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The Distribution and Relative Abundance of Aquatic Oligochaeta in the Upper Cache River System, Southern Illinois, in Relation to Water Quality

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THE DISTRIBUTION AND RELATIVE ABUNDANCE OF AQUATIC OLIGOCHAETA IN THE UPPER CACHE RIVER SYSTEM, SOUTHERN ILLINOIS, IN RELATION TO WATER QUALITY

(TITLE)

BY

MARK JULIAN WETZEL

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THE DISTRIBUTION AND RELATIVE ABUNDANCE OF AQUATIC OLIGOCHAETA IN THE UPPER CACHE RIVER SYSTEM, SOUTHERN ILLINOIS, IN RELATION TO WATER QUALITY

A Thesis
Presented To
The Department Of Zoology
Eastern Illinois University

In Partial fulfillment
Of The Requirements For The Degree
Master Of Science

By

Mark Julian Wetzel

December, 1981

ABSTRACT

Species composition, distribution, abundance, and water quality relationships of aquatic oligochaetes occurring in the upper Cache River system, southern Illinois were investigated. Forty-two taxa of oligochaetes including 16 naidids, 22 tubificids and representatives of the families Aeolosomatidae, Branchiobdellidae, Enchytraeidae, and Lumbriculidae were collected. Four species of oligochaetes new to Illinois, *Limnodrilus psammophilus* Loden, *L. rubripenis* Loden, *Psammoryctides* (*Spencerius*) *californianus* Brinkhurst, and *Haemonais waldvogeli* Bretscher were collected during this study. Another species of *Limnodrilus* new to science is reported here, as yet undescribed. The thesis that aquatic oligochaetes can be used as true water quality indicator organisms is rejected. It is suggested that the relative abundance and species composition of the total invertebrate fauna be used in conjunction with monitored water quality parameters to identify trends in the physical, chemical, and biological communities.

"All the rivers run into the sea, yet the sea is not full; unto the place from whence the rivers come, thither they return again."

Eclesiastes 1:7

GRATIARUM ACTIONES

Numerous people have propelled me to see this project through. First, I must thank Dr. M. R. Matteson, who encouraged my initial interest in aquatic invertebrates and later Hirudinea and Oligochaeta while I was enrolled in Field and Systematic Zoology at the University of Illinois. Dr. R. Weldon Larimore was kind enough to provide an opportunity to work in his laboratory at the Illinois Natural History Survey (INHS) with fish and aquatic macroinvertebrates. Further encouragement to develop a taxonomic expertise, as well as assistance over the years in countless ways, came from Drs. John D. Unzicker, Allison R. and Warren U. Brigham first as co-workers and later employers. Dr. L. Stephen Whitley, first as a co-worker and later as my major professor at Eastern Illinois University (EIU), encouraged my interest in oligochaete taxonomy. Dr. Donald J. Klemm of the U. S. Environmental Protection Agency in Cincinnati and Mr. Donald G. Huggins of the Biological Survey of Kansas provided specimens and encouragement over the last few years. I would like to express my sincere thanks to each of my associates on various INHS projects over the last 9 years, particularly Liane and John Suloway, Lucinda Johnson-Singer, and Drs. Robert G. Singer, J. D. Unzicker, A. R. and W. U. Brigham, and Daryl C. Sweeney. They provided the suggestions and critique which are integral yet usually unheralded. The participants of the recent First International Conference on Aquatic Oligochaeta held in Sidney, British Columbia, in May, 1979, provided invaluable stimulus for my present and

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INTRODUCTION

Water quality has become an increasingly sensitive and multifaceted issue over the last 30 years. The physical and chemical properties of water depend upon the interactions between a stream and its valley. These characteristics then establish areas in which certain species of aquatic organisms exist. Section 101(a) of the Federal Water Pollution Control Act Amendments of 1972 states:

> "It is the national goal that wherever attainable, an interim goal water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983.
> It is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited."

A national goal in managing water quality is to maintain existing healthy populations of aquatic organisms without establishing unnecessarily stringent limitations directed against dischargers or users of land adjacent to streams and lakes. It is important to establish which identity and concentrations at which these pollutants interfere with aquatic life. It is also important to establish levels of control necessary to restore aquatic life to a given level.

The use of aquatic organisms as indicators of water quality is a relatively recent innovation, although Aristotle mentions the white color produced by foul mud and noted 'red worm-like organisms' growing out of it (Thienemann (1912). A review of the literature concerning the use of aquatic oligochaetes as water quality indicators is presented later in this paper.

Reputable analyses of aquatic habitats necessitate the identification of all floral and faunal inhabitants to the species level when at all possible. Resh and Unzicker (1975) have shown that ordinal, familial, and in many cases even generic levels of identification are not sufficient, since members of those taxa often are present over a wide range of water quality. Species within those taxa, however, usually are confined to very narrow ranges of water quality. Distributional records of species, when related to critical physical and chemical parameters, are becoming increasingly important to private and public institutions. Adequate definition of limiting factors, environmental requirements, and habitat preferences at the species level for all organisms are necessary for sound decisions in environmental assessment and water resource management.

OBJECTIVES

The literature establishes aquatic Oligochaeta as important biological indicators of water quality. Unfortunately, while excellent studies concerning oligochaete abundance and distribution, in addition to faunal lists of selected watersheds or geographical areas, have been published in recognized journals and/or presented at scientific meetings, the oligochaete fauna of Illinois, outside of Lake Michigan, has not been studied adequately. The little information which has been documented is less than adequate for the type of watershed management planning necessary in Illinois.

The objectives of this proposed study were: (1) to collect and identify the species of aquatic Oligochaeta from the Cache River

watershed, southern Illinois; (2) to develop taxonomic expertise and working knowledge of this important group of aquatic organisms; and (3) to relate the species collected, their relative abundance, and distribution to the physical and chemical environment. This work will lead to a preliminary publication of the aquatic oligochaetes of Illinois, with keys to species and distributional data based upon this and other investigations.

SCOPE

Much of the field work associated with the present investigation was conducted in conjunction with a faunistic and water quality assessment of the upper Cache River watershed, Alexander, Johnson, Massac, Pope, Pulaski, and Union Counties, Illinois, by the (INHS) (now the Natural History Survey Division of the Illinois Department of Energy and Natural Resources) as a cooperative investigation with the United States Department of Agriculture, Soil Conservation Service (SCS). Limitations of funding imposed by the SCS study precluded changes and additions to my sampling design and laboratory analyses. These aspects will be identified later, when applicable.

I will review the literature discussing distribution of aquatic oligochaetes, with an overview of World, North American, and Illinois research. The literature addressing biological assessment of aquatic systems will be reviewed, with emphasis on the efficacy of aquatic organisms, particularly Oligochaeta, as biological indicators of water quality.

HISTORICAL PERSPECTIVE

INTRODUCTION

Any major work concerning the distribution of one or more species must be preceded by a thorough review of the literature. This often can be a formidable task, especially when many studies are discussed in literature with a limited distribution and unpublished reports. Cross-checking of "literature cited" sections of reports and articles has allowed the author to review most of the published and some of the unpublished information.

There are four parts to this historical perspective. Part one summarizes the major world researchers of freshwater Oligochaeta, with emphasis upon North American research. Part two summarizes past and present research upon the aquatic oligochaetes of Illinois. Part three reviews major works involving the development of aquatic biological regimes, with emphasis upon the use of aquatic organisms as indicators of water quality. Part four reviews the use of aquatic Oligochaeta in water quality analyses.

PART ONE: WORLD AND NORTH AMERICAN RESEARCH

A thorough review of the taxonomic history and phylogenetic development of the Oligochaeta would not be within the objectives of this work. However, I feel it necessary to note the major researchers of aquatic Oligochaeta since the appearance of the Tenth edition of *Systema Naturae* by Carolus Linnaeus in 1758.

Müller (1774) described *Lumbriculus variegatus* (as *Lumbricus*) and defined *Nais*. Lamark (1816) established *Stylaria* and *Tubifex*, and separated Naididae and Tubificidae (as Order Vers hispides) from the

earthworms (Order Annelides apodes). However, Hemprich and Ehrenberg (1831) included Aeolosomatidae and Naididae in the Rhabdocoela (Turbellaria).

Major progress was made in oligochaete systematics during the late 1800's and early 1900's by Claparède (European Lumbriculidae and Tubificidae); Eisen (Arctic and North American Enchytraeidae, Lumbriculidae and Tubificidae); Vejdovský (European Enchytraeidae, Lumbriculidae, Naididae and Tubificidae); Beddard (worldwide Haplotaxidae, Lumbriculidae, Naididae, Phreodrilidae and Tubificidae); Michaelsen (Enchytraeidae); Leidy (North American Tubificidae); F. Smith (North American Lumbriculidae); Stephenson (Eastern and Oriental microdriles); Benham (Tubificidae and Phreodrilidae of the southern hemisphere); Piguet, Bretscher, Černosvitov, and Pierantoni (European, and in the case of Pierantoni, marine oligochaetes); Yamaguchi (Japanese Haplotaxidae and Lumbriculidae); Bell and Welch (North American Enchytraeidae); Issosimov (Russian Lumbriculidae); Marcus (South American Naididae); and Hrabě (European Tubificidae and Lumbriculidae). [It should be noted that there are two researchers by the name of Marcus: Ernesto Marcus, and Eveline Du Bois-Reymond Marcus. Both worked on oligochaetes in South America, and both published during the same time period]. Citation of publications by the above researchers would involve over 150 references. The reader is directed to Vejdovsky (1884), Vaillant (1889), Beddard (1895), Michaelsen (1900), Stevenson (1930), and Brinkhurst and Jamieson (1971) for more specific information.

Goodnight (1940) provided the first organized monograph on

Branchiobdellidae. Recent monographs by Sperber (1948, 1950) organized previously confusing biology and synonomies in the family Naididae. Other monographs by Nielsen and Christiansen (1959) (European Enchytraeidae), Čekanovskaya (1962) (Russian aquatic oligochaetes), and Brinkhurst and Jamieson (1971) (aquatic oligochaetes of the world) provided important reviews of past works as well as inspiring and informative new research. Brinkhurst and Jamieson summarized the anatomical, embryological and ecological knowledge of aquatic oligochaetes, presenting the first phylogenetic analysis since Stephenson (1930).

The systematics, and consequently the distributional and ecological data on aquatic oligochaetes in North America, was quite disorganized and scattered through the literature prior to the 1960's. The vast majority of North American oligochaete research had centered around the Lawrentian Great Lakes, an area encompassing over 246,000 square kilometers and containing some of the largest and deepest freshwater lakes in the world. Spencer (1980) thoroughly reviewed this research, including the taxonomy, zoogeography, distribution, and ecology of Great Lakes spedies and current needs for research in this region. As Spencer indicated, while information on Great Lakes fauna is plentiful, there is still a paucity of information concerning the aquatic oligochaetes of inland waters.

Early works concerning aquatic oligochaetes in inland waters include: Cragin (1886, 1887), Bourne (1891), Galloway (1899, 1911), Eisen (1900), J.P. Moore (1905), F. Smith (1895*a*, 1900*a*, 1905), Walton

(1906), Scott (1911), Ellis (1912, 1918, 1919), Hayden (1912, 1914, 1922), Smith and Green (1916), Smith and Dickey (1918), Muttkowski (1918), Welch (1920), Eggleton (1931, 1952), Altman (1936), Collins (1937), G.M. Moore (1939), Goodnight (1940, 1941, 1942), Pennak (1940), Kenk (1941, 1949), Moffett (1943), Chen (1944), Neel (1948), Causey (1953), and Anderson and Hooper (1956). Other minor contributors are summarized by Brinkhurst (1964*a*, 1965*a*, 1966*a*) and Brinkhurst and Cook (1966). The advent of in-depth water pollution studies in the 1950's included research by Brinkhurst on rivers in Britain. His research provided impetus for water quality monitoring using aquatic organisms. An historical perspective on the use of aquatic organisms as water quality indicators will be reviewed later in this paper.

PART TWO: ILLINOIS RESEARCH

Early research on aquatic Oligochaeta in Illinois include: Forbes (1890*a*, 1890*b*), Garman (1890), F. Smith (1895*a*, 1895*b*, 1896, 1900*a*, 1900*b*, 1918), Kelly (1899), Brace (1901), Galloway (1911), Forbes and Richardson (1913), Smith and Welch (1913) Welch (1914), Kindred (1918), Ellis (1919), Richardson (1921*a*, 1921*b*, 1925*a*, 1925*b*, 1928), Alexander (1925), Forbes (1925), Gersbacher (1937), Evans (1939), and Goodnight (1940).

Recent research documenting the distribution of aquatic oligochaetes, as well as some ecological data, include: Paloumpis and Starrett (1960), Mathis and Cummings (1967), Brigham (1972), Nilsen and Larimore (1973), Whitley (1973), Howmiller (1974*a*), Schacht (1974)*, Metropolitan Sanitary District of Greater Chicago (MSDGC) (1975, 1977*a*,

1977*b*), Schacht and Matsunaga (1975*a*, 1975*b*)*, Tucker and Ettinger (1975, 1976)*, Wapora, Inc. (1976)*, Whitley and Wetzel (1976), Anonymous (1977)*, A.R. Brigham (1977, 1978*a*, 1978*b*, 1979)*, Humphrey (1977*a*, 1977*b*, 1977*c*), Singer (1977, 1978), A.R. Brigham, *et al.* (1978), W.U. Brigham, McCormick, and Wetzel (1978), Matsunaga (1978)*, Polls, *et al.* (1980), and Wetzel (1980)[1].

I also have compiled oligochaete faunal lists for selected watershed studies in conjunction with contracts through the INHS. These watersheds include: Dutchman Creek, Long Point Slough, tributaries of the Middle Fork River, an unnamed tributary of the Kishwaukee River (A.R. Brigham, *et al.* 1978), the Kankakee River, and Coffeen, Sangchris and Shelbyville Lakes. Results of many of these studies currently are being prepared for publication.

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[1]Those citations noted with an asterisk utilize the Illinois Environmental Protection Agency's (IEPA) stream classification system, which unfortunately lists many organisms by order or family. Aquatic Oligochaeta were listed as "Oligochaeta" in these publications.

PART THREE: THE USE OF AQUATIC ORGANISMS AS INDICATORS OF WATER QUALITY

". . . no species is adapted to living in polluted conditions, which are products of civilisation and so very much younger than is any species."

H. B. N. Hynes (1960)

"Pollution is a comparative procedure, not a scientific concept."

R. Margalef (1975)

"It is difficult in this day and age to provide an accurate definition of water pollution. This concept generally implies a negative situation, such as the addition of one or more poisonous substances, or perhaps the adverse effects of eutrophication. The positive side of this concept may imply mild eutrophication, which could very well increase fish and invertebrate production."

G. Milbrink (1980)

The chemistry of bodies of water depends on erosional and solutional processes, surface and groundwater runoff, hydrology, and interactions between water and sediment. This, in turn, determines which aquatic species will thrive, and which water uses are possible. During the past 6,000 years, however, these natural processes have been variously accelerated, augmented, or otherwise affected by the activities of man. As the physical and chemical environment changed, the biological community too changed in response to stresses from these abiotic factors. Monitoring the levels of pollution, or, more appropriately, water-use stresses, and evaluating pollution abatement practices, makes use of these biological responses through the application of water quality indicators or indices. These indicators or indices should allow spatial and temporal comparisons, relate to desired uses of water, and be suited to data obtainable.

Combined actions of the public and state and federal agencies have produced many advances in water resource management practices. Concurrently, numerous indices have been developed for estimating water quality.

I had originally intended to provide a historical perspective on the development and use of aquatic organisms in the biomonitoring analysis of water quality. However, it became very apparent that the literature was much broader than originally thought. In view of this vast literature, the following discussion is restricted to major papers and recent publications which review various aspects of the bioindicator -bioindex concept of water analysis. After this overview, papers stressing the use of aquatic oligochaetes in water quality analysis are reviewed. This discussion concludes with a summary of methods, an analysis of applicability, and suggestions for improvement.

The use of biological indicators is a concept that seemingly has been applied since the "civilization" of man. Rulers in ancient times often had their food tested by animals and lowly subjects in fear of assassination by poisoning. Canaries and often other birds were used frequently by miners to indicate the presence of methane gas. More recently, the concept of indicator species which respond to different levels of water pollution has been developed worldwide.

The "Saprobiensystem" of Kolkwitz and Marsson (1902, 1908, 1909) was among the first systems proposed to monitor, through the use of descriptive indices, the stages of degradation through recovery that a river may experience in response to organic enrichment. This method established taxonomic groupings of organisms which were found in clean

water, polluted waters, or both. The "Saprobiensystem" recognized three zones: the polysaprobic zone, the mesosaprobic zone, and the oligosaprobic zone. This method has been modified, developed and extended for most of this century by numerous European and North American researchers, most notably Richardson (1928), Liebmann (1951, 1962), Beck (1954, 1955), Gaufin (1956, 1958), Caspers and Schultz (1960), Hynes (1962), Fjerdingstad (1964), and Sládeček (1965, 1966, 1967, 1977). Sládeček (1973*a*) provides a comprehensive review of this dynamic system. Wuhrmann (1974) sums up this system: "No other subject has either consumed so much paper in applied limnology or has provoked such heated discussions."

Rosen, *et al.* (1976*a*, 1976*b*, 1976*c*, 1976*d*) of Energy Resources Company, Inc., and Mathmatica, Inc., prepared a four-volume review and evaluation of water quality indices and similar indicators for the Council for Environmental Quality (CEQ), Washington, D.C. This research was sponsored by the CEQ, the U.S. Environmental Protection Agency (U. S. E.P.A.) and the U.S. Geological Survey. They determined that all information reviewed could be arranged into ten generic categories:

1. Single measures as indicators, including the many characteristics and individual constituents of water, which can be utilized as indicators of water quality.

2. Criteria-based and standards-based indicators, which relate water quality measurements to "benchmark" levels that have been associated with the protection of one or more beneficial water uses.

3. Judgmental multiparameter indices, which are based upon the collective or individual judgements of water quality technicians.

4. Empirical multiparameter indices, which are based upon the statistical properties of water quality measurements.

5. Lake indicators, which are developed specifically for the assessment of lakes.

6. Aquatic life indicators, which are based upon the differing tolerance relationships of aquatic biota to various water pollutants and conditions.

7. Water use indicators, which are intended to describe the suitability of waters for offstream uses such as water supply and agriculture.

8. Perception-based indicators, which are based upon the public's observations and uses of waterbodies.

9. Point source indicators, which are intended to report stresses originating from discrete sourcesthat degrade water quality.

10. Non-Point source indicators, which are intended to report stresses originating from diffuse sources that degrade water quality.

The aquatic biologist is primarily concerned with all those applicable systems which come under the heading of "aquatic life indicators": systems which assess differing tolerances of aquatic biota, including microbial, floral, invertebrate, and/or vertebrate taxa, to pollutants. The most obvious and often neglected use of water is for the continuous generation of aquatic life. Water quality continuously influences and often restricts or enhances the species assemblages of aquatic organisms present in any given body or water. Many factors other than water quality may influence the species assemblages present at any time, forcing an *a priori* determination as to the limits of correlation between water quality characteristics and to the usefulness of certain species as water quality indicators. This correlation must be established before the technique in question is accepted into regular programs. Since aquatic biota reflect water quality stresses, it is frequently assumed that if a desirable biotic community is maintained, the other beneficial uses of water will be protected. This goal, however, often can result in a decrease in value

of a particular body of water as a natural resource. The desirable biotic community may not be the most important "use" or attribute of that particular body of water.

Factors which determine the suitability of a biological water quality indicator include: (1) abundance: the population density and/or rate of activity should be subject to quantitative measurement without depleting the population; (2) a qualitative relationship between the biological parameter and the water quality characteristic; (3) should the indicator species be microbial in nature, the organism should not be widely distributed in the form of inactive spores; (4) the indicator should provide information about a water quality characteristic related to water use other than aquatic life. Goodnight and Whitley (1961) also suggest that a good water quality indicator organism or community should exist under both favorable and unfavorable conditions, be present throughout the year, and be limited in mobility.

Numerous techniques for use of aquatic organisms as indicators of water quality have been reviewed in the literature. These techniques include monitoring individual taxa, species populations, energy flow, community mass, community populations, and bioaccumulation. Many of these indicators vary independently and are, thus, independent indicators of water quality. Many theoretical ecosystem studies have attempted to analyze other characteristic properties of bodies of water such as standing crop, biomass, productivity, dominance, and evenness. Field techniques developed for water quality analysis have measured chlorophyll, established certain "indicator species" regimes, and used saprobian systems. Laboratory studies have developed bioassay and

biochemical methods for cell and tissue analysis.

Indicator species, based on presence or absence of certain taxa, equate aquatic organisms with varying levels of water quality. Biomass techniques have been developed to measure the magnitude of a community's resources. Productivity measures production rate of community resources. Abundance ratios monitor the relative presence of natural and polluted water species. Biochemical techniques have been developed to monitor concentrations of enzymes and other chemicals which organisms produce in response to stress.

Indicator species regimes, species abundance ratios, biomass techniques and diversity and dominance indices have ben sufficiently developed. Sampling for productivity data is difficult. Bioassay and biochemical techniques have been hindered by conceptual problems.

Biochemical techniques developed for water quality analysis include use of cell-free enzyme systems, enzyme inhibition by anions, enzyme inhibition by pesticides, enzyme inhibition by trace metals, enzyme activity assays, and tissue culture. Of all these biochemical techniques, only enzyme inhibition by pesticides has been successful in giving a qualitative indication of water quality.

Bioassay techniques attempt to monitor toxicity of water samples to species. Since a bioassay technique requires the use of a single species, data collected cannot be applied uncritically to an existing community in the water body. There is no analytic method presently developed for choosing the species used for any single or range of pollutants. Mortality of laboratory cultured populations often cannot be attributed to the pollutant in question. Productivity techniques

can provide a measurement of production rate of the biological community in the water body. Productivity is usually measured by either tracing C^{14} transport through the system or measuring oxygen production rates. These methods are not suitable for monitoring water quality. Measurement of chlorophyll concentrations have been used to indicate the level of phytoplankton productivity. However, chlorophyll production has a high variance, does not oscillate proportionally to water quality, and is not always correlated with phytoplankton production.

Most indicator species regimes are applicable, measuring biological communities in different, but useful ways. These include relative abundance, biomass, evenness, and diversity. MacArthur (1965) suggested that since the geographical distribution of a species is dependent on a wide range of environmental factors, that rare species often may be present or absent independently of water quality shifts.

Organic degradation of a particular area increases biological oxygen demand (BOD) and chemical oxygen demand (COD), and leads to reduction in species diversity. Often accompanying this decrease in diversity is a decrease in interspecific competition for food and space. For instance, oligochaetes, especially tubificids, can survive quite readily under these conditions, often with an increase in standing crop. This increase in standing crop can be attributed, at least partly, to a decrease in predation on tubificids by common predators which have been eliminated by the decrease in water quality.

Hellawell (1977) divided approaches to freshwater analyses into three categories:

Pollution indices: Express observed responses of certain 'indicator' taxa to selected pollutants;

Diversity indices: Describe community structure and can be used to monitor changes in community structure in response to environmental change; and

Comparative indices: Assess spatial changes, such as similarities between adjacent water bodies or assess temporal changes, such as 'before' and 'after' studies.

Pollution indices include not only the numerous regimes which are modeled after the Saprobien System, but include also approaches such as the Relative Purity Index (Knöpp 1954, 1955), the saprobity indices of Pantle and Buck (1955*a*, 1955*b*), Zelinka and Marvan (1961), and Dittmar (1959), and biotic indices such as the Trent Biotic Index (Woodwiss 1964). Chandler's Biotic Score (Chandler 1970), the Empirical Biotic Index (Chutter 1972), Palmer's Index (Palmer 1969), Beck's Index (Beck 1954), Watanabe's Index (Watanabe 1962), and taxonomic ratios, such as those of King and Ball (1964), Goodnight and Whitley (1961), and Brinkhurst (1966*a*, 1966*c*). (These taxonomic ratios will be discussed more thoroughly in the section entitled "Oligochaeta as indicators of water quality").

Examples of diversity indices include models of community structure, such as the Logarithmic Series Model (Fisher, *et al.* 1943), the Lognormal Distribution Model (Preston 1948), the "Broken-Stick" models (Ordered Random-Interval) (MacArthur 1957; Cohen 1966, 1968; Pielou 1969), community diversity indices such as Simpson's Index (Simpson 1949), Margalef's Index (Margalef 1951), and Menhinick's Index (Menhinick 1964), the information theory indices of Shannon (1948) and Pielou (1969), McIntosh's Index (McIntosh 1967), and the Sequential

Comparison Index (Cairns, *et al.* 1968).

Pollution and diversity indices are generally used to assess single samples or single communities at single stations, used as a basis for comparisons of one station in time or several stations in any given area. Comparative indices, on the other hand, express coefficients of similarity or association, comparing similarities of different water bodies, assessing spacial changes, or detecting biological discontinuities (Hellawell 1978).
Comparative indices include qualitative comparisons, such as the "Species Deficit" concept of Kothé (1962), coefficients of similarity (Jaccard 1912), or the Coefficient of Association T (Looman and Campbell 1960; Orth 1973), quantitative comparisons such as Raabe's Coefficient (Raabe 1952) or Czekanowski's Coefficient (Czekanowski 1913), and measures of distance (Sokal 1961).

The use of specific groups of aquatic organisms for water quality monitoring has been proposed throughout the literature. A guide to important recent works in this literature is presented below, indexed by major group of aquatic organisms.

Bacteria (Hern 1970; Bott 1973; Rao and Jurkovic 1977; Bisson and Cabelli 1980);

Algae (Butcher 1947; Patrick 1949, 1973; Anderson, *et al.* 1965; Cairns, *et al.* 1972; Collins and Weber 1978; Stoermer 1978; Hörnström 1981; Rosen 1981);

Diatoms (Lowe 1974; Bahls 1979; Slock 1979);

Periphyton (Bahls and Bahls 1974; Economou-Amilli 1980);

Protozoa (Cairns, *et al.* 1972; Antipa 1977; Henebry and Ridgeway 1979; Yongue and Cairns 1979; Henebry and Cairns 1980; Sládaček 1981);

Zooperiphyton (Cairns 1978);

Zooplankton (Anderson, *et al.* 1965; Dzyuban and Kuznetsova 1978; Gannon and Stemberger 1978);

Oligochaeta (reviewed later);

Acari (Conroy 1978);

Hirudinea (Sawyer 1974; Matysiak 1976*a*, 1976*b*, 1978; Fialkowski 1979; Lapkina and Flerov 1980);

Polychaeta (Grassle and Grassle 1976; Anger 1977);

Mollusca (Paparo and Sparks 1977; Clarke 1978*a*, 1978*b*, 1979*a*, 1979*b*; Dussart 1979; Jones and Walker 1979; Adams, *et al.* 1981);

Ephemeroptera (Hubbard and Peters 1978; Lewis 1974, 1978);

Plecoptera (Baumann 1978; Surdick and Gaufin 1978);

Trichoptera (Schuhmacher and Schremmer 1970; Harris and Lawrence 1978; Wiggins 1978);

Coleoptera (Sinclair 1964);

Aquatic Diptera (Paine and Gaufin 1956; Saether 1978; Morris and Brooker 1980).

Others have suggested the use of macroinvertebrates in general. These include: Kolkwitz and Marsson (1902, 1908, 1909), Gaufin and Tarzwell (1956), Anderson, *et al.* (1965), Keup *et al.* (1966), Wilhm and Dorris (1966, 1968), Edwards, *et al.* (1972), Gaufin (1973), Goodnight (1973), Roback (1974), Szczęsny (1974), Hocutt (1975), Armitage (1976), Hilsenhoff (1977), Moore (1979), and Ruggiero and Merchant (1979), to name just a few. Hellawell (1977) notes the frequency of groups recommended for use in surveillance.

Other methods proposed for water quality monitoring include the analysis of stream drift (Larimore 1974), chironomid pupal exuviae (Wilson and Bright 1973; Wilson and McGill 1977; McGill, *et al.* 1979;

Wilson 1980), blood serum enzyme analysis (Wieser and Hinterleitner 1980), the ratio of ATP/chlorophyll (Chiaudani and Pagnotta 1978), the use of various bioassay procedures (Cairns and Dickson 1973; Cairns, *et al.* 1977; Peltier 1978), and the use of artificial substrate samplers (reviewed in depth later).

Aesthetic appearance and presence of a diverse fish fauna are probably the two most obvious criteria utilized by the lay person when assessing water quality. Analysis of aesthetic qualities of water bodies is discussed thoroughly by Rosen, *et al.* (1976*a*, 1976*b*, 1976*c*, and 1976*d*). The information on use of fish in water quality is too voluminois to review here. By consulting the following papers and literature cited therein, the reader will be directed to pertinent information. The following papers also address more specific aspects and applications of bioindicator-bioindex regimes: Tarzwell (1957, 1960); Hynes (1960, 1970); Keup, *et al.* (1966, 1967); Hooper (1969); Wilber (1969); Schwoerbel (1970); Wilhm (1970, 1975); Learner, *et al.* (1971); Edwards, *et al.* (1972); Cairns and Dickson (1973); Goodnight (1973); Weber (1973*a*, 1973*b*); Thomas, *et al.* (1973); Nuttall and Purves (1974); Edwards (1975); Resh and Unzicker (1975); Balloch, *et al.* (1976); Cook (1976); Food and Agricultural Organization of the United Nations (FAO) (1976); Gross (1976); Rosen, *et al.* (1976*a*, 1976*b*, 1976*c*, 1976*d*); Alabaster (1977); Cairns, *et al.* (1977); Hellawell (1977, 1978); Cover and Harrel (1978); Jorgensen (1978); Mason (1978); Farnworth, *et al.* (1979); James and Evison (1979); Möller (1979); Moroz (1979); Cairns and van der Schalie (1980); Hocutt and Stouffer (1980); and Krenkel and Novotny (1980).

AQUATIC OLIGOCHAETA AS INDICATORS OF WATER QUALITY

INTRODUCTION

Worms (Phylum Annelida: Class Clitellata: Subclass Oligochaeta) are "typically segmented, bilaterally symmetrical, hermaphroditic annelids with a spacious coelom, a pre-oral prostomium, an anterior ventral mouth and a posterious anus" (Brinkhurst and Jamieson 1971). Annelids inhabiting aquatic habitats range in length from less than 1 mm in some species of *Chaetogaster* (Family Naididae) and Aeolosomatida (*sensu* Singer 1977), to over 400 mm in *Haplotaxis gordioides* (Family Haplotaxidae).

All but one of the 15 families of the Subclass Oligochaeta are represented in the Northern Hemisphere. Of these, 10 families contain aquatic species, including some species of Enchytraeidae, Lumbricidae, and Sparganophilidae. Species in the families Enchytraeidae, Haplotaxidae, Lumbricidae, Lumbriculidae, Naididae, Opistocystidae, Sparganophilidae and Tubificidae) occur in North American aquatic habitats. Two other groups of Annelida, the Aeolosomatida (Family Aeolosomatidae) and the Branchiobdellida (Family Branchiobdellidae) also are aquatic and occur in North America. A more thorough discussion concerning the geographical patterns, endemic and perigrene species, and habitats of aquatic oligochaetes can be found in Brinkhurst and Jamieson (1971).

The phylogeny and classification of annelids is still in flux. Most recent discussions addressing this subject include Holt (1965, 1974), Clark (1964, 1969), Brinkhurst (*In*: Brinkhurst and Jamieson

1971), Singer (1977), and Jamieson (1978, 1980). It will suffice here to say that in absence of any fossil record of this ancient group, present clssifications and phylogenetic regimes must be viewed with reservation. Further systematic studies will serve to broaden our understanding of the evolution of this group.

Aquatic Oligochaeta, and more specifically the family Tubificidae, have gained notoriety over the past 30 years because some species were thought to be good indicators of water quality. More recently, the other families of oligochaetes have been discussed and utilized in this manner. However, little information exists concerning the life history or ecology of most species. Adequate inventories of freshwater species assemblages, as well as their distributions and relative abundances throughout most regions of North America, are lacking. As noted earlier, the region that has been well-documented is the Laurentian Great Lakes system (see Spencer 1980).

REVIEW

The need for biological tools in evaluating short-term as well as long-term effects of pollutants has become increasingly important over the last thirty years. However, taxonomic knowledge has seldom been given priority, as group specialists have remained few; the great diagnostic capacities of benthos, phytoplankton, zooplankton, periphyton, bacteria and fish have rarely been utilized in full.

Early workers most often were unable to overcome taxonomic difficulties when working with lake typologies or saprobiology. Oligochaetes were often left at ordinal, familial or genus levels of identification.

Indeed, *Tubifex tubifex* became the catch-all taxon used for sludge-worms, regardless of their actual identity. This concept is an important link in several of the pollution and biotic indices reviewed in Hellawell (1978). These include the Biotic Score of Chandler, the Trent Biotic Index of Woodwiss, the Empirical Biotic Index of Chutter, the Index of Pantle and Buck, the Saprobity Index of Zelinka and Marvan, the Relative Purity Index of Knöpp and the Species Deficit Index of Kothé (Milbrink 1980).

Early studies in the United States relating tubificids to pollution included a study of the benthos of Lytle Creek, Ohio (Gaufin and Tarzwell 1952), two studies of Green Bay, Wisconsin (Surber and Cooley 1952; Surber 1957), and a limnological survey of western Lake Erie (Wright 1955). While the taxonomy of oligochaetes was insufficient in these studies, the percent of oligochaetes in the total benthos was used to indicate levels of pollution. This method was further refined by Goodnight and Whitley (1961), who proposed a pollution index system based on the percentage composition of the tubificids in the total population of benthic macroinvertebrates. A bottom invertebrate community of which 80% or more of the organisms were oligochaetes would indicate a high degree of organic enrichment or industrial pollution.

Brinkhurst and Kennedy (1962) discussed the aquatic Oligochaeta of the Isle of Man, concluding that the nature of the substratum, the flow rate, and the degree of pollution affect the distribution and abundance of Tubificidae. It was shown that several species of tubificids - indeed, species within the same genus - apparently coexist in the same habitat; a suggestion first made by Brinkhurst (1960).

