INTENSIVE SURVEY OF THE COLORADO RIVER BELOW AUSTIN SEGMENT 1428

December 10-12, 1984

IS-75

TEXAS DEPARTMENT OF WATER RESOURCES

JULY 1985

INTENSIVE SURVEY
OF
THE COLORADO RIVER BELOW AUSTIN
SEGMENT 1428
December 10-12, 1984

Field Measurements,
Water Chemistry,
Biology

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ABSTRACT

An intensive survey was conducted by the Texas Department of Water Resources on Segment 1428 of the Colorado River. The segment receives the City of Austin's wastewater. It was found that the dissolved oxygen levels were less than the criterion in a reach comprising 20 percent of the segment. Carbonaceous oxygen-demanding materials and ammonia nitrogen associated with the treated wastewater were factors causing the low oxygen condition. A nuisance growth of macrophytes was observed and attributed to nutrient loading from the City of Austin wastewater treatment facilities.

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INTENSIVE SURVEY OF

COLORADO RIVER

SEGMENT 1428

INTRODUCTION

Directive

This intensive survey was accomplished in accordance with the Texas Water Quality Act, Section 26.127, as amended in 1977. The report is to be used in developing and maintaining the State Water Quality Strategy published in 40 CFR 35.1511-2 pursuant to Section 303(e) of the Federal Clean Water Act of 1977.

Purpose

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

1. to determine quantitative cause and effect relationships of water quality;
2. to obtain data for updating water quality management plans, setting effluent limits, and where appropriate, verifying the classifications of segments;
3. to set priorities for establishing or improving pollution controls; and
4. to determine any additional water quality management actions required.

METHODS

Field and laboratory procedures used during this survey are described in Appendix A. Methods used to analyze biological data not included in Appendix A are described in detail in Twidwell and Davis (1984). The data were collected December 10-12, 1984 by Texas Department of Water Resources Water Quality Assessment Unit personnel. Laboratory analyses of water samples were conducted by Texas Department of Health Chemistry Laboratory. Bacteriological analyses were conducted by Water Quality Assessment Unit personnel. Parametric coverages, sampling frequencies and spatial relationships of sampling stations are consistent with the objectives of the the survey and with known or suspected forms and variabilities of pollutants entering the river.

RESULTS AND DISCUSSION

An intensive survey of Segment 1428 of the Colorado River was conducted by the Texas Department of Water Resources (TDWR) December 10-12, 1984. The study area consisted of 64 km (40 miles) of the Colorado River downstream of Austin, Texas and tributaries receiving wastewater treatment plant effluent (Figure 1, Table 1).

Segment 1428 of the Colorado River extends from Longhorn Dam in Austin to the State Highway 95 bridge at Smithville. The segment drains the east and south portions of Austin, and is the receiving stream for 45.5 million gallons per day (MGD) of Austin's 51.5 MGD permitted wastewater discharge. The remaining 6 MGD is permitted for discharge into Williamson Creek which flows into Onion Creek, a tributary to Segment 1428. Of the 46 MGD permitted for the segment, 21.2 MGD is discharged from the City of Austin Govalle sewage treatment plant (STP) between Stations A and B, 1.3 MGD is discharged from the City of Austin Hornsby Bend STP between Stations E and F, and 23 MGD is discharged from the City of Austin Walnut Creek STP into Walnut Creek, which flows into the segment. The existing effluent quality parameters are 20 mg/L BOD_5 and 20 mg/L TSS (monthly average). Segment 1428 is also the receiving stream for wastewater treatment plant effluent from the Cities of Bastrop (0.353 MGD) and Smithville (0.310 MGD).

The designated uses for Segment 1428 are contact recreation, high quality aquatic life habitat and public raw water supply. Criteria established to support these uses are: annual average chloride, sulfate and total dissolved solids not to exceed 105, 55, and 425 mg/L, respectively; dissolved oxygen concentration not less than 5 mg/L; pH range 6.5 to 9.0, fecal coliform thirty-day geometric mean not to exceed 200 colonies/100 mL; and temperature not to exceed 95°F.

The Austin area is experiencing a rapid population increase. In 1984, the number of people for which the City of Austin treated wastewater was 415,000. This number is expected to increase to 660,000 by 1990 and to 843,000 by 2000. Industrial activities occurring in the Austin area that could impact Segment 1428 are: manufacturing of semiconductors, residential and commerical construction, and sand and gravel mining. Extensive areas in the flood plain of Colorado River are being mined for sand and gravel.

A flow of 3.66 m^3/s (129.3 ft^3/s) was measured at Station A during the survey. Since the seven-day two-year low flow at this station is 1.65 m^3/s (58.4 ft^3/s), problems related to STP effluents were probably somewhat masked by the moderate headwater flow.

