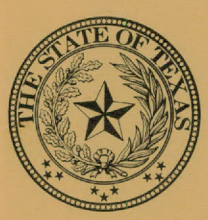
IS 87-08

Intensive Survey of the Comal River Segment 1811



Texas Water Commission

July 1987

INTENSIVE SURVEY OF THE

COMAL RIVER

SEGMENT 1811

Hydrology, Field Measurements and Water Chemistry

By
Donald D. Ottmers

IS 87-08

Texas Water Commission

July 1987

TEXAS WATER COMMISSION

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Published and distributed
by the
Texas Water Commission
Post Office Box 13087
Austin, Texas 78711

ABSTRACT

An intensive water quality survey was conducted on the Comal River (Segment 1811) July 8-9, 1986 by the Texas Water Commission. The Comal River flows through the center of the City of New Braunfels in central Texas. The river is spring-fed, clear, swift and is a major tourist attraction for the city. Parks provide adequate access to the river and swimming, snorkeling and tubing are enjoyed by thousands of area residents and visitors.

Field measurements of dissolved oxygen, pH, temperature and conductivity were made at four main stem stations and five tributary stations. Inflow from the tributaries was measured and water samples were collected for laboratory analyses. A time-of-travel study was also conducted.

No water quality problems were observed during the study. Carbonaceous and nitrogenous oxygen demand was low (< 2.0 mg/L) as were levels of suspended solids (< 10 mg/L). The spring water naturally contains nitrates; however, other nutrient material were not detected and algal production was low. Dissolved oxygen levels were moderately low, however only one early morning measurement was less that the 5 mg/L criterion. Aquatic macrophytes grow abundantly in the clear water and their metabolism may contribute to increasing the range of dissolved oxygen during a diel period.

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COMAL RIVER

SEGMENT 1811

INTRODUCTION

DIRECTIVE

This intensive survey was accomplished in accordance with the Texas Water Code, Section 26.127, as amended in 1985. The report is an intergral part of the State Water Quality Management Program and is utilized for the purposes listed below.

PURPOSE

The purpose of this intensive survey was to provide the Texas Water Commission 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 utilized for this survey are described in Appendix A. Data were collected July 8-9, 1986, by Texas Water Commission Water Quality Assessment Unit personnel. Laboratory analyses were conducted by the Texas Department of Health Chemistry Laboratory, Austin, Texas. Parametric coverages, sampling frequencies, and spatial relationships of sampling stations were consistent with the objectives of the survey and with known or suspected forms and variability of pollutants entering the stream.

RESULTS AND DISCUSSION

SITE DESCRIPTION

The Comal River originates from springs in the northern edge of New Braunfels in Comal County and flows through the center of the city to merge with the Guadalupe River (Figure 1). At 5.2 river kilometers (3.2 mi) in length, the Comal is the shortest river in Texas and is totally contained within the city limits to New Braunfels. It is, nonetheless, state water and is subject to water quality criteria as established by the Texas Surface Water Quality Standards.

The entire Comal River is heavily utilized for recreation by area residents and visitors. Parks, both public and private, abound, providing excellent public access to the river. The crystal clear, swift waters are ideally suited for swimming, snorkeling, and tubing. A small lake near the headwaters, within Landa Park, provides canoeing and paddle boat riding as well. Lush vegetation fills the lake and abundant aquatic life is easily seen in the clear waters.

In addition to the springs at the headwaters, three major springs (collectively called the Comal Springs), discharge into the lake at Landa Park. Numerous other springs exist beneath the lake's surface, greatly increasing the flow downstream. Other tributaries include Blieders Creek at the headwaters which is normally dry, and Dry Comal Creek at kilometer 2.85, which contrary to its name, usually maintains some flow. A secondary stream, probably an old river channel, leaves the Lake and crosses Landa Park to rejoin the Comal River at river kilometer 2.06.

This survey was conducted July 8-9, 1986. Sampling stations were established on the main stem of the river, at the three major springs, and on Dry Comal Creek. The secondary stream was also treated as a tributary. Field data and a water sample for laboratory analyses were collected four times over a diurnal period at most stations. Samples were also collected for fecal coliform analyses at each station. Cross-section measurements were made throughout the segment and a time-of-travel study was conducted.

