until the model-simulated constituent concentrations approximated the measured concentrations. The July diel-study conditions and data were used to calibrate the model.

The rate constants and coefficients determined from the model calibration were then used in conjunction with the August diel-study conditions and data to validate that choice of coefficients. This model verification showed how well the calibration coefficients defined the processes in Richland Creek by identifying the model's ability to simulate the water quality under different hydrologic and waste-load conditions. Table 4 lists several of the rate constants and coefficients used to calibrate and verify the model.

Table 4.--Selected rates and coefficients for the model

Model subreach	Length (mile)	Rate of sediment oxygen demand (milligrams per day per foot)	Decay rate of carbonaceous biochemical oxygen demand (reciprocal days) during diel study		Source/sink rate for ammonia (milligrams nitrogen per day per foot)	Source/sink rate for phosphorus (milligrams phosphorus per day per foot)	Light extinction coefficient (reciprocal feet)
			July	August			
1	0.9	4,000	0.16	0.17	5	5	0.1
2	.6	2,593	.19	.15	5	0	.1
3	.6	10,000	.19	.15	0	0	.1
4	.9	5,885	.19	.09	5	-1,000	.7
5	.4	8,489	.16	.13	5	-1,100	.7
6	.6	10,000	.13	.13	0	-1,100	.7
7	.7	15,000	.14	.10	0	-900	.7
8	.6	98,000	.14	.10	1,000	-800	.7
9	.8	85,000	.14	.08	2,000	-3,000	.7
10	.6	90,000	.15	.08	2,000	-3,000	.7
11	.9	70,000	.14	.07	2,000	-1,500	.7
12	1.6	200	.11	.07	2,500	-2,000	.7
13	1.2	30,000	.10	.07	800	-1,500	.7
14	1.6	30,000	.09	.07	800	0	.7
15	.3	16,000	.09	.08	800	0	.7
16	.4	16,000	.09	.09	800	100	.7
17	.8	16,000	.09	.11	0	120	.7
18	2.0	15,000	.10	.11	-500	300	.7
19	2.0	16,000	.10	.10	-500	500	.7
20	1.2	19,664	.10	.10	0	700	.7
21	1.2	6,861	.10	.10	-800	100	.7
22	2.0	10,508	.10	.10	-800	-500	.7
23	2.0	25,732	.12	.09	-1,000	-500	.7
24	1.4	32,000	.13	.09	-200	-500	.7
25	1.4	36,000	.14	.10	-100	-500	.7

The stream discharge measured during both the July and August diel studies very nearly matched that determined by summing the discharge measured from the headwaters and each of the point sources during the respective studies. Because of this, the measured discharge of the headwaters and point sources were used directly in the model. No additional inflow to the model-simulated stream discharge was necessary.

The water-quality characteristics for the headwaters and point sources were specified as an average of the values measured for each. Tables 5 and 6 show lists of the water-quality characteristics for the headwaters and point sources used in the model for both diel studies.

The QUAL-II model determines stream depth for each model subreach by multiplying the stream discharge by a coefficient of discharge for depth. The stream depths determined from cross-sectional area and width measurements were used in the model by choosing coefficients of discharge that forced the model to simulate measured values.

The capability of the model to simulate a conservative constituent is helpful in identifying the accuracy of the model-simulated streamflow and how well the point sources are accounted for. Conservative constituents are not affected by biological decay or most other interactions in the river. Simulation of a conservative constituent will identify incorrect stream discharge in the model by showing too much or too little dilution of the point sources. These inaccuracies would show up as simulated concentrations that are lower or higher than the measured concentrations. A jump in the measured concentration that is not shown by the simulated concentrations can also indicate an unmeasured point or nonpoint source.

Specific conductance is a relatively conservative constituent and was modeled as such for this study. Figure 11 shows profiles of the simulated and measured specific conductance for the July and August diel-study conditions. Simulated specific conductance very closely approximated the measured values; thus, the streamflow and point sources were accurately simulated in the model. The model slightly underestimates the specific conductance for much of the creek during both diel studies. This could be caused by unmeasured point or nonpoint sources or it could also be caused by a sediment interaction. The values were close enough to consider this as being insignificant. Note there are three sites (11, 12, and 13) between RM 28.0 and RM 25.5 where several values measured during the August diel study appear to be very low. These may have been caused by equipment failure although the same instrument gave reasonable results at other sites. These values were not included in our interpretations.

Ultimate carbonaceous BOD was calibrated by varying the source/sink rate coefficient (a negative rate indicates source). This caused the model to simulate concentrations of carbonaceous BOD within the ranges measured during the July diel study (fig. 12). The BOD source/sink rate coefficients for the model ranged from -0.31 to 5.00 reciprocal days. These rate coefficients were not validated by the carbonaceous BOD concentrations simulated using the August diel study conditions. The BOD source/sink rate coefficients were then calibrated to simulate the ranges measured during the August diel study (fig. 13).

Table 5.--Characteristics and constituent concentrations for the headwaters and point sources in the model for the July diel-study period

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; dashes indicate characteristic or constituent not specified in model]

Point source name	Outfall location (river miles)	Temperature (°C)	Dissolved oxygen (mg/L)	Biochemical oxygen demand (mg/L)	Chlorophyll-a (µg/L)	Ammonia as nitrogen (mg/L)	Nitrite plus nitrate as nitrogen (mg/L)	Phosphorus (mg/L)	Specific conductance (µS/cm)
Headwaters - site 3 Richland Creek at Old Collinsville Road at Belleville, Ill.	34.70	24.3	5.0	8.6	36	0.10	0.13	0.01	529
Wolf Branch	33.50	--	--	--	--	--	--	--	--
Swansea wastewater treatment facility	33.20	24.8	5.2	6.3	1.1	.10	28.0	9.70	914
Richland Creek Tributary No. 1	33.00	24.9	6.9	4.2	14	.10	.86	.04	808
Catawba Creek	32.40	26.5	6.4	16	25	.11	.13	.21	750
Richland Creek Tributary No. 2	30.40	--	--	--	--	--	--	--	--
Belleville Area 1 wastewater treatment facility	30.00	26.4	4.7	34	6.5	2.70	.61	4.52	1,055
Richland Creek Tributary No. 3	28.60	24.7	4.8	7.0	7.9	.21	3.05	3.32	921
Douglas Creek	22.40	25.7	6.9	12	49	.10	.20	1.32	889
Kinney Branch	22.00	24.2	4.4	6.2	12	.10	7.72	2.90	782
West Fork Richland Creek	18.10	25.6	4.9	4.8	2.6	.11	.21	.06	547
Prairie du Long Creek	8.70	25.1	5.6	5.5	24	.10	2.11	.05	430

Table 6.--Characteristics and constituent concentrations for the headwaters and point sources in the model for the August diel-study period

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; dashes indicate characteristic or constituent not specified in model]

Point source name	Outfall location (river miles)	Temperature (°C)	Dissolved oxygen (mg/L)	Biochemical oxygen demand (mg/L)	Chlorophyll-a (µg/L)	Ammonia as nitrogen (mg/L)	Nitrite plus nitrate as nitrogen (mg/L)	Phosphorus (mg/L)	Specific conductance (µS/cm)
Headwaters - site 3 Richland Creek at Old Collinsville Road at Belleville, Ill.	34.70	26.1	4.6	4.5	3.0	0.10	0.10	0.01	496
Wolf Branch	33.50	--	--	--	--	--	--	--	--
Swansea wastewater treatment facility	33.20	24.3	8.4	5.7	1.1	.10	27	11	964
Richland Creek Tributary No. 1	33.00	25.6	8.7	3.6	7.1	.10	.10	.03	790
Catawba Creek	32.40	27.2	6.4	11	8.4	.13	.10	.60	1,121
Richland Creek Tributary No. 2	30.40	25.1	10.3	4.8	18	.11	.78	.03	2,740
Belleville Area 1 wastewater treatment facility	30.00	26.2	7.3	14	6.5	4.2	4.1	2.8	1,041
Richland Creek Tributary No. 3	28.60	25.3	3.9	10	6.6	.19	2.6	4.7	849
Douglas Creek	22.40	25.9	6.4	15	110	.10	.10	.90	876
Kinney Branch	22.00	24.8	4.6	6.3	12	.10	5.9	4.4	778
West Fork Richland Creek	18.10	26.4	3.8	4.6	3.2	.13	.11	.04	597
Prairie du Long Creek	8.70	25.8	6.4	7.9	71	.10	.45	.02	339

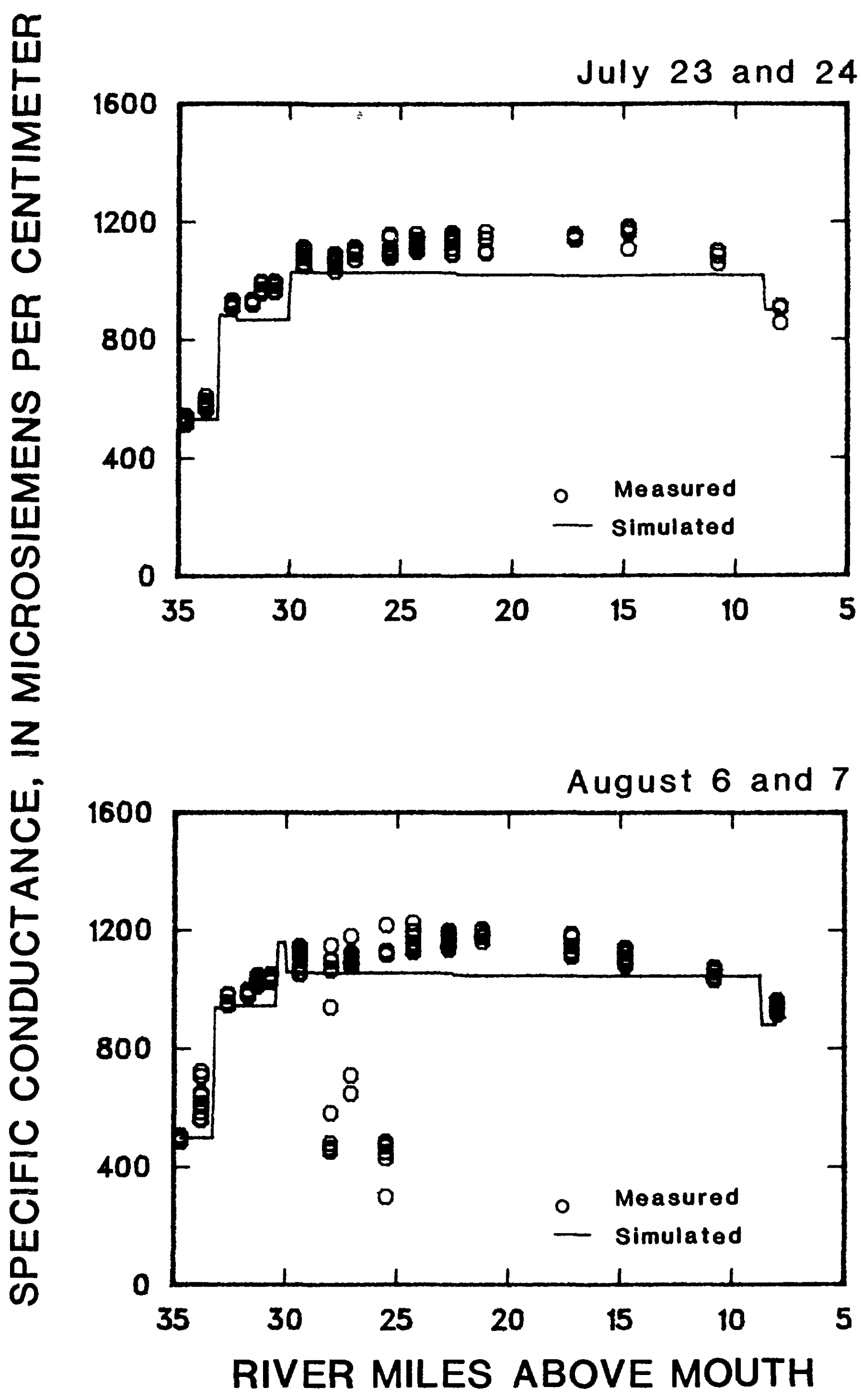

Figure 11.--Profiles of simulated and measured specific conductance in Richland Creek for the July and August diel studies.

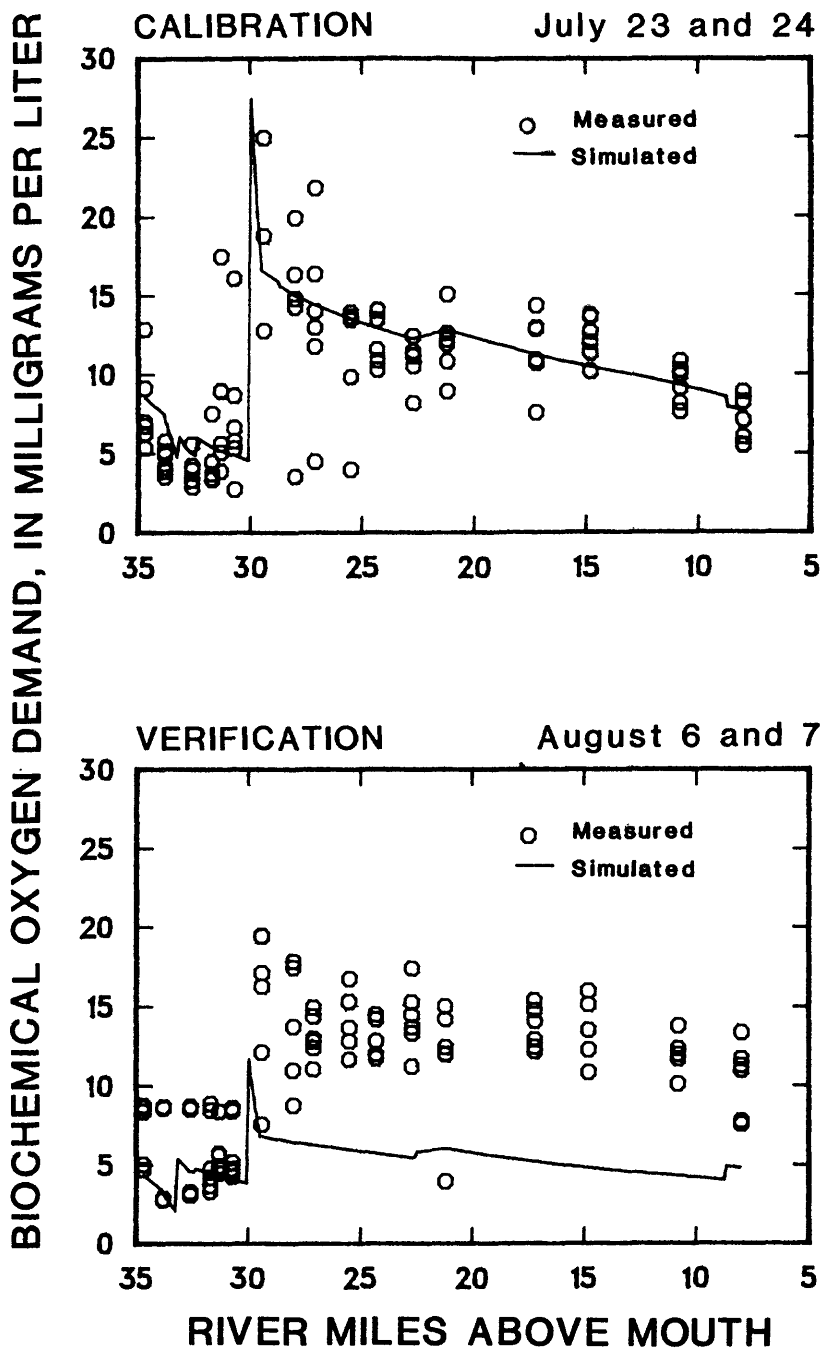

Figure 12.--Profiles of simulated and measured ultimate carbonaceous biochemical oxygen demand in Richland Creek with biochemical oxygen demand source/sink rates calibrated for the July diel study and verified with the August diel study.

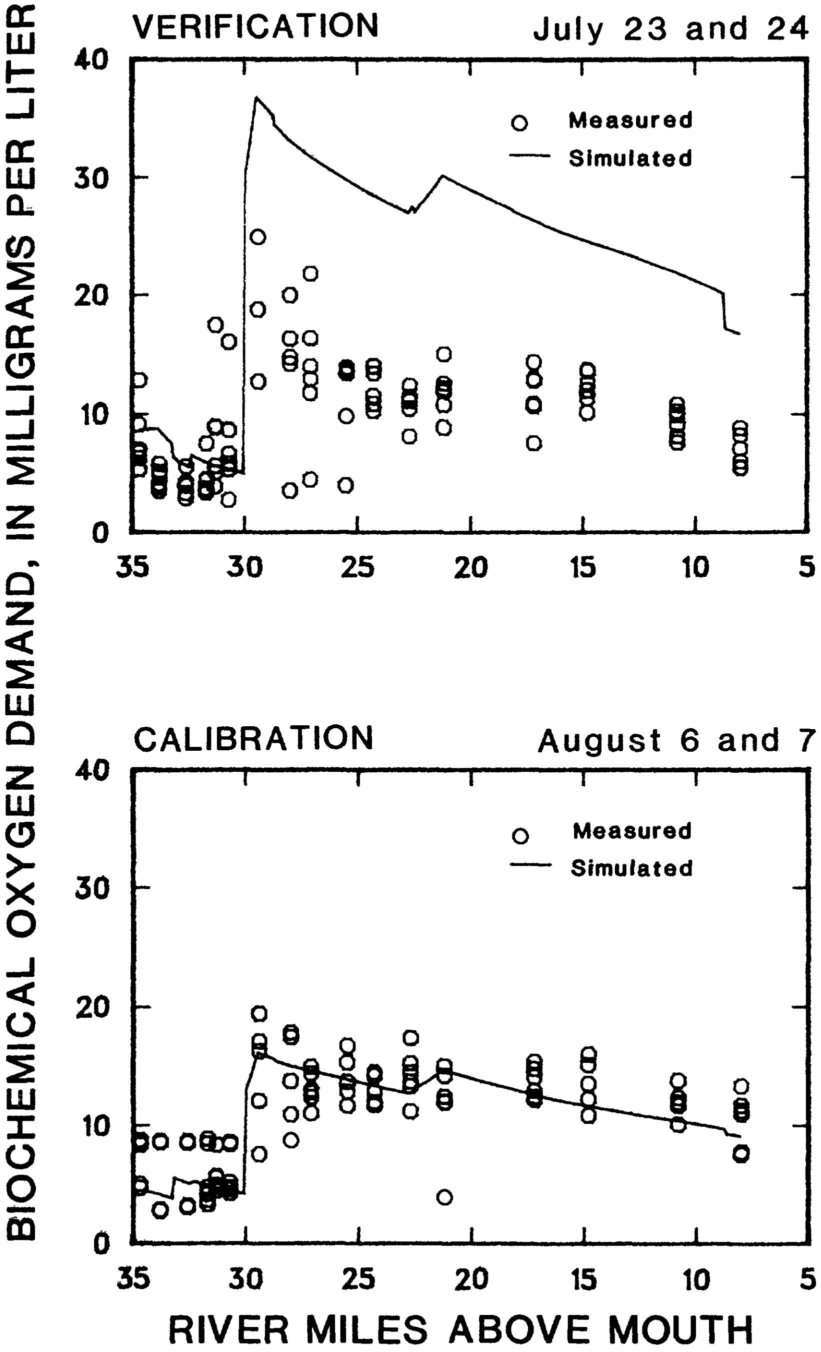

Figure 13.--Profiles of simulated and measured ultimate carbonaceous biochemical oxygen demand in Richland Creek with biochemical oxygen demand source/sink rates calibrated for the August diel study and verified with the July diel study.

The rate coefficients ranged from -2.00 to 0.10 reciprocal days, significantly different from those calibrated to the July conditions. Again these could not be validated because they could not accurately simulate the July diel study conditions. It appears that the point source loads of carbonaceous BOD from the Belleville Area 1 WWTF (RM 30.0) are in error in the model. However, lab analysis results of samples from the facility appear to be valid and indicate no reason to discard them. One possible factor for the inaccuracy is that algae can interfere with BOD measurements. During the BOD analysis, samples are incubated in the dark. Algae will die during these prolonged periods of darkness and the dead algae can contribute significantly to the BOD. This, however, was probably not a major factor because algal populations (as chlorophyll-a) were small during both diel studies.

Computer simulations were done to determine how sensitive the model is to BOD by comparing simulations without including BOD to calibrated model simulations with BOD. Dissolved oxygen, the constituent of primary interest, showed a maximum change of 0.31 mg/L for the July diel conditions and 0.41 mg/L for the August diel conditions (fig. 14). The results indicate that the model is very insensitive to changes in BOD, and that it is probably not an important factor in the dissolved oxygen depletion of Richland Creek at current (1984) point source loadings. The calibrated source/sink rate coefficients for both the July and August conditions were used in the respective data sets for the model.

Algal populations appeared to be small during both diel studies. Visual observations indicated there were very few periphyton, phytoplankton, or macrophyte communities. This is supported by the fact that dissolved oxygen concentrations did not show large diel variations. The model was calibrated so that simulated chlorophyll-a concentrations approximated those measured in the stream. The QUAL-II model simulates algal activity using the following equations (National Council of the Paper Industry for Air and Stream Improvement, 1982):

$$Chla = \alpha_o A \qquad (8)$$

where Chla is the chlorophyll-a concentration, in micrograms per liter;

α_o is the ratio of chlorophyll-a, in micrograms, to algal biomass, in milligrams; and

A is the algal biomass concentration, in milligrams per liter.

$$\frac{dA}{dt} = \mu A - \rho A - \frac{\sigma_1}{H} A \qquad (9)$$

where t is time, in days;

μ is the local algal specific growth rate, in reciprocal days;

ρ is the local algal respiration rate, in reciprocal days;

σ_1 is the local algal settling rate, in feet per day; and

H is the average depth, in feet.

