Intensive Survey of Sulphur River Segment 0303 August 13-17, 1984

Texas Water Commission

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INTENSIVE SURVEY OF
SULPHUR RIVER
SEGMENT 0303

August 13-17, 1984

Hydrology, Field Measurements
and Water Chemistry

By
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TEXAS WATER COMMISSION

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FOREWORD

Effective September 1, 1985, the Texas Department of Water Resources was divided to form the Texas Water Commission and the Texas Water Development Board. A number of publications prepared under the auspices of the Department are being published by the Texas Water Commission. To minimize delays in producing these publications, references to the Department will not be altered except on their covers and title pages.

ABSTRACT

An intensive survey was conducted on Segment 0303 of the Sulphur River by the Texas Department of Water Resources on August 13-17, 1984. The purpose of the survey was to document water quality in the segment and to evaluate the impact of a discharge from the City of Commerce wastewater treatment plant. The study was conducted during low flow conditions. The upstream reaches of the South Sulphur River and a number of tributaries were dry at the time. Stream flow in the segment originated from the Commerce treatment plant outfall and increased downstream. Most of the segment has been channelized by the U. S. Army Corps of Engineers for flood control. During low flow conditions stream velocities are very low and there are no riffle areas or turbulence to promote reaeration. Nutrient materials discharged from the plant encourage high levels of algal production in the quiet pools downstream of the outfall. Algal respiration and decaying algae cells contribute to depressed dissolved oxygen levels in the segment.

TABLE OF CONTENTS

TABLES

TABLE OF CONTENTS CONTINUED

Page

FIGURES

INTENSIVE SURVEY OF

SULPHUR RIVER

SEGMENT 0303

INTRODUCTION

DIRECTIVE

This intensive survey was accomplished in accordance with the Texas Water Code, Section 26.127, as amended in 1985. The report is to be used in developing and maintaining the State Water Quality Strategy, and for the purposes listed below.

PURPOSE

The purpose of this intensive survey was to provide the Texas Department of Water Resources with a valid information source to:

1. determine quantitative cause and effect relationships of water quality;

2. obtain data for updating water quality management plans, setting effluent limits, and where appropriate, verifying the classifications of segments;

3. set priorities for establishing or improving pollution controls; and

4. determine any additional water quality management actions required.

METHODS

Field and laboratory procedures used during this survey are described in Appendix A. Field data and water samples were collected on August 13 and 14, 1984 by the Texas Department of Water Resources Water Quality Assessment Unit personnel. Time-of-travel studies were completed on August 17. Laboratory analyses were conducted by the Texas Department of Health Chemistry Laboratory in Austin, Texas. Parametric coverage, sampling frequencies and spatial relationship of sampling stations are consistent with the objectives of the survey and with known or suspected forms and variability of pollutants entering the segments.

RESULTS AND DISCUSSION

Segment 0303 consists of the Sulphur and South Sulphur Rivers from the headwaters of Lake Wright Patman in extreme northeast Texas to the headwaters of the South Sulphur River in Fannin County. The drainage area consists of approximately 7,500 square kilometers and includes parts of 11 counties. The area is mostly rural with ranching and dairy farming being the principal industries. Some oil production, notably the Talco Oil Fields, also takes place within the watershed.

The Sulphur River and tributary flood plains are subject to frequent floods which may occur at any season of the year. Portions of the South Sulphur, North Sulphur, Middle Sulphur Rivers and Brushy and Cuthand Creeks have been channelized and leveed to provide partial protection to agricultural flood plain areas since the early 1900's (USCE, 1977). Silt and debris have accumulated in the older channels, altering the channel bottom gradient and obstructing flow. The result is elongnated pools of shallow standing water during low flow conditions.

A multi-purpose reservoir impounding the South Sulphur and Middle Sulphur Rivers was proposed in 1950. Construction was scheduled to began in the 1970's, however environmental concerns and budget deficiencies have caused extensive delays. The reservoir will inundate approximately 78.1 Km^2 (19,305) acres of land in Delta County and back water about 33.8 kilometers (21 miles) up the South Sulphur River from the dam site southeast of Cooper.

Major urban centers in the Sulphur River Basin include cities of Commerce, 1980 population 8,136; Cooper, 2,338; Sulphur Springs, 12,804; Mount Vernon, 2,025 and Clarksville, 4,917. The City of Commerce wastewater treatment plant is the only direct point source of wastewater to the segment. The cities of Sulphur Springs and Mount Vernon discharge wastewater into White Oak Creek which merges with the Sulphur River near the headwaters of Lake Wright Patman. The cities of Cooper and Clarksville discharge their wastewater into Doctors Creek and Cuthand Creek, respectively. Other communities in the watershed operate small treatment plants which discharge into tributaries to the segment. Most of the tributaries are intermittent in nature and the relatively small discharges have little impact on the Sulphur River. Texas Power and Light Company pumps water from the Sulphur River to an off channel cooling pond located near Talco. Water is circulated through their plant back to the pond. Excess water is discharged to the river, however, discharges are made infrequently.

The Texas Department of Water Resources has developed specific numerical criteria for selected parameters in all state waters (TWC, 1985). Water uses deemed desirable in Segment 0303 and water quality criteria considered appropriate to meet these uses are presented in Table 2. The segment is classified as water quality limited primarily due to recurrent violations of the dissolved oxygen criterion of 5.0 mg/L (TDWR, 1984).

3

Intensive monitoring surveys were conducted on portions of Segment 0303 by the Department in August 1974 and in July 1979. Both surveys documented low levels of dissolved oxygen in the South Sulphur River downstream of the City of Commerce treatment plant outfall. The plant outfall is located in the area which had been channelized by the U. S. Corps of Engineers. During dry periods there is little or no flow upstream of the plant outfall and a pool of almost stagnant water downstream. Water in this pool was eutrophic due to the accumulated carbonaceous and nitrogenous oxygen demand in the plant effluent (Twidwell, 1976 and Respess, 1980). The City of Commerce replaced its wastewater treatment plant with a new facility at the same location in March, 1983. The new plant was designed to meet future, as well as present, needs and is currently operating at less than its full capacity. The plant had been discharging an average of .06 m³/s (1.36 mgd) for the twelve month period proceeding this survey.

This survey was conducted during August 13-17, 1984. Sampling stations were established at the City of Commerce treatment plant outfall, along the mainstem of the South Sulphur and Sulphur Rivers and on each flowing tributary. Mainstem stations were more closely spaced in the reach down-stream of the plant outfall and more widely spaced in the lower reaches (Figure 1). Measurements of dissolved oxygen, temperature, conductivity and pH were made four times during the diel period on August 13th and 14th at most mainstem stations and major tributaries. Minor tributaries were sampled only once during the period. Data are presented in Table 3.

Dissolved oxygen levels in the treatment plant effluent (Station 1) averaged 7.0 mg/L with little variation during the 24-hour period. The diel range of dissolved oxygen levels was much greater in the pooled area downstream of the outfall, due to algal photosynthesis (Figure 2). The widest diel range of dissolved oxygen observed occurred at Station H (5.6 to 13.2 mg/L), while the highest dissolved oxygen level observed (14.6 mg/L) occurred at Station F. Supersaturated dissolved oxygen conditions (> 110% saturation) existed for part of the day at each of the stations in this reach. Minimum dissolved oxygen levels in this reach were all above the criterion of 5.0 mg/L; however, measurements were not made at Stations F and G early in the morning when the lowest dissolved oxygen level of the day normally occurs. The daily average dissolved level in this reach was higher than levels observed on the 1979 survey (Figure 3). This reach was not sampled extensively during the 1974 survey.

Dissolved oxygen levels were depressed at Stations I and J. The diel range of dissolved oxygen at Station I was 2.4 to 6.8 mg/L and only 3.0 to 4.4 mg/L at Station J. This area had received an unknown amount of runoff from localized showers the week before the survey. The water in this reach was somewhat turbid although stream flow was not elevated.

Dissolved oxygen levels in the lower reaches of the segment, Station K through W, were generally higher and more stable. Most measurements fell between 5.8 and 9.7 mg/L except for two low measurements of 4.0 and 4.4 mg/L at Station O and a high measurement of 10.2 mg/L at Station R. Low levels of dissolved oxygen were observed in Honey Creek (0.0 mg/L), and Doctors Creek (0.9 mg/L). Water in Honey Creek was turbid with no visible flow while Doctors Creek was clear and flowing.

Most pH measurements were within minimum-maximum criteria range (6.0-8.5 standard units). Levels of pH at Stations E, F, G, and H were elevated above the maximum criterion during the afternoon hours. The rise in pH corresponded to the diel rise in dissolved oxygen levels during the daylight hours and is attributed to algal metabolic activities.

Average mainstream conductivity levels ranged from 390 μmhos/cm at Station T to 879 μmhos/cm at Station Q. The North Fork of the Sulphur River and Cuthand Creek were somewhat more highly mineralized with conductivity levels of 1,332 and 1,300 μmhos/cm, respectively. Water temperatures were high as expected in midsummer, ranging up to 30.7°C (87.3°F) in the river and somewhat higher in some tributaries.

