WATER QUALITY OF THE LOWER RED RIVER MONTGOMERY COUNTY, TENNESSEE

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MICHAEL LYNN DAVIS

WATER QUALITY OF THE LOWER RED RIVER
MONTGOMERY COUNTY, TENNESSEE

An Abstract

Presented to

the Graduate Council of

Austin Peay State University

In partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Michael Lynn Davis

January, 1981

ABSTRACT

A water quality study of the lower 11 miles of the Red River was conducted from July 1977 through May 1978. Selected biological, chemical and physical tests were conducted quarterly at 11 permanent stations. The major objective of this research was to define the existing water quality of the river in terms of pollution, biological and physicochemical characteristics.

The water quality criteria used for making the above evaluations were: benthic macroinvertebrates (species composition, diversity and equitability), fecal coliforms, pH, temperature, dissolved oxygen, total hardness, nitrate nitrogen, orthophosphate and Secchi disc transparency.

From benthic macroinvertebrate diversity and equitability data it was concluded that the Red River had areas of mild to heavy pollution at stations in and below the mouth of the Big West Fork. Upstream of this the river was basically in the clean water range. Species composition also changed at the downstream stations. The upstream fauna were dominated by dipteran larvae while oligochaetes comprised most of the downstream fauna.

Fecal coliform counts were higher at the downstream

stations near the Big West Fork and the Clarksville sewage treatment plant. Low flow and higher temperatures correlated with the higher bacteria counts.

Water temperature approximated the monthly mean air temperature and dissolved oxygen was in highest concentrations at the surface. Dissolved oxygen levels at the bottom were too low to allow a diversified fish fauna. Hydrogen-ion concentration (pH) was constant among all depths and stations within each sampling while a seasonal variation was noted. Water transparency was found to be lower at the rural upstream stations. This was mainly a result of excessive silt from agricultural runoff and bank erosion. The high turbidity in the Red River, and the associated light quenching properties, could have been a limiting factor in its productivity.

Nitrate nitrogen and orthophosphate were found in sufficient concentrations to support excessive plant growth. The Red River was found to have moderately hard to hard water with total hardness having an inverse relationship to visual clarity.

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To the Graduate Council:

I am submitting herewith a Thesis written by Michael L. Davis entitled "Water Quality of the Lower Red River, Montgomery County, Tennessee." I recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science, with a major in Biology.

David Snyder

Dr. David H. Snyder
Major Professor

We have read this thesis and
recommend its acceptance:

Floyd M. Ford

Dr. Floyd Ford
Second Committee Member

R. H. McCoy

Dr. R. H. McCoy
Third Committee Member

Accepted for the
Graduate Council:

William N. Ellis

Dean of the Graduate School

ACKNOWLEDGEMENTS

This thesis is dedicated to the memory of Fred W. Keyes, Jr.

I wish also to acknowledge the assistance from my major professor, Dr. David Snyder. In addition, I would like to thank Dr. Floyd Ford and Dr. R. H. McCoy for their constructive criticisms and contributions.

I would like to express gratitude to Drs. Davis and Diane Findley for their support and encouragement throughout my college career. Their enthusiasm and help was very important during the early stages of this project.

Enough cannot be said here about my research partner, Larry Carpenter. The dedication Larry exhibited, not only to his study, but also to mine, contributed greatly to the success of this work.

Appreciation is extended to fellow graduate students Jackie Stack and Ralph Thompson who donated several hours to the project.

I wish also to thank my wife Sherry, daughter Andrea and my parents for their continued encouragement and support which contributed in a major way toward the completion of this thesis.

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CHAPTER I

INTRODUCTION

The quality of this nation's lakes and rivers is an issue that is important to many people for many different reasons. The fisherman, the boater and the aquatic biologist all have an interest in waterways management.

Different segments of our society often have conflicting interests in the use of water resources. Industrial wastes and domestic sewage are discharged into rivers and greatly reduce water quality. Poor agricultural practices result in the siltation of streams and the early eutrophication of lakes. Each special group in society has its own idea of how to use water and how much the water quality can be altered. The problem of water pollution is often economic in nature with many people feeling that the cost of clean water is too high. My interest in freshwater biology and water pollution control prompted this water quality study.

Objectives of the Study

The purpose of this research was to determine the existing water quality of the lower Red River of Montgomery

County, Tennessee (Figure 1) with respect to pollution, biological and physicochemical characteristics. These were evaluated using the following water quality criteria:

(1) benthic macroinvertebrates
    (a) species composition
    (b) diversity
    (c) equitability
(2) fecal coliform bacteria
(3) temperature
(4) dissolved oxygen
(5) pH
(6) total hardness
(7) nitrate nitrogen (NO_3)
(8) orthophosphate (PO_4)
(9) Secchi disc transparency

Certain morphologic and hydrographic features such as depth and width of the stream were also measured.

Description of the Study Area

The Red River is a tributary of the Cumberland River entering at Cumberland River mile 125.3. The Red River has an approximate total length of 158 km and a drainage area of 2343 km^2. The Red River falls an average of 0.398 m per km from mile 51.1 to mile 0.0. Its headwaters lie in Sumner County, Tennessee, and it flows generally northwest through Sumner and Robertson Counties of Tennessee, into southern Simpson and Logan Counties of Kentucky; it then

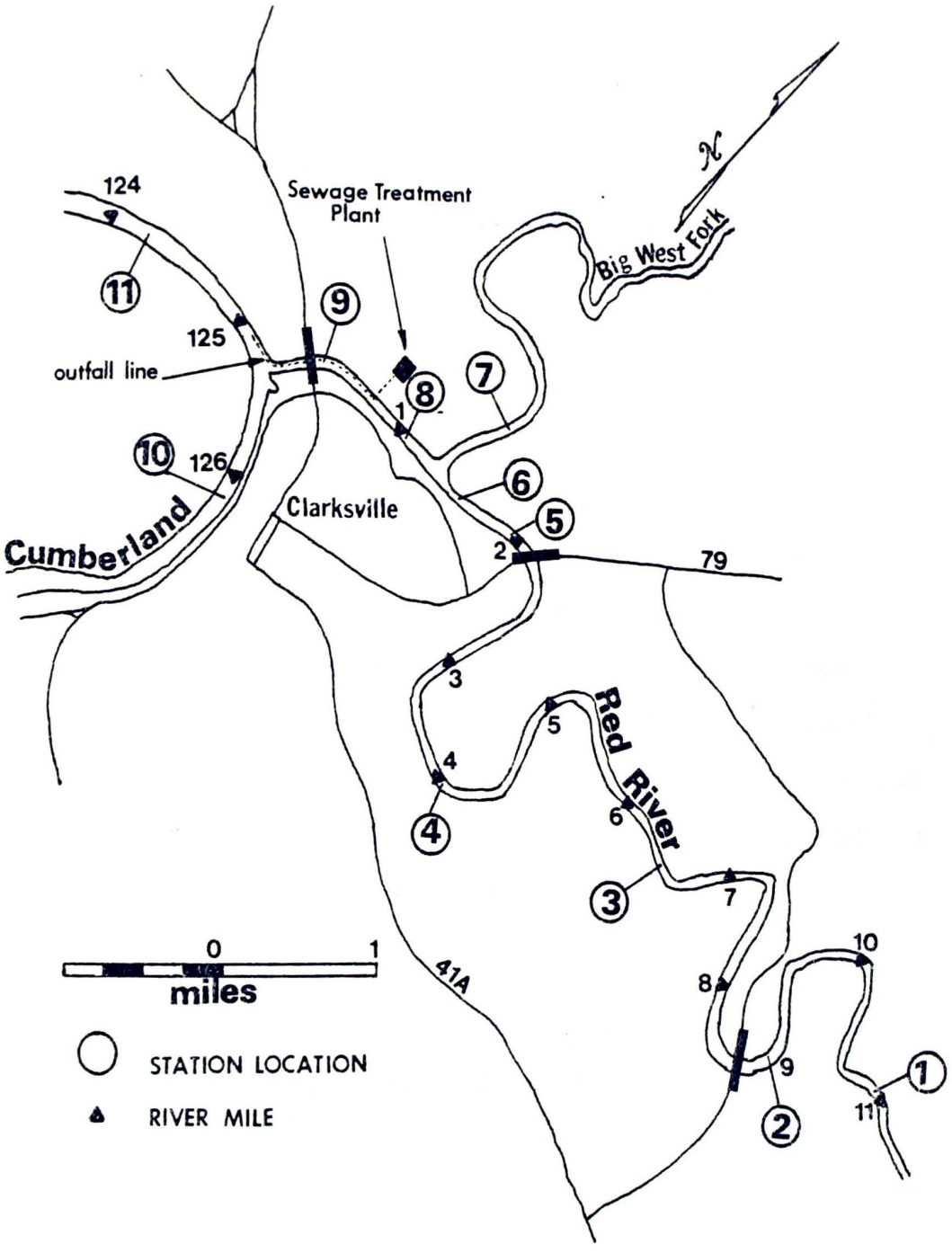

Figure 1. The lower Red and adjacent Rivers with location of research sampling stations marked.

reenters Tennessee and flows in a generally southwesterly direction across Robertson and Montgomery Counties to its confluence with the Cumberland River. The lower 15.0 miles of the Red River are impounded by the Barkley Dam (at Cumberland River mile 30.6). Except for the urban-industrial area at Clarksville, Tennessee (population 62,721 from 1970 census) near the mouth of the river, the Red River Basin is utilized chiefly for agricultural purposes. According to Perlan (1970) the watershed within Montgomery County is about 25% timber, 65% pasture, 5% cultivation and 5% urban. Primary uses of the river include fishing, float trips, municipal water supply, industrial water supply and waste disposal.

Substrate types and their estimated extents are: mud 25%, silt 25%, sand 20%, clay 25%, gravel 2%, rubble 2% and boulders 1% (Perlan, 1970). Throughout my research current velocity was noted as slight to none except during periods of high water due to heavy rainfall.

Other Studies on the Red River

This research was conducted in conjunction with a survey by Mr. Larry Carpenter, a graduate student at Austin Peay State University. Mr. Carpenter sampled phytoplankton, periphyton and ^{14}C productivity at the same stations and on the same dates as did I in this study. I know of no other significant water quality research on the lower Red River.

CHAPTER II

LITERATURE REVIEW

The quality of many of this nation's rivers, streams and lakes has been studied extensively. An enormous amount of general aquatic literature is readily available, such as the works by Hynes (1960, 1970), Hutchinson (1957), Macan (1974), Reid and Wood (1976), Ruttner (1963), Warren (1971) and Wetzel (1975). These sources deal with basic limnology including information on the chemical, physical and biological aspects of freshwater.

Although I found no literature on previous studies of the lower Red River, research on specific streams is common. Most such research, as with the studies by Cairns and Dickson (1971), Daniel and Chadwick (1971), Goodnight and Witley (1961), Howmiller and Beeton (1971), Gaufin and Tarzwell (1956), and Mason, et al. (1970) have related to the use of benthic macroinvertebrates as indicators of water quality. In addition, Mackenthun and Keup (1972) and Warner (1973) published extensive literature reviews on freshwater macroinvertebrates.

References by Bott (1973), Crabtree and Hinsdill

(1974), Davis, et al. (1968) and the State of Tennessee (1976) were very valuable to me in evaluating fecal coliform data. In addition to the general literature mentioned above other works by Chu (1943), Feth (1966), Happey (1970), Harned (1976), Ignjatovic (1968), Lee (1973), McCarty (1970), Muller (1953), Tyler (1968), Viets (1971) and Wanielista et al. (1977) were helpful in evaluating chemical and physical data.

Admittedly, I have only scratched the surface here with this short review. However, as stated above volumes of information are available on the subject of water quality. Therefore, only the most important references as used in this study were noted here. Each investigator should use caution in extrapolating data from another individual's research to a specific study area. Aquatic ecosystems, particularly rivers and streams, are subject to great variations in biological, chemical and physical properties.

CHAPTER III

METHODS AND MATERIALS

This research was designed to detect changes in water quality over the lower 11 miles of the Red River. Each of the tests was sampled quarterly at 11 permanent stations (Table 1). During the winter, only stations 2, 6, 9, 10 and 11 were sampled due to severe weather and boat failure. The sampling dates were as follows:

(1) Summer - 15, 16, 17 July 1977

(2) Fall - 21 October 1977

(3) Winter - 3, 5 March 1978

(4) Spring - 12, 13, 15 May 1978

Using procedures described in Mackenthun (1969) and Kittrell (1969), stations were chosen both without and within the most populated areas of the county. One station was located on the Big West Fork in order to evaluate its effect on the Red River. The two stations on the Cumberland River were used to assess the influence of the Red River on the Cumberland's water quality.

Benthic macroinvertebrates were collected using a 6"x6" Ekman grab. Three samples were taken at each station

Table 1. Station location, average river depth (meters) and average river width (meters).

Station #	River Mile*	Av Depth	Av Width
1	RR 11.0	3.4	38.7
2	RR 9.0	3.9	41.5
3	RR 6.4	4.7	40.0
4	RR 4.0	5.6	44.0
5	RR 2.0	5.6	46.4
6	RR 1.5	6.2	45.8
7	WF 0.4	6.5	39.0
8	RR 1.1	8.1	53.4
9	RR 0.4	8.3	55.8
10	CR 126.1	9.2	170.8
11	CR 124.3	10.1	164.7

*RR, Red River; WF, West Fork; CR, Cumberland River

based on the methods of Kittrell (1969) who noted that generally one point is adequate for streams up to 20 feet wide, two points for streams 20 to 150 feet wide, and three for streams over 150 feet in width. The three samples were combined in a plastic bag for transporting back to the lab. In the laboratory, the samples were washed through a US Standard Sieve, number 30 mesh (0.595 mm openings) in accordance with suggestions of the US Environmental Protection Agency (1973). The retained material was placed in jars of 70 percent ethanol. These samples were then poured into white enamel pans for sorting the invertebrates. All organisms were stored in vials containing 70 percent ethanol plus 5 percent glycerin for later enumeration and identification. Chironomids were permanently mounted with polyvinyl lactophenol (Beck, 1978 personal communication). All organisms were identified to the lowest possible taxonomic level considering my expertise in each group and the availability of keys. The following references and keys were used: Beck (1976), Brinkhurst and Jamieson (1971), Burks (1953), Johannsen (1934, 1935, 1936, 1937), Mason (1973), Merritt and Cummings (1978), Needham and Needham (1962), Parrish (1975), Pennak (1953), Usinger (1971) and Ward and Whipple (1963). Benthos was not collected at stations 10 and 11 because of substrate composition (which was primarily limestone), and the effect of the strong current on the Ekman grab.

