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EFFECTS OF THE RATE OF RELEASES FROM SAM RAYBURN RESERVOIR ON THE AERATION CAPACITY OF THE ANGELINA RIVER, EASTERN TEXAS

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The dominant factors that affected the aeration capacity during the study were time of travel and the dissolved-oxygen deficit of the releases. Aeration was low throughout the study but increased in response to increases in the dissolved-oxygen deficit and the duration of time that the releases were exposed to the atmosphere (time of travel).

The average concentration of dissolved oxygen in flow sustained by releases of 8,800 cubic feet per second decreased from 5.0 milligrams per liter at a site near the power outlet to 4.8 milligrams per liter at a site about 14 miles downstream; the time of travel averaged about 8 hours. The average concentration of dissolved oxygen in flow sustained by releases of 2,200 cubic feet per second increased from 5.2 to 5.5 milligrams per liter; the time of travel averaged about 20 hours.

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Most units of measurements used in this report are inch-pound units. For readers interested in using the metric system, the inch-pound units may be converted to metric units by use of the following factors:

From		Multiply by	To obtain	
Unit	Abbreviation		Unit	Abbreviation
cubic foot per second	ft^3/s	0.02832	cubic meter per second	m^3/s
foot	--	0.3048	meter	m
foot per second	ft/s	0.3048	meter per second	m/s
inch	--	2.54	centimeters	cm
mile	--	1.609	kilometer	km

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ABSTRACT

A three-phase study was conducted during July and August 1979 to determine the effects of varying release rates through the power-outlet works at Sam Rayburn Reservoir on aeration capacity of a 14-mile reach of the Angelina River below Sam Rayburn Dam.

The dominant factors that affected the aeration capacity during the study were time of travel and the dissolved-oxygen deficit of the releases. Aeration was low throughout the study but increased in response to increases in the dissolved-oxygen deficit and the duration of time that the releases were exposed to the atmosphere (time of travel).

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INTRODUCTION

Purpose of Study

Sam Rayburn Reservoir on the Angelina River is owned by the U.S. Government and operated by the U.S. Army Corps of Engineers. The reservoir was designed to control and regulate floodwaters, generate electrical power, and conserve water for municipal supply, industrial use, irrigation, and recreation. Construction of the project by the Corps of Engineers was started in September 1956 and was completed in July 1966. Deliberate impoundment of water began in March 1965.

Data are needed by the Corps of Engineers to determine the effects that varying the rate of releases from Sam Rayburn Reservoir has on the hydraulic properties and the aeration capacity of the Angelina River. The U.S. Geological Survey, in cooperation with the Corps of Engineers, conducted a three-phase study from July to August 1979 to provide data on the aeration capacity of a 14-mile reach of the Angelina River between Sam Rayburn Dam and the headwaters of B. A. Steinhagen Lake (fig. 1).

The Geological Survey, in cooperation with the Corps of Engineers, began a study in April 1965 to monitor and explain the variations of selected water-quality parameters, including dissolved oxygen, in the reservoir and in the Angelina River downstream from the reservoir. The results of this study through February 1969 have been described by Rawson and Lansford (1971). Rawson and Lansford (1971, p. J20) found that the quality of water in the Angelina River before closure of the reservoir was degraded locally upstream from the reservoir, but no serious depletions of dissolved oxygen were noted at downstream sites.

Operation of the reservoir, primarily for flood control and power production, has reduced the magnitude of high flows, but generally has increased the level of low flows of the Angelina River downstream from the reservoir. Regulation of flow has reduced greatly the variations (in concentration) of most dissolved constituents and has resulted in a more uniform chemical quality of water at downstream sites. However, releases of water for power generation through the low-level power intakes (located at the elevation interval between 135 and 105 feet above National Geodetic Vertical Datum of 1929) have resulted in significant variations in the concentrations of dissolved oxygen in the Angelina River.

Dissolved oxygen is necessary for fish and other aquatic organisms to maintain the metabolic processes that produce energy for egg and larvae development, normal activity, and growth. Rawson and Lansford (1971, p. J21) have shown that the distribution of dissolved oxygen in Sam Rayburn Reservoir is related to thermal stratification. Thermal stratification during spring and summer results in a reduction of vertical circulation of water in the reservoir. Oxygen utilized in the decomposition of organic material is not replaced in the lower stagnant stratum, and a vertical dissolved-oxygen gradient develops.

Periodic water-quality surveys of Sam Rayburn Reservoir and the reach of the Angelina River between Sam Rayburn Dam and the headwaters of B. A. Steinhagen Lake (fig. 1) have shown that the dissolved-oxygen concentrations vary seasonally. Concentrations are usually lowest in late summer and early fall

after periods of summer stagnation. The concentrations of dissolved oxygen in releases from the reservoir, which usually begin to decrease in March or April after the onset of thermal stratification, often approach zero during the period of summer stagnation. The surveys have shown generally that the amount of aeration that occurs in the Angelina River downstream from the reservoir is insignificant (Rawson and Lansford, 1971, p. J20).

The aeration capacity of a stream is a function of the biologic, physical, and hydraulic properties of the stream. The velocity and depth of the stream are two of the most important hydraulic properties that affect aeration. Langbein and Durum (1967, p. 2) have shown that the aeration of a stream usually increases in response to increases in velocity but decreases with increasing depth. Other investigators (Mackenthun and others, 1964, p. 26) have shown generally that flows released from reservoirs at low rates are aerated in short distances downstream. Higher discharges require many miles of open-channel flow before oxygen saturation is achieved.

Another important factor that affects the aeration capacity of a stream when the water is unsaturated with oxygen is the dissolved-oxygen deficit (the difference between the saturated concentration and actual concentration at the same temperature). Aeration increases as the dissolved-oxygen deficit increases.

Description of the Study Area

Sam Rayburn Reservoir is in eastern Texas on the Angelina River about 11 miles northwest of Jasper in Jasper County. The drainage area consists mostly of heavily timbered low hills with wide flood plains along the Angelina River. The study area includes a site (C_C) in Sam Rayburn Reservoir about 2 miles upstream from the dam and a 14-mile reach of the Angelina River between Sam Rayburn Dam and the headwaters of B. A. Steinhagen Lake (fig. 1).

Flows in this reach of the Angelina River during the study, except for minor amounts of local runoff from small tributaries, were sustained by releases from Sam Rayburn Reservoir through the power outlets near the right abutment of Sam Rayburn Dam. The water in a 5-mile reach of the old river channel between the power-outlet works and the left side of the dam (McGee Bend) consisted of backwater from power releases and minor amounts of surface runoff. This reach was not included in the study.