Brinkhurst (1964*b*) mentioned earlier usage of oligochaetes in lake classification, although the papers reviewed had limited scientific merit.

King and Ball (1964) proposed the ratio of insect weight to tubificid weight as a measure of pollution. A ratio of 0:1 was obtained from a highly polluted area of the study river, while a ratio of 612:1 was obtained from regions of recovery.

Brinkhurst (1965*b*) demonstrated the faunistic dominance of *T. tubifex* and *Limnodrilus hoffmeisteri* Claparède below a sewage outfall in the Derwent River, England. However, after a sewage treatment plant was installed, ten additional species were collected at one time or another, with both relative as well as absolute numbers of worms significantly reduced. He concluded that oligochaetes, even when identified to species, should not be used as a separate assessment of pollution level, but instead as a supplement to other analyses when assessing water quality.

Brinkhurst (1965*c*) suggested that further information regarding the distribution, habitat requirements, and competitive relationships among worm species is required before groups of oligochaetes can be used for the detection and assessment of the varied types of pollution in freshwater as well as brackish and marine systems. A simple numerical relationship between the numbers of unidentified worm species, or the proportion of all worms in the fauna and pollution was discussed.

Brinkhurst (1965*d*) reviewed previously applied approaches to the use of macroinvertebrates in relation to pollution: (1) the establishment of tolerance limits of physico-chemical parameters for

individual species; (2) the search for indicator species; and (3) biotic and abiotic factorial analysis of community structure. His discussion and conclusions rejected the first approach as laboratory studies of individual components mask the numerous interactions of a species or population in a natural system. As we know now from toxicity studies, synergistic and antagonistic effects of combined pollutants dispute experimental design hypotheses. When addressing the second approach, Brinkhurst categorically rejected the idea of a universal indicator species of worm, and for that matter, any other group. The idea of a universal indicator was founded on the premise that the more widely distributed and catholic a species is in its preferences or requirements, the greater its chances are in surviving in extreme habitats, free of competition from perhaps more efficient species. To illustrate this point, Brinkhurst considered two tubificids, *T. tubifex* and *L. hoffmeisteri*. He noted their presence in any random collection of worms from any location and any habitat (often in the presence of many other species and groups of organisms, as well as by themselves) in large numbers, thus disproving their value as indicators. Brinkhurst's third approach suggested that information obtained from oligochaete diversity surveys below organic influxes in rivers may be used to detect and assess pollution in other rivers. He also noted the sensitivity of oligochaetes and other soft bodied aquatic animals to heavy metals.

Brinkhurst (1966*d*) distinguished between useful and questionable aspects of tubificid pollution biology. This paper challenged former conclusions drawn upon pollution data, such as relationships between populations, sediment constituents, and other selected parameters.

Worms are stated as being non-randomly distributed, in clean as well as polluted waters. Brinkhurst goes on to agree with Korn (1963), that "oligochaetes....are not suitable indicators of water quality," although this statement is directed towards the use of oligochaetes in the "Saprobien System."

Whole families or orders of macroinvertebrates have been classified as tolerant or intolerant to various pollutants. Many state divisions of the Environmental Protection Agency still use this classification. However, as Brinkhurst continued, there is a range of tolerance levels within each species. Brinkhurst concluded that the only true indicator is the relative abundance and identity of all species within any community. As has been noted by Suloway (*pers. comm.*) and others recently, isolated gene populations of the same species may actually tolerate different levels of stress or pollution.

Brinkhurst (1966*b*, 1966*c*) outlined the current state of knowledge on the detection and assessment of water pollution using oligochaete worms, noting responses of oligochaete communities to various physical and chemical parameters. He then discussed the value of quantitative studies, methods of study and identification, listed taxonomic revisions for selected families, and noted regional keys available.

Brinkhurst (1969) considered *T. tubifex* a refuge species, greatly limited by competition in the presence of other tubificids, but able to tolerate more extreme conditions when competition is limited. This species would likely be encountered frequently in unproductive or slightly productive waters, but less abundant or even absent from mesotrophic waters.

Howmiller and Beeton (1970) noted a succession of oligochaete species from unpolluted areas which are dominated by *Tubifex kessleri*, through moderately polluted areas dominated by *Aulodrilus americanus*, *Peloscolex ferox* and *Potamothrix moldaviensis*, to those heavily polluted areas which are dominated by the *Limnodrilus* species, particularly *L. hoffmeisteri*.

Brinkhurst (1972) studied niche discrimination of mixed populations of worms in polluted sites, particularly Toronto Harbour. While tolerance tests have focused on grossly polluted situations, they have avoided, or neglected altogether, comparable studies of clear water systems. Correlations between observed distributions and monitored environmental parameters have not been made.

Aston (1973) provided a review of tubificids and water quality, citing some of the papers reviewed here. His conclusions suggested that, while increases in tubificid numbers and/or increases in the proportion of *L. hoffmeisteri* to other worms has often been equated with organic pollution, life cycles and tolerance limits of each species during each stage in its life cycle must be critically evaluated before quantitative values can be placed on field observations.

Milbrink (1973*a*) studied the biology of tubificid oligochaetes of Lake Hjälmaren in Sweden, considering indicator communities based upon species of Tubificidae and Lumbriculidae and relating the information of past and present works on Lake Hjälmaren to Lake Mälaren and Lake Vättern.

Milbrink (1973*b*) discussed more specifically the use of Tubificidae and Lumbriculidae in assessment of water pollution in Swedish lakes.

Ecological information on the more important oligochaetes was analysed, with different species grouped into specific communities as they were generally found. It was suggested that the specific composition of tolerant and sensitive species in a community has indicator value. The presence of *Limnodrilus profundicola* as an indicator of oligotrophic conditions, as well as an inhabitant of organically polluted waters which are well aerated, was noted.

Brinkhurst and Cook (1974) classified worm species as typical of polluted or unpolluted situations without quantitative reference to particular pollutants.

Smith (1975) suggested the use of aquatic oligochaetes as a diagnostic tool in evaluating water quality. However, his paper merely introduced the reader to the more common families of aquatic worms. Application of data obtained from monitoring of pollution was not discussed.

Gross (1976) proposed a method of determining mild agricultural organic pollution utilizing three criteria: (a) species diversity of oligochaetes; (b) the percentage of oligochaetes in the total benthos; and (c) the association of *T. tubifex*, *L. hoffmeisteri*, and *L. udekemianus* with each other.

Nalepa and Thomas (1976) applied four indices to a pollution situation in Lake Ontario: the indicator species approach, the oligochaeta-density index, a modified "Goodnight-Whitley" index, and the Brinkhurst "*L. hoffmeisteri*" index. They concluded the indicator species approach proved to be the most sensitive of the four because inconsistencies arose when the other indices were applied.

Lafont and Juget (1976) analyzed oligochaete distribution in the River Rhône, France. They noted a significant correlation between stability and relative abundance of recorded species, indicating the importance of pollution in the distribution of worms and other potamobenthos.

Howmiller and Scott (1977) suggested an "Environmental Index" for evaluation of water quality, based upon known ecological demands of present oligochaete species.

Lafont (1977) discussed the distribution of oligochaetes in the Bief Rouge, a polluted mountain stream in France. His results suggested that associations of pollution-resistant species can vary depending upon the type of flowing water and the level of its contamination. He emphasized the usefulness of oligochaetes as indicators of water quality.

Lagauterie and Leroux (1977) used the concept of ecological niche to analyze the sensitivity of river macroninvertebrates to different environmental variables. Their results established classification of macroinvertebrate taxa according to varying levels of water pollution.

Brinkhurst (1978*a*) reviewed past and present relationships of aquatic oligochaetes as indicators of water quality. He stated that these relationships have most often been based upon quantitative estimates of relative abundance. However, these relationships have been less defined or correlated when associated with water quality parameters, usually excluding in-sediment analyses and especially comparative physiology. He concluded that information on *all* existing

benthic organisms should be used when classifications and ordination analyses are performed.

Eyres, *et al.* (1978) studied the distribution and seasonal abundance of oligochaetes occurring in depositional river substrates, and investigated seasonal changes in populations of the three most abundant species of tubificids. The study occurred in the River Irwell, a river polluted by domestic as well as industrial wastes. Tubificids constituted 86.8% of the worm fauna. At one station, low pH and large amounts of ferrous hydroxide severely limited *T. tubifex*, *L. hoffmeisteri*, *L. udekemianus* and *Nais elinguis*, four generally tolerant oligochaetes. However, *Aeolosoma beddardi* and *Pristina idrensis* occurred in greater numbers than at any other site, suggesting greater tolerance to pollutants than was previously thought. The abundance of tubificids in this river, as is probably true universally, resulted primarily from the organic loading. Life history studies on tubificids (Brinkhurst and Kennedy 1965; Kennedy 1965, 1966*a*, 1966*b*; and Ladle 1971) suggested that temperature plays an important role in unproductive environments. But Eyres, *et al.* concluded that the high productivity at sites allows *L. udekemianus* to breed over an extended period, with seasonal changes exerting less of an influence than was expected. This suggestion could, of course, be applied to other species of oligochaetes which are also tolerant of organic loading.

Brinkhurst and Jamieson (1971) as well as Eyres, *et al.* (1978) suggested that traces of poisonous materials, such as heavy metals, may have adverse effects on the oligochaete communities.

Milbrink (1978) proposed a ranking of oligochaetes with reference

to the environment as they were normally encountered in Scandinavian lakes. Howmiller and Scott's (1977) Environmental index was modified, increasing its sensitivity in European situations. Conclusions suggested that standardized use of indicator communities among oligochaetes for use in any kind of lake requires much more information on the connection among indicator communities, morphometric data, and physical and chemical variables. A preliminary scheme was suggested using mean basin depth and total phosphorus.

Petran and Kothé (1978) suggested that bed load transport decreases the number of benthic species, particularly in the middle of the river. However, oligochaetes, and in particular, *Nais* sp. and *Limnodrilus* sp., appeared somewhat more adaptable to shifting substrates. These oligochaetes readily colonized the hyporheon when favorable, loosely packed substrata were available, but were less abundant when tightly packed grains were present.

Lang and Lang-Dobler (1979*a*) quantitatively related presence of individual oligochaete species to concentrations of different pollutants in sediment, attempting to define the value of each species as a pollution indicator. Multivariate analysis was applied to the data, distinguishing between trophic state of the sediment and pollution level, and grouping species accordingly.

Lang and Lang-Dobler (1979*b*) characterized species assemblages of aquatic oligochaetes with concentrations of pollutants in sediments of a lake using multivariate analysis. Their study quantitatively related the presence of every species to measured concentrations of different

pollutants in the sediments, defining the value of each species as a pollution indicator. The multivariate comparison of the chemical environment which appeared typical of each worm species permitted distinction of species characteristic of different pollution levels. Ten chemical variables (organic carbon, total phosphorus, cadmium, zinc, tin, lead, mercury, copper, chromium, and manganese), and four physical variables (percentage of sand, silt, clay and depth) of the sediment were analysed. The most opportunistic species colonized the most polluted areas.

Milbrink (1980) reviewed oligochaete communities in pollution biology with emphasis on European applications. He summarized pollution tolerances of the more cosmopolitan and commonly occurring species. Milbrink concluded with information on morphological aberrations resulting from the presence of pollutants. Other factors such as interspecific competition, resource partitioning and basic ecological information were introduced.

Särkkä and Aho (1980) studied the distribution of oligochaetes in the Finnish Lake District. They suggested that the occurrence of oligochaete species in strongly polluted or eutrophic lakes seemed to be determined predominantly by physical and chemical factors, while oligochaete distribution in unpolluted lakes was more influenced by biological relationships.

Factor analyses for characteristics of water quality and the abundance of six oligochaete species in epilimnetic depths were conducted. In addition, t-tests compared the 6 dominant species with the averages of environmental variables representing habitats in which

each species was either present or absent. These results agreed generally with those of the factorial analyses, although oxygen content seemed to be more important in winter than in summer. The increase in conductivity, water color, total phosphorus and total nitrogen was positively related to the abundances of *L. hoffmeisteri* and *Potamothrix hammoniensis*, and negatively related to the other species. Niche breadth according to Levins (1968) was applied to the 6 most abundant species. This application indicated, in general, the presence of weak competition among the species.

NAIDIDAE

Although the vast majority of papers addressing oligochaetes and pollution focus on the Tubificidae, some works have addressed the responses of Naididae to various pollutants.

Learner, *et al.* (1978) reviewed the biology of the oligochaete family Naididae, with emphasis on the lotic environment, drawing together numerous papers concerning pollution tolerance of naidid species. Naidids occur throughout a wide range of habitats, although they are most prominent in streams and rivers with rocky or stoney substrates. It is generally thought that the majority of naidid species will not colonize the lower reaches of riverine systems, where slower flow will permit very fine sediment and mud deposition, unless plants which provide a suitable substratum between their thalli are present. Several features of aquatic plants provide favored habitats for different species of naidids. These include: (1) large surface area, providing for the development of epiphytic bacteria and algae, increasing the availability of food and living space; (2) the

enhancement of deposition and accumulation of detrital material, a food supply for species tolerant of some silt deposition; (3) reduction of current in those areas of cover, affording some protection from sediment abrasion and dislodging; and (4) as Harrod (1964) suggested, the chemical nature of the plants may increase suitability of the substrate for certain species of invertebrates. The authors stressed the use of species associations as well as the factors which support those species associations.

Wachs (1967) determined that naidids dominated the oligochaete fauna where the substrate was stoney or gravelly, with sands and muds being dominated by other oligochaete families, usually Tubificidae and Lumbriculidae. Species richness and abundance of naidid populations decreased with a decrease in substrate particle size, results also supported by by the research of Edwards, *et al.* (1972), Maitland and Hudspith (1974), Szczęsny (1974), and Kasprzak and Szczęsny (1976).

Most naidid species are intolerant of environmental conditions which prevail in sediments of fine particle size, probably resulting from the decomposition of organic matter trapped by the fine sediment and the subsequent increase in oxygen demand. This is supported by conclusions of Edwards, *et al.* (1972), who found that reaches of a river with low naidid populations were characterized by substrates with deep deposits of fine sediment with low dissolved oxygen concentrations.

As noted by Armitage (1976), substratum alteration of a river by man in different ways can adversely affect naidid populations. After completion of the Cow Green Dam in the River Tees in England, spate frequency and velocity was reduced downstream. Although spates did

occur, they were the result of over-dam releases, not characterized by course particles, and consequently not having the pre-dam scouring effect on the down-stream river bottom.

SUBSTRATUM

The majority of those papers which propose the use of aquatic oligochaetes as indicators of water quality through application of some index concern lentic systems. Lotic systems would appear to reduce the importance of oxygen as a limiting factor, while increasing the importance of substrate preference and availability in the spacial as well as temporal distribution of macroinvertebrates. Substrate is one of the most important factors influencing the distribution of macroinvertebrates (Cummins 1966; Cummins and Lauff 1969). Substrate preference can be a secondary effect of food-habit, oxygen-need, shelter, house-building behavior and respiration (Tolkamp and Both 1978, and citations therein).

Studies by Tolkamp and Both (1978) also suggested the need for more refined division of substrate-types, based on grain size fractions, and the amount of organic detritus present in and on the mineral substrate.

The hyporheic community, or that area beneath the exposed river and stream beds, holds an important part of the biological community. Schwoerbel (1967) suggested that this area also extends horizontally from the exposed channel, indicating a further source of error when estimating lotic biomass. The works of Coleman and Hynes (1970), Hynes (1974) and Williams and Hynes (1974) noted discrepancies between their research and that of Schwoerbel, suggesting that the horizontal distribution and abundance of invertebrates may not be as great as

Schwoerbel suggests, except perhaps in non-glaciated areas where genuine groundwater fauna has survived the Pleistocene.

Studies by Coleman and Hynes (1970), Hynes (1974), and Poole and Stewart (1976) on stratification of macrobenthos have noted organisms occurring at depths of 50 cm below the exposed bed. Numerous other papers (Ford 1962; Kajak and Dusage 1971; Radford and Hartland-Rowe 1971; Bishop 1973; Williams and Hynes 1974, 1976, 1977; Gilpin and Brusvin 1976; Williams 1976; Morris and Brooker 1979) have suggested that since a considerable portion of benthic invertebrate populations does exist below the sampling depths of conventional samples, new sampling programs must be incorporated in order to effectively represent the total population. This knowledge is extremely important when evaluating aquatic system response and recovery to physical as well as chemical stresses which occur frequently in each systems history. Deeply buried fauna are protected against washouts, moderate droughts, and spates of pollution, representing a true reservoir against disasters. The obvious "evasion" of invertebrates by conventional qualitative as well as quantitative sampling devices invalidate previous standing crop and production estimates. The above authors described various sampling devices and programs for sampling the hyporheon.

Ruggiero and Merchant (1979) stress the application of substrate-organism relationships, suggesting that conclusions regarding water quality and community assemblages need to consider substrate preferences of organisms, as well as availability of those substrates. Distribution and abundance of macroinvertebrates was more closely correlated to substrate than to water quality.

COMPETITION

Competition is perhaps the most important factor in oligochaete population dynamics, since the burrowing detritivores' modes of life are uncommon (Howmiller 1977).

Sanders (1968) suggested that worm communities in extremely oligotrophic or eutrophic situations are likely to be physically limited by either food scarcity or oxygen deficit. Competition may become the limiting factor in mesotrophic situations. However, competition does not need to occur very often to be important (MacArthur 1972). Competition in the field is difficult to observe, since data are obtained after competitive exclusion of one or more species has occurred (Lang and Lang-Dobler 1980).

Relative to competitive displacement, Grinnell (1917) suggested "It is, of course, axiomatic that no two species regularly established in a single fauna have precisely the same niche relationships". Hutchinson and Deevey (1949) continued "Two species with the same niche requirements cannot form steady-state populations in the same region." And more recently MacArthur (1958) stated "To permit coexistence it seems necessary that each species, when very abundant, should inhibit its own further increase more than it inhibits the others."

A review of the studies of Whitley and Seng (1976), Brinkhurst and Chua (1969), Brinkhurst, Chua and Batoosingh (1969), Brinkhurst, Chua and Kaushik (1972), and Wavre and Brinkhurst (1971), concerning bacterial gut content analysis, might suggest a dynamic system of interspecific, intrageneric coexistence, subject to the efficacy of the bacteria. Interspecific competition (Lang 1978*a*) as well as inter- and

intra-specific symbiosis (Brinkhurst and Chua 1969; Brinkhurst 1974*a*), are two important considerations when analysing distribution, since truly benthic organisms are non-randomly distributed (Brinkhurst, Chua and Batoosingh 1969; Downing 1979).

These ideas on the niche concept of species and community interaction, division of resources, coexistence and competition bring us back to the true ecological concept of biological community structure and function.

PREDATION

Some aquatic oligochaetes are widely distributed, while others are limited in distribution, or endemic to certain habitats. Tubificids can attain high population densities when competition from other fauna is reduced. Predation may be as important as competition in the maintenance of low populations in relatively unpolluted areas.

Aquatic oligochaetes are important food sources for fish (Brinkhurst 1974*b*; Wiśniewski 1978) often forming a major component of the fishes' diet. Recent publications have also noted the importance of aquatic oligochaetes in the diet of aquatic invertebrates such as dipteran larvae (Howmiller 1977), *Chaoborus* (Jónasson 1955, 1958, 1972; Loden 1973; Swüste, *et al.* 1973); Chironomidae (Miall 1895; Wirth and Stone 1956; Darby 1962; Brinkhurst and Kennedy 1965; Loden 1973; 1974); other aquatic insects (Kowecka 1977); and waterfowl (Rofritz 1977).

Predation susceptability is a factor determining resource value. Many of the tubificid species burrow into the substrate, with their posterior ends continuously undulating while partially extended above the mud-water interface. Other species which don't "advertize" their

presence probably avoid much of the ensuing predation invited by members of this family.

Mean live weights of *Limnodrilus* species (mainly *L. hoffmeisteri)* and *Branchiura sowerbyi* are 3.43 and 38.93 mg, respectively (Diaz, *et al.* 1978). Caloric values for oligochaetes, noted by Cummins and Wuycheck (1971) to be 5575 cal gm^{-1} dry weight, demonstrate that they are an important, nutritious food source for all predators. Oligochaetes have the potential as a high resource value in freshwater communities where they are dominant. Size, density, and availability are important when comparing the resource value (Diaz 1980).

As Diaz continues, the most important trophic role of oligochaetes is the direct transfer of bacterial energy to carnivores, primarily fish, or the indirect transfer, through primary carnivores, to the top carnivores. However, that portion of oligochaete production which is actually utilized by other trophic levels and/or remineralized is unknown.

Predator suppression, absence of space competition and a great availability of nutritional material may rapidly lead to a high density of tubificids. This idea is supported by the studies of Brinkhurst (1965*b*) Carr and Hiltunen (1965) and Johnson and Matheson (1968).

Many oligochaete species, because of their life history patterns, can be considered opportunistic in nature. Populations dominated by oligochaetes often reflect habitats which have been recently, and often temporarily, disturbed.

PHYSIOLOGICAL STUDIES

Few physiological studies relating tubificids to their tolerance of

various pollutants have been conducted. Even fewer studies have used members of other oligochaete families. What we see is a general inference of their pollution tolerances. Organic loading merely increases available and/or preferable substrates. Those papers which discuss physiological responses of oligochaetes to various stresses include Berg and Jónasson (1965), Whitten and Goodnight (1966), Whitley (1968), Naqvi (1973), Van Hoven (1973), Newman and Buikema (1975), and Loden and Harman (1980).

The increase in numbers of oligochaetes, particularly tubificids, in areas of organic enrichment is largely the result of the adaptation of respiratory physiology of the worms to operate at low oxygen tensions, or even under anaerobic conditions, especially when the loss of oxygen has been gradual.

This ability to tolerate low levels of oxygen in the presence of presumably high BOD and COD, when coupled with the disappearance of otherwise density-controlling predators such as fishes, leeches, decapods and insects, allows oligochaete populations to flourish relatively unchecked.

Brinkhurst and Jamieson (1971) and Milbrink (1978) have suggested that different oligochaete species react differently to the quality of food supply, although paucity of information regarding the interactions between organisms at the mud-water interface, oxygen availability at the interface, and the processes of sedimentation of dead phytoplankton and of mineralization prevent any further conclusions. However, the activity of aquatic oligochaetes in sediment, especially tubificids, clearly affect (a) the chemical changes at the mud/water interface (Wood

1975), (b) the nitrification and denitrification of stream sediments (Kikuchi and Kurihara 1977; and Chatarpaul, *et al.* 1979, 1980), (c) the physical nature of the sediment (Davis 1974*a*, 1974*b*; Diaz 1980; McCall and Fisher 1980), (d) the microbiota of the sediment (Brinkhurst and Chua 1969; and Wavre and Brinkhurst 1971), and (e) the productivity of the ecosystem, through conversion of organic sediments and their respective microbiota into food for the upper trophic levels (Kennedy 1969*a*).

Even though certain species may appear to be more tolerant of those changing conditions in water bodies than other species, the mere presence or absence of these collective species cannot be considered a reliable indication of the suitability of waters for human use or otherwise (Goodnight 1973).

DESCRIPTION OF THE STUDY AREA[1]

Location and topography. The Cache River Basin is bounded on the north by the watershed divide of the Big Muddy River and on the northeast by the watershed divide of Bay Creek. To the south and west, it is bounded by the watershed divides of small, direct tributaries to the Ohio and Mississippi Rivers, respectively. The watershed comprises approximately 271,430 ha, 1.9% of the total area of the state, and includes portions of Alexander, Jackson, Massac, Pope, Pulaski, and Union Counties (Figure 1). Drainage is into the Mississippi River, or via the Post Creek Cut-Off into the Ohio River.

The present physiography of the Cache River Basin is complex. Most of the headwaters in the northern portion of the watershed lie within the Shawnee Hills Section of the Interior Low Plateaus Province. This region is an unglaciated area in which much of the high-relief topography is controlled by the bedrock. The extreme west and northwest tributaries to the Cache River lie within the Salem Plateau Section of the Ozark Plateaus Province. This Section, together with the Shawnee Hills Section, often are referred to as the "Illinois Ozark."

The lower Cache River valley has previously been interpreted as the former main channel of the Ohio River, abandoned when the Ohio was diverted into its present valley below Bay City, Illinois. However, a recent study of the regional alluvial morphology has indicated that the course of the Ohio existed along its present course prior to the

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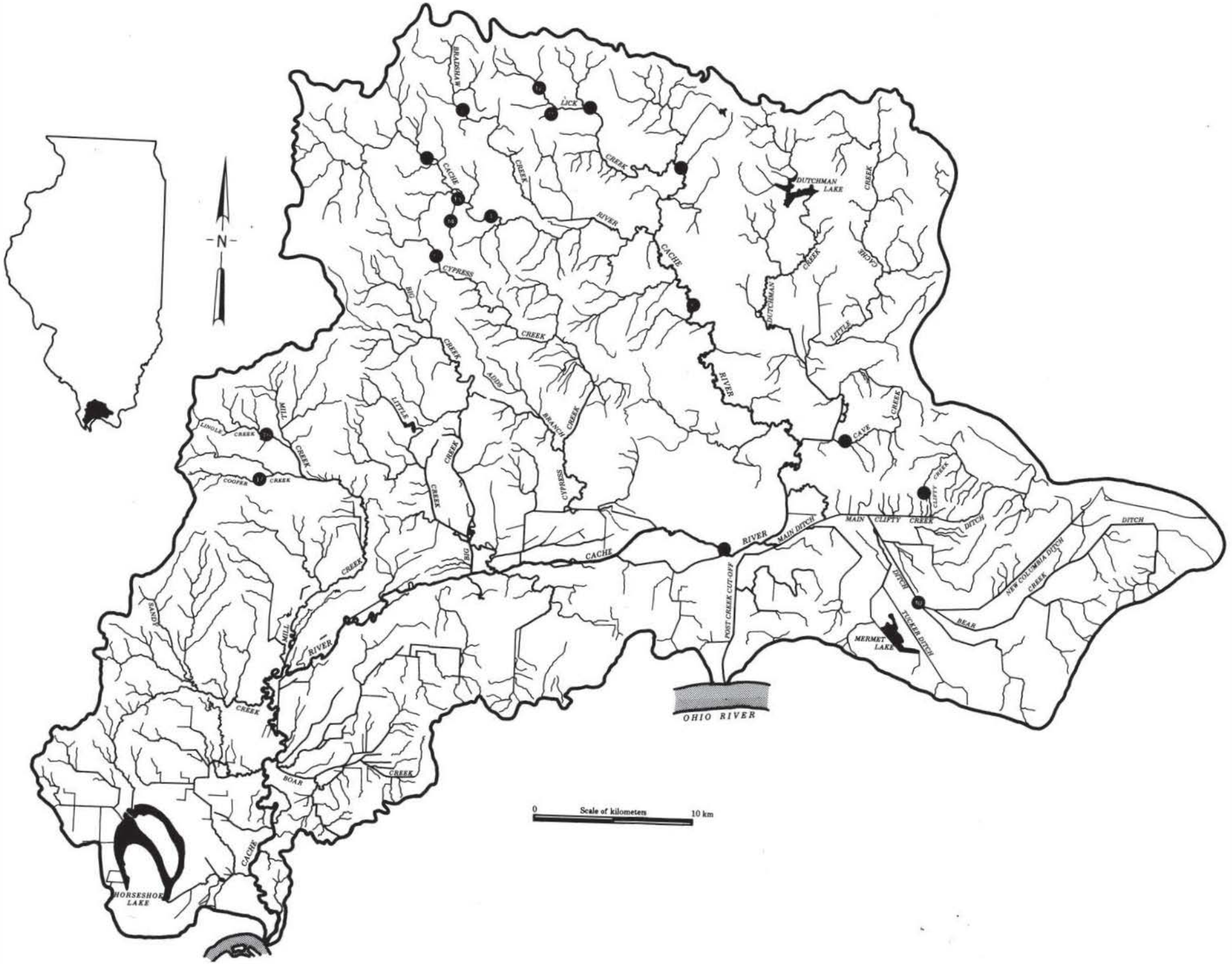
[1]The majority of this background information is taken from A. R. Brigham (1978*a*).

Figure 1. Map of Cache River basin in southern Illinois, noting stations collected during 1976.


N
BRADSHAW
LICK
CREEK
CACHE
RIVER
DUTCHMAN LAKE
CYPRESS
BIG
CREEK
ADDS
BRANCH
LITTLE
MILL
LINGLE
COOPER
CAVE
CLIFTY
MAIN DITCH
DITCH
NEW COLUMBIA DITCH
BEAR
TUCKER DITCH
MERMET LAKE
POST CREEK CUT-OFF
OHIO RIVER
SANDY
BOAR
HORSESHOE LAKE
0
Scale of kilometers
10 km

existence of the Cache Valley (Alexander and Prior 1968). The lower Cache River valley separates the Shawnee Hills from the Coastal Plain Province, the northern tip of which reaches extreme southern Illinois. This Province is characterized by rounded hills developed on relatively soft Cretaceous, Tertiary, and Pleistocene sediments.

Prior to glaciation, the flow of the Ohio River was thought to be westward through the valley now occupied by Bay Creek and the lower Cache River. During the Illinoisan or Wisconsinan glaciation, the Ohio and Cache River valleys were aggraded to the level of the divide between the Ohio and Cumberland Rivers and a lower course for the Ohio River was opened. This southern channel eventually became the permanent course for the river (Leighton, Ekblaw, and Horbert 1948). Alexander and Prior (1968) suggested that the Cache originated during the close of the Wisconsinan glaciation, serving as a spillway for glacial meltwaters and abnormally high floods during more Recent times. The presence of Peoria Loess on the valley walls and radiocarbon dates of organic matter obtained from the Cache alluvium suggest that the final establishment of the valley occurred during the melting of the Woodfordian ice sheet. The valley alluviation, however, commenced with the Twocreekan Substage and continued into the Recent (Alexander and Prior 1968).

Geology. The geological formations in the northern portion of the Cache River Basin include the lower part of the Coal Formation and sandstones and limestones of the Lower Carboniferous Formation. The principal coalbearing strata do not extend into the basin. These strata are

elevated considerably and, at their southern margin facing the bottomlands, form precipitous bluffs. The headwaters of the Cache River in Alexander and Union Counties originate over Devonian bedrock. Most of the eastward course of the river, however, is over Mississippian rock. The lower, westward course of the river is over Cretaceous rock. Finally the Cache flows over Tertiary rock at its junction with the Ohio River. Glacial deposits overlie only the lower portion of the watershed (Halocene and Wisconsinan alluvium, dunes, and gravel terraces and Wisconsinan lake deposits) (Willman and Frye 1970).

Climatology. Southern Illinois has a continental climate with an annual temperature range of about 40°C. Summers are warm, and continuous warm periods can be prolonged, because cool-air invasions from the north often fail to penetrate as far south as extreme southern Illinois. Isotherms are in general from east to west with the northern portions of the Cache River Basin being 1 to 1.5°C cooler than the southern portions. There is no recognizable cline of precipitation within the watershed.

Climatological data from U.S. weather service stations in each of the counties represented in the Cache River Basin are summarized in Table 1. These data show a mean air temperature of near 15°C with extremes from -32°C to 44°C. The growing season varies from 193 to 222 days. Mean annual precipitation of 116.6 cm is distributed fairly evenly throughout the year. September and October normally are the driest months. Mean annual snowfall is 24.7 cm. Monthly summarized

Table 1. Climatological data for eight weather stations in the Cache River basin, southern Illinois (period of record through 1978).

STATION	TEMPERATURE (°C)			PRECIPITATION (cm)		GROWING SEASON (days)
	Min.	Max.	Mean	Rainfall	Snowfall	
Alexander County, Cairo	-20	40	15.3	115.1	22.9	222
Johnson County, New Burnside	-32	44	13.8	118.9	*	193
Massac County, Brookport	-	-	-	118.4	*	200
Pope County, Glendale and Golconda	-23	41	13.6	115.1	25.7	193
Pulaski County	-	-	-	114.3	25.4	208
Union County, Anna and Cobden	-	-	-	117.9	-	-

*Snowfall was not monitored at these stations.

temperature and precipitation data and annual summary (U.S. Department of Commerce 1976*a* through 1976*m*) are listed in Table 2. Data from two reporting stations, Anna in Union County (Lat. 37° 28'; Long. 89° 14') and Dixon Springs Agriculture Research Center in Pope County (Lat. 37° 26'; Long. 88° 40'), are included. A line drawn between these two stations transects the study area.

The depth of freeze in the soil averages about 15 cm, but during much of the average winter the ground and most ponds and lakes are not frozen. The rivers and streams usually remain open during most of the winter.

Vegetation. A detailed classification of biotic provinces in Illinois was expressed by Vestal (1931) who based his divisions on forest types of the original vegetative cover of the state. Two of his provinces occur within the Cache River Basin.

The Ozark Hills

The interesting character of the flora of this province is due, in part, to its age. It was little affected by the Illinoian ice sheet and later glacial advances. Both xeric and mesic trees are well represented here. Distinctive species include the cucumber tree, winged elm, chestnut oak, and tree huckleberry.

The Tertiary Division

The Mississippi Embayment reached the southern base of the Ozark Hills during the Tertiary period. As the waters receded, a coastal plain biological element was left in southern Illinois. Most of the

Table 2. Climatological conditions in the Cache River basin, southern Illinois, during 1976.