Fecal coliform counts were made using the

membrane-filter fecal coliform method. This method is approved by the United States Public Health Service as a reliable test for the detection of fecal coliforms (Crabtree and Hinsdill, 1974). Surface samples were collected in sterile one 1 jars and placed on ice before returning to the lab. At the lab an undiluted sample and three dilutions (10^{-1}, 10^{-2}, 10^{-3}) were processed in order to obtain a plate count between 20 to 60 colonies. Each sample was filtered through a micropore filter (0.45 μm pore size) and placed in a sterile culture dish with Millipore Company fecal coliform (MFC) broth. The dishes were then placed in plastic bags and put in a water bath at 44.5°C $\pm$ 0.2° for 24 hours. At the end of the incubation period, the plates were removed and their colonies counted, using a binocular dissecting microscope.

Nitrate nitrogen (NO_3), orthophosphate (PO_4) and total hardness were tested using surface water and a Hach kit model DR-EL-DC in accordance with the Hach Chemical Company Methods Manual (Hach, 1973). Each Hach kit test was conducted in duplicate, with an average value taken. In the event of two values that were grossly inconsistent, a third measurement was made. A Corning Corporation portable pH meter, model 610 was used for surface pH readings. Temperature and oxygen were taken in situ from surface to bottom at one meter intervals with a Yellow Springs Instrument model 54 meter.

Water transparency was determined with a 20 cm Secchi

disc using the techniques of Tyler (1968). Bottom morphology was mapped with a model 719-B Raytheon Company fathometer and chart recorder, producing a bank-to-bank profile of each station (Appendix I).

CHAPTER IV

RESULTS

Benthic Macroinvertebrates

Benthic macroinvertebrates are defined as invertebrate organisms which live on or in the substrate of lakes, streams and rivers and are retained by a No. 30 U. S. Standard sieve (0.59 mm openings) and can be seen by the unaided eye (Keup, et al., 1966). Tables 2 through 10 list by station the taxa and number of individuals of benthic macroinvertebrates collected during the four sampling periods. During the winter sampling, benthic macroinvertebrates were collected at station nine only.

The benthic fauna at stations two through five were dominated by dipteran larvae (Table 11) with 90% (percentage of the total number of dipteran larvae) of these in the family Chironomidae. Station one benthos samples yielded nearly equal numbers of dipterans, oligochaetes and ephemeropterans. Ephemoroptera numphs, which were also abundant at stations two through four, are generally associated with clean water (Gaufin and Tarzwell, 1956). Oligochaetes at the upstream stations (stations one through

Table 2. Benthic macroinvertebrates collected at station 1 during four sampling periods.

TAXA	Summer	Fall	Winter*	Spring*
Annelida				
Oligochaeta				
Branchiura sowerbyi	18	0	0	0
Unidentified sp.	3	0	0	0
Arthropoda				
Crustacea				
Isopoda				
Asellus sp	1	0	0	0
Insecta				
Ephemeroptera				
Hexagenia limbata	5	21	0	0
Odonata				
Coenagrion sp.	1	0	0	0
Dromogomphus sp.	0	1	0	0
Coleoptera				
Noteridae	0	1	0	0
Unidentified sp	0	1	0	0
Diptera				
Chironomidae				
Ablabesymia ornata	1	0	0	0

Table 2. (continued)

Ablabesymia annulta	0	5	0	0
Chironomus sp.	1	0	0	0
Coelotanypus scapularis	0	3	0	0
Epoicocladius sp.	1	0	0	0
Paracladopelma sp.	3	0	0	0
Polypedilum sp.	4	0	0	0
Procladius sp.	3	0	0	0
Lepidoptera				
Arctiidae	1	0	0	0
Mollusca	1	0	0	0
Pelecypoda				
Corbicula sp.	0	5	0	0
TOTAL	42	37	0	0

*Station not sampled during the winter or spring.

Table 3. Benthic macroinvertebrates collected at station 2 during four sampling periods.

TAXA	Summer	Fall	Winter*	Spring
Annelida				
Oligochaeta				
Branchiura sowerbyi	1	14	0	0
Unidentified Sp.	3	6	0	13
Hirundinea	0	0	0	1
Arthropoda				
Insecta				
Ephemeroptera				
Hexagenia limbata	3	2	0	2
Heptagenia marginalis	0	1	0	0
Coleoptera				
Dubiraphia sp.	2	5	0	2
Diptera				
Chironomidae				
Ablabesymia ornata	0	0	0	1
Chironomus sp.	0	0	0	12
Cladotanytarsus sp.	0	0	0	1
Coelotanypus scapularis	0	1	0	0
Demicryptochironomus sp.	0	1	0	0
Paracladopelma sp.	3	0	0	0

Table 3. (continued)

Paratendipes connectens	1	0	0	18
Phaenopsectra obediens	0	0	0	84
Polypedilum sp.	0	1	0	20
Procladius sp.	2	0	0	7
Psectrocladius sp.	0	0	0	2
Tanytarsus sp.	0	1	0	3
Tribelos sp.	0	0	0	8
Unidentified sp. 1	0	0	0	2
Unidentified sp. 2	0	0	0	2
Ceratopogonidae	1	0	0	2
Trichoptera				
Nectopsyche sp.	0	0	0	1
Mollusca				
Pelecypoda				
Corbicula sp.	4	23	0	6
TOTAL	20	55	0	187

* Station was not sampled during the winter.

Table 4. Benthic macroinvertebrates collected at station 3 during four sampling periods.

TAXA	Summer	Fall	Winter*	Spring
Annelida				
Oligochaeta				
Branchiura sowerbyi	5	8	0	6
Unidentified sp.	3	0	0	0
Arthropoda				
Crustacea				
Hydracarina	0	0	0	1
Insecta				
Ephemeroptera				
Hexagenia limbata	2	13	0	0
Coleoptera				
Dubiraphia sp.	1	2	0	8
Diptera				
Chironomidae				
Ablabesymia annulata	2	6	0	0
Chironomus sp.	1	3	0	0
Coelotanypus scapularis	1	7	0	0
Cryptochironomus sp.	1	0	0	0
Paracladopelma sp.	1	1	0	0
Paratendipes connectens	11	78	0	7

Table 4. (continued)

Epoicocladius sp.	0	2	0	0
Phaenopsectra obediens	0	0	0	6
Polypedilum sp.	3	3	0	1
Procladius sp.	3	0	0	2
Tanytarsus sp.	0	1	0	0
Ceratopogonidae	0	0	0	1
Trichoptera				
Nectopsyche sp.	0	1	0	1
Mollusca				
Pelecypoda				
Corbicula sp.	2	11	0	2
TOTAL	36	136	0	35

*Station was not sampled during the winter.

Table 5. Benthic macroinvertebrates collected at station 4 during four sampling periods.

TAXA	Summer	Fall	Winter*	Spring
Annelida				
Oligochaeta				
Branchiura sowerbyi	0	10	0	2
Unidentified sp.	0	4	0	3
Arthropoda				
Insecta				
Ephemeroptera				
Hexagenia limbata	6	0	0	0
Heptagenia marginalis	0	1	0	0
Coleoptera				
Dubiraphia sp.	0	5	0	4
Elmidae	0	0	0	4
Diptera				
Chironomidae				
Ablabesymia annulata	1	4	0	0
Chironomus sp.	1	1	0	2
Coelotanypus scapularis	0	10	0	1
Epoicocladius sp.	2	0	0	0
Paracladopelma sp.	1	1	0	0
Paratendipes connectens	0	3	0	8

Table 5. (continued)

Phaenopsectra obediens	0	0	0	1
Polypedilum sp.	2	0	0	0
Procladius sp.	0	0	0	1
Unidentified sp.	0	1	0	0
Ceratopogonidae	0	0	0	1
Mollusca				
Pelecypoda				
Corbicula sp.	2	2	0	5
TOTAL	15	42	0	32

*Station was not sampled during the winter.

Table 6. Benthic macroinvertebrates collected at station 5 during four sampling periods.

TAXA	Summer	Fall	Winter*	Spring
Annelida				
Oligochaeta				
Branchiura sowerbyi	0	4	0	0
Unidentified sp.	6	33	0	10
Arthropoda				
Crustacea				
Isopoda				
Asellus sp.	1	0	0	1
Insecta				
Ephemeroptera				
Hexagenia limbata	0	2	0	0
Coleoptera				
Dubiraphia sp.	1	1	0	4
Megaloptera				
Sialis sp.	0	0	0	1
Diptera				
Culicidae				
Chaoborus sp.	1	0	0	0
Chironomidae				
Ablabesymia annulata	0	9	0	0

Table 6. (continued)

Chironomus sp.	0	1	0	15
Coelotanypus scapularis	0	14	0	1
Cryptochironomus sp.	1	0	0	2
Cryptotendipes sp.	0	0	0	1
Paracladopelma sp.	7	0	0	1
Paralauterborniella sp.	0	0	0	2
Paratendipes connectens	4	4	0	10
Polypedilum sp.	10	1	0	4
Procladius sp.	3	3	0	14
Unidentified sp. 1	0	0	0	1
Unidentified sp. 2	0	0	0	1
Ceratopogonidae	0	1	0	3
Mollusca				
Gastropoda				
Pleurocera sp.	0	1	0	0
Pelecypoda				
Corbicula sp.	1	1	0	2
Villosa sp.	0	0	0	1
TOTAL	35	75	0	74

*Station was not sampled during the winter.

Table 7. Benthic macroinvertebrates collected at station 6 during four sampling periods.

TAXA	Summer	Fall	Winter*	Spring
Annelida				
Oligochaeta				
Branchiura sowerbyi	0	2	0	0
Unidentified sp.	4	19	0	11
Arthropoda				
Insecta				
Coleoptera				
Dubiraphia sp.	0	2	0	3
Macronychus sp.	0	0	0	1
Diptera				
Chironomidae				
Ablabesymia ornata	0	1	0	0
Coelotanypus scapularis	0	3	0	0
Cryptochironomus sp.	0	1	0	1
Polypedilum sp.	2	2	0	1
Procladius sp.	0	1	0	2
Tribelos sp.	1	0	0	2
Unidentified sp.	0	0	0	1

Table 7. (continued)

Mollusca				
Pelecypoda				
Corbicula sp.	0	14	0	2
TOTAL	7	45	0	24

*Station was not sampled during the winter.

Table 8. Benthic macroinvertebrates collected at station 7 during four sampling periods.

TAXA	Summer	Fall	Winter*	Spring
Annelida				
Oligochaeta				
Branchiura sowerbyi	0	2	0	0
Unidentified sp.	0	72	0	126
Arthropoda				
Insecta				
Ephemeroptera				
Caenis sp.	0	0	0	2
Diptera				
Culicidae				
Chaoborus sp.	0	0	0	1
Chironomidae				
Ablabesymia ornata	0	0	0	2
Chironomus sp.	2	3	0	26
Coelotanypus scapularis	0	1	0	1
Cryptochironomus sp.	3	1	0	0
Paracladopelma sp.	0	1	0	3
Paralauterborniella sp.	0	0	0	2

Table 8. (continued)

Polypedilum sp.	0	0	0	1
Procladius sp.	9	7	0	10
Ceratopogonidae	0	0	0	2
TOTAL	31	87	0	176

*Station was not sampled during the winter.

Table 9. Benthic macroinvertebrates collected at station 8 during four sampling periods.

TAXA	Summer	Fall	Winter*	Spring
Annelida				
Oligochaeta				
Branchiura sowerbyi	1	2	0	0
Unidentified sp.	2	59	0	88
Arthropoda				
Crustacea				
Hydracarina	0	0	0	1
Insecta				
Ephemeroptera				
Hexagenia limbata	0	0	0	1
Coleoptera				
Dubiraphia sp.	0	0	0	2
Diptera				
Chironomidae				
Ablabesymia annulata	1	0	0	0
Chironomus sp.	1	2	0	0
Coelotanypus scapularis	0	3	0	1
Cryptochironomus sp.	0	2	0	0

Table 9. (continued)

Paracladopelma sp.	0	0	0	1
Polypedilum sp.	2	0	0	2
Procladius sp.	6	2	0	12
Mollusca				
Pelecypoda				
Corbicula sp.	0	0	0	11
TOTAL	13	70	0	119

*Station was not sampled during the winter.

Table 10. Benthic macroinvertebrates collected at station 9 during four sampling periods.

TAXA	Summer	Fall	Winter*	Spring
Annelida				
Oligochaeta				
Branchiura sowerbyi	0	1	0	0
Unidentified sp.	20	63	30	45
Arthropoda				
Insecta				
Ephemeroptera				
Hexagenia limbata	0	0	3	0
Diptera				
Culicidae				
Chaoborus sp.	0	0	0	3
Chironomidae				
Chironomus sp.	0	0	0	3
Cryptochironomus sp.	0	0	0	1
Epoicocladius sp.	0	0	0	1
Glyptotendipes sp.	0	0	0	1
Phaenopsectra obediens	0	0	0	3
Polypedilum sp.	0	0	0	1
Procladius sp.	0	0	0	4

Table 10. (continued)

Psectrocladius sp.	0	0	0	3
Unidentified Dipteran	0	0	0	1
Ceratopogonidae	0	0	3	0
TOTAL	20	64	36	66

Table 11. Percentage of major taxonomic groups of all individuals collected for all sampling periods.

STATION #	1	2	3	4	5	6	7	8	9
TAXA*									
Oligochaeta	26.5	16.2	10.6	21.3	28.8	47.4	73.8	75.2	85.5
Isopoda	1.2	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0
Ephemeroptera	32.9	3.4	7.2	7.9	1.1	0.0	0.7	0.5	1.6
Odonata	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coleoptera	2.5	3.8	5.3	14.6	3.3	7.9	0.0	1.0	0.0
Diptera	26.6	73.6	67.6	46.1	62.0	23.7	25.5	17.3	12.9
Lepidoptera	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trichoptera	0.0	0.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Megaloptera	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Hydracarina	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.5	0.0
Mollusca	6.3	14.0	7.2	10.1	3.3	21.1	0.0	5.4	0.0

*All groups are not at the same taxonomic level.

five) did not constitute more than 28.8% (percentage of the total number of individuals collected) of the total population. During the entire study, only one genus of Trichoptera larvae was collected; three specimens of Nectopsyche sp. were collected, one at station two and two at station three. As with mayflies, caddisflies are usually associated with clean water (Gaufin and Tarzwell, 1956). Corbicula sp., the Asiatic clam, were present at stations one through six. Although presenting severe competition for native pelecypods, Corbicula sp. is generally intolerant of organic waste. This genus was not collected at stations seven and nine.

Between stations five and six, the composition of the benthos changed dramatically. Oligochaetes made up 47.4% of the total population at station six and were proportionately and absolutely progressively more abundant at each subsequent downstream station (Table 11). At station nine, these worms made up 85.5% of all organisms collected.

Benthic macroinvertebrate diversity ($\bar{d}$) of the lower Red River was calculated using the Shannon-Weaver function and the machine formula of Lloyd et al. (1968). This formula is found in the U. S. Environmental Protection Agency's (EPA) Methods Manual (U. S Environmental Agency, 1973) and is:

$$\bar{d} = \frac{C}{N} (N\log_{10}N - \Sigma n_i \log_{10} n_i)$$

where C = 3.321928 (converts base 10 to base 2 (bits); N = total number of taxa, n_i = the number of individuals in

the i^{th} species. Wilhm and Dorris (1968) found $\bar{d}$ values of 0 - 1 to indicate heavy pollution, values from 1 - 3 moderate pollution and greater than 3, clean water.