Climatological Conditions

Climatological conditions often have a significant effect on the oxygen content of a stream. Oxygen enters a stream by plant photosynthesis, by absorption from the atmosphere, and by direct surface runoff into the stream. Photosynthesis is the process by which aquatic plants, principally algae, convert carbon dioxide and water into carbohydrates and oxygen. Sunlight is necessary to supply energy for this reaction; and the concentration of dissolved oxygen in a stream usually will be higher during the day than at night and higher on a sunny day than on a cloudy day because of photosynthetic activity.

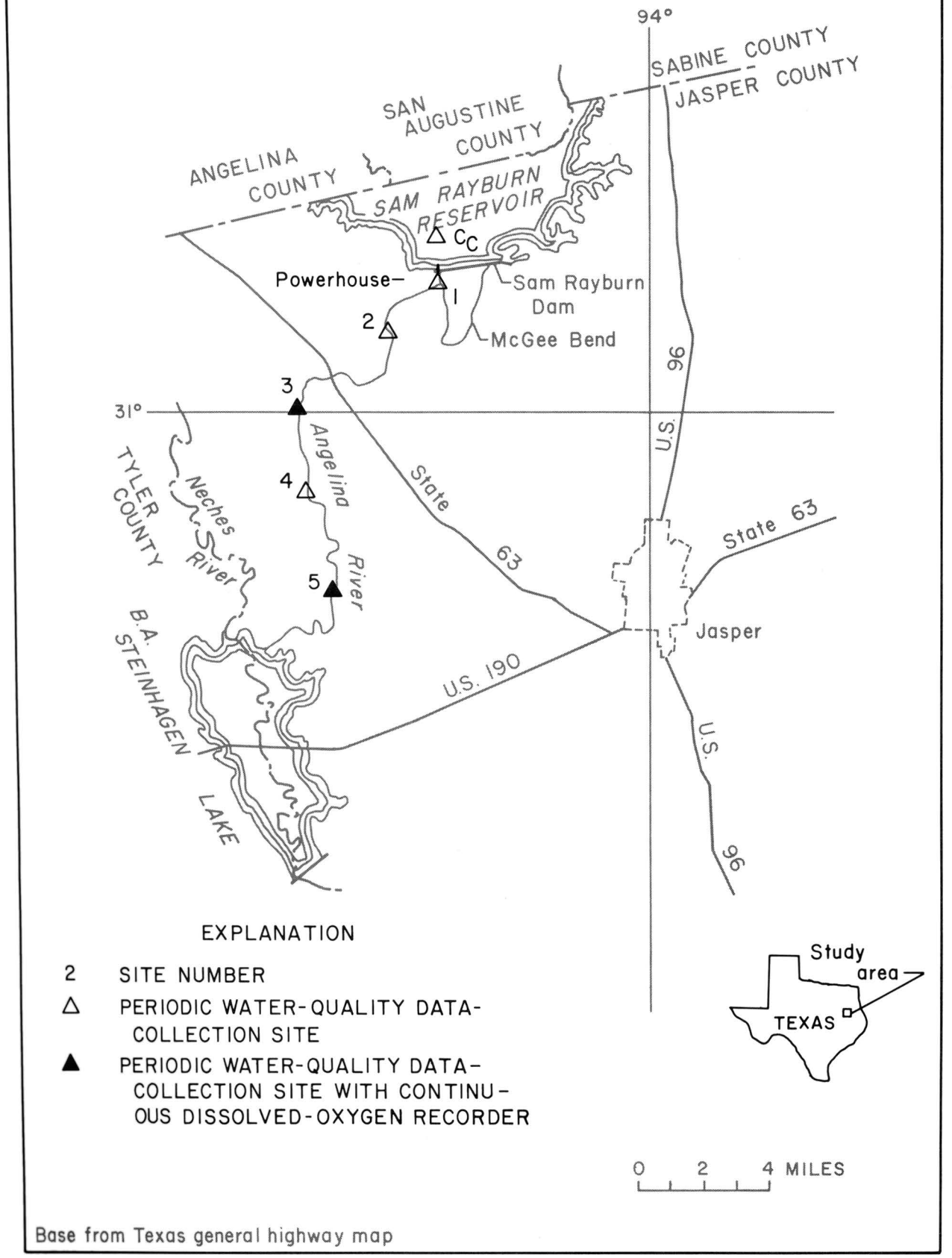

FIGURE 1.-Locations of water-quality data-collection sites

Brief descriptions of the climatological conditions that existed during this study are included in table 1. Rainfall data in the table were obtained from the Corps of Engineers weather station at Sam Rayburn Dam.

Weather conditions were variable during each phase of the study. Sunny skies predominated during the first phase of the study (July 17 and 18); but 0.40 inch of rain was recorded on July 18. Skies were overcast throughout most of the second phase of the study (July 26 and 27); 1.77 inches of rain were recorded on July 26. Skies were clear to partly cloudy during the third phase of the study (August 1 and 2); 0.10 inch of rain was recorded on each day.

METHOD OF INVESTIGATION

Because most of the critical conditions affecting the concentrations of dissolved oxygen in releases from Sam Rayburn Reservoir are related to thermal stratification in the reservoir, the study was conducted during a 3-week period in July and August 1979 when water at site C_C near the power outlet in the reservoir was thermally stratified (fig. 2).

Locations of the data-collection sites in the reservoir and the 14-mile reach of the Angelina River downstream from the power outlet are shown on figure 1 and are described in table 2.

Selected water-quality parameters (dissolved oxygen, specific conductance, temperature, and pH) for site C_C in the reservoir were measured at depth intervals of about 10 feet at the beginning and near the conclusion of the study (table 3). The data-collection program for five sites in the Angelina River downstream from the power outlet (fig. 1) was conducted in three phases.

A release of 8,800 ft^3/s (cubic feet per second) was begun at least 8 hours before the start of data collection on July 17 and was maintained throughout the first phase of the study.

A release of 4,400 ft^3/s was begun at least 8 hours before the start of the second phase of the study on July 26 and was maintained throughout daylight hours on both July 26 and July 27. However, the release was unintentionally interrupted from 1900 hours to 2400 hours on July 26.

A release rate of 2,200 ft^3/s was begun at least 8 hours before the start of the third phase on August 1 and was maintained until the conclusion of the study.