Dissolved oxygen (DO) concentrations were not compliant with the segment DO criterion (5 mg/L) from Station D to Station I (Table 2, Figure 2). This reach is 26.8 km (16.6 miles) and represents about 20 percent of the segment. Factors causing the DO sag were oxidation of carbonaceous biochemical oxygen-demanding (CBOD) substances, nitrification, and respiration of algae and macrophytes. Most of the CBOD is exerted in the reach from Station B to Station D (Table 3). The highest nitrification

occurs in the reach from Station E to Station H. Noncompliance of the DO criterion at Station I was attributed to algal and macrophyte respiration. Water quality problems would likely become more severe under lower flow conditions.

Chlorophyll a levels were low throughout the study area indicating phytoplankton densities were low. Although not measured, visual inspection of macrophyte beds revealed dense periphyton growth covering the macrophytes. Macrophyte densities were moderate at Station A, and non-existent at Stations B and C. Densities increased from Stations D to G. At Stations G to K a nuisance condition existed due to extremely dense macrophyte growths.

Elevated levels of ammonia nitrogen (NH_3-N) were being discharged from the City of Austin Govalle STP (Table 3). Consequently, instream NH_3-N concentrations were high at Stations B - G. High NH_3-N concentrations can be harmful to the stream in three ways. Under the right combinations of pH and temperature, high concentrations of NH_3-N are toxic to aquatic organisms. Ammonia is also a DO sink; bacteria, consuming oxygen, convert NH_3 to nitrate (NO_3). Ammonia and NO_3 are also macronutrients for algae and macrophytes and high concentrations can cause proliferation of aquatic plants. Ammonia nitrogen concentrations exceeding the EPA Red Book criterion for chronic toxicity (0.0164 mg/L unionized NH_3-N) were found at Stations B, C, and E and the concentration of NH_3-N in the Govalle STP effluent exceeded the Red Book acute toxicity criterion (0.164 mg/L unionized NH_3-N).

All chloride (Cl^-) and total dissolved solids (TDS) were less than the Segment 1428 criteria. Sulfate (SO_4) levels exceeded the criterion at Stations D thru K. Since the SO_4 concentration increased down river, the values in excess of the criterion were probably from natural causes.

Fecal coliform bacteria levels were low throughout the survey area with the exception of Station G6a (Table 4). The source of the contamination at this station is unknown.

Nitrogen and phosphorus levels showed a downstream decreasing trend except between Stations A and B and Stations C and D. The downstream decrease of N and P was attributed to the assimilation of the nutrients by biota and also sedimentation. The measured increases can be attributed to point source discharges.

To evaluate biological health in the study reach, benthic macroinvertebrates were collected at nine stations. Riffle (erosional) habitats were sampled if available; in the absence of riffles, deeper-water (depositional) habitats were utilized. To provide controls for both types of samples, separate samples were collected near Station A, one from riffles and another from deeper water. One hundred and sixteen benthic macroinvertebrate species were collected, a high total which reflects the physically diverse nature of the study reach and the general prevalence of favorable environmental conditions. Each station was assigned a macrobenthic health rating on the basis of 11 different biological indices (Tables 6 and 7). Six stations were rated good-to-excellent (A depositional, D, G, H, I, K), reflecting relatively unimpacted water quality and healthy environmental conditions. Two stations

were rated good (A erosional, J), with characteristics slightly less favorable than the best expected situation due to slightly depressed diversity and trophic structure imbalance. At the Station A erosional site, this resulted from dominance by the periphyton-grazing microcaddisfly, Hydroptila sp. (which is, however, a clean-water indicative species). Its abundance was a response to dense periphyton supported by high water clarity and full sunlight penetration resulting from the sediment-removal effects of Town Lake upstream. At Station J, the filter-feeding clam, Corbicula fluminea, occurred in dominant numbers, indicating an increase in the amount of fine suspended solids on which it feeds. These solids were apparently mainly in the form of phytoplankton, as indicated by slightly elevated chlorophyll a levels, with increased primary productivity attributed to nutrient inputs from the City of Austin sewage treatment plants.

Station B received a rating of poor due to depressed diversity and imbalanced trophic structure resulting from dominant numbers of pollution-tolerant species. In addition, a degree of toxicity appeared to exist, perhaps due to elevated ammonia levels observed at the site. Organic enrichment in the absence of toxicity normally causes a reduction in the number of species and an increase in the standing crop. However, in this case both the number of species and the standing crop were reduced. Macrobenthic health at Station C was rated very poor due to depressed diversity and extreme trophic structure imbalance, with pollution-tolerant species assuming almost total dominance. The percentage composition of tubificid oligochaetes (77.8% of the community) was near the range generally associated with severe organic pollution (i.e., 80-100%; Goodnight and Whitley, 1960). Water quality degradation at Stations B and C is attributable to the effects of the Govalle STP discharge.