Equitability (e) as used in this study is a measure of the amount of organic enrichment. Methods of the U. S. Environmental Protection Agency (1973) were used for calculating e. The formula used is:

$$e = \frac{s'}{s}$$

where s = the number of taxa and s', a number taken from a table in the EPA Methods Manual (U. S. Environmental Protection Agency, 1973) and based on the calculated diversity ($\bar{d}$). Equitability values have been found to be sensitive to slight levels of degradation (U. S. Environmental Protection Agency, 1973). Values of e in the range of 0.0 - 0.5 indicate the presence of oxygen-demanding wastes and values of 0.5 - 1.0 the absence of such wastes.

Diversity indices and equitability values are plotted on Figures 2 and 3 respectively. Stations one, three, four, and five all had $\bar{d}$ values in the clean water range (3.0). Equitability for these same stations was greater than 0.5 with a high of 1.06 at station four. As noted by the U. S. Environmental Protection Agency (1973) highs of this nature often result from a sample with only a few specimens and several taxa. Station two samples exhibited slight pollution according to both $\bar{d}$ and e values.

Beginning with station six and continuing downstream through nine, $\bar{d}$ and e values dropped considerably.

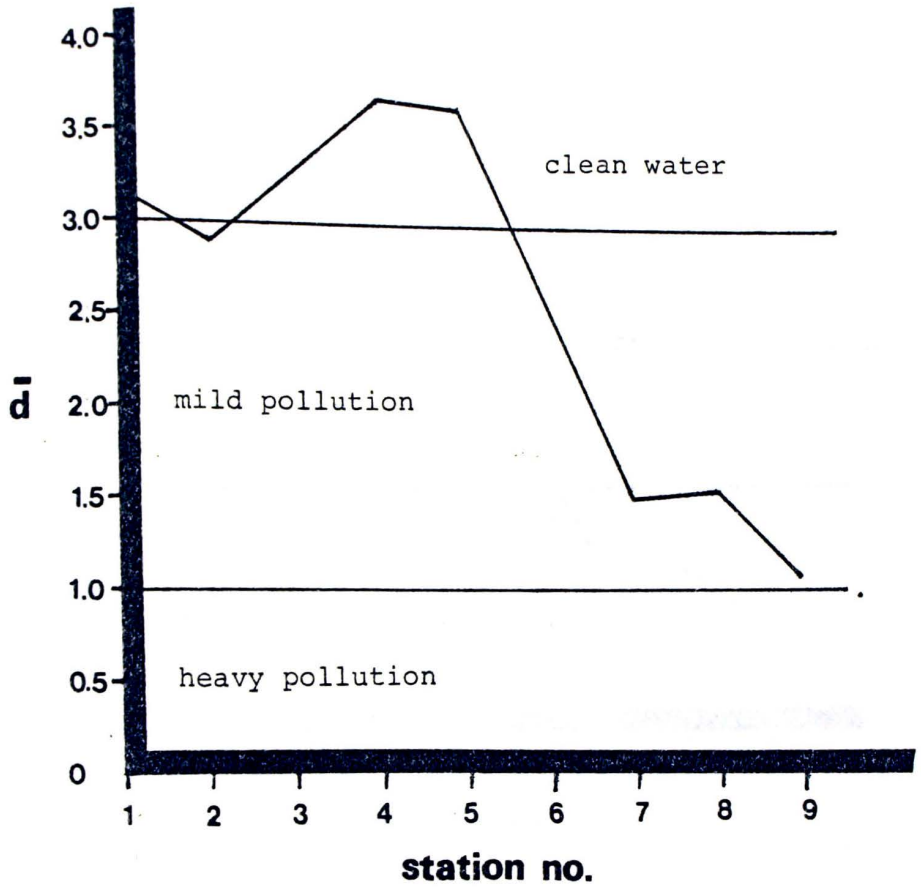

Figure 2. Benthic macroinvertebrate diversity indices ($\bar{d}$) of the lower Red River.

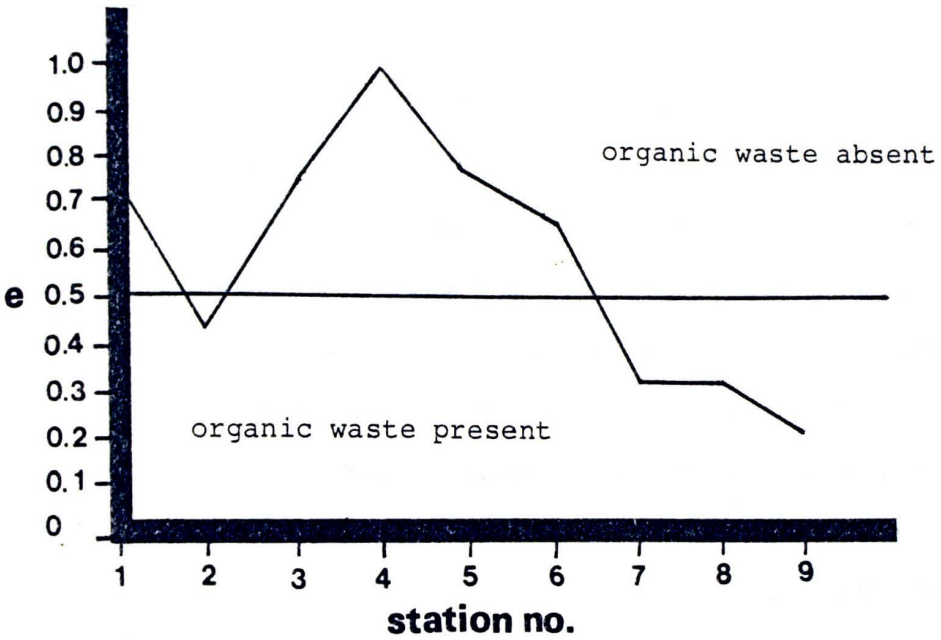

Figure 3. Benthic macroinvertebrate equitability (e) of the lower Red River.

Diversity and equitability both indicated pollution at station seven and approached heavy pollution at station nine. Below the confluence of the Big West Fork (station eight) $\bar{d}$ and e values dropped to 1.57 and 0.31 respectively.

Temperature

Temperature data for the summer, fall and spring sampling periods are listed in Tables 12, 13 and 14 respectively. No temperature or dissolved oxygen measurements were taken during the winter sampling. A consistent pattern in both vertical and horizontal temperature profiles was observed. During the summer and fall samplings, early morning temperatures (0700 - 0930 hrs.) were approximately the same at all depths. As air temperature increased, surface waters warmed faster than did deeper strata. This was not observed during the spring sampling, probably due to the complete mixing by the swift current. The maximum temperature variation from surface to one meter was 2.4°C, and the maximum surface to bottom change was 5.0° C. During all three seasons the mean surface water temperature was within 2.8° C of the mean air temperature. Summer mean air and surface water temperatures were 30.6 and 28.9° C respectively. For the fall these measurements were 16.4° C (air) and 13.6° C (water).

Dissolved Oxygen

Tables 15 through 17 list dissolved oxygen (DO) concentrations by depth for each season sampled. Oxygen

Table 12. Temperatures (^{o}C) at one meter depth intervals on the lower Red and Cumberland Rivers on 15, 16, 17 July 1977.

Station No.	1	2	3	4	5	6	7	8	9	10	11
Depth (m) surface	26.8	29.2	30.0	27.5	28.0	29.9	30.0	27.5	29.0	29.9	30.0
1m	26.8	27.1	27.6	27.1	26.7	28.6	28.0	27.2	28.5	28.8	28.9
2m	26.7	27.0	27.0	27.1	26.5	27.9	26.8	27.1	28.2	28.6	28.7
3m	26.7	27.0	27.0	27.1	26.5	26.3	26.0	27.0	28.0	28.6	28.6
4m			27.0	27.1	26.5	26.1	25.2	26.8	27.1	28.6	28.5
5m				27.0	26.5	26.9	25.0	26.3	27.0	28.6	28.5
6m							25.0	26.0	26.9	28.6	28.5
7m								26.0	26.5	28.6	28.5
8m										28.5	28.5
9m										28.5	28.2
10m											28.2

Table 13. Temperatures (°C) at one meter depth intervals on the lower Red and Cumberland Rivers on 21 October 1977.

Station No.	1	2	3	4	5	6	7	8	9	10	11
Depth (m) surface	10.5	11.5	11.5	12.0	14.0	15.0	14.7	15.0	16.1	14.0	15.0
1m	10.5	11.0	11.0	10.9	12.0	13.5	13.5	14.0	15.0	15.0	15.0
2m	10.5	11.0	11.0	10.9	11.0	12.0	12.2	13.2	13.9	15.0	15.0
3m	10.5	11.0	11.0	10.9	11.0	11.5	11.0	11.7	12.0	15.0	15.0
4m			11.0	10.8	11.0	11.5	11.0	11.2	11.8	15.0	15.0
5m				10.8	11.0	11.5	11.0	11.2	11.5	15.0	15.0
6m							11.0	11.2	11.5	-*	15.0
7m								11.2	11.5	-	15.0
8m										-	15.0
9m											
10m											

*No reading taken at 6, 7 and 8 meters due to swift current.

Table 14. Temperatures (^{o}C) at one meter depth intervals on the lower Red and Cumberland Rivers on 12, 13, 15 May 1978.

Station No.	1	2	3	4	5	6	7	8	9	10	11
Depth (m) surface											
1m		17.1	17.1	17.1	18.0	15.0	13.0	14.0	15.0	15.8	15.6
2m		17.1	17.1	17.1	18.0	15.0	13.0	14.0	15.0	-*	-*
3m		17.1	17.1	17.1	17.9	15.0	13.0	14.0	15.0	-	-
4m		17.1	17.1	17.1	17.9	15.0	13.0	14.0	15.0	-	-
5m		17.1	17.1	17.1	17.9	15.0	13.0	14.0	15.0	-	-
6m			17.1	17.1	17.9	15.0	13.0	14.0	15.0	-	-
7m				17.1	17.9	15.0	13.0	14.0	15.0	-	-
8m						15.0	13.0	14.0	15.0	-	-
9m								14.0	15.0	-	-
10m									15.0	-	-

*No reading taken below the surface due to boat failure.

Table 15. Dissolved oxygen concentrations (ppm) at one meter depth intervals on the lower Red and Cumberland Rivers on 15, 16, 17 July 1977.

Station No.	1	2	3	4	5	6	7	8	9	10	11
Depth (m) surface	6.6	7.2	8.1	5.6	6.3	7.2	8.1	5.9	6.7	6.6	8.1
1m	6.3	6.2	6.9	5.3	5.5	6.8	7.7	5.8	5.9	6.5	7.5
2m	6.3	5.4	6.0	5.2	5.4	5.3	6.1	5.4	5.9	6.2	6.2
3m	6.3	5.7	5.6	5.5	5.3	5.1	5.3	5.4	5.6	6.2	5.7
4m			5.3	5.4	5.2	5.3	4.6	5.0	5.3	6.3	5.7
5m				5.2	5.2	5.2	4.4	4.5	4.6	6.3	5.5
6m							4.0	4.2	4.4	6.2	5.4
7m								3.9	4.1	6.2	5.3
8m										6.2	5.3
9m										6.2	5.2
10m											5.0

Table 16. Dissolved oxygen concentrations (ppm) at one meter depth intervals on the lower Red and Cumberland Rivers on 21 October 1977.

Station No.	1	2	3	4	5	6	7	8	9	10	11
Depth (m) surface	10.8	10.0	9.7	8.1	8.4	8.0	5.6	6.8	6.5	8.0	6.4
1m	5.1	5.4	4.6	5.2	3.8	3.8	4.2	3.2	3.2	2.3	2.2
2m	3.6	4.2	4.4	4.0	4.1	3.6	3.2	3.1	3.0	2.1	2.2
3m	3.6	4.4	4.4	4.0	3.9	3.6	3.4	3.6	3.2	2.0	2.1
4m			3.8	4.2	4.0	3.6	4.0	3.7	3.4	2.0	2.0
5m				4.0	4.0	3.6	3.4	3.7	3.4	2.0	2.0
6m							3.4	3.6	3.4	-*	2.0
7m								3.6	3.4	-	2.0
8m										-	2.0
9m											
10m											

*No reading taken at 6, 7 and 8 meters due to swift current.

Table 17. Dissolved oxygen concentrations (ppm) at one meter depth intervals on the lower Red and Cumberland Rivers on 12, 13, 15 May 1978.

Station No.	1	2	3	4	5	6	7	8	9	10	11
Depth (m) surface		6.9	8.0	8.2	6.1	7.8	9.1	10.2	10.5	9.6	7.2
1m		3.7	4.6	6.4	4.6	5.2	6.5	7.2	6.6	-*	-*
2m		2.8	3.6	7.0	3.2	3.4	4.6	4.9	5.1	-	-
3m		2.5	4.0	4.2	2.8	3.2	3.8	3.8	4.2	-	-
4m		2.4	3.0	3.5	2.6	2.7	3.5	3.3	3.9	-	-
5m			3.4	3.2	2.5	2.6	3.3	3.2	3.5	-	-
6m				5.1	2.4	2.4	3.1	3.1	3.4	-	-
7m						2.4	3.0	3.1	3.3	-	-
8m								3.1	3.3	-	-
9m									3.3	-	-
10m											

*No reading taken below the surface due to boat failure.

saturation levels for the surface, at one meter and at the bottom are plotted in Figure 4. At all stations the highest DO readings were taken at the surface and the lowest generally at the bottom.

In the summer sampling (Table 15), a gradual decline in DO occurred with increasing depth, while in the fall and spring the decrease was much more pronounced (Table 16 and 17). The highest concentrations and percent saturation occurred during peak sunlight on unshaded reaches of river. Supersaturation was observed at the surface on four occasions during this study (Figure 4). At depths of one meter or greater, saturation levels dropped considerably. During the spring sampling the bottom water was approximately 24% saturated with oxygen at several stations, compared to about 80% saturation at the surface at those stations.