Water samples were collected over a diel period at most stations and composited before delivery to the laboratory. Four separate grab samples were collected at the treatment plant outfall in addition to the composite sample. Single grab samples were collected on minor tributaries (Table 4).

The treatment plant effluent was clear with total suspended solids (TSS) of 10 mg/L and a carbonaceous oxygen demand ($CBOD_5$) averaging 2.4 mg/L. Nutrient levels in the effluent were high, nitrate nitrogen 11.98 mg/L and ortho-phosphorus 4.21 mg/L in the composited sample. Nitrite nitrogen and ammonia nitrogen levels were below detectable levels of 0.01 mg/L and 0.02 mg/L, respectively.

Total suspended solids levels were higher in the pooled area downstream of the plant outfall, made up mostly of algal cells. $CBOD_5$ levels were also higher due to algal respiration and cell decay. Chlorophyll a levels were very high at Station F (144 μg/L) but lower at downstream stations (3 μg/L at Station J). Nutrient levels also declined from high levels at Station C to very low levels at Station K due to algal uptake (Figure 4). Nitrate nitrogen levels in the downstream reaches of the segment were mostly below detectable levels while ortho-phosphorus levels ranged from 0.01 to 0.8 mg/L. The highest level of ammonia nitrogen detected was in Doctors Creek (0.68 mg/L) which receives treated wastewater from the City of Cooper. Ortho-phosphorus levels in the creek were also elevated, 5.36 mg/L. $CBOD_5$ levels in the lower reaches of the segment ranged from 1 mg/L at Station J to 3 mg/L at Station Q. TSS levels ranged from 33 to 91 mg/L. Chlorophyll a levels became elevated at Stations S and T (38 μg/L and 36 μg/L, respectively) but did not reach concentrations as great as those in the pooled area upstream.

Chloride and sulfate levels were low and relatively consistent in the Sulphur and South Sulphur Rivers. Chloride levels ranged from 15 to 74 mg/L and sulfate levels ranged from 21 to 158 mg/L. Specific conductance ranged from 411 to 966 μmhos/cm at the mainstream stations. Conductivity was somehow higher in the tributary streams, 1,540 μmhos/cm at Stations QA and 1,507 μmhos/cm at Station TA. Levels of chloride, sulfate and total dissolved solids were also higher in these two tributary stations than levels found in the Sulphur River.

The survey was conducted under low flow conditions. A few localized showers had fallen near Cooper in Delta County the week prior to the survey. Although the area covered by the rain was small, there was some runoff which may have had some impact on the flow patterns in the river. The South Sulphur River was dry at FM 1218 upstream of the City of Commerce wastewater treatment plant. A pool of standing water originated at the outfall and extended downstream. The maximum discharge from the plant during the survey was 0.026 cubic meters per second (m^3/s) (0.93 ft^3/s) and the minimum discharge observed was 0.004 m^3/s (0.15 ft^3/s) (Table 5). Stream flow measurements in the South Sulphur ranged from 0.021 m^3/s (0.73 ft^3/s) at Station K to 0.46 m^3/s (1.64 ft^3/s) at Station Q. Tributary inflow to the South Sulphur River, including the North Sulphur River totaled 0.032 m^3/s (1.14 ft^3/s). The flow at Station S downstream of the confluence was 0.274 m^3/s (9.68 ft^3/s). Flow was lower at Stations T and U, 1.204 m^3/s and 0.155 m^3/s respectively (7.22 ft^3/s and 5.46 ft^3/s). Flow again increased at Station V, 3.00 m^3/s (10.47 ft^3/s) and Station W, 0.559 m^3/s (19.73 ft^3/s). Cuthand Creek which merges with the river between Stations U and V was contributing 0.021 m^3/s (0.74 ft^3/s).

Stream velocities were very low in the South Sulphur River, 0.009 m/s in the reach downstream of the discharge (Table 6). The highest velocity observed (0.061 m/s) was in the reach between Stations T and U. This reach had recently been channelized, the sides were straight, and the bottom clean and smooth. Areas which had been channelized for a number of years were originally straight and smooth; however, washed in debris, mud bars and bank cave-ins tend to occasionally impede stream flow in the older channels.

Flow was not measured in White Oak Creek which runs roughly parallel to the lower reaches of the Sulphur River. White Oak Creek is also channelized and has many of the same characteristics of the Sulphur River. White Oak Creek merges with the Sulphur River downstream of Station W.

CONCLUSIONS

Highly eutrophic conditions exist in the upstream reaches of the South Sulphur River. Stream flow in this reach is dominated by wastewater from the City of Commerce treatment plant during low flow conditions. High levels of nitrate nitrogen and ortho-phosphorus create favorable conditions conducive to algal blooms in the pooled area downstream of the outfall. Poor quality water in Honey Creek and Doctors Creek also contribute to the problem. The large standing crop of algae efficiently assimilates the nutrients; however, algal respiration and cell decay contribute to depressed dissolved oxygen levels further downstream.

Water quality in the South Sulphur River appears to have improved significantly as a result of the new treatment plant at Commerce. Although algal production was still high, the dissolved oxygen sag downstream of the plant outfall was less pronounced. Average dissolved oxygen levels were higher and only a few measurements of less than 5.0 mg/L were observed during this study.

The Sulphur River is classified as suitable for contact recreation and high quality aquatic life habitat. In reality, the artificially straightened channels and enriched waters have little potential for recreational pursuits. Public access to the river is also limited.

The greatest foreseeable impact on Segment 0303 will be the construction of Cooper Dam and Reservoir on the South Sulphur River near Cooper. This project has been planned since 1955, however environmental considerations and budget restraints have caused long delays. It now appears construction may begin in the near future. The reservoir will completely change the nature of the Sulphur River. Backwater will extend up the South Sulphur River almost to Commerce and up Doctors Creek to Cooper. Eutrophic conditions now existing in the river will probably extend into the headwaters of the reservoir. Water quality downstream of the dam, however, will probably be enhanced. The proposed dam is designed to permit selective withdrawal of water avoiding the release of oxygen deficient water from the hypolimnion when the lake becomes stratified in the summer. The operating plan also calls for a continuous minimum release of at least 0.142 m^3/s (5.0 ft^3/s) during the summer months. The dam will also entrap sediment and algae, releasing clear water.

7

PRESENTATION OF DATA

TABLE 1

Description of Sampling Stations

Station Number	Description	River Kilometer
1	City of Commerce STP outfall	81.9
A	South Sulphur River at FM 1218	82.5
C	South Sulphur River 600 meters downstream of STP outfall	81.3
D	South Sulphur River at SH 11	79.7
E	South Sulphur River 300 meters downstream of railroad bridge	78.4
F	South Sulphur River 1300 meters downstream of railroad bridge	77.4
G	South Sulphur River 2000 meters upstream of SH 71	73.9
H	South Sulphur River at SH 71	71.9
I	South Sulphur River at Deep Well Crossing southeast of Cooper	50.2
J	South Sulphur River at Harpers Crossing southeast of Cooper	42.3
K	South Sulphur River at SH 19	31.8
P	South Sulphur River near Red Branch	8.2
Q	South Sulphur River north of Sulphur Bluff	5.3
R	Sulphur River at SH 37	196.4
S	Sulphur River at SH 271	176.5

TABLE 1 CONTINUED

Description of Sampling Stations

Station Number	Description	River Kilometer
T	Sulphur River at FM 2152	163.2
U	Sulphur River near Harts Bluff	151.6
V	Sulphur River upstream of US 259	100.0
W	Sulphur River at US 259	94.2
IA	Honey Creek south of Cooper	58.2/2.0*
JB	Doctors Creek near Cooper	39.1/5.6
QA	North Sulphur River near Bogata	0.0/5.6
QB	Sandy Creek at FM 1497	7.3/1.7
TA	Cuthand Creek at FM 1487	133.8/14.2
WA	White Oak Creek at US 259	75.4/15.8