MONTH / Station	TEMPERATURE							No. of Days				PRECIPITATION					No. of Days		
								Max.		Min.					Snow, Sleet				
	Average Maximum	Average Minimum	Average	Departure From Normal	Highest	Lowest	Degree Days	90° or Above	32° or Below	32° or Below	0° or Below	Total	Departure From Normal	Greatest Day	Total	Maximum Depth on Ground	.10 or More	.50 or More	1.00 or More
JANUARY																			
Anna	40.9	22.7	31.8	-2.4	62	-2	1023	0	6	24	2	2.15	-1.62		2.6	2			
Dixon Springs	41.0	21.6	31.3		63	-8	1037	0	7	23	2	1.80		1.01	3.8	3	5	1	1
FEBRUARY																			
Anna	56.5	34.6	45.6	8.0	72	8	561	0	1	13	0	3.58	.13	1.39	4.5	4	5	3	1
Dixon Springs	56.3	35.6	46.0		73	6	545	0	2	13	0	3.71		1.21	2.9	3	5	4	2
MARCH																			
Anna	63.5	42.2	52.9	7.4	76	24	380	0	0	6	0	4.03	- .86	1.42	1.1	0	7	3	1
Dixon Springs	64.6	42.8	53.7		76	23	350	0	0	10	0	3.25		.68	.0	0	8	3	0
APRIL																			
Anna	70.0	46.8	58.4	.6	83	33	226	0	0	0	0	2.58	-2.12	1.15	.0	0	6	2	1
Dixon Springs	70.8	45.0	57.9		83	28	249	0	0	4	0	2.81		1.58	.0	0	3	2	1
MAY																			
Anna	73.4M	51.0M	62.2M	-4.2	85	34	110	0	0	0	0	3.93	-1.41	1.48	.0	0	9	2	1
Dixon Springs	72.4	49.4	60.9		83	29	152	0	0	2	0	4.21		.89	.0	0	8	4	0
JUNE																			
Anna	81.7	61.6	71.7	-3.1	90	54	3	2	0	0	0	5.27	.88	1.47	.0	0	10	4	1
Dixon Springs	81.2	60.9	71.1		88	51	5	0	0	0	0	6.68		1.97	.0	0	10	3	2
JULY																			
Anna	87.5	66.4	77.0	- .8	99	57	0	14	0	0	0	7.62	4.04	3.22	.0	0	9	5	2
Dixon Springs	87.1	63.9	75.5		96	52	0	12	0	0	0	5.54		2.53	.0	0	7	3	2
AUGUST																			
Anna	85.1	62.4	73.8	-2.8	91	55	0	7	0	0	0	.36	-3.71	.36	.0	0	1	0	0
Dixon Springs	84.3	59.2	71.8		90	49	0	2	0	0	0	.42		.26	.0	0	1	0	0
SEPTEMBER																			
Anna	81.0	55.5	68.3	-1.5	88	41	27	0	0	0	0	1.41	-2.20	.84	.0	0	2	2	0
Dixon Springs	80.6	53.1	66.9		87	36	43	0	0	0	0	1.11		.81	.0	0	2	1	0
OCTOBER																			
Anna	64.0M	40.6M	52.3M	-7.4	86	23	398	0	0	6	0	3.34	.49	1.33	.0	0	5	3	1
Dixon Springs	65.9	40.9	53.4		84	19	367	0	0	6	0	4.23		1.22	.0	0	5	4	1
NOVEMBER																			
Anna	50.6	29.3	40.0	-6.6	66	9	746	0	2	19	0	1.06	-2.70	1.06	T	T	1	1	1
Dixon Springs	51.0	27.7	39.4		67	6	762	0	2	19	0	1.45		.82	T	T	2	2	0
DECEMBER																			
Anna	44.5	22.8	33.7	-3.0	64	-5	965	0	5	28	1	.91	-2.78	.55	T	0	2	1	0
Dixon Springs	45.5	22.8	34.2		65	-5	950	0	4	27	1	.67		.37	1.1	1	2	0	0
ANNUAL SUMMARY																			
Anna			55.6M	-1.4	99	-5	4439	22	14	96	3	36.24	-11.86	3.22	8.2	4	62	27	10
Dixon Springs			55.2		96	-8	4460	14	15	104	3	35.88		2.53	7.8	3	53	26	8

[1]Adapted from climatological data, Illinois (U. S. Department of Commerce, National Oceanographic and Atmospheric administration, Environmental Data Service 1976*a*, 1976*b*, 1976*c*, 1976*d*, 1976*e*, 1976*f*, 1976*g*, 1976*h*, 1976*i*, 1976*j*, 1976*k*, 1976*l*, 1976*m*). The letter 'M' indicates missing data from one or more days; if average value is entered, less than 10 days record is missing. he letter 'T' indicates trace, an amount too small to measure.

tree species which characterize this element are swamp forest species, including bald cypress, tupelo, water locust, Mississippi hackberry, pumpkin ash, water hickory, swamp cottonwood, and willow oak.

It should be noted that Vestal (1931) was writing of original vegetative cover, much of which was altered even in his day. In spite of timber cutting, wetland drainage, and intensive agriculture, Smith (1961) found that the state's herpetofauna tended to coincide with Vestal's provinces. This implies an underlying influence of climatology, geography, and geology which transcends, in part, man-induced changes in vegetation and land use. For a detailed account of the flora of southern Illinois, the reader is directed to the excellent account of Voigt and Mohlenbrock (1964).

Population and land use. Most of the available population and land-use data are county-wide summaries. As such, these data reflect an area greater than the study area, but they are thought to be representative of the watershed. The following data are projections from the county summaries provided by Fehrenbacher and Walker (1959), Parks and Fehrenbacher (1968), Allen (1968, 1969, 1970, 1971*a*, 1971*b*), and Parks (1975).

The principal early settlement near the Cache River Basin occurred during the 18th century. These settlements were along the Ohio and Mississippi rivers with little penetration inland until the late 18th century. The population of the area showed a fairly steady increase until the 1930's and 1940's when a decline began. The present population of the area is approximately 60,000. The mean 10-year rate

of decrease is 7.1%, but ranges from 1% (Massac and Pope Counties) to 21% (Alexander County). Current population forecasts show these decreases continuing into the 1980's, but reversing by the year 2000. Population densities range from 10.7 to 72 persons km^{-1} (Pope and Alexander Counties, respectively), with a mean of 41.9 persons km^{-1}. Population distribution is considered nearly 100% rural throughout most of the basin, but Massac County is divided 49% rural and 51% urban.

Agricultural woodlands and the Shawnee National Forest account for 46% of the land in the Cache River Basin. Cropland is next in abundance with 29%. The principal crops are corn and soybeans. Pasture land accounts for 18% of the watershed, with cattle and hogs representing most of the livestock. Only 7% of the land is non-farm or non-forest. These lands support urban development and mineral extraction activities, principally limestone, fluorospar, and coal.

STREAM SYSTEMS

Stream Ordering. Stream order here is based upon the Horton-Strahler classification (Horton 1945; Strahler 1954, 1957). In this system, ultimate unbranched tributary streams are defined as order 1 streams. Whenever two streams of equal order join, the resulting stream is designated as the next higher order. Thus, two order 1 streams join to make an order 2 stream, two order 2 streams make an order 3 stream, and so forth. Stream order is not affected by the confluence of a lower order stream. A stream link is defined as a reach of stream from its source to its first confluence with another stream or the reach of stream from one confluent stream to the next confluent stream. Data

were derived from U.S. Geological Survey quadrangle maps with scales of 1:24,000 and 1:62,500. Morisawa (1957) determined that such maps are sufficiently accurate to depict virtually all order 1 streams.

In a fully bifurcate dendritic drainage net, each order 1 link joins with another to form an order 2 stream. Each order 2 link then joins with another to form an order 3 stream. This pattern continues until maximum stream order is reached, here equal to the characteristic, or integral portion of $1+\log_2$ of the number of order 1 links. When the number of order 1 links is not an even power function of 2, the"extra" order 1 links appear as the mantissa of the base 2 logarithm. Lick Creek would be an order 7 stream if the drainage net were of the fully bifurcate dendritic pattern. The stream would then have 68 order 1 links, 34 order 2 links, and 17 order 3 links, 8 order 4 links, 4 order 5 links, 2 order 6 links, and 1 order 7 link. It may be seen that Lick Creek approaches this closely for orders 1,2, and 3, but that it has six times too many order 4 links. Hence, it is overdeveloped at the order 4 level. The stream never reaches the order 7 level.

Trellis drainage nets are characteristic of long, narrow valleys where numerous small streams flow down from the valley walls to join the principal stream following the thalweg of the valley. In an optimum trellis system, order 1 streams only flow into the principal stream. The confluence of the first two order 1 streams would produce an order 2 stream. All remaining influent order 1 streams increase the number of order 2 links, but not the order of the principal stream.

Cache River. The Cache River was named by Pere Mermet circa 1702. It originates near Cobden, Union County, Illinois, and flows through

Alexander, Johnson, and Pulaski Counties, Illinois (Figure 1). The general course of the upper reaches of the river is southeasterly. South of Vienna, the river flows southward to the Post Creek Cut-Off, a flood relief channel just north of Karnak. The river at normal pool flows westerly from Karnak in its natural channel, eventually turning south near Tamms, and emptying southeasterly into the Ohio River south of Mound City.

The Cache River and its major tributaries, Dutchman Creek, Little Cache Creek, and Post Creek Cut-Off, are low gradient streams (0.38 m km^{-1}, 0.95 m km^{-1}, 1.33 m km^{-1}, and 1.51 m km^{-1}, respectively), draining approximately 271,342 ha. The drainage pattern is intermediate between a fully bifurcate dendritic pattern and a trellis pattern. The Cache River is an order 5 stream at its confluence with the Mississippi River and, with backflow through the Post Creek Cut-Off, an order 6 stream at its confluence with the Ohio River. The Cache River is overdeveloped at the order 1, 2, 3, 5, and especially 4 levels. It is underdeveloped at the order 6 level. The Cache River never reaches the potential order 11 stream of a fully bifurcate dendritic drainage pattern. Morphometric data are summarized as follows:

Order	Number Links	Mean Length (km)	Total Length (km)
1	1,146	1.35	1,551.0
2	572	0.83	476.0
3	278	0.86	239.6
4	208	1.02	212.6
5	79	1.33	105.2
6	12	1.63	19.6
		Total =	2,604.0

Little Cache Creek is an order 4 and Dutchman Creek is an order 5 stream at their respective confluences with the Cache River. Post Creek Cut-Off is a drainage ditch. Flap valves prevent water from flowing into the Cache River at Karnak. When the water in Post Creek Cut-Off is at a low level, water in the Cache River west of the cut-off levee can flow back through the flap valves and into Post Creek Cut-Off.

Southern Illinois, unlike most of the state, possesses topography that is only in part and indirectly related to glaciation. For the most part, the hills and valleys of this area originated in a more remote period and are a relic and reminder of what the rest of Illinois was like before it was covered with glacial ice. The soils of the Cache River watershed consist of a variety of silt loams with varying problems of erosion, drainage, and fertility.

Most of the hilly portion has brown, crumbly silt loam soil formed of loess and is thin and stony on many slopes. The bottomlands are characterized by grayish-brown alluvial silt loams. The following soil associations occur:

1. *Tice-Riley-Landes:* moderately dark colored, generally moderately fine textured bottomlands often underlain by sandy strata, imperfectly drained, nearly neutral.
2. *Littleton-Proctor-Plano-Camden-Hurst-Ginat:* in general, developed from medium and fine textured outwash, varying in color from light to dark and occurring over a wide range of slope.

3. *Lawson-Beaucoup-Darwin-Haymond-Belknap*: bottomland soils developed primarily from alluvium and are generally nearly level to gently sloping, varying in color from light to dark, in texture from sandy to clayey, and in drainage from poorly drained to well drained.

4. *Hosmer-Stoy-Weir:* light colored, strongly developed soils formed under forest vegetation, occurring on nearly level to very strongly sloping uplands.

5. *Wartrace-Hosmer:* light colored, medium textured soils developed under forest vegetation, occurring on gently sloping to steep topography.

6. *Alford-Stookey:* light colored soils developed under forest vegetationn, occurring on rolling to very steep slopes.

7. *Ginat-Weinbach-Sciotoville:* light colored soils developed under forest vegetation, occurring on nearly level to moderately sloping topography.

8. *Alvin-Roby-Ruark-Unity:* light colored soils developed under forest vegetation and occurring on nearly level to very strongly sloping topography, poor drainage on level areas.

9. *Alford-Muren:* deep, moderately permeable soils, some with weak fragipans, rolling to steep.

10. *Stookey-Bodine:* deep, permeable, generally weakly developed steep soils, and very steep, shallow, cherty soils.

11. *Bonnie-Karnak:* light colored, medium and fine textured bottomland soils, poorly to very poorly drained, strongly acidic.

12. *Grantsburg-Robbs-Wellston:* developed primarily from loess, occurring on gently sloping to very steep topography.

Main Ditch. Main Ditch is the collecting ditch for an extensive drainage network. It flows northwest through Massac County, Illinois, enters the old channel of the Cache River, continues as a drainage ditch through the old channel, and leaves Massac County flowing westerly toward Post Creek Cut-Off in Pulaski County, Illinois. The entire watershed of Main Ditch lies in the floodplain of the pre-glacial Ohio River. Bay Creek drains the eastern portion of this floodplain and the lower course of the Cache River drains the western portion. The low divide between these two streams once was more extensively covered with wetlands than at present. Main Ditch was excavated to drain this low watershed divide so that the land could be farmed. The Main Ditch drains an area of approximately 16,317 ha.

As would be expected on a river floodplain, Main Ditch is a low gradient stream, less than 0.19 m km^{-1}. It is an order 5 stream at its confluence with the Cache River. The drainage pattern is trellis-like. Main Ditch is overdeveloped at all levels, except the order 3 level. It never reaches the potential order 8 stream of a fully bifurcate dendritic drainage pattern.

The major tributaries of Main Ditch are Clifty Creek Ditch and New Columbia Ditch, both order 4 streams at their confluences with Main Ditch.

Dutchman Creek. Dutchman Creek is located entirely within Johnson County, Illinois. It rises southeast of Goreville and flows in a southerly direction, emptying into the Cache River below Vienna. Dutchman Creek drains an area of approximately 18,130 ha.

Dutchman Creek is a low gradient stream, 0.95 m km^{-1}. It is an order 5 stream at its confluence with the Cache River. The drainage pattern is intermediate between a fully bifurcate dendritic pattern and a trellis pattern. The stream is overdeveloped at the order 1,2,3, and, especially, the order 4 levels. It never reaches the potential order 8 stream of a fully bifurcate dendritic drainage pattern.

The only major tributary of Dutchman Creek is Little Cache Creek, an order 4 stream which joins Dutchman Creek approximately 1.5 km southwest of Vienna. Vienna discharges approximately 0.06 mgd of wastewater treatment plant effluent into Little Cache Creek. Since 1962 wastewater treatment has been via a secondary stabilization pond. Measured population equivalents of untreated wastewater was 1,000 (1960

population 1,094). Measured population equivalents of treated wastewater was 1,000. Thus, the treatment process had no effect upon the wastewater with unstabilized sewage entering Little Cache Creek. Brigham and Brigham (1976) provided an assessment of the water quality of this stream system. (An additional water quality and biological assessment of Dutchman Creek is in preparation by the staff of the INHS). Cave Creek is a minor tributary of Dutchman Creek. It rises 3 mi southwest of Vienna and flows in a west-southwesterly direction, emptying into Dutchman Creek 1.2 mi northeast of Forman. It is an order 3 stream at its confluence with Dutchman Creek.

Lick Creek. The Lick Creek watershed is located in Johnson and Union Counties, Illinois. The creek drains approximately 7,511 ha and enters the Cache River south of Elvira. The level of the land in the Cache River basin drops from the Shawnee Hills and Salem Plateau Sections to the Coastal Plains Province in two stages each of about 60 m. Lick Creek runs south-eastward along the "step" in the bluffline. Thus, tributary streams from the north are short, high-gradient streams with gravel and rock substrates while those from the south tend to greater length, shallower gradients, and smaller-sized particles in the substrate.

Lick Creek is a high gradient stream (4.5 m km^{-1}) which reaches order 4 prior to its confluence with the Cache River. The drainage pattern is intermediate between a fully bifurcate dendritic pattern and a trellis pattern. Lick Creek is overdeveloped at all levels, especially the order 4 level. It never reaches the potential order 7 stream of a fully bifurcate dendritic drainage pattern.

Bradshaw Creek. Bradshaw Creek is located entirely within Union County, Illinois. It flows in a southeasterly direction, emptying into the Cache River northwest of Mount Pleasant. Bradshaw Creek drains an area of approximately 4,662 ha.

Like Lick Creek to the east, Bradshaw Creek flows southeastward along the step in the bluffline. Here, too, the tributaries from the north are short, high-gradient streams while those from the south are longer and have shallower gradients.

Bradshaw Creek is a high gradient stream, 3.95 m km^{-1}. It is an order 4 stream at its confluence with the Cache River. The drainage pattern is trellis-like. Bradshaw Creek is overdeveloped at the orders 1, 2, and 4 levels and underdeveloped at the order 3 level. It never reaches the potential order 6 stream of a fully bifurcate dendritic drainage patterns.

Mill Creek. Mill Creek is located in Pulaski and Alexander Counties, Illinois. It originates in the Shawnee National Forest near the Union-Alexander County line and empties into the Cache River just east of Tamms. Mill Creek drains an area of approximately 10,619 ha.

Although several of its headwater streams are high-gradient creeks draining highly dissected uplands, Mill Creek quickly drops to near the level of the Cache River floodplain. Thus, it is a low gradient stream (0.95 m km^{-1}). It is an order 4 stream at its confluence with the Cache River. The drainage pattern is intermediate between a fully bifurcate dendritic pattern and a trellis pattern. Mill Creek is overdeveloped at all levels, except the order 2 level. It never reaches the potential

order 7 stream of a fully bifurcate dendritic drainage pattern. The major tributaries of Mill Creek are Cooper, Hartline, and Lingle Creeks, all order 3 streams at their confluences with Mill Creek.

Cypress Creek. Cypress Creek is located in Pulaski and Union Counties, Illinois. It originates east of Anna and flows in a southeasterly direction, emptying into the Cache River south of White Hill. Cypress Creek drains an area of approximately 9,842 ha.

Cypress Creek is a low-gradient stream (2.74 m km^{-1}) which becomes an order 5 stream before its confluence with the Cache River. The drainage pattern is intermediate between a fully bifurcate dendritic pattern and a trellis pattern. Cypress Creek is overdeveloped at the order 2, 4, and 5 and never reaches the potential order 7 streeam of a fully bifurcate dendritic drainage pattern. Cypress Creek flows southeast along a step in the bluffline crossing southern Illinois. Thus, the tributary streams from the north are short, high-gradient streams. Just prior to its reaching the Cache River floodplain, Cypress Creek flows through a rather extensive cypress swamp known locally as Hogans Bottoms. The lower 6 km of Cypress Creek has been channelized. A single named tributary of Cypress Creek, Add Creek, is an order 3 stream at its confluence with Cypress Creek.

MATERIALS AND METHODS

Station Selection

Seventeen sites were selected for macroinvertebrate sampling (Figure 1). Station number, general description, and legal description of these stations are listed in Table 3. Photographs of each site are provided in Appendix 1. Legal locations were obtained from U. S. Geological Survey Quadrangle maps with scales of either 1:24,000 or 1:62,500.

Several factors were considered when sampling sites were selected. Emphasis was placed on similarity of habitats among sites, as well as diversity of habitats within any single site. The presumption was that diverse habitats would theoretically support the most diverse communities. Environmental factors such as substrate particle size and type, stream width and depth, current velocity and vegetation were considered.

Stations 1 through 10 were established by the contracting agency prior to the study. Stations 11 through 17 were added by me to broaden the collections of macroinvertebrates from areas most representative as well as unique within the entire drainage basin.

Selected watersheds within the upper Cache drainage were excluded as these areas were considered under separate SCS projects. These include Little Cache Creek, Mill Creek, and Dutchman Creek. Aquatic oligochaetes recorded from Dutchman Creek are noted in Appendix 2.

Table 3. Location of stream sites sampled in the Cache River basin, southern Illinois, during 1976.

1. ILL., Union Co., Cache River, 1.3 km WSW Saratoga. T.12S, R.1W, NW/4, NW/4, SW/4, Sec. 1. Makanda (7.5', 1966ed) quad.

2. ILL., Union Co., Bradshaw Creek, 2.3 km NNE Saratoga. T.11S, R.1E, SE/4, SW/4, SW/4, Sec. 30. Makanda (7.5', 1966ed) quad.

3. ILL., Union Co., Lick Creek, 1.1 km NE Lick Creek (town). T.11S, R.1E, SE/4, NW/4, SE/4, Sec. 26. Lick Creek (7.5', 1966ed) quad.

4. ILL., Union Co., Cache River, 9.7 km E Anna. T.12S, R.1E, SE/4, SE/4, NW/4, Sec. 17. Anna (7.5', 1966ed) quad.

5. ILL., Johnson Co., Lick Creek, 7.2 km SSW Goreville, (1.5 mi E Elvira). T.12S, R.2E, NE/4, NE/4, NE/4, Sec. 8. Mt. Pleasant (7.5', 1966ed) quad.

6. ILL., Johnson Co., Cache River, 1.9 km W West Vienna. T.12S, R.2E, NE/4, NE/4, SW/4, Sec. 33. Vienna (7.5', 1966ed) quad.

7. ILL., Johnson Co., Cave Creek, 6.0 km NE Belknap (1.3 mi NE Forman). T.13S, R.3E, SE/4, SE/4, NW/4, Sec. 28. Karnak (7.5', 1966ed) quad.

8. ILL., Massac Co., Clifty Creek, 6.0 km N Mermet. T14S, R.3E, SE/4, SE/4, NW/4, Sec. 1. Mermet (7.5', 1966ed) quad.

9. ILL., Pulaski Co., Cache River, N edge of Karnak. T.14S, R.2E, SE/4, SW/4, NE/4, Sec. 15 Karnak (7.5', 1966ed) quad.

10. ILL., Massac Co., Main Ditch, 1.2 km NE Mermet. T.14S, R.3E, NE/4, SW/4, SW/4, Sec. 24 (from NE corner of section). Mermet (7.5', 1966ed) quad.

11. ILL., Union Co., Unnamed tributary of Lick Creek, 1.9 km NW Lick Creek (town). T.11S, R.1E, NW/4, NE/4, SW/4, Sec. 27. Lick Creek (7.5', 1966ed) quad.

12. ILL., Union Co., Lick Creek, 2.7 km NW Lick Creek (town). T.11S, R.1E, NE/4, NW/4, NW/4, Sec. 27. Lick Creek (7.5', 1966ed) quad.

13. ILL., Union Co., Cache River, 8.0 km ENE Anna. T.12S, R.1E, NE/4, SW/4, SW/4, Sec. 7. Anna (7.5', 1966ed) quad.

14. ILL., Union Co., Unnamed trib. Cache River. 8.0 km E Anna. T.12S, R.1E, SW/4, NW/4, SW/4, Sec. 18. Anna (7.5', 1966ed) quad.

15. ILL., Union Co., Cypress Creek, 7.2 km E Anna. T.12S, R.1W, SE/4, NW/4, NE/4, Sec. 25. Anna (7.5', 1977ed) quad.

16. ILL., Union Co., Lingle Creek, 4.2 km WNW Mill Creek (town). T.13S, R.2W, SW/4, SW/4, NE/4, Sec. 26. Mill Creek (7.5', 1948ed) quad.

17. ILL., Alexander Co., Cooper Creek, just below junction with You-Be Hollow, 1.3 km SW Mill Creek (town). T.14S, R.1W, NE/4, NW/4, NW/4, Sec. 6. Mill Creek (7.5', 1948ed) quad.

Sampling Design

Aquatic oligochaetes were collected using the kick-net method. A D-ring net with an opening of 640 cm^2 was used. In riffle areas, the net was placed perpendicular to the substrate, with the opening facing upstream. An area of approximately 1 square meter was agitated directly upstream of the open net, with the subsequent disturbed silt, sand, and organisms washed into the net. Additional collections with this net were made by sweeping it through silt areas, leaf packets, overhanging riparian vegetation, and submerged as well as emergent aquatic vegetation. Large substrates such as cobble, rocks, boulders, logs, and other debris, both natural and man-induced, were either hand-picked or gently washed off into the net. Epiphytic mosses and algae were collected from various substrates, fixed, and returned to the laboratory for dissection under a stereomicroscope. Many specimens of naidids were obtained this way. Every effort was made to consistently sample the same substrate types and microhabitats during each collecting period. Each substrate type and habitat was collected for the same length of time, between stations as well as between sampling periods, to assure compatible results. Specimens were immediately fixed in either Kahle's fluid (Appendix 3) or 10% buffered formalin, and returned to the laboratory for processing.

The use of the D-ring net is less quantitative than many other devices and methods described in the literature, such as the Eckman, Petersen and Ponar dredges, single or multiple bore corers, the Surber sampler, and multiplate and basket artificial substrate samplers.

However, the use of the d-ring net allows a rapid collection of invertebrates from a wide range of microhabitats in streams and rivers. Quantitative devices such as the Eckman, Petersen, and Ponar dredges, as well as various corers are often suited for (or work most efficiently) in selected substrates. These devices have also been shown to introduce shock waves in front of them on descent, often greatly reducing the numbers of individuals obtained. Artificial substrate samplers, used for over 40 years (Moon 1940; Wene and Wickliff 1940) to sample aquatic invertebrates, (1) have been shown to be biased towards such groups as Oligochaeta and Diptera (Fullner 1971), (2) must be left out in the field for a period of at least 6 weeks, and (3) may not always reflect the effects of substrate changes on species assemblages.

Discussions concerning the use, effectiveness and reliability of substrate samplers can be found in Anderson (1959), Cummins (1962), Arthur and Horning (1969), Mason, *et al.* (1970), Brooks and Hilsenhoff (1971), Dickson, *et al.* (1971), Simmons and Winfield (1971), Beak, *et al.* (1973), Mason, *et al.* (1973), Benfield, *et al.* (1974), McConville (1975, 1979), Voshell and Simmons (1977), Armitage, *et al.* (1978), Harrold (1978), Kathman (1978), Armitage (1979), Downing (1979), Resh (1979), Wise and Molles (1979), and Lowe and Gale (1980).

The Surber sampler is only quantitative when fairly uniform substrates are sampled. It certainly cannot be used to effectively sample the side of a stream channel. Anyone who has tried to effectively recover an otherwise quantitative sample from the inside of a stiff Surber net can understand the frustration in using this device.

It has been noted recently by Jacobi (1978) that the Surber sampler underestimates by a factor of 2.5.

Horning and Pollard (1978) compared the Surber sampler method (SSM) and the unit-effort traveling kick method (UETKM) for collecting aquatic macroinvertebrates. They concluded that the UETKM was more efficient and cost-effective than the SSM for number of taxa, percentage of data for the common taxa, and diversity index values. Fewer replicates were required to obtain reproducible estimates of faunal composition. The UETKM was shown to be more versatile than the SSM (usable for areas up to 1 m in depth) and overcome those sampling limitations usually associated with site suitability, while minimizing the number of replicates needed. The UETKM was recommended for fauna-poor areas of gravelly-sandy substrates, with little or no vegetation, and depths of 15 to 60 cm. Many of the advantages of this method also may be applied to a variety of other habitats.

Pollard and Kenney (1979) tested the efficiency of three sampling macrobenthic methods (the Surber sampler, the PIBS sampler and the standardized traveling kick method (STKM) in selected riffle habitats of the White River, Colorado. The authors concluded that the STKM was decidedly superior or at least as effective as the Surber sampler and PIBS in terms of collection efficiency, cost efficiency and ease of sampling, particularly in fauna-poor stream reaches with patchy invertebrate distributions.

The reader is directed to Armitage, *et al.* (1974), Hughes (1975), Elliott and Tullett (1978), Downing (1979), and Resh (1979) for

discussion concerning effectiveness and reliability of most collecting devices.

Specimen Preparation

Correct specimen preparation is vital to further research with any group. I have reviewed and tried numerous methods of specimen preparation. Indeed, a method used primarily for one family of Oligochaeta may be totally unsuitable for another family. Singer (1977) suggested that difficulties involved in the preparation of *Aeolosoma* spp. for microscopical examination probably accounted for more investigators abandoning study of this group than any other single factor.

Aeolosomatida do occur in the Cache River system. However, this group of aquatic annelids requires "special handling" throughout diagnosis, and since little is known about these annelids in relation to their water quality requirements, they have not been included in this work. This does not preclude their importance in aquatic systems.

Researchers concerned with biomass-weight in accordance with their particular sampling designs should consult Howmiller (1972), Stanford (1973), Donald and Paterson (1977), Wiederholm and Eriksson (1977), and Senapati and Dash (1980) for information regarding weight loss resulting from various fixation/preservation techniques.

After specimens were returned to the lab, they were sorted under a stereo dissecting microscope and temporarily stored in either 10% buffered formalin or 70% ethanol. Specimens were then cleared in Amman's lactophenol (Appendix 3) for periods of 1 to 3 days. After

clearing, specimens were blotted momentarily on tissues, and mounted on slides with either Gurr Hydramount[1] or Gurr polyvinyl lactophenol.[1] Most large specimens were mounted under 22 mm square, #1 coverslips, while smaller specimens were mounted under 18 mm square or 18 mm circular, #0 coverslips. Slides were allowed to "cure" for one week before identifications were made. Recently, I have learned from other recognized oligochaete taxonomists that the use of Amman's lactophenol, polyvinyl lactophenol, Hydramount, CMC-9, and other clearing-mountants tend to readily destroy the internal structures, particularly the soft tissues of the gonads. This renders the specimen useless for β and ϒ taxonomy. It is suggested that in the future, researchers should return to the old standby method of alcohol dehydration series through absolute alcohol, clearing in oil of wintergreen (methyl salicylate), cedar wood oil, or xylene, and mounting in Canada balsam, Harleco's Xylene Coverbound[2], or some other resinous medium. This method takes more time, but maintains the specimen for further diagnostic study. After mounting, specimens were identified and counted. Only whole individuals and fragments identifiable as anterior ends were counted. A total of 1,426 oligochaetes were examined.

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[1]Available from Bio/Medical Specialties, Box 1687, Santa Monica, CA 90406.

[2]Available from Scientific Products, 1430 Waukegan Road, McGraw Park, Il 60085.

Taxonomic Interpretations

Oligochaete! Thou taxonomic pain!
My mouth and mind and memory affirm,
'Twould be much less a stress upon the brain
To designate you merely as a worm.
But then again, perhaps it is untrue
To brand you as too simple for your name.
For possibly, the tests we put you through
Just don't quite fit your undulating frame.
Psychologists are on the highest ground
When studying the ways of mice and men.
But with invertebrates they're often found
Quite ignorant of how they should begin.
The object of my study is to try
To help both man and worm see eye to eye.

D. N. Howell (1974)

This group of aquatic invertebrates has always had the reputation for being the most difficult to identify. It was often thought that sectioning was necessary for accurate identifications. However, the more recent works of researchers discussed in the historical perspective have clarified much of the confusion in the older literature. Keys to most families are available for most continental areas. Reynolds and Cook (1976) compiled *Nomenclatura Oligochaetologica,* a catalog of generic, specific, subspecific and varietal names of all known oligochaetes. This catalog also provides the citation for original descriptions, historical records of the generic disposition of species, and the location or fate of type specimens, when known.

Identifications were made using either an Olympus model BH compound microscope with fluorite phase, or a Zeiss Standard 14 compound microscope with Nomarski interference contrast. Identifications and taxonomic interpretations followed: Barbour, *et al*. (1979), Brinkhurst (1960, 1962*a*, 1962*b*, 1963*a*, 1963*b*, 1964*a*, 1964*b*, 1965*a*, 1966*a*, 1966*e*, 1966*f*, 1971, 1975, 1976, 1978*b*, 1979*a*, 1979*b*), Brinkhurst and Cook (1966), Brinkhurst and Jamieson (1971), Cook (1967, 1969), Dixon (1915), Goodnight (1940), Harman (1965, 1966, 1969, 1973, 1975, 1977), Harman and Harrell (1975), Harman and Loden (1978*a*, 1978*b*), Harman, Loden and Davis (1979), Harman and McMahan (1975), Hiltunen (1967, 1973), Hiltunen and Klemm (1980), Hoffman (1963), Holt (1953, 1965, 1969, 19873*a*, 1973*b*, 1974, 1978), Howmiller (1974*a*, 1974*b*, 1974*c*, 1977), Howmiller and Loden (1976), Kennedy (1969*b*), Loden (1977, 1978), Loden and Dugas (1978), Singer (1977), Smith (1900*a*), Spencer (1977, 1978*a*, 1978*b*, 1980), Sperber 1948, 1950), Ward (1976), Wetzel (1980), and Whitley and Wetzel (1976). Nomenclatural information followed Reynolds and Cook (1976).

WATER QUALITY MONITORING

The funding agency for the overall study on the Cache River basin established a 17 month water quality sampling program, which was begun on 19 December 1975 and concluded on 23 March 1977 for the 10 stations originally chosen. Additional water quality collections were taken at the 7 supplementary stations chosen by me. These collections were made four times between 28 February 1976 and 1 October 1976. Although collections of both water and biological samples were taken over a period of 2 to 3 days each sampling period, these sampling periods are referred to as one date for clarity and simplification. Data for physical and chemical parameters determined at each of the stations are summarized in Appendix 4. Each physical and chemical parameter, except flow, was measured in triplicate. Field measurements included water temperature, dissolved oxygen, free carbon dioxide, hydrogen ion concentration (as *p*H), conductivity, and water velocity. Water velocity was measured by "partitioning" the cross-sectional area of the stream into rectangles 0.50 m by 0.25 m (0.125 m^2). Velocity was then recorded for each 0.125 m^2 area as m sec^{-1}. Flow (as m^3 sec^{-1}) was determined for each 0.125 m^2 area by multiplying it by the corresponding water velocity. All individual flows were summed to determine total flow at each station on each date. All remaining analyses were performed in the laboratory on unpreserved raw water samples. Most of the analytical procedures used for water analysis in this study are described in detail in the 13th edition of Standard Methods for the Examination of Water and Wastewater (American Public Health Association, American Water Works

Association, and Water Pollution Control Federation 1970) (Standard Methods). Table 4 summarizes the particular method or equipment used for analysis where more than one was approved and also lists those parameters where selected methods were not included in Standard Methods or deviated from those methods. The procedural modifications for EDTA hardness, ammonia, and nitrite methods resulted from the use of autoanalysers (Technicon Corporation, Tarrytown, New York).