Nitrate Nitrogen

Nitrate nitrogen (NO_3) concentrations for the lower Red River are plotted in Figure 5. During the entire sampling period NO_3 concentrations were never below 2.0 ppm. Levels were usually highest at stations one through four on the Red River and stations 10 and 11 on the Cumberland River. The highest readings occurred during spring sampling when concentrations ranged from a low of 3.8 ppm to a reading too high for quantitation by the Hach kit. The

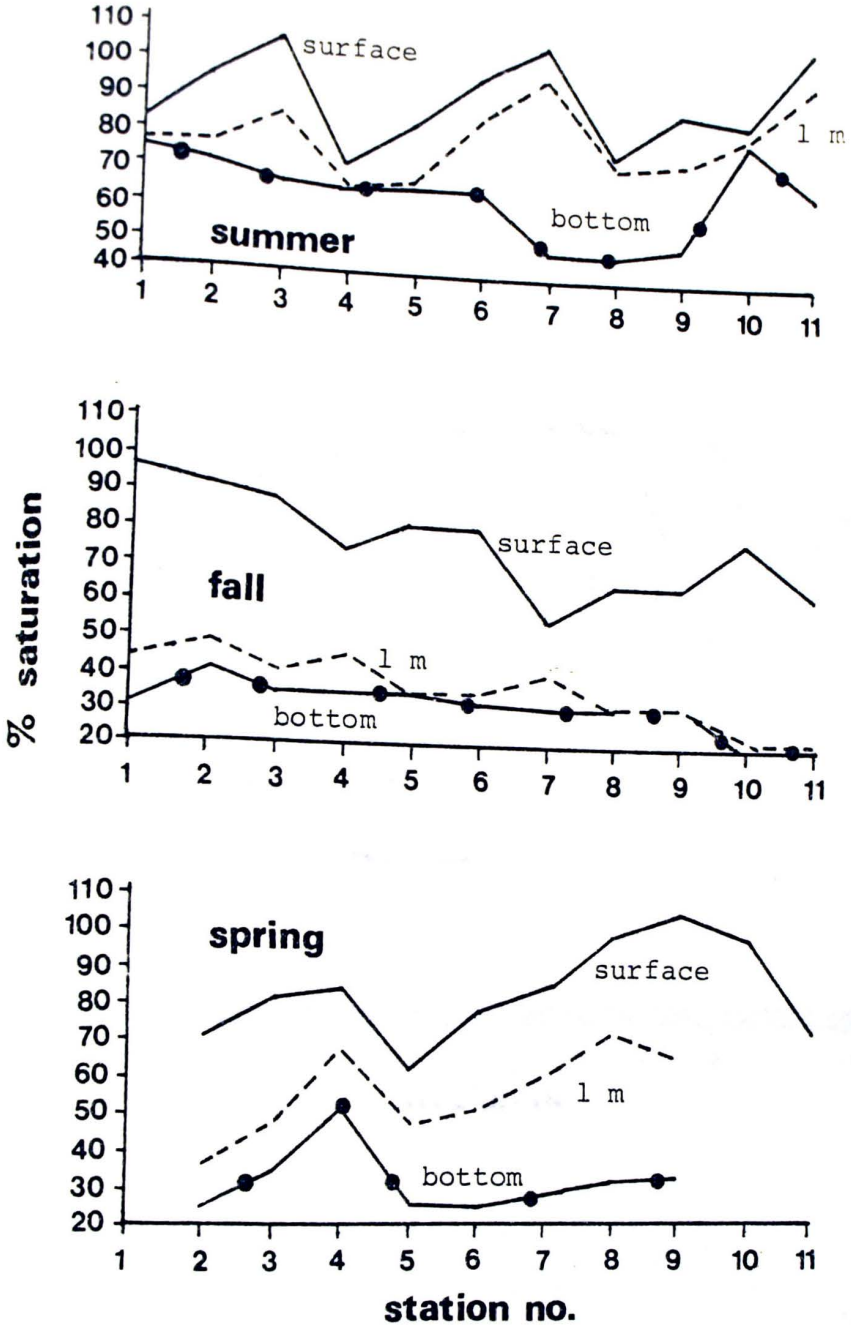

Figure 4. Percent oxygen saturation at the surface, at one meter and at the bottom of the lower Red and Cumberland Rivers during the summer (15, 16, 17 July 1977), fall (21 October 1977) and spring (12, 13, 15 May 1978).

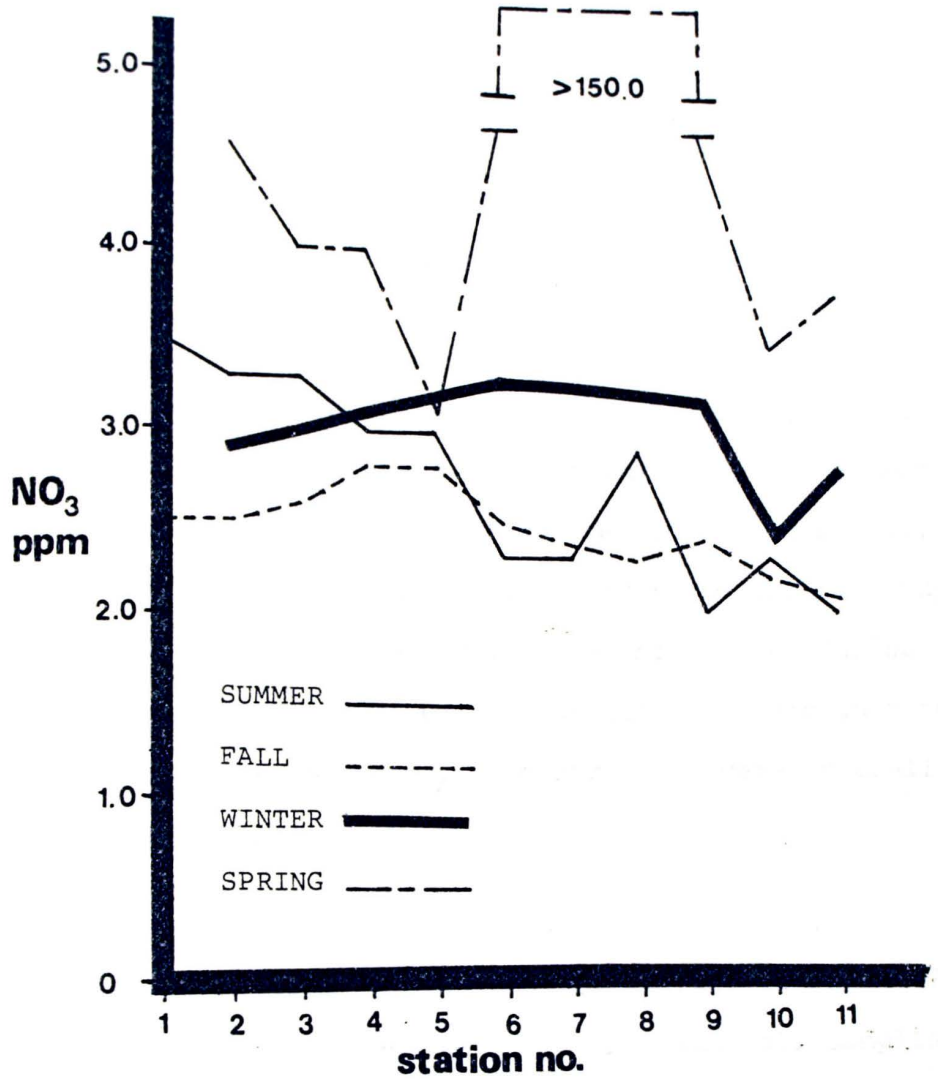

Figure 5. Nitrate nitrogen (NO_3) concentrations (ppm) at selected stations on the lower Red and Cumberland Rivers during four sampling periods.

high spring values were probably accounted for by the spring high water and rain. Reid and Wood (1976) indicate that during flood times, nitrate nitrogen content may be expected to increase significantly, and Hynes (1970) states that rain contributes fairly large amounts of nitrate.

Orthophosphate

Orthophosphate concentrations in the Red River (Figure 6) ranged from a low of 0.04 ppm in the winter to a high of 0.95 ppm in the fall. Throughout the winter and spring, PO_4 levels remained fairly constant over the entire study area. The highest PO_4 readings were encountered during the summer and fall sampling at station five through nine. Other than these peaks, PO_4 concentrations were generally around 0.15 ppm.

Secchi Disc

Water transparency readings are plotted in Figure 7. The general situation during the summer and fall samplings was lower readings at the upstream stations, usually between 30 and 55 cm. At the downstream stations, during these same samplings, the reading increased to the 60 to 84 cm range. During the first day of spring sampling, upstream station readings were comparable to those of summer and fall. However, on the second day, heavy rains and the subsequent run-off lowered the downstream station readings to 10 cm.

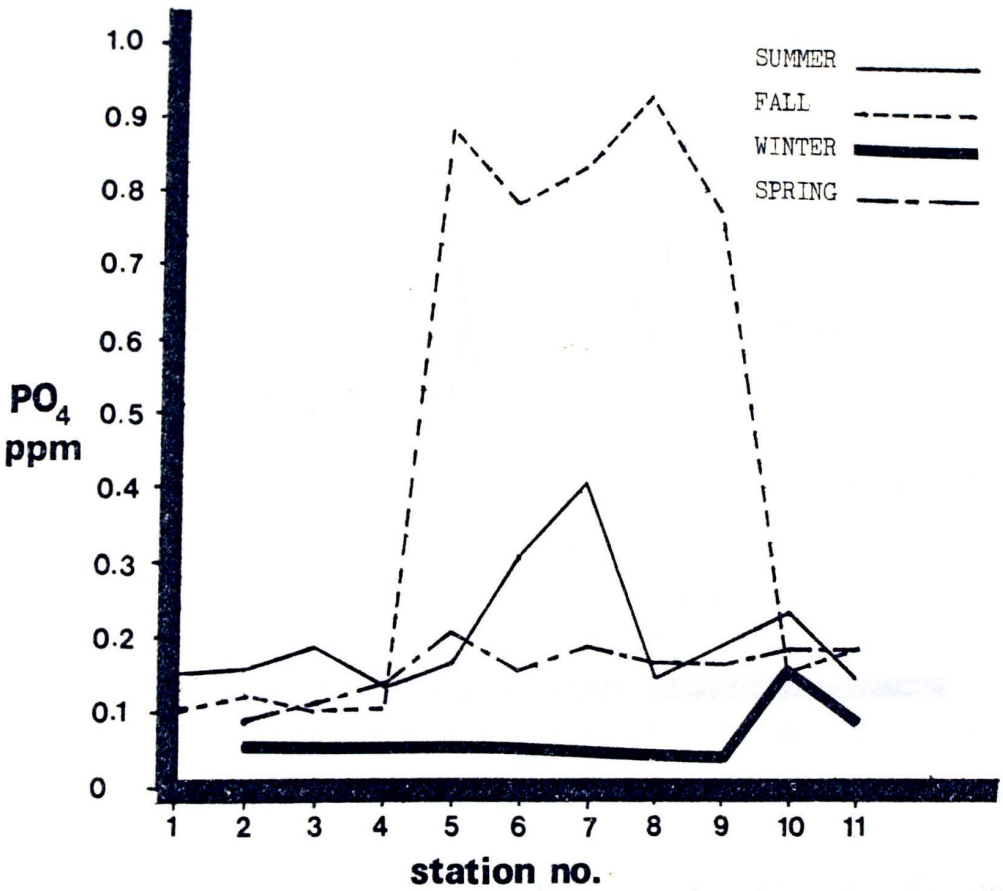

Figure 6. Orthophosphate (PO_4) concentrations (ppm) at selected stations on the lower Red and Cumberland Rivers during four sampling periods.

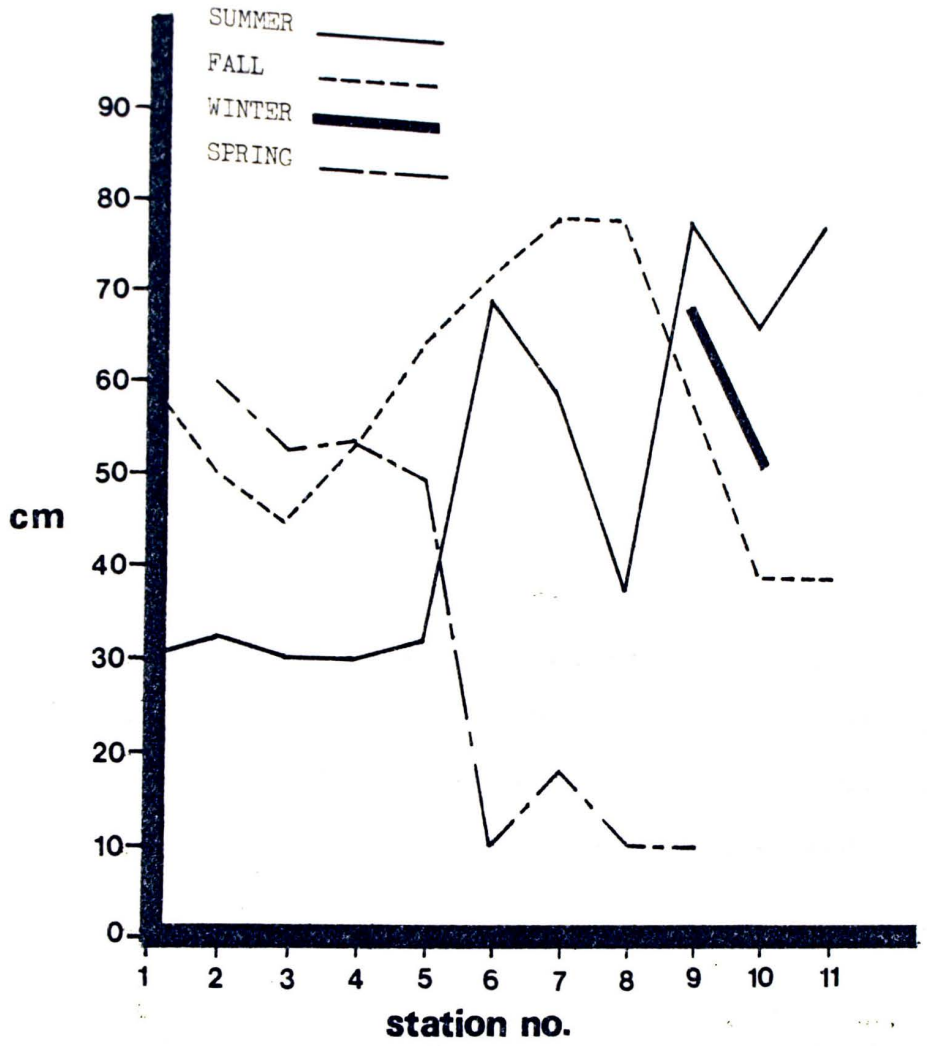

Figure 7. Secchi disc transparency (cm) at selected stations on the lower Red and Cumberland Rivers during four sampling periods.

Total Hardness

Total hardness of the lower Red River (Figure 8) followed a consistent pattern throughout this investigation. At upstream stations (stations one through five) readings were greater than 160 ppm at all times. Beginning at station six, readings dropped to 70 ppm. A high reading of 220 ppm was observed at stations two through four during fall samplings.

pH

Hydrogen ion concentration (pH) of the lower Red River is plotted in Figure 9. Within each seasonal sampling period very little variation in pH occurred throughout the reach of river tested. During the summer sampling pH ranged from 7.1 to 8.3 while the range was generally between 6 and 7 during the fall, winter and spring samplings.