* Location of confluence/distance up tributary to sampling point
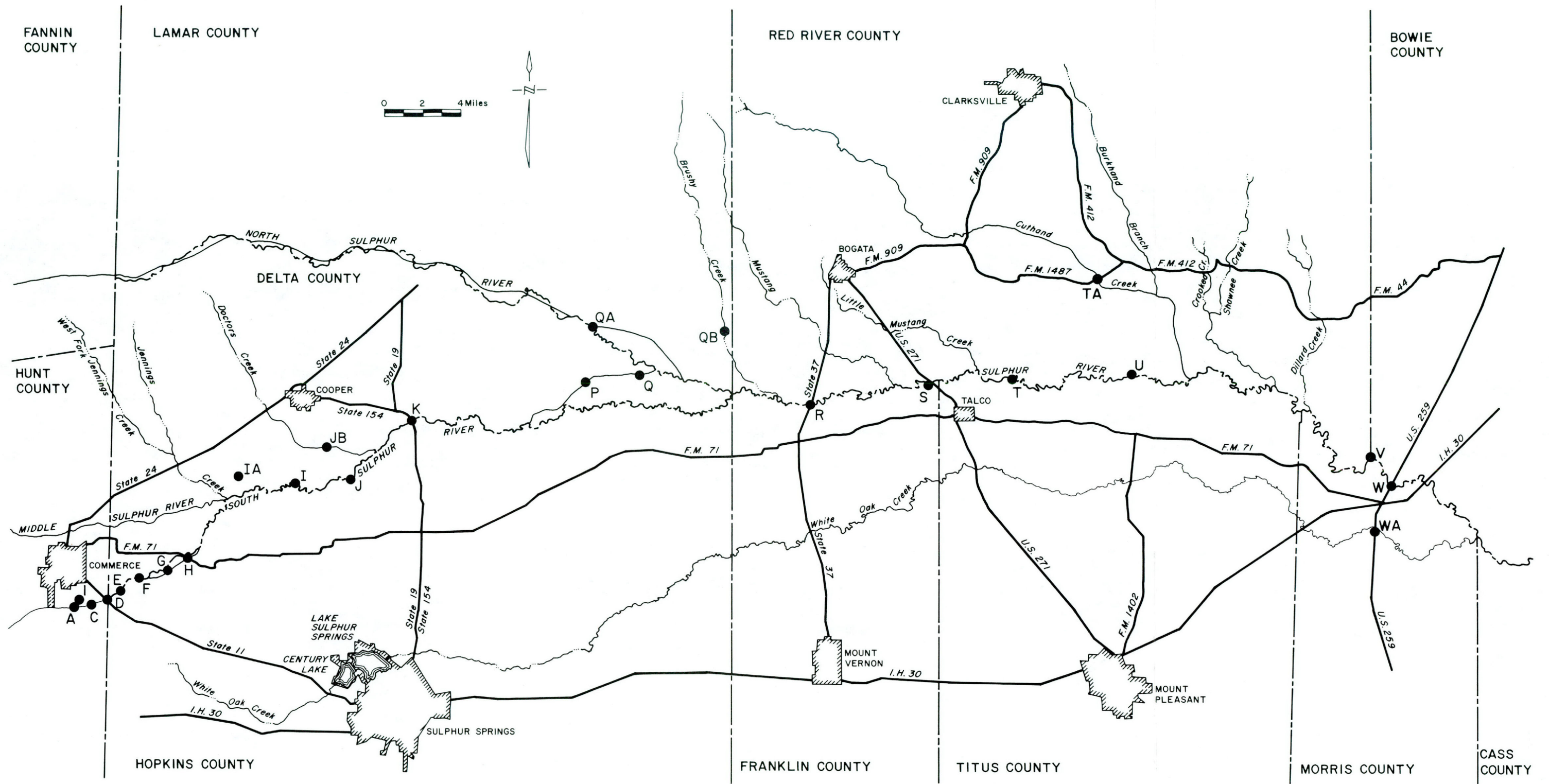
Figure 1
Map of Survey Area

TABLE 2

Texas Surface Water Quality Standards
For Segment 0303 of the Sulphur River

SULPHUR RIVER BASIN		USES				CRITERIA						
SEGMENT NUMBER	SEGMENT NAME	RECREATION	AQUATIC LIFE	DOMESTIC WATER SUPPLY	OTHER	CHLORIDE (mg/L) Annual Average not to exceed	SULFATE (mg/L) Annual Average not to exceed	TOTAL DISSOLVED SOLIDS Annual average not to exceed	DISSOLVED OXYGEN Not less than	pH RANGE	FECAL COLIFORM (#/100 mls) Thirty-day geometric mean not to exceed	TEMPERATURE °F Not to exceed
0303	Sulphur/South Sulphur River	CR	H	No	None	60	150	600	5.0	6.0-8.5	200	95

12
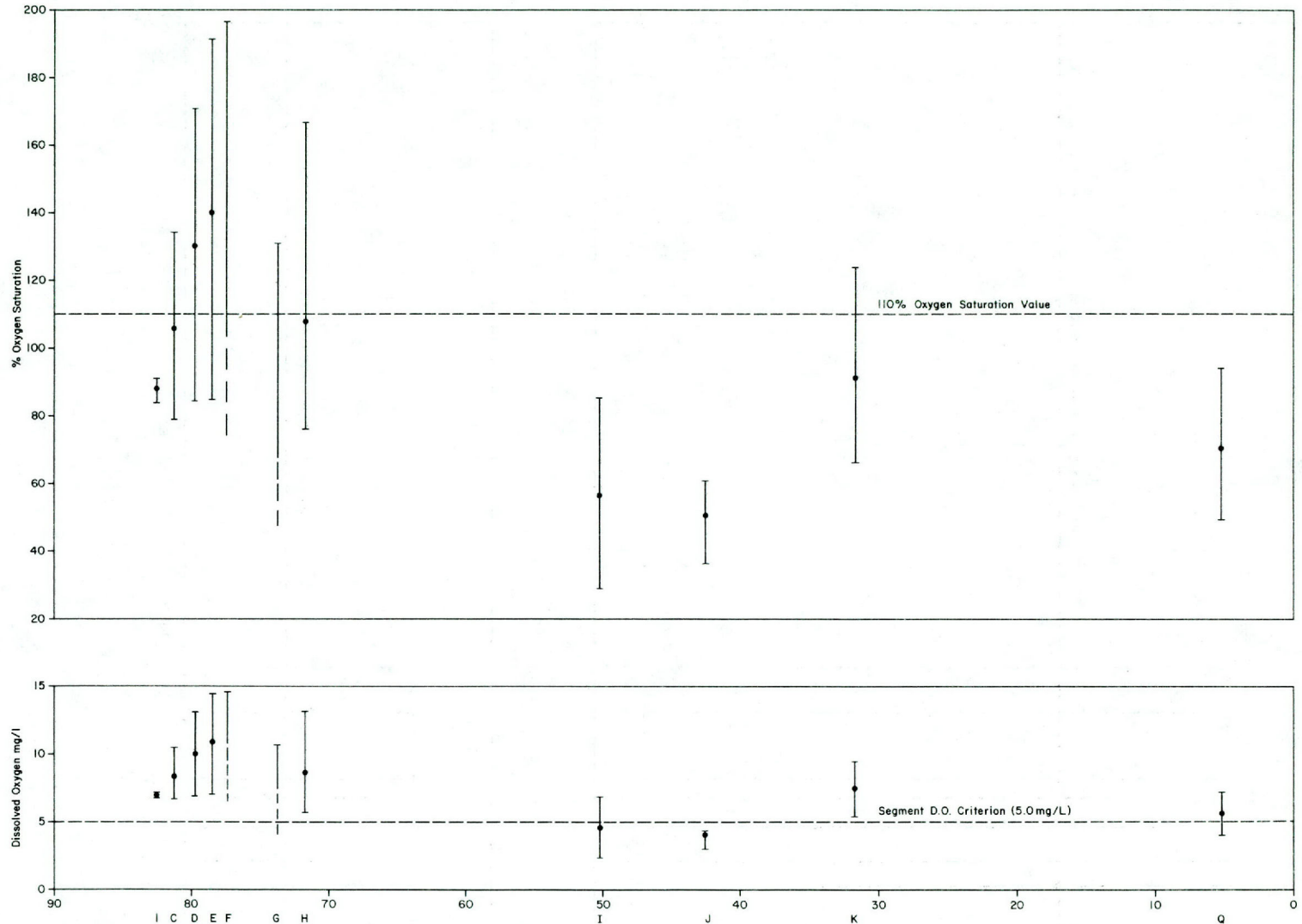
Figure 2
Range and Mean of Dissolved Oxygen Levels and Percent
Saturation From the South Sulphur River by River Kilometer and
Station Number, August 13 and 14, 1984
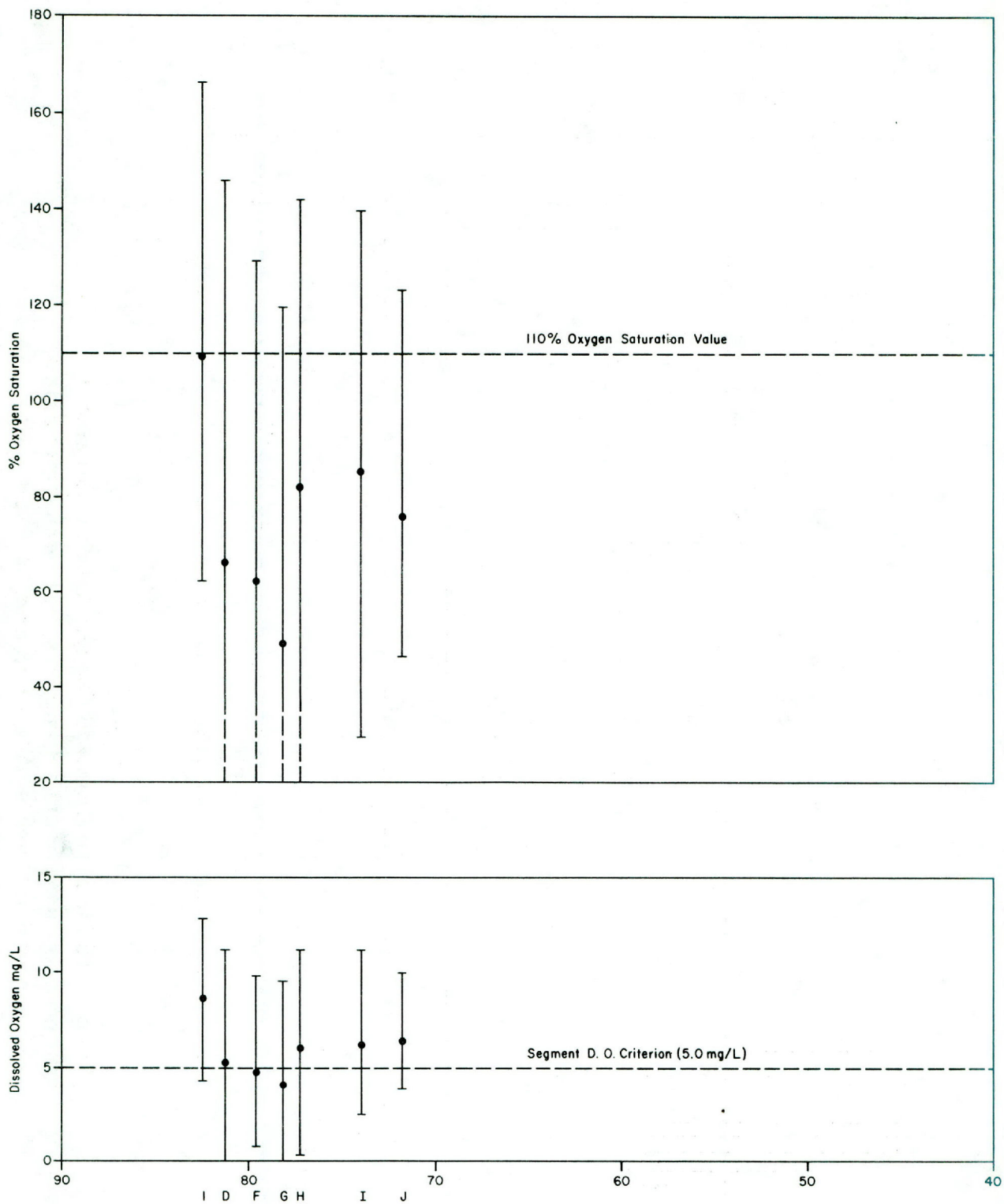
Figure 3
Range and Mean of Dissolved Oxygen Levels and Percent Saturation From the
South Sulphur River by River Kilometer and Station Number, July 18, 1979