Water quality data gathered from the sampling sites are summarized in Appendix 4, noting the maximum, minimum, mean, standard deviation, and number of observations for each parameter. These data were examined further using Model I one-way analysis of variance techniques. Although analysis of variance indicated whether or not there were significant differences between stations for those parameters measured, a modified Duncan New Multiple-Range Test (Kramer 1956) was applied to these data to determine which stations were significantly different from the others. Further discussion of each physical and chemical parameter will not be included because application of this information to the available biological information would not result in any significant findings.

Table 4. Methods for physical and chemical parameters monitored in the Cache River basin, southern Illinois, between 19 December 1975 and 23 March 1977.

PARAMETERS	METHODS
Water Temperature (C)	Thermocouple Circuitry
Dissolved Oxygen	YSI Model 51A DO Meter
Dissolved Oxygen (% saturation)	By Calculation
Free Carbon Dioxide	Nomographic Method[1]
Hydrogen Ion Concentration (*p*H)	Sargent-Welch Model PBX *p*H Meter
Conductivity	YSI Model 33 S-C-T Conductivity Meter
Total Alkalinity (as $CaCO_3$)	Metrohm Autotitrator to *p*H 4.6[1]
Total Dissolved Ionizable Solids (as NaCl)	By Calculation from Specific Conductance Table
EDTA Hardness (as $CaCO_3$)	EDTA Colorimetric Method (Autoanalyser)
Turbidity (JTU)	Monitek Model 150 Turibidimeter
Total Phosphorus (as P)	Stannous Chloride Method[1]
Soluble Orthophosphate (as P)	Ascorbic Acid Method (Autoanalyser)[1]
Nitrate (as N)	Cadmium Reduction Method (Autoanalyser)[1]
Nitrite (asN)	Diazotization Method (Autoanalyser)
Ammonia (as N)	Berthelot Reaction Method (Autoanalyser)
Organic Nitrogen (as N)	Modified Berthelot Reaction Method (Autoanalyser)
Total Nitrogen (aa N)	Sum All Forms
Total Iron	Phenanthroline Method[1]
Ferrous Iron	Phenanthroline Method[1]
Sulfate (as S)	Turbidimetric Method[1]
Residue, Total	Constant Weight Upon Drying @ 180 C, unfiltered[1]
Residue, Dissolved	Constant Weight Upon Drying @ 180 C, filtered[1]
Residue, Particulate	By Difference
Molybdate-Reactive Silica (as SiO_2)	Molybdosilicate Method[1]
Chloride	Argentometric Method[1] with Metrohm Autotitrator
Flow (m^3 sec^{-1})	Small Price AA Direct Reading Current Meter
Heavy Metals	Flame Spectophotometer
Total Coliform	Selective Medium Plate Incubation[1]
Fecal Coliform	Selective Medium Plate Incubation[1]
Fecal Streptococcus	Selective Medium Plate Incubation[1]

[1]Standard Methods

RESULTS AND DISCUSSION

ANNELID SYSTEMATICS

Forty-two taxa of aquatic annelids were collected from the upper Cache River drainage, including sixteen taxa of Naididae, twenty-two taxa of Tubificidae, and representatives of the families Aeolosomatidae, Branchiobdellidae, Enchytraeidae, and Lumbriculidae (Table 5).

AEOLOSOMATIDAE

Members of this family are often overlooked because of their extremely small size (0.5 to 3.5 mm). Only one specimen of *Aeolosoma* was collected during this study, probably *A. hemprichi* Ehrenberg. Species within this family are extremely delicate, demanding the utmost care in collecting, observation, and permanent retention. I suggest that material believed to contain aeolosomatids should be returned to the laboratory as quickly as possible, unfixed, so as to observe live specimens under a dissecting microscope for further diagnosis. I should note here that the single specimen collected was inadvertently destroyed during permanent mounting. Field fixation will almost always result in lysed specimens, useless for diagnosis.

Aeolosomatid distribution is generally limited by oxygen deprivation and lack of suitable organic substrate for feeding. In lentic habitats, members of the genus *Aeolosoma* are most commonly found grazing on detritus-covered macrophytes and substrate areas. Aeolosomatids are also collected frequently in slow-flowing streams which pass through woodlands. Fast-flowing streams and rivers cannot

Table 5. Checklist of aquatic Oligochaeta collected from the Cache River basin, southern Illinois, during 1976.

AEOLOSOMATIDAE
Aeolosoma hemprichi Ehrenberg

BRANCHIOBDELLIDAE
Cambarincola Ellis

ENCHYTRAEIDAE

LUMBRICULIDAE

NAIDIDAE
Amphichaeta Tauber
Chaetogaster Von Baer
Dero Oken
Dero (Dero) digitata (Müller)
Nais Müller
Nais communis Piguet
Nais pardalis Piguet
Nais simplex Piguet
Nais variabilis Piguet
Paranais frici Hrabě
Pristina Ehrenberg
Pristina idrensis Sperber
Pristina leidyi Smith
Slavina appendiculata (d'Udekem)
Stylaria lacustris (Linnaeus)

TUBIFICIDAE
Aulodrilus Bretscher
Aulodrilus pigueti Kowalewski
Branchiura sowerbyi Beddard
Ilyodrilus templetoni (Southern)
Limnodrilus Claparède
Limnodrilus sp. *A*
Limnodrilus new species
Limnodrilus angustipenis Brinkhurst & Cook
Limnodrilus cervix Brinkhurst
Limnodrilus claparedeianus Ratzel
Limnodrilus clap.- cerv. complex
Limnodrilus hoffmeisteri Claparède
Limnodrilus hoffmeisteri variant
Limnodrilus maumeensis Brinkhurst & Cook
Limnodrilus profundicola (Verrill)
Limnodrilus psammophilus Loden
Limnodrilus rubripenis Loden
Limnodrilus udekemianus Claparède
Peloscolex Leidy
Peloscolex multisetosus (Smith)
Psammoryctides (Spencerius) californianus Brinkhurst
Tubifex kessleri americanus Brinkhurst & Cook

support populations of these annelids because of the grinding action of currents and waves. However, backwater areas and shallow mudflats along waterways could provide suitable habitats for this group (Singer 1977). Singer (1977) discusses the biology of *Aeolosoma* thoroughly, with discussion and reassignment of its phylogenetic position in the Subclass Oligochaeta, Order Aeolosomatida.

BRANCHIOBDELLIDAE

Branchiobdellids compose a monotypic order, Branchiobdellida (Holt 1965) of annelid worms, consisting of 17 recognized genera and 120 nominal species, of which 14 and 90, respectively, occur in North America. These worms are known as epizoites, or commensal "parasites" on freshwater Holarctic crustaceans, primarily the astacoidean crayfishes. Other minor hosts include a freshwater crab (Hobbs and Villalobos 1958), freshwater shrimp (Liang 1963), cave isopods (Holt 1963, 1973*a*), the gill chambers of the marine crab *Callinectes sapidus* Rathbun (Blackford 1966), and the freshwater snail *Physa* sp. (Robt. Singer, pers. comm.).

Since these annelids are epizoites on crustaceans, their water quality requirements are reflected at least in those of the host species. Holt (1974) suggested that branchiobdellids are extremely intolerant to some inorganic pollutants such as coal-mine effluents and sulfates. Blackford (1966) demonstrated the tolerance of these worms to low oxygen concentrations, suggesting the possibility that they are facultative anaerobes.

A generic key is provided by Holt (1978). Specific identification

usually requires dissection and/or sectioning. At least one species in the genus *Cambarincola* occurs in the upper Cache River drainage. Too few specimens of this genus were collected to justify further diagnosis at this time.

ENCHYTRAEIDAE

The current taxonomic knowledge of this family in North America is insufficient for species identifications (Hiltunen 1967, (Howmiller 1974*c*, Cook 1975, and Maciorowski, *et al.* 1977). Howmiller (1974*c*) reviewed the major Great Lakes research reports concerning oligochaetes. The most common taxon of the enchytraeids seemed to be the genus *Lumbricillus*. One other specimen collected from Lake Michigan appears to be of the *Henlea-Enchytraeus* group. Since the majority of the known enchytraeids are thought to be terrestrial, the possibility exists that some of these same species may also tolerate highly organically enriched water systems in the presence of marginal dissolved oxygen. Currently, two of R.O. Brinkhurst's students and two of W. J. Harman's former students are working with this family. It is hoped that their research will clarify some of the questions heretofore left unanswered.

HAPLOTAXIDAE

Two species in this family are known to occur in North America: *Haplotaxis gordioides* (Hartmann), and *H. brinkhursti* Cook. Only *H. gordioides* is thought likely to occur in the upper Cache River drainage. This species is known to be primarily an inhabitant of ground waters, springs and wells. Subterranean sources of water

entering the open waters of this study area may account for its presence. No specimens were collected during this study. This species has never been collected in its sexually mature state.

LUMBRICIDAE

This family of oligochaetes is almost entirely terrestrial, although two species are known to occur in aquatic and semi-aquatic habitats: *Eiseniella tetraedra* (Savigny), occurring in mountain streams and stream reaches which are polluted or have soft substrates (Wachs 1967; Ward 1976; Ward and Short 1978), and *Eisenia foetida* Savigny, often collected from highly organically enriched substrates, as well as among leaf packets in enriched streams and rivers. Neither species was collected during this study, although both are thought likely to occur here.

LUMBRICULIDAE

Seven genera and fifteen species of lumbriculids are known to occur in North America. Species identification of sexually mature lumbriculids is possible. However, prior fixation and preservation, and the absence of sexually mature individuals prevented identification beyond family. *Lumbriculus variegatus* (Müller) would probably be the dominant lumbriculid within this river system. The restriction of this species to littoral hibitats (Brinkhurst and Jamieson 1971) and its previous collection from other lotic habitats suggest that it may be more widespread than is presently known. This species probably does not tolerate highly eutrophic conditions, but probably can be found occasionally in waters of good to high quality.

NAIDIDAE

Twenty-one genera and sixty-two species of naidids are known to occur in North America. Eight of these genera and at least thirteen of these species were collected during this study. Another naidid, *Haemonais waldvogeli* Bretscher, was collected from Mermet Lake, a natural area adjacent to the Main Ditch of the Cache River (station 10). This represents a new record for Illinois.

External morphological features, such as presence or absence of probosces, eyes and gills, as well as number, type and arrangement of setae were the characters used for naidid identification. Loden and Harman (1980) discussed chaetotaxy and the problems encountered when setae are the primary characters used in identification. Improper or inconsistent fixation of North American *Dero* species often render them indistinguishable from each other, particularly if some setae may be lacking or poorly oriented. *Nais communis* Piguet and *N. variabilis* Piguet can often be confused when poorly mounted. *Nais pardalis* Piguet, *N. bretscheri* (Michaelsen) and *N. variabilis* often have subtle differences among their setae.

Loden and Harman (1980) also discuss ecophenotypic variation of species populations in relation to setal variation, suggesting synonomy for two previously recognized species, *Pristina aequiseta* Bourne and *P. foreli* (Piguet). Specimens identified as Naididae or *Nais* sp. consisted of individuals lacking clarity due to factors such as presence of silt-sand tube, numerous incomplete setal bundles, or poorly oriented setae. Four species in the genus *Nais* were collected

during this study: *N. communis, N. pardalis, N. simplex* Piguet, and *N. variabilis*.

Elements of the branchial fossa are used to distinguish species within the genus *Dero*. However, these structures are naturally contractile, with fixation techniques often causing contraction at death.

Individuals identified as *Dero* sp. possessed definite gills as those in the genus, but lacked enough clarity in some characters to take them past generic identification, usually the result of poor orientation on the slide. Only one species in this genus was collected during this study: *Dero (Dero) digitata* (Müller).

A few specimens were collected which closely fit the description of *Amphichaeta* Tauber, a poorly known genus in North America. These were left at the generic level, although Hiltunen and Klemm (1980) provided new information on the occurrence of 2 species, *A. americana* Chen and *A. leydigi* Tauber in North America.

At least two species of *Chaetogaster* were recognized. I do not feel confident enough at this time to take these taxa past the generic level, as precise descriptions are heavily weighted towards lengths and widths.

Individuals identified as *Pristina* sp. lacked clarity and/or characters necessary for species level identification. Two species in this genus were collected during this study: *Pristina idrensis* Sperber and *P. leidyi* Smith.

Three other naidids were collected during this study: *Paranais*

fričí Hrabě, *Slavina appendiculata* (d'Udekem), and *Stylaria lacustris* (Linnaeus).

OPISTOCYSTIDAE

Harman (1969) and Harman and Loden (1978*a*) review and reevaluate this family. Only one species, *Crustipellis tribranchiata* (Harman), occurs in North American (Louisiana, Mexico: Veracruz, Florida, Mississippi, and North Carolina). This species was not collected during this inventory.

SPARGANOPHILIDAE

The Nearctic family Sparganophilidae Michaelsen is monogeneric (*Sparganophilus* Benham). While this genus is generally considered to be aquatic, limicolous is a more habitat-specific descriptor. Distributional data to date suggest that all species in this genus are confined to wet soil or muck at the edges of ponds, lakes, rivers and streams, although they have been collected on occasion from profundal silt-mud substrates.

Reynolds (1980) reviewed the occurrence of this family in North America, describing six new species, two new subspecies, and seven previously known species. Only one species, *Sparganophilus eiseni* Smith is known to occur in Illinois. This is the only species to date which has been recorded from glaciated areas of North America. The distributional range of *S. eiseni* extends from Guatemala northward into southern Ontario. Most records are east of the Mississippi River, with several records noted in central Illinois. No specimens of this species were collected during this study, although its occurrence in

southern Illinois is likely. None of the other species are thought likely to occur in Illinois. *Sparganophilus tamesis* Benham was reported from Lake Michigan (Howmiller 1974*c*), Mexico, St. Mary's River and Ontario (Brinkhurst and Jamieson 1971) although these identifications were questioned by Reynolds (1980).

TUBIFICIDAE

Fourteen genera and fifty-eight species of this family are known to occur in North America. Seven genera and fifteen known species were collected during this study.

The somatic setae and morphology of the male genitalia were the primary structures used for species identifications. Those specimens identified to the generic level lacked enough characteristics for species level identification. The species *Aulodrilus pigueti* Kowalewski, *Branchiura sowerbyi* Beddard, and *Peloscolex multisetosus* (Smith) were identifiable regardless of sexual maturity. Other species in the family Tubificidae collected during this study include: *Ilyodrilus templetoni* (Southern), *Limnodrilus angustipenis* Brinkhurst and Cook, *L. cervix* Brinkhurst, *L. claparedeianus* Ratzel, *L. hoffmeisteri* Claparède, *L. maumeensis* Brinkhurst and Cook, *L. profundicola* (Verrill), *L. psammophilus* Loden, *L. rubripenis* Loden, *L. udekemianus* Claparède, *Psammoryctides (Spencerius) californianus* Brinkhurst, and *Tubifex kessleri americanus* Brinkhurst and Cook. These species are identifiable only in the sexually mature state. Immature tubificids were divided into two groups: (A) unidentifiable immature with capilliform setae (UW/CS), or (B) unidentifiable immature without capilliform setae (UIW/OCS).

Limnodrilus represents the largest and perhaps most complex and controversial genus in this family. Those specimens collected during this study and identified as *Limnodrilus* sp. possessed at least part of a penis sheath. Most often, the observed character was either underdeveloped, or partially obscured by gut content.

Numerous specimens of *Limnodrilus* collected during this study possessed atypical penis sheaths. This phenomenon has been observed in most of the collections I have made. Several other authors (Brinkhurst 1965*a*, 1975,1976; Hiltunen 1967, 1969*a*, 1969*b*, 1969*c*, 1973; Kennedy 1969*b*; Howmiller and Beeton 1970; Brinkhurst and Jamieson 1971; Cook and Johnson 1974; Howmiller 1974*a*; Stimpson, *et al.* 1975; Howmiller and Loden 1976; Loden 1977; Maciorowski, *et al.* 1977; Barbour, *et al.* 1979; Spencer 1980; and Whitley 1981) have noted this occurrence in their research, although the morphological and systematic explanations for these variations are still unclear.

The most common variation appears to be an intermediate between *L. claparedeianus* and *L. cervix*. I refer to this as the *L. clap. - cerv.* complex. I have also seen variation from true form within each of these two species. I refer to these as *L. claparedeianus* variant or *L. cervix* variant when observed; however none were collected during this study. Many variants of *L. hoffmeisteri* occur. These are referred to as *L. hoffmeisteri* variant. At least one species new to science was collected during this study. It is referred to herein as *Limnodrilus* new species. Noteworthy characteristics which distinguish this species from others in the genus *Limnodrilus* are the lengths and the length to width ratios of the penes. The penes are significantly longer, with

significantly greater length to width ratios than any other members of this genus. A more complete description of this species will be published at a later date.

The status of another species of *Limnodrilus* collected during this study, referred to here as *Limnodrilus* sp. *A*, is questionable. It is perhaps a variant of another known species, but is not near any of the other species or their variants collected during this study. I have collected this variant from other Illinois habitats. Wetzel (1981) will note the occurrence of *L. rubripenis* in Illinois, collected during this study for the first time outside its type locality. Another species, *L. psammophilus,* was collected during this study, again for the first time in Illinois. The exact status of *L. psammophilus* is currently being investigated. The one specimen of *Limnodrilus udekemianus* identified for this study was sexually mature. However, Kennedy (1969*b*) and others maintain that the distinctive setae of this species separates it from all other members of the genus, allowing accurate identification in the immature state.

Two subspecies of *Peloscolex multisetosus* (Smith) have been described: *Peloscolex multisetosus typica* Brinkhurst and Cook, and *P. multisetosus longidentus* Brinkhurst and Cook. Recently, Loden and Dugas (1978) noted the presence of both of these subspecies in the same locality of Louisiana. They suggested that, since the International Code of Zoological Nomenclature (in article 45 (d) (ii)) requires that there be a geographical area characteristic of each subspecies, the presence of these two supposedly valid subspecies in the same location prevents the application of the Code to these two entities, invalidat-

ing them as subspecies. I have adopted this interpretation and conclusion for my systematic work. Only specimens resembling *P. m. typica* were collected during this study. This species will hence be referred to in this study simply as *P. multisetosus*.

Three specimens of *Psammoryctides (Spencerius) californianus* were collected during this study. This represents the first time this species has been taken from Illinois waters. It was previously known to occur only in California (type locality: Coyote Creek, Santa Clara County), Canada (Airport Creek, Saanich Peninsula, British Columbia), New York (Cayuga Lake), and Michigan (Black River, St. Claire County) (Wetzel 1980).

One other tubificid, *Tubifex kessleri americanus*, was also collected during this study, although very infrequently.

DISTRIBUTION AND RELATIVE ABUNDANCE

A total of 1,129 oligochaetes were collected from 17 different localities on four separate occasions. Tables 6 through 9 list the species between February and October 1976, and their abundance by station and date.

An additional collection of oligochaetes was made on 29 January 1976 when seven additional sampling sites were being chosen (Table 10). In addition, collections were made at stations 2 and 4 on this date. A total of 297 additional oligochaetes were collected from these sites. No water quality parameters were monitored during the 29 January 1976 collection. Of these nine sites collected on this date, oligochaetes were taken from only four.

Table 6. Total number of oligochaetes (by taxon) collected from the Cache River basin, southern Illinois, on 27 through 29 February 1976.

TAXON	STATION[1] 1	3	4	5	7	8
BRANCHIOBDELLIDAE						
Cambarincola sp.	-	-	-	-	-	-
ENCHYTRAEIDAE	-	1	-	2	-	2
LUMBRICULIDAE	-	1	2	1	1	-
NAIDIDAE	2	-	-	-	-	8
Dero (Dero) digitata	-	-	-	-	-	-
Nais sp.	-	-	-	-	-	9
Nais pardalis	-	-	-	-	-	16
Nais simplex	-	-	-	-	-	2
Nais variabilis	-	-	-	-	-	2
Pristina leidyi	-	-	-	-	-	-
Stylaria lacustris	-	-	-	-	-	-
TUBIFICIDAE						
Aulodrilus pigueti	-	-	-	-	-	-
Branchiura sowerbyi	-	-	-	-	1	-
Limnodrilus spp.	-	2	-	1	2	-
Limnodrilus sp. *A*	-	-	-	-	1	-
Limnodrilus new species	-	-	-	-	1	-
Limnodrilus angustipenis	-	1	-	3	3	1
Limnodrilus cervix	-	-	-	3	-	-
Limnodrilus claparedeianus	-	2	-	3	-	-
Limnodrilus hoffmeisteri	6	42	1	8	4	-
Limnodrilus hoffmeisteri variant	-	1	1	1	3	-
Limnodrilus maumeensis	-	-	1	-	-	-
Limnodrilus psammophilus	-	-	-	-	-	-
Limnodrilus rubripenis	-	-	-	2	2	-
Peloscolex sp.	-	1	-	-	-	-
Peloscolex multisetosus	-	-	-	-	1	-
Tubifex kessleri americanus	-	4	-	3	6	-
UIW/OCS	-	8	-	28	4	1
UW/CS	-	1	-	12	1	-
Total by station	8	64	5	67	30	41
Species diversity ($\bar{d}$)	0.81	1.45	1.92	3.01	3.16	2.26

concluded on the next page

[1]Samples also were obtained from stations 2, 6, 9, 13, and 17 but did not contain oligochaetes.

Table 6 (concluded). Total number of oligochaetes (by taxon) collected from the Cache River basin, southern Illinois, on 27 through 29 February 1976.

TAXON	STATION[1] 10	11	12	14	15	17
BRANCHIOBDELLIDAE						
Cambarincola sp.	-	-	9	-	1	-
ENCHYTRAEIDAE	1	1	-	-	-	7
LUMBRICULIDAE	-	-	-	-	-	1
NAIDIDAE	-	-	-	-	1	1
Dero (Dero) digitata	-	-	-	1	-	1
Nais sp.	-	-	-	-	-	4
Nais pardalis	-	-	-	-	-	-
Nais simplex	-	-	-	-	-	-
Nais variabilis	-	-	-	-	-	-
Pristina leidyi	-	-	-	-	-	1
Stylaria lacustris	-	-	-	-	1	-
TUBIFICIDAE						
Aulodrilus pigueti	-	-	-	-	1	-
Branchiura sowerbyi	-	-	-	-	-	-
Limnodrilus sp.	-	-	-	-	-	-
Limnodrilus sp. *A*	-	-	-	-	-	-
Limnodrilus new species	-	-	-	-	-	-
Limnodrilus angustipenis	-	-	-	-	-	-
Limnodrilus cervix	-	-	-	-	-	-
Limnodrilus claparedeianus	-	-	-	6	-	-
Limnodrilus hoffmeisteri	-	-	-	2	-	1
Limnodrilus hoffmeisteri variant	-	-	-	-	-	1
Limnodrilus maumeensis	-	-	-	-	-	-
Limnodrilus psammophilus	-	-	-	-	-	1
Limnodrilus rubripenis	-	-	-	-	-	-
Peloscolex sp.	-	-	-	-	-	-
Peloscolex multisetosus	2	-	-	-	-	-
Tubifex kessleri americanus	-	-	-	4	-	-
UIW/OCS	6	-	-	5	-	11
UW/CS	-	1	-	11	-	1
Total by station	9	2	9	29	4	30
Species diversity ($\bar{d}$)	0.92	0	0	1.74	1.99	2.63

[1]Samples also were obtained from stations 2, 6, 9, 13, and 17 but did not contain oligochaetes.

Table 7. Total number of oligochaetes (by taxon) collected from the Cache River basin, southern Illinois, on 29 and 30 April 1976.

TAXON	STATION[1] 7	9	10	13	17
ENCHYTRAEIDAE	2	-	-	-	-
LUMBRICULIDAE	-	2	2	-	-
NAIDIDAE	11	-	-	-	3
Amphichaeta sp.	2	-	-	-	-
Chaetogaster sp.	4	-	-	-	-
Dero (Dero) digitata	8	-	-	-	5
Nais sp.	5	-	1	-	-
Nais pardalis	70	-	1	-	-
Nais simplex	2	-	-	-	-
Pristina leidyi	1	-	-	-	-
Slavina appendiculata	1	-	-	-	-
TUBIFICIDAE					
Ilyodrilus templetoni	1	-	-	-	-
Limnodrilus sp.	-	-	3	1	-
Limnodrilus angustipenis	2	-	3	-	-
Limnodrilus hoffmeisteri	2	-	2	4	-
Limnodrilus hoffmeisteri variant	-	-	3	1	-
Limnodrilus maumeensis	-	-	-	1	-
Peloscolex multisetosus	1	-	2	-	-
UIW/OCS	6	-	16	25	1
UW/CS	3	1	-	-	-
Total by station	121	3	33	32	9
Species diversity ($\bar{d}$)	2.16	0	2.90	1.66	0.96

[1]Samples also were obtained from stations 1, 2, 3, 4, 5, 6, 8, 11, 12, 14, 15, and 16 but did not contain oligochaetes.

Table 8. Total number of oligochaetes (by taxon) collected from the Cache River basin, southern Illinois, on 21 and 22 June 1976.

TAXON	STATION[1] 9	10	11	16
ENCHYTRAEIDAE	-	-	-	1
NAIDIDAE	-	-	1	2
Chaetogaster sp.	-	-	33	-
Nais sp.	-	-	2	-
Nais communis	-	1	2	-
Nais pardalis	1	-	13	-
Nais simplex	-	-	1	-
Pristina idrensis	-	-	2	-
Pristina leidyi	-	-	23	-
Stylaria lacustris	1	-	-	-
TUBIFICIDAE				
Branchiura sowerbyi	-	1	-	-
UIW/OCS	-	1	-	4
UW/CS	1	-	-	2
Total by station	3	3	77	9
Species diversity ($\bar{d}$)	0.99	0.99	2.05	0.92

[1]Samples also were obtained from stations 1, 2, 3, 4, 5, 6, 7, 8, 12, 13, 14, 15, and 17 but did not contain oligochaetes.

Table 9. Total number of oligochaetes (by taxon) collected from the Cache River basin, southern Illinois, on 29 September through 1 October 1976.

TAXON	STATION[1] 1	2	4	5	7	9
ENCHYTRAEIDAE	-	-	-	-	1	-
NAIDIDAE	1	1	8	5	64	14
Chaetogaster sp.	1	2	1	-	-	-
Dero sp.	-	1	-	5	12	6
Dero (Dero) digitata	-	1	5	21	80	14
Nais sp.	-	1	1	-	4	-
Nais communis	-	-	-	-	-	-
Nais pardalis	-	-	2	-	1	-
Nais simplex	-	-	-	-	-	-
Nais variabilis	-	-	-	-	-	-
Paranais frici	-	-	-	-	-	-
Pristina sp.	-	1	-	-	-	4
Pristina idrensis	1	3	-	-	-	-
Pristina leidyi	3	-	3	-	-	-
Stylaria lacustris	1	4	-	-	-	2
TUBIFICIDAE						
Aulodrilus sp.	1	1	-	-	15	1
Aulodrilus pigueti	1	-	-	1	40	-
Branchiura sowerbyi	-	-	-	-	-	18
Ilyodrilus templetoni	-	-	-	-	1	-
Peloscolex multisetosus	-	-	-	-	2	8
UIW/OCS	-	-	-	-	2	-
UW/CS	-	-	-	1	5	2
Total by station	11	15	20	33	227	69
Species diversity ($\bar{d}$)	2.64	2.92	2.20	1.39	2.26	2.62

concluded on the next page

[1]Samples also were obtained from stations 3, 6, 8, 16, and 17 but did not contain oligochaetes.

Table 9 (concluded). Total number of oligochaetes (by taxon) collected from the Cache River basin, southern Illinois, on 29 September through 1 October 1976.

TAXON	STATION[1] 10	11	12	13	14	15
ENCHYTRAEIDAE	-	-	-	-	-	-
NAIDIDAE	5	8	1	1	-	5
Chaetogaster sp.	1	-	1	-	-	1
Dero sp.	2	-	-	-	-	2
Dero (Dero) digitata	6	-	-	-	-	21
Nais sp.	4	4	-	-	-	-
Nais communis	2	3	-	-	-	-
Nais pardalis	1	2	2	-	-	-
Nais simplex	-	2	-	-	-	-
Nais variabilis	-	2	-	-	-	-
Paranais frici	1	-	-	-	-	-
Pristina sp.	-	3	-	-	-	-
Pristina idrensis	4	13	-	-	-	-
Pristina leidyi	6	6	2	-	-	3
Stylaria lacustris	5	1	-	-	-	1
TUBIFICIDAE						
Aulodrilus sp.	-	-	-	-	-	-
Aulodrilus pigueti	14	-	-	-	-	2
Branchiura sowerbyi	1	-	-	-	-	-
Ilyodrilus templetoni	-	-	-	-	-	-
Peloscolex multisetosus	-	-	-	-	-	-
UIW/OCS	-	25	-	-	1	1
UW/CS	2	-	-	-	1	1
Total by station	54	69	6	1	2	37
Species diversity ($\bar{d}$)	3.25	2.93	1.92	0	-	1.91

[1]Samples also were obtained from stations 3, 6, 8, 16, and 17 but did not contain oligochaetes.

Table 10. Total number of oligochaetes (by taxon) collected from the Cache River basin, southern Illinois, on 29 January 1976.

TAXON	STATION[1] 2	4	12	15
ENCHYTRAEIDAE	-	-	-	4
LUMBRICULIDAE	-	-	-	1
NAIDIDAE	-	-	-	1
Nais communis	-	-	-	3
TUBIFICIDAE				
Limnodrilus sp.	-	6	1	4
Limnodrilus sp. *A*	-	1	-	4
Limnodrilus angustipenis	-	7	-	1
Limnodrilus cervix	-	-	-	4
Limnodrilus claparedeianus	2	-	-	27
Limnodrilus clap. - cerv. complex	-	-	-	1
Limnodrilus hoffmeisteri	5	12	5	26
Limnodrilus hoffmeisteri variant	1	-	-	3
Limnodrilus profundicola		4	-	15
Limnodrilus psammophilus	-	5	-	-
Limnodrilus rubripenis	-	-	2	-
Limnodrilus udekemianus	-	-	1	1
Psammoryctides californianus	-	1	1	-
UIW/OCS	3	21	20	102
UW/CS	-	-	1	1
Total by station	11	57	31	198
Species diversity ($\bar{d}$)	1.30	2.45	1.96	2.88

[1]Samples also were obtained from stations 11, 13, 14, 16, and 17 but did not contain oligochaetes.

By studying Tables 6 through 10, the reader can see that although oligochaetes were taken from all locations (except Sta. 6) on at least one occasion during the four or five sampling periods, they were not taken from each location on each sampling date. The reader will also note that while the number of taxa (42) collected from the study area during the entire period is substantial when compared to other faunal studies, the greatest number of taxa collected from any one station (16: January and April, 1976) or from all stations on any one date (26: February 1976) is significantly less. I suggest two reasons for this: (1) species not collected each date, but collected on one or more dates did, in fact, occur at all locations continuously throughout the study but were not collected for one or more reasons such as poor or inconsistent sampling effort, increased inter- and/or intra-specific competition resulting in widely dispersed or disjunct distributions, or reduction of preferred substrate; or (2) those species did not occur at each location on each sampling date because of lack of suitable or preferred substrate, water quality changes, or disjunct life cycles.

No oligochaetes were collected from station 6 on any of the sampling dates. This station is located in the Cache River, where the river is 12 m wide and 1 to 1.4 m deep. The banks are almost vertical, complicating collecting and limiting habitats and vegetation. The substrate is a mixture of mud, clay and sand. No explanation can be given for the absence of oligochaetes at this location during these collections. Another Survey employee, in conjunction with a study of his own in the Cache River basin, placed substrate samplers at this location. Two sets of samplers were placed for approximately six

weeks. The first set, retrieved on 24 May 1976, yielded seven taxa of oligochaetes: Naididae, *D. digitata, Nais* sp., *Aulodrilus* sp., *B. sowerbyi, I. templetoni, and L. maumeensis*. The second set, retrieved 16 October 1976, yielded five taxa: Naididae, *Dero* sp., *D. digitata, N. variabilis,* and *B. sowerbyi*. This information might suggest that this station lacked suitable habitats for oligochaetes but I must reject that suposition as too little data is presently available.

ANALYSES OF DATA

Data were obtained from all stations during the period February through October 1976. An additional set of collections, taken on 29 January 1976, was obtained from stations 2, 4, 11, 12, 13, 14, 15, 16, and 17. Rather than disregarding these additional data, two sets of analyses were performed, one set based upon data obtained from January through October 1976 from the nine stations listed above and one set based upon data obtained from February through October 1976 from all stations.

Three mathematical techniques for data analysis were to be applied: the index of similarity (Jaccard 1908); the species diversity index (Shannon and Weaver 1949); and the heterogeneity index (Margalef 1958). While the categories "UIW/OCS" and "UW/CS" are included in Tables 6 through 10, they are not considered true taxonomic entities and hence are not included in any of the following analyses (see systematics section for further explanation). Collections yielding only a single individual or taxon were exluded, as these would not permit calculation of the indices.