Fecal Coliform Bacteria

Table 18 lists the fecal coliform densities (number colonies/100 ml) as sampled in the Red and Cumberland Rivers during four sampling periods. During the summer and fall samplings, densities at stations 1 through 4 were consistently lower than those of the remaining Red River stations. On the Red River, low counts of 75 colonies/100 ml and 45 colonies/100 ml were observed during the summer and fall respectively. This was significantly less than the Red River high readings of 3,050 colonies/100 ml and

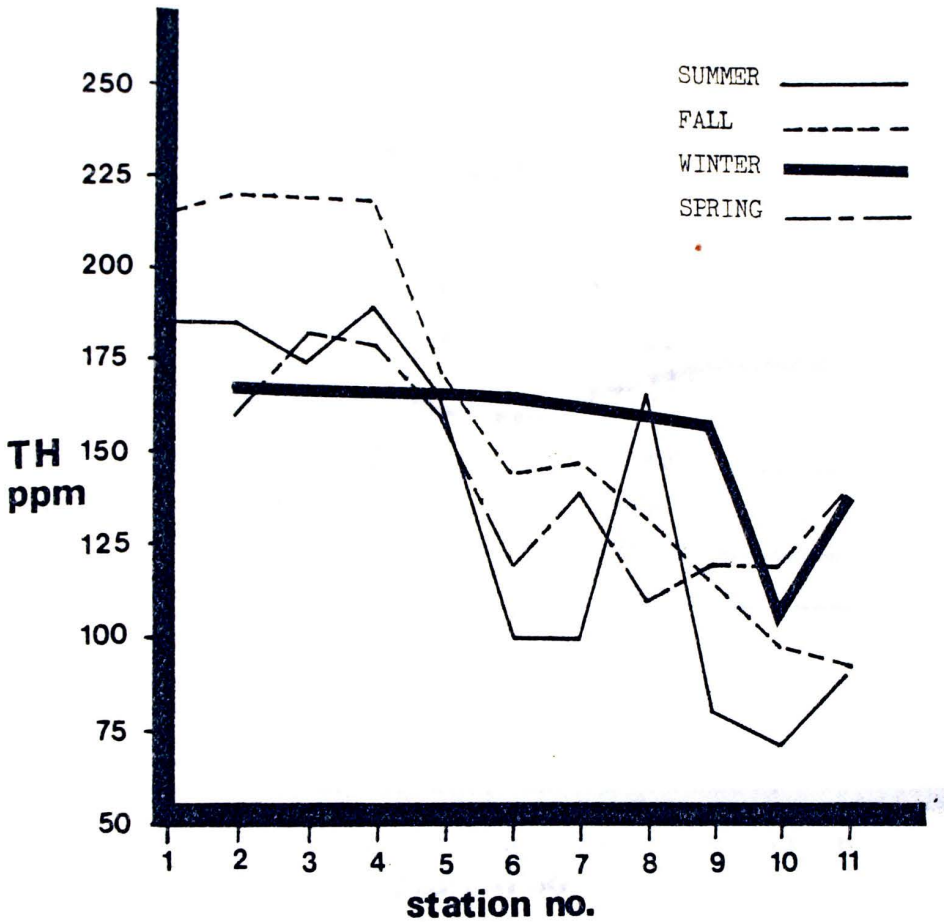

Figure 8. Total hardness (ppm) at selected stations on the lower Red and Cumberland Rivers during four sampling periods.

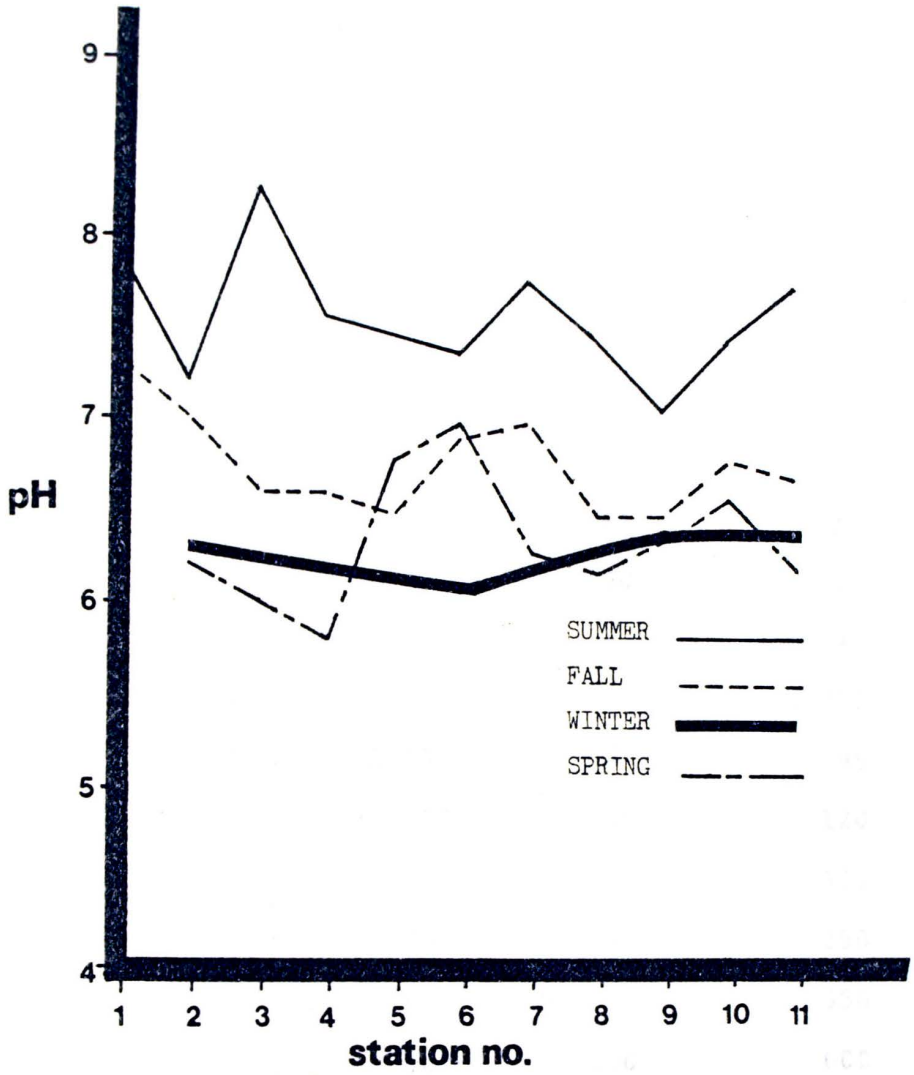

Figure 9. Hydrogen-ion concentrations (pH) at selected stations on the lower Red and Cumberland Rivers during four sampling periods.

Table 18. Seasonal variation in fecal coliform counts (#/100 ml) at selected stations on the lower Red and Cumberland Rivers.

Season	Summer	Fall	Winter	Spring
Station				
1	290	45	-**	-***
2	195	90	50	195
3	75	65	-	145
4	225	55	-	255
5	500	1,050	-	95
6	3,050	37,600	135	120
7	1,450	104,000	-	350
8	-*	252,500	-	350
9	2,900	2,600	50	550
10	65	400	250	600
11	550	900	95	390

*sample jar broken
**no access to stations
***station was not sampled during the spring

252,500 colonies/100 ml at the downstream stations during the summer and fall samplings. On the Cumberland River, station 11 counts were higher than those of station 10 during summer and fall tests. This indicates that the Red River is a source of fecal pollution in the Cumberland River. Fecal coliform counts taken during the winter and spring were more consistent throughout the entire study area. This was most likely a result of the high water and its diluting and mixing effects.

CHAPTER V

DISCUSSION

Benthic Macroinvertebrates

In the past, water quality studies often consisted of chemical and physical analyses, and completely ignored the fact that water pollution is basically a biological problem. The organisms which live in the aquatic habitat are the ones directly affected by the introduction of pollutants. If an aquatic organism is to perpetuate itself, water quality must permit survival 24 hours a day for its entire life (Cairns and Dickson, 1971). Generally, benthic invertebrates live in a particular habitat because the conditions there have remained somewhat constant in the past. Chemical and physical tests may not detect occasional pollution if the samplings are not conducted soon after the time of discharge. Egloff and Brakel (1973) state that the benthic community reflects the environmental conditions during a time period at least equal to the time required for the youngest organisms to have settled and grown.

Macroinvertebrates vary widely in their tolerance to various levels of water quality. Each of these animals is

adapted in some way to occupy its niche in the aquatic community. A chemical or physical factor which limits one species may allow another to thrive. Goodnight (1973) noted that low dissolved oxygen concentrations may eliminate gill-breathing insects like mayflies, stoneflies and caddisflies but species such as Culex pipiens (sewage mosquito) and Eristalis bastard (rat-tailed maggot) may occur in such situations in large numbers. These particular species can tolerate these low dissolved oxygen conditions because of special adaptations that permit breathing of the atomospheric oxygen.

A close look at the entire benthic community will often give a good indication of the existing water quality of an area even though the presence or absence of one particular species may mean little to a water quality study. Since pollution tolerant species may be found in both clean and degraded habitats, a simple record of their presence or absence is of no significance (U. S. Environmental Protection Agency, 1973).

The concept of diversity as defined by Pielou (1975) is based on the richness and variety of natural ecological communities. Each such community has a characteristic flora and fauna which have resulted from interactions with each other and with the abiotic factors of the environment.

Diversity indices are mathematical expressions which describe community structure and permit summarization of large amounts of information about numbers and kinds of

organisms (Wilhm and Dorris, 1968). Nonpolluted environments are typically characterized by biotic communities with many species and few individuals, while polluted situations normally have few species with many individuals (Cairns and Dickson, 1971). However, in a few natural unpolluted communities the latter may be observed as was reported by Hendricks et al. (1974).

Benthic macroinvertebrate diversity is frequently used in water quality surveys to evaluate water quality of streams and rivers. The index of community structure is often more valuable than a list of species divided into tolerant and intolerant forms. Gaufin and Tarzwell (1956), in their study of Lytle Creek, noted that the diversity of benthic macroinvertebrates provided a more reliable indication of the degree of organic pollution than did the mere presence or absence of indicator species. Other studies by Egloff and Brakel (1973), Hendricks et al (1974), Stoneburner et al. (1976) and Wilhm and Dorris (1966) have used diversity in evaluating the impact of pollutants on benthic macroinvertebrates.

Based on the results noted in the previous chapter it is clear that the Red River exhibits two distinct zones of water quality. From stations one through five, the river was found to be clean while stations six through nine had polluted waters. This sharp demarcation in water quality was very evident in benthos community composition (Tables 2-11), diversity (Figures 3) and equitability

(Figure 4). The clean water stations were dominated by various clean water species, with a few pollution tolerant species also present. However, below station five, pollution tolerant species, primarily oligochaetes, dominated.

I believe that effluents from sewage treatment plants were responsible for the polluted conditions at the lower stations. Between stations eight and nine (Figure 1) was the effluent discharge of the main sewage treatment plant for Clarksville. Original construction plans called for the sewage effluent not to be discharged into the Red River but to be released instead into the Cumberland River via a pipe down the Red River. The pipe entered between stations eight and nine, then turned downstream for approximately 0.5 miles where it entered the Cumberland River. Somewhere near its entrance into the Red River, there was a rupture in the pipe causing a discharge instead between stations eight and nine. Evidence of this leak was observed by Larry Carpenter and me during July, 1977. In August 1977, while mapping bottom morphology with Hildon M. Davis, large amounts of suspended material were detected by sonar equipment (Figure 10). I question the efficiency of an operation discharging such quantities of suspended solids.

Pollutants at station seven on the Big West Fork were probably from three sewage treatment plants on the Little West Fork, a tributary of the Big West Fork entering

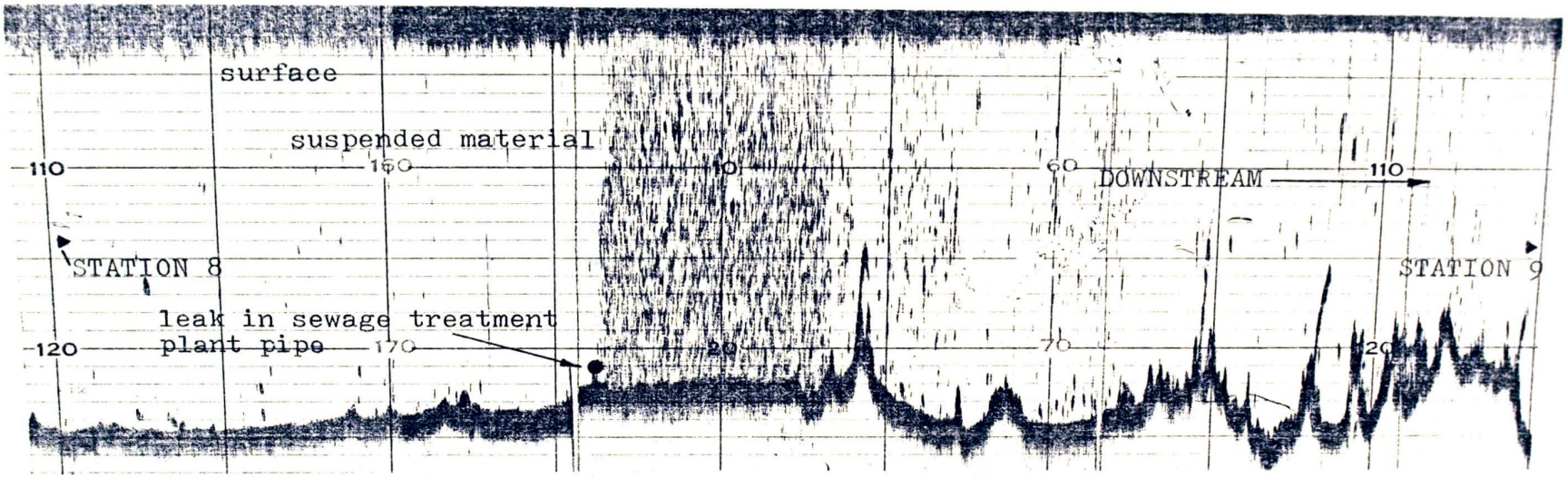

Figure 10. Sonar recording of the lower Red River between stations 8 and 9. Note the abundance of suspended material below the leak in the sewage treatment plant outfall pipe.

at mile 5.5. These plants were located at Fort Campbell, mile 12.5; Edgoten, mile 7.5; and New Providence, mile 2.9. A report by the U. S. Soil Conservation Service (1978) noted that by-passes of raw sewage to both surface and ground water occurred in numerous locations.

The diversity and equitability values from station seven suggest that the Big West Fork contributed considerable amounts of organic matter to the Red River. Possibly due to the ruptured sewage pipe previously mentioned, diversity and equitability at station nine dropped further to 1.14 and 0.21 respectively.