14
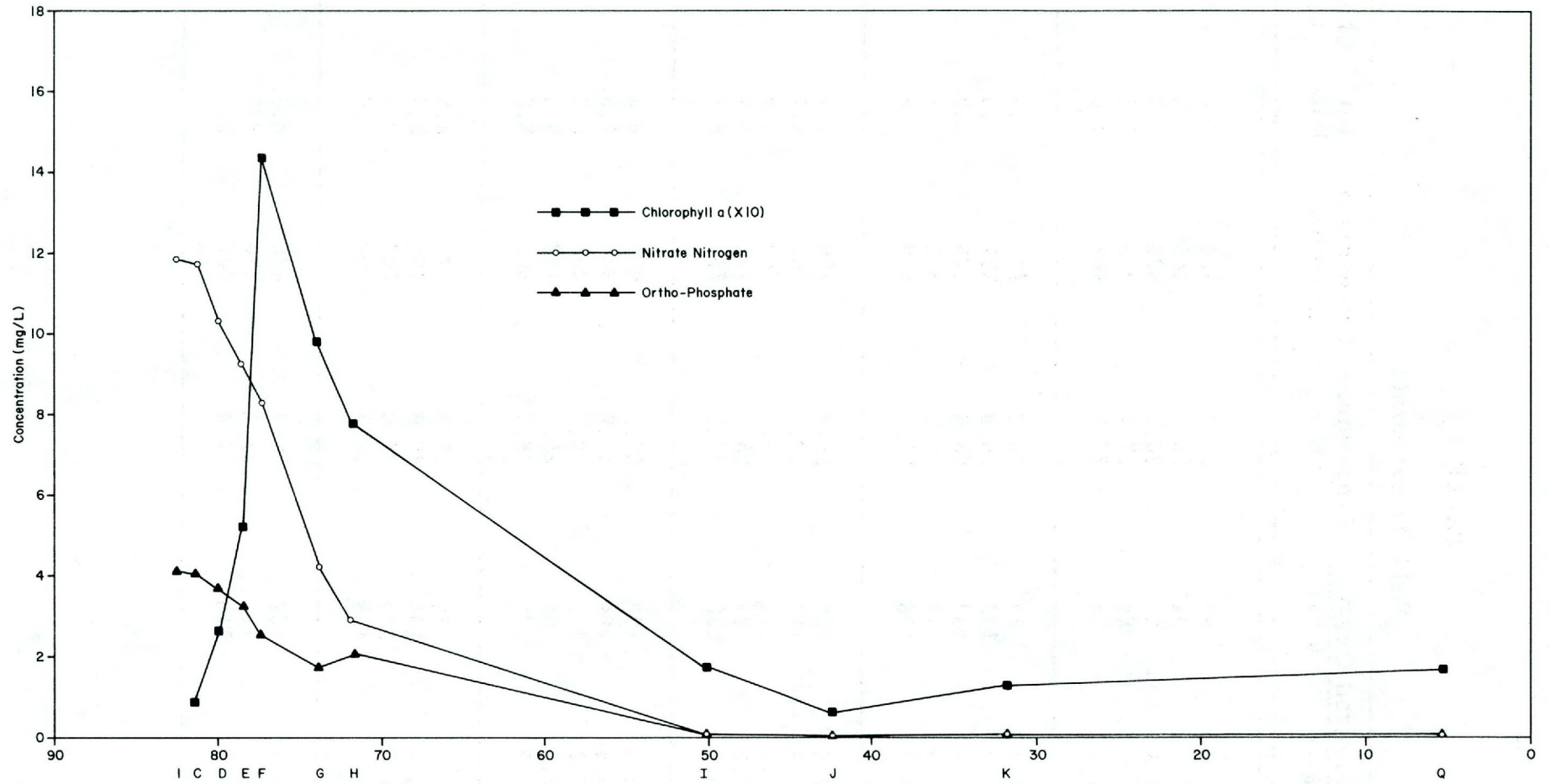
Figure 4
Nitrate Nitrogen, Ortho-Phosphate and Chlorophylla Levels From the
South Sulphur River by River Kilometer and Station Number,
August 13 and 14, 1984

15

TABLE 3

Field Measurements

Time Hours	Station Number	Dissolved Oxygen mg/L	% Sat	Temperature °C	Conductivity μmhos/cm	pH Units	Chlorine mg/L
0910	1	6.9	86	27.4	834	7.0	3.4
1452		7.1	91	29.1	846	7.5	0.7
1852		7.1	90	28.1	876	7.6	1.9
0512		6.8	84	27.1	879	7.2	1.3
x̄d		7.0	88	27.9	862	7.3	
0930	C	7.2	88	26.2	783	7.4	
1523		9.2	123	30.9	801	7.9	
1917		10.5	134	28.4	825	8.2	
0534		6.6	79	25.1	841	7.7	
x̄d		8.4	106	27.5	816	7.8	
1000	D	7.8	96	26.2	778	7.7	
1538		12.9	172	30.7	763	8.7	
1930		13.1	173	29.9	749	8.8	
0555		6.9	84	25.2	771	8.1	
x̄d		10.0	130	27.9	764	8.3	
1115	E	9.9	126	27.9	811	8.3	
1605		14.5	194	30.9	806	9.0	
1953		13.7	176	28.7	801	8.9	
0624		7.0	85	25.7	798	8.4	
x̄d		10.9	140	28.0	803	8.6	
1045	F	12.1	152	27.4	790	8.5	
1625		14.6	195	30.6	786	9.4	
2016		11.0	140	28.0	794	9.3	
x̄d		12.2	156	28.3	791	9.0	
1155	G	8.1	102	27.4	665	8.8	
1700		10.6	133	27.4	673	9.2	
x̄d		9.4	118	27.4	669	9.0	