In summary, the biological data indicate that macrobenthic communities are relatively healthy through most of the study reach, with the exception of the subreach from the Govalle STP to an undetermined point downstream from Station C. A high degree of recovery was evident at Station D. Evidently, adverse biological impacts from wastewater sources other than the Govalle STP are minimal at the present time. However, the dissolved oxygen minima observed at Stations D-I were very near critical levels for many aquatic organisms. Therefore, minor changes from conditions existing during this survey, such as decreased streamflow, increased temperature, and/or increased waste loading, could produce critically low dissolved oxygen levels that would begin to eliminate sensitive species and cause appreciable deterioration of the aquatic community.

CONCLUSIONS

Segment 1428 of the Colorado River was found to have water quality problems related to wastewater treatment plant discharges. High levels of cabonaceous oxygen demanding materials and ammonia nitrogen caused the dissolved oxygen level to be less than the dissolved oxygen criterion in a reach comprising 20 percent of the segment. This condition may be alleviated by ongoing STP construction and rehabilitation by the City of Austin. A waste load evaluation is being conducted by TDWR to determine whether advanced treatment will be needed to attain the designated uses of the segment.

A nuisance growth of macrophytes was also observed and attributed to the high nitrogen and phosphorus loadings from the City of Austin STPs. Reducing the nutrient loading may require nutrient limitations to be added to treatment requirements.

PRESENTATION OF DATA

COLORADO RIVER SURVEY

Table 1

Descriptions and Locations of Sampling Stations

Map Code	SMN Number	River Kilometer	Description
A	1402.0750	465.3	Colorado River at US 183
B	1402.0740	465.2	Colorado River at Capitol Aggregates Bridge
C	1402.0730	461.6	Colorado River below Boggy Creek
D	1402.0720	458.6	Colorado River below Walnut Creek
E	1402.0710	456.0	Colorado River above Carson Creek
F	1402.0700	449.9	Colorado River at FM 973
G	1402.0690	441.4	Colorado River above Onion Creek
H	1402.0680	433.9	Colorado River below Gulliland Creek
I	1402.0670	431.6	Colorado River at Webberville
J	1402.0660	422.5	Colorado River below Webberville
K	1402.0640	400.8	Colorado River at FM 969
C2	1400.2320	4.4[1]	Walnut Creek at FM 969
C1	1400.2310	2.0[1]	Walnut Creek at Southern Pacific RR Bridge
G6a	1400.1152	4.6[2]	Williamson Creek at Nuckols Crossing Road
G6	1427.0080	25.2[2]	Onion Creek at Nuckols Crossing Road
G2	1427.0060	11.7[3]	Onion Creek at FM 973
G1	1427.0005	0.1[2]	Onion Creek above Colorado River
1A	1400.9001	463.8	City of Austin Govalle STP; Plants A, B, & C effluent
1B	1400.9002	463.8	City of Austin Govalle STP; Plant D effluent
2	1400.9003	4.0[1]	City of Austin Walnut Creek STP
3	1400.9004	3.5[2]	City of Austin Williamson Creek STP

1 - Kilometers up Walnut Creek, which enters the Colorado at kilometer 459.9
2 - Kilometers up Williamson Creek, which enters Onion Creek at kilometer 20.8
3 - Kilometers up Onion Creek, which enters the Colorado at kilometer 441.2

Table 2

Field Data

Station Number	Time	Temp. °C	pH	Dissolved Oxygen mg/L	Conductivity µmhos/cm
A	0925	17.3	7.0	7.8	606
	1320	19.4	8.2	12.6	586
	1605	20.2	8.3	14.5	580
	0549	17.4	8.0	7.0	606
$\bar{X}d^1$		18.6	8.0	10.5	594
B	1018	18.4	7.1	6.3	665
	1350	19.7	7.8	8.2	667
	1626	20.3	7.7	10.8	669
	0607	18.7	7.7	6.1	669
	0747	18.6	7.7	5.8	669
$\bar{X}d$		19.3	7.6	8.0	668
C	1215	19.2	7.8	6.8	669
	1455	19.3	7.7	5.9	666
	1727	19.0	7.7	5.8	664
	0624	19.0	7.7	7.2	664
	0807	19.0	7.7	7.1	677
$\bar{X}d$		19.1	7.7	6.5	666
D	1030	18.6	7.1	3.7	705
	1350	20.1	6.9	5.3	698
	1700	20.2	7.2	5.4	695
	0645	18.6	7.1	2.8	718
$\bar{X}d$		19.4	7.1	4.2	705
E	1010	18.1	7.2	4.2	685
	1330	19.7	7.3	7.2	686
	1645	19.8	7.3	6.5	688
	0830	18.2	7.3	3.4	699
$\bar{X}d$		19.0	7.3	5.2	691