The combined discharge of inefficiently treated waste from all four plants could present a serious health problem for the residents of Montgomery County. The reduction in macroinvertebrate species may limit fish production. In general, the recreation potential of the Red River and West Fork, both public resources, is greatly reduced. In regard to the very mild pollution at station two, I suspect that septic tank seepage from a new subdivision less than 300 meters from the river was the source. Possibly such seepage entered the ground water and returned to the river. Paloumpis and Starrett (1960) in their study of three Illinois River flood plain lakes noted septic tank seepage as a minor source of pollution. Carpenter (1981), in his research on the Red River, observed at station two an abundance of the blue-green algae Anabaena and Oscillatoria, both of which are often associated with polluted

water (Palmer, 1962).

Temperature

Metabolic rates of living organisms are affected significantly by the temperatures in which the organisms live. In natural lakes, streams and rivers the temperature is primarily a function of solar radiation (Wetzel, 1975). Hynes (1970) noted that the temperatures of large rivers are usually more or less equal to the mean monthly air temperature. I believe the Red River follows this pattern of maintaining a temperature close to the mean monthly air temperature of its drainage area. Rapid changes in temperature, although not observed in this study, do occur in streams and rivers (Hynes, 1970). The most notable short term change in water temperature occurred on the second day of spring sampling, when heavy rains caused a reduction of 3.0° C. Considering the absence of any thermal pollutants, it seems logical that temperature in the Red River is regulated primarily by the amount of solar radiation striking the water surfaces.

Dissolved Oxygen

Of all the chemicals in natural waters, oxygen is one of the most significant to life (Reid and Wood, 1976). The concentration of dissolved oxygen (DO) and the percent saturation of the water with oxygen often are good indications of stream pollution. The Federal Water Pollution Control Administration (1968) concluded that for a diversified

warm-water biota including fish, the DO concentration should be above 5.0 ppm, assuming minima associated with normal seasonal and daily variations are above this level. Welch (1952) stated that dissolved oxygen at levels of 3.0 ppm or lower should be regarded as hazardous to lethal under average stream conditions; and that 5.0 ppm or more of DO should be present in waters, if conditions are to be favorable for freshwater fishes.

The two primary sources of DO in the Red River appear to be photosynthesis and physical aeration. As stated earlier, the highest DO readings occurred during peak sunlight in the near-surface waters of the river. Based on the size of the euphotic zone, as indicated by Secchi disc readings (Figure 7), I do not think much photosynthetic activity occurred below the one meter depth. Happey (1970), in a study of Abbot's Pool, Somerset, found that algae produce high concentrations of dissolved oxygen in the surface layers. Below this zone, DO is removed as substances from the trophogenic zone settle and are oxidized by bacterial and enzymatic breakdown of organic matter (Ruttner, 1963). With the exception of the spring sampling, when flows were high, physical aeration probably contributed less DO than photosynthesis. This is suspected because of the slow currents normally found in the Red River and the fact that oxygen derived from the atmosphere is dependent upon turbulent transport (Reid and Wood, 1976). From a water quality standpoint, the DO concentration in the Red

River would not provide a very healthy environment for a diverse assemblage of organisms that require well-oxygenated water. Such organisms include both game fish and game fish food organisms.

NITRATE NITROGEN

Nitrogen compounds in water may significantly affect aquatic life and therefore are important determinants of water quality (Turk et al., 1974). Nitrogen functions in the synthesis and maintenance of proteins, carbohydrates and fats. Nitrate (NO_3), an inorganic compound, is important in determining the productivity of an aquatic community and can be a limiting factor in algal populations. Allochthonous sources of NO_3 include agricultural runoff, urban runoff, sewage effluents and rain water. Nitrate nitrogen usually occurs in relatively small concentrations in unpolluted freshwaters, the world average being 0.30 ppm (Reid and Wood, 1976). Feth (1966) found NO_3 concentrations in rivers and streams throughout the United States to have an average of about 0.8 ppm for rivers receiving a low areal discharge and concentrations down to 0.5 ppm for those with a relatively high discharge. The U. S. Geological Survey (1962) obtained a mean of 0.7 ppm for NO_3 during their survey of streams and rivers.

In unpolluted situations the concentration of nitrate is determined by the amount of metabolic activity in the water, i.e., production and decomposition of organic

matter. Nitrates can be incorporated into the organic matter of both plants and animals or may be reduced to mitrite (NO_2) or nitrogen gas (N_2). If the concentration is above a certain level, excessive growth of algae and other plants may occur. Muller (1953) found that these growths could be avoided if the concentration of NO_3 was kept below 0.3 ppm. Nitrate levels of 0.9 to 3.5 ppm were found by Chu (1943) to be optimum for growth of cultured plants.

Based on the data mentioned above for average NO_3 concentrations (ca 0.5 ppm), the Red River is well above average, even during periods of low flow. Again, noting the major sources of NO_3 as urban runoff, rural runoff and sewage treatment plant effluents, a possible source or sources of these high concentrations might be determined. From a consideration of the location of the Clarksville sewage treatment plant (Figure 1) and the nitrate data (Figure 5), one can eliminate the sewage plant as a major source of such high levels. The general trend of slightly higher readings at the upstream stations suggests rural runoff as the major sources of NO_3. Rural nonpoint sources include both agricultural and non-agricultural land. Agricultural pollutants such as fertilizers, pesticides or animal waste diffuse over the land surface and eventually enter the aquatic environment in some form (Wanielista, et al., 1977). McCarty (1970) stated that agricultural drainage waters may contain nitrogen concentrations

from 1 ppm to more than 100 ppm, mostly in the form of nitrate. Hill and McCague (1974), in a study comparing nitrate levels in a stream passing through both fertilized and unfertilized land, found that a clear relation exists between the fertilized fields and higher NO_3 levels in the river. They concluded that most of the NO_3 was carried into the river by groundwater runoff and not surface runoff.

The significance of high nitrate concentrations in water quality studies lies in the actual or potential plant growth, primarily algae, that they may stimulate and the problems associated with such growth. In correct combination with other nutrients, such as orthophosphate (PO_4), plant growth could be stimulated far in excess of that which would occur naturally.

Orthophosphate

The amount of phosphorus in a body of water will often be the limiting factor in that body's productivity. It is often considered the most critical factor in the maintenance of biogeochemical cycles (Reid and Wood, 1976). Orthophosphate (PO_4), an inorganic phosphorus compound, occurs in scant concentrations in natural waters. Ruttner (1963) noted that algae have the ability to utilize these small concentrations and store any excess available. During normal algal growth orthophosphate may be released back into the water or converted to organic phosphorus compounds. During algal lysis and decomposition, bacteria function as

particulate phosphorus intermediaries in the degradation of dissolved organic phosphorus to dissolved inorganic phosphorus (Wetzel, 1975).

In natural streams and rivers phosphorus is derived mainly from the weathering and solution of phosphate minerals (McCarty, 1970). Three main allochthonous sources were noted by Vercuin (1967) to be sewage, phosphorus containing detergents and agricultural runoff. Excess phosphate from these or other sources may be the key element in causing the excessive fertilization of natural waters (Lee, 1973). A correlation was found by Sawyer et al. (1945) and Vollenweider (1968) to exist between excessive fertilization of waters and concentrations of soluble orthophosphate greater than 0.01 ppm.

Based on the orthophosphate concentrations observed throughout this study, at no time was this nutrient a limiting factor in plant productivity. In fact, concentrations were generally an order of magnitude higher than the levels needed for excessive fertilization as mentioned above. As noted in the section on nitrate nitrogen, these high concentrations of PO_4 might, in correct combination, afford the Red River the potential for high plant populations. It is possible that in the Red River, agricultural lands contributed significant portions of the phosphate detected. Viets (1971) found that little phosphorus leaches through the soil or runs off as inorganic phosphate, but it can wash off with soil as phosphorus absorbed on sediments.

Readings taken above and below the sewage treatment plant were similar, indicating that this was not a major source of additional PO_4.

Another factor involved with high orthophosphate levels is the potential high oxygen demand. The Federal Water Pollution Control Administration (1968) pointed out that one mg of organic phosphorus demands 160 mg of oxygen in a single pass of the phosphorus cycle to complete oxidation.

Secchi Disc

Secchi disc transparency is essentially a function of the reflection of light from the water surface and is therefore influenced by both absorption characteristics of the water and its dissolved and particulate matter (Wetzel, 1975). It is well known that light is a very important factor in the productivity of an aquatic community.

In the Red River, water transparency is primarily associated with suspended particulate matter such as silt. Bank erosion is a prominent feature, with whole trees sliding into the river a common occurrence. At the upstream stations Secchi disc readings (Figure 7) were lower, generally around 40 cm. As the water passes very slowly downstream, some of this silt settles out and the readings become greater. One exception to this was observed during the spring sampling when heavy rains occurred on the second day of sampling. The extra particulates added from the upstream runoff lowered the readings at the downstream stations

to 10 cm. Harned (1976), in his work in a farm pond, noted a decrease in visibility during periods of heavy rainfall; he attributed this decrease to surface runoff.

Based on calibrations with a submarine photometer, Secchi disc transparency in this study represents the zone of about one percent transmission of light. This would correspond very closely to the lower limits of primary productivity. Carpenter (1981), using ^{14}C methods, found productivity reduced significantly below depths of one meter in the Red River (Table 19). From the ^{14}C data it is apparent that productivity increased at the downstream stations. This could have been associated with the increased light availability at those stations since major plant nutrients were abundant at all stations.

Turbidity in the Red River could be a main factor in its productivity of plants and its diversity of benthic macroinvertebrates. The decrease in light reduces the photosynthetic activity which in turn reduces the dissolved oxygen for the animals. This could bring about a reduction in total species in the river and a reduction in the numbers of the intolerant species. Hynes (1960) concluded that suspended solids often reduce the growth of algae and other plants and may alter the benthic fauna by blanketing over the stream bed.

Total Hardness

Ruttner (1963) defined total hardness of water as the

Table 19. Carbon 14 productivity measured at the Surface to 2.5 meters. Numbers represent disintegrations per 10 minutes. Data from Carpenter (1981).

Depth (m)	surface	0.5	1.0	2.0	2.5
Station No.					
1	1220.1	1146.9	239.4	1050.2	383.1
2	890.6	656.4	254.9	54.2	-
3	4643.5	1821.1	413.3	131.5	85.1
4	7789.6	4858.9	890.9	226.1	172.4
5	21507.7	9746.1	1592.8	210.9	158.3
6	54922.2	16896.8	5740.8	736.8	143.6
7	36646.8	13305.4	7151.5	702.4	276.8
8	50002.8	29555.4	15135.8	2250.4	690.9
9	32630.7	31956.7	19131.4	5768.3	2476.2
10	55982.9	27972.3	13663.3	8356.0	4295.5
11	39798.9	18936.5	9623.1	4872.1	3619.1

amount of alkaline earths present (not including the anions to which they are bound), and sulphates and chlorides of calcium and magnesium. Water with a hardness between 60 and 120 is defined by the N.T.A.R.C. (1969) as moderately hard, and values less than these as moderately soft to soft. Water with a total hardness above 120 ppm is considered very hard.

Based on the above criteria and total hardness data (Figure 8), the water of the lower Red River was moderately hard to very hard. As was noted with nitrate nitrogen, runoff at rural stations (stations one through five) appears to have been the major source of high hardness concentrations. An inverse relationship was observed between total hardness and Secchi disc readings, also suggesting runoff as the likely cause of the hard water. It was noted by the Federal Water Pollution Control Administration (1968) that hardness in natural waters may be caused by an accumulation of calcium and magnesium salts from contact with soils and other geological formations.

pH

Hydrogen-ion concentration (pH) in streams and rivers is primarily determined by current, biological processes and chemical nature of the substrate (Reid and Wood, 1976). The current acts to move and to mix chemical substances while photosynthesis and respiration affect pH through the production and reduction of carbon dioxide. In natural

waters pH values usually are between 6 and 9 (Wetzel, 1975).

Throughout this study pH readings (Figure 9) for each sampling period remained fairly constant. The highest readings were taken in the summer (pH 8.3) and the lowest in the winter and spring (pH 5.8). This seasonal variation might be explained by fluctuations in planktonic populations and their utilization of CO_2. Ruttner (1963) found that pH was very strikingly linked to species composition of communities and their life processes. Carpenter (1981), in his studies of the Red River phytoplankton, found the highest algal populations in summer and the lowest in winter and spring. Harned (1976) observed this same seasonality in a Kentucky farm pond.

From the pH data in Figure 9 it seems likely that hydrogen-ion concentration is not a limiting factor in the Red River. I know of no allochthonous sources which would alter the pH in a detrimental way.

Fecal Coliform Bacteria

Fecal coliforms are residents of the intestinal tracts of human and other homoiothermic animals. Coliform bacteria are gram negative, nonsporeforming bacilli, which ferment lactose with acid and gas production within 24 to 48 hours when incubated at 35° C (Crabtree and Hinsdell, 1974).

Human fecal material is carried away by water in sewage systems that may discharge into lakes and rivers

which supply drinking water for other communities (Crabtree and Hinsdill, 1974). Since this material may contain pathogens, there is a need for a bacteriological test to indicate the presence or absence of fecal organisms. Not all coliform organisms are fecal in origin; other possible sources are soil, water and vegetation. The Federal Water Pollution Control Administration (1968) stated that it is necessary to consider all fecal coliform organisms as indicators of dangerous contamination, and Geldreich (1965) concluded that fecal coliforms can be a measure of the potential hazard to public health.

The State of Tennessee (1976) established these standards for fecal coliform bacteria(FC):

Use	Mean FC/100ml	Max. FC/100ml
Domestic Raw Water	1,000	5,000
Industrial Water	1,000	5,000
Fish and Aquatic Life	1,000	5,000
Recreation	200	1,000

The mean values are based on monthly averages and the maximum values represent the highest count from any one sample during the month. During this study samples were not taken throughout the month; therefore, only approximate indications of the sanitary conditions may be estimated. From the fecal coliform data in Table 18, it should be observed that the highest concentrations occurred at or below Station 6. Davis et al. (1968), in their study of Lake Barkley, found that the worst bacteriological pollution they encountered was at the mouth of the Red River. They

noted untreated industrial wastes as a probable cause for such readings, with the Clarksville sewage treatment plant as a possible source.

Since counts were high above the Big West Fork, it is possible that seepage from a local meat packing plant (Frosty Morn) was a source of fecal coliforms. A settling lagoon owned by the company is located less than 100 meters from station 6. This company is no longer in operation at this location as of December 1977. The fecal coliform bacteria counts from the Big West Fork indicate a possible contribution by the sewage plants on the Little West Fork mentioned in the benthic macro-invertebrate section. The reading of 104,000/100ml in the fall would favor a point source such as a sewage effluent since rainfall was low, and nonpoint sources usually depend on runoff as their source of entry. The highest counts for the entire study occurred in the fall at station eight and were 252,000/100ml. These high counts could have resulted from the upstream movement of surface water near the leaking sewage pipe. During periods of low flow, the force of even slight winds can push the surface water upstream.