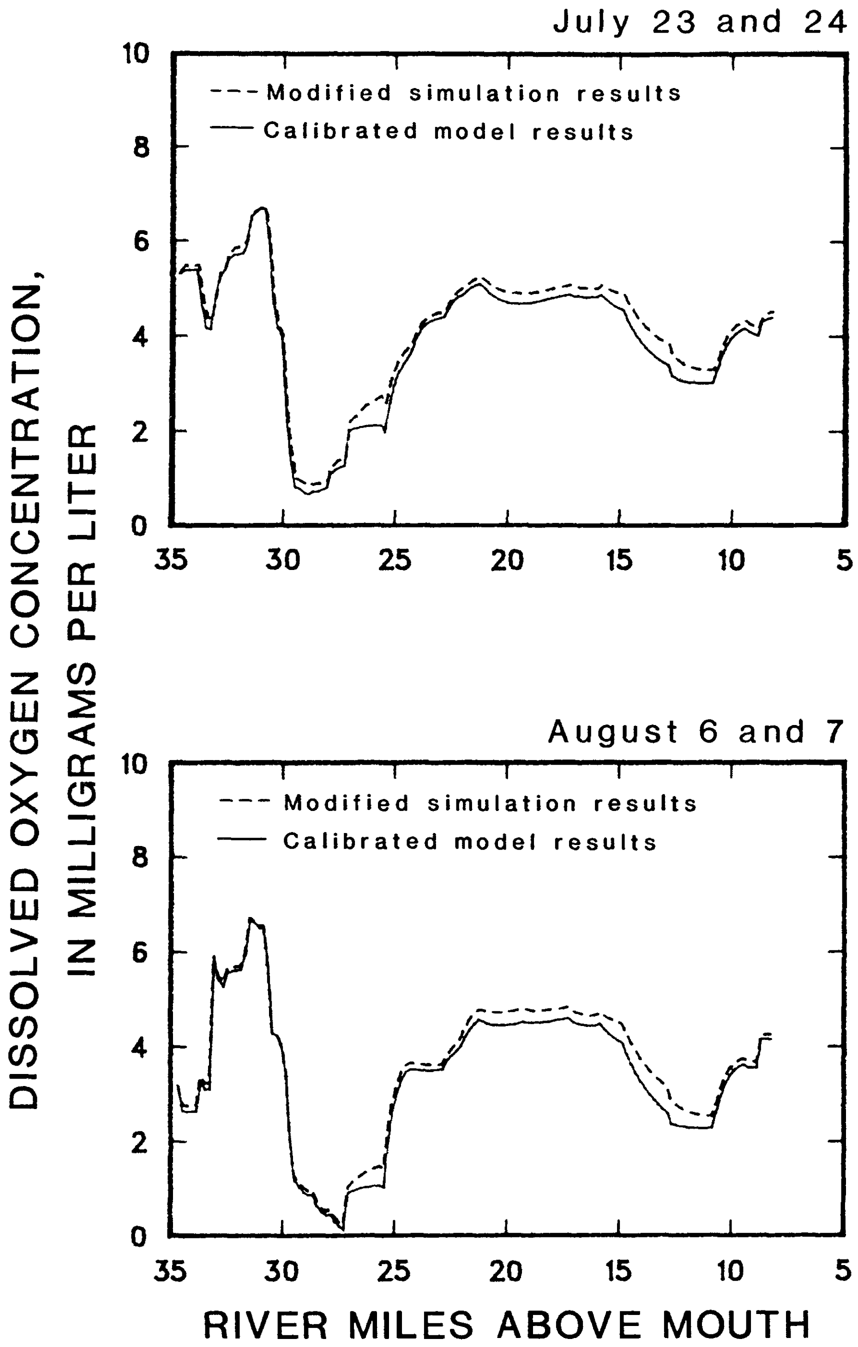

Figure 14.--Profiles of predicted dissolved oxygen concentrations in Richland Creek for the calibrated model and a simulation with biochemical oxygen demands removed for the July and August diel studies.

$$\mu = \mu\max \frac{N_3}{N_3 + K_n} \frac{P}{P + K_p} \frac{1}{\lambda H} \ln \frac{K_L + L'}{K_L + L' e^{-\lambda H}} \quad (10)$$

where $\mu\max$ is the maximum algal specific growth rate, in reciprocal days;
N_3 is the local concentration of nitrate nitrogen, in milligrams per liter;
P is the local concentration of phosphorus, in milligrams per liter;
K_n and K_p are empirical half saturation constants for nitrogen (n) and phosphorus (p), in milligrams per liter;
λ is the light extinction coefficient, in reciprocal feet;
L' is the local intensity of light, in langleys per minute; and
K_L is the empirical half saturation constant for light, in langleys per minute.

The ratio of chlorophyll-a to algal biomass (α_o) is important in determining the contribution of algae from the measured point sources. The suggested range for this ratio is 20 to 100 micrograms per milligram (Bowie and others, 1985). Model simulations using the extremes of this range showed negligible changes in all the modeled constituent concentrations. Tables 7 and 8 summarize these and other sensitivity analysis results. The ratio used in the model was specified at 60 micrograms per milligram, which is the mean of the suggested range.

Plants utilize nitrogen and phosphorus as nutrients for growth and release these nutrients upon death through decomposition. Figure 9 indicates these interactions as they were modeled. The nitrogen content of algae can range from 0.006 to 0.16 mg (milligram) nitrogen per milligram algae. The range for the phosphorus content of algae is 0.0008 to 0.05 mg phosphorus per milligram algae (Bowie and others, 1985). Simulations using the extremes of these ranges showed that the model was insensitive to these coefficients. Subsequently, mean coefficient values were selected and specified as 0.08 mg nitrogen per milligram algae and 0.025 mg phosphorus per milligram algae. The empirical half-saturation constants for nitrogen, phosphorus, and light (K_n, K_p, and K_L) were specified as 0.3 mg/L, 0.04 mg/L, and 0.03 langleys per minute, respectively, which were the means of the suggested ranges (National Council of the Paper Industry for Air and Stream Improvement, 1982).

Algal respiration rates (ρ) can range from 0.005 to 0.60 reciprocal day and algal maximum specific growth rates ($\mu\max$) can range from 0.2 to 8.0 reciprocal days (Bowie and others, 1985). One limitation of the QUAL-II model, however, is that these rates are specified for the entire model rather than for the model subreaches and thus cannot be varied relative to the varieties of plants present in each subreach. The algal respiration rate was specified as 0.5 reciprocal day, and the algal maximum specific growth rate was specified as 4.0 reciprocal days. These values were chosen from preliminary model simulations of dissolved oxygen and nutrient concentrations. These values were maintained throughout the remaining model calibration.

Table 7.--Sensitivity analyses showing maximum changes in constituent concentrations in the Richland Creek model from simulations using ranges in values of model coefficients for the July diel-study conditions

[mg/L, milligrams per liter; μg/L, micrograms per liter]

Change in coefficients	Dissolved oxygen (mg/L)	Chlorophyll-a (μg/L)	Nitrite plus nitrate nitrogen (mg/L)	Ammonia nitrogen (mg/L)	Phosphorus (mg/L)
Reaeration-rate coefficients					
decreased 0.82 or 2.81 reciprocal days from the calculated values for the Krenkel and Orlob and the Padden and Gloyna equations, respectively.	4.03	0.01	0.00	0.00	0.00
increased 0.82 or 2.81 reciprocal days from the calculated values for the Krenkel and Orlob and the Padden and Gloyna equations, respectively.	2.18	.01	.00	.00	.00
Velocity					
decreased 33.3 percent from the calculated values.	1.74	73.24	.74	.67	.11
increased 49.8 percent from the calculated values.	1.63	19.83	.63	.65	.05
Ammonia oxidation rate range from 0.003 to 0.5 reciprocal days.	1.47	12.84	2.93	2.97	.01
Nitrite oxidation rate range from 0.09 to 20.0 reciprocal days.	.34	11.13	2.29	.02	.01
Chloraphyll-a to algae ratio range from 20 to 100 micrograms chlorophyll-a per milligram algae.	.58	5.14	.41	.09	.06
Nitrogen content of algae range from 0.006 to 0.16 milligram nitrogen per milligram algae.	.05	8.72	.26	.06	.01
Phosphorus content of algae range from 0.0008 to 0.05 milligram phosphorus per milligram algae.	.04	3.57	.02	.01	.10
Oxygen production and uptake per unit of algae photosynthesis and respiration range from uptake of 1.6 and production of 1.8 to an uptake of 2.3 and production of 1.4 milligrams oxygen.	.12	.00	.00	.00	.00

Table 8.--Sensitivity analyses showing maximum changes in constituent concentrations in the Richland Creek model from simulations using ranges in values of model coefficients for the August diel-study conditions

[mg/L, milligrams per liter; μg/L, micrograms per liter]

Change in coefficients	Dissolved oxygen (mg/L)	Chlorophyll-a (μg/L)	Nitrite plus nitrate nitrogen (mg/L)	Ammonia nitrogen (mg/L)	Phosphorus (mg/L)
Reaeration-rate coefficients decreased 0.82 or 2.81 reciprocal days from the calculated values for the Krenkel and Orlob and the Padden and Gloyna equations, respectively.	3.90	0.01	0.00	0.00	0.00
increased 0.82 or 2.81 reciprocal days from the calculated values for the Krenkel and Orlob and the Padden and Gloyna equations, respectively.	2.56	.01	.00	.00	.00
Velocity decreased 33.3 percent from the calculated values.	1.44	62.73	.82	.87	.10
increased 49.8 percent from the calculated values.	1.47	19.83	.82	.86	.03
Ammonia oxidation rate range from 0.003 to 0.5 reciprocal days.	2.15	4.76	4.29	4.31	.01
Nitrite oxidation rate range from 0.09 to 20.0 reciprocal days.	.49	4.23	3.22	.01	.01
Chloraphyll-a to algae ratio range from 20 to 100 micrograms chlorophyll-a per milligram algae.	.59	2.55	.38	.11	.05
Nitrogen content of algae range from 0.006 to 0.16 milligram nitrogen per milligram algae.	.05	.54	.27	.07	.01
Phosphorus content of algae range from 0.0008 to 0.05 milligram phosphorus per milligram algae.	.05	3.91	.03	.01	.07
Oxygen production and uptake per unit of algae photosynthesis and respiration range from uptake of 1.6 and production of 1.8 to an uptake of 2.3 and production of 1.4 milligrams oxygen.	.14	.00	.00	.00	.00

The light extinction coefficient (λ) can range from 0.03 reciprocal foot in very clear water, to 0.9 reciprocal foot in very turbid water (Bowie and others, 1985). Values were specified for each model subreach and ranged from 0.10 to 0.70 reciprocal foot. The light extinction coefficients were chosen in relation to measured stream depth and turbidity.

Bowie and others (1985) describe algal settling rates as being highly variable, and they suggest that these rate coefficients (σ_1) can range from negative values, indicating a source of algae, to a maximum of about 30.0 ft/d (feet per day), indicating algal sink or loss. Algal settling-rate coefficients were specified for each model subreach and were used as the primary means of calibrating the model to simulate chlorophyll-a concentrations in Richland Creek. Algal settling rates were calibrated for the July diel-study conditions, but these rate coefficients were not well validated by a simulation with the August diel-study conditions (fig. 15). Algal settling rates were then calibrated for the August diel-study conditions; however, these also were not validated with a simulation using the July conditions (fig. 16).

Simulations were then performed to determine how sensitive the model was to algae (as chlorophyll-a) by comparing simulations without including algae to calibrated model simulations with algae. Dissolved oxygen showed a maximum change of 0.41 and 0.47 mg/L for the July and August diel-study conditions, respectively (fig. 17). The results show that the model is very insensitive to changes in chlorophyll-a and that algae is probably not an important factor in the dissolved oxygen depletion. The calibrated algal settling rates for both the July and August conditions were used in the respective data sets for the model. The specified algal settling rate coefficients ranged from 0.01 to 2.6 ft/d for the July diel-study conditions and from -1.9 to 3.2 ft/d for the August diel-study conditions.

Algal growth and respiration affect the nutrient concentrations in the stream. Assuming this effect is accurately simulated by the model, the other coefficients affecting the nutrient concentrations must then be specified. The oxidation rates of ammonia to nitrite and of nitrite to nitrate must first be specified and then the source/sink rates for ammonia and phosphorus can be adjusted to calibrate these constituents in the model (fig. 9).

The ammonia oxidation rate can range from 0.003 to 0.50 reciprocal day (Bowie and others, 1985). Simulations were performed with this range to identify the sensitivity of the model to the ammonia oxidation rate. Several of the constituent concentrations changed significantly (tables 7 and 8) indicating that the model is fairly sensitive to changes in this rate. The oxidation rate for ammonia was not measured so it was specified as 0.25 reciprocal day, the mean the suggested range.

The nitrite oxidation rate can range from 0.09 to 20.0 reciprocal days (Bowie and others, 1985). Simulations performed with this range showed that the model was less sensitive to changes in this rate. This rate was specified as 20 reciprocal days because, as discussed previously, a high oxidation rate forces the model to simulate nitrite plus nitrate, the constituent actually measured. This rate is within reason because nitrite concentrations are typically low and nitrite oxidation rates are generally high (Bowie and others, 1985).

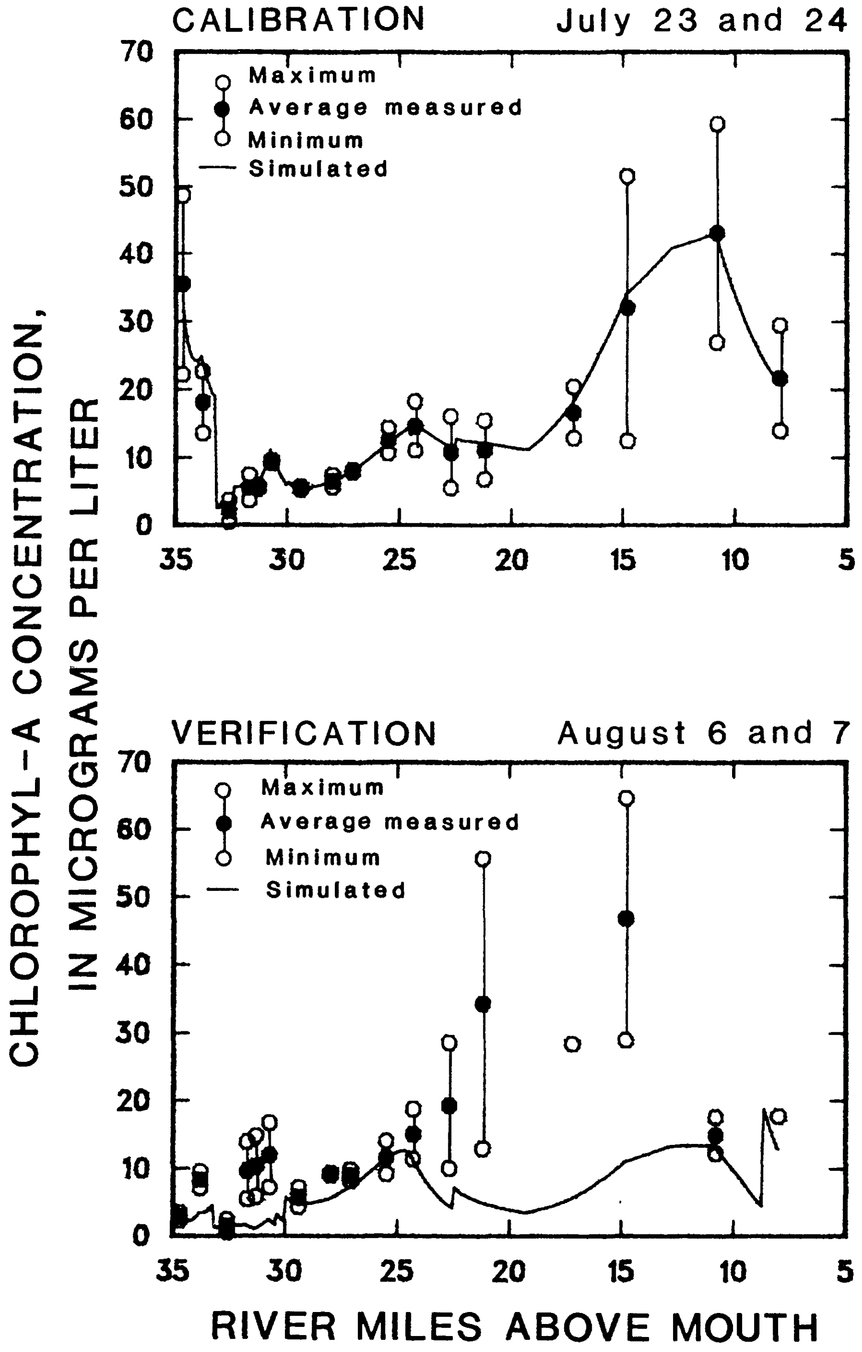

Figure 15.--Profiles of simulated and measured chlorophyll-a concentrations in Richland Creek with algal settling rates calibrated for the July diel study and verified with the August diel study.

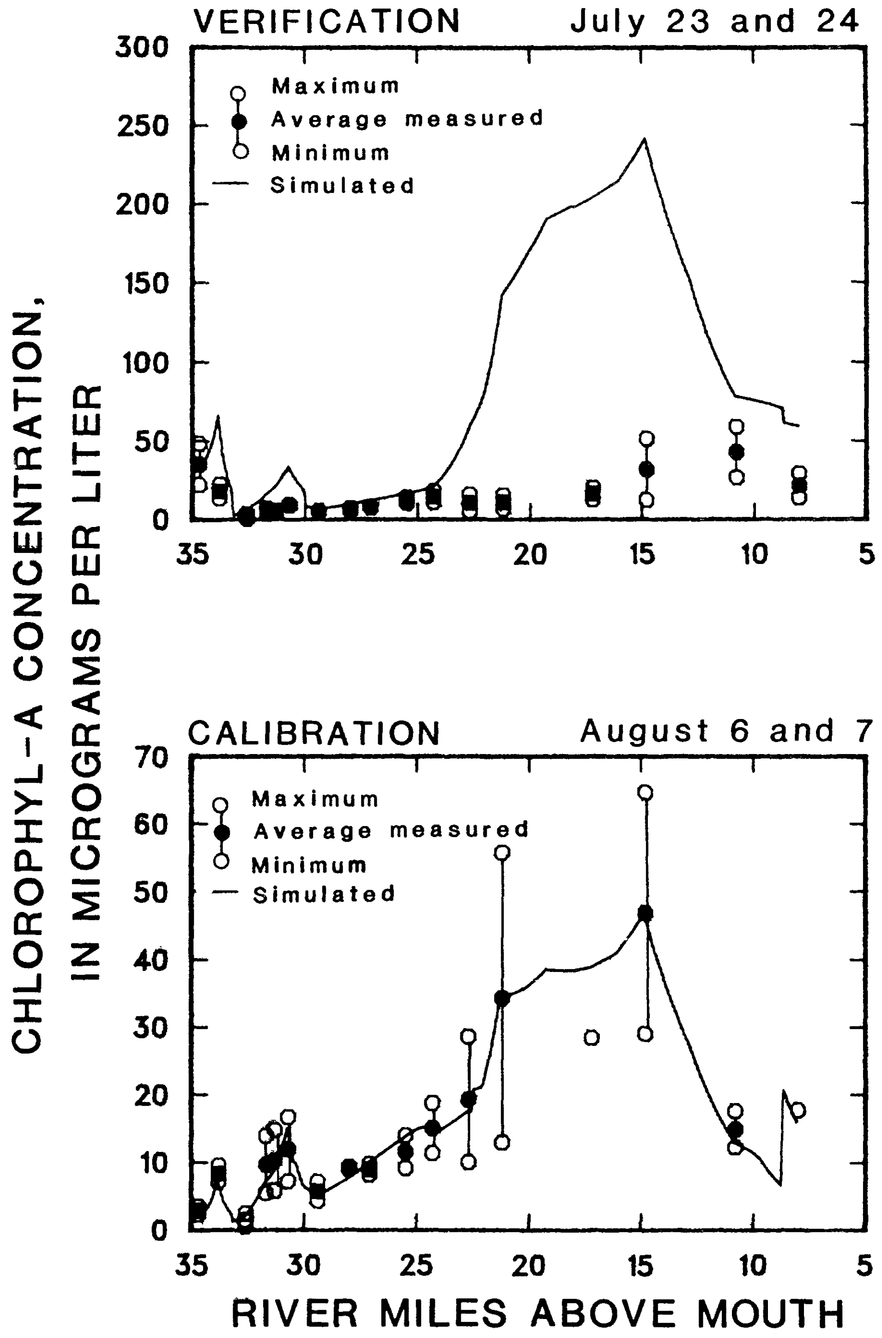

Figure 16.--Profiles of simulated and measured chlorophyll-a concentrations in Richland Creek with algal settling rates calibrated for the August diel study and verified with the July diel study.

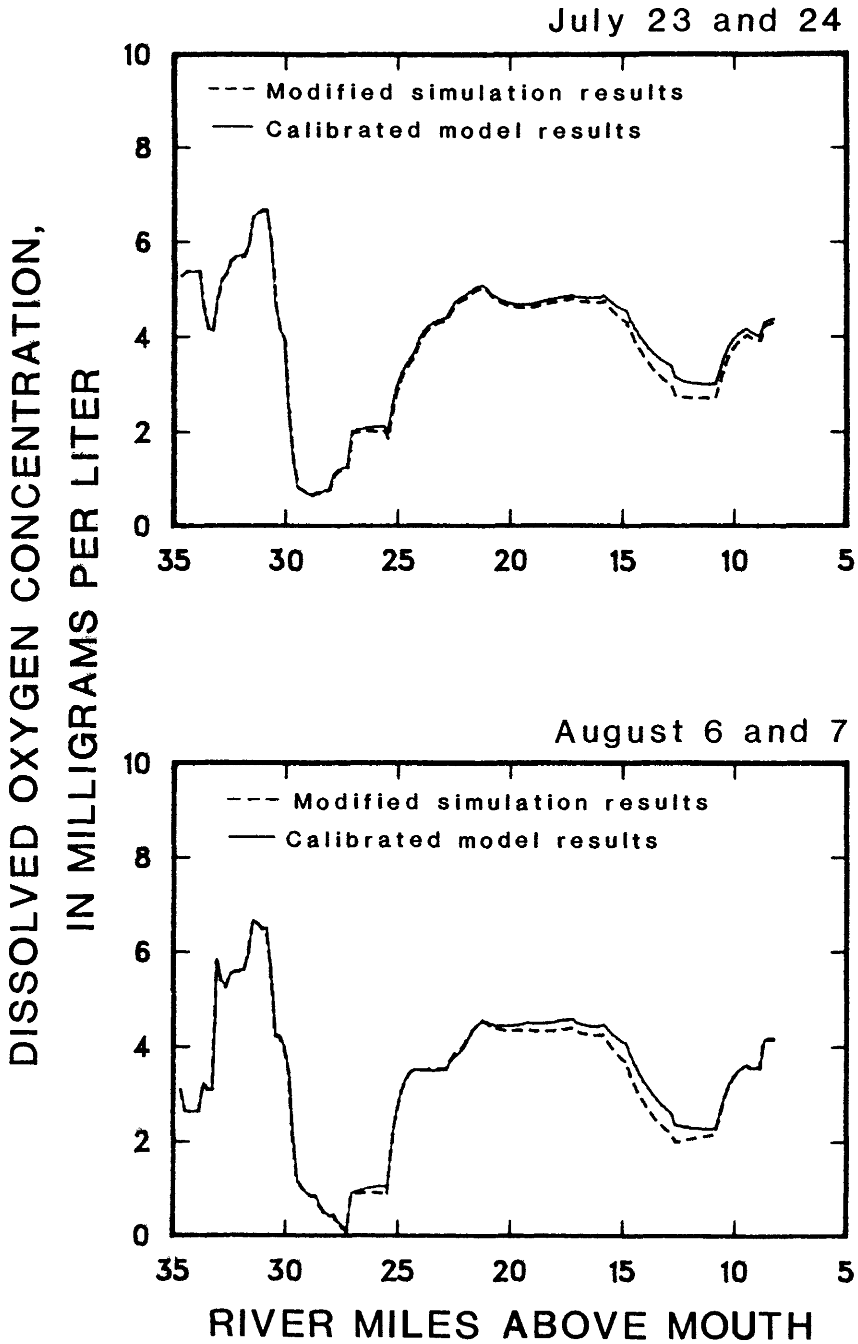

Figure 17.--Profiles of predicted dissolved oxygen concentrations in Richland Creek for the calibrated model and a simulation with algae removed for the July and August diel studies.

The source/sink rates for ammonia and phosphorus were then adjusted until the model-simulated concentrations approximated those measured during the July diel study. Figures 18 and 19 show the ammonia and nitrite plus nitrate profiles for the model calibration and verification. The model underestimates the ammonia concentrations for the August diel-study conditions, but the trends are followed indicating that the coefficients are fairly well validated. It appears that ammonia loads from the Belleville Area 1 WWTF are in error in the model. Results from the sample analyses give no indication of a reason not to trust the values. The verification for nitrite plus nitrate is also fairly good although concentrations are overestimated downstream of RM 23.0 for both the July and August diel studies.

Figure 20 shows the phosphorus profiles for the model calibration and verification. The model is again fairly well verified although it tends to underestimate the concentrations for the August diel study.