Index of Similarity. Data were examined for patterns of similarity in the distribution of species among the various sampling stations. Several coefficients of similarity exist, but for my purpose, it was essential that the coefficient employ presence-absence data while omitting from consideration mutual absences of species from stations. Negative matches must be omitted from consideration because without this criterion, two stations would be considered similar to each other because of all the species absent from both of them. The Jaccard coefficient of similarity (Jaccard 1908) appears to be a suitable data treatment. The probability of observing any one species remains constant for all pairs, while everywhere an item is present contributes to the probability of the item. Jaccard coefficients were computed from two-by-two contingency tables of the cross-products of the probability of each item occurring individually. The following is an example of the calculation of a modified Jaccard coefficient of similarity where the index is

$$J'_{ij} = P_i \cdot P_j$$

sample data are

Abundance of Species

Station	a	b	c	d	e	f	g
i	0	3	60	2	1	0	3
j	1	5	0	1	0	0	6

and the contingency table becomes

		j	
		Present	Absent
i	Present	20	61
	Absent	1	0

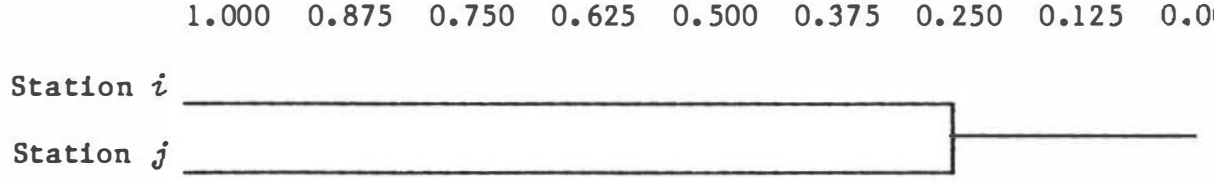
where

$$P_i = (81 \div 82) = 0.99;\ P_j = (21 \div 82) = 0.26;$$

and

$$J'_{ij} = (0.99) \cdot (0.26) = 0.25.$$

The Jaccard coefficient varies from 0 to 1, with data sets with an index value greater than 0.5 being more similar than different, and data set values less than 0.5 being more different than similar. Clustering of Jaccard coefficients was determined by computing unweighted averages for each station. Interpretations of the cluster analyses were enhanced by displaying the results in dendrograms. A dendrogram is a graph of clusters obtained in the analysis. The hierarchy of clusters is displayed as connected elements of a tree diagram. The strength of the similarity of items in a cluster is shown by the proximity of the branching of the dendrogram to the left margin (index = 1.0). The results of the example given above would be mapped out as:

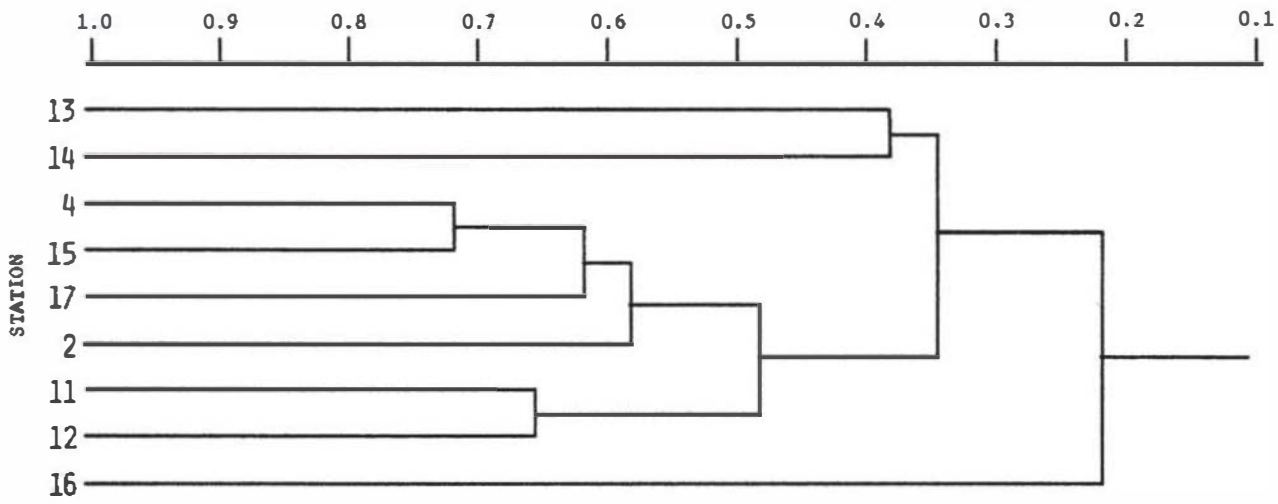


January through October 1976 Collections: Figure 2 illustrates the dendrogram generated from numbers and species of oligochaetes collected from stations 2, 4, 11, 12, 13, 14, 15, 16, and 17. The first major branch of the dendrogram indicates that station 16 differs substantially from the rest. Only three specimens were collected from this station during the entire project, all in June 1976. This station was located in a 1 m pool on a shallow (10 cm mean depth) stream. The stream was dry during the September collection, with the pool reduced to 20 cm in depth. The lack of data eliminates this station from further discussion.

The second major branch indicates that stations 13 and 14 are dissimilar to each other and dissimilar to the rest of the stations. Very few specimens were collected from these two stations, with station 13 reporting 8 specimens (total) on two sampling dates, and station 14 reporting 12 specimens collected on only one sampling date. Again, the dearth of specimens precludes further discussion.

The third major branch indicates that stations 11 and 12 are relatively similar to each other, while the remaining stations are more similar to each other than to 11 and 12. Station 11 is an unnamed tributary of station 12, located approximately 1.6 nautical kilometers and 6.5 stream kilometers from each other. Station 11 reports 8 exclusive taxa and station 12 reports 6 exclusive taxa; 4 taxa are common to both stations. The remaining four stations (2, 4, 15, and 17) generally share a common oligochaete fauna.

Figure 2. Dendrogram illustrating results of cluster analysis for aquatic Oligochaeta collected at stations 2, 4, 11, 12, 13, 14, 15, 16, and 17 in the Cache River basin, southern Illinois, during 1976.

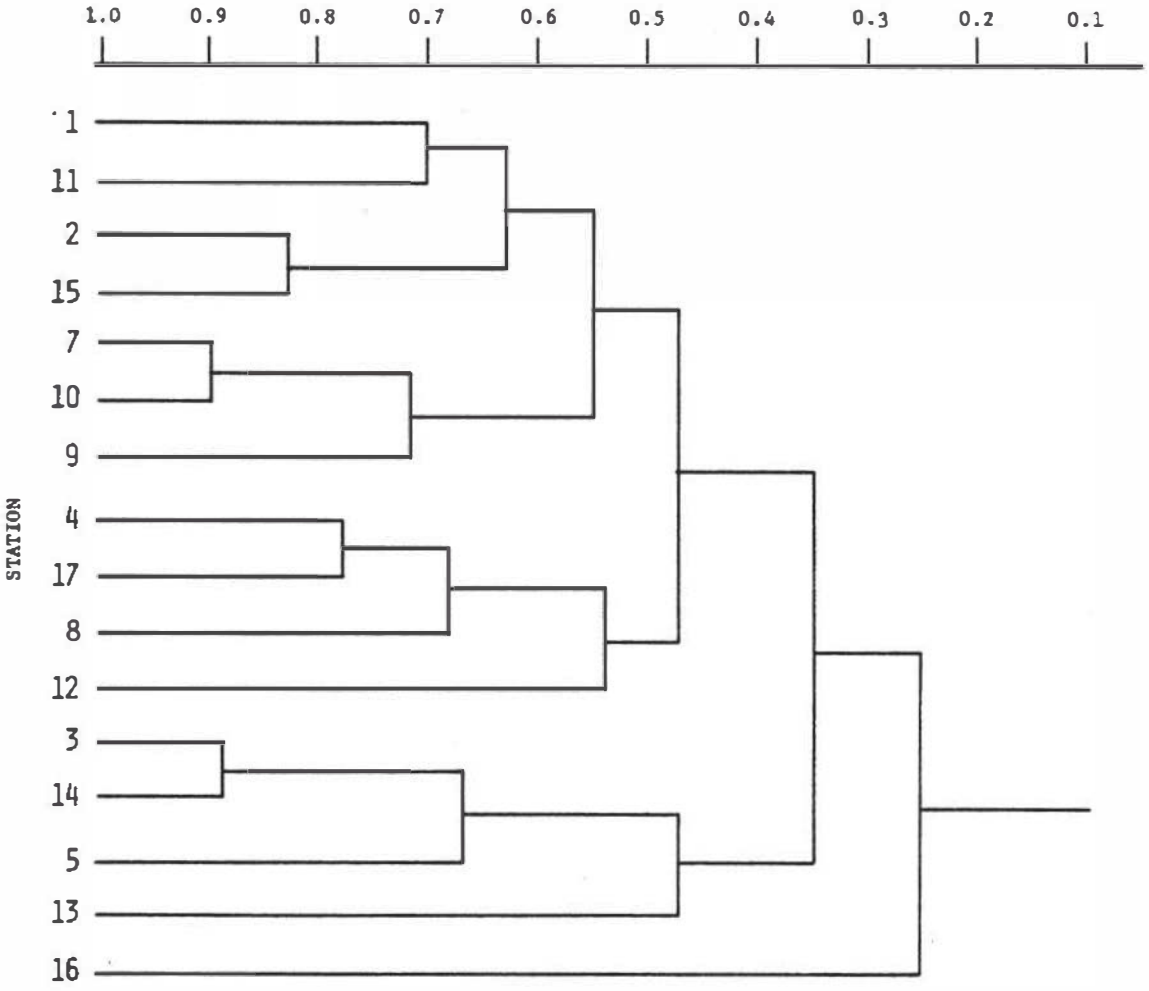


February through October, 1976 collections: Figure 3 illustrates the dendrogram generated from numbers and species of oligochaetes collected from stations 1 through 17. The first major branch again separates station 16 from all other stations for the reasons given previously. The second major branch separates four stations from the remaining stations. Of these four, station 13 is distinct from three other stations (5, 3, and 14). Station 13 is located on the Cache River, 4 km downstream from station 1, and 4 km upstream of station 4. Unfortunately, between June and September 1976, this station and indeed the river was moved approximately 60 m east of its natural location to facilitate construction of a new bridge over the river while concurrently channelizing approximately 0.7 km of river. The new station location was devoid of any available habitat other than a clay bottom channel. Station 13 will not be considered further in these analyses.

Of the three other stations (3, 14, and 5) included in the second major branch, station 3 and 14 are most similar, reporting nine and four taxa, respectively, with three taxa common to each. Station 5 is less similar to stations 3 and 14, and more diverse, reporting 14 taxa. Station 5 reported six taxa exclusive of, and four taxa in common with station 14.

The last major branch separates 4 sites (4, 17, 8, and 12) from the balance of the stations (1, 11, 2, 15, 7, 10, and 9). No apparent trends separate these two final branches. Stations 3, 5, 7, and 10 report taxa equally divided, generally, between the families Naididae and Tubificidae, yet each is included in a different major branch.

Figure 3. Dendrogram illustrating results of cluster analysis for aquatic Oligochaeta collected at stations 1 through 17 in the Cache River basin, southern Illinois, during 1976.



Most of the primary branches were produced by a station yielding only a few taxa or individuals, and these on only one or two dates. The rest of the clusters are difficult to explain. Perhaps inclusion of these sites masked any real similarities by introducing such data and thereby grouping all the rest of the stations together. There must be some level of information below which this index of similarity is inconclusive or even misleading.

Species Diversity and Heterogeneity. Use of species diversity and heterogeneity indices permit the summarization of large amounts of information about the numbers and kinds of organisms. These indices will only estimate the amount of information required to define community structure at a given location; they will not explain causal phenomena. These indices are generally considered valid ecological parameters, describing community structure and suggesting successional status.

Species diversity indices provide little if any new information about communities being examined. In fact, they are a process whereby much information is reduced to one number. Therefore, information is lost. The indiscriminate use of a diversity index, as an end unto itself rather than as an intermediate product within a larger set of analyses, will often result in a loss of information through summarization.

The diversity index of Shannon and Weaver (1949) provides information on the structure of the community being sampled, reflecting community composition through distribution of individuals among species. These indices assume that relatively undisturbed environments can support communities having large numbers of species where no one species is in

great abundance. Environments subjected to stress may show a reduction in diversity, with replacement of at least some species and/or an increase in the abundance of other species in response to competetive advantage of reduction in predation. However, most diversity indices can be biased when applied to extreme environments such as bedrock-bottomed high gradient streams or profundal areas of deep lakes (W. U. Brigham 1978).

Two components of species diversity, richness of species, and distribution of individuals among the species, are incorporated into this index. The value calculated for diversity of the habitat is relatively unaffected by
sample size variations or presence or absence of rare species in a population.

The Shannon and Weaver index is provided here:

$$D = \sum_{i=1}^{n} p_i \log_2 p_i$$

where p_i = fraction of individuals belonging to the $_i$th species

or

$$D = 3.3219(\log_{10} N - 1/N\ n_i \log_{10} n_i$$

where

N = total number of individuals, and

n_i = number of individuals of the $_i$th species.

The machine formula for this function is presented by Lloyd, Zar, and Karr (1968):

$$\bar{d} = C/N \; (N \log_{10} N - n_i \log_{10} n_i)$$

where

C = 3.3219828 (converting base 10 to base 2)

N = total number of individuals; and

n_i = total number of individuals in the ith species.

The species diversity ($\bar{d}$) for each collection is listed at the bottom of tables 6 through 10. Although the estimate of diversity increases with sample size, samples containing less than 100 specimens should be evaluated by this method with caution, if at all (Weber 1973*b*). While those mean diversities listed at the bottom of tables 6 through 10 are calculated only for individuals of actual taxa (excluding "UIW/OCS" and "UW/CS"), the total by station of individuals *includes* these categories. The total information used in calculating diversity is less than the table summaries would indicate. Since these calculations should be accepted with extreme caution as they are, no further suggestion as to the meaning of these diversities will be made. The calculation of heterogeneity according to Margalef (1958) will not be attempted as one additional generation of numbers is neither warranted nor justified.

Since the numbers of individuals collected from each station are less than that needed for application to quantitative methods of analysis, it was thought that application of the information to a semi-quantitative method of analysis, such as that of Kendeigh (1961),

might provide some conclusions. Kendeigh suggested that a basis for classifying species is exclusiveness or fidelity to the community. A species is exclusive when it occurs in only one area, habitat, or community. A characteristic species is one that is abundant in one area while occurring in small numbers elsewhere. A more or less equally distributed species (which is often a highly subjective conclusion) is considered ubiquitous. While exclusive species are usually inconsequential to the dynamics of a community, they are often considered as indicator species, used for identifying and recognizing community units.

But, as Kendeigh continued, how much more abundant must a species be before its preference (or dominance) over another species is indicated? Kendeigh cited three studies to illustrate this point. The first study involved breeding birds. A bird species was considered characteristic of a particular type of vegetation when it (the bird species) was at least three times more abundant in that vegetation than in any other type of vegetation when the density of the density of the bird population in the study area consisted of from 1 to 9 pairs. When populations of birds were in densities of 10 to 100 pairs, preference was considered demonstrated when the bird species was twice as abundant in one type of vegetation as in any other. Kendeigh suggested that stricter tests should be applied to small populations, since errors in the measurement of population size and random population fluctuations in response to other factors can produce disturbances in the data. Another experimental study which measured foliage insect populations suggested

that populations differing by a ratio of 3 to 1 could be accepted as statistically significant. A third study comparing the bottom fauna of two ponds suggested that true differences could be detected when the minimum ratios between their populations were 1.9:1.

When looking at the oligochaete data in tables 6 through 10, no single species seems to be consistently dominant. The two most common species, *Limnodrilus hoffmeisteri* and *Nais pardalis*, seem to be slightly more abundant more times and in more collections throughout the sampling period, but then these are two of the most cosmopolitan species found in Illinois, and indeed, at least for *L. hoffmeisteri*, in the world. So, as Kendeigh suggested, and as Malley and Reynolds (1979) discussed at length, the importance of life history of each species needs to be considered. Most discussions throughout the literature concerning benthic sampling strategies do not emphasize the life history aspect. The time and duration of a species in any community affects the amount of influence it exerts [presumably on other species] (Kendeigh 1961). Malley and Reynolds suggested that a pilot study be first instituted using two sampling techniques before a strategy is developed to adequately address the objectives. Funding and time limitations usually restrict this idealistic approach, but it is a concept that must be kept in mind.

After much discussion with various colleagues and consideration of other available diversity indices and methods of analysis, I concluded that no matter which analysis was applied, the available information from the sample sets was less than that needed for successful application to any of the available analyses.

While the number of individuals of any one taxonomic group collected from any given site may be too low for analysis by any biological index, the number of individuals for all taxonomic groups from an area will most likely provide acceptable conclusions when analyzed by these indices.

CONCLUSIONS

The vastness of the literature, as well as the information and critiques available in that literature, testifies to the value of biological surveillance in monitoring water quality. The conclusions of many papers conflict with those of others. Compromises are often proposed, and, in other cases, must be made. As these concepts of water quality analysis are applied to present and future work, experience will allow for the testing of controversial methods.

The purpose of water quality surveillance is to assess and safeguard biological communities, maintaining waters suitable for fishing, swimming, and drinking. Macroinvertebrate communities should receive preference when sampling programs are proposed. Quantitative as well as qualitative programs should be considered together, providing complementary information. Specific water quality criteria should be established for the more common aquatic macroinvertebrates, with greater attention focusing on those apparently highly sensitive species. Biomonitoring programs should assess what a pollutant does to a body of water, as well as what the body of water does to the pollutant.

It is sometimes apparent that many biologists are convinced that their favorite taxonomic group furnishes unique or self-supportive

information. A more objective overview would not arrive at this conclusion. Perhaps we should restrict the amount or diversity of data we feel necessary to obtain, while focusing on the specific problem at hand. Certain groups may have a greater diversity, or potential for diversity in one type of watershed than another. Economics, such as cost per unit of information, and redundancy or comparison of data, and the subsequent costs, are obviously important considerations. Whatever methods are used for the detection, measurement, and assessment of change should be objective.

Reice (1980) suggested that in streams, community level measurement such as species diversity may obscure insight, sometimes contradicting patterns at the population level due to the large influence of rare species on this measurement. Reice concluded that lotic invertebrates are generally distributed in species-specific patterns, with little insight gained from species diversity measures. Community level phenomena concerning the highly mobile fauna associated with lotic habitats should be interpreted as the transitory result of many individual population dynamics. Gleason (1926) first proposed this "individualistic" hypothesis of community structure. Although Gleason worked with terrestrial plant communities, the premise is basically the same. Component communities may exist in streams, but are very fluid. Structural factors controlling the system still need to be defined.

While I have primarily addressed water quality analysis from a biological point of view, water basin parameters should be included in those physical and chemical variables which are synthesized using

multivariate statistics. White (1975) used factor analysis to assess flood behavior, including drainage density, channel slope, shape factors and geometric factor as basin parameters. Her results suggested that watersheds may be clustered according to their basin and precipitation parameters.

Theoretical concepts in lotic ecology are far behind that of lentic systems. Many of the approaches towards aquatic system classification have been previously reviewed. However, not a single method of analysis has universal application. None of the proposed methods include physical, chemical, biological and productivity aspects together in a cooperative, or more importantly, four-dimensional, interacting concept. Cushing, *et al.* (1980) attempted to approach a theoretically applicable system of pattern analysis. This method involved the combination of both classification and ordination approaches of pattern analysis, analyzing 15 physical and chemical parameters by separating data gathered from 34 stations on 26 rivers into clusters. Cluster orientation was analysed relative to the physical and chemical variables. This new three dimentional structure and its mathematical derivation has been referred to as a "canonical analysis of discriminance". The conclusions drawn from the analyses suggested that watershed area, phosphate-phosphorus, total dissolved solids, solar radiation, annual precipitation, the ratio of channel length to watershed area, and terrestrial litter inputs were important in the initial segregation of streams. Of secondary importance were diurnal temperature fluctuation and nitrate-nitrogen content. Of lesser importance were summer base water flows. The authors suggested that

usefulness of different physical and chemical variables need further evaluation.

Relative biological variables still need to be added to this matrix. Lack of comparable data as well as critical evaluation of biological variables are problems which are currently being addressed by the authors, under the River Continuum Project (see Vannote, *et al.* 1980).

Temporal chemical analyses of selected sites are just that - temporal. Conversely, benthic communities respond to and integrate autotrophic as well as heterotrophic processes, and interruptions of these processes. Sessile animals are generally confined to those habitats which accumulate autochtonous and allochtonous material, so it is not surprising that we see oligochaetes are frequently used in water quality indices.

The concept of indicator species can generally be rejected, as inference neither can nor should be drawn from the absence or presence of a particular taxon at a particular site. Pollution is only one of the many "environmental" factors which may affect a taxon; life history data, taxonomic relationships of species, competition and reproductive requirements are not sufficiently known.

Community composition appears to offer a more reliable method for stress analysis. Proponents of diversity indices strongly imply evenness of distribution of individuals among taxa, while opposing the use of numbers of individuals or number of taxa. It is the interactions between the biotic and the abiotic components which result in the observed and presumed characteristic organism assemblages.

Hocutt (1975) rejected the theory that eveness of distribution occurs, even in healthy aquatic communities. Intrinsic as well as extrinsic factors to which I have previously referred (competition, predation, and climatological changes) will promote fluctuations of populations. Even in the absence of external stress in the ecosystem, the redundancy values of many macrobenthic collections may be high. Hocutt described healthy communities as those with the greatest number of both taxa and individuals. Diversity indices are influenced by the evenness with which individuals are distributed among taxa. Communities with a large number of individuals in a single taxon should not necessarily be considered less healthy than a community with few individuals representing many taxa. The rationale for this opinion can be supported by the interpretation that very clean streams are probably low in nutrients and unable to support large numbers of taxa or individuals. A moderate amount of nutrient input could actually enhance species diversity without eliminating previously existing taxa.

Natural ecosystems experience intrinsic changes, which can be grouped accordingly: (a) cyclical - such as "simple" predator-prey interactions, or intraspecific population density regulation; (b) successional - such as habitat modification; or (c) stochastic - such as responses to severe climatic conditions, or floods, fires, epidemics of diseases or parasites.

We must also remain constantly aware of the predominant human influence on "natural" ecosystems. Since the virtually all-inclusive influence for change on any ecosystem is man-induced, system responses

are altered far beyond that expected as response to within-system change.

When considering the "indicator species" concept, we must keep in mind that the ecosystem is a large group of species, species assemblages and communities. It would be ideal, of course, if the tolerances, preferences, and relationships of all species were documented; a concept which, in reality, is premature. All species are indicators. Species assemblages and communities are more useful in detecting temporal and/or spacial changes or trends.

The reader has been directed toward a large amount of literature describing and evaluating indicators and indices of water quality. I have refrained from a single technique or complementary set of techniques. There is no panacea. Specific goals of any one research program should dictate applicability of one or more methods. Rosen, *et al.* (1976*a*) concluded that two groups of indicators, individual chemical and physical measures, and biological methods, were most applicable. Two biological methods of measurement, diversity and equitability, appeared most relevant to water quality. When considered together, these measures reflect a level of community stability.

Continued testing and quantifying of the relationships between temporal and spacial heterogeneity and the structure of aquatic communities will aid in the policy decisions needed for preservation and management of watersheds.

LITERATURE CITED

Adams, T. G., G. J. Atchison, and R. J. Vetter. 1981. The use of the three-ridge clam (*Amblema perplicata*) to monitor trace metal contamination. Hydrobiologia 83(1):67-72.

Alabaster, J. S., ed. 1977. Biological monitoring of inland fisheries. Applied Science Publ., Ltd., London. 226 pp.

Alexander, C. S., and J. C. Prior. 1968. The origin of the Cache Valley, southern Illinois. Pp. 19-26. *In*: R. E. Bergstrom, ed. The Quaternary of Illinois. University of Illinois College of Agriculture Special Publication No. 14.

Alexander, C. P. 1925. An entomological survey of the Salt Fork of the Vermilion River in 1921, with a bibliography of aquatic insects. Bull. Illinois St. Lab. Nat. Hist. 15(8):439-535.

Allen, J. S. 1968. Alexander County surface water resources. Illinois Dept. Conserv., Div. Fisheries, Springfield. 51 pp.

Allen, J. S. 1969. Pulaski County surface water resources. Illinois Dept. Conserv., Div. Fisheries, Springfield. 41 pp.

Allen, J. S. 1970. Pope County surface water resources. Illinois Dept. Conserv., Div. Fisheries, Springfield. 44 pp.

Allen, J. S. 1971*a*. Johnson County surface water resources. Illinois Dept. Conserv., Div. Fisheries, Springfield. 47 pp.

Allen, J. S. 1971*b*. Massac County surface water resources. Illinois Dept. Conserv., Div. Fisheries, Springfield. 44 pp.

Altman, L. C. 1936. Oligochaeta of Washington. Univ. Washington Publ. Biol. 4(1):1-137.

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1970. Standard methods for the examination of water and wastewater, 13th ed. Washington, D. C. 874 pp.

Anderson, J. B., E. B. Henson, and C. I. Weber. 1965. The role of benthos and plankton studies in a water pollution surveillance program. Proc. 20th Indust. waste Conf., May 4-6, 1965. Purdue Univ., Lafayette, IN. Eng. Ext. Serv. 118:275-296.

Anderson, R. O. 1959. A modified floatation technique for sorting bottom fauna samples. Limnol. Oceanogr. 4(2):222-225.

Anderson, R. O., and F. F. Hooper. 1956. Seasonal abundance and production of littoral bottom fauna in a southern Michigan lake. Trans. Amer. Microsc. Soc. 75(3):259-270.

Anger, K. 1977. Benthic invertebrates as indicators of organic pollution in the Western Baltic Sea. Int. Revue ges. Hydrobiol. 62(2):245-254.

Anonymous. 1977. Biological investigations conducted in Illinois. 1971-1977. Illinois Environmental Protection Agency, Division of Water Pollution Control, Field Operations Section. [Springfield] 80 pp.

Antipa, G. A. 1977. Use of commensal protozoa as biological indicators of water quality and pollution. Trans. Amer. Microsc. Soc. 96(4):482-489.

Armitage, B. J., T. D. Forsythe, E. B. Rodgers, and W. B. Wrenn. 1978. Browns Ferry biothermal research series. I. Colonization by periphyton, zooplankton, and macroinvertebrates. EPA-600/3-78-020. Ecol. Res. Ser., Environ. Res. Lab., Office Res. Devel., U. S. Environ. Protect. Agency, Duluth, MN 55804.

Armitage, P. D. 1976. A quantitative study of the invertebrate fauna of the River Tees below Cow Green Reservoir. Freshw. Biol. 6(3):229-240.

Armitage, P. D. 1979. A folding artificial substratum sampler for use in standing water. Hydrobiologia 66(3):245-248.

Armitage, P. D., A. M. MacHale, and D. C. Crisp. 1974. A survey of stream invertebrates in the Cow Green basin (Upper Teesdale) before inundation. Freshw. Biol. 4(4):369-398.

Arthur, J. W., and W. B. Horning, II. 1969. The use of artificial substrates in pollution surveys. Amer. Midl. Nat. 82(1):83-89.

Aston, R. J. 1973. Tubificids and water quality: a review. Environ. Pollut. 5(1):1-10.

Bahls, L. L. 1979. Benthic diatom diversity as a measure of water quality. Proc. Montana Acad. Sci. 38:1-6.

Bahls, P. A., and L. L. Bahls. 1974. Trophic response to a hatchery effluent. Proc. Montana Acad. Sci. 34:5-11.

Balloch, D., C. E. Davies, and F. H. Jones. 1976. Biological assessment of water quality in three British rivers: the North Esk (Scotland), the Ivel (England) and the Taf (Wales). Water Pollut. Contr. 75:92-114.

Barbour, M. T., D. G. Cook, and R. S. Pomerantz. 1979. On the question of hybridization and variation in the oligochaete genus *Limnodrilus*. Paper presented at the 27th annual meeting of the North American Benthological Society, Erie, PN. 20 April.

Baumann, R. W. 1978. Stoneflies as water quality indicators. [Abstract] Paper presented at the 26th Annual Meeting of the North Amererican Benthological Society, 10 May.

Beak, T. W., T. C. Griffing, and A. G. Appleby. 1973. Use of artificial substrate samplers to assess water pollution, pp. 227-241. *In*: J. Cairns, Jr., and K. L. Dickson, eds. Biological methods for the assessment of water quality. American Society for Testing and Materials. ASTM Spec. Publ. 528.

Beck, W. M., Jr. 1954. Studies in stream pollution biology I. A simplified ecological classification of organisms. Quart. J. Florida Acad. Sci. 17(4):211-227.

Beck, W. M., Jr. 1955. Suggested method for reporting biotic data. Sewage Ind. Wastes 27(10):1193-1197.

Beddard, F. E. 1895. A monograph of the order of Oligochaeta. The Clarendon Press, Oxford. 769 pp.

Benfield, E. F., A. C. Hendricks, and J. Cairns, Jr. 1974. Proficiencies of two artificial substrates in collecting stream invertebrates. Hydrobiologia 45(4):431-440.

Berg, K., and P. M. Jónasson. 1965. Oxygen consumption of profundal lake animals at low oxygen content of the water. Hydrobiologia 26(1-2):131-143.

Bishop, J. E. 1973. Observations on the vertical distribution of the benthos in a Malaysian stream. Freshw. Biol. 3(2):147-156.

Bisson, J. W., and V. J. Cabelli. 1980. *Clostridium perfringens* as a water pollution indicator. J. Water Pollut. Control Fed. 52(2):241-248.

Blackford, S. 1966. A study of certain aspects of the ecology and morphology of branchiobdellid annelids epizoic on *Callinectes sapidus*. Unpubl. senior thesis, Newcomb College, Tulane Univ. [*as seen in* Holt 1974]

Bott, T. L. 1973. Bacteria and the assessment of water quality, pp. 61-75, *In*: J. Cairns, Jr., and K. L. Dickson, eds. Biological methods for the assessment of water quality. Amererican Society for Testing and Materials Special Tech. Publ. 528.

Bourne, A. G. 1891. Notes on the naidiform Oligochaeta; containing a description of new species of the genera *Pristina* and *Pterostylarides*, and remarks upon cephalization and gemmation as generic and specific characters in the group. Quart. J. Micr. Soc. (n. s.) 32:335-356.

Brace, E. M. 1901. Notes on *Aeolosoma tenebrarum*. J. Morph. 17:177-183.

Brigham, A. R. 1977. An assessment of the water quality of the Mississippi River Basin - North derived from a biological investigation. Illinois Nat. Hist. Surv., Urbana. 78 pp.

Brigham, A. R. 1978*a*. An assessment of the water quality of the Cache River basin derived from a biological investigation. Illinois Nat. Hist. Surv., Urbana. 73 pp.

Brigham, A. R. 1978*b*. An assessment of the water quality of the Rock River basin derived from a biological investigation. Illinois Nat. Hist. Surv., Urbana. 175 pp.

Brigham, A. R. 1979. An assessment of the water quality of the Wabash River basin derived from a biological investigation. Illinois Nat. Hist. Surv., Urbana. 297 pp.

Brigham, A. R., W. U. Brigham, R. Moran, and U. Gunthner. 1978. Economic impact of a suspension of Rule 404(f) as it applies to an unnamed tributary of the Kishwaukee River (R77-8). Illinois Nat. Hist. Surv., Urbana. 70 pp.

Brigham, W. U. 1972. The ecology of a polluted stream, Salt Fork, Champaign County, Illinois. Unpubl. Ph.D. thesis, University of Illinois Graduate College, Urbana-Champaign. 134 pp.

Brigham, W. U., ed. 1978. The role of aquatic communities in evaluating strategies and establishing standards and monitoring programs for water quality management. Unpubl. progr. rept. to the U. S. Environ. Protect. Agency, Cincinnati, OH. November. 157 pp.

Brigham, W. U., and A. R. Brigham. 1976. Water quality assessment of Little Cache Creek - Dutchman Creek watershed, Johnson County, Illinois, with notes on the biota. Illinois Nat. Hist. Surv., Urbana. 44 pp.

Brigham, W. U., D. A. McCormick, and M. J. Wetzel. 1978. The watersheds of northeastern Illinois: quality of the aquatic environment based upon water quality and fishery data. Northeastern Illinois Planning Commission Staff Paper No. 31. 251 pp.

Brinkhurst, R. O. 1960. Introductory studies on the British Tubificidae (Oligochaeta). Arch. Hydrobiol. 56(4):395-412.

Brinkhurst, R. O. 1962*a*. A re-description of *Peloscolex variegatus* Leidy (Oligochaeta, Tubificidae) with a consideration of the diagnosis of the genus *Peloscolex*. Int. Revue ges. Hydrobiol. 47(2):301-306.

Brinkhurst, R. O. 1962*b*. A check-list of British Oligochaeta. Proc. Zool. Soc. Lond. 138(2):317-330.

Brinkhurst, R. O. 1963*a*. Taxonomical studies on the Tubificidae (Annelida, Oligochaeta). Int. Revue ges. Hydrobiol., Syst. Beih. 2:1-89.

Brinkhurst, R. O. 1963*b*. A guide for the identification of British aquatic Oligochaeta. Freshwater Biological Association Spec. Publ. No. 22. 55 pp.

Brinkhurst, R. O. 1964*a*. Studies on the North American aquatic Oligochaeta. I. Naididae and Opistocystidae. Proc. Acad. Nat. Sci. Philadelphia 116:195-230.

Brinkhurst, R. O. 1964*b*. Observations on the biology of lake-dwelling Tubificidae. Arch. Hydrobiol. 60(4):385-418.

Brinkhurst, R. O. 1965*a*. Studies on the North American aquatic Oligochaeta. II. Tubificidae. Proc. Acad. Nat. Sci. Philadelphia 117(4):117-172.

Brinkhurst, R. O. 1965*b*. Observations on the recovery of a British river from gross organic pollution. Hydrobiologia 25(1-2):9-51.

Brinkhurst, R. O. 1965*c*. The use of sludge-worms (Tubificidae) in the detection and assessment of pollution. [Abstract] Great Lakes Res. Div. Publ. No. 13:209-210. [Proc. 8th Confr. Great Lakes Res., Ann Arbor, MI, 29-30 March 1965]

Brinkhurst, R. O. 1965*d*. The biology of the Tubificidae with special reference to pollution, pp. 57-66. *In*: C. M. Tarzwell, ed. Biological problems in water pollution. 3rd Seminar. 1962. Environ. Health Series: Water supply and pollution control. No. 25. U. S. Public Health Service Publ. No. 999-WP-25.

Brinkhurst, R. O. 1966*a*. Studies on the North American aquatic Oligochaeta. III. Lumbriculidae and additional notes and records of other families. Proc. Acad. Nat. Sci. Philadelphia 118(1):1-33.

Brinkhurst, R. O. 1966*b*. Detection and assessment of water pollution using oligochaete worms. Part 1. Water and Sewage Works 113(10):398-401.

Brinkhurst, R. O. 1966*c*. Detection and assessment of water pollution using oligochaete worms. Part 2. Water and Sewage Works 113(11):438-441.