Dissolved oxygen, specific conductance, temperature, and pH of the water at five sites on the Angelina River (fig. 1) were measured periodically with boat-mounted equipment during the daylight hours of each phase of the study (table 4). Continuously recording dissolved-oxygen meters were installed at sites 3 and 5 before each phase of the study to supplement the periodic manual measurements. The dissolved-oxygen data obtained periodically during daylight hours at each site on the Angelina River and the corresponding continuous records of dissolved oxygen throughout the daylight hours and intervening nights for sites 3 and 5 are summarized in table 5. The periodic and continuous records for sites 3 and 5 are compared on figure 3; the periodic records for each site are summarized on figure 4.

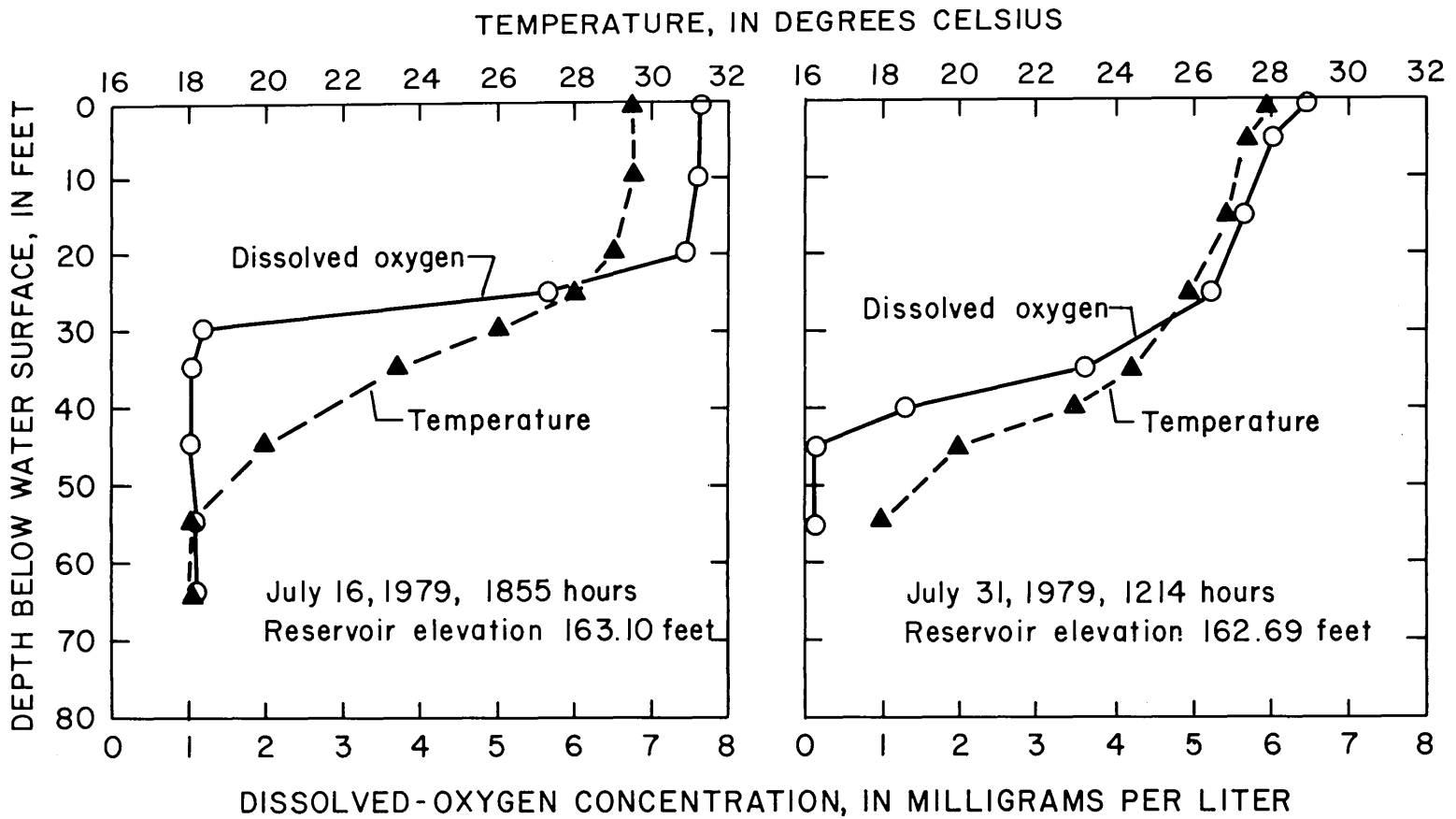

FIGURE 2.-Profiles of dissolved oxygen and water temperature for site C_C in Sam Rayburn Reservoir