Table 2 Continued

Station Number	Time	Temp. °C	pH	Dissolved Oxygen mg/L	Conductivity µmhos/cm
F	0930	18.1	7.1	3.1	687
	1320	19.7	7.4	5.7	682
	1630	19.2	7.3	4.8	687
	0615	18.4	7.2	2.6	697
$\bar{X}$		18.8	7.2	3.9	690
G	1120	18.0	7.2	4.2	703
	1450	19.0	7.8	6.9	687
	1735	19.3	7.8	8.4	680
	0730	18.5	7.5	1.6	676
$\bar{X}$		18.8	7.6	5.0	683
H	1000	17.5	7.5	6.4	687
	1415	19.1	8.0	9.6	684
	1656	19.3	8.0	10.2	685
	0654	17.8	7.5	4.7	690
$\bar{X}$		18.5	7.7	7.6	687
I	1050	16.9	7.4	7.3	688
	1410	18.5	7.7	10.4	685
	1720	18.4	7.7	10.2	689
	0705	17.4	7.3	4.0	707
$\bar{X}$		17.8	7.5	7.5	695
J	1105	16.8	7.5	7.6	686
	1425	18.0	7.8	10.8	684
	1745	18.3	7.1	12.0	683
	0730	17.1	7.5	6.0	697
$\bar{X}$		17.6	7.4	9.0	687
K	1125	16.4	7.9	11.0	673
	1445	17.3	8.2	12.7	667
	1810	17.2	7.0	12.1	674
	0750	16.8	7.8	7.5	687
$\bar{X}$		17.0	7.6	10.4	678

Table 2 Continued

Station Number	Time	Temp. °C	pH	Dissolved Oxygen mg/L	Conductivity µmhos/cm
C2	1058	15.0	7.8	10.2	717
	1402	16.9	8.1	10.8	706
	1638	17.0	8.2	10.3	701
	0658	15.0	8.1	8.7	710
$\bar{X}$		15.9	8.1	9.7	707
C1	1128	20.0	7.6	7.6	797
	1430	21.0	7.5	7.9	793
	1705	20.8	7.6	7.8	799
	0645	20.1	7.6	7.3	915
$\bar{X}$		20.4	7.6	7.6	842
G6a	1223	16.8	7.5	8.3	725
	1548	17.1	8.0	13.5	734
	1837	16.7	7.9	11.1	738
	0840	15.6	7.6	6.0	767
$\bar{X}$		16.4	7.7	9.1	746
G6	1215	14.6	7.7	8.8	650
	1535	16.4	7.9	9.5	638
	1827	15.2	7.9	9.3	638
	0829	14.8	7.8	7.3	648
$\bar{X}$		15.1	7.8	8.5	644
G2	1150	15.1	7.7	8.9	703
	1515	15.5	8.0	8.2	694
	1803	15.3	8.0	8.0	696
	0800	15.1	7.8	7.3	702
$\bar{X}$		15.2	7.9	7.9	644
G1	1445	14.4	7.8	9.2	713
	1455	15.2	8.0	9.2	703
	1740	15.3	8.0	9.3	700
	0736	15.0	7.9	6.7	702
$\bar{X}$		15.0	7.9	8.3	703

Table 2 Continued

Station Number	Time	Temp. °C	pH	Dissolved Oxygen mg/L	Conductivity µmhos/cm	Chlorine Residual mg/L
1A	1000	21.6	7.0	5.6	843	1.7
	1340	22.3	7.5	5.0	843	0.8
	1618	22.4	7.2	4.7	879	2.0
	0734	22.1	7.3	5.8	872	2.0
$\bar{X}$		22.2	7.3	5.3	867	
1B	0950	20.9	7.2	6.8	820	2.0
	1335	22.2	7.4	6.8	811	3.4
	1615	22.2	7.5	6.8	812	1.0
	0729	21.9	7.5	6.7	808	1.2
$\bar{X}$		21.9	7.4	6.8	867	
2	1030	22.0	6.6	5.5	822	0.4
	1408	22.4	7.6	6.5	824	1.0
	1646	22.4	7.4	5.9	834	0.8
	0710	22.4	7.2	5.9	973	0.8
$\bar{X}$		22.3	7.2	5.9	882	
3	1304	21.8	8.0	8.1	698	1.0
	0845	22.2	7.2	7.7	702	1.6
$\bar{X}$		22.0	7.6	7.9	700	