16

TABLE 3 CONTINUED

Field Measurements

Time Hours	Station Number	Dissolved Oxygen mg/L	% Sat	Temperature °C	Conductivity µmhos/cm	pH Units	Chlorine mg/L
0900	H	5.6	69	25.8	581	8.3	
1430		7.8	99	27.7	587	8.7	
1850		13.2	167	28.0	594	9.1	
0515		6.7	80	25.2	619	8.7	
x̄d		8.7	108	26.7	597	8.7	
0935	I	2.4	29	24.8	628	7.4	
1515		5.0	65	28.7	639	7.7	
1930		6.8	85	27.4	640	7.9	
0540		3.1	37	24.4	668	7.6	
x̄d		4.5	56	26.3	646	7.7	
1020	J	3.0	36	25.0	567	7.5	
1540		4.0	50	27.4	568	7.6	
1950		4.0	61	27.1	568	7.6	
0600		4.4	52	24.3	588	7.5	
x̄d		4.2	51	25.9	574	7.5	
1045	K	5.4	66	26.1	749	7.8	
1630		9.4	124	29.7	741	8.1	
2020		8.4	107	27.7	755	8.0	
0630		6.4	77	24.6	792	7.8	
x̄d		7.4	93	26.8	762	7.9	
0935	Q	4.4	52	24.5	1012	7.1	
1405		6.2	80	29.3	839	7.3	
1855		7.1	94	29.8	850	7.4	
0555		4.0	49	26.0	862	7.2	
x̄d		5.5	70	27.6	879	7.3	
1022	QA	9.1	113	27.1	1335	7.7	
1554		8.2	123	36.3	1315	8.5	
1920		8.0	107	31.0	1320	8.2	
0627		7.0	83	13.8	1352	7.4	
x̄d			104	29.0	1332	7.9	

17

TABLE 3 CONTINUED

Field Measurements

Time Hours	Station Number	Dissolved Oxygen mg/L	% Sat	Temperature °C	Conductivity µmhos/cm	pH Units	Chlorine mg/L
1050	R	6.4	81	28.2	856	7.2	
1526		7.0	93	30.2	870	7.4	
1945		10.2	135	30.2	840	7.7	
0650		5.2	65	27.5	830	7.3	
x̄d		8.0	96	29.0	845	7.4	
1120	S	6.7	84	27.3	425	7.2	
1500		8.2	106	28.7	431	7.6	
2010		7.9	100	28.1	452	7.5	
0713		6.4	79	26.4	492	7.4	
x̄d		7.3	92	27.5	456	7.4	
1120	T	6.5	82	27.6	409	6.7	
1512		6.9	90	29.5	397	7.1	
1820		8.4	107	28.5	389	7.6	
0605		7.1	88	27.0	379	7.5	
x̄d		7.4	93	27.9	390	7.3	
1220	TA	7.8	99	27.7	1380	7.5	
1620		10.1	139	32.1	1373	7.6	
2027		9.9	131	30.2	1371	7.8	
0540		5.8	71	25.8	1390	7.7	
x̄d		8.1	105	28.5	1380	7.7	
1040	U	6.4	79	27.0	530	6.3	
1553		9.7	125	29.3	527	8.4	
1950		8.1	104	28.8	524	7.5	
0702		6.4	83	26.4	510	7.5	
x̄d		7.6	97	27.8	521	7.5	
1350	W	6.7	85	28.3	713	7.4	
1720		7.1	91	28.9	713	7.4	
2140		7.2	89	27.7	715	7.5	
0450		6.7	83	26.4	712	7.4	
x̄d		6.9	86	27.6	713	7.4	

TABLE 3 CONTINUED

Field Measurements

Time Hours	Station Number	Dissolved Oxygen mg/L	% Sat	Temperature °C	Conductivity μmhos/cm	pH Units	Chlorine mg/L
1410	WA	6.4	82	29.2	498	6.8	
1730		7.5	98	29.4	499	7.2	
2150		6.0	74	27.1	494	7.2	
0425		5.1	63	25.9	495	7.0	
$\bar{x}d$		6.0	76	27.6	496	7.0	
1815	IA	0.0	00	26.8	315	7.8	
1940	JB	0.9	12	26.7	85	9.7	
1045	QA	8.4	105	27.5	950	8.2	
1047	QB	8.0	98	25.8	228	8.2	
1350	TA	10.9	154	33.3	560	7.6	

TABLE 4

Laboratory Water Analyses

Station Number	BOD5 N-Supp. mg/l	Filt., BOD5 N-Supp. mg/l	BOD20 N-Supp. mg/l	Filt., BOD20 N-Supp. mg/l	TSS mg/l	VSS mg/l	Filt. TOC mg/l	Kjel-N mg/l as N	Org. N mg/l as N	NH3-N mg/l as N	NO2-N mg/l as N	NO3-N mg/l as N	NO2-N + NO3-N mg/l as N	T-N mg/l as N	O-P mg/l as P	T-P mg/l as P	Chl. a μg/l	Pheo. a μg/l as P	Cl mg/l	SO4 mg/l	TDS mg/l	T-Alk. mg/l as CaCO3	Cond. μmhos/cm	pH
Grab 1 1	2.5	2.5	4	4	<10	<10	7	0.8	0.8	<0.02	<0.01	11.38	11.38	12.18	4.16	4.27	---	--	62	69	478	177	846	7.4
Grab 2 1	2.5	2.0	5	3.5	<10	<10	7	1.2	1.15	0.05	<0.01	13.02	13.02	14.22	4.10	4.20	---	--	62	71	492	176	876	7.5
Grab 3 1	2.5	2.0	4	3	<10	<10	7	1.0	1.0	<0.02	<0.01	12.37	12.37	13.37	4.03	4.26	---	--	63	71	526	187	900	7.5
Grab 4 1	2	2	3.5	3	<10	<10	5	1.1	1.1	<0.02	<0.01	10.42	10.42	11.52	4.16	4.21	---	--	61	75	524	197	900	7.5
Comp 1	3	3	7	4.5	<10	<10	5	1.1	1.1	<0.02	<0.01	11.89	11.89	12.99	4.16	4.21	---	--	62	72	524	186	894	7.5
Comp C	1	1	2.5	2	40	10	6	1.2	1.12	0.08	0.07	11.72	11.79	12.00	4.03	4.21	9	6	61	68	480	171	834	7.9
Comp D	3	1	5	1.5	84	15	6	1.1	1.04	0.06	0.14	10.30	10.44	11.54	3.74	4.05	26	21	61	66	450	151	780	8.5
Comp E	6	4	15	4.5	69	15	6	1.4	1.36	0.04	0.15	9.25	9.40	10.80	3.23	3.65	52	19	63	71	464	170	822	8.7
Comp F	7	2	13	3	96	20	6	1.6	1.6	<0.02	0.12	8.25	8.37	9.97	2.54	3.08	144	16	61	74	450	166	810	9.1
Comp G	6	3	12	4	62	20	8	1.9	1.9	<0.02	0.14	4.20	4.34	6.24	1.70	2.16	98	31	55	70	398	148	690	9.0
Comp H	4.5	1	8.5	2.5	52	17	7	1.2	1.2	<0.02	0.07	2.93	3.00	4.20	2.10	2.34	78	21	43	58	344	142	600	8.4
Comp I	1.5	1	3	2	87	22	9	1.1	1.03	0.07	0.04	0.19	0.23	1.33	0.34	0.49	17	5	50	58	385	178	670	7.8
Comp J	<1	<1	2	2	91	14	8	1.0	0.89	0.11	0.05	0.17	0.22	1.22	0.22	0.35	6	3	43	52	351	161	596	7.6
Comp K	1.5	<1	2.5	1.5	35	8	9	0.9	0.9	<0.02	0.01	0.03	0.04	0.94	0.08	0.14	13	8	58	59	464	230	800	7.9
Comp Q	3	2	5	3	36	8	7	1.1	1.1	<0.02	<0.01	0.04	0.04	0.14	0.02	0.07	17	7	74	127	538	193	966	7.8