WATER QUALITY STANDARDS

Water uses deemed desirable for the Comal River include high quality aquatic life habitat, contact recreation, and public water supply. Specific numerical criteria developed to insure that the segment will meet these uses include: dissolved oxygen of not less than 5.0 mg/L; pH range between 6.5 and 9.0 standard units, temperature of not more than 90°F, and a fecal coliform level of no more than 200 organisms per 100 mL of water (geometric mean of at least five samples collected within a thirty day period). Additional criteria include an annual average maximum limit on chloride (25 mg/L), sulfate (30 mg/L), and total dissolved solids (400 mg/L)(TWC, 1985).

HISTORICAL WATER QUALITY

The Texas Water Commission maintains a stream monitoring station at river kilometer 1.77 (mile 1.1) (Station B, Figure 1). A United States Geological Survey (USGS) stream flow gaging station is also located at this point. The Texas Water Commission collects field data, water samples for laboratory analyses, and fecal coliform samples at this point four times a year. Data are on file at the Texas Water Commission central office in Austin. A summary of selected data collected during the past four water years is presented in Table 2 as it appears in the State of Texas Water Quality Inventory, 8th Edition, 1986 (TWC, 1986). There were no dissolved oxygen, pH, or temperature violations observed during the period. Chloride levels exceeded 25 mg/L 3 times and sulfate levels exceeded 30 mg/L one time. Fecal coliform levels were higher than 200/100 mL on two occasions. None of these high readings are necessarily violations since compliance with the standards for these parameters are based on a number of samples collected within a specified time limit.

INTENSIVE SURVEY DATA

Field Measurements

Dissolved oxygen levels were lowest at the headwaters of the river, averaging 5.0 mg/L at Station D, and increased progressively at each downstream station to an average of 8.0 mg/L at Station A (Table 3). The dissolved oxygen levels in the springs at Landa Park were relatively low, averaging 5.7 mg/L at Station F, 5.6 mg/L at Station G and 5.5 mg/L at Station H. The diurnal ranges of dissolved oxygen levels induced by photosynthesis of algae and/or aquatic macrophytes were moderate with the greatest range (5.0 to 9.3 mg/L) occurring at Station C. Only one early morning dissolved oxygen measurement at Station D, 4.8 mg/L, was less than the stream criterion. Dissolved oxygen saturation levels ranged from 56% at Station D to 119% at B. Water temperatures were uniform throughout the segment, averaging 24.6°C in the main stem and 25.4°C in Dry Comal Creek. Conductivity levels ranges from 552 to 563 µmhos/cm in the river and springs, and somewhat higher in Dry Comal Creek (772 µmhos/cm.) All pH measurements were within the criterion range (6.5-9.0 units).

Laboratory Analyses

The results of laboratory analyses of water samples collected in the Comal River and Comal Springs are indicative of clean water unaffected by wastewater discharges (Table 4). Five-day carbonaceous oxygen demand ($CBOD_5$) levels were low at all stations, ranging from 0.5 to 1.0 mg/L on both filtered and unfiltered samples. Total suspended solids levels were less than 10.0 mg/L. Chloride levels ranged from 15 to 16 mg/L, sulfate levels ranged from 26 to 27 mg/L and total residue from 224 to 277 mg/L. Levels of chloride, sulfate and total residue were slightly higher in Dry Comal Creek (73 mg/L, 76 mg/L and 412 mg/L, respectively).

Ammonia nitrogen levels were less than 0.02 mg/L at all of the main stream stations and above that at only one tributary, 0.03 mg/L at Station I. Nitrate nitrogen, probably occurring naturally in spring water, was detected at all of the stations in concentrations ranging from 1.59 to 1.76 mg/L.

Orthophosphorus levels were less than 0.01 mg/L at all stations. These low levels suggest that this nutrient was limiting to algal growth in the river at the time of the survey. Chlorophyll a and pheophytin a were not detected (less than 2 µg/L).

Fecal Coliform Bacteria

Numbers of fecal coliform organisms ranged from 10 organisms/100 mL of water at Station D to 85 organisms/100 mL of water at Station A in the mainstem, well below the level (200/100 mL) considered acceptable for contact recreation.

Fecal coliform levels in the tributary streams ranged from 5/100 ml at Station F to 165/100 mL at Station E.

Hydrology

Due to instrument malfunction, flow measurements were not obtained at all stations on the main stem of the Comal River. The flows at the major springs and in the tributary streams were measured, and flow data obtained at the USGS gaging station at river kilometer 1.77 (mile 1.1) were recorded (Table 6). The average velocity of the river was obtained by tracking florescent dye from Station D to Station A (Table 7). Cross-section widths were obtained throughout the segment (Table 8).