The most important and complex constituent modeled was dissolved oxygen. Figure 9 shows which factors can affect the dissolved oxygen concentration in the QUAL-II model. The model simulates dissolved oxygen using the following equation (National Council of the Paper Industry for Air and Stream Improvement, 1982):

$$\frac{dO}{dt} = K_2(O^*-O) + A(\alpha_3\mu-\alpha_4\rho)-(K_1L)-(0.0353\ K_4/A_x)-(\alpha_5\beta_1N_1)-(\alpha_6\beta_2N_2) \quad (11)$$

where t is time, in days;

O is the concentration of dissolved oxygen, in milligrams per liter;

O^* is the saturation concentration of dissolved oxygen at the local temperature and pressure, in milligrams per liter;

K_1 is the carbonaceous BOD decay rate, in reciprocal days;

K_2 is the reaeration-rate coefficient, in reciprocal days;

K_4 is the sediment oxygen demand rate, in milligrams per foot per day;

α_3 is the rate of oxygen production per unit of algal growth, in milligrams oxygen per milligram algae;

α_4 is the rate of oxygen uptake per unit of algal respiration, in milligrams oxygen per milligram algae;

α_5 is the rate of oxygen uptake per unit of ammonia oxidation, in milligrams oxygen per milligram of ammonia nitrogen;

α_6 is the rate of oxygen uptake per unit of nitrite oxidation, in milligrams oxygen per milligram nitrite nitrogen;

β_1 is the ammonia oxidation rate constant, in reciprocal days;

β_2 is the nitrite oxidation rate constant, in reciprocal days;

A is the algae concentration, in milligrams per liter;

A_x is the average cross-sectional area, in feet squared;

μ is the local specific growth rate of algae, in reciprocal days;

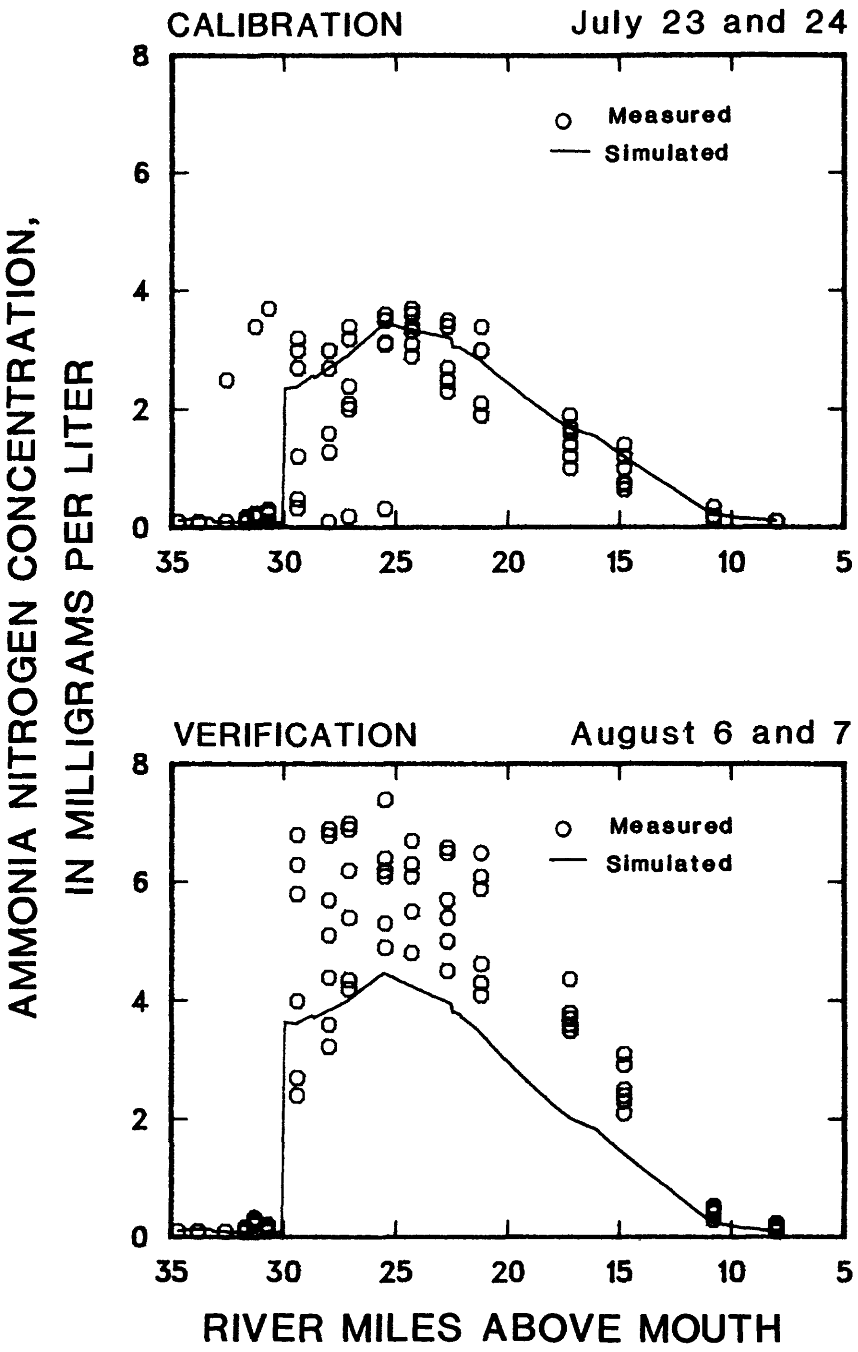

Figure 18.--Profiles of simulated and measured ammonia nitrogen concentrations in Richland Creek for the July and August diel studies.

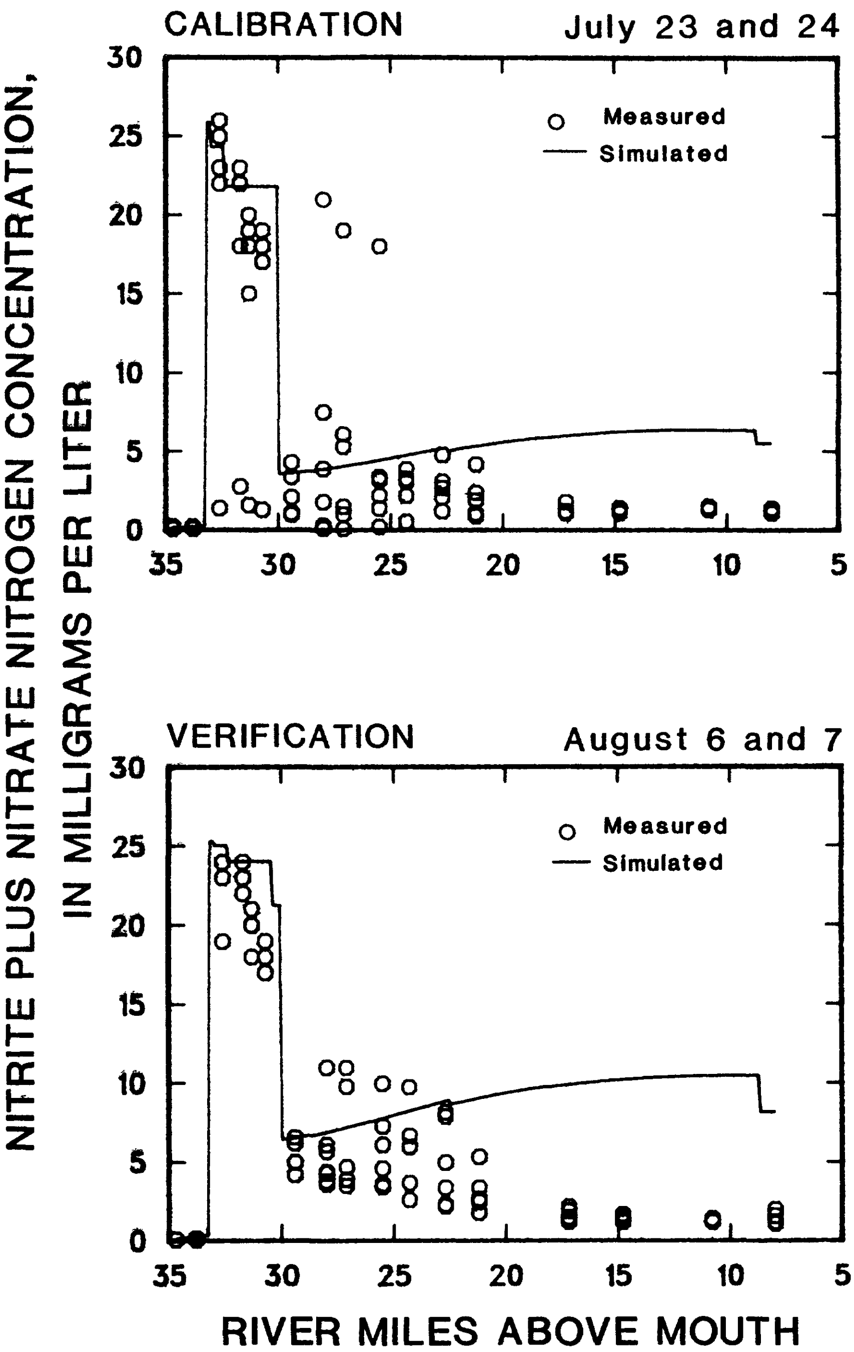

Figure 19.--Profiles of simulated and measured nitrite plus nitrate nitrogen concentrations in Richland Creek for the July and August diel studies.

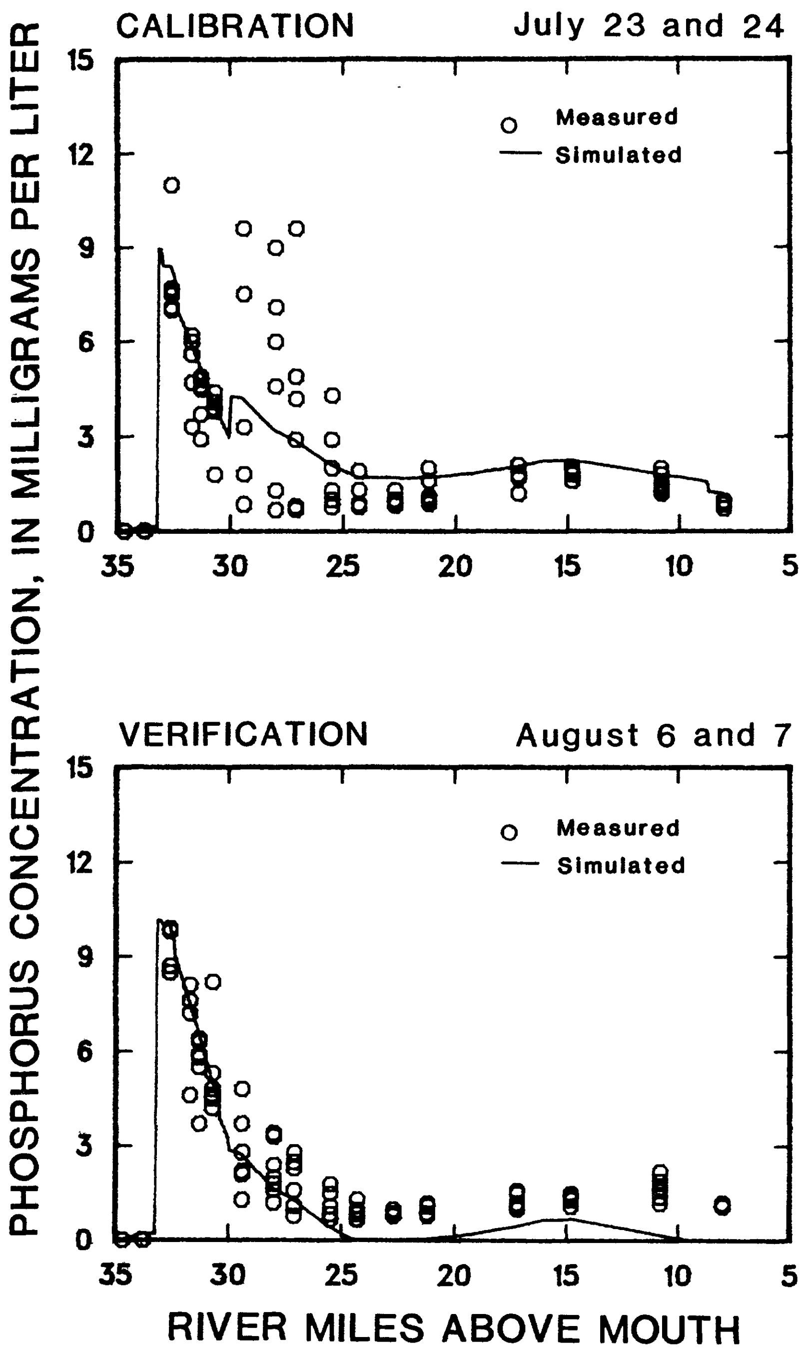

Figure 20.--Profiles of simulated and measured phosphorus concentrations in Richland Creek for the July and August diel studies.

ρ is the local respiration rate of algae, in reciprocal days;

L is the ultimate carbonaceous BOD, in milligrams per liter;

N_1 is the concentration of ammonia nitrogen, in milligrams per liter;

N_2 is the concentration of nitrite nitrogen, in milligrams per liter; and

0.0353 is a constant to convert cubic feet to liters.

Measured values of the carbonaceous BOD decay rate coefficient (K_1) were specified for each model subreach. The rate of oxygen uptake for both the ammonia (α_5) and nitrite (α_6) oxidation reactions were specified as the stoichiometric equivalent amounts necessary to balance the chemical reactions. The oxygen uptake rates were specified as 3.43 mg oxygen per milligram ammonia nitrogen oxidized to nitrite, and 1.14 mg oxygen per milligram nitrite nitrogen oxidized to nitrate (Bowie and others, 1985).

The reaeration rate coefficients (K_2) for Richland Creek were determined from equations 6 and 7. Both equations 6 and 7 predict the reaeration-rate coefficient as a function of depth. A simulation was performed to identify the sensitivity of the model to changes in depth. The simulation compared a 20-percent increase and decrease in the modeled stream depths with the calibrated model. The modified simulation showed a large impact on the dissolved oxygen concentrations. Concentrations changed as much as 3.18 mg/L for the July conditions and 2.89 mg/L for the August conditions (fig. 21).

The largest impact was between RM 16.0 and RM 10.0 and occurred because a 20 percent change in depth caused a change in the equation used to predict the reaeration-rate coefficients. As discussed previously, depths were determined by dividing cross-sectional area by top width for each site. The values from each two consecutive sites were then averaged to determine a depth for the subreach between those two sites.

Oxygen production per unit of algal growth (α_3) can range from 1.4 to 1.8 mg oxygen per milligram algae, and oxygen uptake per unit of algal respiration (α_4) can range from 1.6 to 2.3 mg oxygen per milligram algae (National Council for the Paper Industry on Air and Stream Improvement, 1982). The sensitivity of the model to these coefficient ranges was tested by comparing a simulation using the maximum of the oxygen production and the minimum of the uptake rates with a simulation using the minimum production and the maximum uptake rates. Comparison of these simulations showed an insignificant impact on all the constituents. The median values of 1.6 mg oxygen per milligram algae for the oxygen production rate and 1.95 mg oxygen per milligram algae for the oxygen uptake rate were specified in the model.

The SOD rate (K_4) was used for calibrating the dissolved oxygen in the model. SOD rate coefficients can be highly variable depending on the amounts of biologically oxidizable material in the sediments. Often these rates are site specific and can differ even in a cross section of the stream. The SOD rate coefficients were specified such that the model-simulated dissolved oxygen concentrations approximated the measured dissolved oxygen concentrations.

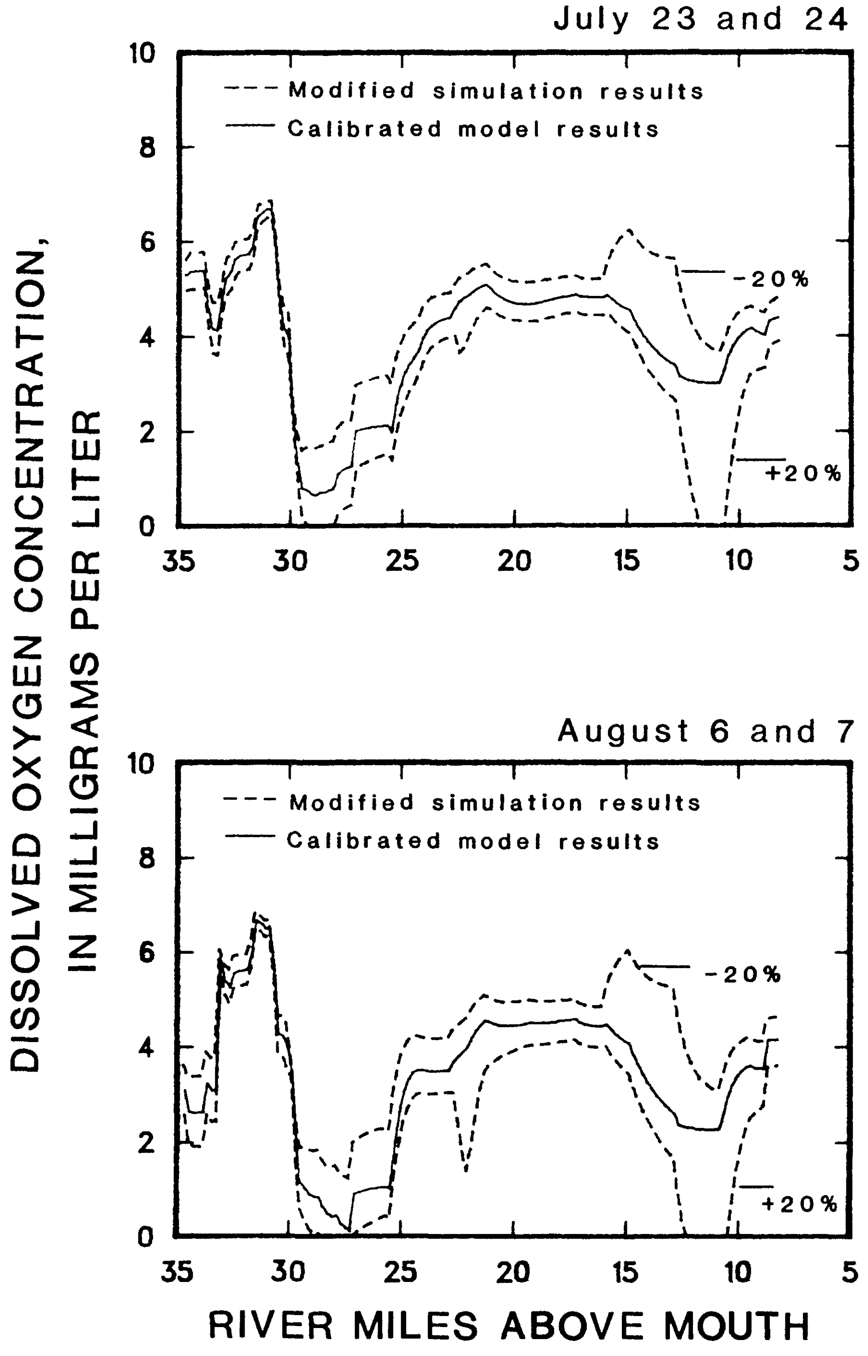

Figure 21.--Profiles of predicted dissolved oxygen concentrations in Richland Creek for the calibrated model and a simulation with modeled stream depths changes by ±20 percent for the July and August diel studies.

SOD coefficients specified for the model ranged from 200 to 98,000 mg oxygen per foot per day. These coefficients are dependent on the average width of the subreach, and to obtain comparable values, the coefficients were divided by the average width of their respective model subreach. The resulting ranges then became 5 to 1,841 mg oxygen per square foot per day. These values were comparable to the measured SOD values throughout much of the creek. Table 9 shows a comparison of the simulated and measured SOD. The highest demands in the model correspond to an area around RM 29.0 where a large sludge deposit was identified. Those subreaches with high demands also correspond with the most critical subreaches of the creek, RM 29.0 to RM 23.0. To observe the effects of SOD on dissolved oxygen, a simulation with SOD rates reduced by 20 percent was performed (fig. 22). It is apparent from this simulation that SOD is a major factor affecting dissolved oxygen depletion and that the model is sensitive to SOD changes.

Figure 23 shows profiles of the simulated and measured dissolved oxygen concentrations. The July calibration coefficients are well validated by the August simulations. As discussed previously, the section of Richland Creek from around RM 29.0 to RM 23.0 has the most severe water-quality problems, in terms of dissolved oxygen, of the entire study reach.

The model is fairly sensitive to both reaeration rate and traveltime (velocity). As discussed previously, equations were developed to predict the traveltimes (eq. 5) and the reaeration-rate coefficients (eqs. 6 and 7) for the model. Model simulations using plus and minus the standard error of these equations were performed for both of these parameters. The resulting constituent concentrations were then compared with the simulation concentrations determined from the equation-predicted coefficient values. Although the model is sensitive to the reaeration-rate coefficients (tables 7 and 8), a change of one standard error did not significantly improve dissolved oxygen concentrations in the critical subreaches of the creek (fig. 24). The model is also sensitive to changes in traveltime (fig. 25). It is apparent then, that incorrect traveltimes or reaeration rates could have a significant effect on the modeled water quality. The values used in this model are the best estimates from equations based on field measurements made between June and September 1984.

Every attempt was made to use the most reasonable and accurate coefficients for model calibration. It is important to note, however, that due to the many interrelated factors affecting constituent concentrations in the model, some coefficients may be in error, with that error compensated by other related coefficients. The model coefficients for the simulation of carbonaceous BOD were not validated. Some problems also were evident in the simulation of ammonia concentrations. The impact of SOD on the dissolved oxygen concentrations was large enough to have an overshadowing effect on the calibration of other less important factors. Nevertheless, August verification results indicate that the combination of model coefficients used are valid, and the model can simulate low-flow water quality in Richland Creek under some differing hydrologic and waste-load conditions.