TABLE 4 CONTINUED

Station Number	BOD5 N-Supp. mg/l	Filt., BOD5 N-Supp. mg/l	BOD20 N-Supp. mg/l	Filt., BOD20 N-Supp. mg/l	TSS mg/l	VSS mg/l	Filt. TOC mg/l	Kjel-N mg/l as N	Org. N mg/l as N	NH$_3$-N mg/l as N	NO$_2$-N mg/l as N	NO$_3$-N mg/l as N	NO$_2$-N + NO$_3$-N mg/l as N	T-N mg/l as N	O-P mg/l as P	T-P mg/l as P	Chl. a µg/l	Pheo. a µg/l as P	Cl mg/l	SO$_4$ mg/l	TDS mg/l	T-Alk. mg/l as CaCO$_3$	Cond. µmhos/cm	pH
Comp R	2.5	1	5	2	33	15	7	0.8	0.8	<0.02	<0.01	<0.01	<0.02	0.8	<0.01	0.06	9	29	65	158	530	157	936	7.9
Comp S	1.5	<1	4	1	42	11	9	1.1	1.1	<0.02	<0.01	<0.01	<0.02	1.1	0.01	0.08	38	8	21	39	262	145	462	8.0
Comp T	1.5	<1	4	2	50	16	11	1.0	0.97	0.03	<0.01	0.07	0.07	1.07	0.02	0.10	36	6	15	21	237	153	411	8.0
Comp U	1	<1	3.5	1	80	13	8	0.9	0.9	<0.02	<0.01	<0.01	<0.02	0.9	0.03	0.13	24	8	27	56	311	161	560	8.0
Comp W	2	1	6	3.5	40	15	8	0.8	0.8	<0.02	<0.01	<0.01	<0.02	0.8	0.02	0.07	7	5	47	96	446	185	780	7.9
Comp QA	3	1	7.5	2.5	39	21	7	1.3	1.3	<0.02	<0.01	<0.01	<0.02	1.3	<0.01	0.06	43	<2	190	289	794	52	1540	7.9
Comp TA	2	<1	5	2	41	13	6	0.6	0.6	<0.02	<0.01	<0.01	<0.02	0.6	0.52	0.66	23	7	152	115	812	346	1507	8.2
Comp WA	2	<1	2	2	50	13	9	1.2	1.2	<0.02	<0.01	<0.01	<0.02	1.2	0.02	0.15	29	14	57	30	272	119	516	7.5
Grab IA	5	2.5	11	6	34	14	14	2.4	2.35	0.05	0.04	0.57	0.61	3.01	0.26	0.42	24	6	7	9	94	55	155	7.5
Grab JB	1.5	<1	3.5	2	14	1	13	1.5	0.82	0.68	0.02	0.03	0.05	1.55	5.36	5.57	<2	2	55	77	386	139	675	7.5
Grab QA	3	1	7	2	28	11	7	1.6	1.6	<0.02	<0.01	0.01	0.02	0.62	<0.01	0.08	46	12	182	274	802	56	1485	8.1
Grab QB	2	1	3.5	2.5	14	4	4	0.5	0.5	<0.02	0.18	1.28	1.46	1.96	0.03	0.09	25	6	12	24	166	83	276	8.1
Grab TA	3	1	5.5	2.5	25	11	7	0.9	0.9	<0.02	<0.01	0.02	0.02	0.92	0.57	0.67	15	2	153	116	822	340	1507	8.4

TABLE 5

Flow Measurements

Station Number	Date	Time Hours	Method	Flow m³/s	Flow ft³/s
1	08/14/84	0910	Recorder	.026	0.93
1	08/14/84	1492	Recorder	.004	0.15
1	08/14/84	1852	Recorder	.026	0.93
D	08/15/84	1900	Flow Meter	.043	1.53
I	08/14/84	1850	Flow Meter	.027	0.95
J	08/16/84	1310	Flow Meter	.026	0.93
K	08/15/84	1107	Flow Meter	.021	0.73
Q	08/16/84	1100	Flow Meter	.046	1.64
S	08/16/84	1623	Flow Meter	.274	9.68
T	08/14/84	1140	Flow Meter	.204	7.22
U	08/16/84	0920	Flow Meter	.155	5.46
V	08/13/84	1935	Flow Meter	.296	10.47
W	08/16/84	1315	Flow Meter	.559	19.73
JB	08/13/84	1940	Flow Meter	.006	0.20
QA	08/14/84	1003	Flow Meter	.026	0.87
QB	08/14/84	1041	Flow Meter	.002	0.07
TA	08/14/84	1535	Flow Meter	.021	0.74

Chart recorder at STP outfall
Marsh-McBirney electronic flow meter

TABLE 6

Time-of-Travel

From Station	To Station	Distance Meters	Time Hours	Velocity	
				Meters/Second	Feet/Second
STP	C	600	17.42	.009	.03
K	K	650	7.43	.012	.04
P	Q	2450	86.0	.009	.03
T	U	11600	54.2	.061	.20
V	W	5800	55.4	.030	.10

TABLE 7

Stream Widths

Station Number	Range (meters)		Mean (meters)	Number of Measurements
C	22.0	– 5.8	8.4	9
H	10.7	– 4.0	6.0	10
I	8.8	– 2.4	6.0	14
J	10.3	– 4.9	6.4	15
K	11.3	– 4.0	6.6	19
Q	12.2	– 3.4	6.1	9
R			26.5	1
S			24.0	1
T	22.0	– 13.5	16.1	5
U	12.0	– 7.8	9.7	3
V	13.2	– 9.0	11.6	3
W	20.0	– 15.0	16.8	5

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APPENDIX A

FIELD AND LABORATORY PROCEDURES

The following methods are utilized for field and laboratory determina-
tions of specified physical and chemical parameters. Unless otherwise
indicated composite water samples are collected at each sampling sta-
tion and stored in polyethylene containers on ice until delivery to the
laboratory. Sediment samples are collected with a dredge or coring
device, decanted, mixed, placed in appropriate containers (glass for
pesticides analyses and plastic for metals analyses), and stored on
ice until delivery to the laboratory. Laboratory chemical analyses
are conducted by the Water Chemistry Laboratory of the Texas Department
of Health unless otherwise noted.

WATER ANALYSES

Field Measurements

Parameter	Unit of Measure	Method
Temperature	°C	Hand mercury thermometer, Hydrolab Model 60 Surveyor, or Hydrolab 4041.
Dissolved Oxygen (DO)	mg/l	Azide modification of Winkler titration method, Hydrolab Model 60 Surveyor, or Hydro-lab 4041.
pH	Standard Units	Hydrolab Model 60 Surveyor, Hydrolab 4041 or Sargent-Welch portable pH meter.
Conductivity	μmhos/cm	Hydrolab Model 60 Surveyor, Hydrolab 4041, or Hydrolab TC-2 conductivity meter
Phenolphthalein Alkalinity (P-Alk)	mg/l as $CaCO_3$	Titration with sulfuric acid using phenolphthalein indicator(1).
Total Alkalinity (T-Alk)	mg/l as $CaCO_3$	Titration with sulfuric acid acid using phenolphthalein and methyl red/bromcresol green indicators(1).
Chlorine Residual	mg/l	N,N-diethyl-p-phenylene-diamine (DPD) Ferrous Tetrimetric method(1).
Transparency	m or cm	Secchi disc

Laboratory Analyses

Parameter	Unit of Measure	Method
Five Day, Nitrogen Suppressed, Biochemical Oxygen Demand (BOD_5, N-Supp.)	mg/l	Membrane electrode method(1). Nitrogen Suppression using 2-chloro-6-(trichloromethyl)-pyridine (TCMP) method(2).
Five Day, Filtered, Nitrogen Suppressed, Biochemical Oxygen Demand (BOD_5, Filt., N-Supp.)	mg/l	Samples filtered with glass fiber filter. Analysis conducted on filtrate. Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
Twenty Day, Nitrogen Suppressed, Biochemical Oxygen Demand (BOD_{20}, N-Supp.)	mg/l	Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
Twenty Day, Filtered, Nitrogen Suppressed, Biochemical Oxygen Demand (BOD_{20}, Filt., (N-Supp.)	mg/l	Samples filtered with glass fiber filter. Analyses conducted on filtrate. Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
One through Seven Day, Nitrogen-Suppressed, Biochemical Oxygen Demand (BOD_{1-7}, N-Supp.)	mg/l	Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
Total Suspended Solids (TSS)	mg/l	Gooch crucibles and glass fiber disc(1).
Volatile Suspended Solids (VSS)	mg/l	Gooch crucibles and glass fiber disc(1).
Kjeldahl Nitrogen (Kjel-N)	mg/l as N	Micro-Kjeldahl digestion and automated colorimetric phenate method(3).
Ammonia Nitrogen (NH_3-N)	mg/l as N	Distillation and automated colorimetric phenate method(3).
Nitrite Nitrogen (NO_2-N)	mg/l as N	Colorimetric method(1).
Nitrate Nitrogen (NO_3-N)	mg/l as N	Automated cadmium reduction method(3).

Laboratory Analyses - Continued

Parameter	Unit of Measure	Method
Total Phosphorus (T-P)	mg/l as P	Persulfate digestion followed by ascorbic acid method(1).
Orthophosphorus (O-P)	mg/l as P	Ascorbic acid method(1).
Sulfate (SO_4)	mg/l	Turbidimetric method(1).
Chloride (Cl)	mg/l	Automated thiocyanate method(3).
Total Dissolved Solids (TDS)	mg/l	Evaporation at 180°C(3).
Total Organic Carbon (TOC)	mg/l	Beckman TOC analyzer
Conductivity	μmhos/cm	Wheatstone bridge utilizing 0.01 cell constant(1).
Chlorophyll a	μg/l	Trichromatic method(1).
Pheophytin a	μg/l	Pheophytin correction method(1).

SEDIMENT ANALYSES

Field Measurements

Sediment Oxygen Demand

A benthic respirometer, constructed of clear plexiglass, is utilized on intensive surveys to measure benthal oxygen demand(14). A dissolved oxygen probe, paddle, solenoid valve and air diffuser are mounted inside the test chamber. The paddle issued to simulate stream velocity and produce circulation over the probe. The solenoid valve allows air to escape from the test chamber during aeration. The air diffuser is connected by plastic tubing to a 12-volt air compressor which is used to pump air into the test chamber if required.