1 $\bar{X}$d is the time-weighted diel mean

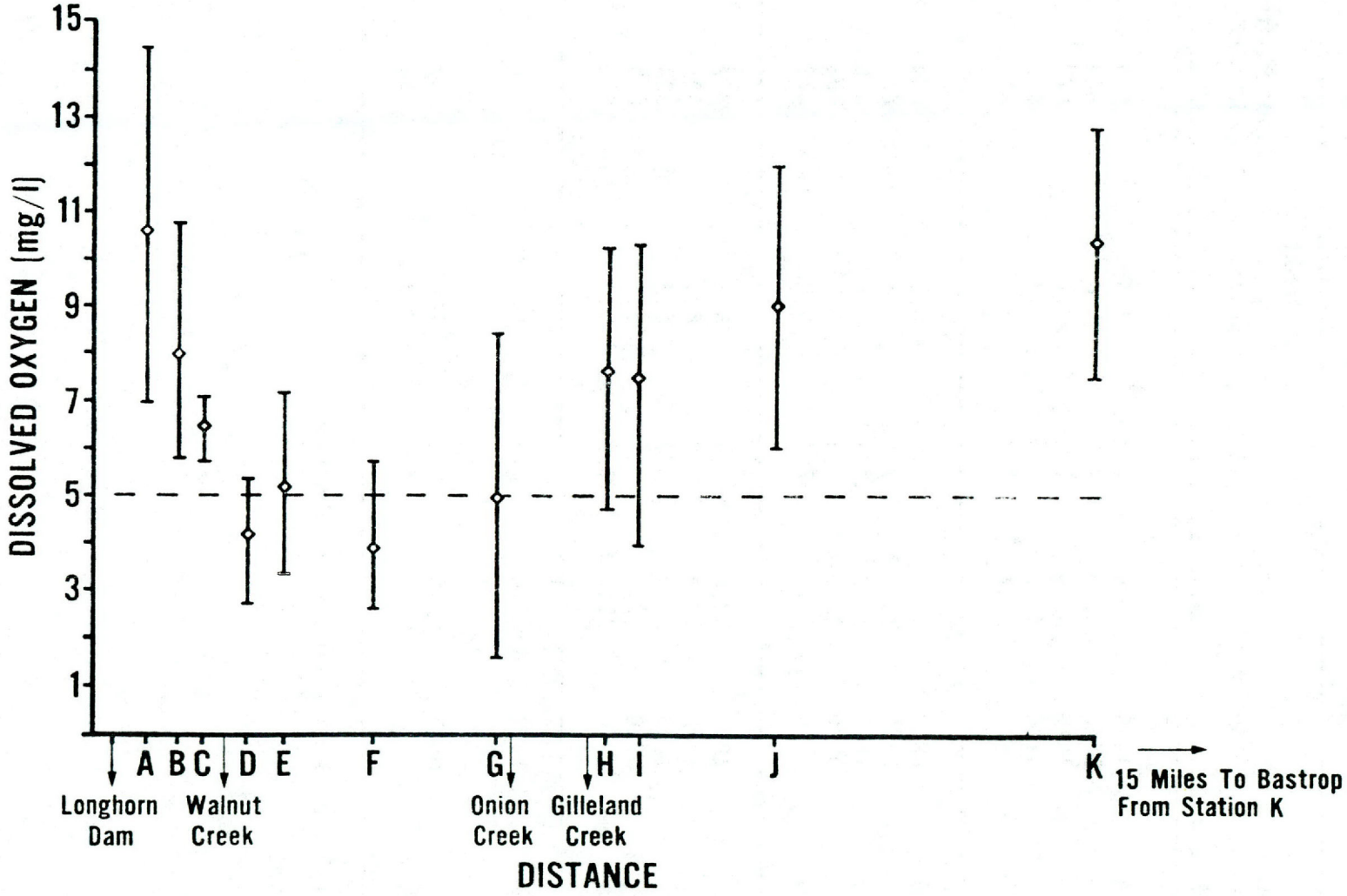

FIGURE 2

DISSOLVED OXYGEN RANGES AND DIEL MEANS

TABLE 3

Laboratory Analyses

Station Number	BOD_5 N-Supp. mg/l	Filt., BOD_5 N-Supp. mg/l	BOD_{20} N-Supp. mg/l	Filt., BOD_{20} 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
A 1402.0750	1	1	2	2	<10	<10	3	3.0	0	0.03	0.02	0.53	0.55	0.85	<0.01	0.02	<2	<2	45	42	376	197	635	8.3
B 1402.0740	9	6	17	12	14	7	4	6.1	1.94	4.16	0.03	0.37	0.40	6.50	1.46	1.76	2	<2	54	52	374	190	695	8.1
C 1402.0730	6	3.5	12	10	11	3	4	5.8	1.48	4.32	0.04	0.34	0.38	6.18	1.61	1.90	3	<2	55	52	380	190	693	8.2
D 1402.0720	3	2	8	6	<10	<10	1	4.4	1.23	3.17	0.15	2.60	2.75	7.15	2.33	2.51	2	<2	62	59	408	174	740	8.2
E 1402.0710	2.5	2	7	6	<10	<10	2	4.6	1.16	3.44	0.21	2.25	2.45	7.05	2.23	2.29	2	2	60	57	400	174	725	8.2
F 1402.0700	2.5	1.5	5.5	5	10	2	3	3.6	1.09	2.51	0.34	2.24	2.58	6.18	2.17	2.31	<2	<2	59	58	386	168	710	7.9
G 1402.0690	1.5	1.5	5	4	<10	<10	1	1.9	0.87	1.03	0.38	3.15	3.53	5.43	2.04	2.13	<2	<2	61	58	408	169	725	8.1
H 1402.0680	1.5	1.5	4.5	4	14	2	1	1.1	0.76	0.34	0.25	3.71	3.96	5.06	1.63	1.84	<2	<2	60	60	412	174	735	8.3
I 1402.0670	1.5	1.5	4	4	10	2	3	1.1	0.73	0.37	0.23	3.63	3.86	4.96	1.62	1.76	4	<2	59	58	406	177	730	8.3
J 1402.0660	1	1	3.5	3	<10	<10	2	0.9	0.72	0.18	0.19	3.67	3.86	4.76	1.50	1.61	5	<2	58	58	416	178	725	8.3