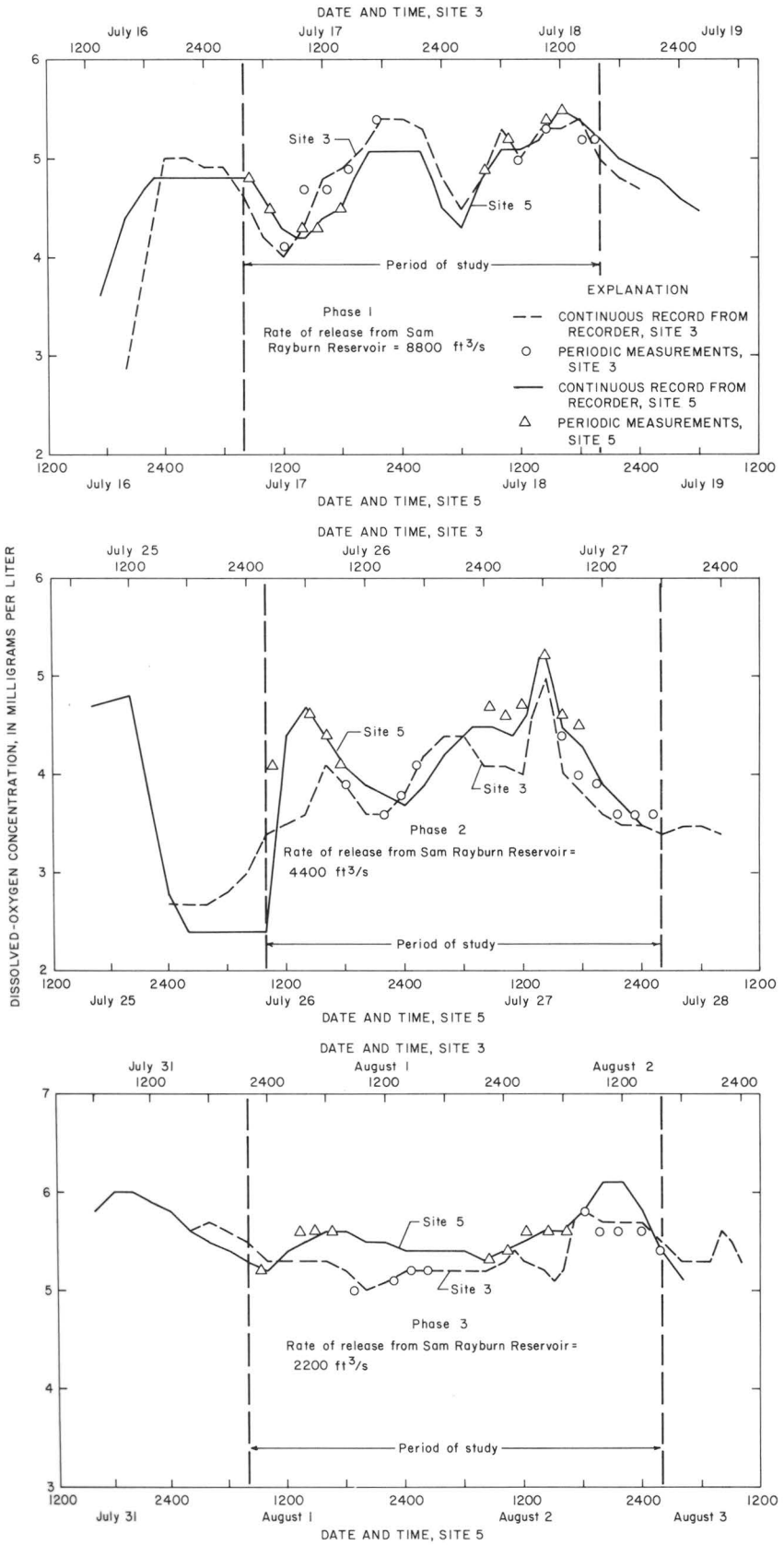

FIGURE 3.-Variations of dissolved-oxygen concentrations at sites 3 and 5 on the Angelina River

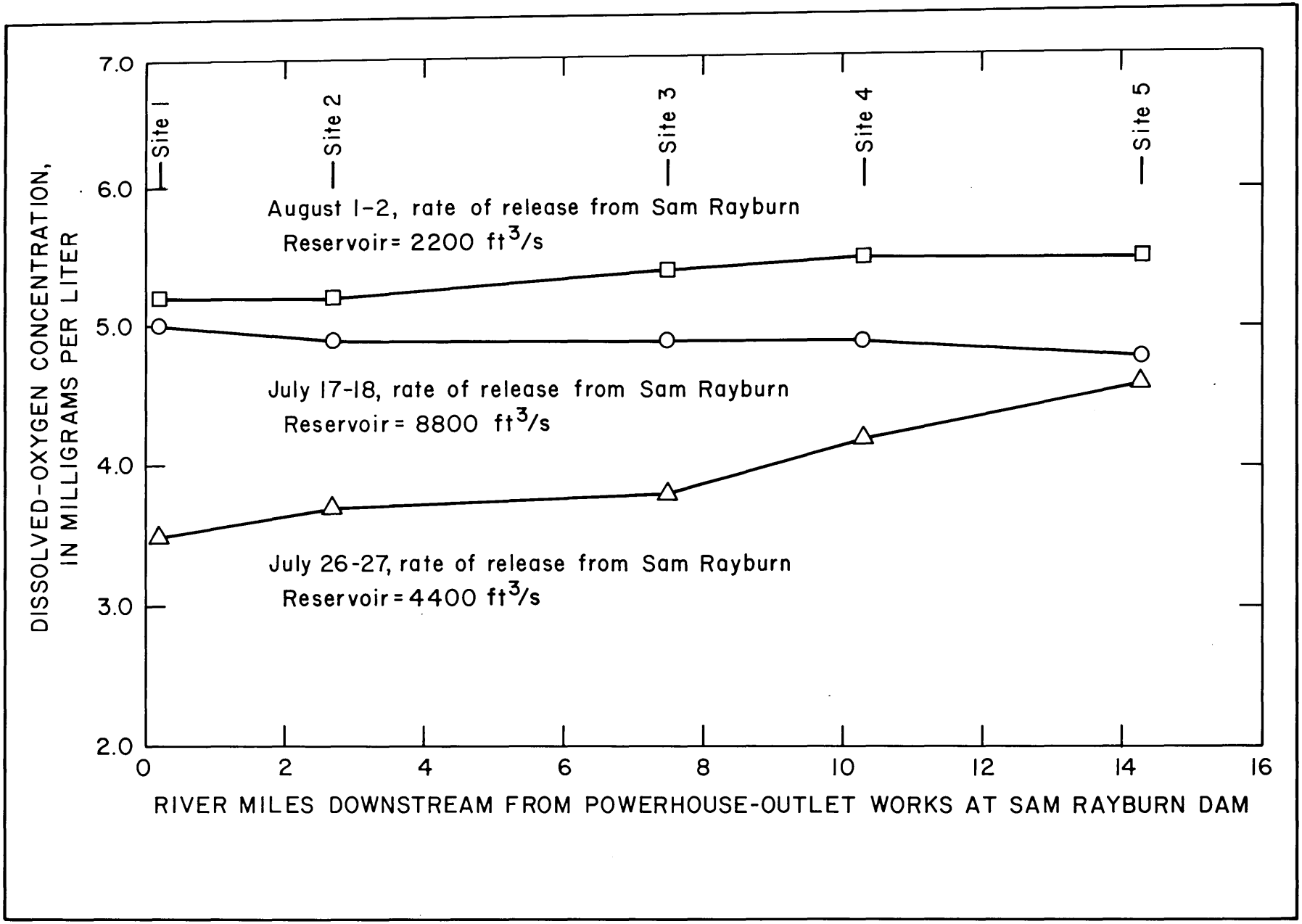

FIGURE 4.-Profiles of average concentrations of dissolved oxygen for the Angelina River

Table 1.--Climatological conditions during water-quality surveys of the Angelina River