Brinkhurst, R. O. 1966*d*. The Tubificidae (Oligochaeta) of polluted waters. Verh. Internat. Verein. Limnol. 16(2):854-859.

Brinkhurst, R. O. 1966*e*. A taxonomic revision of the family Haplotaxidae (Oligochaeta). J. Zool., London 150:29-51.

Brinkhurst, R. O. 1966*f*. Taxonomical studies on the Tubificidae (Annelida, Oligochaeta). Supplement. Int. Revue ges. Hydrobiol. 51(5):727-742.

Brinkhurst, R. O. 1969. Changes in the benthos of Lakes Erie and Ontario. Bull. Buffalo Soc. Nat. Sci. 25(1):45-84.

Brinkhurst, R. O. 1971. A guide for the identification of British aquatic Oligochaeta. Freshwater Biological Association Spec. Publ. No. 22. 2nd. ed. 55 pp.

Brinkhurst, R. O. 1972. The role of sludge worms in eutrophication. EPA-R3-72-004. U. S. Environmental Protection Agency, Ecological Research Series. 68 pp.

Brinkhurst, R. O. 1974*a*. Factors mediating interspecific aggregation of tubificid oligochaetes. J. Fish. Res. Board Canada 31(4):460-462.

Brinkhurst, R. O. 1974*b*. The benthos of lakes. St. Martin's Press, New York. 190 pp.

Brinkhurst, R. O. 1975. Oligochaeta, pp. 69-85. *In*: F. K. Parrish, ed. Keys to the water quality indicative organisms of the southeastern United States. U. S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring and Support Laboratory, Cincinnati, OH. 195 pp.

Brinkhurst, R. O. 1976. Aquatic Oligochaeta recorded from Canada and the St. Lawrence Great Lakes. Unpubl. Manuscript, Inst. Ocean Sci., Patricia Bay, Victoria, B. C. 49 pp.

Brinkhurst, R. O. 1978*a*. Water quality indicators: Oligochaeta. [Abstract] Paper presented at the 26th Annual Meeting of the North American Benthological Society, 10 May. Winnepeg, Manitoba.

Brinkhurst, R. O. 1978*b*. Freshwater Oligochaeta in Canada. Canadian J. Zool. 56(10):2166-2175.

Brinkhurst, R. O. 1979*a*. On the types in the genus *Peloscolex* Leidy (Oligochaeta: Tubificidae). Proc. Biol. Soc. Washington 92(4):677-681.

Brinkhurst, R. O. 1979*b*. Distribution of aquatic Oligochaeta in some habitats of lower British Columbia. Pacific Marine Science Rept. 79-4. Fisheries and Oceans Canada. Inst. Ocean Sciences, Patricia Bay, Sidney, B. C. 19 pp.

Brinkhurst, R. O., and K. E. Chua. 1969. Preliminary investigation of the exploitation of some potential nutritional resources by three sympatric tubificid oligochaetes. J. Fish. Res. Board Canada 26(10):2659-2668.

Brinkhurst, R. O., K. E. Chua, and E. Batoosingh. 1969. Modifications in sampling procedures as applied to studies on the bacteria and tubificid oligochaetes inhabiting aquatic sediments. J. Fish. Res. Board Canada 26(10):2581-2593.

Brinkhurst, R. O., K. E. Chua, and N. K. Kaushik. 1972. Interspecific interactions and selective feeding by tubificid oligochaetes. Limnol. Oceanogr. 17(1):122-133.

Brinkhurst, R. O., and D. G. Cook. 1966. Studies on the North American aquatic Oligochaeta III. Lumbriculidae and additional note and records of other families. Proc. Acad. Nat. Sci. Philadelphia 118(1):1-33.

Brinkhurst, R. O., and D. G. Cook. 1974. Aquatic earthworms (Annelida: Oligochaeta), pp. 143-156. *In*: C. W. Hart, Jr., and S. L. H. Fuller, eds. Pollution ecology of freshwater invertebrates. Academic Press, Inc., New York.

Brinkhurst, R. O., and B. G. M. Jamieson. 1971. Aquatic Oligochaeta of the world. Univ. Toronto Press, Buffalo, New York. 860 pp.

Brinkhurst, R. O., and C. R. Kennedy. 1962. Some aquatic Oligochaeta from the Isle of Man with special reference to the Silver Burn Estuary. Arch. Hydrobiol. 58(3):367-376.

Brinkhurst, R. O., and C. R. Kennedy. 1965. Studies on the biology of the Tubificidae (Annelida, Oligochaeta) in a polluted stream. J. Anim. Ecol. 34(2):429-443.

Brooks, J. G., and W. L. Hilsenhoff. 1971. Artificial substrate samples as indicators of water quality. Office Res. Devel., Environ. Res. Center, U.S. Environ. Protect. Agency, Cincinnati, OH 45268. 76 pp.

Butcher, R. W. 1947. Studies in the ecology of rivers. VII. The algae of organically enriched streams. J. Ecol. 35:186-191.

Cairns, J., Jr. 1978. Zooperiphyton (especially Protozoa) as indicators of water quality. Trans. Amer. Microsc. Soc. 97(1):44-49.

Cairns, J., Jr., D. W. Albaugh, F. Busey, and M. D. Chanay. 1968. The sequential comparison index - a simplified method for non-biologists to estimate relative differences in biological diversity in stream pollution studies. J. Water Pollut. Control Fed. 40(9):1607-1613.

Cairns, J., Jr., and K. L. Dickson, eds. 1973. Biological methods for the assessment of water quality. American Society for Testing and Materials. Spec. Tech. Publ. 528. 256 pp.

Cairns, J., Jr., K. L. Dickson, and G. F. Westlake, eds. 1977. Biological monitoring of water and effluent quality. American Society for Testing and Materials. Spec. Tech. Publ. 607. 246 pp.

Cairns, J., Jr., G. R. Lanza, and B. C. Parker. 1972. Pollution related structural and functional changes in aquatic communities with emphasis on freshwater algae and Protozoa. Proc. Acad. Nat. Sci. Philadelphia 124:79-127.

Cairns, J. Jr., and W. H. van der Schalie. 1980. Review paper: Biological monitoring. Part I - Early warning systems. Water Res. 14(9):1179-1196.

Carr, J. F., and J. K. Hiltunen. 1965. Changes in the bottom fauna of western Lake Erie from 1930-1961. Limnol. Oceanogr. 10(4):551-569.

Caspers, H., and H. Schulz. 1960. Studien zur wertung der saprobiensysteme. Int. Revue ges. Hydrobiol. 45(4):535-565.

Causey, D. 1953. Microdrili in artificial lakes in northwest Arkansas. Amer. Midl. Nat. 50(2):420-425.

Čekanovskya, O. V. 1962. [The aquatic Oligochaeta of the U. S. S. R.] [in Russian]. Opred. Faune S. S. S. R. 78:3-411.

Chandler, J. R. 1970. A biological approach to water quality management. Water Pollut. Contr., London 69:415-422.

Chatarpaul, L., J. B. Robinson, and N. K. Kaushik. 1979. Role of tubificid worms on nitrogen transformations in stream sediment. J. Fish. Res. Board Canada 36(6):673-678.

Chatarpaul, L., J. B. Robinson, and N. K. Kaushik. 1980. Effects of tubificid worms on denitrification and nitrification in stream sediment. Canadian J. Fish. Aquat. Sci. 37(4):656-663.

Chen, Y. 1944. Notes on naidomorph Oligochaeta of Philadelphia and vicinity. Not. Nat. 136:1-8.

Chiaudani, G., and R. Pagnotta. 1978. Ratio ATP/chlorophyll as an index of river's water quality. Verh. Internat. Verein. Limnol. 20(3):1897-1901.

Chutter, F. M. 1972. An empirical biotic index of the quality of water in South African streams and rivers. Water Res. 6(1):19-20.

Clark, R. B. 1964. Dynamics in metazoan evolution. The origin of the coelom and segments. Oxford Univ. Press (Clarendon), Oxford. 313 pp.

Clark, R. B. 1969. Systematics and phylogeny: Annelida, Echiura, Sipuncula, pp. 1-68. *In*: M. Florkin and B. T. Scheer, eds. Chemical Zoology. Vol. 4. Annelida, Echiura, and Sipuncula. Academic Press, New York.

Clarke, A. M. 1978*a*. Sphaeriidae communities as indicators. [Abstract] Paper presented at the 26th Annual Meeting of the North American Benthological Society, Winnipeg, Manitoba. 10 May.

Clarke, A. M. 1978*b*. Gastropod communities as indicators. [Abstract] *ibid*.

Clarke, A. H. 1979*a*. Gastropods as indicators of trophic lake stages. Nautilus 93(4):138-142.

Clarke, A. M. 1979*b*. Sphaeriidae as indicators of trophic lake stages. Nautilus 93(4):178-184.

Cohen, J. E. 1966. A model of simple competition. Harvard Univ. Press, Cambridge, Mass.

Cohen, J. E. 1968. Alternate derivations of a species-abundance relation. Amer. Nat. 102(924):165-172.

Coleman, M. J., and H. B. N., Hynes. 1970. The vertical distribution of the invertebrate fauna in the bed of a stream. Limnol. Oceanogr. 15(1):31-40.

Collins, D. S., Jr. 1937. The aquatic earthworms (microdrili) of Reelfoot Lake. J. Tennessee Acad. Sci. 12(2):188-205.

Collins, G. B., and C. I. Weber. 1978. Phycoperiphyton (algae) as indicators of water quality. Trans. Amer. Microsc. Soc. 97(1):36-43.

Conroy, J. C. 1978. Water mites as water quality indicators. [Abstract] Paper presented at the 26th Annual Meeting of the North American Benthological Society, Winnepeg, Manitoba. 10 May.

Cook, D. G. 1967. Studies on the Lumbriculidae (Oligochaeta) in Britain. J. Zool., London 153:353-368.

Cook, D. G. 1969. Observations on the life history and ecology of some Lumbriculidae (Annelida, Oligochaeta). Hydrobiologia 34(3-4): 561-574.

Cook, D. G. 1975. Cave-dwelling aquatic Oligochaeta (Annelida) from the eastern United States. Trans. Amer. Microsc. Soc. 94(1):24-37.

Cook, D. G., and M. G. Johnson. 1974. Benthic macroinvertebrates of the St. Lawrence Great Lakes. J. Fish. Res. Board Canada 31(5):763-782.

Cook, S. E. K. 1976. Quest for an index of community structure sensitive to water pollution. Environ. Pollut. 11(4):269-288.

Cover, E. C., and R. C. Harrel. 1978. Sequences of colonization, diversity, biomass, and productivity of macroinvertebrates on artificial substrates in a freshwater canal. Hydrobiologia 59(1):81-95.

Cragin, F. W. 1886. Miscellaneous notes. Bull. Washburn Coll. Lab. Nat. Hist. 1(7):212.

Cragin, F. W. 1887. First contribution to knowledge of the lower invertebrata of Kansas. Bull. Washburn Coll. Lab. Nat. Hist. 2(8):27-32.

Cummins, K. W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. Amer. Midl. Nat. 67(2):477-504.

Cummins, K. W. 1966. A review of stream ecology with special emphasis on organism-substrate relationships, pp. 2-51. *In*: K. W. Cummins, C. A. Tyron, and R. T. Hartman, eds. Organism-substrate relationships in streams. Spec. Publ. Pymatuning Lab. Ecol. 4. Univ. Pittsburgh.

Cummins, K. W., and G. H. Lauff. 1969. The influence of substrate particle size on the microdistribution of stream macrobenthos. Hydrobiologia 34(2):145-181.

Cummins, K. W., and J. C. Wuycheck. 1971. Caloric equivalents for investigations in ecological energetics. Mitt. Int. Verein. Limnol. 18:1-158.

Cushing, C. E., C. D. McIntire, J. R. Sedell, K. W. Cummins, G. W. Minshall, R. C. Petersen, and R. L. Vannote. 1980. Comparative study of physical-chemical variables of streams using multivariate analyses. Arch. Hydrobiol. 89(3):343-352.

Czekanowski, J. 1913. Zarys metod statystycznych (Die Grundzuge der statischen Metoden). Warsaw.

Darby, R. E. 1962. Midges associated with California rice fields, with special reference to their ecology (Diptera: Chironomidae). Hilgardia 32(1):1-206.

Davis, R. B. 1974*a*. Tubificids alter profiles of redox potential and *p*H in profundal lake sediment. Limnol. Oceanogr. 19(2):342-346.

Davis, R. B. 1974*b*. Stratigraphic effects of tubificids in profundal lake sediments. Limnol. Oceanogr. 19(3):466-488.

Diaz, R. J. 1980. Ecology of tidal freshwater and estuarine Tubificidae (Oligochaeta), pp. 319-330. *In*: R. O. Brinkhurst and D. G. Cook, eds. Aquatic oligochaete biology. Plenum Press, New York.

Diaz, R. J., D. F. Boesch, J. L. Hauer, C. A. Stone, and K. Munson. 1978. Appendix D: Environmental impacts of marsh development with dredged material: Botany, soils, aquatic biology, and wildlife, pp. 18-54. *In*: Habitat development field investigations, Windmill Point marsh development site, James River, Virginia. U. S. Army Corps Engin. Tech. Rept. D-77-23.

Dickson, K. L., J. Cairns, Jr., and J. C. Arnold. 1971. An evaluation of the use of a basket-type artificial substrate for sampling macrobenthic invertebrate organisms. Trans. Amer. fish. Soc. 100(3):553-559.

Dittmar, H. 1959. Reicht das bischerige Saprobiensystem für die Gütebeurteilung eines Gewässers aus? Forschung und Beratung, A, 8:263-265.

Dixon, G. C. 1915. *Tubifex*. Liverpool Marine Biology Committee Memoirs 23. Williams and Norgate, London. 100 pp. + 7 pl.

Donald, G. L., and C. G. Paterson. 1977. Effect of preservation on wet weight biomass of chironomid larvae. Hydrobiologia 53(1):75-80.

Downing, J. A. 1979. Aggregation, transformation, and the design of benthos sampling programs. J. Fish. Res. Board Canada 36(12):1454-1463.

Dussart, G. B. J. 1979. Life cycles and distribution of the aquatic gastropod molluscs *Bithynia tentaculata* (L.), *Gyraulus albus* (Muller), *Planorbus planorbus* (L.) and *Lymnaea peregra* (Muller) in relation to water chemistry. Hydrobiologia 67(3):223-239.

Dzyuban, N. A., and S. P. Kuznetsova. 1978. Zooplankton as an indicator of pollution in reservoirs. Hydrobiol. J. 14(6):35-39.

Economou-Amilli, A. 1980. Periphyton analysis for the evaluation of water quality in running waters of Greece. Hydrobiologia 74(1):39-48.

Edwards, R. W. 1975. A strategy for the prediction and detection of effects of pollution on natural communities. Schweiz. Z. Hydrobiol. 37(1):135-143.

Edwards, R. W., K. Benson-Evans, M. A. Learner, P. Williams, and R. Williams. 1972. A biological survey of the River Taff. Water Pollut. Contr. 71(2):144-166.

Eggleton, F. E. 1931. A limnological study of the profundal bottom fauna of certain fresh-water lakes. Ecol. Monogr. 1(3):231-331.

Eggleton, F. 1952. Dynamics of interdepression benthic communities. Trans. Amer. Microsc. Soc. 71(3):189-228.

Eisen, G. 1900. Researches in American Oligochaeta, with especial reference to those of the Pacific coast and adjacent islands. Proc. California Acad. Sci. Third Series. 2(2):85-276.

Elliott, J. M., and P. A. Tullett. 1978. A bibliography of samplers for benthic invertebrates. Freshw. Biol. Assoc. Occ. Publ. 4. 61pp.

Ellis, M. M. 1912. A new discodrilid worm from Colorado. Proc. U. S. Nat. Mus. 42(1912):481-486.

Ellis, M. M. 1918. Branchiobdellid worms (Annelida) from Michigan crayfishes. Trans. Amer. Microsc. Soc. 37(1):49-51.

Ellis, M. M. 1919. The branchiobdellid worms in the collection of the United States National Museum, with descriptions of new genera and new species. Proc. U. S. Nat. Mus. 55(2267):241-365.

Evans, C. R. 1939. The Branchiobdellidae (Annelida) on crayfishes of Champaign County, Illinois. J. Parasitol. 25:448.

Eyres, J. P., N. V. Williams, and M. Pugh-Thomas. 1978. Ecological studies on Oligochaeta inhabiting depositing substrata in the Irwell, a polluted English river. Freshw. Biol. 8(1):25-32.

Farnworth, E. G., M. C. Nichols, C. N. Vann, L. G. Wolfson, R. W. Bosserman, P. R. Hendrix, F. B. Golley, and J. L. Cooley. 1979. Impacts of sediment and nutrients on biota in surface waters of the United States. EPA-600/3-79-105. Environmental Systems Branch, Environmental Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Athens, GA. 315 pp.

Fehrenbacher, J. B., and G. A. Walker. 1959. Soil Survey: Johnson County, Illinois. Univ. Illinois Agr. Exp. Sta. Soil Rept. No. 82. 72 pp.

Fialkowski, W. 1979. Ecology of leeches (Hirudinea) in the organically polluted part of Drwinka stream. Acta Hydrobiol. 21(4):475-488.

Fisher, R. A., A. S. Corbet, and C. B. Williams. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. J. Anim. Ecol. 12:42-58.

Fjerdingstad, E. 1964. Pollution of streams estimated by benthal phytomicro-organisms. I. A saprobic system based on communities of organisms and ecological factors. Int. Revue ges. Hydrobiol. 49(1):63-131.

Food and Agriculture Organization of the United Nations [FAO]. 1976. Indices for measuring responses of aquatic ecological systems to various human influences. FAO Fisheries Tech. Pap. No. 151. 66 pp.

Forbes, S. A. 1890*a*. Note on an American species of *Phreoryctus*. Amer. Nat. 24:477-478.

Forbes, S. A. 1890*b*. An American earthworm of the family Phreoryctidae. Bull. Illinois St. Lab. Nat. Hist. 3(7):107-116.

Forbes, S. A. 1925. The lake as a microcosm. Bull. Illinois St. Lab. Nat. Hist. 15(9):537-550.

Forbes, S. A., and R. E. Richardson. 1913. Studies on the biology of the upper Illinois River. Bull. Illinois St. Lab. Nat. Hist. 9(10):481-574.

Ford, J. B. 1962. The vertical distibution of larval Chironomidae (Dipt.) in the mud of a stream. Hydrobiologia 19(3):262-272.

Fullner, R. W. 1971. A comparison of macroinvertebrates collected by basket and modified multiple-plate samplers. J. Water Pollut. Control Fed. 43(3):494-499.

Galloway, T. W. 1899. Observations on non-sexual reproduction of *Dero vaga*. Bull. Mus. Comp. Zool. (Harvard College) 35(5):115-140.

Galloway, T. W. 1911. The common fresh-water Oligochaeta of the United States. Trans. Amer. Microsc. Soc. 30(4):285-317.

Gannon, J. E., and R. S. Stemberger. 1978. Zooplankton (especially crustaceans and rotifers) as indicators of water quality. Trans. Amer. Microsc. Soc. 97(1):16-35.

Garman, H. 1890. A preliminary report on the animals of the Mississippi Bottoms near Quincy, Illinois, on August, 1888. Part I. Bull. Illinois St. Lab. Nat. Hist. 3(9):123-184.

Gaufin, A. R. 1958. The effects of pollution on a midwestern stream. Ohio J. Sci. 58(4):197-208.

Gaufin, A. R. 1973. Use of aquatic invertebrates in the assessment of water quality, pp. 96-116. *In*: J. Cairns, Jr., and K. L. Dickson, eds. Biological methods for the assessment of water quality. American Society for Testing and Materials, Spec. Tech. Publ. 528.

Gaufin, A. R., and C. M. Tarzwell. 1952. Aquatic invertebrates as indicators of stream pollution. U. S. Publ. Health Serv., Publ. Health Repts. 67(1):57-64.

Gaufin, A. R., and C. M. Tarzwell. 1956. Aquatic macro-invertebrate communities as indicators of organic pollution in Lytle Creek. Sew. Ind. Wastes 28(7):906-924.

Gersbacher, W. M. 1937. Development of stream bottom communities in Illinois. Ecology 18:359-390.

Gilpin, B. R., and M. A. Brusven. 1976. Subsurface sampler for determining vertical distibution of stream-bed benthos. Progr. Fish-Cult. 38(4): 192-194.

Gleason, H. A. 1926. The individualistic concept of the plant association. Bull. Torrey Bot. Club 53(1):7-26.

Goodnight, C. J. 1940. The Branchiobdellidae (Oligochaeta) of North American crayfishes. Illinois Biol. Mongr. 17(3):1-75.

Goodnight, C. J. 1941. The Branchiobdellidae (Oligochaeta) of Florida. Trans. Amer. Microsc. Soc. 60(1):69-74.

Goodnight, C. J. 1942. A new species of branchiobdellid from Kentucky. Trans. Amer. Microsc. Soc. 61(3):272-273.

Goodnight, C. J. 1973. The use of aquatic macroinvertebrates as indicators of stream pollution. Trans. Amer. Microsc. Soc. 92(1):1-13.

Goodnight, C. J., and L. S. Whitley. 1961. Oligochaetes as indicators of pollution. Proc. 15th Industr. Waste Confr., 3-5 May 1960. Purdue Univ. Engineering Extention Service Bulletin Series No. 106:139-142.

Grassle, J. P., and J. F. Grassle. 1976. Sibling species in the marine pollution indicator *Capitella* (Polychaeta). Science 192(4239): 567-569.

Gross, F. 1976. [The oligochaete communities of a lowland stream and their value as indicators of organic pollution.] [in French with English summary] Annls. Limnol. 12(1):75-87.

Harman, W. J. 1965. A new species of the genus *Pristina* (Oligochaeta: Naididae) from Louisiana. Proc. Louisiana Acad. Sci. 28:28-31.

Harman, W. J. 1966. Some aquatic oligochaetes from Mississippi. Amer. Midl. Nat. 76(1):239-242.

Harman, W. J. 1969. Revision of the family Opistocystidae (Oligochaeta). Trans. Amer. Microsc. Soc. 88(4):472-478.

Harman, W. J. 1973. New species of Oligochaeta (Naididae) with additional distributional records from Oklahoma and Texas. Southwest. Nat. 18(2):151-164.

Harman, W. J. 1975. A new species of *Stephensoniana* (Oligochaeta: Naididae) from North America. Proc. Biol. Soc. Washington 88(1):1-4.

Harman, W. J. 1977. Three new species of Oligochaeta (Naididae) from the southeastern U. S. Proc. Biol. Soc. Washington 90(3):483-490.

Harman, W. J., and R. C. Harrell. 1975. *Haemonais waldvogeli* (Naididae: Oligochaeta) now established in North America. Texas J. Sci. 26(3+4):621-623.

Harman, W. J., and M. S. Loden. 1978*a*. A re-evaluation of the Opistocystidae (Oligochaeta) with descriptions of two new genera. Proc. Biol. Soc. Washington 91(2):453-462.

Harman, W. J., and M. S. Loden. 1978*b*. *Bratislavia unidentata* (Oligochaeta: Naididae), a re-description. Southwest. Nat. 23(4):541-544.

Harman, W. J., M. S. Loden, and J. R. Davis. 1979. Aquatic Oligochaeta new to North America with some further records of species from Texas. Southwest. Nat. 24(3):509-525.

Harman, W. J., and M. L. McMahan. 1975. A reevaluation of *Pristina longiseta* (Oligochaeta: Naididae) in North America. Proc. Biol. Soc. Washington 88(17):167-178.

Harris, T. L., and T. M. Lawrence. 1978. Environmental requirements and tolerance of Trichoptera. EPA-600/4-78-063. Environmental Monitoring and Support Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, OH. 310 pp.

Harrod, J. J. 1964. The distribution of invertebrates on submerged aquatic plants in a chalk stream. J. Anim. Ecol. 33(2):335-348.

Harrold, J. F., Jr. 1978. Relation of sample variations to plate orientation in the Hester-Dendy plate sampler. Progr. Fish-Cult. 40(1):24-25.

Hayden, H. E., Jr. 1912. Preliminary note on *Pristina* and *Naidium*. Science (N. Y.) (n. s.) 36(929):530-531.

Hayden, H. E., Jr. 1914. Further notes on *Pristina* with descriptions of three new species. Trans. Amer. Microsc. Soc. 33:135-138.

Hayden, H. E., Jr. 1922. Studies on American naid oligochaetes. I. Preliminary note on naids of Douglas Lake, Michigan. Trans. Amer. Microsc. Soc. 41(4):167-171.

Hellawell, J. M. 1977. Change in natural and managed ecosystems: detection, measurement and assessment. Proc. Roy. Soc. London B 197(1126):31-57.

Hellawell, J. M. 1978. Biological surveillance of rivers. Water Research Centre, Stevenage Laboratory, Elder Way, Stevenage, Herts. SG1 1TH, England. xii + 332 pp.

Hemprich, F. G., and C. G. Ehrenberg. 1831. *In*: C. G. Ehrenberg. 1828 and 1831. Symbolae Physicae, seu Icones et descriptiones Corporum Naturalium novorum aut minus cognitorum, quae ex itineribus per Libyam, Aegyptum, Nubiam, Dongelam, Syriam, Arabiam et Habessiniam. Berolini.

Henebry, M. S., and J. Cairns, Jr. 1980. Monitoring of stream pollution using protozoan communities on artificial substrates. Trans. Amer. Microsc. Soc. 99(2):151-160.

Henebry, M. S., and B. T. Ridgeway. 1979. Epizoic ciliated protozoa of planktonic copepods and cladocerans and their possible use as indicators of organic water pollution. Trans. Amer. Microsc. Soc. 98(4):495-508.

Hern, S. C. 1970. Bacterial indicators of water quality of Flathead Lake and Flathead River, Montana. M. S. thesis, Univ. Utah, Salt Lake City. 80 pp.

Hilsenhoff, W. L. 1977. Use of arthropods to evaluate water quality of streams. Wisconsin Dept. Nat. Resour. Tech. Bull. No. 100. unpaged.

Hiltunen, J. K. 1967. Some oligochaetes from Lake Michigan. Trans. Amer. Microsc. Soc. 86(4):433-454.

Hiltunen, J. K. 1969*a*. Invertebrate macrobenthos of western Lake Superior. Mich. Acad. 1(3+4):123-133.

Hiltunen, J. K. 1969*b*. The benthic macrofauna of Lake Ontario. Great Lakes Fish. Comm. Tech. Rept. 14:39-50.

Hiltunen, J. K. 1969*c*. Distribution of oligochaetes in western Lake Erie, 1961. Limnol. Oceanogr. 14:260-264.

Hiltunen, J. K. 1973. A laboratory guide. Keys to the tubificid and naidid Oligochaeta of the Great Lakes Region. Not a publication. Great Lakes Fishery Laboratory, Ann Arbor, MI. 2nd ed. mimeo. 24 pp.

Hiltunen, J. K., and D. J. Klemm. 1980. A guide to the Naididae (Annelida: Clitellata: Oligochaeta) of North America. EPA-600/4-80-031. Environmental Monitoring and Support Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, OH 45268. 48 pp.

Hobbs, H. H., Jr., and A. Villalobos. 1958. The exoskeleton of a freshwater crab as a microhabitat for several invertebrates. [Abstract] Virginia J. Sci. 9:395-396.

Hocutt, C. H. 1975. Assessment of a stressed macroinvertebrate community. Water Res. Bull. 11(4):820-835.

Hocutt, C. H., and J. R. Stouffer, Jr. 1980. Biological monitoring of fish. LexingtonBooks, D. C. Heath & Company, Lexington, Mass. xi + 416 pp.

Hoffman, R. L. 1963. A revision of the North American annelid worms of the genus *Cambarincola* (Oligochaeta: Branchiobdellidae). Proc. U.S. Nat. Mus. 114(3470):271-371.

Holt, P. C. 1953. Characters of systematic importance in the family Branchiobdellidae (Oligochaeta). Virginia J. Sci. (n. s.) 4(2):57-61.

Holt, P. C. 1963. A new branchiobdellid (Branchiobdellidae: *Cambarincola*). J. Tennessee Acad. Sci. 38(3):97-100.

Holt, P. C. 1965. The systematic position of the Branchiobdellidae (Annelida: Clitellata). Syst. Zool. 14(1):25-32.

Holt, P. C. 1969. The relationships of the branchiobdellid fauna of the southern Appalachians, pp. 191-219. *In*: P. C. Holt, R. L. Hoffman, and C. W. Hart, Jr., eds. The distributional history of the biota of the southern Appalachians. Part 1. Invertebrates. Research Division Monograph 1. Virginia Polytechnic Institute, Blacksburg, VA [A symposium sponsored by V. P. I. and the Association of Southeastern Biologists, held 27 to 29 June, 1968 in Blacksburg].

Holt, P. C. 1973*a*. Branchiobdellids (Annelida: Clitellata) from some eastern North American caves, with descriptions of new species of the genus *Cambarincola*. Int. J. Speleol. 5(3/4):219-256.

Holt, P. C. 1973*b*. A summary of the branchiobdellid (Annelida: Clitellata) fauna of Mesoamerica. Smithson. Contrib. Zool. 142:1-40.

Holt, P. C. 1974. The branchiobdellid (Annelida: Clitellata) associates of astacoidean crawfishes. Paper presented at the 2nd International Crayfish Symposium, Baton Rouge, LA. April.

Holt, P. C. 1978. [Key to the genera of Branchiobdellida], pp. 292-295. *In*: R. W. Pennak. Fresh-water invertebrates of the United States. 2nd ed. John Wiley and Sons, Inc., New York.

Hooper, F. F. 1969. Eutrophication indices and their relation to other indices of ecosystem change, pp. 225-235. *In*: Eutrophication: Causes, consequences, correctives. National Academy of Sciences, Washington, D. C.

Hornig, C. E., and J. E. Pollard. 1978. Macroinvertebrate sampling techniques for streams in semi-arid regions. Comparison of the Surber method and a unit-effort traveling kick method. EPA-600/4-78-040. Environmental Monitoring Series, U. S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Las Vegas, NV 89114. 21 pp.

Hörnström, E. 1981. Trophic characterization of lakes by means of qualitative phytoplankton analysis. Limnologica (Berl.) 13(2):249-261.

Horton, R. E. 1945. Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Bull. Geol. Soc. Amer. 56:275-370.

Howell, D. N. 1974. The worm turns: An investigation of experimentation on learning abilities of earthworms. Megadrilogica 1(10):1-6.

Howmiller, R. P. 1972. Effects of preservatives on weights of some common macrobenthic invertebrates. Trans. Amer. Microsc. Soc. 101(4):743-746.

Howmiller, R. P. 1974*a*. Studies on aquatic Oligochaeta in inland waters of Wisconsin. Trans. Wisc. Acad. Sci. Arts Letts. 62:337-356.

Howmiller, R. P. 1974*b*. Some Naididae and Tubificidae from Central America. Hydrobiologia 44(1):1-12.

Howmiller, R. P. 1974*c*. Composition of the oligochaete fauna of central Lake Michigan. Internat. Assoc. Great Lakes Res. 17(1):589-592.

Howmiller, R. P. 1977. On the abundance of Tubificidae (Annelida: Oligochaeta) in the profundal benthos of some Wisconsin lakes. Amer. Midl. Nat. 97(1):211-216.

Howmiller, R. P., and A. M. Beeton. 1970. The oligochaete fauna of Green Bay, Lake Michigan. Internat. Assoc. Great Lakes Res. 13:15-46.

Howmiller, R., and M. S. Loden. 1976. Identification of Wisconsin Tubificidae and Naididae. Trans. Wisc. Acad. Sci. Arts Letts. 64:185-197.

Howmiller, R. P., and M. A. Scott. 1977. An environmental index based on relative abundance of oligochaete species. J. Water Pollut. Control Fed. 49(5):809-815.

Hubbard, M. D., and W. L. Peters. 1978. Environmental requirements and pollution tolerance of Ephemeroptera. EPA-600/4-78-061. Environmental Monitoring and Support Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, OH 461 pp.

Hughes, B. D. 1975. A comparison of four samplers for benthic macro-invertebrates inhabiting coarse river deposits. Water Res. 9(1):61-69.

Humphrey, S. A. 1977*a*. A biological investigation of the Kaskaskia River basin. 1976. Nalco Environmental Sciences, Northbrook, IL. Vol. 1. pp. 1-168.

Humphrey, S. A. 1977*b*. A biological investigation of the Kaskaskia River basin. 1976. Nalco Environmental Sciences, Northbrook, IL. Vol. 2. pp. 168A-376.

Humphrey, S. A. 1977*c*. A biological investigation of the Kaskaskia River basin. 1976. Nalco Environmental Sciences, Northbrook, IL. Vol. 3. pp. 376A-595.

Hutchinson, G. E., and E. S. Deevey. 1949. Ecological studies on populations. Surv. Biol. Progr. 1:325-359.

Hynes, H. B. N. 1960. The biology of polluted waters. Univ. Toronto Press, Buffalo, N. Y. 202 pp.

Hynes, H. B. N. 1970. The ecology of running waters. Univ. Toronto Press, Toronto, Canada. 555 pp.

Hynes, H. B. N. 1974. Further studies on the distribution of stream animals within the substratum. Limnol. Oceanogr. 19(1):92-99.

Jaccard, P. 1908. Nouvelles recherches sur la distribution florale. Bull. Soc. Vaud. Sci. Nat. 44:223-270.

Jaccard, P. 1912. The distribution of the flora in the alpine zone. New Phytol. 11:37-50.

Jacobi, G. Z. 1978. An inexpensive circular sampler for collecting benthic macroinvertebrates in streams. Arch. Hydrobiol. 83(1):126-131.

James, A., and L. Evison. 1979. Biological indicators of water quality. John Wiley and Sons, New York. [xvi + 597 pp.]

Jamieson, B. G. M. 1978. Phylogenetic and phenetic systematics of the opisthoporous Oligochaeta (Annelida: Clitellata). Evol. Theor. 3(4):195-233.