A swimming pool is built into the river bed at the head of the Comal River. Downstream of the pool, the river is relatively shallow, gradually becoming wider and forming a shallow lake at Landa Park. Stream velocities through this reach averaged (0.068 m/s) 0.2 ft/s. Three major springs (Comal Springs) flow into the lake at Landa Park. Other springs exist in the lake below the surface and stream flow is greatly increased downstream of the lake.

Stream velocities were higher downstream of the lake, averaging 0.238 m/s (0.8 ft/s). This reach is popular with swimmers and tubers and it supports a high volume of contact recreation. An in-channel dam at river kilometer 1.9 creates another swimming pool. The spillway of the dam is designed to permit tubers to ride over it and swimmers congregate above and below the dam. The USGS gaging station is just downstream of this dam. Two other smaller dams between the USGS station and the mouth of the river constrict the flow and provide fast water areas for tubers.

CONCLUSIONS

The Comal River is a clear, clean free-flowing stream in the heart of an urban area. The high quality of the water and the easy accessibility of the river to the public make it an exceptional recreation area for the City of New Braunfels and for Texans in general. There are presently no continuous discharges of wastewater to the river. The low phosphorus levels measured during this survey suggests that this nutrient is probably limiting to algal growth in the river. The clear waters, flowing springs and streamside parks make the Comal river unique among Texas streams. Every reasonable effort to protect this outstanding natural resource should be employed.