Table 9.--Simulated and measured sediment oxygen demands

Simulated sediment oxygen demand			Measured sediment oxygen demand	
Model subreach number	River miles	Demand (milligrams per day per square foot)	River mile	Demand (milligrams per day per square foot)
1	34.7 - 33.8	312	34.4	371
			34.1	446
2	33.8 - 33.2	296	33.4	212
3	33.2 - 32.6	363	33.1	291
			32.8	318
4	32.6 - 31.7	273	32.4	594
			32.4	169
			32.3	127
			32.0	117
			31.8	332
5	31.7 - 31.3	172	31.3	388
6	31.3 - 30.7	219	31.2	159
7	30.7 - 30.0	555	30.4	707
			30.3	615
			30.3	523
8	30.0 - 29.4	1,644		
9	29.4 - 28.6	1,693		
10	28.6 - 28.0	1,841		
11	28.0 - 27.1	1,504	27.4	596
			27.4	1,433
12	27.1 - 25.5	5		
13	25.5 - 24.3	530		
14	24.3 - 22.7	769		
15	22.7 - 22.4	614		
16	22.4 - 22.0	548		
17	22.0 - 21.2	453		
18	21.2 - 19.2	364	21.0	530
19	19.2 - 17.2	397	18.9	763
20	17.2 - 16.0	602		
21	16.0 - 14.8	282	15.0	603
			15.0	454
22	14.8 - 12.8	450		
23	12.8 - 10.8	927	12.7	468
24	10.8 - 9.4	1,012		
25	9.4 - 8.0	948		

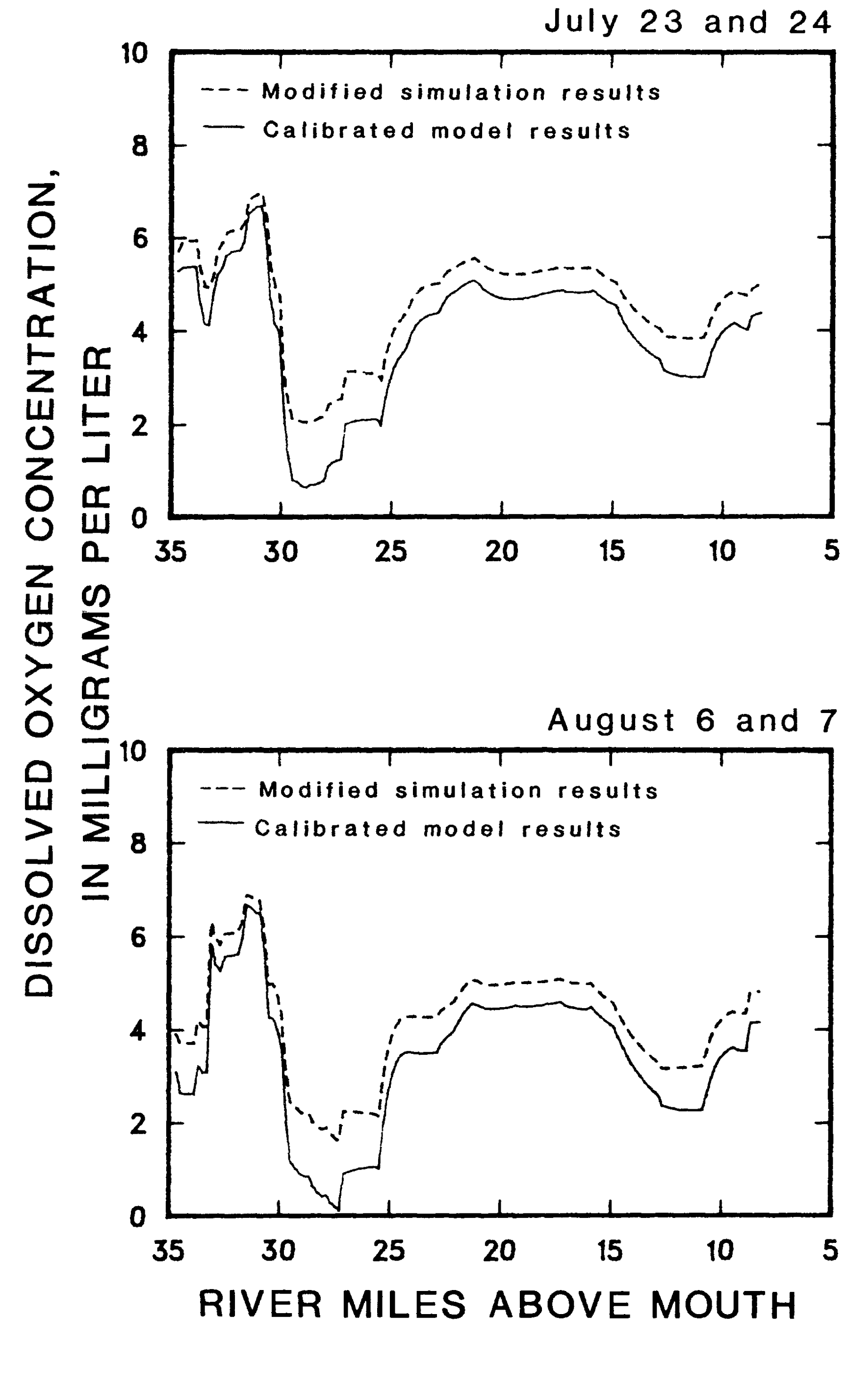

Figure 22.--Profiles of predicted dissolved oxygen concentrations in Richland Creek for the calibrated model and a simulation with SOD rates reduced 20 percent for the July and August diel studies.

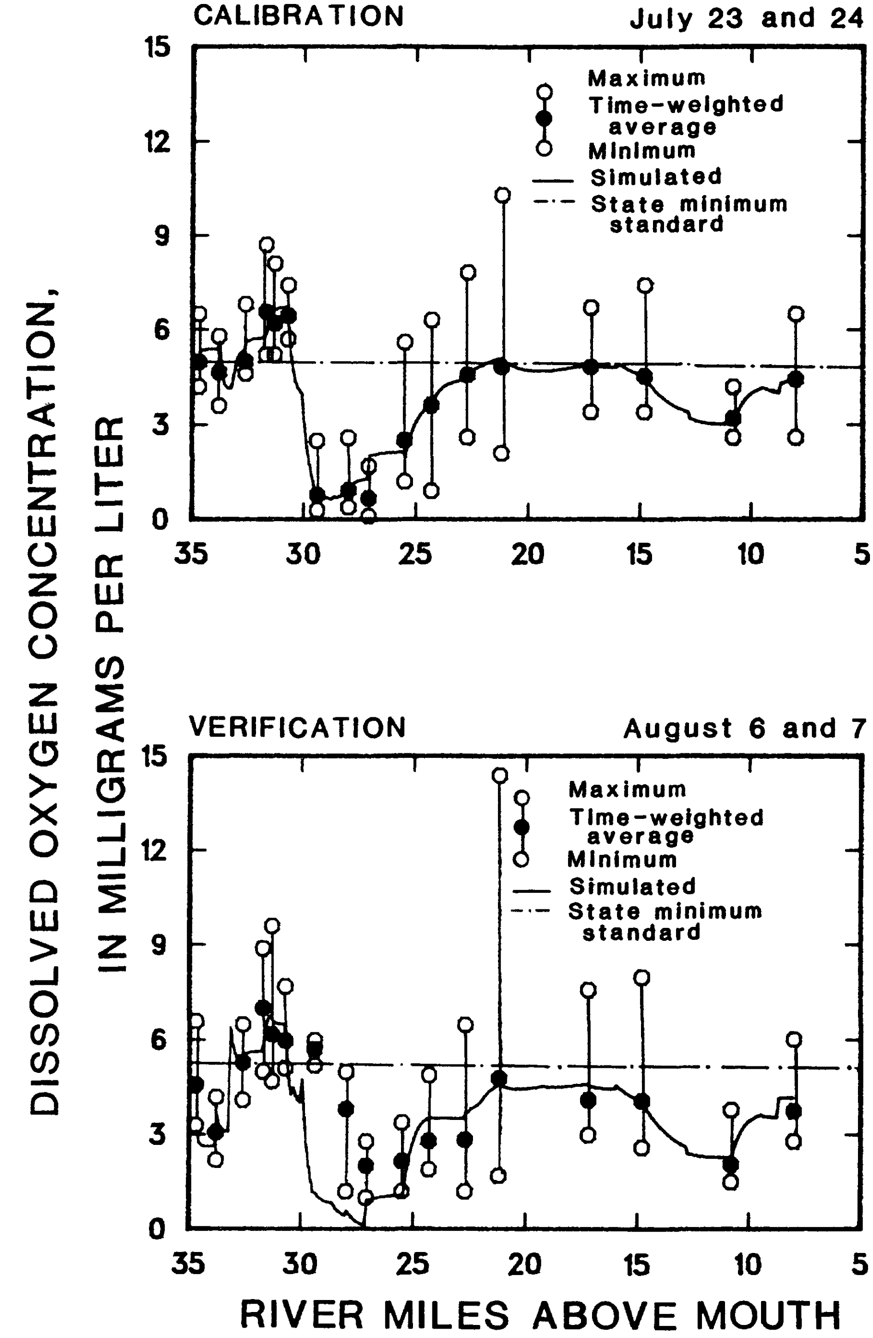

Figure 23.--Profiles of simulated and measured dissolved oxygen concentrations in Richland Creek for the July and August diel studies.

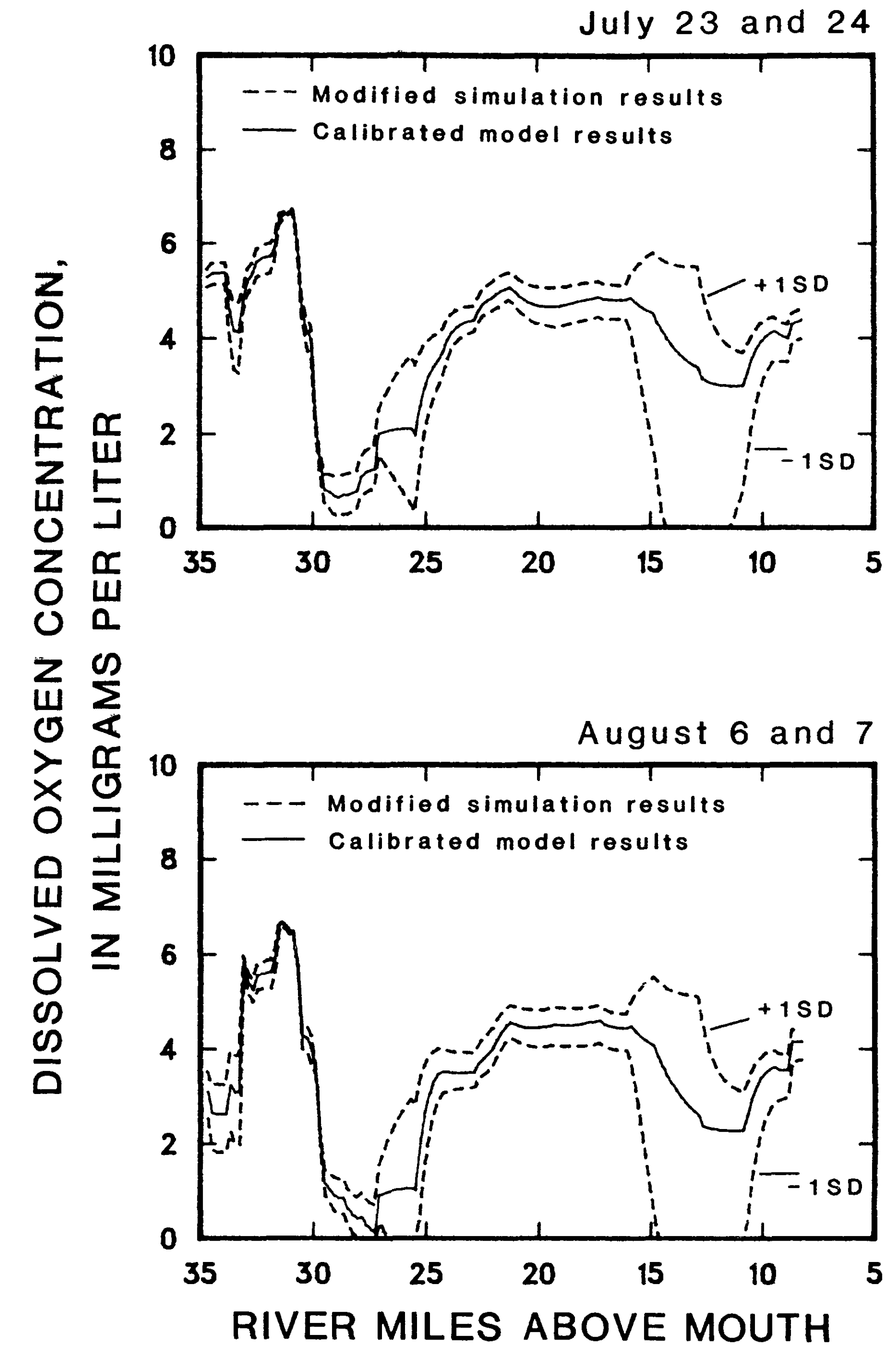

Figure 24.--Profiles of predicted dissolved oxygen concentrations in Richland Creek for the calibrated model and simulations with plus and minus one standard deviation (SD) in the reaeration-rate coefficients for the July and August diel studies.

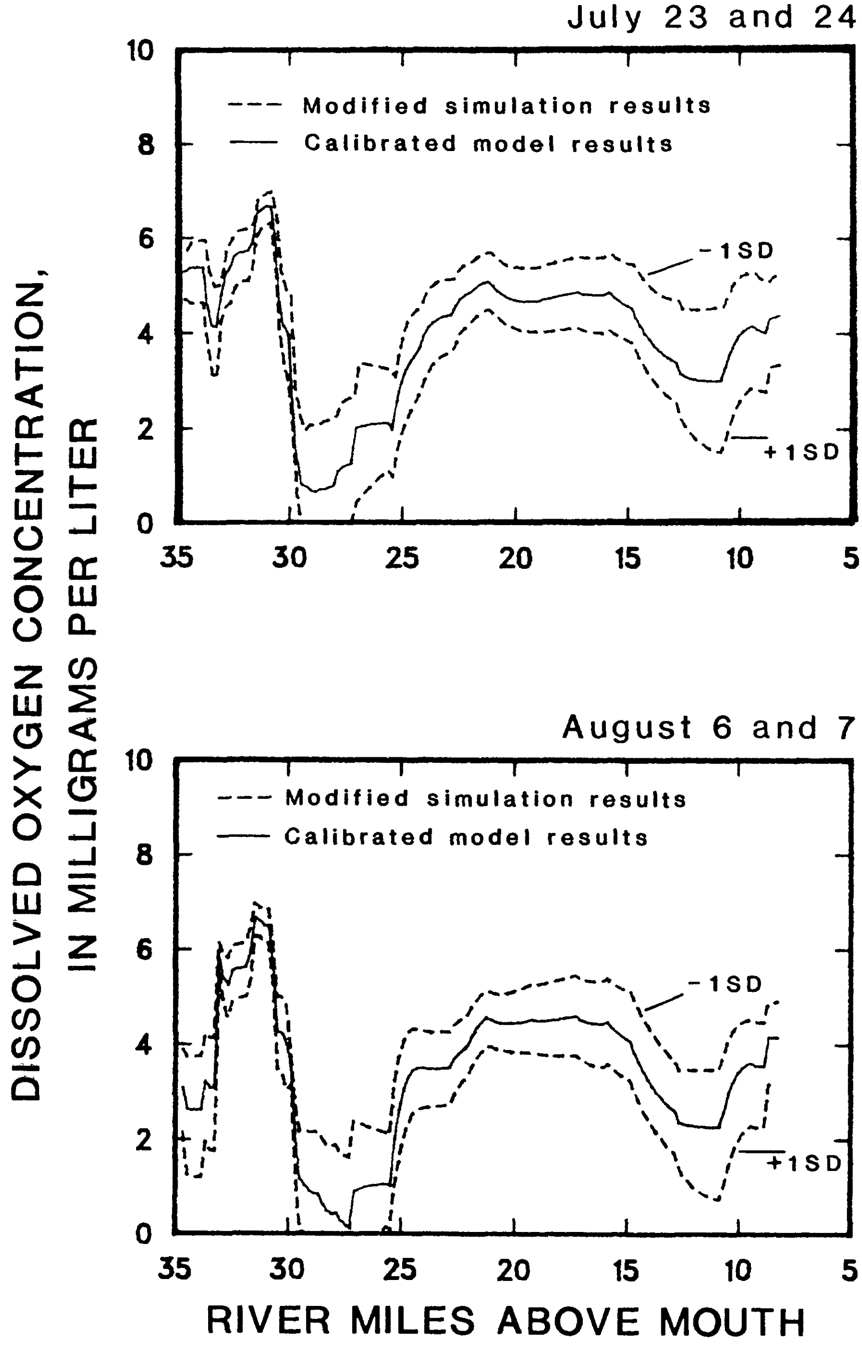

Figure 25.--Profiles of predicted dissolved oxygen concentrations in Richland Creek for the calibrated model and simulations with plus and minus one standard deviation (SD) in the stream velocity for the July and August diel studies.

Simulations Using Alternative Conditions

Simulated conditions were imposed on the model to demonstrate the model's use as a tool to predict the effect of alternative management strategies. The output from the simulation was compared with that from the calibrated model to evaluate the impact of changing the conditions.

One set of simulated conditions involved a reduction of the SOD in the critical subreaches of the creek. For this simulation, SOD was reduced to 10,000 mg oxygen per foot per day between RM 30.0 and RM 27.1. Dividing by the modeled stream width, this corresponds to SODs from 177 to 256 mg oxygen per square foot per day.

Figure 26 shows the dissolved oxygen results for this simulation compared with the calibrated model results. This reduction in SOD had a large effect on the dissolved oxygen concentrations in the subreaches of the stream where demands were reduced. A reduction in SOD of this magnitude brought dissolved oxygen concentrations well above the State minimum standard of 5.0 mg/L.

Another simulated condition was to restrict all WWTF effluents to a maximum ammonia concentration of 1.5 mg/L. Most of the WWTF effluents were already near or below this concentration of ammonia. The effects of ammonia oxidation on the dissolved oxygen concentration were small compared to the effects of SOD in the model; thus, this simulation did not significantly improve dissolved oxygen concentrations in the creek (fig. 27). It did reduce ammonia concentrations (fig. 28). However, assuming similar pH and temperature values as during the diel studies, this did not bring all the sites into compliance with the State un-ionized ammonia standard.

A last simulation used WWTF effluent ammonia and BOD concentrations as measured by the IEPA for the years 1978-80. The concentrations measured from June, July, and August of those years were averaged for WWTFs that discharge directly into Richland Creek. Data from WWTFs that discharge into tributaries were first modified to account for assimilation by the tributaries into which the effluent is discharged. It is apparent from looking at the yearly average ammonia and BOD concentrations that the effluent quality of several of the WWTFs is becoming worse. The exception to this is the Swansea WWTF which was completely rebuilt, and now (1984) discharges an effluent of fairly good quality.

The 1978-80 BOD data received from the IEPA has been analyzed as 5-day BODs. The BOD decay rates measured from the WWTFs in 1984 were used with these 5-day BODs to calculate the ultimate BODs for use in the model. The 1978-80 effluent quality data were simulated using both the July and August model coefficients because the model's ability to simulate BOD could not be verified. Downstream from the Swansea WWTF the BOD levels were much higher than in 1984 because of the higher contribution from the old Swansea WWTF. This effect was compensated for because the Belleville Area 1 WWTF did not discharge BOD concentrations as high as those measured in 1984. Figure 29 shows the dissolved oxygen concentrations for this simulation and the calibrated model. Dissolved oxygen concentrations were reduced to less than the State minimum for a short distance downstream of the Swansea WWTF, but there

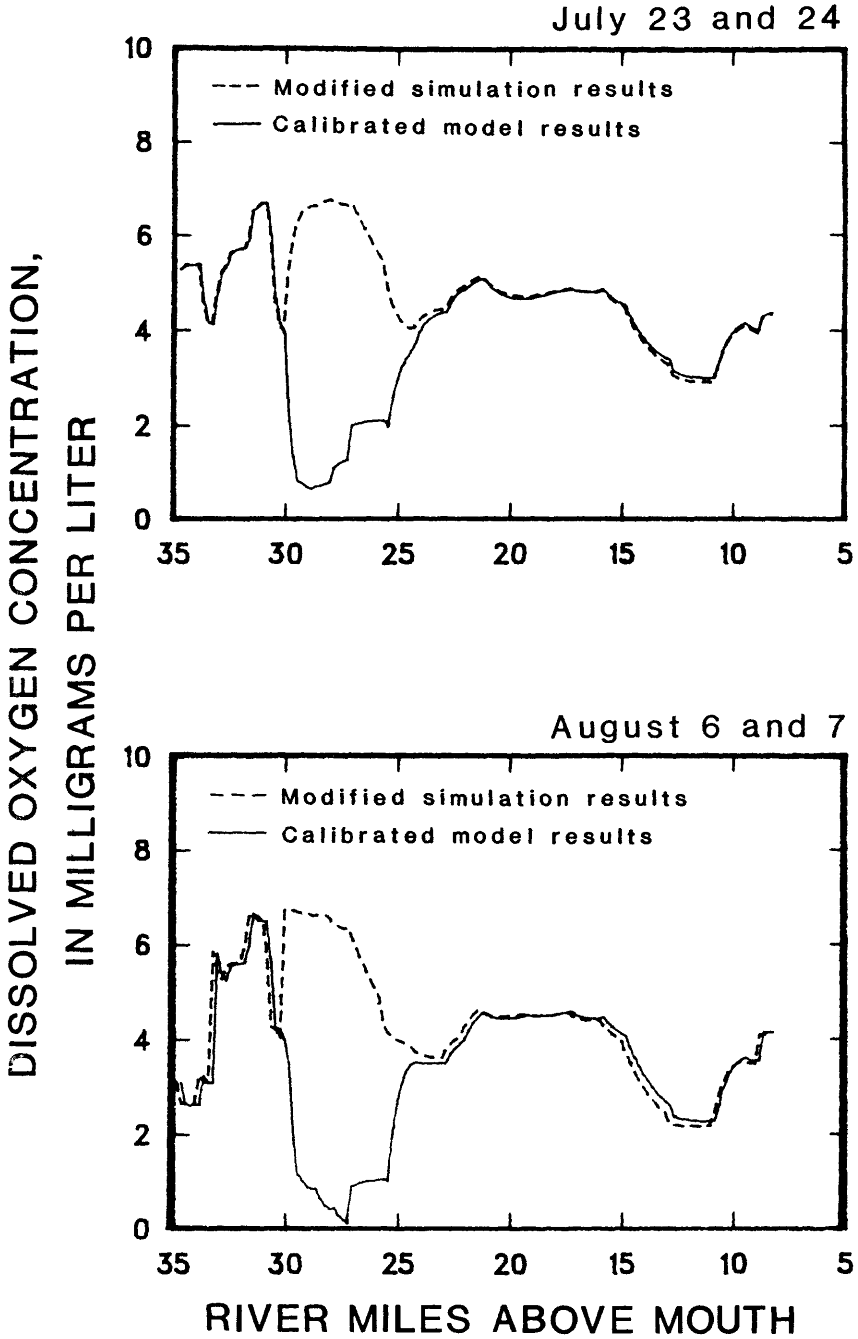

Figure 26.--Profiles of predicted dissolved oxygen concentrations in Richland Creek for the calibrated model and a simulation with sediment oxygen demands between river mile 30.0 and river mile 27.1 reduced to 10,000 milligrams oxygen per foot day for the July and August diel studies.

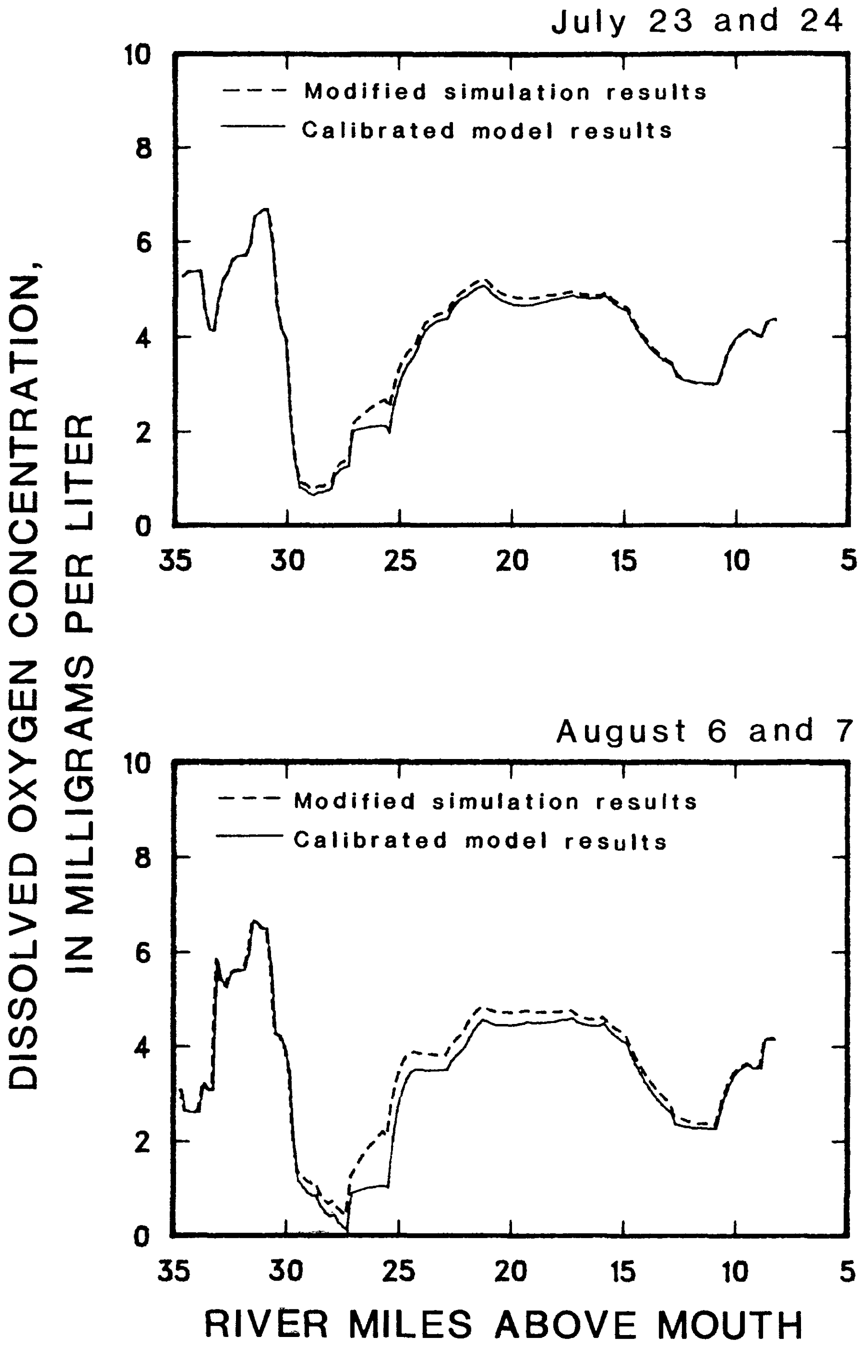

Figure 27.--Profiles of predicted dissolved oxygen concentrations in Richland Creek for the calibrated model and a simulation with the wastewater treatment facility effluent ammonia concentrations reduced to 1.5 milligrams per liter for the July and August diel studies.