Jamieson, B. G. M. 1980. Preliminary discussion of an Hennigian analysis of the phylogeny and systematics of opisthoporous oligochaetes. Rev. Ecol. Biol. Sol 17(2):261-275.

Johnson, M. G., and D. H. Matheson. 1968. Macroinvertebrate communities of the sediments of Hamilton Bay and adjacent Lake Ontario. Limnol. Oceanogr. 13:99-111.

Jónasson, P. M. 1955. The efficiency of sieving techniques for sampling bottom fauna. Oikos 6(2):183-207.

Jónasson, P. M. 1958. The mesh factor in sieving techniques. Verh. Int. Verein. Limnol. 13(2):860-866.

Jónasson, P. M. 1972. Ecology and production of the profundal benthos in relation to phytoplankton in Lake Esrom. Oikos Suppl. 14:1-148.

Jones, W. G., and K. F. Walker. 1979. Accumulation of iron, manganese, zinc and cadmium by the Australian freshwater mussel *Velesunio ambiguus* (Phillipi) and its potential as a biological indicator. Austr. J. Mar. Freshw. Res. 30(6):741-751.

Jørgensen, G. F. 1978. Use of biotic indices as a tool for water quality analysis in rivers. Verh. Int. Verein. Limnol. 20(3):1772-1778.

Kajak, Z., and K. Dusage. 1971. The regularities of vertical distribution of benthos in bottom sediments of three Masurian lakes. Ekol. Polska 19:485-499.

Kasprzak, K., and B. Szczęsny. 1976. Oligochaetes (Oligochaeta) of the Rievr [sic] Raba. Acta Hydrobiol. 18(1):75-87.

Kathman, D. 1978. Artificial substrate sampler for benthic invertebrates in ponds, small lakes, and reservoirs. Progr. Fish-Cult. 40(3):114-115.

Kawecka, B. 1977. The food of dominant species of bottom fauna larvae in the River Raba (southern Poland). Acta Hydrobiol. 19(3):191-213.

Kelly, H. M. 1899. A statistical study of the parasites of the Unionidae. Bull. Illinois St. Lab. Nat. Hist. 5(8):399-418.

Kendeigh, S. C. 1961. Animal ecology. Prentice-Hall, Inc., Englewood Cliffs, N. J. 468 pp.

Kenk, R. 1941. Notes on three species of *Aeolosoma* (Oligochaeta) from Michigan. Occ. Pap. Mus. Zool., Univ. Michigan. 435:1-7.

Kenk, R. 1949. The animal life of temporary and permanent ponds in southern Michigan. Misc. Publ. Mus. Zool., Univ. Michigan 71:1-66.

Kennedy, C. R. 1965. The distribution and habitat of *Limnodrilus* Claparède (Oligochaeta: Tubificidae). Oikos 16(2):26-38.

Kennedy, C. R. 1966*a*. The life history of *Limnodrilus udekemianus* Clap. (Oligochaeta: Tubificidae). Oikos 17(1):10-18.

Kennedy, C. R. 1966*b*. The life history of *Limnodrilus hoffmeisteri* Clap. (Oligochaeta: Tubificidae) and its adaptive significance. Oikos 17(2):158-168.

Kennedy, C. R. 1969*a*. Tubificid oligochaetes as food of dace *Leuciscus leuciscus* (L.). J. Fish. Biol. 1(1):11-15.

Kennedy, C. R. 1969*b*. The variability of some characters used for species recognition in the genus *Limnodrilus* Claparède (Oligochaeta: Tubificidae). J. Nat. Hist. 3:53-60.

Keup, L. E., W. M. Ingram, and K. M. Mackenthun. 1966. The role of bottom-dwelling macrofauna in water pollution investigations. Environmental Health Series: Water Supply and Pollution Control No. 38. Public Health Service Publ. No. 999-WP-38. U. S. Dept. Health, Education, and Welfare, Public Health Service, Division of Water Supply and Pollution Control, Cincinnati, OH. 23 pp.

Keup, L. E., W. M. Ingram, and K. M. Mackenthun. 1967. Biology of water pollution. A collection of selected papers on stream pollution, waste water and water treatment. U. S. Dept. Interior, Fed. Water Pollut. Control Admin. 290 pp.

Kikuchi, E., and Y. Kurihara. 1977. *In vitro* studies on the effects of tubificids on the biological, chemical and physical characteristics of submerged ricefield soil and overlying water. Oikos 29(2):348-356.

Kindred, J. E. 1918. A representative of the genus *Trichodrilus* from Illinois. Bull. Illinois St. Lab. Nat. Hist. 13(4):49-52.

King, D. L., and R. C. Ball. 1964. A quantitative biological measure of stream pollution. J. Water Pollut. Control Fed. 36(5):650-653.

Knöpp, H. 1954. Ein neuer Weg zur Darstellung biolischer Vorfluteruntersuchungen, erläutert an einem Gütelangsschritt des Maines. Wasserwirtisch 45:9-15.

Knöpp, H. 1955. Grundsätzliches zur Frage biologischer Vorfluteruntersuchungen, erläutert an einem Gutelangsschritt des Maines. Arch. Hydrobiol./ Suppl. 22(3/4):363-368.

Kolkwitz, R., and M. Marsson. 1902. Grundsätze für die biolog. Beurteilung des Wassers nach seiner Fauna und Flora. Mitteil. d. Kgl. Prüfungsanstalt f. Wasserversorgung u. Abwässerbeseitigung. 1:33-72.

Kolkwitz, R., and M. Marsson. 1908. Ökologie der pflanzlichen Saprobien. Berichte der Deutschen Botanischen Gesellschaft 26(Part 1, No. 59):505-519.

Kolkwitz, R., and M. Marsson. 1909. Ökologie der tierischen Saprobien. Beiträge zur Lehre von der biologischen gewässerbeurteilung. Int. Rev. ges Hydrobiol. Hydrogr. 2:126-152.

Korn, H. 1963. Studien zur Ökologie der Oligochaeten in der oberen Donau unter Berücksichtigung der Abwassereinwirkungen. Arch. Hydrobiol., Suppl. 7:131-182.

Kothé, P. 1962. Der 'Artenfehlbetrag', ein einfaches Gütekriterium und seine Anwendung bei biologischen Vorfluteruntersuchungen. Dt. Gewässerkundl. Mitt. 6:60-65.

Kramer, C. Y. 1956. Extension of multiple range tests to group means with unequal numbers of replications. Biometrics 12:307-310.

Krenkel, P. A., and V. Novotny. 1980. Water quality management. Academic Press, Inc., N. Y. xii + 671 pp.

Ladle, M. 1971. Studies on the biology of oligochaetes from the phreatic water of an exposed gravel bed. Int. J. Speleol. 3(1/2):311-316.

Lafont, M. 1977. [The oligochaetes of a polluted mountain stream: the Bief Rouge.] [in French with English summary] Annls. Limnol. 13(2):157-167.

Lafont, M., and J. Juget. 1976. [Oligochaetes of the River Rhône. I. General Survey.] [in French with English summary] Annls. Limnol. 12(3):253-268.

Lagauterie, P., and P. Leroux. 1977. [A method for testing the response of benthic macro-invertebrates to environmental factors in running waters.] [In French with English summary] Terre Vie 31(2):327-342.

Lapkina, L. N., and B. A. Flerov. 1980. The use of leeches to identify pesticides in water. Hydrobiol. J. 16(3):78-83.

Larmark, J. B. P. A. L. de M., C. de 1816. Classe Cinquime. Les Vers (Vermes), pp. 542-676. *In*: Histoire naturelle des animaux sans vertebres. Vol. 3. J. B. Bailliere, Libraire, Paris.

Lang, C. 1978*a*. [Multivariate approach to biological and chemical detection of pollution in Lake Geneva (Switzerland).] [in French with English summary] Arch. Hydrobiol. 83(2):158-178.

Lang, C., and B. Lang-Dobler. 1979*a*. The chemical environment of tubificid and lumbriculid worms according to the pollution level of the sediment. Hydrobiologia 65(3):273-282.

Lang, C., and B. Lang-Dobler. 1979*b*. MELIMEX, an experimental heavy metal pollution study: Oligochaetes and chironomid larvae in heavy metal loaded and control limno-corrals. Schweiz. Z. Hydrol. 41(2):271-276.

Lang, C., and B. Lang-Dobler. 1980. Structure of tubificid and lumbriculid worm communities, and three indices of trophy based upon these communities, as descriptors of eutrophication level of Lake Geneva (Switzerland), pp. 457-470. *In*: R. O. Brinkhurst and D. G. Cook, eds. Aquatic olgigochaete biology. Plenum Press, New York.

Larimore, R. W. 1974. Stream drift as an indication of water quality. Trans. Amer. Fish. Soc. 103(3):507-517.

Learner, M. A., G. Lockhead, and B. D. Hughes. 1978. A review of the biology of British Naididae (Oligochaeta) with emphasis on the lotic environment. Freshw. Biol. 8(4):357-375.

Learner, M. A., R. Williams, M. Harcup, and B. D. Hughes. 1971. A survey of the macro-fauna of the River Cynon, a polluted tributary of the River Taff (South Wales). Freshw. Biol. 1(4):339-367.

Leighton, M. M., G. E. Ekblaw, and L. Hornberg. 1948. Physiographic divisions of Illinois. J. Geol. 56(1):16-33.

Levins, R. 1968. Evolution in changing environments. Princeton University Press, Princeton, N. J. ix + 120 pp.

Lewis, P. A. 1974. Taxonomy and ecology of *Stenonema* mayflies (Heptageniidae: Ephemeroptera). EPA-670/4-74-006. National Environmental Research Center, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, OH. 81 pp.

Lewis, P. A. 1978. Mayfly communities as indicators of water quality. [Abstract] Paper presented at the 26th annual meeting of the North American Benthological Society, 10 May. Winnipeg, Manitoba.

Liang, Y.-L. 1963. Studies on the aquatic Oligochaeta of China. 1. Descriptions of new naids and branchiobdellids. Acta Zool. Sinica 15(4):560-570.

Liebmann, H. 1960. Handbuch der Frischwasser- und Abwasserbiologie. Vol. II. Verlag Oldenbourg, Munich. Verlag G. Fischer, Jena. 588 pp.

Liebmann, H. 1962. Handbuch der Frischwasser- und Abwasserbiologie. Vol. I, 2nd edition. R. Oldenbourg, Munich. 1149 pp.

Linnaeus, C. 1758. Systema Naturae. 10th edition.

Lloyd, M., J. H. Zar, and J. R. Karr. 1968. On the calculation of information-theoretical measures of diversity. Amer. Midl. Nat. 79(2): 257-272.

Loden, M. S. 1973. Predation of aquatic organisms on oligochaetes. Unpubl. M. S. thesis, Auburn University, Auburn, AL. vi + 64 pp.

Loden, M. S. 1974. Predation by chironomid (Diptera) larvae on oligo-chaetes. Limnol. Oceanogr. 19(1):156-159.

Loden, M. S. 1977. Two new species of *Limnodrilus* (Oligochaeta: Tubificidae) from the southeastern United States. Trans. Amer. Microsc. Soc. 96(3):321-326.

Loden, M. S. 1978. A revision of the genus *Psammoryctides* (Oligochaeta: Tubificidae) in North America. Proc. Biol. Soc. Washington 91(1):74-84.

Loden, M. S., and D. W. Dugas. 1978. New records of fresh-water Tubificidae (Oligochaeta) from southern Louisiana. Proc. Louisiana Acad. Sci. 41:94-101.

Loden, M. S., and W. J. Harman. 1980. Ecophenotypic variation in setae of Naididae (Oligochaeta), pp. 33-39. *In*: R. O. Brinkhurst and D. G. Cook, eds. Aquatic oligochaete biology. Plenum Press, New York.

Looman, J., and J. B. Campbell. 1960. Adaptation of Sorensen's K (1948) for estimating unit affinities in prairie vegetation. Ecology 41(3):409-416.

Lowe, R. L. 1974. Environmental requirements and pollution tolerance of freshwater diatoms. EPA-670/4-74-005. National Environmental Research Center, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, OH. 334 pp.

Lowe, R. L., and W. F. Gale. 1980. Monitoring river periphyton with artificial benthic substrates. Hydrobiologia 69(3):235-244.

MacArthur, R. H. 1957. On the relative abundance of bird species. Proc. Nat. Acad. Sci. Washington 43(3):293-295.

MacArthur, R. H. 1958. Population ecology of some warblers of northeastern coniferous forests. Ecology 39:599-619.

MacArthur, R. H. 1965. Patterns of species diversity. Biol. Rev. 40(4):510-533.

MacArthur, R. H. 1972. Geographical ecology: Patterns in the distribution of species. Harper and Row, New York. 269 pp.

Maciorowski, A. F., E. F. Benfield, and A. C. Hendricks. 1977. Species composition, distribution, and abundance of oligochaetes in Kanawha River, West Virginia. Hydrobiologia 54(1):81-91.

Maitland, P. S., and P. M. G. Hudspith. 1974. The zoobenthos of Loch Levin, Kinross, and estimates of its production in the sandy littoral area during 1970 and 1971. Proc. Royal Soc. Edinburgh B 74(14):219-239.

Malley, D. F., and J. B. Reynolds. 1979. Sampling strategies and life history of non-insectan freshwater invertebrates. J. Fish. Res. Board Canada 36(3):311-318.

Margalef, R. 1951. Diversitad de especies in las comunidades natureles. Publ. Inst. Biol. Apl. Barc. 9:5-27.

Margalef, R. 1958. Temporal succession and spatial heterogeneity in phytoplankton. Pp. 323-349, *In*: A. A. Buzzati-Traverso, ed. Perspectives in marine biology. Univ. California Press, Berkeley.

Margalef, R. 1975. External factors and ecosystem stability. Schweiz. Z. Hydrol. 37(1):102-117.

Mason, W. T., Jr. 1978. Methods for the assessment and prediction of mineral mining impacts on aquatic communities: a review and analysis. Eastern Energy and Land Use Group, Office of Biological Sevices, Fish and Wildlife Service, U. S. Dept. Interior. 157 pp.

Mason, W. T., Jr., J. B. Anderson, R. D. Kreis, and W. C. Anderson. 1970. Artificial substrate sampling, macroinvertebrates in a polluted reach of the Klamath River, Oregon. J. Water Pollut. Control Fed. 42(8, part 2):R315-R328.

Mason, W. T., Jr., P. A. Lewis, and E. C. Julian. 1973. Factors affecting the performance of basket and multiplate macroinvertebrate samplers. Freshw. Biol. 3(5):409-436.

Mathis, B. J., and T. F. Cummings. 1967. Distribution of selected metals in bottom sediments, water, clams, tubificid annelids, and fishes of the middle Illinois River. Water Res. Rept. No. 41. Univ. Illinois, Water Resour. Cent., 2535 Hydrosystems Lab., Urbana. 45 pp.

Matsunaga, W. O. 1978. Biological investigation of the Kishwaukee River and its tributaries (segment A-02 of the Rock River basin). April-July, 1976. Illinois Environ. Protect. Agency, Div. Water Pollut. Control, State of Illinois [Maywood]. 38 pp.

Matysiak, K. 1976*a*. Structure of leech groups (Hirudinea) in polluted parts of the catchment area of the Rivers Bzura and Ner Part 1. Field investigations. Acta Hydrobiol. 18(3):259-276.

Matysiak, K. 1976*b*. Contribution to the knowledge of the influence of water pollution on the occurrence of leeches in the river Ner. [In Polish with English summary] Przegl. Zool. 20(3):326-328.

Matysiak, K. 1978. Structure of leech groups (Hirudinea) in polluted parts of the catchment area of the Rivers Bzura and Ner. Part 2. Experimental-laboratory investigation. Acta Hydrobiol. 20(2):187-194.

McCall, P. L., and J. B. Fisher. 1980. Effects of tubificid oligochaetes on physical and chemical properties of Lake Erie sediments, pp. 253-317. *In*: R. O. Brinkhurst and D. G. Cook, eds. Aquatic oligochaete biology. Plenum Press, New York.

McConville, D. R. 1975. Comparison of artificial substrates in bottom fauna studies on a large river. J. Minnesota Acad. Sci. 41:21-24.

McConville, D. R. 1979. Macroinvertebrate populations in the upper Mississippi River. J. Minnesota Acad. Sci. 45(3):4-8.

McGill, J. D., R. S. Wilson, and A. M. Brake. 1979. The use of chironomid pupal exuviae in the surveillance of sewage pollution within a drainage system. Water Res. 13(9):887-894.

McIntosh, R. P. 1967. An index of diversity and the relation of certain concepts to diversity. Ecology 48(3):392-404.

Menhinick, E. F. 1964. A comparison of some species-individuals diversity indices applied to samples of field insects. Ecology 45(4):859-861.

Metropolitan Sanitary District of Greater Chicago. 1975. Part II, summary of biological data within the waterways of the Metropolitan Sanitary District. 67 pp. Mimeo.

Metropolitan Sanitary District of Greater Chicago, Department of Research and Development. 1977*a*. 1974 annual summary report, water quality within the waterways system of the Metropolitan Sanitary District of Greater Chicago. Vol. 2. Biol. Rept. No. 77-25-B. 69 pp.

Metropolitan Sanitary District of Greater Chicago, Department of Research and Development. 1977*b*. Sediment oxygen demand of bottom deposits in deep draft waterways in Cook County. 51 pp.

Miall, L. C. 1895. The natural history of aquatic insects. Macmillan, London. ix + 395 pp.

Michaelsen, W. 1900. Oligochaeta. Das Terreich 10. R. Friedlander und Sohn, Berlin. xxix + 575 pp.

Milbrink, G. 1973*a*. Communities of Oligochaeta as indicators of the water quality in Lake Hjälmaren. Zoon 1(1):77-88.

Milbrink, G. 1973*b*. On the use of indicator communities of Tubificidae and some Lumbriculidae in the assessment of water pollution in Swedish lakes. Zoon 1(2):125-139.

Milbrink, G. 1978. Indicator communities of oligochaetes in Scandinavian lakes. Verh. Internat. Verein. Limnol. 20(4): 2406-2411.

Milbrink, G. 1980. Oligochaete communities in pollution biology: the European situation with special reference to lakes in Scandinavia, pp. 433-455. *In*: R. O. Brinkhurst and D. G. Cook, eds. Aquatic oligochaete biology. Plenum Press, New York.

Moffett, J. W. 1943. A limnological investigation of the dynamics of a sandy, wave-swept shoal in Douglas Lake, Michigan. Trans. Amer. Microsc. Soc. 62(1):1-23.

Möller, F. 1979. Manual of methods in aquatic environment research. Part 5 - Statistical test. FAO Fish. Tech. Pap. No. 182. 131 pp.

Moon, H. P. 1940. An investigation of the movements of fresh-water invertebrate faunas. J. Anim. Ecol. 9:76-83.

Moore, G. M. 1939. A limnological investigation of the microscopic benthic fauna of Douglas Lake, Michigan. Ecol. Monogr. 9(4):537-582.

Moore, J. P. 1905. Hirudinea and Oligochaeta collected in the Great Lakes region. Bull. Bur. Fish. 25:153-171.

Moore, J. W. 1979. Diversity and indicator species as measures of water pollution in a subarctic lake. Hydrobiologia 66(1):73-80.

Morisawa, M. 1957. Accuracy of determination of stream lengths from topographic maps. Trans. Amer. Geophys. Union 38:86-88.

Moroz, T. G. 1979. Comparison of various methods for estimating the quality of water based on bottom-dwelling indicator invertebrates. Hydrobiol. J. 14(3):96-99.

Morris, D. L., and M. P. Brooker. 1979. The vertical distribution of macro-invertebrates in the substratum of the upper reaches of the River Wye, Wales. Freshw. Biol. 9(6):573-583.

Morris, D. L., and M. P. Brooker. 1980. An assessment of the importance of the Chironomidae (Diptera) in biological surveillance, pp. 195-202. *In*: D. A. Murray, ed. Chironomidae: Ecology, systematics, cytology and physiology. Pergamon Press, New York.

Muller, O. F. 1774. Vermium terrestrium et fluviatilium. Havniae & Lipsiae.

Muttkowski, R. A. 1918. The fauna of Lake Mendota: a qualitative and quantitative survey with special reference to the insects. Trans. Wisconsin Acad. Sci. Arts Letts. 19:374-482.

Nalepa, T. F., and N. A. Thomas. 1976. Distribution of macrobenthic species in relation to sources of pollution and sediment parameters. J. Great Lakes Res. 2(1):150-163.

Naqvi, S. M. Z. 1973. Toxicity of twent-three insecticides to a tubificid worm *Branchiura sowerbyi* from the Misissippi delta. J. Econ. Entomol. 66(1):70-74.

Neel, J. K. 1948. A limnological investigation of the psammon in Douglas Lake, Michigan, with especial reference to shoal and shoreline dynamics. Trans. Amer. Microsc. Soc. 67(1):1-53.

Newman, J. P., Jr., and A. L. Buikema, Jr. 1975. Zinc stimulation of pygidial budding in *Aeolosoma headlyi* Beddard (Annelida). [Abstract]. Virginia J. Sci. 26(2):59.

Nielsen, C. O., and B. Christensen. 1959. The Enchytraeidae: Critical revision and taxonomy of European species (Studies on Enchytraeidae VII). Nat. Jutl. 8-9:1-160.

Nielsen, C. O., and B. Christensen. 1961. The Enchytraeidae: Critical revision and taxonomy of European species. Nat. Jutl. (Suppl. 1): 1-23.

Nielsen, C. O., and B. Christensen. 1963. The Enchytraeidae: Critical revision and taxonomy of European species. Nat. Jutl. (Suppl. 2):1-19.

Nilsen, H. C., and R. W. Larimore. 1973. Establishment of invertebrate communities in the Kaskaskia River, Illinois. Ecology 54(2):366-374.

Nuttall, P. M., and J. B. Purves. 1974. Numerical indices applied to the results of a survey of the macro-invertebrate fauna of the Tamar Catchment (southwest England). Freshw. Biol. 4(3):213-222.

Orth, R. J. 1973. Benthic infauna of eelgrass, *Zostera marina* beds. Chesapeake Sci. 14(4):258-269.

Paine, G. H., Jr., and A. R. Gaufin. 1956. Aquatic Diptera as indicators of pollution in a midwestern stream. Ohio J. Sci. 56(5):291-304.

Palmer, C. M. 1969. A composite rating of algae tolerating organic pollution. J. Phycol. 5(1):78-82.

Paloumpis, A. A., and W. C. Starrett. 1960. An ecological study of benthic organisms in three Illinois River flood plain lakes. Amer. Midl. Nat. 64(2):406-435.

Pantle, R., and H. Buck. 1955*a*. Die biologische Überwachung der Gewässer und die Darstellung der Ergebnisse. Bes. Mitt. Deutsch. Gewasserkundl. Jahrbuch Nr 12:135-143.

Pantle, R., and H. Buck. 1955*b*. Die biologische Überwachung der Gewässer und die Darstellung der Ergebnisse. Gas -u. Wasserfach 96:604.

Paparo, A. A., and R. E. Sparks. 1977. Rapid assessment of water quality using the fingernail clam, *Musculium transversum*, pp. 96-109. *In*: J. Cairns, Jr., K. L. Dickson, and G. F. Westlake, eds. Biological monitoring of water and effluent quality. American Society for Testing and Materials. ASTM STP 607.

Parks, W. D. 1975. Soil survey of Pope, Hardin, and Massac Counties, Illinois. Univ. Illinois Agric. Exp. Sta. Soil Rept. No. 94. 126 pp.

Parks, W. D., and J. B. Fehrenbacher. 1968. Soil survey: Pulaski and Alexander Counties, Illinois. Univ. Illinois Agric. Exp. Sta. Soil Rept. No. 85. 121 pp.

Patrick, R. 1949. A proposed biological measure of stream conditions, based on a survey of the Conestoga basin, Lancaster County, Pennsylvania. Proc. Acad. Nat. Sci. Philadelphia 101:277-341.

Patrick, R. 1973. Use of algae, especially diatoms, in the assessment of water quality, pp. 76-95. *In*: J. Cairns, Jr., and K. L. Dickson, eds. Biological methods for the assessment of water quality. American Society for Testing and Materials. Spec. Tech. Publ. 528.

Peltier, W. 1978. Methods for measuring the acute toxicity of effluents to aquatic organisms. EPA-600/4-78-012. Environmental Monitoring and Support Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, OH. 52 pp.

Pennak, R. W. 1940. Ecology of the microscopic metazoa inhabiting the sandy beaches of some Wisconsin lakes. Ecol. Monogr. 10(4):537-615.

Petran, M., and P. Kothé. 1978. Influence of bedload transport on the macrobenthos of running waters. Verh. Internat. Verein. Limnol. 20(3):1867-1872.

Pielou, E. C. 1969. An introduction to mathematical ecology. Wiley-Interscience, New York. 286 pp.

Pollard, J. E., and W. L. Kenney. 1979. Assessment of macroinvertebrate monitoring techniques in an energy development area. A test of the efficiency of three macrobenthic sampling methods in the White River. EPA-600/7-79-163. Environmental Monitoring and Support Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Las Vegas, NE. 26 pp.

Pclls, I., C. Lue-Hing, D. R. Zenz, and S. J. Sedita. 1980. Effects of urban runoff and treated municipal wastewater on a man-made channel in northeastern Illinois. Water Res. 14(3):207-215.

Poole, W. C., and K. W. Stewart. 1976. The vertical distribution of macrobenthos within the substratum of the Brazos River, Texas. Hydrobiologia 50(2):151-160.

Preston, F. W. 1948. The commoness, and rarity, of species. Ecology 29(2):254-283.

Raabe, E.-W. 1952. Über den "Affinitätswert" in der Pflanzensoziologie. Vegetatio, Acta Geobotanica 4(1):53-68.

Radford, D. S., and R. Hartland-Rowe. 1971. Subsurface and surface sampling of benthic invertebrates in two streams. Limnol. Oceanogr. 16(1):114-120.

Rao, S. S., and A. A. Jurkovic. 1977. Differentiation of the trophic status of the Great Lakes by means of bacterial index ratio. J. Great Lakes Res. 3(3-4):323-326.

Reice, S. R. 1980. The role of substratum in benthic macroinvertebrate microdistribution and litter decomposition in a woodland stream. Ecology 61(3):580-590.

Resh, V. H. 1979. Sampling variability and life history features: Basic considerations in the design of aquatic insect studies. J. Fish. Res. Board Canada 36(3):290-311.

Resh, V. H., and J. D. Unzicker. 1975. Water quality monitoring and aquatic organisms: the importance of species identification. J. Water Pollut. Contr. Fed. 47(1):9-19.

Reynolds, J. W. 1980. The earthworm family Sparganophilidae (Annelida, Oligochaeta) in North America. Megadrilogica 3(12):189-204.

Reynolds, J. W., and D. G. Cook. 1976. Nomenclatura oligochaetologica. A catalogue of names, descriptions and type specimens of the Oligochaeta. Univ. New Brunswick. Fredericton, New Brunswick, Canada. 217 pp.

Richardson, R. E. 1921*a*. The small bottom and shore fauna of the middle and lower Illinois River and its connecting lakes, Chillicothe to Grafton: its valuation; its sources of food supply; and its relation to the fishery. Bull. Illinois Nat. Hist. Surv. 13(15):363-522.

Richardson, R. E. 1921*b*. Changes in the bottom and shore fauna of the middle Illinois River and its connecting lakes since 1913-1915 as a result of the increase, southward, of sewage pollution. Bull. Illinois Nat. Hist. Surv. 14(4):33-75.

Richardson, R. E. 1925*a*. Changes in the small bottom fauna of Peoria Lake, 1920 to 1922. Bull. Illinois Nat. Hist. Surv. 15(5):327-388.

Richardson, R. E. 1925*b*. Illinois River bottom fauna in 1923. Bull. Illinois Nat. Hist. Surv. 15(6):391-422.

Richardson, R. E. 1928. The bottom fauna of the middle Illinois River, 1913-1925. Its distribution, abundance, valuation, and index value in the study of stream pollution. Bull. Illinois Nat. Hist. Surv. 17(12):87-475.

Roback, S. S. 1974. Insects (Arthropoda: Insecta), pp. 313-376. *In*: C. W. Hart, Jr., and S. L. H. Fuller, eds. Pollution ecology of freshwater invertebrates. Academic Press, New York.

Rofritz, D. 1977. Oligochaeta as a winter food source for the old squaw. J. Wildl. Manage. 41(3):590-591.

Rosén, G. 1981. Phytoplankton indicators and their relations to certain chemical and physical factors. Limnologica (Berl.) 13(2):263-290.

Rosen, R. H., R. Beck, V. P. Bennett, J. A. Orlando, and R. B. Wrightington. 1976*a*. A review and evaluation of water quality indices and similar indicators. Vol. I. Summary and user's guide. Prepared by Energy Resources Co., Inc., and Mathmatica, Inc., for Council on Environmental Quality. xxxii + 235 pp.

Rosen, R. H., R. Beck, V. P. Bennett, J. A. Orlando, and R. B. Wrightington. 1976*b*. A review and evaluation of water quality indices and similar indicators. Vol. II. A review of available indices. Prepared by Energy Resources Co., Inc., and Mathmatica, Inc., for Council on Environmental Quality. xiv + 270 pp.

Rosen, R. H., R. Beck, V. P. Bennett, J. A. Orlando, and R. B. Wrightington. 1976*c*. A review and evaluation of water quality indices and similar indicators. Vol. III. Evaluation of available indices. Prepared by Energy Resources Co., Inc., and Mathmatica, Inc., for Council on Environmental Quality. xiv + 188 pp.

Rosen, R. H., R. Beck, V. P. Bennett, J. A. Orlando, and R. B. Wrightington. 1976*d*. A review and evaluation of water quality indices and similar indicators. Vol. IV. Evaluation of non-point sources. prepared by Energy Resources Co., Inc., and Mathmatica, Inc., for Council on Environmental Quality. [not seen]

Ruggiero, M. A., and H. C. Merchant. 1979. Water quality, substrate, and distribution of macroinvertebrates in the Patuxant River, Maryland. Hydrobiologia 64(2):183-189.

Särkkä, J., and J. Aho. 1980. Distribution of aquatic Oligochaeta in the Finnish lake district. Freshw. Biol. 10(3):197-206.

Saether, O. A. 1978. Chironomid communities as indicators. [Abstract] Paper presented at the 26th annual meeting of the North American Benthological Society, 10 May 1978.

Sanders, H. L. 1968. Marine benthic diversity: A comparative index. Amer. Nat. 102:243-282.

Sawyer, R. T. 1974. Leeches (Annelida: Hirudinea), pp. 81-142. *In*: C. W. Hart, Jr., and S. L. H. Fuller. Pollution ecology of freshwater invertebrates. Academic Press, New York.

Schacht, R. A. 1974. A biological investigation of the South Branch of the Kishwaukee River. Illinois Environmental Protection Agency, Springfield. 18 pp.

Schacht, R. A., and W. Matsunaga. 1975*a*. A biological investigation of the DuPage River. Illinois Environmental Protection Agency, Springfield. 28 pp.

Schacht, R. A., and W. Matsunaga. 1975*b*. A biological investigation of the Des Plaines River from the Wisconsin state line to Joliet, Illinois. Illinois Environmental Protection Agency, Springfield. 59 pp.

Schuhmacher, H., and F. Schremmer. 1970. Die Trichopteren des Odenwaldbaches "Steinbach" und ihr okologischer Ziegerwert. [in German with English summary] Int. Rev. ges. Hydrobiol. 55(3):335-358.

Schwoerbel, J. 1970. Methods of hydrobiology (freshwater biology). Pergamon Press, Inc., Elmsford, New York. 200 pp.

Scott, W. 1911. The fauna of a solution pond. Proc. Indiana Acad. Sci. 1910:395-442.

Senapati, B. K., and M. C. Dash. 1980. Effect of formalin preservation on the weight of tropical earthworms. Rev. Ecol. Biol. Sol. 17(3):371-377.

Shannon, C. E. 1948. A mathmatical theory of communication. Bell Systems Tech. J. 27(3):379-423.

Shannon, C. E., and Weaver. 1949. The mathmatical theory of communication. Univ. Illinois Press, Urbana. 117 pp.

Simmons, G. M., Jr., and A. Winfield. 1971. A feasibility study using conservation webbing as an artificial substrate in macrobenthic studies. Virginia Acad. Sci. 22(2):52-59.

Simpson, E. H. 1949. Measurement of diversity. Nature, London. 163(4148):688.

Sinclair, R. M. 1964. Water quality requirements of the family Elmidae (Coleoptera) (with keys to the larvae and adults of the eastern genera). Tennessee Stream Pollution Control Board, Nashville. 14 pp.

Singer, R. G. 1977. The biology of *Aeolosoma* (Annelida). Unpubl. Ph.D. thesis, Univ. Illinois, Urbana. 166 pp.

Singer, R. G. 1978. Suction-feeding in *Aeolosoma* (Annelida). Trans. Amer. Microsc. Soc. 97(1):105-111.

Sládaček, V. 1965. The future of the saprobity system. Hydrobiologia 25(3-4):518-537.

Sládaček, V. 1966. Water quality system. Verh. Internat. Verein. Limnol. 16(2):809-816.

Sládaček, V. 1967. The ecological and physiological trends in the saprobity. Hydrobiologia 30(3-4):513-526.

Sládaček, V. 1973*a*. System of water quality from the biological point of view. Ergebn. Limnol. 7:1-218.

Sládaček, V., ed. 1977. Symposium on saprobiology. Ergebn. Limnol. 9:1-245.

Sládaček, V. 1981. Indicator value of the genus *Opercularia* (Ciliata). Hydrobiologia 79(3):229-232.

Slock, J. A. 1979. The use of short-count methods on field collected diatom communities to determine water quality of small streams. Proc. Iowa Acad. Sci. 86(4):141-144.

Smith, F. 1895*a*. Notes on species of North American Oligochaeta. Bull. Illinois St. Lab. Nat. Hist. 4(8):285-297.

Smith, F. 1895*b*. A preliminary account of two new Oligochaeta from Illinois. Bull. Illinois St. Lab. Nat. Hist. 4(5):138-148.