PRESENTATION OF DATA

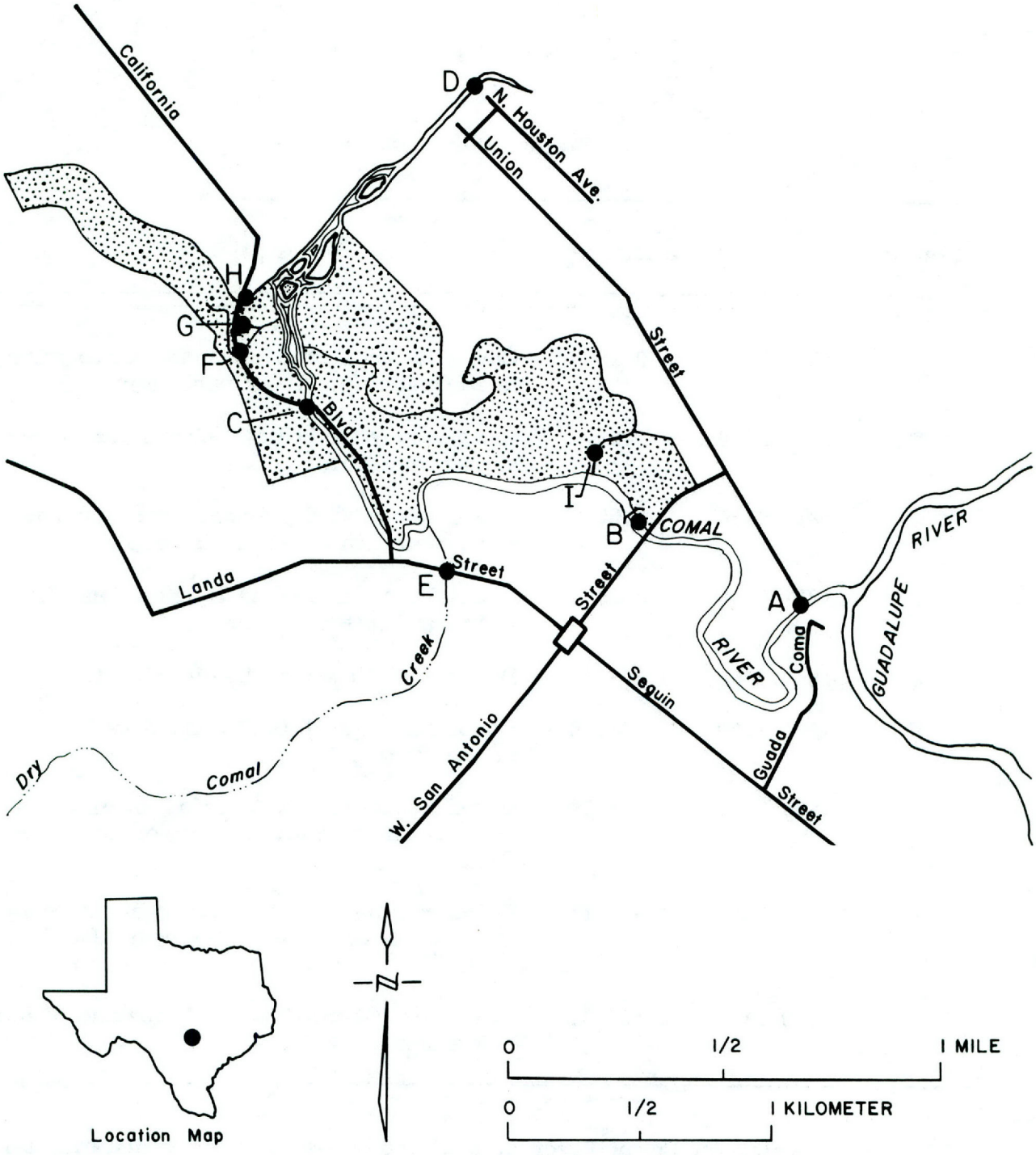

Figure 1
Map of Comal River Study
Area and Station Locations

TABLE 1

Station Descriptions

Station	SMN Number	River* Kilometer	Description
A	1811.0005	0.15	Comal River at end of Guada Coma Street, near Guadalupe River confluence
B	1811.0100	7.78	Comal River in Prince Solms Park, downstream of Chute
C	1811.0150	3.57	Comal River at California Street in Landa Park near miniature train depot
D	1811.0200	5.05	Comal River at end of N. Houston Street near headwaters
E	1800.2150	2.80/.14	Dry Comal Creek at Landa Street
F	1800.2200	3.92/.20	Comal Springs at California Street in Landa Park
G	1800.2210	3.92/.20	Comal Springs, small spring originating near mouth of Panther Canyon in Landa Park
H	1800.2220	4.04/.12	Comal Springs, large spring discharging into Landa Lake near Gazebo in Landa Park
I	1800.2100	2.22/.30	Old River Channel at park road in Prince Solms Park

* River Kilometer on Comal River at confluence with tributary/distance up tributary to sampling point

TABLE 2

Summary of Water Quality Data
October 1, 1981 through September 30, 1985

Parameter	Criterion	Number of Samples	Minimum	Maximum	Mean	Number above Criterion	Mean of Value above Criterion
Dissolved Oxygen (mg/L)	5.0	23	6.5	13.2	8.6	0	0
Temperature (°F)	90.0	25	66.2	84.2	74.0	0	0
pH	6.5-9.0	18	6.8	8.3	7.5	0	0
Chloride (mg/L)	25	16	9	55	19	3	43
Sulfate (mg/L)	30	16	15	41	24	1	41
Total Dissolved Solids (mg/L)	400	25	230	350	288	0	0
Fecal Coliform (#/100 mL)	200	26	0	570	25	2	406

TABLE 3

Field Measurements

Station	Time/Date	D.O. mg/L	Temp. C	pH	Cond. µmhos/cm
A	1540/07-08-86	9.1	25.5	6.9	557
	2000/07-08-86	8.7	25.4	7.2	555
	0505/07-09-86	6.7	23.6	7.3	558
	1100/07-09-86	7.4	24.1	7.5	558
B	1540/07-08-86	9.9	25.6	7.1	556
	2015/07-08-86	8.1	24.9	7.1	556
	0600/07-09-86	6.3	23.5	7.3	561
	1112/07-09-86	7.9	24.2	7.3	557
C	1615/07-08-86	9.3	25.1	7.1	555
	2025/07-08-86	6.5	24.0	7.0	555
	0615/07-09-86	5.0	23.4	7.2	555
	1130/07-09-86	7.9	24.5	7.1	557
D	1500/07-08-86	6.8	25.8	6.5	556
	1950/07-08-86	5.5	24.8	7.0	552
	0540/07-09-86	4.8	23.8	7.0	563
	1050/07-09-86	6.5	24.6	7.4	556
E	1600/07-08-86	7.4	26.1	7.1	765
	1935/07-08-86	6.4	26.3	7.0	762
	0601/07-09-86	5.6	24.5	7.3	776
	1120/07-09-86	6.1	24.7	7.4	769

TABLE 3 CONTINUED

Station	Time/Date	D.O. mg/L	Temp. C	pH	Cond. µmhos/cm
F	1650/07-08-86	5.8	23.9	6.9	554
	2030/07-08-86	5.5	23.7	7.1	553
	0625/07-09-86	5.6	23.5	7.2	550
	1140/07-09-86	5.9	24.0	7.4	555
G	1630/07-08-86	5.6	23.8	6.9	555
H	1640/07-08-86	5.5	23.9	6.8	554
I	1030/07-08-86	6.6	25.2	7.4	573