K 1402.0650	1	1	3	2.5	13	1	3	0.8	0.75	0.05	0.10	3.42	3.52	4.32	1.24	1.38	3	2	55	57	408	179	725	8.4
C2 1400.2320	1	1	2	2	<10	<10	<1	0.4	<0.38	<0.02	0.01	1.23	1.24	1.64	0.03	0.05	<2	<2	49	62	418	208	750	8.3
C1 1400.2310	2	1.5	5	4	<10	<10	4	1.4	1.23	0.17	0.12	8.72	8.84	10.24	4.62	5.06	<2	<2	91	88	500	121	870	8.1
G6a 1400.1152	1	1	2	2	13	5	2	0.4	<0.38	<0.02	<0.01	0.15	0.16	<0.56	0.56	0.02	2	<2	46	67	394	195	700	7.9
G6 1427.0080	2	1.5	4	3	<10	<10	<1	0.5	<0.48	<0.02	<0.01	0.28	<0.29	<0.79	0.01	0.03	2	<2	31	63	378	194	645	8.0

TABLE 3

Laboratory Analyses Continued

Station Number	BOD_5 N-Supp. mg/l	Filt., BOD_5 N-Supp. mg/l	BOD_{20} N-Supp. mg/l	Filt., BOD_{20} 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
G2 1427.0060	1	1	2.5	2	15	2	1	0.6	<0.58	<0.02	0.05	0.66	0.71	0.31	0.65	0.69	2	<2	49	63	400	216	745	8.5
G1 1427.0005	1.5	1	3	2.5	18	4	1	0.7	0.66	0.04	0.02	0.92	0.94	1.64	0.39	0.44	<2	<2	47	68	408	217	760	8.4
1A 1400.9001	16	8	60	30	32	24	6	20.6	3.35	17.25	0.02	<0.01	<0.03	<20.60	5.81	6.51	3	2	81	82	476	176	900	8.0
1B 1400.9002	9	6	25	18	15	5	4	16.0	1.83	14.17	0.09	0.04	0.13	16.13	3.55	3.99	<2	3	88	77	432	156	810	8.1
2 1400.9003	2.5	1.5	8	4.5	11	3	3	1.7	1.41	0.29	0.13	11.53	11.66	13.36	6.34	6.61	<2	<2	106	97	518	84	906	7.8
3 1400.9004	1	<1	2.5	1.5	11	3	4	1.3	1.05	0.25	<0.01	7.64	7.65	8.95	5.00	5.88	<2	<2	74	85	422	95	740	8.0