The paddle, solenoid valve, and air compressor are actuated by switches on a control panel which is housed in an aluminum box. The control box also contains two 12-volt batteries, the air compressor, a stripchart recorder (for automatic recordings of dissolved oxygen meter readings), a battery charger, and a battery test meter.

Selection of a specific test site must be made in the field by the investigator with the depth, velocity, and benthic substrate taken into consideration. At the test site the dissolved oxygen meter, and strip-chart recorder are calibrated, the respirometer is dry tested by opening and closing switches and testing batteries; a stream velocity measurement is taken (for paddle calibration), and a water sample is collected just above the stream bottom near the sampling site. Portions of this water sample are poured into separate BOD bottles, one of which is opaque. The opaque bottle is placed on the respirometer and left for the remainder of the test. The initial dissolved oxygen value in the other bottle is measured when the test begins, while the dissolved oxygen in the opaque bottle is measured at the end of the benthic uptake test. The difference in the two dissolved oxygen values represents the oxygen demand of the water column.

The respirometer can be lowered from a boat or bridge, or can be placed by hand in shallow streams. Care is taken to insure that the sediment at the test location is not disturbed and that a good seal between the base of the instrument and bottom of the stream is made. After the respirometer has been placed in the stream, the dissolved oxygen is recorded. In shallow, clear streams the instrument is covered to prevent photosynthesis from occurring within the chamber. The test chamber is then closed and the paddle frequency adjusted. Recordings of dissolved oxygen are made until oxygen is depleted within the chamber or 6 hours has elapsed.

Paddle Frequency

$$f = 36 v$$

where: f = Paddle frequency in revolutions per minute

v = Velocity to be simulated in m/s (measureed with current meter)

Benthic Oxygen Uptake

$$B^T DO_1 - DO_2 = 196 \frac{(DO_1 - DO_2) - BOD_t}{\Delta t}$$

where: $B^T DO_1 - DO_2$ = Oxygen uptake rate in g/m^2/d corresponding to the sample temperature, T

DO_1 = Initial DO reading in mg/l

DO_2 = Final DO reading in mg/l

$$\Delta t = \text{Time interval between } DO_1 \text{ and } DO_2$$

$$T = \text{Temperature of sample in } °C$$

$$BOD_t = \text{Measured difference in DO between the two BOD bottles}$$

Laboratory Analyses

Parameter	Unit of Measure	Method
Arsenic (As)	mg/kg	Silver diethylidithcocarbonate method(3).
Mercury (Hg)	mg/kg	Potassium permanganate digestion followed by atomic absorption(3,4).
All other metals	mg/kg	Atomic absorption(3,4).
Volatile Solids	mg/kg	Ignition in a muffle furnace(3).
Chemical Oxygen Demand (COD)	mg/kg	Dichromate reflux method(3).
Kjeldahl Nitrogen (Kjel-N)	mg/kg	Micro-Kjeldahl digestion and automated colorimetric method(3).
Total Phosphorus (T-P)	mg/kg as P	Ammonium molybdate(3).
Pesticides	µg/kg	Gas chromatographic method(4,5).
Oil and Grease	mg/kg	Soxhlet extraction method(3).

BACTERIOLOGICAL

Bacteriological samples are collected in sterilized bottles to which 0.5 ml of sodium thiosulfate is added to dechlorinate the sample. Following collection, the samples are stored on ice until delivery to a laboratory or until cultures are set up by survey personnel (within 6 hours of collection). Bacteriological analyses are conducted by survey personnel or a suitable laboratory in the survey area.

Parameter	Unit of Measure	Method
Total Coliform	Number/100 ml	Membrane filter method(1)
Fecal Coliform	Number/100 ml	Membrane filter method(1)
Fecal Streptococci	Number/100 ml	Membrane filter method(1)

BENTHIC MACROINVERTEBRATES

Benthic macroinvertebrates are collected with a Surber sampler (0.09 m^2) in riffles and an Ekman dredge (0.02 m^2) in pools. Samples are preserved in 5 percent formalin, stained with Rose Bengal, and sorted, identified, and enumerated in the laboratory.

Diversity ($\bar{d}$) is calculated according to Wilhm's(6) equation:

$$\bar{d} = - \sum_{1}^{s} (n_i/n) \log_2 (n_i/n)$$

where n is the total number of individuals in the sample, n_i is the number of individuals per taxon, and s is the number of taxa in the sample.

Redundancy ($\bar{r}$) is calculated according to the equations derived by Young et al.(7)

(1) $\bar{d}$ max $= \log_2 s$

(2) $\bar{d}$ min $= - \dfrac{s-1}{n} \log_2 \dfrac{1}{n} - \dfrac{n-(s-1)}{n} \log_2 \dfrac{n-(s-1)}{n}$

(3) $\bar{r} = \dfrac{\bar{d}\text{ max} - \bar{d}}{\bar{d}\text{ max} - \bar{d}\text{ min}}$

where s is the number of taxa in the sample and n is the total number of individuals in the sample.

Equitability is (e) is calculated according to Pielow's(8) equation:

$$e = \frac{\bar{d}}{\log_2 s}$$

where $\bar{d}$ is the calculated diversity value and s is the number of taxa in the sample.

The number of individuals per square meter is determined by dividing the total number of individuals by the area sampled.

PERIPHYTON

Periphyton are collected from streams and reservoirs from natural sub-
strates or from artificial substrates placed in the water. Standard
size, frosted microscope slides are commonly used as artificial sub-
strates and are held in place a few centimeters beneath the water surface
at the sampling sites in floating periphytometers. Following a 25 to 30
day incubation period the accrued materials are analyzed for chlorophyll a,
pheophytin a, and for identification and enumeration of the attached
organisms.

In the field, following retrieval of the periphytometer, two slides are
placed in a brown glass container containing 100 ml of 90 percent aqueous
acetone. The material from these two slides is used for pigment measure-
ments. Two slides are placed in another brown glass container containing
100 ml of 5 percent buffered formalin. The material from these two slides
is used for biomass measurements. The remaining slides are also placed in
buffered formalin and utilized for identification and enumeration of organ-
isms according to procedures discussed for the phytoplankton. The brown
glass jars containing the material for laboratory analyses (pigment and
biomass measurements) are placed in a deep freeze and kept frozen prior to
analysis.

The autotrophic index is calculated according to the equation given by
Weber and McFarland(9).

$$\text{Autotrophic Index} = \frac{\text{Biomass (g/m2)}}{\text{Chlorophyll a (g/m2)}}$$

Periphyton samples may also be collected from natural substrates by scraping
areas from each type of substrate available at each sampling location.
Scrapings are made from a range of depths from subsurface to the stream
bottom, from bank to bank, and at points spanning the range in stream
velocity. The scrapings from each sampling location are composited into
a container, preserved with Lugols solution and returned to the laboratory
for identification and enumeration following procedures discussed in the
phytoplankton section. Diversity, redundancy, and equitability statistics
are calculated as described previously.

PLANKTON

Phytoplankton

Stream phytoplankton are collected immediately beneath the water surface
with a Van Dorn sampler or by immersing a sampling container. Phyto-
plankton samples are collected with a Van Dorn water sampler at depths
evenly spaced throughout the water column of reservoirs.

Samples are stored in quart cubitainers on ice and transferred to the laboratory where aliquots of each sample are analyzed live to aid in taxonomic identification. Samples (950 ml) are then preserved with 50 ml of 95 percent buffered formalin or 9.5 ml of Lugols solution and stored in the dark until examination is completed. The phytoplankton are concentrated in sedimentation chambers, and identification and enumeration are conducted with an inverted microscope utilizing standard techniques. If diatoms are abundant in the samples, slide preparations are made using Hyrax mounting medium(10). The diatoms are identified at high magnification under oil until a minimum of 250 cells are tallied. Diversity, redundancy, and equitability statistics are calculated as described previously.

Zooplankton

Zooplankton are concentrated at the site by either filtering a known volumne of water through a number 20 mesh standard Wisconsin plankton net or vertically towing the net a known distance or time. Concentrated samples are preserved with Lugols solution or in a final concentration of 5 percent buffered formalin. The organisms are identified to the lowest taxonomic level possible, and counts are made utilizing a Sedgwick-Rafter cell. Diversity, redundancy, and equitability statistics are calculated as described previously.

NEKTON

Nekton samples are collected by the following methods(1):

Common-sense minnow seine - 6 m x 1.8 m with 0.6 cm mesh

Otter trawl	- 3 m with 3 cm outer mesh and 1.3 cm stretch mesh liner
Chemical fishing	- rotenone
Experimental gill nets	- 38.1 m x 2.4 m (five 7.6 m sections ranging in mesh size from 1.9 to 6.4 cm).
Electrofishing	- backpack and boat units (both equipped with AC or DC selection). Boat unit is equipped with variable voltage pulsator.

Nekton are collected to determine: (1) species present, (2) relative and absolute abundance of each species, (3) species diversity (4) size distribution, (5) condition, (6) success of reproduction, (7) incidence of disease and parasitism, (8) palatability, and (9) presence or accumulations of toxins.