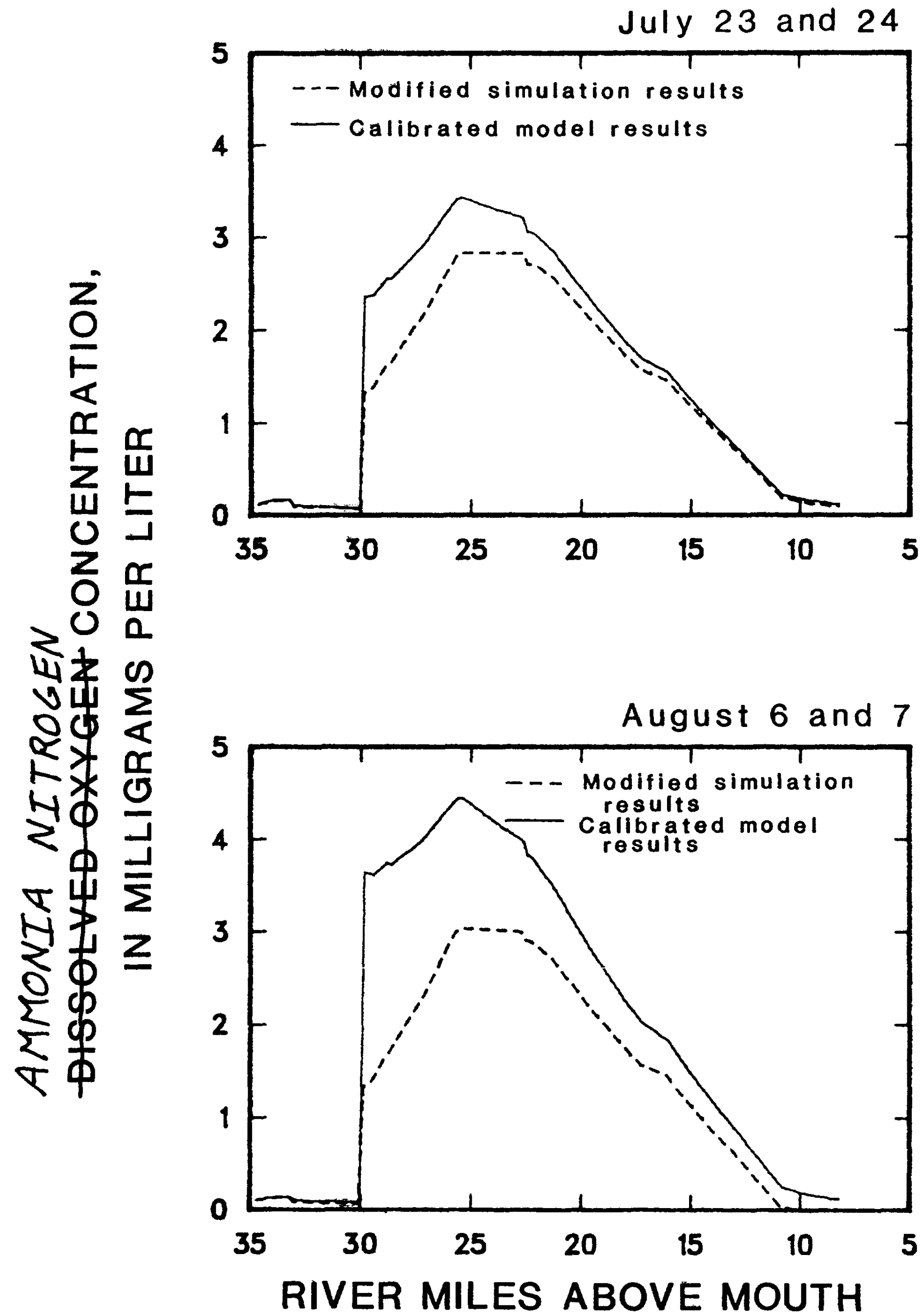

Figure 28.--Profiles of predicted ammonia nitrogen concentrations in Richland Creek for the calibrated model and a simulation with the wastewater treatment facility effluent ammonia concentrations reduced to 1.5 milligrams per liter for the July and August diel studies.

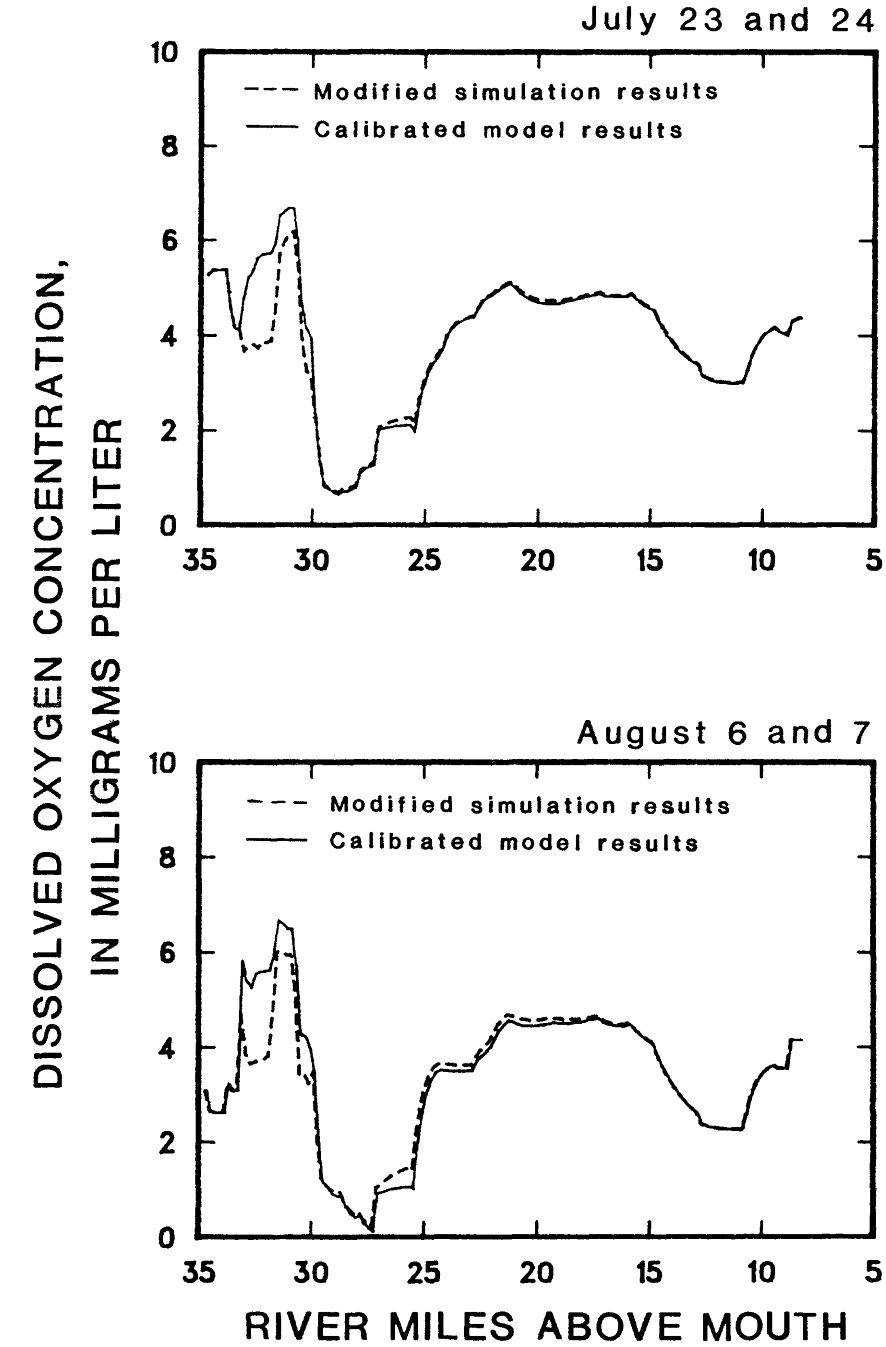

Figure 29.--Profiles of predicted dissolved oxygen concentrations in Richland Creek for the calibrated model and a simulation using average wastewater treatment facility effluent ammonia and biochemical oxygen demand concentrations from 1978 to 1980 for the July and August diel studies.

was little change in the rest of the creek. This simulation indicated that the improvements made to the Swansea WWTF between 1980 and 1984 improved the stream quality downstream of its discharge, but that otherwise there has been little change since 1978.

SUMMARY AND CONCLUSIONS

Channel and streamflow characteristics, atmospheric reaeration rates, and chemical-quality measurements were made on Richland Creek during low-flow periods from June through September 1984. Water-quality data were collected during two diel studies. Several subreaches of Richland Creek were identified where the water quality exceeded the State general-use, water-quality standards. The lowest dissolved oxygen concentrations were in the subreaches from RM 29.0 to RM 23.0 of Richland Creek. In these subreaches, dissolved oxygen concentrations were generally below 6.0 mg/L and most were below the State minimum standard of 5.0 mg/L during both diel studies. Model simulations indicate that depletion of dissolved oxygen in these subreaches was caused primarily by high SOD rates.

Ammonia nitrogen concentrations, pH, and temperature were at levels that caused the un-ionized ammonia concentrations to exceed the water-quality standard of 0.04 mg/L at four sites during the July diel study and at six sites during the August diel study. Wastewater treatment facility effluent appeared to be the major source of ammonia, but simulations using effluent with reduced ammonia concentrations did not lower the un-ionized ammonia concentrations to levels within the State standard at most of these sites.

The pH dropped slightly below the minimum standard of 6.5 standard units at one site during the July diel study and at two sites during the August diel study.

Boron concentrations in Catawba Creek exceeded the standard of 1,000 µg/L during both diel studies. The boron concentration in Richland Creek Tributary No. 2 also exceeded the standard during the August diel study. The total dissolved solids and sulfate concentrations in Richland Creek Tributary No. 2 during the August diel study exceeded their respective standards of 1,000 mg/L and 500 mg/L. Within Richland Creek, however, these constituent concentrations were all within State standards during both diel studies.

Total iron concentrations exceeded the State standard of 1,000 µg/L throughout much of Richland Creek. Mass balance calculations indicated that the point sources were not a major contributing factor to these high concentrations.

Total copper concentrations exceeded the State standard Of 20 µg/L at one site during the July diel study and at three sites during the August diel study. Mass balance calculations indicated that point sources probably were a major factor influencing these concentrations.

Manganese concentrations exceeded the State standard of 1,000 µg/L at one site during both diel studies. Mass balance calculations indicated that point sources were not the major factor causing these high concentrations.

The QUAL-II one-dimensional, steady-state, water-quality model was calibrated for Richland Creek using water-quality measurements made during a low-flow period in July 1984. The model coefficients derived from this calibration were verified by simulating the water quality under different hydrologic and wasteload conditions. This verification used water-quality measurements made during a low-flow period in August 1984. The model was not verified for the coefficients that affect carbonaceous BOD and chlorophyll-a concentrations. These coefficients were redefined for the verification data set so that the simulated concentrations of these constituents approximated those that were measured.

Hypothetical SOD and effluent-quality conditions were imposed on the model to simulate their effect on the water quality of Richland Creek. The simulations indicated that reductions in SOD between RM 30.0 and RM 27.1 would improve dissolved oxygen concentrations in the most critical subreaches of the creek. Simulations also indicated that a reduction in ammonia concentrations in WWTF effluent would have little effect on other constituent concentrations in the creek. A final simulation showed that changes in effluent quality since 1978 have had little effect on stream quality except in the vicinity of the Swansea WWTF.

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TABLES 10 and 11

page ~~70~~ 68 follows

Table 10.--Constituent concentrations determined from samples collected routinely from Richland Creek and its tributaries on July 23-24 and August 6-7, 1984

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; <, less than; dashes indicate no data]

Site number	Date (month/ day)	Time (hours)	Temperature, water (°C)	Temperature, air (°C)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	pH (standard units)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Oxygen demand, biochemical ultimate carbonaceous (mg/L)
1	07/23	1940	23.5	25.0	629	4.3	7.4	<0.10	0.6	2.30	0.77	0.67	3.8
		2110	23.0	23.0	640	4.8	7.0	--	--	--	--	--	--
		2335	22.0	21.0	595	5.3	7.3	<.10	.4	1.70	.77	.67	4.1
	07/24	0154	21.0	19.0	580	4.9	7.1	--	--	--	--	--	--
		0330	20.0	19.0	576	4.8	7.3	<.10	.4	1.60	.65	.49	4.2
		0435	20.0	18.0	575	5.0	7.4	--	--	--	--	--	--
		0645	19.5	24.0	623	4.6	7.4	<.10	.5	2.10	.91	.81	5.5
		0840	20.0	27.0	586	--	7.3	--	--	--	--	--	--
		1030	21.5	32.0	620	5.0	7.4	<.10	.5	1.90	.71	.69	4.1
		1150	22.0	33.0	607	4.7	7.4	--	--	--	--	--	--
		1400	23.5	31.0	611	4.8	7.4	<.10	.6	1.62	.75	.70	3.9
		1555	24.5	31.0	624	5.2	7.5	--	--	--	--	--	--
	08/06	1745	25.0	31.0	554	5.6	7.7	<.10	.3	.67	.18	.10	3.5
		1950	24.5	27.0	560	5.3	7.9	--	--	--	--	--	--
		2130	24.0	25.0	564	4.9	7.9	<.10	.2	.64	.18	.11	9.0
		2400	23.0	23.0	540	5.8	7.5	--	--	--	--	--	--
	08/07	0150	22.5	23.0	540	4.5	7.6	<.10	.5	.63	.24	.12	8.4
		0350	22.0	22.0	539	4.5	7.5	--	--	--	--	--	--
		0620	22.0	21.0	537	4.4	7.6	<.10	.5	.60	.41	.31	3.3
		0800	21.5	24.5	536	6.2	7.7	--	--	--	--	--	--
		1010	23.0	29.0	536	6.5	7.7	<.10	.6	.61	.24	.13	3.9
		1145	23.5	33.0	545	6.1	7.8	--	--	--	--	--	--
		1415	25.0	37.5	548	5.8	7.8	<.10	.5	.72	.31	.21	3.1
		1555	26.5	35.0	558	4.1	7.6	--	--	--	--	--	--
2	07/23	1930	23.5	27.0	554	4.4	6.4	<.10	.2	.50	.03	.02	2.4
		2045	23.0	24.0	554	5.1	6.5	--	--	--	--	--	--
		2315	22.5	22.0	549	4.9	6.0	<.10	.3	.49	.03	.01	2.3
	07/24	0135	22.0	20.0	536	4.2	6.6	--	--	--	--	--	--
		0300	21.5	19.0	538	4.1	6.8	<.10	.1	.49	.03	.03	2.6
		0415	21.0	20.0	536	3.9	6.6	--	--	--	--	--	--
		0710	21.0	23.0	553	3.8	6.3	<.10	.2	.48	.03	.03	2.8
		0930	22.0	32.0	611	4.1	6.2	--	--	--	--	--	--
		1050	22.0	32.0	572	4.2	6.2	--	--	--	--	--	5.2
		1205	23.0	33.0	571	4.2	6.4	--	--	--	--	--	--
		1435	25.5	32.0	561	4.4	6.1	.16	.3	.50	.15	.12	3.6
		1610	24.5	32.0	551	4.1	6.1	--	--	--	--	--	--

3	07/23	1900	26.0	28.0	532	5.7	7.8	<.10	.5	<.10	.04	.01	5.4
		2030	25.5	26.0	531	6.0	6.9	--	--	--	--	--	--
		2235	24.5	23.5	521	6.5	6.8	<.10	.5	.26	.05	.01	7.0
	07/24	0120	24.0	22.0	520	5.4	6.9	--	--	--	--	--	--
		0245	23.5	21.0	515	4.4	6.8	<.10	.6	<.10	.07	.01	12.9
		0455	23.0	20.0	518	4.3	7.0	--	--	--	--	--	--
		0745	22.5	25.0	532	4.5	7.1	<.10	.5	<.10	.06	.01	6.3
		0900	23.0	30.0	521	4.3	6.7	--	--	--	--	--	--
		1115	24.0	34.0	541	4.2	6.7	<.10	.6	<.10	.05	.01	6.8
		1215	24.0	33.0	539	4.4	6.7	--	--	--	--	--	--
		1500	25.5	32.0	544	5.0	6.8	<.10	.9	<.10	.09	.03	9.2
		1520	26.0	32.0	536	5.0	6.8	--	--	--	--	--	--
	08/06	1830	28.0	31.0	504	6.6	7.4	<.10	.6	<.10	.02	.01	8.6
		2005	27.5	28.0	498	4.5	7.5	--	--	--	--	--	--
		2205	26.5	25.0	504	4.4	7.6	<.10	.6	<.10	.05	.01	5.1
	08/07	0020	25.5	25.0	491	5.2	7.2	--	--	--	--	--	--
		0225	25.0	25.0	496	3.3	7.3	<.10	.6	<.10	.03	.01	8.4
		0410	24.0	23.0	496	3.4	7.4	--	--	--	--	--	--
		0635	24.0	22.0	490	4.1	7.1	<.10	.5	<.10	.04	.01	8.4
		0815	24.0	23.0	489	4.1	7.1	--	--	--	--	--	--
		1035	25.0	30.5	487	4.5	7.0	<.10	.7	<.10	.04	.01	8.8
		1200	26.0	34.5	499	5.8	7.2	--	--	--	--	--	--
		1440	28.5	36.5	495	5.8	7.2	<.10	.7	<.10	.04	.02	4.7
		1605	28.5	39.0	507	4.4	7.3	--	--	--	--	--	--
4	07/23	1800	25.5	30.5	584	5.3	6.9	<.10	.5	.12	.06	.01	5.2
		2010	24.5	26.0	584	5.4	7.1	--	--	--	--	--	--
		2210	24.5	23.0	578	5.8	6.9	<.10	.5	.25	.06	.01	5.8
	07/24	0105	24.0	21.0	572	4.9	7.6	--	--	--	--	--	--
		0215	23.0	21.0	565	4.6	7.2	<.10	.4	.13	.06	.01	3.6
		0400	22.5	19.5	568	4.7	7.1	--	--	--	--	--	--
		0630	22.0	22.0	595	4.0	6.9	<.10	.5	.14	.05	.01	4.2
		0820	22.0	28.0	576	3.6	6.7	--	--	--	--	--	--
		1000	22.5	31.0	611	3.8	6.8	<.10	.4	.13	.04	.01	3.9
		1130	23.5	33.0	584	4.1	6.8	--	--	--	--	--	--
		1520	25.5	34.0	578	4.9	6.9	<.10	.5	.10	.06	.03	4.9
		1630	26.0	32.0	571	5.1	6.9	--	--	--	--	--	--
	08/06	1850	26.0	31.0	616	3.7	7.2	<.10	.4	.17	.03	<.01	2.9
		2020	25.5	28.0	643	2.8	7.4	--	--	--	--	--	--
		2230	25.0	25.0	586	2.9	7.4	.11	.4	<.10	.07	<.01	8.7
	08/07	0033	24.0	25.0	563	3.5	7.2	--	--	--	--	--	--
		0247	23.5	24.0	566	2.7	7.3	<.10	--	<.10	.71	.01	8.6
		0425	23.5	24.0	561	3.2	7.4	--	--	--	--	--	--
		0700	23.0	23.5	561	4.1	7.1	<.10	.5	<.10	.04	.01	2.8
		0830	23.0	23.0	565	4.2	6.9	--	--	--	--	--	--
		1100	23.5	32.0	725	2.3	6.5	<.10	--	<.10	.12	.02	3.8
		1215	24.0	34.5	708	2.7	6.8	--	--	--	--	--	--
		1455	25.0	36.0	614	2.4	6.9	<.10	.6	<.10	.03	.01	3.5
		1520	25.0	40.0	651	2.2	6.9	--	--	--	--	--	--

Table 10.--Constituent concentrations determined from samples collected routinely from Richland Creek and its tributaries on July 23-24 and August 6-7, 1984--Continued