Date	Rainfall (inches)	Remarks
1979		
July 16	0.00	Afternoon skies clear, bright, and mostly sunny.
July 17	0.00	Early morning clouds, clearing by 0900 hours; followed by clear, bright, sunny skies. Thundershowers approached from the south at about 1800 hours.
July 18	0.40	Early morning clouds until 1000 hours, followed by hazy to bright sunny skies. Thundershowers approached from the northeast at about 1700 hours.
July 19	1.30	--
July 25	0.36	--
July 26	1.77	Intermittent, light drizzle throughout entire day. Skies were overcast and drab.
July 27	0.05	Light drizzle in morning, turning to mostly cloudy, hazy skies the remainder of the day.
July 28	0.22	--
July 31	0.00	Afternoon and evening skies were mostly cloudy with intermittent sunshine.
August 1	0.10	Sunny, bright skies until 0900 hours, turning to partly cloudy during afternoon and evening.
August 2	0.10	Foggy until 0900 hours, turning to mostly clear, bright, sunny skies. Evening hours were mostly cloudy.
August 3	0.00	--

Table 2.--Locations and descriptions of data-collection sites

Site	River miles from Sam Rayburn Dam	Location	Remarks
C_C	2.0	Lat 31°04'05", long 094°06'20", 0.5 mile above powerhouse outlet.	Water-quality parameters measured on July 16 and 31.
1	5.3	Lat 31°03'26", long 094°05'22", 0.2 mile downstream from powerhouse outlet.	Water-quality parameters measured manually during daylight hours of each study phase.
2	7.8	Lat 31°02'08", long 094°07'48", (at site of discontinued stream-gaging station 08039500), 2.7 miles downstream from powerhouse outlet.	Water-quality parameters measured manually during daylight hours of each study phase.
3	12.6	Lat 31°00'09", long 094°10'36", (at site of old State Highway 63), 7.5 miles downstream from powerhouse outlet.	Water-quality parameters measured manually during daylight hours of each study phase. Site of continuous dissolved-oxygen recorder.
4	15.4	Lat 30°57'48", long 094°09'24", 10.3 miles downstream from powerhouse outlet.	Water-quality parameters measured manually during daylight hours of each study phase.
5	19.4	Lat 30°55'24", long 094°09'24", 14.3 miles downstream from powerhouse outlet.	Water-quality parameters measured manually during daylight hours of each study phase. Site of continuous dissolved-oxygen recorder.

Table 3.--Results of water-quality surveys for site C_C in Sam Rayburn Reservoir, July 16 and 31, 1979

Date and time	Depth (feet)	Specific conductance (micromhos)	pH (units)	Dissolved oxygen (mg/L)	Percent saturation	Temperature (°C)
July 16, 1979 at 1855 hours	1	168	7.0	7.6	100	29.5
	10	168	7.0	7.6	100	29.5
	20	168	6.9	7.4	96	29.0
	25	168	6.6	5.7	72	28.0
	30	168	6.2	1.2	15	26.0
	35	190	6.2	1.0	12	23.5
	45	200	6.2	1.0	11	20.0
	55	205	6.2	1.1	12	18.0
	63	210	6.2	1.1	12	18.0
July 31, 1979 at 1214 hours	1	168	6.9	6.5	82	28.0
	5	168	6.8	6.1	77	27.5
	15	168	6.6	5.7	71	27.0
	25	168	6.4	4.8	59	26.0
	35	175	6.4	3.7	44	24.5
	40	190	6.3	1.3	15	23.0
	45	205	6.2	0.2	2	20.0
	55	210	6.2	0.2	2	18.0

Table 4.--Results of periodic water-quality survey for the Angelina River, July 17 to August 2, 1979

Date	Time	Rate of release from Sam Rayburn Reservoir (ft^3/s)	Specific conductance (micromhos)	pH (units)	Dissolved oxygen (mg/L)	Percent saturation	Temperature (°C)
			SITE 1				
July 17, 1979	0720	8,800	165	6.5	4.6	57	26.5
	0925	8,800	165	6.5	4.9	61	27.0
	1205	8,800	165	6.6	5.2	66	28.0
	1410	8,800	165	6.6	5.4	68	28.0
	1705	8,800	165	6.5	5.4	68	28.0
July 18	0715	8,800	165	6.6	5.1	64	27.0
	1000	8,800	165	6.5	5.1	64	27.0
	1330	8,800	165	6.5	4.5	57	27.5
	1515	8,800	165	6.5	4.7	59	27.5
July 26	0804	4,400	170	6.2	3.8	44	23.0
	1335	4,400	170	6.3	3.9	46	24.0
	1523	4,400	170	6.3	3.8	45	24.0
	1651	4,400	170	6.3	3.6	43	24.0
July 27	0734	4,400	170	6.2	3.0	35	23.5
	0917	4,400	170	6.2	3.0	35	23.5
	1107	4,400	170	6.2	2.8	33	23.0
	1317	4,400	170	6.3	3.2	37	23.5
	1507	4,400	170	6.3	3.5	41	23.5
	1645	4,400	165	6.3	4.0	47	24.0
August 1	0830	2,200	165	6.3	4.7	56	24.5
	1226	2,200	165	6.4	5.0	60	25.0
	1407	2,200	165	6.4	5.5	67	25.5
	1539	2,200	165	6.4	5.5	67	26.0
August 2	0743	2,200	165	6.3	5.0	60	25.0
	0929	2,200	165	6.4	4.9	59	25.0
	1126	2,200	165	6.5	5.1	62	25.5
	1333	2,200	165	6.6	5.6	68	26.0
	1534	2,200	165	6.6	5.6	68	26.0

Table 4.--Results of periodic water-quality survey for the Angelina River, July 17 to August 2, 1979--Continued

Date	Time	Rate of release from Sam Rayburn Reservoir (ft^3/s)	Specific conductance (micromhos)	pH (units)	Dissolved oxygen (mg/L)	Percent saturation	Temperature (°C)
			SITE 2				
July 17, 1979	0730	8,800	165	6.5	4.5	55	26.0
	0940	8,800	165	6.5	4.7	59	27.0
	1215	8,800	165	6.5	4.8	61	28.0
	1424	8,800	165	6.6	5.0	63	28.0
	1715	8,800	165	6.6	5.2	66	28.0
July 18	0728	8,800	165	6.6	5.1	64	27.0
	1012	8,800	165	6.5	5.2	65	27.5
	1343	8,800	165	6.5	4.9	62	27.5
	1522	8,800	165	6.5	4.9	62	27.5
July 26	0822	4,400	170	6.2	4.1	47	23.0
	1344	4,400	170	6.3	3.9	46	24.0
	1533	4,400	165	6.3	4.2	50	24.0
	1659	4,400	165	6.3	4.2	50	24.0
July 27	0746	4,400	170	6.2	3.6	42	23.5
	0928	4,400	170	6.2	3.2	37	23.5
	1117	4,400	170	6.3	3.3	39	23.5
	1329	4,400	170	6.3	3.2	37	23.5
	1516	4,400	170	6.3	3.4	40	23.5
	1655	4,400	165	6.3	3.7	44	24.0
August 1	0838	2,200	165	6.3	4.7	56	24.5
	1237	2,200	165	6.4	5.2	63	25.0
	1417	2,200	165	6.4	5.2	63	25.5
	1556	2,200	165	6.4	5.2	63	25.5
August 2	0743	2,200	165	6.4	5.4	65	25.5
	0941	2,200	165	6.4	5.1	62	25.5
	1136	2,200	165	6.4	5.1	62	25.5
	1347	2,200	165	6.5	5.2	63	25.5
	1545	2,200	165	6.5	5.4	66	26.0