Nekton collected for palatability are iced or frozen immediately. Samples collected for heavy metals analyses are placed in leak-proof plastic bags and placed on ice. Samples collected for pesticides analyses are wrapped in alumnium foil, placed in a waterproof plastic bag, and placed on ice.

As special instances dictate, specimens necessary for positive identification or parasite examination are preserved in 10 percent formalin containing 3 borax and 50 ml glycerin per liter. Specimens over 15 cm in length are slit at least one-third of the length of the body to enhance preservation of the internal organs. As conditions dictate, other specimens are weighed and measured before being returned to the reservoir or stream.

ALGAL ASSAYS

The "Selenastrum capricornutum Printz Algal Assay Bottle Test" procedure(11) is utilized in assaying nutrient limitation in freshwater situations, whereas the "Marine Algal Assay Procedure Bottle Test"(12) is utilized in marine and estuarine situations. Selenastrum capricornutum is the freshwater assay organism and Dunaliella tertiolecta is the marine assay alga.

PHOTOSYNTHESIS AND RESPIRATION

In areas where restricted flow produces natural or artifical ponding of sufficient depth, standard light bottle-dark bottle techniques are used. In flowing water the diurnal curve analysis is utilized.

Light Bottle-Dark Bottle Analyses

The light and dark bottle technique is used to measure net production and respiration in the euphotic zone of a lentic environment. The depth of the euphotic zone is considered to be three times the Secchi disc transparency. This region is subdivided into three sections. Duplicate light bottles (300 ml BOD bottles) and dark bottles (300 ml BOD bottles covered with electrical tape, wrapped in aluminum foil, and enclosed in a plastic bag) are filled with water collected from the mid-point of each of the three vertical sections, placed on a horizontal metal rank, and suspended from a flotation platform to the mid-point of each vertical section. The platform is oriented in a north-south direction to minimize shading of the bottles. An additional BOD bottle is filled at each depth for determining initial dissolved oxygen concentrations (modified Winkler method). The bottles are allowed to incubate for a varying time interval, depending on the expected productivity of the waters. A minimum of 4 hours incubation is considered necessary.

The following equations are used to calculate respiration and photosynthesis:

(1) For plankton community respiration (R), expressed as mg/l O_2/hour,

$$R = \frac{DO_I - DO_{DB}}{\text{Hours incubated}}$$

where DO_I = initial dissolved oxygen concentration

and DO_{DB} = average dissolved oxygen concentration
of the duplicate dark bottles

(2) For plankton net photosynthesis (P_N), expressed as
mg/l O_2/hour,

$$P_N = \frac{DO_{LB} - DO_I}{\text{Hours incubated}}$$

where DO_{LB} = average dissolved oxygen concentration of duplicate
light bottles

(3) For plankton gross photosynthesis (P_G), expressed as mg/l
O_2/hour,

$$P_G = P_N + R$$

Conversion of respiration and phtotsynthesis volumetric values to an aerial
basis may be accomplished by multiplying the depth of each of the three
vertical zones (expressed in meters) by the measured dissolved oxygen levels
expressed in g/m^3. These products are added and the result is expressed
in g O_2/m^2/d by multiplying by the photoperiod. Conversion from oxygen
to carbon may be accomplished by multiplying grams O_2 by 0.32 [1 mole of
O_2 (32 g) is released for each mole of carbon (12 g) fixed].

Diurnal Curve Analysis

In situations where the stream is flowing, relatively shallow, and may
contain appreciable growths of macropytes or filamentous algae, the
diurnal curve analysis is tuilized to determine productivity and respira-
tion. The procedure is adopted from the United States Geological Survey[13].
Both the dual station and single station analyses are utilized, depending
upon the various controlling circumstances.

Dissolved oxygen and temperature data are collected utilizing the Hydrolab
surface units, sondes, data scanners, and strip chart recorders. Diffusion
rate constants are directly measured in those instances where atmospheric
reaeration rate studies have been conducted. In situations where direct
measurements are not made, either the diffusion dome method is utilized,
or an appropriate alternative. These alternatives are: (1) calculations
from raw data, (2) substitution into various published formulas for de-
termination of K_2, and (3) arbitrary selection of a value from tables
of measured diffusion rates for similar streams.

HYDROLOGICAL

Parameter	Unit of Measure	Method
Flow Measurement	m^3/s	Pygmy current meter (Weather Measure Corporation Model F583), Marsh-McBirney Model 201 electronic flow meter, Price current meter (Weather Measure Corporation Model F582), or gage height readings at USGS gaging stations.
Time-of-Travel	m/s	Tracing of Rhodamine WT dye using a Turner Model 110 or 111 fluorometer(15).
Stream Width	m	Measured with a range finder
Tidal Period	hours	Level recorder
Tidal Amplitude	m	Level recorder
Changes in Stream Surface Level	m	Level recorder

Stream Reaeration Measurements

The stream reaeration technique is utilized to measure the physical reaeration capacity of a desired stream segment(16). The method depends on the simultaneous release of three tracers in a single aqueous solution: a tracer for detecting dilution and dispersion (tritiated water molecules), a dissolved gaseous tracer for oxygen (krypton-85), and Rhodamine WT dye to indicate when to sample for the radiotracers in the field. The tracer release location is chosen to meet two requirements: (1) it must be upstream of the segment for which physical reaeration data are desired, and (2) it must be at least 0.6 m deep and where the most complete mixing takes place. Before the release, samples are collected at the release site and at designated sampling stations to determine background levels of radiation. The first samples are collected 15 to 60 m downstream from the release site in order to establish the initial ratio of drypton 85 to tritium. Sampling sites are located downstream to monitor the dye cloud every 4 to 6 hours over a total period of 35 to 40 hours. The Rhodamine WT dye is detected with Turner 111 flow-through fluorometers. Samples are collected in glass bottles (30 ml) equipped with polyseal caps which are sealed with black electrical tape. Samples are generally collected every 2 to 5 minutes during the passage of the dye cloud peak. The three samples collected nearest the peak are designated for analysis in the laboratory (three alternate samples collected near the peak are also designated). Extreme caution is exercised throughout the field and laboratory handling of samples to prevent entrainment of air.

Samples are transferred to the laboratory for analyses within 24 hours of the collection time. Triplicate counting vials are prepared from each primary sample. All counting vials are counted in a Tracor Analytic 6892 LSC Liquid Scintillation Counter which has been calibrated. For each vial, counting extends for a minimum of three 10-minute cycles. The data obtained are analyzed to determine the changes in the krypton-85 to tritium ratio as the tracers flow downstream.

The calculations utilized in determining the physical reaeration raes from a stream segment from the liquid scintillation counter data are included here. Krypton-85 transfer in a well-mixed water system is described by the expression:

$$\frac{dC_{kr}}{dt} = - K_{kr}(C_{kr}, t) \tag{1}$$

where: C_{kr}, t = concentration of krypton-85 in the water at time(t)

K_{kr} = gas transfer rate coefficient for krypton-85

The concentration of krypton-85 present in the earth's atmosphere can be assumed zero for practical purposes. Therefore, any krypton-85 dissolved in water which is exposed to the atmosphere will be steadily lost from the water to the atmosphere according to equation 1.

The gas transfer rate coefficient for oxygen (K_{ox}) is related to K_{kr} by the equation:

$$\frac{K_{kr}}{K_{ox}} = 0.83 \pm 0.04 \tag{2}$$

Equation 2 is the basis for using krypton-85 as a tracer for oxygen transfer in stream reaeration because the numerical constant (0.83) has been experimentally demonstrated to be independent of the degree of turbulent mixing, of the direction in which the two gases happen to be moving, and of temperature. The disperion or dilution tracer (tritiated water) is used simultaneously with the dissolved gas tracer (krypton-85) to correct for the effects of dispersion and dilution in the stream segment being studied.

A single homogeneous solution containing the dissolved krypton-85 gas, tritiated water, and dye is released at the upstream reach of the stream segment being studied. As the tracer mass moves downstream, multiple samples are collected as the peak concentration passes successive sampling stations. In the laboratory, peak concentration samples from each station are analyzed and the krypton-85/tritium concentration ratio (R) is established by the equation:

$$R = \frac{C_{kr}}{C_h} \qquad (3)$$

where: C_{kr} = concentration of krypton-85 in water at time of peak concentration

C_h = concentration of tritium in the water at time of peak concentration

Applying this ratio concept, equation 1 can be modified to:

$$\frac{dR}{dt} = -K_{kr} R \qquad (4)$$

with terms as previously defined

Equation 4 can be transformed to:

$$K_{kr} = \frac{n(R_d/R_u)}{-t_f} \qquad (5)$$

where: R_u and R_d = peak ratios of krypton-85 to tritium concentrations at an upstream and downstream station

t_f = travel time between the upstream and downstream station determined by dye peaks

The tracers are used to evaluate the actual krypton-85 transfer coefficient (K_{kr}), and the conversion to the oxygen transfer coefficient (K_{ox}) is from the established gas exchange ratio:

$$K_{ox} = \frac{K_{kr}}{0.83}$$

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