Site number	Date (month/ day)	Time (hours)	Temper- ature, water (°C)	Temper- ature, air (°C)	Spe- cific con- duct- ance (µS/cm)	Oxygen, dis- solved (mg/L)	pH (stand- ard units)	Nitro- gen, ammonia dis- solved (mg/L as N)	Nitro- gen, am- monia + organic total (mg/L as N)	Nitro- gen, NO_2+NO_3 dis- solved (mg/L as N)	Phos- phorus, total (mg/L as P)	Phos- phorus, dis- solved (mg/L as P)	Oxygen demand, bio- chemical ultimate carbon- aceous (mg/L)
5	07/23	1800	25.0	32.0	934	6.7	7.4	<0.10	1.4	22.0	7.10	7.00	5.6
		2000	23.5	27.0	931	5.6	7.5	--	--	--	--	--	--
		2200	23.5	24.0	927	4.6	7.3	<.10	1.2	25.0	7.80	7.50	2.9
	07/24	0050	24.0	22.0	917	4.9	7.3	--	--	--	--	--	--
		0215	24.5	22.0	914	6.8	7.5	<.10	1.3	23.0	7.50	7.10	4.3
		0420	24.0	21.0	914	6.0	7.5	--	--	--	--	--	--
		0605	23.5	20.0	913	6.3	7.2	--	--	--	--	--	--
		0850	23.5	26.0	915	5.9	7.3	--	--	--	--	--	--
		1000	23.5	29.0	917	5.2	7.3	<.10	2.0	25.0	7.70	7.60	3.4
		1145	24.0	30.0	927	5.5	7.2	--	--	--	--	--	--
		1425	24.0	31.0	909	5.6	7.3	.10	1.1	26.0	7.90	7.70	4.0
		1700	24.0	34.0	912	5.6	7.3	--	--	--	--	--	--
		2200	23.5	24.0	927	4.6	7.3	--	--	--	--	--	--
	08/06	1920	25.5	31.0	984	6.4	7.5	<.10	.8	24.0	10.0	9.80	3.4
		2030	25.5	28.0	980	5.1	7.6	--	--	--	--	--	--
		2255	25.5	26.0	985	6.5	7.6	<.10	1.3	24.0	10.0	9.90	8.7
	08/07	0050	25.5	25.0	950	5.8	7.3	--	--	--	--	--	--
		0310	25.0	24.0	949	5.0	7.4	<.10	1.3	23.0	8.60	8.50	8.6
		0440	25.0	23.0	949	5.2	7.4	--	--	--	--	--	--
		0715	24.5	24.0	952	5.8	7.4	<.10	1.3	24.0	8.80	8.50	3.1
		0840	24.5	27.0	950	5.5	7.3	--	--	--	--	--	--
		1130	25.5	33.0	957	4.7	7.1	<.10	1.4	19.0	8.90	8.50	8.7
		1225	25.5	36.5	949	5.0	7.4	--	--	--	--	--	--
		1515	25.0	38.0	950	4.1	7.4	--	8.6	--	9.10	8.70	--
		1630	25.5	40.0	949	4.5	7.4	--	--	--	--	--	--
6	07/23	1820	27.5	33.0	933	8.7	7.6	<.10	1.0	22.0	5.80	5.60	4.5
		2015	27.0	30.0	934	8.3	7.6	--	--	--	--	--	--
		2225	26.5	25.0	935	7.2	7.6	<.10	1.3	22.0	5.00	4.70	3.8
	07/24	0110	25.0	22.0	925	6.0	7.5	--	--	--	--	--	--
		0245	24.5	21.0	928	5.6	7.5	<.10	1.5	18.0	6.20	5.60	3.4
		0425	24.0	20.0	929	5.4	7.5	--	--	--	--	--	--
		0650	23.5	22.0	930	5.2	7.4	--	--	--	--	--	7.6
		0900	23.5	27.0	930	5.3	7.4	--	--	--	--	--	--
		1020	23.5	29.0	929	5.5	7.4	<.10	2.1	23.0	6.30	6.20	3.5
		1150	25.0	31.0	935	6.4	7.5	--	--	--	--	--	--
		1500	28.0	33.0	920	7.6	8.1	--	--	--	--	--	4.5
		1720	28.5	33.0	921	8.5	7.7	--	--	--	--	--	--

	08/06	1745	28.5	29.0	984	8.3	7.7	--	--	--	--	--	--
		1800	28.5	35.0	985	8.9	7.6	.11	1.5	22.0	7.90	7.60	8.5
		2200	27.5	25.0	986	7.5	7.7	.13	1.4	22.0	7.70	7.60	3.7
		2330	27.0	24.0	991	6.6	7.6	--	--	--	--	--	--
	08/07	0200	26.0	21.5	980	5.7	7.4	<.10	1.2	23.0	8.20	8.10	3.4
		0345	25.5	21.0	992	5.4	7.4	--	--	--	--	--	--
		0600	25.0	20.0	993	5.0	7.5	.14	1.4	23.0	5.00	4.60	8.9
		0800	24.5	24.0	993	5.0	7.4	--	--	--	--	--	--
		1000	24.5	30.5	993	5.1	7.5	.18	1.3	24.0	8.00	7.60	4.2
		1115	25.5	33.0	990	5.8	7.5	--	--	--	--	--	--
		1400	28.5	35.0	999	7.6	7.5	<.10	1.5	23.0	7.50	7.20	4.8
		1545	29.5	36.0	997	8.4	7.6	--	--	--	--	--	--
7	07/23	1845	27.5	30.0	996	8.1	7.7	.20	1.5	19.0	5.20	4.80	5.7
		2025	27.0	28.0	997	7.7	7.7	--	--	--	--	--	--
		2250	26.0	24.0	990	6.7	7.7	.24	1.3	19.0	3.90	3.70	5.1
	07/24	0120	25.5	22.0	968	6.0	7.6	--	--	--	--	--	--
		0300	25.0	23.0	967	5.6	7.5	.18	1.5	18.0	5.20	4.60	9.0
		0440	24.5	23.0	969	5.5	7.5	--	--	--	--	--	--
		0700	24.0	23.0	966	5.4	7.5	--	--	--	--	--	17.5
		0905	24.0	29.0	969	5.5	7.4	--	--	--	--	--	--
		1035	24.5	30.0	967	5.2	7.5	.19	1.7	15.0	5.00	4.50	3.9
		1200	26.0	29.0	968	5.8	7.6	--	--	--	--	--	--
		1530	29.5	31.0	958	7.0	7.7	.18	1.7	20.0	5.00	4.90	9.0
		1730	28.5	34.0	971	7.8	7.7	--	--	--	--	--	--
	08/06	1830	28.5	34.0	1,030	8.5	7.9	.29	1.7	18.0	6.10	5.90	4.9
		2000	28.0	29.0	1,040	7.5	7.8	--	--	--	--	--	--
		2215	27.0	24.5	1,050	6.2	7.8	.26	1.5	20.0	6.60	6.30	8.4
		2345	26.5	23.0	1,040	5.7	7.7	--	--	--	--	--	--
	08/07	0245	26.0	22.0	1,020	5.0	7.6	.33	1.5	20.0	6.70	6.40	5.8
		0400	25.5	21.0	1,020	4.9	7.6	--	--	--	--	--	--
		0630	25.0	21.0	1,030	4.7	7.5	.32	1.6	20.0	3.90	3.70	5.6
		0815	25.0	24.5	1,030	4.8	7.5	--	--	--	--	--	--
		1015	25.5	29.5	1,020	5.3	7.6	.22	1.5	21.0	6.10	5.80	5.0
		1130	31.0	26.0	1,010	6.2	7.6	--	--	--	--	--	--
		1415	30.0	33.0	1,040	8.8	7.9	.10	1.1	20.0	5.70	5.50	4.5
		1600	31.0	35.0	1,040	9.6	8.0	--	--	--	--	--	--
8	07/23	1855	27.5	29.0	991	7.2	7.7	<.10	1.5	18.0	4.30	3.90	6.7
		2030	27.0	28.0	991	6.7	7.7	--	--	--	--	--	--
		2300	26.5	24.0	995	6.0	7.6	<.10	1.5	17.0	4.30	3.90	8.7
	07/24	0130	25.5	22.0	989	5.7	7.6	--	--	--	--	--	--
		0320	25.0	22.0	998	5.7	7.6	.23	2.1	18.0	4.50	4.10	2.8
		0445	24.5	23.0	998	5.9	7.6	--	--	--	--	--	--
		0730	24.0	25.0	994	6.2	7.6	--	--	--	--	--	16.1
		0917	24.0	28.0	989	6.2	7.5	--	--	--	--	--	--
		1050	25.0	30.0	984	6.4	7.6	.30	2.0	19.0	4.60	4.40	5.4
		1218	27.0	31.0	986	7.1	7.6	--	--	--	--	--	--
		1605	28.0	31.0	961	7.4	7.8	.25	1.5	18.0	4.20	3.80	5.8
		1732	28.0	33.0	968	6.8	7.7	--	--	--	--	--	--

Table 10.--Constituent concentrations determined from samples collected routinely from Richland Creek and its tributaries on July 23-24 and August 6-7, 1984--Continued

Site number	Date (month/ day)	Time (hours)	Temper- ature, water (°C)	Temper- ature, air (°C)	Spe- cific con- duct- ance (µS/cm)	Oxygen, dis- solved (mg/L)	pH (stand- ard units)	Nitro- gen, ammonia dis- solved (mg/L as N)	Nitro- gen, am- monia + organic total (mg/L as N)	Nitro- gen, NO_2+NO_3 dis- solved (mg/L as N)	Phos- phorus, total (mg/L as P)	Phos- phorus, dis- solved (mg/L as P)	Oxygen demand, bio- chemical ultimate carbon- aceous (mg/L)
8	08/06	1900	29.0	33.0	1,030	7.1	7.8	0.12	1.1	17.0	4.80	4.50	4.8
(Cont.)		2015	28.0	28.0	1,030	6.5	7.8	--	--	--	--	--	--
		2245	27.5	24.0	1,030	5.7	7.7	<.10	1.5	17.0	5.00	4.60	4.6
		2400	27.0	23.0	1,030	5.5	7.7	--	--	--	--	--	--
	08/07	0300	26.0	22.0	1,040	5.2	7.6	.15	1.6	18.0	5.20	4.20	8.4
		0415	25.5	21.0	1,040	5.1	7.6	--	--	--	--	--	--
		0645	25.0	21.0	1,050	5.1	7.5	.22	1.6	18.0	8.50	8.20	4.3
		0815	25.0	25.0	1,050	5.2	7.6	--	--	--	--	--	--
		1030	25.5	29.0	1,050	5.9	7.6	.18	1.6	19.0	5.50	5.30	8.6
		1130	26.5	31.5	1,040	6.8	7.7	--	--	--	--	--	--
		1445	29.0	35.0	1,040	7.7	7.8	--	1.6	18.0	5.00	4.80	5.2
		1600	29.5	36.0	1,040	7.4	7.8	--	--	--	--	--	--
9	07/23	1930	26.5	25.0	1,100	2.5	7.3	3.20	5.4	3.40	2.20	1.80	18.8
		2045	26.0	28.0	1,100	.7	7.3	--	--	--	--	--	--
		2330	26.0	24.0	1,110	.6	7.3	.33	6.0	2.10	3.80	3.30	32.7
	07/24	0145	25.5	22.0	1,110	1.4	7.3	--	--	--	--	--	--
		0350	25.0	22.0	1,100	.4	7.3	3.00	5.6	1.00	8.30	7.50	34.3
		0500	25.0	23.0	1,110	.3	7.2	--	--	--	--	--	--
		0745	24.5	24.0	1,100	.8	7.2	--	--	--	--	--	12.8
		0930	25.5	29.0	1,080	.8	7.2	--	--	--	--	--	--
		1100	27.0	31.0	1,060	.7	7.2	1.20	4.8	1.10	11.0	9.60	33.8
		1228	28.0	31.0	1,050	.4	7.2	--	--	--	--	--	--
		1630	28.5	34.0	1,060	.8	7.3	.48	3.6	.99	8.50	7.50	25.0
	08/06	1915	27.0	31.0	1,140	5.8	7.5	6.80	9.1	6.20	2.50	2.20	19.5
		2025	27.0	28.0	1,150	5.7	7.6	--	--	--	--	--	--
		2300	26.5	22.0	1,140	6.0	7.6	6.30	8.4	5.00	3.10	2.80	19.4
	08/07	0015	26.5	22.0	1,130	5.9	7.6	--	--	--	--	--	--
		0330	26.0	21.0	1,120	5.8	7.5	5.80	7.2	4.20	5.00	4.80	7.6
		0430	26.0	19.5	1,120	5.6	7.5	--	--	--	--	--	--
		0700	25.5	21.0	1,120	5.2	7.5	4.00	5.8	4.20	3.70	3.70	12.1
		0830	25.5	26.0	1,110	5.5	7.4	--	--	--	--	--	--
		1045	28.0	32.0	1,060	5.9	7.5	2.70	4.9	5.00	2.50	2.10	17.1
		1145	28.5	37.0	1,050	6.0	7.5	--	--	--	--	--	--
		1500	29.0	40.0	1,060	5.5	7.5	2.40	4.5	6.60	1.60	1.30	16.3
		1630	29.0	36.0	1,070	5.6	7.5	--	--	--	--	--	--

10	07/23	1845	27.5	31.5	934	6.2	7.0	.17	1.4	2.80	4.00	3.60	6.1
		1942	27.0	30.5	926	6.1	7.2	--	--	--	--	--	--
		2150	26.5	23.0	927	5.0	7.2	.16	1.4	2.60	3.50	2.90	8.0
	07/24	0012	25.0	22.0	928	4.6	7.2	--	--	--	--	--	--
		0203	24.0	19.0	950	3.8	7.3	.20	2.0	3.20	3.10	2.60	8.8
		0632	22.0	21.0	920	3.9	7.1	--	--	--	--	--	3.6
		0845	21.5	24.0	899	4.0	7.2	--	--	--	--	--	--
		1000	22.0	28.0	898	3.9	7.2	.24	1.7	3.40	3.70	3.30	7.0
		1230	24.0	32.0	904	4.7	7.2	--	--	--	--	--	--
		1405	25.5	32.0	919	4.8	7.3	.27	1.6	3.24	4.40	4.20	8.4
		1629	27.5	33.0	922	5.5	7.3	--	--	--	--	--	--
	08/06	1855	27.5	33.5	903	--	--	.20	1.2	2.80	5.60	5.30	6.6
		2059	27.0	29.0	898	4.3	7.4	--	--	--	--	--	--
		2237	26.5	24.5	851	3.5	7.1	.20	1.5	2.70	5.00	4.70	5.8
	08/07	0056	25.5	23.5	854	3.3	7.2	--	--	--	--	--	--
		0212	25.0	21.0	858	3.0	7.2	.13	1.6	2.40	4.70	4.30	11.9
		0358	24.5	21.0	868	3.6	7.2	--	--	--	--	--	--
		0612	23.5	21.5	887	5.3	7.3	.17	1.9	2.30	5.80	5.30	12.0
		0825	23.5	23.5	898	4.8	7.3	--	--	--	--	--	--
		0930	23.5	27.5	891	4.9	7.3	.24	2.0	2.60	5.00	4.20	12.3
		1110	24.0	32.0	886	4.7	7.3	--	--	--	--	--	--
		1320	26.0	37.0	872	4.4	7.1	.18	1.7	2.68	4.70	4.30	11.6
		1530	27.0	36.0	521	1.2	5.8	--	--	--	--	--	--
11	07/23	1815	28.0	32.5	1,080	2.6	7.0	1.60	3.5	7.50	1.10	.67	14.2
		1957	27.0	27.5	1,090	1.3	8.2	--	--	--	--	--	--
		2205	26.0	23.5	1,090	1.4	6.6	3.00	4.8	3.90	1.70	1.30	14.8
	07/24	0031	25.0	19.0	1,080	.5	7.7	--	--	--	--	--	--
		0240	--	--	--	--	--	3.00	5.2	1.80	5.00	4.60	16.4
		0306	24.5	19.5	1,090	.5	6.6	--	--	--	--	--	--
		0658	23.5	21.0	1,080	1.2	7.7	--	--	--	--	--	3.6
		0900	24.0	28.0	1,070	.9	7.1	--	--	--	--	--	--
		1024	24.5	27.0	1,080	.7	6.9	2.70	6.0	<.10	7.80	7.10	34.5
		1240	26.5	31.0	1,060	.6	7.0	--	--	--	--	--	--
		1440	30.0	31.0	1,050	.6	7.3	1.27	3.8	.30	9.70	9.00	20.0
		1445	30.5	31.0	1,030	.4	7.0	--	--	--	--	--	--
	08/06	1916	28.5	30.0	480	--	--	4.40	6.0	11.0	1.40	1.20	14.4
		2113	27.5	--	1,150	--	7.6	--	--	--	--	--	--
		2300	27.0	24.0	464	3.1	7.1	6.80	8.7	6.10	2.00	1.80	17.9
	08/07	0109	26.0	23.0	460	3.3	7.2	--	--	--	--	--	--
		0240	25.5	22.0	1,070	3.4	7.2	6.90	8.4	4.30	2.80	2.40	13.8
		0414	25.5	21.0	1,070	3.7	7.2	--	--	--	--	--	--
		0635	25.0	23.5	454	4.0	7.3	5.70	7.7	3.80	3.70	3.30	17.3
		0835	25.0	24.0	1,100	4.2	7.3	--	--	--	--	--	--
		0955	25.5	26.5	1,100	4.3	7.3	5.10	6.7	3.60	3.70	3.40	11.0
		1123	26.5	32.0	1,100	5.0	7.4	--	--	--	--	--	--
		1400	30.0	33.5	941	4.2	3.4	3.22	4.9	4.39	2.40	2.00	8.8
		1550	29.5	34.5	583	1.2	5.2	3.60	5.7	5.70	2.20	1.60	17.5

Table 10.--Constituent concentrations determined from samples collected routinely from Richland Creek and its tributaries on July 23-24 and August 6-7, 1984--Continued

Site number	Date (month/day)	Time (hours)	Temperature, water (°C)	Temperature, air (°C)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	pH (standard units)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Oxygen demand, biochemical ultimate carbonaceous (mg/L)
12	07/23	1905	29.0	31.0	1,100	1.2	6.9	2.10	3.5	6.10	0.98	0.69	14.0
		2019	28.0	26.5	1,110	1.7	7.1	--	--	--	--	--	--
		2240	26.5	23.0	1,110	.8	7.9	2.40	4.1	5.30	1.10	.80	13.0
	07/24	0054	25.5	20.0	1,100	.9	7.1	--	--	--	--	--	--
		0329	24.0	--	1,110	--	7.0	3.40	5.4	1.00	3.40	2.90	16.4
		0725	23.5	22.0	1,110	1.0	7.2	--	--	--	--	--	4.5
		0918	23.5	26.5	1,120	.9	7.1	--	--	--	--	--	--
		1050	24.0	29.0	1,110	.8	7.1	3.20	4.9	1.50	4.80	4.20	11.8
		1327	26.5	31.0	1,110	.2	7.1	--	--	--	--	--	--
		1520	28.5	32.0	1,090	.1	7.1	2.01	4.5	.10	10.0	9.60	21.8
		1706	30.0	32.0	1,070	.4	7.0	--	--	--	--	--	--
	08/06	1950	29.5	29.5	1,180	2.0	7.3	4.20	5.7	11.0	1.00	.78	14.4
		2340	27.0	22.5	1,110	1.6	7.1	5.40	6.6	9.80	1.40	1.10	15.0
	08/07	0131	26.0	23.0	1,100	1.7	7.1	--	--	--	--	--	--
		0320	25.5	22.5	1,090	1.7	7.1	6.90	8.6	4.70	1.90	1.60	11.1
		0435	25.5	21.5	1,080	2.0	7.1	--	--	--	--	--	--
		0705	25.0	21.5	1,130	2.5	7.3	7.00	8.8	3.90	2.60	2.30	12.8
		0855	25.0	25.0	1,120	2.2	7.2	--	--	--	--	--	--
		1015	25.0	29.0	1,120	2.4	7.2	6.20	7.9	3.50	3.20	2.80	13.0
		1142	25.5	--	1,100	2.8	7.4	--	--	--	--	--	--
		1510	30.0	36.5	648	1.7	7.1	4.35	6.5	3.90	2.90	2.50	12.4
		1610	29.5	36.0	713	1.0	6.3	--	--	--	--	--	--
13	07/23	1915	28.0	30.5	1,160	2.8	8.5	3.60	5.1	3.40	1.10	.78	9.8
		2032	27.5	27.0	1,150	2.2	7.2	--	--	--	--	--	--
		2300	27.5	22.0	1,110	1.2	7.2	3.10	4.5	3.20	1.20	1.00	13.7
	07/24	0407	--	--	--	--	--	3.60	5.2	2.20	1.70	1.30	13.9
		0745	23.5	22.0	1,090	1.9	7.2	--	--	--	--	--	4.0
		0933	23.5	26.0	1,080	1.5	7.2	--	--	--	--	--	--
		1118	24.5	--	1,080	2.1	7.2	--	--	--	--	--	13.7
		1345	28.0	32.0	1,100	5.3	7.4	--	--	--	--	--	--
		1550	29.5	33.0	1,110	5.6	7.5	3.13	4.6	1.39	3.40	2.90	13.5
		1722	28.5	33.0	1,100	3.5	7.3	--	--	--	--	--	--

	08/06	2007	29.0	28.0	1,220	2.9	7.5	6.20	7.3	4.60	.92	.67	15.3
		2350	28.0	23.5	485	1.4	7.1	5.30	6.4	7.30	.91	.67	8.2
	08/07	0146	27.5	23.0	1,120	1.5	7.1	--	--	--	--	--	--
		0331	26.5	22.5	474	1.6	7.1	4.90	6.3	10.0	1.10	.84	16.8
		0455	26.0	22.0	470	1.7	7.1	--	--	--	--	--	--
		0720	25.0	21.5	1,130	2.3	7.2	6.10	8.5	6.10	1.40	1.10	11.7
		0910	25.0	25.0	1,120	2.3	7.2	--	--	--	--	--	--
		1035	25.0	30.0	450	2.6	7.3	7.40	9.3	3.60	1.80	1.50	13.7
		1155	26.5	--	451	3.4	7.4	--	--	--	--	--	--
		1450	31.0	35.0	430	2.6	--	6.40	8.2	3.42	2.00	1.80	12.9
		1625	28.0	37.0	300	1.2	5.7	--	--	--	--	--	--
14	07/23	1820	29.0	34.0	1,160	.9	7.9	3.70	4.6	2.20	1.00	.82	10.9
		1945	28.0	27.5	1,140	3.9	7.8	--	--	--	--	--	--
		2215	27.0	24.5	1,160	3.5	7.8	3.60	4.7	3.10	1.10	.78	10.3
	07/24	0045	26.5	20.5	1,130	2.3	7.5	--	--	--	--	--	--
		0220	25.5	20.5	1,110	2.4	7.5	3.10	4.3	3.30	1.10	.85	14.1
		0240	--	--	--	--	--	2.90	4.1	3.90	1.20	.87	11.6
		0420	24.5	19.5	1,100	2.7	7.6	--	--	--	--	--	--
		0737	24.0	23.0	1,120	2.6	7.5	--	--	--	--	--	--
		1140	25.5	27.0	1,110	3.9	7.7	3.40	4.9	2.20	1.60	1.30	14.1
		1355	27.5	29.0	1,100	5.7	7.9	--	--	--	--	--	--
		1530	29.0	30.0	1,100	6.3	7.9	3.30	5.0	.55	2.30	1.90	13.5
		1818	29.5	29.0	1,130	5.1	7.8	--	--	--	--	--	--
	08/06	1820	30.5	32.0	1,180	4.7	7.9	6.70	7.7	2.60	.82	.65	14.5
		1955	29.0	31.0	1,180	3.6	7.8	--	--	--	--	--	--
		2215	28.0	24.5	1,200	2.7	7.7	6.30	8.0	3.70	.89	.65	12.0
	08/07	0005	27.5	22.5	1,230	2.2	7.6	--	--	--	--	--	--
		0225	27.0	22.0	1,150	2.4	7.6	5.50	7.0	6.00	.89	.68	12.9
		0435	26.5	22.0	1,160	2.2	7.2	--	--	--	--	--	--
		0650	25.5	20.0	1,150	1.9	7.3	4.80	6.3	9.80	1.10	.84	14.2
		0920	25.5	29.0	1,130	2.4	7.2	--	--	--	--	--	--
		1035	25.5	31.5	1,130	2.4	7.1	6.10	7.8	6.70	1.20	.96	74.5
		1252	27.5	35.0	1,140	4.5	7.2	--	--	--	--	--	--
		1450	29.5	36.0	1,130	4.9	7.5	--	8.3	--	1.50	1.30	11.8
		1650	30.5	33.0	1,130	4.3	7.5	--	--	--	--	--	--
15	07/23	1900	28.5	30.5	1,110	5.7	7.9	2.50	3.3	1.20	1.60	1.30	11.1
		2010	28.0	26.0	1,140	5.2	7.9	--	--	--	--	--	--
		2245	27.0	22.5	1,140	3.5	7.8	3.40	4.4	2.10	1.20	.96	11.5
	07/24	0115	26.0	20.5	1,160	2.8	7.5	--	--	--	--	--	--
		0255	25.5	20.5	1,130	2.8	7.5	3.50	4.5	2.70	6.60	.85	8.2
		0445	24.5	19.5	1,150	2.6	7.5	--	--	--	--	--	--
		0900	24.5	25.0	1,110	3.2	7.4	2.70	4.0	4.80	1.10	.83	11.2
		1200	--	--	--	--	--	2.30	3.7	4.80	1.10	.90	10.5
		1245	27.0	28.0	473	6.6	7.8	--	--	--	--	--	--
		1430	28.0	29.5	470	7.8	8.0	--	--	--	--	--	--
		1645	29.5	30.0	1,100	7.5	8.0	2.48	3.9	3.10	1.20	1.00	12.4
		1840	29.0	29.0	1,090	5.5	7.8	--	--	--	--	--	--