Table 4

Fecal Coliform Data

Station	Fecal Coliform #/100 mL
A	15
B	50
C	170
D	30
E	5
F	50
G	0
H	10
I	16
J	16
K	4
C2	105
C1	30
G6a	235
G6	30
G2	20
G1	15
1A	10
1B	10
2	0
3	0

Table 5

Total Phophorus (TP) and Total Nitrogen (TN) Loading

Station	1A	1B	2	3	A	C2	G6 & G6a
Flow (MGD)	18.26	8.45	28.7	3.2	83.4	7.74	6.45
TP (lb/d)	991	281	1,587	157	13.9	3.2	2.7
TN (lb/d)	3,137	1,136	3,201	239	591	106	72.6

Table 6

Benthic Macroinvertebrate Community Indices and Checklist of Species

Station	A*	A**	B**	C**	D*	G*	H*	I*	J**	K*
Number of Individuals/m^2	2,776	5,122	1,836	60,835	4,770	4,136	1,725	1,715	3,134	522
Number of Species	30	47	12	12	36	40	33	36	32	25
Diversity	3.22	4.24	2.45	2.34	4.05	4.18	4.03	4.37	3.32	3.67
Redundancy	0.38	0.25	0.34	0.35	0.23	0.23	0.23	0.18	0.37	0.30
Equitability	0.66	0.76	0.68	0.65	0.78	0.79	0.80	0.84	0.66	0.79

Taxon	Number of Individuals/m^2									
COLENTERATA										
Hydra sp.	4	29							29	
TURBELLARIA										
Dugesia tigrina					4	93				
Macrostomum appendiculatum		136								
NEMERTEA										
Prostoma rubrum	7	786				54				4
NEMATODA	72	205	29		83	14	4		29	4
HIRUDINEA										
Helobdella elongata		47	122	233						
Helobdella stagnalis		29								
Helobdella triserialis		4					22			
Mooreobdella microstoma		11								

Table 6 Continued

Taxon	Number of Individuals/m²								
OLIGOCHAETA									
Aeolosoma sp.					22	18	7		14
Aulodrilus limnobius		22		25	165				
Aulodrilus pigueti			886	4					
Branchiura sowerbyi	39							158	
Bratislavia unidentata			14						
Chaetogaster diaphanus				230	205	11			
Chaetogaster diastrophus	4								7
Dero digitata				11,073	14				
Dero nivea		14							
Dero trifida			14	1,704		244			
Ilyodrilus templetoni				12,777					
Limnodrilus cervix			183	19,515	108		7	86	
Limnodrilus hoffmeisteri	39	165	258	13,304	201	111	47	29	61
Limnodrilus udekemianus		104	47		72	165	32		111
Lumbricidae	7								
Nais pardalis					90	337	7	111	29
Nais variabilis		14			115	276		36	29
Pristina aequiseta		14							
Pristina americana			283		43				
Pristina leidyi					4				
Pristina sima		115							
Rhyacodrilus sodalis				850			4		
Slavina appendiculata	14								
Sparganophilus tamesis									4
Stephensoniana trivandrana	29					61			
GASTROPODA									
Biomphalaria obstructus	4	11							
Gundlachia radiata	298	513	14		301	603	323	197	
Helisoma anceps								14	
Physa virgata	4	140			7	122	7	18	4
PELECYPODA									
Corbicula fluminea	449	771			549	736	219	158	1,482	83
Pisidium casertanum									29
Pisidium compressum									57

Table 6 Continued

Taxon	Number of Individuals/m^2								
COPEPODA									
Cyclops sp.	47								
Harpacticoida	4	118							
AMPHIPODA									
Hyallela azteca		93				29			
OSTRACODA									
Candona nr caudata								144	
Eucypris sp.		4							
HYDRACARINA									
Atractides sp.					4				
COLEOPTERA									
Berosus sp.							4		
Dubiraphia sp.		4						4	
Heterelmis sp.								4	
Stenelmis bicarinata							7		
Stenelmis mexicanus							25	25	
Stenelmis sp.					43	14			4
DIPTERA									
Ablabesmyia annulata					22				
Ablabesmyia mallochi		283						14	7
Ablabesmyia parajanta		22							
Chironomus carus					22				
Chironomus decorus gr.			836	255			176		
Chironomus stigmaterus					93				
Cladotanytarus sp. A	32					36	111	54	7
Cladotanytarus sp. B									22
Conchapelopia sp.								14	29
Cricotopus bicinctus	316	61			599	36	11	29	14
Cricotopus festivellus gr.	25				115		7		14
Cricotopus sp. A									151
Cricotopus sp. B									11
Cryptochironomus fulvus					22		97		54