During the winter and spring samplings, fecal coliform counts were down considerably. This may have been due in part to cold temperatures in the winter and the dilution factor of the spring high water. The closing of the Frosty Morn packing plant may also have had some impact

on the lower numbers.

From the small amount of bacteriological data in this study, one can get some indication of the fecal pollution in the Red River. During times of low flow and higher temperature fecal coliforms indicate the possibility of high concentrations of pathogens. These pathogens could be a serious health hazard to the residents of Clarksville. Some of the health problems were listed by Bott (1973) as typhoid fever, gastrointestinal disorders, diarrheal diseases, nausea, dehydration, kidney, liver and nervous system infections, polio, infectious hepatitis, aseptic meningitis, flu and eye infections.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

A water quality study was conducted from July 1977 to May 1978 on the lower eleven miles of the Red River. Existing water quality was evaluated, based on biological, chemical and physical parameters, tested during four seasons.

The Red River is a tributary of the Cumberland River and has a total length of 158 km. The total drainage area is 2343 km^2. With the exception of the urban industrial area at Clarksville, Tennessee, the basin is primarily used for agriculture. The river is chiefly used for recreation, municipal and industrial water supply and waste disposal.

Samples of benthic macroinvertebrates obtained by an Ekman grab were studied for species composition, diversity and equitability. Based on the above criteria a good indication of the water quality was obtained.

Above the confluence of the West Fork, the Red River exhibited clean water at all but one station, which was

only mildly polluted. At these upstream stations the benthic fauna was dominated by dipteran larvae, Ephemeroptera larvae, mollusca and oligochaetes. The largest family represented was the Chironomidae. Diversity was above 3.0 and equitability above 0.5, indicating clean water.

In the West Fork and the Red River below its confluence with the West Fork, the faunal composition changed to one comprised primarily of oligochaete worms. Diversity and equitability declined into the mild polluted zones and approached heavy pollution on one occasion.

Water temperature was found to be close to the mean monthly air-temperature. No significant changes in temperature were noted over the eleven mile study.

Dissolved oxygen was greatest at the surface during all samplings. Surface water contained a concentration of dissolved oxygen greater than 5.0 ppm at all times. Dissolved oxygen declined at depths greater than one meter, often below 3.0 ppm.

Hydrogen-ion concentration of the water varied little among stations at each sampling but seasonal variation was observed. This variation was expected, considering fluctuations in aquatic plant populations and their utilization of CO_2. Hydrogen-ion concentration was within the accepted state standards of 6.0 to 9.0 with only one exception; in that instance the pH dropped to 5.8.

Red River water was found to be moderately hard to hard. The highest total hardness readings occurred at the

upstream stations, probably as a result of contact with alkaline earths from runoff and erosion. An inverse relationship was noted between total hardness and water transparency.

Water transparency was greater at the downstream urban stations, reaching a maximum of 80 cm. Bank erosion and runoff from upstream stations contributed silt in significant quantities to lower the transparency at those stations.

Levels of two major nutrients, nitrate and orthophosphate, were found in sufficient concentrations to support blooms of aquatic plants. Both compounds, although present in high concentrations, were fairly uniformly present throughout the entire study area. A considerable increase in nitrate was noted during high water periods in the spring. This was explained by the excessive runoff also observed at that time.

Fecal coliform data implied water quality patterns similar to those implied by the benthic macroinvertebrates. Low fecal coliform counts, usually within state standards for recreation, were found at upstream stations. Downstream, near the confluence of the West Fork, counts exceeded state standards for recreation by as much as 1262 times and by as much as 252 times for fish and aquatic life standards.

Conclusions

The lower Red River can be described in terms of water quality as having areas of both clean and polluted water. Man has played the major role in shaping the water quality of the Red River into what it is today, either directly by wastes discharges or indirectly through the runoff of soil and chemicals from agricultural lands.

The rural upstream reaches of the study area were basically free from organic waste. However, this section was subject to erosion problems and the runoff from agricultural land. The resulting increase in turbidity was an important factor in the diversity and productivity of the river. The reduction in the photic zone limits plant growth, including photosynthesis, to the surface. This, in turn reduced the dissolved oxygen at the lower depths. As a result of the low oxygen concentrations, game fish populations may be reduced or eliminated. In addition, macroinvertebrate populations, which are vital in the aquatic food web, are reduced or replaced by less beneficial, pollution tolerant species.

The increase in plant nutrients, possibly from the runoff of fertilizers, speed up the euthrophication process in both the Red and Cumberland Rivers. Combined with organic waste added downstream, the Red River exhibited an environment which can support substantial plant populations, mostly in the form of algae. As these

organisms die and settle to the bottom, natural decomposition processes break them down. These processes use significant amounts of dissolved oxygen thus depriving aquatic animals of the same.

The main problems associated with organic wastes occur at and below the confluence of Big West Fork. Effluents from four sewage treatment plants, three on the Little West Fork and one on the Red River, are primarily responsible for these polluted conditions. Inadequate treatment and complete by-passing often result in the discharge of raw sewage directly into the river.

Based on the data obtained from this study, I conclude that the lower Red River, in its present condition, is unsuitable for recreational purposes. At this time the river is of little value in terms of a diversified aquatic fauna. However, with appropriate mitigative measures, the river could return to a healthy and productive ecosystem.

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APPENDIX I

STREAM BOTTOM PROFILES

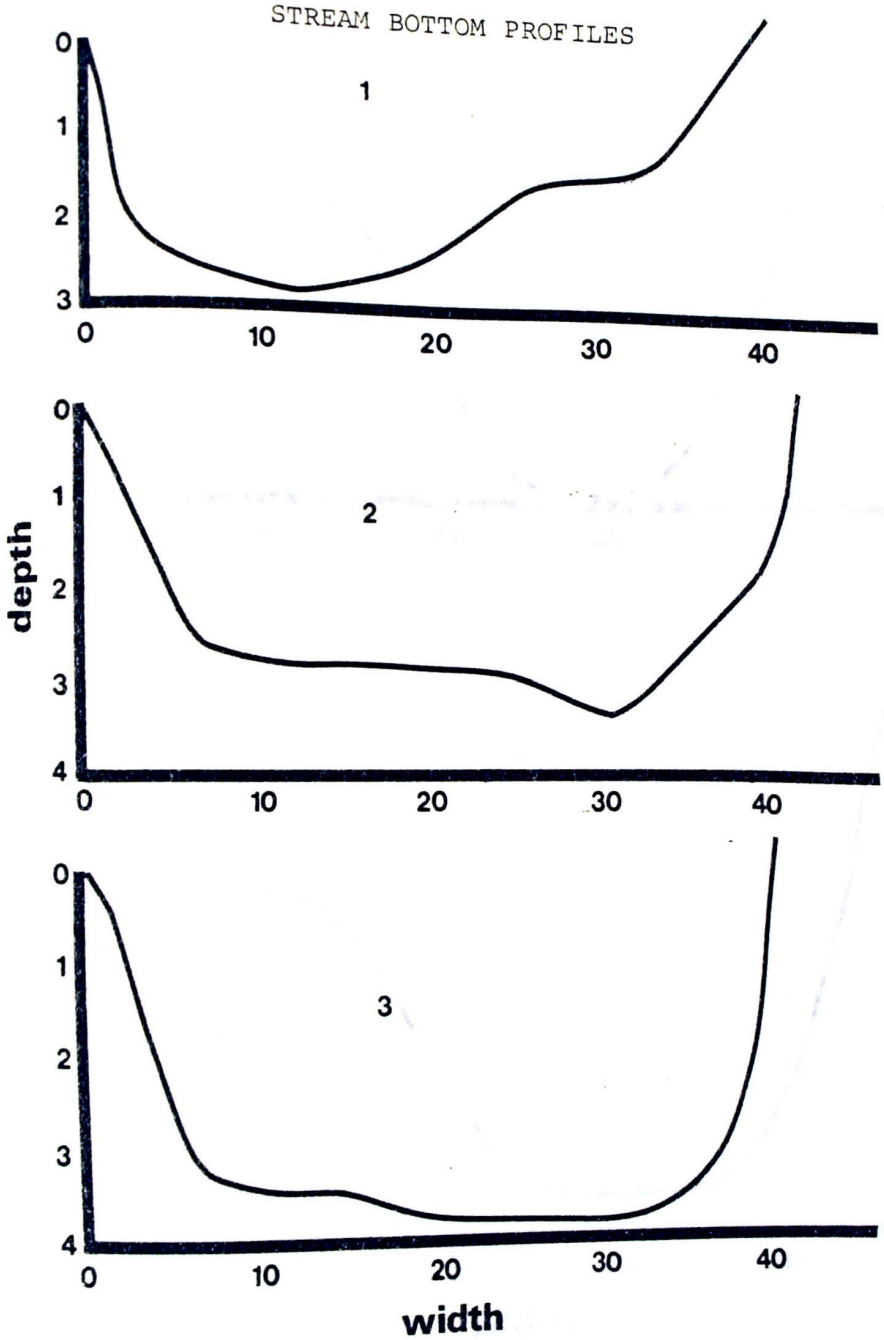

Figure 11. Bank to bank profiles at each station, made from left to right bank, with depth and width expressed in meters.

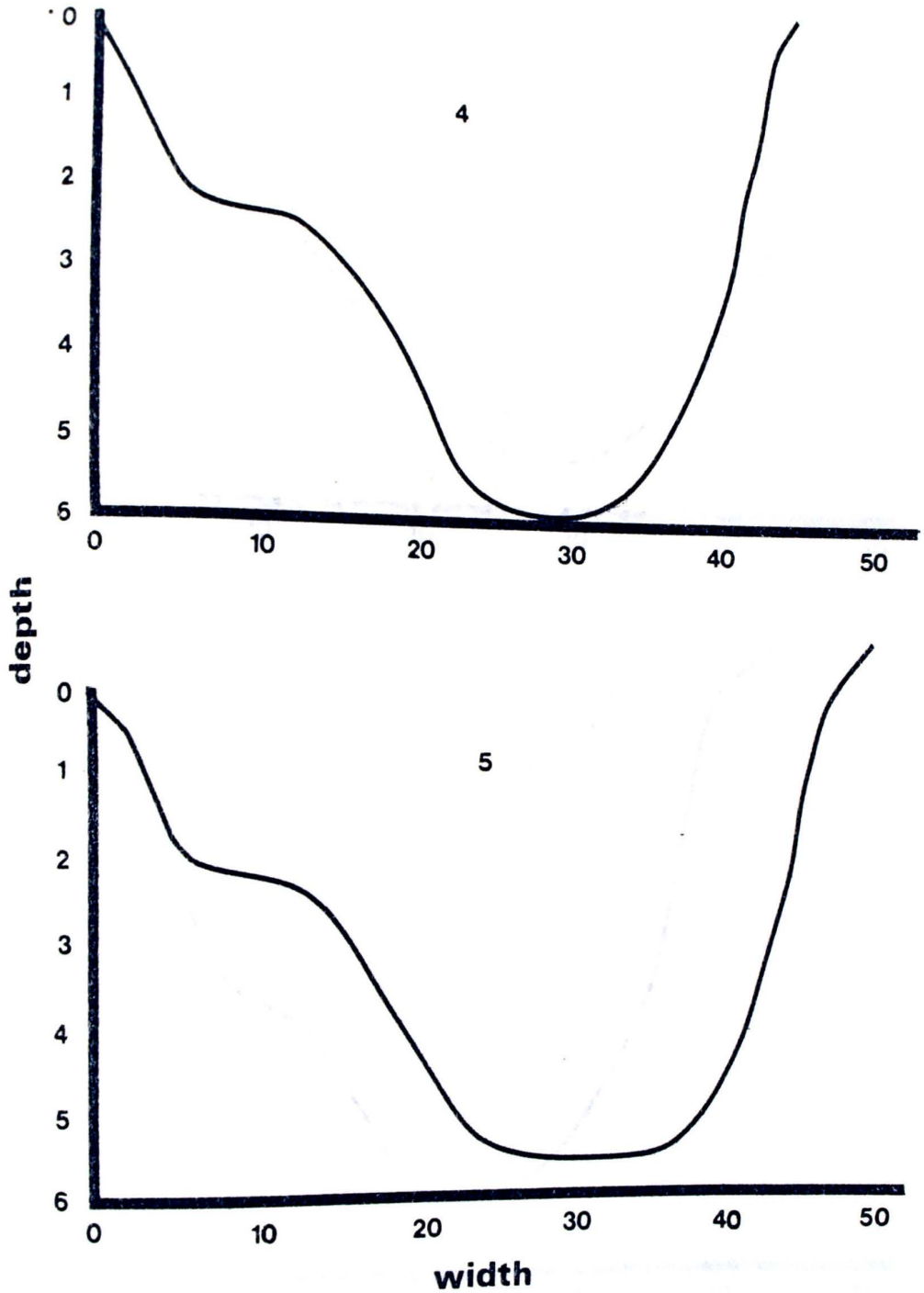

Figure 11. (continued)