Table 10.--Constituent concentrations determined from samples collected routinely from Richland Creek and its tributaries on July 23-24 and August 6-7, 1984--Continued

Site number	Date (month/day)	Time (hours)	Temperature, water (°C)	Temperature, air (°C)	Specific conductance (μS/cm)	Oxygen, dissolved (mg/L)	pH (standard units)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Oxygen demand, biochemical ultimate carbonaceous (mg/L)
15 (Cont.)	08/06	1850	29.5	31.0	1,170	3.7	7.8	5.40	6.8	2.30	1.20	0.99	14.5
		2015	29.0	27.0	1,140	2.2	7.8	--	--	--	--	--	--
		2245	28.5	23.0	1,200	1.5	7.6	6.60	7.9	2.20	.95	.79	15.3
	08/07	0050	27.5	22.5	1,200	1.6	7.6	--	--	--	--	--	--
		0305	26.5	22.5	1,170	1.1	7.7	6.30	5.4	3.40	.96	.81	11.2
		0500	26.0	22.0	1,190	1.3	7.2	--	--	--	--	--	--
		0740	25.5	23.0	1,180	1.2	7.2	5.70	7.0	5.00	.94	.79	13.7
		0950	26.0	30.0	1,160	2.3	7.1	--	--	--	--	--	--
		1115	26.5	32.0	1,150	3.7	7.2	5.00	6.4	8.20	.89	.81	17.4
		1324	28.0	34.0	1,160	6.4	7.5	--	--	--	--	--	--
		1540	30.0	33.0	1,150	6.5	7.6	4.50	6.3	7.92	.96	.87	13.3
		1715	30.5	33.0	1,150	5.6	7.4	--	--	--	--	--	--
16	07/23	1803	28.0	32.5	817	5.5	8.6	<.10	.7	.23	.13	.08	6.2
		1935	27.0	27.5	824	12.2	8.7	--	--	--	--	--	--
		2155	25.0	25.0	834	11.3	8.7	<.10	.5	.18	.64	.52	4.6
	07/24	0030	24.5	21.0	838	9.3	8.2	--	--	--	--	--	--
		0200	23.5	20.5	840	8.1	8.2	<.10	.2	.20	.12	.07	2.9
		0405	23.0	20.0	846	8.1	8.1	--	--	--	--	--	--
		0640	22.5	22.0	863	5.0	7.8	<.10	.6	.20	.12	.07	3.9
		1115	24.0	28.0	852	5.7	8.1	<.10	.8	.17	.13	.07	10.7
		1340	26.5	28.0	643	6.8	8.4	--	--	--	--	--	--
		1500	26.5	31.5	820	8.3	8.5	<.10	.7	.16	.11	.07	10.4
		1800	27.5	27.5	831	14.6	8.6	--	--	--	--	--	--
	08/06	1810	27.5	31.5	875	11.4	8.5	<.10	.7	<.10	.11	.05	18.3
		1945	27.5	30.0	884	11.4	8.4	--	--	--	--	--	--
		2205	26.5	24.5	895	9.8	8.5	<.10	.6	<.10	.10	.05	6.0
		2350	25.5	22.5	901	9.0	8.2	--	--	--	--	--	--
	08/07	0200	25.0	22.5	894	7.4	8.2	.88	.3	<.10	.10	.05	11.9
		0425	24.5	22.5	888	6.2	7.5	--	--	--	--	--	--
		0615	24.5	20.0	885	4.2	7.8	<.10	.6	<.10	.12	.05	8.3
		0900	24.0	29.0	896	3.7	7.8	--	--	--	--	--	--
		1020	24.0	32.0	891	4.6	7.6	<.10	1.0	<.10	.17	.05	32.1
		1240	25.0	37.0	909	5.4	7.4	--	--	--	--	--	--
		1415	25.5	37.0	904	8.5	7.8	<.10	2.5	--	.33	.22	19.5
		1637	26.0	33.5	926	8.9	8.4	--	--	--	--	--	--

17	07/23	1710	--	--	--	--	--	<.10	.8	.18	.92	.84	12.5
		1910	27.0	30.0	871	7.8	8.5	--	--	--	--	--	--
		2015	26.5	25.0	877	8.3	8.4	--	--	--	--	--	--
		2305	25.5	23.5	888	6.3	8.4	<.10	1.0	.22	1.30	1.20	7.5
	07/24	0125	24.5	22.5	886	6.4	8.0	--	--	--	--	--	--
		0310	23.5	20.0	890	5.9	8.1	<.10	1.2	.23	1.40	1.30	12.9
		0455	23.0	19.5	896	6.1	8.1	--	--	--	--	--	--
		0935	23.0	29.0	907	6.8	7.9	<.10	1.4	.22	1.50	1.40	9.9
		1310	27.0	28.5	895	7.7	8.4	<.10	1.4	.19	1.80	1.60	17.3
		1440	28.0	29.0	892	8.9	8.5	--	--	--	--	--	--
		1725	27.5	29.5	888	6.6	8.5	<.10	1.4	.17	1.70	1.60	10.9
		1855	27.5	27.5	890	5.2	8.4	--	--	--	--	--	--
	08/06	1905	27.5	29.0	867	6.4	8.3	<.10	1.1	<.10	1.00	.89	12.5
		2025	27.0	26.5	868	6.3	8.3	--	--	--	--	--	--
		2300	26.0	23.0	875	6.1	8.3	<.10	.9	<.10	.90	.78	11.7
	08/07	0100	25.0	22.0	884	6.1	8.0	--	--	--	--	--	--
		0325	23.0	22.5	886	5.2	8.1	<.10	.6	<.10	.97	.90	12.4
		0515	24.0	22.0	869	5.3	7.6	--	--	--	--	--	--
		0800	23.5	24.0	870	5.3	7.5	<.10	1.5	<.10	1.10	.90	17.8
		1130	25.5	33.0	868	7.0	7.6	<.10	1.7	<.10	1.10	.99	13.5
		1349	29.0	35.5	886	9.2	8.0	--	--	--	--	--	--
		1615	28.5	36.0	876	7.5	8.0	<.10	2.7	<.10	1.40	.91	22.7
		1730	28.0	33.0	892	6.6	8.0	--	--	--	--	--	--
18	07/23	1840	25.5	30.5	769	7.1	7.7	<.10	1.4	8.40	2.90	2.70	8.9
		2000	25.5	25.5	776	6.8	7.7	--	--	--	--	--	--
		2230	25.0	24.5	784	4.7	7.8	<.10	1.2	8.00	3.30	3.20	8.5
	07/24	0105	23.5	20.5	787	3.5	7.3	--	--	--	--	--	--
		0240	--	--	--	--	--	<.10	1.2	6.30	3.30	3.00	5.5
		0430	21.5	19.0	791	2.8	7.3	--	--	--	--	--	--
		0820	21.0	23.5	794	3.2	7.4	<.10	1.2	8.10	3.20	3.00	4.4
		1220	25.5	27.5	745	4.8	7.7	<.10	1.3	7.80	3.20	3.10	5.2
		1414	25.0	28.5	786	4.4	7.7	--	--	--	--	--	--
		1615	25.0	29.5	794	4.2	7.6	.10	1.4	--	2.80	2.40	4.7
		1830	26.5	28.5	788	4.1	7.7	--	--	--	--	--	--
	08/06	1840	25.0	31.0	765	5.5	7.5	<.10	1.4	5.90	4.50	4.40	4.5
		2010	26.0	31.0	781	5.1	7.8	--	--	--	--	--	--
		2235	25.0	23.5	791	4.2	7.6	<.10	1.4	6.10	5.10	4.70	8.5
	08/07	0040	24.0	22.5	783	3.7	7.5	--	--	--	--	--	--
		0245	23.5	21.5	752	3.0	7.4	<.10	1.9	5.90	4.80	4.60	5.5
		0450	22.5	22.0	772	3.3	7.1	--	--	--	--	--	--
		0715	22.0	22.5	773	3.6	7.2	.10	1.5	6.10	4.80	4.40	5.2
		0940	23.0	29.5	774	3.4	7.1	--	--	--	--	--	--
		1100	24.0	32.0	768	4.5	7.2	<.10	1.5	6.10	4.90	3.90	8.6
		1310	26.0	35.5	787	5.7	7.4	--	--	--	--	--	--
		1515	28.0	36.0	788	6.5	7.7	<.10	2.1	5.48	5.00	4.60	5.7
		1700	28.5	32.0	796	6.2	7.6	--	--	--	--	--	--

Table 10.--Constituent concentrations determined from samples collected routinely from Richland Creek and its tributaries on July 23-24 and August 6-7, 1984--Continued

Site number	Date (month/ day)	Time (hours)	Temperature, water (°C)	Temperature, air (°C)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	pH (standard units)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Oxygen demand, biochemical ultimate carbonaceous (mg/L)
19	07/23	1900	29.0	28.0	1,100	8.0	7.7	1.90	3.2	0.89	2.30	2.00	15.1
		2300	--	--	--	--	--	1.90	3.3	1.10	1.80	1.60	10.8
	07/24	0300	25.5	18.0	--	2.1	--	3.00	4.4	1.90	1.30	1.10	11.9
		0600	24.5	19.0	1,170	2.5	7.7	--	--	--	--	--	--
		0630	--	--	--	--	--	3.40	5.4	2.40	1.80	1.00	12.2
		1055	25.0	30.0	1,140	5.7	7.8	3.00	4.5	2.40	1.20	1.00	8.9
		1355	28.5	36.0	1,100	10.3	8.2	2.10	3.4	4.20	1.10	.88	12.6
	08/06	1807	30.0	31.0	1,180	13.4	8.4	4.30	5.5	1.80	1.40	1.20	15.1
		2000	29.0	28.0	1,180	7.7	8.2	--	--	--	--	--	--
		2200	28.5	24.0	1,190	2.9	7.8	4.10	5.5	2.70	1.30	1.10	12.0
	08/07	0015	27.5	22.0	1,190	1.7	7.4	--	--	--	--	--	--
		0215	27.0	21.0	1,200	1.7	7.5	6.10	7.3	1.80	1.00	.84	14.2
		0415	26.5	19.5	1,190	1.7	7.5	--	--	--	--	--	--
		0625	26.0	20.5	1,180	1.9	7.4	6.50	3.2	2.50	1.00	.88	12.5
		0850	25.5	28.5	1,190	3.1	7.4	--	--	--	--	--	--
		1000	26.0	30.0	1,210	5.1	7.5	5.90	7.7	3.40	.97	.82	4.0
		1220	27.5	34.5	1,190	10.2	7.9	--	--	--	--	--	--
		1400	29.5	35.0	1,160	14.4	8.2	4.62	6.6	5.36	.92	.80	12.1
20	07/23	1940	28.0	26.0	1,150	6.3	7.4	1.90	3.0	1.20	2.10	1.80	10.9
	07/24	0030	27.5	--	--	4.7	--	1.20	2.5	1.20	2.10	1.80	14.4
		0345	26.5	18.0	--	4.5	8.1	1.00	2.7	1.20	2.40	2.10	12.8
		0730	25.0	21.0	1,140	3.4	7.8	1.40	3.4	1.10	2.40	2.10	12.9
		1130	25.5	31.0	1,150	5.1	7.8	1.60	2.5	1.20	1.90	1.70	7.6
		1230	28.0	34.0	1,160	6.7	7.9	--	--	--	--	--	--
		1430	--	--	--	--	--	1.70	2.6	1.80	1.40	1.20	10.7
	08/06	1840	29.0	31.5	1,110	6.4	7.8	3.50	4.9	1.20	1.90	1.60	14.8
		2020	28.5	29.0	1,120	4.8	7.9	--	--	--	--	--	--
		2220	28.5	25.0	1,120	3.9	7.9	3.60	4.9	1.30	1.70	1.50	12.2
	08/07	0100	28.5	23.5	1,150	3.5	7.6	--	--	--	--	--	--
		0245	27.5	23.0	--	3.6	7.8	3.70	5.0	1.50	1.40	1.10	12.5
		0430	27.5	22.5	1,190	3.4	7.0	--	--	--	--	--	--
		0700	26.0	23.0	1,180	3.0	7.6	3.50	3.0	1.90	1.50	1.20	14.1
		0905	26.0	29.0	1,180	3.2	7.5	--	--	--	--	--	--
		1030	26.0	32.0	1,130	3.7	7.4	3.80	5.2	2.20	1.30	1.10	13.0
		1235	27.0	35.5	1,180	5.4	7.6	--	--	--	--	--	--
		1430	29.0	36.5	1,180	7.6	7.7	4.36	5.8	1.92	1.20	1.00	15.4

21	07/23	2000	28.0	22.0	1,110	5.0	7.5	.72	2.0	1.40	2.30	2.00	12.0
	07/24	0100	26.5	20.0	--	3.5	--	.75	2.0	1.30	2.20	1.90	13.7
		0415	25.5	18.0	--	3.7	7.7	1.00	2.6	1.10	2.30	1.90	11.3
		0800	25.5	23.0	1,180	3.4	7.8	1.40	2.7	1.20	2.10	1.80	10.2
		1200	27.0	34.0	1,190	5.5	7.8	1.20	2.3	1.40	1.90	1.60	13.6
		1510	28.5	34.0	1,160	7.4	8.0	.64	2.0	1.40	1.90	1.60	12.7
	08/06	1900	29.0	31.0	1,120	6.3	7.9	2.50	3.9	1.50	1.80	1.50	11.8
		2030	28.5	28.0	1,130	4.7	7.8	--	--	--	--	--	--
		2240	27.5	24.0	1,130	3.8	7.8	2.30	3.8	1.50	1.70	1.50	15.2
	08/07	0115	27.0	23.0	1,110	3.1	7.4	--	--	--	--	--	--
		0300	26.5	22.0	1,100	2.7	7.5	2.10	2.6	1.30	1.60	1.30	12.3
		0445	26.5	22.0	1,080	2.6	7.5	--	--	--	--	--	--
		0725	26.0	23.5	1,090	2.7	7.4	2.40	2.1	1.40	1.70	1.50	10.9
		0920	26.5	28.0	1,090	3.7	7.4	--	--	--	--	--	--
		1050	27.0	30.0	1,110	4.6	7.5	3.10	4.6	1.20	1.60	1.40	13.6
		1245	28.0	34.5	1,120	6.3	7.6	--	--	--	--	--	--
		1450	29.5	36.0	1,140	8.0	7.8	2.92	4.6	1.69	1.40	1.10	16.0
22	07/23	2030	27.5	19.5	1,060	4.2	7.2	.15	1.6	1.30	1.80	1.50	10.8
	07/24	0120	26.5	18.5	--	2.6	--	.13	1.3	1.30	1.60	1.30	8.2
		0445	--	18.0	--	--	7.7	.15	2.5	1.30	1.50	1.20	7.6
		0840	25.5	24.0	1,080	2.8	7.7	.19	2.0	1.40	1.70	1.40	10.2
		1230	26.5	32.0	1,100	3.8	7.7	.34	1.7	1.50	2.10	1.80	9.1
		1550	28.0	34.0	1,100	4.0	7.7	.38	1.8	--	2.40	2.00	9.9
	08/06	1915	28.0	31.0	1,080	3.1	7.6	.53	1.8	1.40	2.20	2.20	11.7
		2045	28.0	27.0	1,070	2.6	7.7	--	--	--	--	--	--
		2300	27.5	24.0	1,070	2.2	7.7	.53	2.0	1.40	2.20	1.90	12.0
	08/07	0130	27.0	23.0	1,070	1.9	7.4	--	--	--	--	--	--
		0325	27.0	22.5	1,060	1.8	7.4	.45	1.7	1.40	1.90	1.70	11.3
		0500	26.5	22.5	1,060	1.7	7.4	--	--	--	--	--	--
		0745	26.0	24.5	1,060	1.5	7.3	.48	1.0	1.20	2.10	1.20	12.4
		0930	26.0	28.0	1,050	1.7	7.3	--	--	--	--	--	--
		1105	26.5	31.0	1,050	2.0	7.3	.41	1.9	1.20	1.80	1.60	13.9
		1255	27.5	34.0	1,030	3.0	7.4	--	--	--	--	--	--
		1320	28.5	34.5	1,040	3.8	7.3	--	--	--	--	--	--
		1520	--	--	--	--	--	.30	1.8	1.30	1.70	1.40	10.1
23	07/23	2045	26.5	19.0	856	5.6	7.5	<.10	1.0	1.40	.88	.72	6.0
	07/24	0012	26.5	19.0	--	2.6	--	--	--	--	--	--	--
		0140	25.0	19.5	--	3.8	--	<.10	.9	1.30	1.10	.89	5.5
		0500	--	18.0	--	--	7.8	<.10	1.5	1.30	1.10	.96	5.5
		0910	24.5	26.0	912	4.3	7.7	<.10	1.5	1.30	1.10	.96	7.1
		1300	26.0	32.0	915	5.2	7.7	<.10	1.0	1.30	1.00	.93	8.9
		1630	27.5	33.0	907	6.5	7.8	<.10	1.0	1.10	.99	.86	8.3

Table 10.--Constituent concentrations determined from samples collected routinely from Richland Creek and its tributaries on July 23-24 and August 6-7, 1984--Continued

Site number	Date (month/day)	Time (hours)	Temperature, water (°C)	Temperature, air (°C)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	pH (standard units)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Oxygen demand, biochemical ultimate carbonaceous (mg/L)
23 (Cont.)	08/06	1930	28.0	30.0	951	5.3	7.8	0.24	1.4	1.60	1.30	1.10	11.3
		2100	28.0	27.5	946	4.6	7.8	--	--	--	--	--	--
		2330	27.0	24.0	964	3.4	7.7	.21	1.4	2.00	1.20	1.10	11.0
	08/07	0145	26.0	24.0	957	2.8	7.4	--	--	--	--	--	--
		0345	26.0	23.0	950	2.8	7.4	.16	1.2	1.20	1.30	1.10	7.8
		0515	25.5	23.0	944	2.8	7.5	--	--	--	--	--	--
		0805	25.0	26.0	939	3.0	7.4	.12	.8	1.20	1.30	1.20	11.7
		0940	25.5	30.0	928	3.2	7.4	--	--	--	--	--	--
		1120	26.0	32.5	928	3.8	7.4	.10	1.3	1.20	1.30	1.10	7.6
		1305	27.0	36.0	927	5.0	7.5	--	--	--	--	--	--
		1555	28.5	36.5	917	6.3	7.4	--	1.3	1.10	1.30	1.10	13.4
25	07/23	0415	22.0	22.5	839	3.7	6.9	<.10	.5	.51	.08	.04	3.4
	07/24	1615	28.0	37.5	776	10.0	7.8	<.10	.2	1.20	.05	.04	4.9
	08/06	0415	23.0	24.5	792	9.9	4.3	<.10	.2	<.10	.04	.02	2.4
	08/07	1426	28.0	--	788	7.5	7.7	<.10	.3	<.10	.06	.04	4.8
26	07/23	0445	24.0	22.0	758	4.3	7.4	.15	1.6	.17	.56	.22	24.6
	07/24	1535	29.0	36.0	741	8.5	7.8	<.10	.7	<.10	.27	.20	7.8
	08/06	0450	24.0	25.0	1,130	9.9	5.7	<.10	2.1	<.10	1.50	.67	73.0
	08/07	1456	30.5	--	1,110	2.8	9.3	.15	1.2	<.10	.76	.52	10.9
27	07/26	1000	--	--	--	--	--	--	.4	--	.11	--	2.6
	08/06	0530	23.5	23.5	2,750	9.8	8.5	.12	.5	1.10	.05	.03	4.1
	08/07	1530	26.5	38.0	2,730	10.7	9.5	.03	.6	.45	.05	.03	5.4
31	07/23	0645	22.5	21.0	546	1.5	7.0	.11	.8	.25	.08	.06	5.1
	07/24	1430	28.5	36.0	548	8.2	7.3	.10	.5	.16	.07	.05	4.4
	08/06	0630	22.5	22.0	589	3.2	7.5	.15	.5	.12	.07	.04	4.7
	08/07	1605	30.5	32.0	605	4.4	9.2	<.10	.7	<.10	.08	.04	4.5

32	07/23	0722	24.5	21.5	418	4.6	7.0	.10	.9	3.30	.15	.04	4.4
	07/24	1400	26.0	34.0	441	6.5	7.3	<.10	.7	.92	.10	.05	6.5
	08/06	0655	24.5	21.5	262	5.2	7.5	<.10	.7	.59	.11	.02	5.1
	08/07	1632	27.5	35.0	415	7.6	8.1	<.10	1.2	.30	.13	.02	10.8

Table 11.--Constituent concentrations determined from samples collected once during the diel study on July 23-24 and again during the diel study on August 6-7, 1984, from Richland Creek and its tributaries

[NTU, nephelometric turbidity units; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; N, nitrogen; CN, cyanide; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Cl, chlorine; SO_4, sulfate; F, fluorine; As, arsenic; Ba, barium; Be, beryllium; B, boron; Cd, cadmium; Cr, chromium; Co, cobalt; Cu, copper; Fe, iron; Pb, lead; Mn, manganese; Ni, nickel; Ag, silver; Sr, strontium; V, vanadium; Zn, zinc; Al, aluminum; Hg, mercury; <, less than; dashes indicate no data]

Site number	(month/ day)	Time (hours)	Tur- bid- ity (NTU)	Oxygen demand, chem- ical (low level) (mg/L)	Alka- linity field (mg/L as $CaCO_3$)	Solids, residue at 105 deg. C, sus- pended (mg/L)	Solids, vola- tile, sus- pended (mg/L)	Nitro- gen, ammonia total (mg/L as N)	Nitro- gen NO_2+NO_3 total (mg/L as N)	Cyanide total (mg/L as CN)	Hard- ness (mg/L as $CaCO_3$)
1	07/24	1400	14	17	215	45	8	0.07	1.64	<0.01	290
	08/07	1415	.8	10	241	2	--	--	.73	<.01	290
2	07/24	1435	1.6	7	22	3	2	.17	.49	<.01	230
3	07/24	1500	6.3	20	84	8	4	.06	<.10	<.01	230
	08/07	1440	6.7	17	122	57	8	.06	<.10	<.01	210
4	07/24	1520	3.5	19	81	5	2	<.10	.10	<.01	250
	08/07	1455	5.8	14	103	36	5	.12	.06	<.01	240
5	07/24	1425	3.6	33	130	14	2	.10	26.0	<.01	300
	08/07	1520	3.9	30	148	23	3	.07	24.0	<.01	290
6	08/07	1400	4.2	24	156	42	7	.08	23.0	<.01	310
7	07/24	1530	3.1	31	150	12	2	.19	20.0	<.01	330
	08/07	1415	4.7	21	163	12	5	.10	21.0	<.01	320
8	07/24	1605	2.9	32	141	9	2	.26	19.0	<.01	340
	08/07	1445	4.1	22	169	11	2	<.10	18.0	<.01	340
9	07/24	1630	8.8	54	206	23	10	.51	.98	.01	360
	08/07	1500	3.8	36	195	29	7	2.40	6.60	.01	350
10	07/24	1405	24	31	189	107	17	.28	3.32	<.01	290
	08/07	1325	22	32	182	139	25	.20	2.74	<.01	240
11	07/24	1440	7.0	53	229	54	16	1.33	.30	.01	340
	08/07	1400	6.7	46	209	23	7	3.22	4.27	<.01	330
12	07/24	1525	8.7	52	232	22	12	2.09	.10	.01	380
	08/07	1510	6.3	27	214	21	5	4.49	3.00	<.01	360
13	07/24	1550	8.4	34	225	22	5	3.25	1.43	<.01	390
	08/07	1445	5.9	27	216	19	6	6.40	3.73	<.01	340
14	07/24	1530	5.5	34	216	13	4	3.32	.58	.01	370