Table 4.--Results of periodic water-quality survey for the Angelina River, July 17 to August 2, 1979--Continued

Date	Time	Rate of release from Sam Rayburn Reservoir (ft^3/s)	Specific conductance (micromhos)	pH (units)	Dissolved oxygen (mg/L)	Percent saturation	Temperature (°C)
			SITE 3				
July 17, 1979	0805	8,800	165	6.4	4.1	50	26.0
	1007	8,800	165	6.4	4.7	59	27.0
	1235	8,800	165	6.5	4.7	59	28.0
	1438	8,800	165	6.5	4.9	62	28.0
	1732	8,800	165	6.6	5.4	68	28.0
July 18	0756	8,800	165	6.5	5.0	62	27.0
	1025	8,800	165	6.5	5.3	67	27.5
	1407	8,800	165	6.5	5.2	66	28.0
	1542	8,800	165	6.5	5.2	66	28.0
July 26	1010	4,400	170	6.2	3.9	46	23.5
	1357	4,400	170	6.2	3.6	42	23.5
	1542	4,400	165	6.2	3.8	45	23.5
	1712	4,400	165	6.3	4.1	49	24.0
July 27	0757[a/]	4,400	165	6.2	4.4	51	23.5
	0941	4,400	170	6.3	4.0	47	23.5
	1127	4,400	170	6.3	3.9	46	23.5
	1342	4,400	170	6.3	3.6	42	23.5
	1527	4,400	170	6.3	3.6	42	23.5
	1711	4,400	165	6.3	3.6	42	23.5
August 1	0851	2,200	165	6.3	5.0	60	25.0
	1249	2,200	165	6.3	5.1	61	25.0
	1434	2,200	165	6.3	5.2	63	25.5
	1613	2,200	165	6.3	5.2	63	25.5
August 2	0809	2,200	165	6.4	5.8	70	26.0
	0953	2,200	165	6.5	5.6	68	26.0
	1147	2,200	165	6.5	5.6	68	26.0
	1401	2,200	165	6.5	5.6	68	26.0
	1557	2,200	165	6.5	5.4	66	26.0

a/ Measurements of specific conductance, pH, and dissolved oxygen reflect the presence of intruding surface runoff.

Table 4.--Results of periodic water-quality survey for the Angelina River, July 17 to August 2, 1979--Continued

Date	Time	Rate of release from Sam Rayburn Reservoir (ft^3/s)	Specific conductance (micromhos)	pH (units)	Dissolved oxygen (mg/L)	Percent saturation	Temperature (°C)
			SITE 4				
July 17, 1979	0817	8,800	165	6.4	4.4	54	26.5
	1020	8,800	165	6.4	4.6	58	27.0
	1245	8,800	165	6.5	4.5	57	28.0
	1510	8,800	165	6.5	4.7	59	28.0
	1740	8,800	165	6.6	5.0	63	28.0
July 18	0803	8,800	165	6.5	5.0	62	27.0
	1034	8,800	163	6.5	5.2	65	27.5
	1416	8.800	165	6.5	5.3	67	28.0
	1552	8.800	165	6.5	5.3	67	28.0
July 26	1024	4,400	170	6.3	4.5	53	23.5
	1409	4,400	170	6.2	3.8	45	23.5
	1559	4,400	165	6.2	3.8	45	23.5
	1724	4,400	165	6.2	3.8	45	23.5
July 27	0819[a/]	4,400	140	6.1	5.1	60	24.0
	0945[a/]	4,400	140	6.1	5.0	68	23.5
	1141	4,400	165	6.3	4.3	50	23.5
	1354	4,400	170	6.3	4.1	48	24.0
	1540	4,400	170	6.3	3.8	45	24.0
	1724	4,400	165	6.3	3.8	44	23.5
August 1	0906	2,200	160	6.3	5.2	63	25.5
	1304	2,200	165	6.3	5.4	65	25.5
	1445	2,200	165	6.3	5.3	64	25.5
	1625	2,200	165	6.3	5.3	64	25.5
August 2	0827	2,200	165	6.4	5.3	64	25.5
	1006	2,200	165	6.5	5.6	68	25.5
	1203	2,200	165	6.5	5.9	72	26.0
	1414	2,200	165	6.5	5.8	71	26.0
	1611	2,200	165	6.5	5.7	70	26.0

a/ Measurements of specific conductance, pH, and dissolved oxygen reflect the presence of intruding surface runoff.

Table 4.--Results of periodic water-quality survey for the Angelina River, July 17 to August 2, 1979--Continued

Date	Time	Rate of release from Sam Rayburn Reservoir (ft^3/s)	Specific conductance (micromhos)	pH (units)	Dissolved oxygen (mg/L)	Percent saturation	Temperature (°C)
			SITE 5				
July 17, 1979	0843	8,800	165	6.4	4.8	59	26.5
	1035	8,800	165	6.4	4.5	56	27.0
	1258	8,800	165	6.4	4.3	54	28.0
	1525	8,800	165	6.5	4.3	54	28.0
	1753	8,800	165	6.5	4.5	57	28.0
July 18	0817	8,800	165	6.5	4.9	61	27.0
	1045	8,800	165	6.5	5.2	65	27.5
	1426	8,800	165	6.6	5.4	68	28.0
	1603	8,800	165	6.6	5.5	70	28.0
July 26	1036	4,400	165	6.3	4.1	48	23.5
	1421	4,400	165	6.3	4.6	54	23.5
	1611	4,400	165	6.3	4.4	52	23.5
	1736	4,400	165	6.4	4.1	48	23.5
July 27	0829	4,400	165	6.3	4.7	55	24.0
	1006	4,400	165	6.3	4.6	54	24.0
	1155	4,400	155	6.3	4.7	55	24.0
	1406[a/]	4,400	120	6.1	5.2	61	24.0
	1557	4,400	165	6.3	4.6	54	24.0
	1740	4,400	165	6.3	4.5	53	24.0
August 1	0917	2,200	160	6.3	5.2	63	25.5
	1317	2,200	165	6.4	5.6	68	25.5
	1459	2,200	165	6.4	5.6	68	26.0
	1638	2,200	165	6.4	5.6	68	26.0
August 2	0839	2,200	165	6.4	5.3	64	25.5
	1018	2,200	165	6.4	5.4	65	25.5
	1214	2,200	160	6.4	5.6	68	26.0
	1425	2,200	165	6.4	5.6	68	26.0
	1624	2,200	165	6.4	5.6	68	26.0

a/ Measurements of specific conductance, pH, and dissolved oxygen reflect the presence of intruding surface runoff.