Table 6 Continued

Taxon	Number of Individuals/m²									
DIPTERA CONTINUED										
Dicrotendipes neomodestus	32	466		4	161	90		111	108	11
Empididae					29					
Eukiefferiella bavarica gr.										29
Goeldichironomus holoprasinus		22				54				11
Larsia sp.					22				14	
Limnophora sp.		4				4				
Micropsectra sp.								14		
Nanocladius distinctus		100								
Orthocladius sp.	25	384				90	36	236	122	
Palpomyia tibialis		7								
Pentaneura sp.						18				
Polypedilum convictum	104	22			671	36	219	83		22
Polypedilum illinoense		100	18		761	388		29	29	
Polypedilum nr scalaenum		22				18	7		29	
Pseudochironomus sp.	133				22		11	43		7
Simulium nr bivittatum										4
Simulium sp.							7	4		
Stictochironomus devinctus		22								
Tanypus neopunctipennis			18							
Tanytarsus sp.		22						29	14	
Thienemanniella nr xena	14				115	54	115	14		
EPHEMEROPTERA										
Baetis quilleri	18					4	4			
Caenis sp.				4		4			29	
Hexagenia limbata venusta									122	
Leptohyphes packeri	4					14	47	4		
Pseudocloeon sp.								18		25
Stenonema sp.							11	7		4
Thraulodes gonzalesi							4	14		
Tricorythodes albilineatus gr.	65	4			118	14	29	54	57	29
HEMIPTERA										
Hebrus sp.								4		

Table 6 Continued

Taxon	Number of Individuals/m^2							
LEPIDOPTERA								
Parargyractis sp.	11							
MEGALOPTERA								
Corydalus cornutus						11		
ODONTA								
Argia sp.	18	65	72	68	36	18		
Dythemis nigrescens		4						
Enallagma sp.				4				
Erpetogomphus sp.		4	18	39	29	97	39	
Hetaerina sp.	4							
Macromia sp.				4				
Progomphus obscurus			4					
TRICHOPTERA								
Cheumatopsyche sp.	22							
Culoptila sp.								36
Cyrnellus sp.		4						
Helicopsyche sp.				14	47	115		18
Hydroptila sp.	976		32		14			4
Nectopsyche gracilis	39	29					14	
Ochrotrichia sp.						14		
Oecetis sp.	7	36				4		
Protoptila sp.				18	97	79		
Smicridea sp.				50	86	18		4

* - erosional habitat; 3 subsamples collected using a Surber square foot sampler
** - depositional habitat; 3 subsamples collected using a square foot Peterson dredge

Table 7

Additional Benthic Macroinvertebrate Community Indices

Station	Percentage Composition of Functional Feeding Groups[a]						Mayflies		Tubificid Oligochaetes	Biotic Index[b]	Similarity Index[c]	Macrobenthic Health Rating[d]
	gr	ga	mi	fi	sh	pr	# of species	percent of community	percent of community			
A*	49.1	3.9	17.4	17.9	8.9	2.8	3	3.1	4.2	2.2	----	good
A**	14.3	9.6	27.7	18.9	1.7	27.9	1	0.1	5.7	2.3	----	good-to-excellent
B**	0.8	23.3	66.6	0.0	0.9	8.5	0	0.0	26.6	3.1	0.20	poor
C**	0.0	0.2	99.0	0.0	0.0	0.8	1	0.01	77.8	3.1	0.10	very poor
D*	7.7	6.0	33.5	14.0	21.3	17.4	1	2.5	8.6	2.4	0.42	good-to-excellent
G*	19.4	4.5	47.0	21.5	3.8	3.8	4	0.9	10.7	2.6	0.46	good-to-excellent
H*	31.6	10.9	20.8	24.3	4.9	7.4	5	5.5	22.6	2.1	0.54	good-to-excellent
I*	29.2	4.0	41.5	13.8	2.1	9.3	5	5.7	1.7	2.0	0.45	good-to-excellent
J**	0.0	10.7	31.9	57.3	0.0	0.0	3	6.6	13.3	2.8	0.43	good
K*	16.5	11.1	29.3	20.3	19.1	3.7	3	11.1	0.0	2.0	0.40	good-to-excellent

* - erosional station
** - depositional station
a - determined using the 12 most abundant species at each station; gr = grazers, ga = gatherers, mi = miners, fi = filterers, sh = shredders, pr = predators
b - determined using the 12 most abundant species at each station
c - with reference to the appropriate control station (i.e., Station A erosional, or Station A depositional)
d - based on the biotic integrity classification system of Karr (1981), with classes including excellent, good, fair, poor, very poor, and extremely poor

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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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