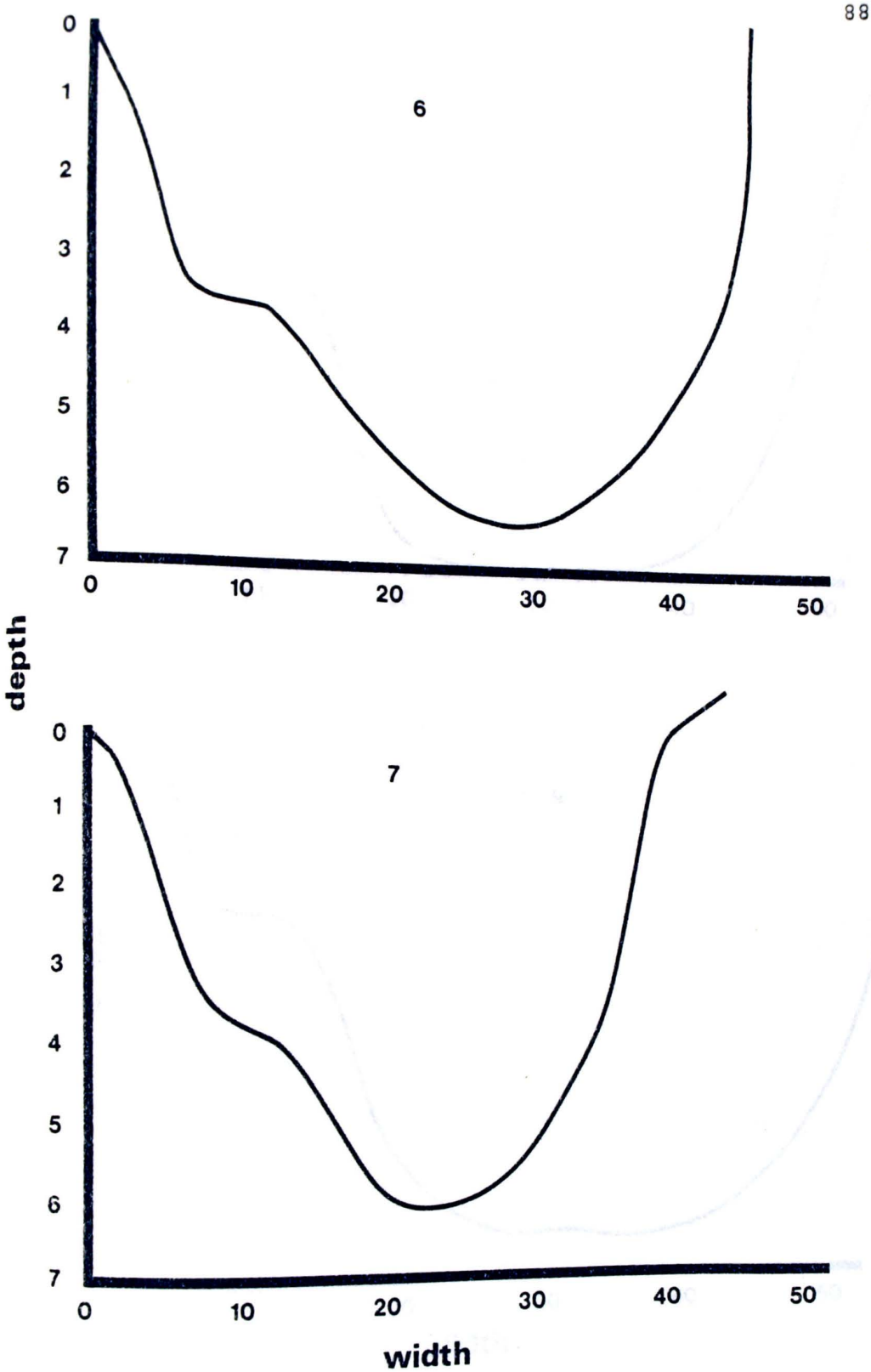

Figure 11. (continued)

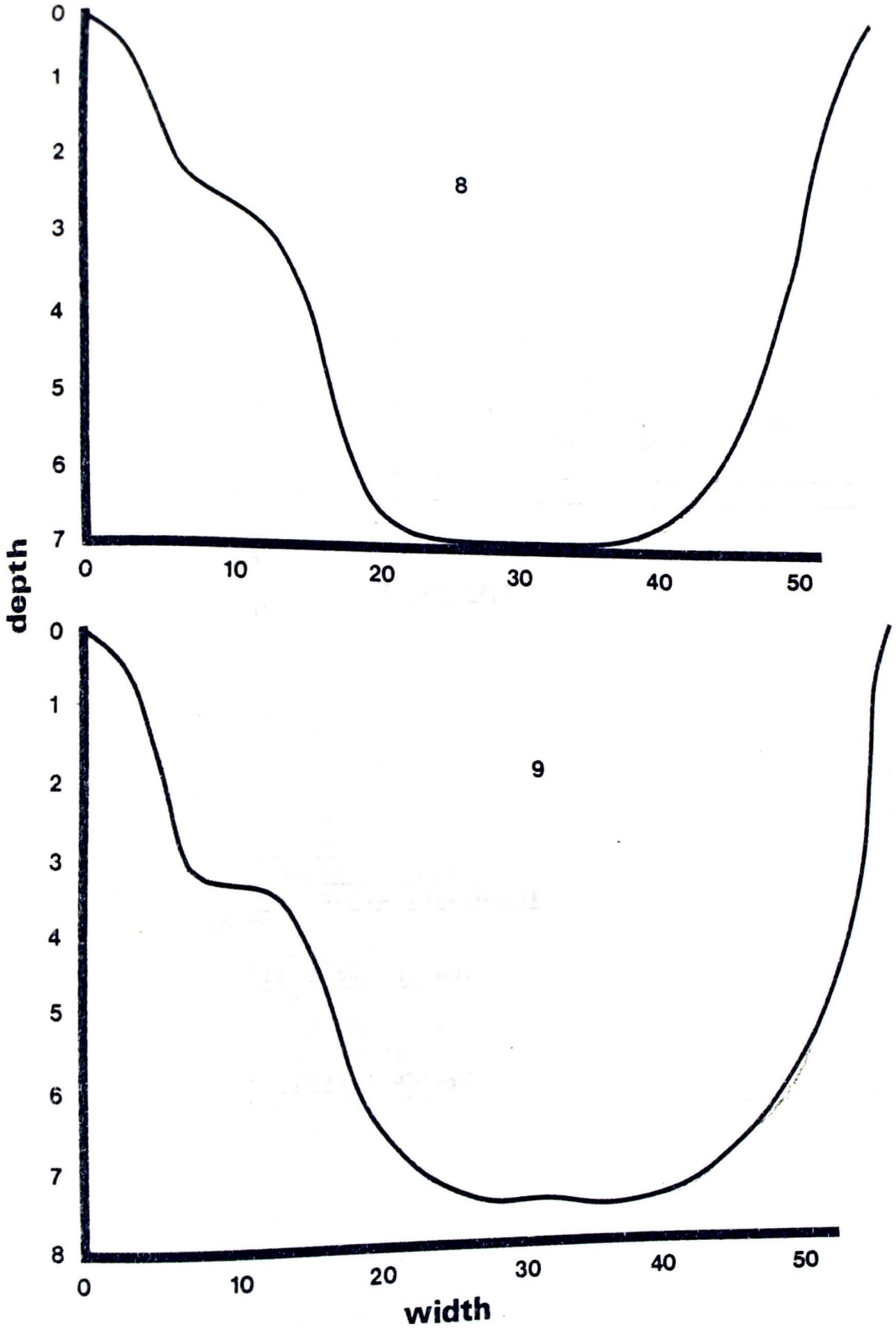

Figure 11. (continued)

APPENDIX II

CHECKLIST OF BENTHIC MACROINVERTEBRATES

Table 20. Benthic Macroinvertebrates of the Lower Red River (Montgomery County, Tennessee).

- Annelida
  - Oligochaeta
    - *Branchiura sowerbyi*
    - sp. 2
- Arthropoda
  - Crustacea
    - Isopoda
      - *Asellus* sp.
    - Hydracarina (Order)
  - Insecta
    - Ephemeroptera
      - *Caenis* sp.
      - *Hexagenia limbata*
      - *Heptagenia marginalis*
    - Odonata
      - *Coenagrion* sp.
      - *Dromogomphus* sp.
    - Coleoptera
      - *Dubiraphia* sp.
      - *Macronychus* sp.
      - *Elmidae* (Family)
      - *Noteridae* (Family)
    - Megaloptera
      - *Sialis* sp.
    - Diptera
      - Culicidae
      - *Chaoborus* sp.
      - *Ablabesymia annulata*
      - *Ablabesymia ornata*
      - *Chironomus* sp.
      - *Cladotanytarsus* sp.

Table 20 continued.

- *Coelotanypus scapularis*
- *Cryptochironomus* sp.
- *Cryptotendipes* sp.
- *Demicryptochironomus* sp.
- *Epoicocladius* sp.
- *Glyptotendipes* sp.
- *Paracladopelma* sp.
- *Paralauterborniella* sp.
- *Paratendipes* sp.
- *Phaenopsectra obediens*
- *Polypedilum* sp.
- *Procladius* sp.
- *Psectrocladius* sp.
- *Tanytarsus* sp.
- *Tribelos* sp.
- Unidentified 1
- Unidentified 2
- Unidentified 3
- Ceratopogonidae (Family)
- Unidentified Dipteran

Trichoptera
- *Nectopsyche* sp.

Lepidoptera
- Arctiidae (Family)

Mollusca

Gastropoda
- *Pleurocera* sp.

Pelecypoda
- *Corbicula* sp.
- *Villosa* sp.

APPENDIX III

RAW DATA

Table 21. Raw data collected at station 1 during four sampling periods.

Season	Summer	Fall	Winter	Spring
Data				
Secchi disc (cm)	30	60	-	-
Nitrate (ppm)	3.5	2.5	-	-
Orthophosphate (ppm)	0.15	0.10	-	-
pH	7.9	7.3	-	-
Total Hardness (ppm)	185	215	-	-
Diversity ($\bar{d}$)	combined samples, 3.17			
Equitability (e)	combined samples, 0.72			
Depth (m)	3.5	3.3	-	-
Air-temperature (^{o}C)	25.5	7.0	-	-
Time started	0700	0745	-	-

Table 22. Raw data collected at station 2 during four sampling periods.

Season	Summer	Fall	Winter	Spring
Data				
Secchi disc (cm)	32	50	-	60
Nitrate (ppm)	3.25	2.5	2.9	4.6
Orthophosphate (ppm)	0.16	0.12	0.05	0.09
pH	7.2	7.0	6.3	6.2
Total Hardness (ppm)	185	220	169	160
Diversity ($\bar{d}$)	combined samples, 2.77			
Equitability (e)	combined samples, 0.42			
Depth (m)	3.7	3.5	-	4.5
Air temperature (^{o}C)	31.5	8.0	-	21.9
Time started	1145	0920	1345	1600

Table 23. Raw data collected at station 3 during four sampling periods.

Season	Summer	Fall	Winter	Spring
Data				
Secchi disc (cm)	30	45	-	53
Nitrate (ppm)	3.3	2.6	-	4.0
Orthophosphate (ppm)	0.18	0.10	-	0.11
pH	8.3	6.6	-	6.0
Total Hardness (ppm)	175	220	-	183
Diversity ($\bar{d}$)	combined samples, 3.25			
Equitability (e)	combined samples, 0.74			
Depth (m)	4.2	4.0	-	6.0
Air-temperature (^{o}C)	35.0	14.0	-	15.0
Time started	1440	1025	-	0810

Table 24. Raw data collected at station 4 during four sampling periods.

Season	Summer	Fall	Winter	Spring
Data				
Secchi disc (cm)	30	53	-	54
Nitrate (ppm)	3.0	2.8	-	4.0
Orthophosphate (ppm)	0.13	0.11	-	0.14
pH	7.6	6.6	-	5.8
Total Hardness (ppm)	190	220	-	180
Diversity ($\bar{d}$)	combined samples, 3.72			
Equitability (e)	combined samples, 1.06			
Depth (m)	5.2	5.3	-	6.3
Air-temperature (^{o}C)	25.0	15.0	-	15.0
Time started	0710	1130	-	0910

Table 25. Raw data collected at station 5 during four sampling periods.

Season	Summer	Fall	Winter	Spring
Data				
Secchi disc (cm)	32	65	-	50
Nitrate (ppm)	3.0	2.8	-	3.1
Orthophosphate (ppm)	0.17	0.90	-	0.21
pH	7.5	6.5	-	6.8
Total Hardness (ppm)	165	173	-	160
Diversity ($\bar{d}$)	combined samples, 3.61			
Equitability (e)	combined samples, 0.78			
Depth (m)	5.1	5.0	-	6.4
Air-temperature (^{o}C)	27.0	17.0	-	16.0
Time started	0920	1240	-	1050

Table 26. Raw data collected at station 6 during four sampling periods.

Season	Summer	Fall	Winter	Spring
Data				
Secchi disc (cm)	70	73	-	10
Nitrate (ppm)	2.3	2.5	3.3	-
Orthophosphate (ppm)	0.31	0.80	0.05	0.16
pH	7.4	6.9	6.1	7.0
Total Hardness (ppm)	100	145	168	120
Diversity ($\bar{d}$)	combined samples, 2.58			
Equitability (e)	combined samples, 0.67			
Depth (m)	5.3	5.8	-	7.6
Air-temperature (^{o}C)	30.0	18.5	-	10.0
Time started	1130	1345	1245	0845

Table 27. Raw data collected at station 7 during four sampling periods.

Season	Summer	Fall	Winter	Spring
Data				
Secchi disc (cm)	60	80	-	18
Nitrate (ppm)	2.3	2.4	-	-
Orthophosphate (ppm)	0.42	0.85	-	0.19
pH	7.8	7.0	-	6.3
Total Hardness (ppm)	100	148	-	140
Diversity ($\bar{d}$)	combined samples, 1.50			
Equitability (e)	combined samples, 0.31			
Depth (m)	6.0	6.0	-	7.6
Air-temperature (^{o}C)	35.0	24.5	-	11.0
Time started	1320	1430	-	1020

Table 28. Raw data collected at station 8 during four sampling periods.

Season	Summer	Fall	Winter	Spring
Data				
Secchi disc (cm)	38	80	-	10
Nitrate (ppm)	2.9	2.3	-	-
Orthophosphate (ppm)	0.15	0.95	-	0.17
pH	7.5	6.5	-	6.2
Total Hardness (ppm)	168	133	-	110
Diversity ($\bar{d}$)	combined samples, 1.57			
Equitability (e)	combined samples, 0.31			
Depth (m)	7.2	8.2	-	8.8
Air-temperature (^{o}C)	26.0	19.5	-	11.0
Time started	0715	1510	-	1100

Table 29. Raw data collected at station 9 during four sampling periods.

Season	Summer	Fall	Winter	Spring
Data				
Secchi disc (cm)	80	60	70	10
Nitrate (ppm)	2.0	2.4	3.2	-
Orthophosphate (ppm)	0.18	0.80	0.04	0.17
pH	7.1	6.5	6.4	6.4
Total Hardness (ppm)	80	60	70	120
Diversity ($\bar{d}$)	combined samples, 1.14			
Equitability (e)	combined samples, 0.21			
Depth (m)	7.7	7.8	4.0	9.5
Air-temperature (^{o}C)	30.0	21.0	-	11.0
Time started	0900	1545	1130	1140

Table 30. Raw data collected at station 10 during four sampling periods.

Season	Summer	Fall	Winter	Spring
Data				
Secchi disc (cm)	68	40	53	-
Nitrate (ppm)	2.3	2.2	2.4	3.5
Orthophosphate (ppm)	0.23	0.16	0.16	0.18
pH	7.5	6.8	6.4	6.6
Total Hardness (ppm)	70	98	106	120
Diversity ($\bar{d}$)	benthos not sampled			
Equitability (e)	"	"	"	
Depth (m)	7.6	-	-	-
Air-temperature (^{o}C)	37.0	18.0	-	27.0
Time started	1145	1630	0825	1150

Table 11. Raw data collected at station 11 during four sampling periods.

Season	Summer	Fall	Winter	Spring
Data				
Secchi disc (cm)	80	40	-	-
Nitrate (ppm)	2.0	2.1	2.8	3.8
Orthophosphate (ppm)	0.15	0.19	0.09	0.18
pH	7.8	6.7	6.4	6.2
Total Hardness (ppm)	90	93	138	135
Diversity ($\bar{d}$)	benthos not sampled			
Equitability (e)	"	"	"	
Depth (m)	10.8	-	-	-
Air-temperature (^{o}C)	34.0	17.8	-2.0	-
Time started	1030	1535	1125	1220