Water stage was measured periodically at the site of the discontinued stream-gaging station 08039500 Angelina River at Horger (site 2) so that supplemental information on the velocity and depth of flow could be obtained from previous streamflow records.

ANALYSIS OF DATA

Reservoir Water-Quality Records

Water at site C_C in Sam Rayburn Reservoir was thermally stratified throughout the duration of the study (fig. 2 and table 3). Water temperature on July 16 ranged from 29.5°C at a depth of 1.0 foot to 18.0°C at a depth of 63 feet near the reservoir bottom. The temperature on July 31 ranged from 28.0° to 18.0°C. Three fairly distinct thermal strata were present in the reservoir: (1) The epilimnion, a warm freely circulating surface stratum; (2) the thermocline or metalimnion, a middle stratum characterized by an abrupt temperature change; and (3) the hypolimnion, a cold stagnant lower stratum.

The distribution of dissolved oxygen and the variations of other selected water-quality parameters measured in the reservoir at site C_C were closely related to thermal stratification (table 3). The concentrations of dissolved oxygen on July 16 decreased from 7.6 mg/L (milligrams per liter) at the water surface to 1.1 mg/L at a depth of 63 feet near the reservoir bottom. Water below the thermocline at a depth of about 30 feet contained less than 1.2 mg/L of dissolved oxygen. Specific conductance increased from 168 micromhos at the water surface to 210 micromhos near the reservoir bottom, and pH decreased from 7.0 to 6.2

The concentration of dissolved oxygen on July 31 decreased from 6.5 mg/L near the water surface to 0.2 mg/L at a depth of 55 feet near the reservoir bottom. Water below the thermocline at a depth of about 40 feet contained less than 1.3 mg/L of dissolved oxygen. Specific conductance increased from 168 micromhos at the water surface to 210 micromhos near the reservoir bottom, and pH decreased from 6.9 to 6.2.

Water Discharge, Velocity, Depth, and Time of Travel

Streamflow records and past measurements of discharge at site 2, supplemented by continuous records of dissolved oxygen for sites 3 and 5 on July 17 and 18 (fig. 3), indicate that the velocity of the flow throughout the reach averaged about 2.5 ft/s (feet per second) and that the time of travel through the 14-mile reach averaged about 8 hours. The depth of the water averaged about 15 feet.

Streamflow records and past measurements of discharge for site 2, supplemented by continuous records of dissolved oxygen for sites 3 and 5 on July 26 and 27 (fig. 3), indicate that the velocity of the flow averaged about 2.0 ft/s and that time of travel through the 14-mile reach averaged about 10 hours. The depth of the water averaged about 10 feet.

Streamflow records and past measurements of discharge for site 2, supplemented by continuous records of dissolved oxygen for sites 3 and 5 on August 1 and 2 (fig. 3), indicate that the velocity of the flow averaged about 1.0 ft/s and that time of travel through the 14-mile reach averaged about 20 hours. The depth of the water averaged about 10 feet.

Stream Water-Quality Records

The ranges and averages of periodic manual measurements of dissolved oxygen during daylight hours for sites 3 and 5 agree well with the ranges and averages of the values recorded continuously (table 5 and fig. 3). The agreement between the two sets of values indicate that the periodic records for each of the five sites are representative of conditions in the stream and are adequate to determine the effects that varying release rates from Sam Rayburn Reservoir have on the aeration capacity for the Angelina River.

Phase 1 (July 17 and 18, 1979)

The concentration of dissolved oxygen in releases from the reservoir at site 1 on the Angelina River during daylight hours of July 17 and 18 ranged from 4.5 to 5.4 mg/L. Water temperature ranged from 26.5° to 28.0°C; ph ranged from 6.5 to 6.6; specific conductance was 165 micromhos (tables 4 and 5). A comparison of these data (table 4) with data for site C_C in Sam Rayburn Reservoir on July 16 (table 3) indicates that most of the water passing through the power plant was withdrawn from the reservoir at a depth interval between 25 and 30 feet below the water surface.

The concentration of dissolved oxygen in the Angelina River during daylight hours on July 17 and 18 averaged 5.0 mg/L at site 1 and 4.8 mg/L at site 5 The dissolved-oxygen deficit at sites 1 and 5 averaged 3.0 and 3.2 mg/L, respectively. The decrease in dissolved oxygen and increase in dissolved-oxygen deficit when releases from the reservoir were maintained at 8,800 ft^3/s indicate that deoxygenation resulting from oxidation of organic material in the water exceeded aeration during the 8 hours required for the water to travel through the 14-mile reach.

Phase 2 (July 26 and 27, 1979)

More than 1.7 inches of rain was recorded at the Corps of Engineers weather station on July 26, the first day of phase 2 of the study (July 26 and 27). The quality of the flow was modified significantly by the interruption of the releases from 1900 hours to 2400 hours on July 26. (See water-quality data in table 4 for sites 3, 4, and 5 on July 27.)

The concentration of dissolved oxygen at site 1 during daylight hours on July 26 ranged from 3.6 to 3.9 mg/L. Water temperature ranged from 23.0° to 24.0°C; pH ranged from 6.2 to 6.3; and specific conductance was 170 micromhos. A comparison of these data (table 4) with data for site C_C in Sam Rayburn Reservoir on July 16 and 31 (table 3) indicates that most of the water was withdrawn from the reservoir at a depth interval between 30 and 35 feet below the water surface.

Interruption of the releases from 1900 hours to 2400 hours on July 26 resulted in the initial release of less oxygenated water from the depth interval between 35 and 40 feet during the morning of July 27. As releases continued, more highly oxygenated water from the depth interval between 30 and 35 feet was drawn through the power plant.