	08/07	1440	3.1	30	213	110	14	6.76	3.54	<.01	350
15	07/24	1645	6.7	30	190	7	3	2.51	3.11	<.01	370
16	07/24	1500	3.4	24	171	30	8	.06	.16	<.01	340
	08/07	1400	14	39	352	30	10	<.10	.06	<.01	380
17	07/24	1725	8.8	32	178	113	17	.08	.18	<.01	310
	08/07	1605	18	60	174	80	16	<.10	<.10	<.01	320
18	07/24	1615	13	24	130	66	8	.13	7.44	<.01	230
	08/07	1510	21	35	154	105	10	<.10	6.00	<.01	220
19	07/24	1355	4.9	43	173	6	2	2.20	4.10	<.01	380
	08/07	1400	1.3	33	200	7	5	4.84	5.48	<.01	370
20	07/24	1430	4.6	36	192	8	2	1.70	1.80	<.01	400
	08/07	1430	4.3	30	229	17	6	4.37	1.93	<.01	370
21	07/24	1515	6.6	39	220	15	4	.64	1.50	<.01	380
	08/07	1450	6.1	32	227	25	6	2.98	1.72	<.01	370
22	07/24	1550	11	42	224	68	12	.38	1.50	<.01	380
	08/07	1520	9.7	33	222	45	7	.30	1.30	<.01	350
23	07/24	1630	12	38	200	52	6	<.10	1.10	<.01	320
	08/07	1555	9.3	31	225	45	7	.11	1.10	<.01	320
25	07/24	1615	3.5	13	199	39	5	<.10	1.20	<.01	360
	08/07	1426	4.2	16	192	13	2	.05	<.10	<.01	350
26	07/24	1535	3.5	21	346	10	4	.06	.10	<.01	350
	08/07	1456	3.1	29	404	8	2	.16	.03	<.01	440
27	08/07	1530	2.8	14	223	10	3	.04	.47	<.01	1,300
31	07/24	1430	5.9	17	198	8	2	.10	.16	<.01	200
	08/07	1605	5.1	21	218	20	2	<.10	<.10	<.01	210
32	07/24	1400	19	18	162	12	4	.08	.92	<.01	200
	08/07	1632	9.8	23	192	63	12	.04	.30	<.01	220

Table 11.--Constituent concentrations determined from samples collected once during the diel study on July 23-24 and again during the diel study on August 6-7, 1984, from Richland Creek and its tributaries--Continued

Site number	Date (month/ day)	Calcium dis-solved (mg/L as Ca)	Calcium total recov-erable (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Magne-sium, total recov-erable (mg/L as Mg)	Sodium, total recov-erable (mg/L as Na)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Potas-sium, total recov-erable (mg/L as K)	Chlo-ride, dis-solved (mg/L as Cl)	Sulfate dis-solved (mg/L as SO_4)
1	07/24	68	69	29	29	25	25	2.4	2.7	22	55
	08/07	68	69	28	28	15	15	1.3	1.5	6.6	45
2	07/24	53	52	24	24	22	22	2.7	2.7	25	170
3	07/24	56	57	23	23	21	21	3.8	3.9	24	120
	08/07	53	53	20	20	20	20	4.1	4.1	26	90
4	07/24	58	60	25	25	23	23	3.7	3.8	28	140
	08/07	57	58	24	25	25	24	3.8	3.9	34	120
5	07/24	72	73	28	28	80	78	10	10	61	110
	08/07	73	73	27	27	95	95	12	12	79	110
6	08/07	77	78	28	28	96	95	12	12	84	120
7	07/24	81	83	30	30	81	80	9.6	9.7	73	120
	08/07	82	83	29	30	100	99	12	12	95	120
8	07/24	85	85	30	31	79	79	9.4	9.3	82	130
	08/07	86	84	30	30	96	98	12	11	94	130
9	07/24	88	92	33	34	100	94	12	13	77	190
	08/07	87	87	31	31	100	100	12	13	82	170
10	07/24	74	77	26	27	88	85	9.3	9.7	99	100
	08/07	60	64	23	25	99	96	11	11	110	96
11	07/24	84	89	32	34	99	94	13	13	76	180
	08/07	82	87	30	32	100	98	12	12	86	180
12	07/24	94	97	36	37	100	97	13	13	77	200
	08/07	--	88	--	33	100	--	--	13	88	200
13	07/24	98	100	36	37	100	96	11	12	74	220
	08/07	85	88	31	32	100	100	12	13	90	200
14	07/24	93	93	33	33	95	95	11	11	73	200
	08/07	89	90	32	32	100	100	13	13	100	190
15	07/24	94	95	33	33	93	93	10	10	73	190
16	07/24	90	89	28	28	58	58	6.9	7.0	38	190
	08/07	100	100	30	31	61	57	8.4	8.9	43	240
17	07/24	81	81	26	26	80	80	8.6	8.6	57	180

	08/07	86	90	26	28	73	73	9.2	9.7	53	200
18	07/24	59	61	21	22	76	74	9.4	9.8	60	120
	08/07	55	57	21	22	86	84	9.8	10	67	110
19	07/24	99	99	33	33	91	91	9.8	9.9	72	230
	08/07	94	94	32	32	110	110	12	12	110	220
20	07/24	100	100	35	35	96	97	9.9	9.9	74	240
	08/07	95	98	33	33	110	110	12	12	80	230
21	07/24	95	96	34	34	100	100	10	10	75	230
	08/07	93	92	33	33	100	100	12	12	77	230
22	07/24	95	96	34	35	91	91	11	11	71	200
	08/07	88	88	32	32	88	89	11	11	74	180
23	07/24	82	83	28	28	71	71	8.5	8.5	56	150
	08/07	81	80	28	27	80	80	9.6	9.6	60	140
25	07/24	90	92	32	32	33	32	4.5	4.5	47	130
	08/07	88	92	31	32	35	36	4.7	4.7	46	130
26	07/24	88	89	31	31	100	100	5.5	5.6	54	83
	08/07	110	110	39	40	95	96	7.5	7.5	67	69
27	08/07	340	340	120	120	200	200	9.7	9.7	56	1,400
31	07/24	52	52	18	18	47	46	5.2	5.3	19	47
	08/07	53	55	19	20	51	53	5.4	5.5	18	54
32	07/24	57	57	13	14	22	21	4.6	5.2	10	36
	08/07	64	63	14	14	27	27	4.5	4.6	11	43

Table 11.--Constituent concentrations determined from samples collected once during the diel study on July 23-24 and again during the diel study on August 6-7, 1984, from Richland Creek and its tributaries--Continued

Site number	Date (month/day)	Fluoride, total (mg/L as F)	Arsenic total (µg/L as As)	Barium, dissolved (µg/L as Ba)	Barium, total recoverable (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Beryllium, total recoverable (µg/L as Be)	Boron, dissolved (µg/L as B)	Boron, total recoverable (µg/L as B)	Cadmium dissolved (µg/L as Cd)	Cadmium total recoverable (µg/L as Cd)
1	07/24	0.3	4	110	100	<1	<1	<50	60	3	4
	08/07	.3	5	120	200	<.5	<1	<50	<50	<3	<3
2	07/24	.2	<1	47	50	<.5	<1	110	110	<3	<3
3	07/24	.3	2	58	60	<2	<1	90	90	<3	3
	08/07	.4	1	64	70	<1	<1	90	80	<3	<3
4	07/24	.3	2	56	60	<1	<1	140	170	4	3
	08/07	.4	<1	59	70	<.5	<1	180	180	<3	<3
5	07/24	.6	4	35	40	<.5	<1	430	430	4	5
	08/07	.6	2	29	40	<.5	<1	540	540	<3	3
6	08/07	.6	3	33	50	<.5	<1	590	580	<3	<3
7	07/24	.6	4	49	60	<1	<1	490	500	<3	4
	08/07	.6	4	42	50	<.5	<1	570	580	<3	<3
8	07/24	.6	4	45	50	<1	<1	570	540	<3	3
	08/07	.6	4	41	60	<.5	<1	650	630	<3	4
9	07/24	1.0	4	25	40	<1	<2	590	620	<3	<3
	08/07	1.0	3	29	40	<.5	<1	780	790	<3	4
10	07/24	.6	8	68	100	<.5	<1	350	360	<3	<3
	08/07	.6	7	56	100	<1	<1	430	440	<3	<3
11	07/24	1.0	5	28	60	<1	<1	650	680	<3	<3
	08/07	1.0	5	29	40	<1	<1	740	760	<3	3
12	07/24	1.0	6	46	60	<2	<2	740	700	<3	<3
	08/07	1.0	5	--	50	--	<1	--	770	--	4
13	07/24	1.0	6	52	80	<1	<2	700	700	<3	<3
	08/07	1.0	5	42	60	<.5	<1	700	720	<3	4
14	07/24	1.0	4	55	70	<2	<1	620	620	<3	<3
	08/07	1.0	6	56	80	<.5	<1	650	650	<3	4
15	07/24	1.0	5	58	70	<2	<1	590	590	<3	<3
16	07/24	.5	3	90	90	<.5	<1	200	200	<3	<3
	08/07	.5	2	110	100	<.5	<1	200	220	<3	<3
17	07/24	--	4	81	90	<1	<1	300	290	<3	<3

	08/07	.5	5	84	100	<.5	<1	250	260	<3	4
18	07/24	--	8	68	100	<.5	<1	380	390	<3	<3
	08/07	.6	10	59	100	<.5	<1	430	440	<3	<3
19	07/24	--	6	59	70	<1	<1	590	590	<3	<3
	08/07	.9	4	54	70	<1	<2	650	650	5	<3
20	07/24	--	7	58	70	<1	<1	580	580	<3	<3
	08/07	.9	6	59	70	<1	<1	640	650	<3	4
21	07/24	.8	9	53	70	<.5	<1	650	640	<3	<3
	08/07	1.0	7	63	80	<.5	<1	650	640	<3	<3
22	07/24	.9	12	68	90	<.5	<1	580	590	<3	<3
	08/07	.9	10	63	80	<1	<1	580	580	<3	<3
23	07/24	.7	8	95	100	<.5	<1	410	420	<3	4
	08/07	.7	9	84	100	<1	<2	430	440	<3	<3
25	07/24	.5	2	56	60	<1	<2	350	360	<3	3
	08/07	.5	1	56	60	<.5	<1	370	380	<3	<3
26	07/24	1.2	6	200	200	<1	<1	1,800	1,800	<3	4
	08/07	1.4	11	270	300	<.5	<1	2,500	2,400	<3	<3
27	08/07	.9	1	74	80	<1	<2	1,100	1,100	<3	<3
31	07/24	.4	4	100	100	<1	<1	60	90	<3	<3
	08/07	.5	3	100	100	<1	<1	70	100	<3	<3
32	07/24	.4	4	140	200	<1	<2	<50	50	<3	7
	08/07	.3	3	150	200	<1	<2	<50	<50	<3	<3

Table 11.--Constituent concentrations determined from samples collected once during the diel study on July 23-24 and again during the diel study on August 6-7, 1984, from Richland Creek and its tributaries--Continued

Site number	Date (month/ day)	Chromium, dissolved (µg/L as Cr)	Chromium, total recoverable (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)	Cobalt, total recoverable (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Copper, total recoverable (µg/L as Cu)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lead, total recoverable (µg/L as Pb)
1	07/24	<5	<5	5	10	<5	6	2,800	120	<50	<50
	08/07	<5	<5	<5	<5	30	47	3,000	180	<50	<100
2	07/24	<5	<5	6	<5	<5	10	210	86	<50	<50
3	07/24	<5	<5	<5	7	15	12	310	<50	<50	<50
	08/07	<5	<5	<5	<5	8	46	240	<50	<50	<50
4	07/24	7	8	<5	5	6	30	710	64	<50	<100
	08/07	<5	<5	<5	<5	6	<5	710	50	<50	<50
5	07/24	9	<5	7	<5	18	19	490	<50	<100	<50
	08/07	<5	<5	<5	<5	25	31	1,100	<50	<50	<50
6	08/07	<5	<5	<5	<5	16	16	1,000	<50	<50	<50
7	07/24	<5	<5	<5	<5	5	12	730	<50	<50	<50
	08/07	<5	<5	<5	<5	12	13	520	<50	<50	<50
8	07/24	<5	<5	<5	<5	12	13	560	<50	<50	<50
	08/07	<5	<5	<5	<5	8	10	610	<50	<50	<50
9	07/24	<5	<5	<5	<5	<5	<5	1,400	190	<50	<50
	08/07	<5	7	<5	8	<5	6	920	59	<50	<50
10	07/24	<5	<5	<5	<5	<5	7	2,500	63	<50	<50
	08/07	<5	7	<5	<5	<5	8	3,300	<50	<50	<50
11	07/24	<5	<5	<5	6	<5	6	1,900	140	<50	<50
	08/07	8	16	<5	9	<5	<5	860	55	<50	<50
12	07/24	<5	<5	<5	<5	<5	<5	1,400	710	<50	<50
	08/07	--	13	--	6	--	<5	950	--	--	<50
13	07/24	<5	<5	7	<5	<5	<5	1,300	140	<50	<50
	08/07	<5	9	<5	<5	<5	<5	970	<50	<50	<50
14	07/24	<5	<5	<5	<5	<5	<5	1,100	120	<50	<50
	08/07	<5	6	<5	6	<5	11	1,900	130	<50	<50
15	07/24	<5	<5	<5	<5	<5	<5	890	76	<50	<50
16	07/24	<5	<5	<5	<5	<5	<5	460	<50	<50	<50
	08/07	6	<5	<5	<5	<5	8	880	110	<50	<50
17	07/24	<5	<5	<5	<5	<5	<5	1,300	<50	<50	<50

	08/07	<5	9	<5	8	<5	6	3,200	<50	<50	<50
18	07/24	<5	<5	<5	<5	<5	<5	1,900	<50	<50	<50
	08/07	<5	8	<5	<5	6	8	4,400	52	<50	<50
19	07/24	<5	<5	<5	<5	<5	<5	620	140	<50	<50
	08/07	12	7	<5	<5	<5	<5	590	<50	<50	<50
20	07/24	<5	<5	<5	8	<5	<5	610	<50	<50	<50
	08/07	<5	9	<5	5	<5	<5	730	<50	<50	<50
21	07/24	<5	<5	<5	6	6	<5	780	<50	<50	<50
	08/07	<5	<5	<5	<5	<5	<5	900	<50	<50	<50
22	07/24	<5	<5	10	9	<5	<5	1,300	<50	<100	<50
	08/07	<5	<5	<5	<5	<5	<5	1,500	<50	<50	<50
23	07/24	<5	7	10	20	<5	<5	1,000	200	<50	<100
	08/07	<5	<5	<5	<5	<5	<5	1,400	<50	<50	<50
25	07/24	<5	<5	<5	<5	7	<5	390	<50	<50	<100
	08/07	<5	<5	<5	<5	<5	<5	470	<50	<50	<50
26	07/24	<5	<5	<5	<5	13	<5	600	<50	<50	<50
	08/07	<5	7	<5	9	5	<5	950	57	<50	<50
27	08/07	8	8	8	7	<5	6	350	<50	<50	<50
31	07/24	<5	<5	<5	<5	<5	<5	540	<50	<50	<50
	08/07	<5	8	7	6	11	11	1,400	<50	<50	<50
32	07/24	<5	9	<5	7	<5	6	5,900	60	<50	<100
	08/07	7	<5	<5	<5	<5	<5	1,900	<50	<50	<50

Table 11.--Constituent concentrations determined from samples collected once during the diel study on July 23-24 and again during the diel study on August 6-7, 1984, from Richland Creek and its tributaries--Continued

Site number	Date (month/ day)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)	Nickel, dissolved (µg/L as Ni)	Nickel, total recoverable (µg/L as Ni)	Silver, dissolved (µg/L as Ag)	Silver, total recoverable (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Strontium, total recoverable (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Vanadium, total (µg/L as V)
1	07/24	290	120	<5	<5	<3	<3	140	140	<5	9
	08/07	290	140	<5	16	<3	<3	130	130	<5	<5
2	07/24	590	600	<5	<5	<3	<3	130	130	<5	<5
3	07/24	350	250	<5	<5	<3	<3	160	160	<5	<5
	08/07	350	340	7	<5	<3	<3	150	150	<5	<5
4	07/24	410	340	<5	10	<3	4	160	160	<5	<5
	08/07	640	450	<5	6	<3	<3	160	160	<5	<5
5	07/24	140	120	22	14	5	<3	180	190	5	<5
	08/07	110	78	<5	<5	<3	<3	190	190	<5	<5
6	08/07	160	94	8	8	<3	<3	200	200	<5	<5
7	07/24	210	170	<5	<5	<3	<3	210	220	<5	<5
	08/07	150	120	10	<5	<3	<3	220	220	<5	<5
8	07/24	170	140	<5	<5	<3	<3	220	220	<5	<5
	08/07	120	82	<5	12	<3	<3	220	220	<5	<5
9	07/24	310	280	58	54	<3	<5	250	260	<5	<5
	08/07	240	210	94	110	<3	<3	260	260	<5	<5
10	07/24	530	450	12	<5	<3	<3	210	220	8	7
	08/07	400	330	6	16	<3	<3	170	180	5	10
11	07/24	370	310	59	65	<3	<3	240	260	<5	<5
	08/07	270	240	86	98	<3	<3	240	250	<5	<5
12	07/24	420	390	42	35	<3	<5	280	300	<5	<5
	08/07	300	--	--	85	--	<3	--	260	--	<5
13	07/24	400	350	47	42	<3	<3	300	310	<5	<5
	08/07	300	270	56	75	<3	<3	250	260	<5	<5
14	07/24	370	350	29	25	<3	<5	280	290	<5	<5
	08/07	390	330	61	64	<3	<3	280	280	<5	<5
15	07/24	290	260	23	12	<3	<5	290	290	<5	<5
16	07/24	160	96	<5	<5	<3	<3	310	310	<5	<5
	08/07	350	240	<5	<5	<3	<3	240	350	<5	<5
17	07/24	340	170	<5	<5	<3	<3	280	290	<5	<5

	08/07	690	240	<5	11	<3	<3	300	310	<5	12
18	07/24	260	160	<5	<5	<3	<3	190	190	<5	7
	08/07	390	210	<5	9	<3	<3	170	180	7	13
19	07/24	320	300	22	28	<3	<3	300	310	<5	<5
	08/07	270	220	45	48	<3	<3	290	290	<5	<5
20	07/24	680	650	20	35	<3	<3	320	330	<5	7
	08/07	670	620	45	53	<3	<3	300	300	<5	<5
21	07/24	750	680	35	47	<3	<3	290	300	<5	<5
	08/07	830	770	41	37	<3	<3	290	290	<5	<5
22	07/24	1,000	930	60	55	3	<3	290	290	10	5
	08/07	1,000	970	60	64	<3	<3	270	270	<5	<5
23	07/24	580	490	40	46	<3	5	270	270	7	10
	08/07	860	780	56	50	<3	<3	260	260	<5	<5
25	07/24	270	230	5	7	<3	<3	250	250	<5	<5
	08/07	380	330	<5	<5	<3	<3	250	260	<5	<5
26	07/24	360	330	16	22	<3	<3	290	300	<5	<5
	08/07	1,000	950	20	21	<3	<3	370	380	<5	<5
27	08/07	610	590	11	8	<3	<3	1,500	1,500	<5	<5
31	07/24	1,000	980	<5	[illegible]	<3	<3	230	230	<5	<5
	08/07	960	810	8	<5	<3	<3	260	270	<5	<5
32	07/24	460	300	<5	12	<3	<3	220	220	<5	10
	08/07	410	280	<5	<5	<3	<3	260	250	<5	<5

Table 11.--Constituent concentrations determined from samples collected once during the diel study on July 23-24 and again during the diel study on August 6-7, 1984, from Richland Creek and its tributaries--Continued

Site number	Date (month/ day)	Zinc, dis- solved (µg/L as Zn)	Zinc, total recov- erable (µg/L as Zn)	Alum- inum, total recov- erable (µg/L as Al)	Alum- inum, dis- solved (µg/L as Al)	Phenols total (µg/L	Solids, residue at 180 deg. C dis- solved (mg/L)	Mercury total recov- erable (µg/L as Hg)
1	07/24	<50	<100	2,200	80	<5	398	<0.1
	08/07	<50	<50	2,300	130	<5	419	<.1
2	07/24	<100	<100	<50	<50	<5	409	<.1
3	07/24	<50	<50	150	<50	<5	387	<.1
	08/07	<100	<50	120	<50	<5	354	<.1
4	07/24	<50	300	370	<50	<5	424	<.1
	08/07	<50	<50	240	<50	<5	419	<.1
5	07/24	<50	<50	260	<50	<5	629	<.1
	08/07	<100	<100	730	<50	<5	694	<.1
6	08/07	<50	<50	620	<50	<5	697	<.1
7	07/24	<50	<50	410	<50	<5	659	<.1
	08/07	<50	<50	290	<50	<5	823	<.1
8	07/24	290	<50	220	120	<5	658	<.1
	08/07	<50	<50	300	<50	<5	657	<.1
9	07/24	<50	<100	220	<50	<5	720	<.1
	08/07	<100	<100	300	<50	<5	680	<.1
10	07/24	<50	110	2,200	60	<5	610	<.1
	08/07	<100	<100	2,900	<50	<5	543	<.1
11	07/24	<100	<50	650	<50	<5	723	<.1
	08/07	<50	<50	350	<50	<5	691	<.1
12	07/24	510	<50	190	280	<5	737	<.1
	08/07	--	<50	420	--	<5	709	<.1
13	07/24	360	<100	550	170	<5	737	<.1
	08/07	<50	<50	440	<50	<5	715	<.1
14	07/24	<50	<50	270	<50	<5	703	<.1
	08/07	<50	<100	1,100	70	<5	734	<.1
15	07/24	<50	<50	280	<50	<5	726	<.1
16	07/24	<50	<50	440	<50	<5	597	<.1
	08/07	<50	<100	780	90	<5	689	<.1
17	07/24	270	120	1,300	130	<5	565	<.1

	08/07	<50	<50	2,900	<50	<5	597	<.1
18	07/24	<50	<50	2,000	<50	<5	541	.1
	08/07	<50	<50	4,100	<50	<5	490	<.1
19	07/24	<50	<50	150	<50	<5	837	<.1
	08/07	<50	<50	260	<50	<5	773	<.1
20	07/24	<50	<50	150	--	<5	842	<.1
	08/07	<50	<50	260	<50	<5	746	<.1
21	07/24	<50	<50	280	<50	<5	813	<.1
	08/07	<50	<50	390	<50	<5	705	<.1
22	07/24	<50	<50	860	<50	<5	680	<.1
	08/07	<50	<50	1,100	<50	<5	667	<.1
23	07/24	<100	<50	780	<50	<5	563	<.1
	08/07	<50	<50	1,200	<50	<5	569	<.1
25	07/24	<50	<50	110	<50	<5	531	<.1
	08/07	<50	<50	230	<50	<5	612	<.1
26	07/24	<50	<50	60	<50	<5	600	<.1
	08/07	<50	<50	70	<50	<5	679	<.1
27	08/07	<50	<50	160	<50	<5	2,510	<.1
31	07/24	<50	<50	340	<50	<5	327	<.1
	08/07	<50	<50	1,100	<50	<5	352	<.1
32	07/24	<100	150	5,000	<50	<5	277	<.1
	08/07	<50	<50	1,500	<50	<5	311	<.1