TABLE 4

Laboratory Measurements

Parameter (*)	Stations A	B	C	D	E	F	G	H	I
$CBOD_5$	1	1	1	0.5	0.5	0.5	0.5	1	1
f-$CBOD_5$	1	1	1	0.5	0.5	0.5	0.5	1	1
$CBOD_{20}$	1.5	1.5	1	1	1	1.5	1	2	3
f-$CBOD_{20}$	1	1	0.5	1	1	1	1	1	1
TOC	<1	<1	<1	<1	2	<1	<1	<1	<1
TSS	8	<5	<5	<5	6	<5	<5	<5	<5
VSS	2	<5	<5	<5	1	<5	<5	<5	<5
Kjel-N	0.2	0.1	0.2	<0.1	0.3	0.1	0.1	0.1	0.2
NH_3-N	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.03
NO_3-N	1.59	1.59	1.68	1.58	0.77	1.74	1.74	1.76	1.4
NO_2-N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
O-PO_4	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
T-PO_4	0.02	0.02	0.01	0.02	0.04	0.01	0.01	<0.01	<0.01
Cl	15	15	15	16	33	15	15	15	15
SO_4	26	26	26	26	76	26	26	27	27
TR	239	238	277	260	412	224	266	246	310
Cond. µmhos/cm	576	568	576	576	810	572	576	576	592
pH Units	7.7	7.8	7.5	7.5	7.7	7.5	7.4	7.5	7.8

TABLE 4 CONTINUED

Parameter (*)	Stations A	B	C	D	E	F	G	H	I
Chl a µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
Phe a µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
Alk	233	230	232	229	268	229	229	234	237

* mg/L unless otherwise noted

TABLE 5

Fecal Coliform

Station Number	Number of Organisms/100 mL
A	85
B	50
C	55
D	10
E	165
F	5
I	95

TABLE 6

Flow Measurements

Station	m^3/s	Flow (ft^3/s)	Date	Time	Method
B	9.232	326	07/08/86	0834	USGS Gaging Station
B	9.119	322	07/09/86	0810	USGS Gaging Station
E	0.034	1.2	07/08/86	1910	Electronic Flow Meter
F	0.796	28.1	07/08/86	1700	Electronic Flow Meter
G	0.048	1.7	07/08/86	1715	Electronic Flow Meter
H	1.127	39.8	07/08/86	1725	Electronic Flow Meter
I	0.462	16.3	07/09/86	1000	Electronic Flow Meter

TABLE 7

Time-of-Travel Data

Dye Release Point Station	Monitoring Point Station	Distance Kilometers	Time Hours	Average Velocity m/s	Average Velocity ft/s
D	C	1.48	6.1	0.068	0.223
C	A	3.42	4.0	0.237	0.778

TABLE 8

Cross-section Measurements

From Station To Station	Number of Measurements	Average Width (meters)	Extremes High/Low
A to B	12	21.8	26/77.6
B to C	11	25.1	44/14
C to D	14	47.7	120/17.8

LITERATURE CITED

Texas Water Commission. 1985. Texas Surface Water Quality Standards. Informational Draft Copy.

Texas Water Commission. 1986. The State of Texas Water Quality Inventory, Report LP 86-07, 8th Edition, Texas Water Commission, Austin.

APPENDIX A

FIELD AND LABORATORY PROCEDURES

The following methods are utilized for field and laboratory determinations of specified physical and chemical parameters. Unless otherwise indicated composite water samples are collected at each sampling station 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 Hydrolab 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

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

where: $B^{T}DO_1\text{-}DO_2$ = 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

Δt = Time interval between DO_1 and DO_2

T = Temperature of sample in °C

BOD_t = 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) $\bar{d}\ min = - \frac{s-1}{n} \log_2 \frac{1}{n} - \frac{n-(s-1)}{n} \log_2 \frac{n-(s-1)}{n}$

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

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 substrates or from artificial substrates placed in the water. Standard size, frosted microscope slides are commonly used as artificial substrates 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 measurements. 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 organisms 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).

$$\text{Autotrophic Index} = \frac{\text{Biomass } (g/m^2)}{\text{Chlorophyll } a \ (g/m^2)}$$

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. Phytoplankton 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 respiration. 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 determination 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:

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

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:

$$\frac{K_{kr}}{K_{ox}} = 0.83 \pm 0.04 \qquad (2)$$

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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