The concentration of dissolved oxygen in releases at site 1 during daylight hours on July 26 and 27 averaged 3.5 mg/L (table 5). The concentration

Table 5.--Summary of dissolved-oxygen records for the Angelina River, July 17 and 18, 26 and 27, and August 1 and 2, 1979

Date	Rate of release from Sam Rayburn Reservoir (ft^3/s)	Site no.	Range of dissolved-oxygen concentrations (mg/L)		Averages (mg/L)	
			Continuous recorder	Periodic measurements during daylight hours	Periodic measurements	Continuous recorder
July 17-18, 1979	8,800	1	-- --	4.5 - 5.4	5.0	--
		2	-- --	4.5 - 5.2	4.9	--
		3	4.0 - 5.4	4.1 - 5.4	4.9	5.0
		4	-- --	4.4 - 5.3	4.9	--
		5	4.2 - 5.5	4.3 - 5.5	4.8	4.8
July 26-27	4,400	1	-- --	2.8 - 4.0	3.5	--
		2	-- --	3.2 - 4.2	3.7	--
		3	3.0 - 5.0	3.6 - 4.4	3.8	3.9
		4	-- --	3.8 - 5.1	4.2	--
		5	2.4 - 5.2	4.1 - 5.2	4.6	4.2
August 1-2	2,200	1	-- --	4.7 - 5.6	5.2	--
		2	-- --	4.7 - 5.4	5.2	--
		3	5.0 - 5.8	5.0 - 5.8	5.4	5.4
		4	-- --	5.2 - 5.9	5.5	--
		5	5.3 - 6.1	5.2 - 5.6	5.5	5.5

of dissolved oxygen in flow of the Angelina River at site 5 during daylight hours averaged 4.6 mg/L. The dissolved-oxygen deficit for sites 1 and 5 during daylight hours averaged 5.1 and 3.9 mg/L, respectively. Velocity of the flow in the reach averaged about 2.0 ft/s; and time of travel averaged about 10 hours.

A comparison of these data with those for phase 1 indicates that the increases in the time of travel and dissolved-oxygen deficit for releases during phase 2 resulted in an increase in aeration. Part of the increase of dissolved oxygen in the flow at site 5 resulted from the inflow of more highly oxygenated backwater from the McGee Bend reach on July 27. Interruption of releases from the reservoir on July 26 allowed the more highly oxygenated backwater resulting from 1.77 inches of rainfall to pass from McGee Bend through the reach on July 27 (fig. 3 and table 4).

Phase 3 (August 1 and 2, 1979)

The concentration of dissolved oxygen in releases from the reservoir at site 1 during daylight hours on August 1 and 2 ranged from 4.7 to 5.6 mg/L. Water temperature ranged from 24.5° to 26.0°C; ph ranged from 6.3 to 6.6; and specific conductance was 165 micromhos. A comparison of these data (table 4) with data for site C_C in Sam Rayburn Reservoir on July 16 and 31 (table 3) indicates that most of the water was withdrawn from the reservoir at a depth interval between 20 and 30 feet below the water surface.

The concentrations of dissolved oxygen during daylight hours on August 1 and 2 averaged 5.2 mg/L at site 1 and 5.5 mg/L at site 5. The dissolved-oxygen deficits for sites 1 and 5 averaged 3.1 and 2.7 mg/L, respectively. The 0.3-mg/L increase in the average concentration of dissolved oxygen between sites 1 and 5 indicates that aeration of the Angelina River is very low.

A comparison of dissolved-oxygen data for Sam Rayburn Reservoir and the dissolved-oxygen data and hydraulic properties for the Angelina River during the three phases of the study shows that time of travel and dissolved-oxygen deficit are the dominant factors that affect aeration of the river. The comparison shows generally that the aeration is insignificant during periods of large releases when the time of travel through the reach is small, but increases during periods of low releases when the time of travel and the dissolved-oxygen deficit are large. The dissolved-oxygen deficit of the releases is related to the pattern of stratification in the reservoir and the depth interval from which the water is withdrawn, both of which are affected by the rate and pattern of releases.

SUMMARY OF CONCLUSIONS

Most of the critical conditions that affect the concentrations of dissolved oxygen in releases from Sam Rayburn Reservoir are related to thermal stratification in the reservoir. The concentrations of dissolved oxygen in releases usually begin to decrease in March or April after the onset of stratification and often approaches zero by late summer and early fall.

Water at site C_C, a deep site near Sam Rayburn Dam, was thermally stratified throughout the duration of a three-phase study conducted in July and August 1979 to determine the effects of varying the release rate on the aera-

tion capacity of the Angelina River. The concentration of dissolved oxygen on July 16 decreased from 7.6 mg/L near the water surface to 1.1 mg/L near the reservoir bottom. The concentration of dissolved oxygen on July 31 decreased from 6.5 mg/L near the water surface to 0.2 mg/L near the reservoir bottom. Water below the thermocline at depths of about 30 to 40 feet contained less than 1.3 mg/L of dissolved oxygen.

Flows in the 14-mile reach of the Angelina River downstream from the power-outlet works at Sam Rayburn Dam, except for minor amounts of local runoff, were sustained by releases through the power outlet. The depth interval from which the releases were withdrawn was related to the rate and pattern of releases. Most of the water was withdrawn from the depth interval between 25 and 30 feet when releases were maintained at 8,800 ft^3/s and between 20 and 30 feet when releases were maintained at 2,200 ft^3/s.

The concentration of dissolved oxygen in the releases depended upon the depth interval in the reservoir from which the water was withdrawn. The dissolved-oxygen content of the water averaged 5.0 mg/L when the releases were maintained at 8,800 ft^3/s and 5.2 mg/L when the releases were maintained at 2,200 ft^3/s.

Deoxygenation of the water in the 14-mile reach of the Angelina River downstream from the power outlet exceeded aeration when the releases were maintained at 8,800 ft^3/s, but aeration exceeded deoxygenation slightly when the releases were decreased. The average concentration of dissolved oxygen in the water decreased from 5.0 mg/L at site 1 near the power outlet to 4.8 mg/L at site 5 near the headwaters of B. A. Steinhagen Lake when releases were maintained at 8,800 ft^3/s. The average concentration of dissolved oxygen in the reach increased from 5.2 to 5.5 mg/L when releases were maintained at 2,200 ft^3/s.

The dominant factors that affected aeration of the Angelina River were the time of travel through the 14-mile reach and the dissolved-oxygen deficit of the releases. The time of travel in the reach averaged about 8 hours when releases were maintained at 8,800 ft^3/s and about 20 hours when releases were maintained at 2,200 ft^3/s. The dissolved-oxygen deficits of the releases during these periods averaged 3.0 and 3.1 mg/L, respectively.

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