Smith, F. 1896. Notes on species of North American Oligochaeta. II. Bull. Illinois St. Lab. Nat. Hist. 4(14):396-413.

Smith, F. 1900*a*. Notes on species of North American Oligochaeta. IV. On a new lumbriculid genus from Florida, with additional notes on the nephridial and circulatory systems of *Mesoporodrilus asymmetricus* Smith. Bull. Illinois St. Lab. Nat. Hist. 5(11):459-478.

Smith, F. 1900*b*. Notes on species of North American Oligochaeta. III. List of species found in Illinois, and descriptions of Illinois Tubificidae. Bull. Illinois St. Lab. Nat. Hist. 5(10):441-458.

Smith, F. 1905. Notes on species of North American Oligochaeta. V. The systematic relationships of *Lumbriculus (Thinodrilus) inconstans* (Smith). Bull. Illinois St. Lab. Nat. Hist. 7(5):45-51.

Smith, F. 1918. A new North American oligochaete of the genus *Haplotaxis*. Bull. Illinois St. Lab. Nat. Hist. 13(3):43-48.

Smith, F. 1919. Lake Superior lumbriculids, including Verrill's *Lumbricus lacustris*. Proc. Biol. Soc. Washington 32:33-40.

Smith, F., and L. B. Dickey. 1918. A new species of *Rhynchelmis* in North America. Trans. Amer. Microsc. Soc. 37(4):207-214.

Smith, F., and B. R. Green. 1916. The Porifera, Oligochaeta, and certain other groups of invertebrates in the vicinity of Douglas Lake, Michigan. 17th Rept. Michigan Acad. Sci. (1915) 17:81-84.

Smith, F., and P. S. Welch. 1913. Some new Illinois Enchytraeidae. Bull. Illinois St. Lab. Nat. Hist. 9(12):615-636.

Smith, K. R. 1975. Use of aquatic oligochaetes as a diagnostic tool in evaluating water quality. Ohio Biol. Surv. Inform. Circ. 8:55-57.

Smith, P. W. 1961. The amphibians and reptiles of Illinois. Illinois Nat. Hist. Surv. Bull. 28(1):1-298.

Sokal, R. R. 1961. Distance as a measure of taxonomic similarity. Syst. Zool. 10(2):70-79.

Spencer, D. R. 1977. A species of *Pristina* (Oligochaeta: Naididae) new to Lake Erie. Ohio J. Sci. 77(1):24-25.

Spencer, D. R. 1978*a*. The Oligochaeta of Cayuga Lake, New York with a redescription of *Potamothrix bavaricus* and *P. bedoti*. Trans. Amer. Microsc. Soc. 97(2):139-147.

Spencer, D. R. 1978*b*. *Pristina acuminata* Liang, a naidid oligochaete new to North America. Trans. Amer. Microsc. Soc. 97(2):236-239.

Spencer, D. R. 1980. The aquatic Oligochaeta of the St. Lawrence Great Lakes region, pp. 115-164. *In*: R. O. Brinkhurst and D. G. Cook, eds. Aquatic oligochaete biology. Plenum Press, New York.

Sperber, C. 1948. A taxonomical study of the Naididae. Zool. Bidr. Uppsala 28:1-296.

Sperber, C. 1950. A guide for the determination of European Naididae. Zool. Bidr. Uppsala 29:45-77.

Stanford, J. A. 1973. A centrifuge method for determining live weights of aquatic insect larvae, with a note on weight loss in preservation. Ecology 54(2):449-451.

Stephenson, J. 1930. The Oligochaeta. Clarendon Press, Oxford. 978 pp.

Stimpson, K. S., J. R. Brice, M. T. Barbour, and P. Howe. 1975. Distribution and abundance of inshore oligochaetes in Lake Michigan. Trans. Amer. Microsc. Soc. 94(3):384-394.

Stoermer, E. F. 1978. Phytoplankton assemblages as indicators of water quality in the Laurentian Great Lakes. Trans. Amer. Microsc. Soc. 97(1):2-16.

Strahler, A. N. 1954. Quantitative geomorphology of erosional landscapes. 19th Internat. Geol. Congr. Sec. 13:341-354.

Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. Trans. Amer. Geophys. Union 38:913-920.

Surber,E. W. 1957. Biological criteria for the determination of lake pollution, pp. 1164-174. *In*: C. M. Tarzwell, ed. Biological problems in water pollution. 1st seminar. U. S. Public Health Serv. Publ. W57-36.

Surber, E. W., and H. L. Cooley. 1952. Bottom fauna studies of Green Bay, Wisconsin, in relation to pollution. U. S. Public Health Serv. and Wisconsin Comm. Water Pollution. 7 pp.

Surdick, R. F., and A. R. Gaufin. 1978. Environmental requirements and pollution tolerance of Plecoptera. EPA-600/4-78-062. Environmental Monitoring and Support Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, OH. 417 pp.

Swüste, H. F. J., R. Cremer, and S. Parma. 1973. Selective predation by larvae of *Chaoborus flavicans* (Diptera, Chaoboridae). Verh. Internat. Verein. Limnol. 18(3):1559-1563.

Szczęsny, B. 1974. The effect of sewage from the town of Krynica on the benthic invertebrates communities of the Kryniczanka stream. Acta Hydrobiol. 16(1):1-29.

Tarzwell, C. M., ed. 1957. Biological problems in water pollution. U.S. Dept. Health, Education, and Welfare. U. S. Public Health Service. 272 pp.

Tarzwell, C. M., ed. 1960. Biological problems in water pollution. U.S. Dept. Health, Education, and Welfare. U. S. Public Health Service. Tech. Rept. W60-3. 285 pp.

Thienemann, A. 1912. Aristotles und die Abwasserbiologie. Festschrift Medizinisch -Naturwissenschaftlichen Gesellschaft Münster. Coppenrath Münster, Commissionsverlag, Universitäts Buchhandlung Franz.

Thomas, W. A., G. Goldstein, and W. H. Wilcox. 1973. Biological indicators of environmental quality. Ann Arbor Science Publishers, Inc., Ann Arbor, MI. 254 pp.

Tolkamp, H. H., and J. C. Both. 1978. Organism-substrate relationship in a small Dutch lowland stream. Preliminary results. Verh. Internat. Verein. Limnol. 20(3):1509-1515.

Tucker, W. J., and W. H. Ettinger. 1975. A biological investigation of the South Fork, Sangamon River and tributaries. Illinois Environmental Protection Agency, Division of Water Pollution Control, State of Illinois, [Springfield]. 56 pp.

Tucker, W. J., and W. H. Ettinger. 1976. Biological investigation of Mississippi River central and north central basins - A-01, A-02 and B-01, B-02. Illinois Environmental Protection Agency, Division of Water Pollution Control, State of Illinois. Springfield]. 115 pp.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*a*. Climatological data, Illinois, January, 1976. Asheville, North Carolina. 81(1):1-15.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*b*. Climatological data, Illinois, February, 1976. Asheville, North Carolina. 81(2):1-16.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*c*. Climatological data, Illinois, March, 1976. Asheville, North Carolina. 81(3):1-16.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*d*. Climatological data, Illinois, April, 1976. Asheville, North Carolina. 81(4):1-16.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*e*. Climatological data, Illinois, May,1976. Asheville, North Carolina. 81(5):1-15.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*f*. Climatological data, Illinois, June, 1976. Asheville, North Carolina. 81(6):1-15.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*g*. Climatological data, Illinois, July, 1976. Asheville, North Carolina. 81(7):1-25.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*h*. Climatological data, Illinois, August, 1976. Asheville, North Carolina. 81(8):1-15.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*i*. Climatological data, Illinois, September, 1976. Asheville, North Carolina. 81(9):1-14.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*j*. Climatological data, Illinois, October, 1976. Asheville, North Carolina. 81(10):1-16.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*k*. Climatological data, Illinois, November, 1976. Asheville, North Carolina. 81(11):1-16.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*l*. Climatological data, Illinois, December, 1976. Asheville, North Carolina. 81(12):1-15.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1976*m*. Climatological data, Illinois, Annual Summary, 1976. Asheville, North Carolina. 81(13):1-13.

Van Hoven, W. 1975. Aspects of the respiratory physiology and oxygen preferences of four aquatic oligochaetes (Annelida). Zool. Africana 10(1):29-45.

Vaillant, L. 1889. Histoire naturelle des anneles marins et d'eau douce. Vol. 3. Lombriciniens, Hirudiniens, Bdellomorphes, Terretulariens et Planariens. Paris.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian J. Fish. Aquat. Sci. 37(1):130-137.

Vejdovský, F. 1884. System und Morphology der Oligochaeten. Prague. 166 pp. + 16 pl.

Vestal, A. G. 1931. A preliminary vegetation map of Illinois. Trans. Illinois St. Acad. Sci. 23(3):204-217.

Voigt, J. W., and R. H. Mohlenbrock. 1964. Plant communities of southern Illinois. Southern Illinois University Press, Carbondale. 202 pp.

Voshell, J. R., Jr., and G. M. Simmons, Jr. 1977. An evaluation of artificial substrates for sampling macrobenthos in reservoirs. Hydrobiologia 53(3):257-269.

Wachs, B. 1967. Die Oligochaeten-Fauna der fließgewässer unter besonderer Berücksichtigung der Beziehungen swischen der Tubificiden-Besiedling und dem substrat. Arch. Hydrobiol. 63(3):310-386.

Walton, L. B. 1906. Naididae of Cedar Point, Ohio. Amer. Nat. 40:683-706.

Wapora, Inc. 1976. A biological investigation of the Sangamon River basin in Illinois. Charleston, IL 314 pp.

Ward, J. V. 1976. Lumbricid earthworm populations in a Colorado mountain river. Southwest. Nat. 21(1):71-78.

Ward, J. V., and R. A. Short. 1978. Macroinvertebrate community structure of four special lotic habitats in Colorado, U. S. A. Verh. Internat. Verein. Limnol. 20(2):1382-1387.

Watanabe, T. 1962. On the biotic index of water pollution based upon the species number of Bacillariophyceae in the Tokoro River in Hokkaido. Japanese J. Ecol. 12(6):216-222.

Wavre, M., and R. O. Brinkhurst. 1971. Interactions between some tubificid oligochaetes and bacteria found in the sediments of Toronto Harbour, Ontario. J. Fish. Res. Bd. Canada 28(3):335-341.

Weber, C. I. 1973*a*. Biological monitoring of the aquatic environment, pp. 46-60. *In*: J. Cairns, Jr., and K. L. Dickson, eds. 1973. Biological methods for the assessment of water quality. American Society for Testing and Materials. Spec. Tech. Publ. 528.

Weber, C. I., ed. 1973*b*. Biological field and laboratory methods for measuring the quality of surface waters and effluents. Environmental Research Series. EPA-670/4-73-001. Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, OH. xi + [172] pp.

Welch, P. S. 1914. Studies on the Enchytraeidae of North America. Bull. Illinois St. Lab. Nat. Hist. 10(3):123-212.

Welch, P. S. 1920. The genera of Enchytraeidae (Oligochaeta). Trans. Amer. Microsc. Soc. 39(1):25-50.

Wene, G., and E. L. Wickliff. 1940. Modification of a stream bottom and its effect on the insect fauna. Canadian Entomol. 72(7):131-135.

Wetzel, M. J. 1980. *Limnodrilus rubripenis* Loden and *Psammoryctides californianus* Brinkhurst, two aquatic worms (Annelida: Oligochaeta: Tubificidae) new to Illinois. Trans. Illinois St. Acad. Sci. 73(3):36-38. [published 1981]

White, E. L. 1975. Factor analysis of drainage basin properties: Classification of flood behavior in terms of basin geomorphology. Water Resour. Bull. 11(4):676-687.

Whitley, L. S. 1968. The resistance of tubificid worms to three common pollutants. Hydrobiologia 32(1-2):193-205.

Whitley, L. S. 1973. The tubificid population of a small central Illinois stream system. Unpubl. rept., Illinois Natural History Survey. Unpaged.

Whitley, L. S. 1981. Aquatic Oligochaeta. *In*: A. R. Brigham, W. U. Brigham, and A. Gnilka. eds. Aquatic insects and oligochaetes of North and South Carolina. A study sponsored by Duke Power Company. *In press.*

Whitley, L. S., and T. N. Seng. 1976. Studies on the bacterial flora of tubificid worms. Hydrobiologia 48(1):79-83.

Whitley, L. S., and M. J. Wetzel. 1976. Aquatic Oligochaeta bibliography and faunal list. *In*: W. U. Brigham, ed. Illinois Coastal Zone Management Program: Component study of biological communities. Final Report. Limited distribution. Illinois Natural History Survey, Urbana.

Whitten, B. K., and C. J. Goodnight. 1966. Toxicity of some common insecticides to tubificids. J. Water Pollut. Control Fed. 38(2):227-235.

Wiederholm, T., and L. Eriksson. 1977. Effects of alcohol-preservation on the weight of some benthic invertebrates. Zoon 5(1):29-31.

Wieser, W., and S. Hinterleitner. 1980. Serum enzymes in rainbow trout as tools in the diagnosis of water quality. Bull. Environ. Contam. Toxicol. 25(2):188-193.

Wiggins, G. B. 1978. Caddisfly communities as indicators. [Abstract] Paper presented at the 26th annual meeting of the North American Benthological Society, 10 May. Winnepeg, Manitoba.

Wilber, C. G. 1969. The biological aspects of water pollution. Charles C. Thomas, Publisher. Springfield, IL 296 pp.

Wilhm, J. L. 1970. Range of diversity index in benthic macroinvertebrate populations. J. Water Pollut. Control Fed. 42(5, Part 2):R221-R224.

Wilhm, J. L. 1975. Biological indicators of pollution, pp. 375-402. *In*: B. A. Whitton, ed. River ecology. Univ. California Press, Berkeley.

Wilhm, J. L., and T. C. Dorris. 1966. Species diversity of benthic macro-invertebrates in a stream receiving domestic and oil refinery effluents. Amer. Midl. Nat. 76(2):427-449.

Wilhm, J. L., and T. C. Dorris. 1968. Biological parameters for water quality criteria. BioScience 18(6):477-481.

Williams, D. D. 1976. The recolonization mechanisms of stream benthos. Oikos 27(2):265-272.

Williams, D. D., and H. B. N. Hynes. 1974. The occurrence of benthos deep in the substratum of a stream. Freshw. Biol. 4(3):233-256.

Williams, D. D., and H. B. N. Hynes. 1976. The ecology of temporary streams. I. The faunas of two Canadian streams. Int. Revue ges. Hydrobiol. 61(6):761-787.

Williams, D. D., and H. B. N. Hynes. 1977. The ecology of temporary streams. II. General remarks on temporary streams. Int. Revue ges. Hydrobiol. 62(1):53-61.

Willman, H. B., and J. C. Frye. 1970. Pleistocene stratigraphy of Illinois. Bull. Illinois St. Geol. Surv. No. 94. 204 pp.

Wilson, R. S. 1980. Classifying rivers using chironomid pupal exuviae, pp. 209-216. *In*: D. A. Murray, ed. Chironomidae: Ecology, systematics, cytology, and physiology. Pergamon Press, New York.

Wilson, R. S., and P. L. Bright. 1973. The use of chironomid pupal exuviae for characterizing streams. Freshw. Biol. 3(3):283-302.

Wilson, R. S., and J. D. McGill. 1977. A new method of monitoring water quality in a stream receiving sewage effluent, using chironomid pupal exuviae. Water Res. 11(11):959-962.

Wirth, W. W., and A. Stone. 1956. Aquatic Diptera, pp. 372-482. *In*: R. L. Usinger, ed. Aquatic insects of California, with keys to North American genera and California species. Univ. California Press, Berkeley.

Wise, D. H., and M. C. Molles, Jr. 1979. Colonization of artificial substrates by stream insects: influence of substrate size and diversity. Hydrobiologia 65(1):69-74.

Wiśniewski, R. J. 1978. Effect of predators on Tubificidae groupings and their production in lakes. Ekol. Polska 26(4):493-512.

Wood, L. W. 1975. Role of oligochaetes in the circulation of water and solutes across the mud-water interface. Ver. Internat. Verein. Limnol. 19(2):1530-1533.

Woodwiss, F. S. 1964. The biological system of stream classification used by the Trent River Board. Chemy. Ind. 11:443-447.

Wright, S. 955. Limnological survey of western Lake Erie. U. S. Dept. Interior, Fish and Wildlife Service. Special Science Report - Fisheries No. 139. 341 pp.

Wuhrmann, K. 1974. Some problems and perspectives in applied limnology. Mitt. Internat. Verein. Limnol. 20:324-402.

Yongue, W. H., Jr., and J. Cairns, Jr. 1979. Effects of Radford army ammunition plant wastes on protozoan communities in the New River, Virginia. Rev. Biol. 11(1-4):65-78.

Zelinka, M., and P. Marvan. 1961. Zur Prazisierung der biologischen Klassifikation der Reinheit fließbender Gewasser. Arch. Hydrobiol. 57(3):389-407.

APPENDICES

Appendix 1. Photographs of sampling sites collected in the Cache River basin, southern Illinois, during 1976.

STATION 1

Cache River

STATION 2

Bradshaw Creek

STATION 3

Lick Creek

Appendix 1 (continued). Photographs of sampling sites collected in the Cache River basin, southern Illinois, during 1976.

STATION 4

Cache River

STATION 5

Lick Creek

STATION 6

Cache River

Appendix 1 (continued). Photographs of sampling sites collected in the Cache River basin, southern Illinois, during 1976.

STATION 7

Cave Creek

STATION 9

Cache River

STATION 8

Clifty Creek

Appendix 1 (continued). Photographs of sampling sites collected in the Cache River basin, southern Illinois, during 1976.

STATION 10

Main Ditch

STATION 11

Unnamed tributary of Lick Creek

STATION 12

Lick Creek

Appendix 1 (continued). Photographs of sampling sites collected in the Cache River basin, southern Illinois, during 1976.

STATION 13

Cache River

STATION 14

Unnamed tributary
of Cache River

STATION 15

Cypress Creek

Appendix 1 (concluded). Photographs of sampling sites collected in the Cache River basin, southern Illinois, during 1976.

STATION 16

Lingle Creek

STATION 17

Cooper Creek

Appendix 2. Checklist of aquatic Oligochaeta collected from Dutchman Creek, Cache River basin, southern Illinois during March, June, and July 1978.

BRANCHIOBDELLIDAE
Cambarincola Ellis

ENCHYTRAEIDAE

NAIDIDAE
Chaetogaster VonBaer
Dero (Dero) digitata (Muller)
Nais communis Piguet
Nais pardalis Piguet
Nais variabilis Piguet
Pristina leidyi Smith
Stylaria lacustris (Linnaeus)

TUBIFICIDAE
Aulodrilus pigueti Kowalewski
Branchiura sowerbyi Beddard
Ilyodrilus templetoni (Southern)
Limnodrilus new species
Limnodrilus angustipenis Brinkhurst and Cook
Limnodrilus hoffmeisteri Claparede
Limnodrilus hoffmeisteri variant

Appendix 3. Reagents used in the fixation and processing of aquatic Oligochaeta.

KAHLE'S FLUID

Ethanol (95%)	15 parts	or	300 ml
Tap Water	30 parts	or	600 ml
Formalin (37% Formaldehyde)*	6 parts	or	180 ml
Acetic acid	1 part	or	20 ml

*Formalin should be buffered with a cup of either magnesium carbonate or borax before use.

AMMAN'S LACTOPHENOL

Phenol Crystals**	100 gm
Lactic Acid	100 ml
Glycerin	200 ml
Tap Water	100 ml

**100 ml of liquified phenol may be substituted for phenol crystals.

Appendix 4. Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 1.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	18.	14.078	7.251	22.500	0.500
DISSOLVED OXYGEN	18.	10.317	2.301	13.000	7.100
DISSOLVED OXYGEN (% SAT)	18.	97.022	14.438	124.500	77.000
FREE CARBON DIOXIDE	18.	3.622	4.359	14.000	0.0
HYDROGEN ION CONC (PH)	18.	7.944	0.294	8.300	7.400
ALKALINITY (CACO3)	18.	134.278	19.952	159.000	77.000
TOT DIS ION SOL (NACL)	18.	316.833	50.242	421.000	227.000
EDTA HARDNESS (CACO3)	18.	150.944	25.614	173.000	105.000
TURBIDITY (JTU)	18.	78.389	29.637	130.000	31.000
TOTAL PHOSPHORUS (P)	18.	2.356	1.489	6.300	1.330
SOL ORTHOPHOSPHATE (P)	18.	0.633	0.522	1.540	0.200
NITRATE (N)	18.	1.166	0.484	1.820	0.350
NITRITE (N)	18.	0.150	0.080	0.320	0.050
AMMONIA (N)	18.	0.146	0.124	0.450	0.030
ORGANIC NITROGEN (N)	18.	0.582	0.215	0.900	0.150
TOTAL NITROGEN (N)	18.	2.044	0.566	2.830	1.000
TOTAL IRON	18.	1.473	0.632	2.400	0.460
FERROUS IRON	18.	0.266	0.219	0.890	0.080
TOTAL RESIDUE (180 C)	18.	422.667	107.594	608.000	212.000
DIS RESIDUE (180 C)	18.	310.444	64.456	404.000	200.000
PART RESIDUE (180 C)	18.	112.222	93.250	300.000	12.000
SULFATE (S)	18.	17.861	5.246	26.400	12.300
CHLORIDE	18.	27.450	13.967	55.200	11.200
SILICA (SIO2)	18.	13.954	1.325	15.700	11.400
TOTAL ARSENIC*	15.	0.018	0.004	0.020	0.010
TOTAL BARIUM*	15.	0.189	0.180	0.600	0.090
TOTAL BORON*	15.	2.400	1.056	4.000	1.000
TOTAL CADMIUM*	15.	0.010	0.000	0.010	0.010
TOTAL CHROMIUM*	15.	0.035	0.035	0.160	0.020
TOTAL COPPER*	15.	0.023	0.005	0.030	0.020
TOTAL LEAD*	15.	0.118	0.043	0.200	0.090
TOTAL MANGANESE*	15.	0.382	0.062	0.510	0.300
TOTAL MERCURY*	15.	0.010	0.000	0.010	0.010
TOTAL NICKEL*	15.	0.068	0.004	0.070	0.060
TOTAL SELENIUM*	13.	0.022	0.006	0.030	0.010
TOTAL SILVER*	15.	0.014	0.005	0.020	0.010
TOTAL ZINC*	15.	0.022	0.010	0.040	0.010
FLOW (M3/SEC)	6.	0.617	0.387	1.200	0.170
TOTAL COLIFORM (#/.1 L)	18.	930.444	2305.469	7300.000	0.0
FECAL COLIFORM (#/.1 L)	18.	253.556	159.378	500.000	0.0
FECAL STREP (#/.1 L)	18.	150.667	170.168	544.000	2.000

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 2.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	18.	14.006	7.762	23.300	0.200
DISSOLVED OXYGEN	18.	9.967	2.344	13.400	5.400
DISSOLVED OXYGEN (% SAT)	18.	93.733	15.672	129.300	58.700
FREE CARBON DIOXIDE	18.	4.422	1.612	7.500	2.000
HYDROGEN ION CONC (PH)	18.	7.683	0.220	8.100	7.400
ALKALINITY (CACO3)	18.	95.667	27.592	124.000	42.000
TOT DIS ION SOL (NACL)	18.	208.889	20.251	245.000	173.000
EDTA HARDNESS (CACO3)	18.	104.667	22.734	131.000	60.000
TURBIDITY (JTU)	18.	36.000	8.317	50.000	23.000
TOTAL PHOSPHORUS (P)	18.	0.289	0.068	0.440	0.200
SOL ORTHOPHOSPHATE (P)	18.	0.031	0.036	0.120	0.010
NITRATE (N)	18.	0.122	0.130	0.400	0.010
NITRITE (N)	18.	0.077	0.051	0.130	0.010
AMMONIA (N)	18.	0.062	0.037	0.150	0.010
ORGANIC NITROGEN (N)	18.	0.674	0.962	3.350	0.100
TOTAL NITROGEN (N)	18.	0.936	1.113	3.950	0.300
TOTAL IRON	18.	0.996	0.370	1.400	0.260
FERROUS IRON	18.	0.254	0.118	0.540	0.110
TOTAL RESIDUE (180 C)	18.	250.667	64.876	380.000	164.000
DIS RESIDUE (180 C)	18.	186.889	38.484	260.000	116.000
PART RESIDUE (180 C)	18.	63.778	54.163	192.000	16.000
SULFATE (S)	18.	14.211	4.674	24.200	9.900
CHLORIDE	18.	8.428	2.225	11.300	5.200
SILICA (SIO2)	18.	10.197	2.277	13.300	5.600
TOTAL ARSENIC*	15.	0.018	0.004	0.020	0.010
TOTAL BARIUM*	15.	0.175	0.179	0.700	0.090
TOTAL BORON*	15.	2.400	1.056	4.000	1.000
TOTAL CADMIUM*	15.	0.010	0.000	0.010	0.010
TOTAL CHROMIUM*	15.	0.024	0.005	0.030	0.020
TOTAL COPPER*	15.	0.022	0.004	0.030	0.020
TOTAL LEAD*	15.	0.118	0.043	0.200	0.090
TOTAL MANGANESE*	15.	0.386	0.127	0.630	0.270
TOTAL MERCURY*	15.	0.010	0.000	0.010	0.010
TOTAL NICKEL*	15.	0.069	0.005	0.080	0.060
TOTAL SELENIUM*	15.	0.020	0.007	0.030	0.010
TOTAL SILVER*	15.	0.012	0.004	0.020	0.010
TOTAL ZINC*	15.	0.019	0.013	0.060	0.010
FLOW (M3/SEC)	6.	0.083	0.063	0.150	0.0
TOTAL COLIFORM (#/.1 L)	18.	883.111	3279.862	14000.000	0.0
FECAL COLIFORM (#/.1 L)	17.	63.412	93.169	260.000	0.0
FECAL STREP (#/.1 L)	16.	74.625	87.656	266.000	0.0

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 3.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	18.	11.906	7.026	22.200	1.200
DISSOLVED OXYGEN	18.	8.467	2.584	11.600	4.600
DISSOLVED OXYGEN (% SAT)	18.	75.317	17.617	98.500	52.000
FREE CARBON DIOXIDE	18.	10.356	4.610	16.000	4.400
HYDROGEN ION CONC (PH)	18.	7.444	0.189	7.800	7.200
ALKALINITY (CACO3)	18.	118.389	26.789	152.000	71.000
TOT DIS ION SOL (NACL)	18.	292.278	132.715	583.000	201.000
EDTA HARDNESS (CACO3)	18.	125.222	32.834	173.000	78.000
TURBIDITY (JTU)	18.	26.000	13.218	62.000	14.000
TOTAL PHOSPHORUS (P)	18.	0.181	0.113	0.390	0.010
SOL ORTHOPHOSPHATE (P)	18.	0.012	0.004	0.020	0.010
NITRATE (N)	18.	0.107	0.086	0.230	0.010
NITRITE (N)	18.	0.066	0.044	0.120	0.010
AMMONIA (N)	18.	0.051	0.034	0.120	0.010
ORGANIC NITROGEN (N)	18.	0.283	0.163	0.670	0.120
TOTAL NITROGEN (N)	18.	0.506	0.212	0.850	0.280
TOTAL IRON	18.	0.679	0.231	1.200	0.330
FERROUS IRON	18.	0.229	0.084	0.390	0.100
TOTAL RESIDUE (180 C)	18.	347.333	148.405	680.000	192.000
DIS RESIDUE (180 C)	18.	269.556	144.171	596.000	152.000
PART RESIDUE (180 C)	18.	77.778	59.650	188.000	4.000
SULFATE (S)	18.	29.039	35.296	111.000	10.100
CHLORIDE	18.	13.239	8.824	32.400	5.100
SILICA (SIO2)	18.	12.659	1.859	16.500	10.500
TOTAL ARSENIC*	15.	0.018	0.004	0.020	0.010
TOTAL BARIUM*	15.	0.235	0.298	1.100	0.090
TOTAL BORON*	15.	2.400	1.056	4.000	1.000
TOTAL CADMIUM*	15.	0.010	0.000	0.010	0.010
TOTAL CHROMIUM*	15.	0.023	0.005	0.030	0.020
TOTAL COPPER*	15.	0.022	0.004	0.030	0.020
TOTAL LEAD*	15.	0.118	0.043	0.200	0.090
TOTAL MANGANESE*	15.	0.627	0.310	1.170	0.370
TOTAL MERCURY*	15.	0.010	0.000	0.010	0.010
TOTAL NICKEL*	15.	0.068	0.004	0.070	0.060
TOTAL SELENIUM*	14.	0.021	0.006	0.030	0.010
TOTAL SILVER*	15.	0.014	0.005	0.020	0.010
TOTAL ZINC*	15.	0.032	0.016	0.080	0.010
FLOW (M3/SEC)	6.	0.070	0.057	0.180	0.020
TOTAL COLIFORM (#/.1 L)	18.	135.778	166.764	460.000	0.0
FECAL COLIFORM (#/.1 L)	18.	187.444	252.212	720.000	0.0
FECAL STREP (#/.1 L)	18.	114.889	94.476	252.000	12.000

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 4.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	18.	14.311	7.196	21.800	0.300
DISSOLVED OXYGEN	18.	8.239	2.436	11.800	5.100
DISSOLVED OXYGEN (% SAT)	18.	77.167	14.395	98.800	56.500
FREE CARBON DIOXIDE	18.	6.344	4.694	15.500	0.0
HYDROGEN ION CONC (PH)	18.	7.706	0.381	8.500	7.300
ALKALINITY (CACO3)	18.	119.389	33.889	150.000	49.000
TOT DIS ION SOL (NACL)	18.	278.611	61.086	394.000	194.000
EDTA HARDNESS (CACO3)	18.	144.278	33.390	201.000	96.000
TURBIDITY (JTU)	18.	79.111	35.627	158.000	42.000
TOTAL PHOSPHORUS (P)	18.	1.070	0.294	1.610	0.640
SOL ORTHOPHOSPHATE (P)	18.	0.149	0.134	0.450	0.050
NITRATE (N)	18.	0.787	0.667	2.120	0.090
NITRITE (N)	18.	0.147	0.076	0.250	0.010
AMMONIA (N)	18.	0.104	0.073	0.300	0.020
ORGANIC NITROGEN (N)	18.	0.368	0.140	0.620	0.050
TOTAL NITROGEN (N)	18.	1.406	0.712	2.780	0.450
TOTAL IRON	18.	1.504	0.596	2.600	0.770
FERROUS IRON	18.	0.287	0.144	0.590	0.130
TOTAL RESIDUE (180 C)	18.	351.556	67.142	456.000	228.000
DIS RESIDUE (180 C)	18.	282.667	57.329	372.000	208.000
PART RESIDUE (180 C)	18.	68.889	44.427	164.000	8.000
SULFATE (S)	18.	16.472	5.790	24.700	10.100
CHLORIDE	18.	22.594	15.505	57.200	9.700
SILICA (SIO2)	18.	11.907	1.829	14.600	9.200
TOTAL ARSENIC*	15.	0.018	0.004	0.020	0.010
TOTAL BARIUM*	15.	0.195	0.194	0.600	0.090
TOTAL BORON*	15.	2.400	1.056	4.000	1.000
TOTAL CADMIUM*	15.	0.010	0.000	0.010	0.010
TOTAL CHROMIUM*	15.	0.025	0.013	0.070	0.020
TOTAL COPPER*	15.	0.022	0.004	0.030	0.020
TOTAL LEAD*	15.	0.118	0.043	0.200	0.090
TOTAL MANGANESE*	15.	0.393	0.103	0.550	0.240
TOTAL MERCURY*	15.	0.010	0.000	0.010	0.010
TOTAL NICKEL*	15.	0.069	0.006	0.080	0.060
TOTAL SELENIUM*	15.	0.020	0.007	0.030	0.010
TOTAL SILVER*	15.	0.012	0.004	0.020	0.010
TOTAL ZINC*	15.	0.023	0.007	0.030	0.010
FLOW (M3/SEC)	6.	0.142	0.256	0.660	0.010
TOTAL COLIFORM (#/.1 L)	18.	176.444	467.702	2000.000	0.0
FECAL COLIFORM (#/.1 L)	18.	263.889	291.500	890.000	0.0
FECAL STREP (#/.1 L)	17.	184.000	232.862	678.000	2.000

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 5.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	18.	13.578	6.170	21.000	3.700
DISSOLVED OXYGEN	18.	8.267	3.340	12.900	3.000
DISSOLVED OXYGEN (% SAT)	18.	75.744	24.923	111.000	33.000
FREE CARBON DIOXIDE	18.	5.200	3.823	11.800	0.0
HYDROGEN ION CONC (PH)	18.	7.700	0.526	8.800	7.300
ALKALINITY (CACO3)	18.	77.722	28.315	119.000	35.000
TOT DIS ION SOL (NACL)	18.	188.444	32.643	233.000	129.000
EDTA HARDNESS (CACO3)	18.	94.444	26.402	124.000	57.000
TURBIDITY (JTU)	18.	62.778	19.931	100.000	37.000
TOTAL PHOSPHORUS (P)	18.	0.306	0.069	0.400	0.190
SOL ORTHOPHOSPHATE (P)	18.	0.026	0.027	0.120	0.010
NITRATE (N)	18.	0.101	0.096	0.310	0.010
NITRITE (N)	18.	0.061	0.041	0.120	0.010
AMMONIA (N)	18.	0.059	0.026	0.100	0.020
ORGANIC NITROGEN (N)	18.	0.308	0.147	0.630	0.100
TOTAL NITROGEN (N)	18.	0.529	0.193	0.910	0.260
TOTAL IRON	18.	1.577	0.620	2.500	0.430
FERROUS IRON	18.	0.347	0.187	0.890	0.210
TOTAL RESIDUE (180 C)	18.	263.556	76.400	424.000	160.000
DIS RESIDUE (180 C)	18.	185.111	59.453	292.000	92.000
PART RESIDUE (180 C)	18.	78.444	48.800	160.000	16.000
SULFATE (S)	18.	11.961	5.688	24.200	6.000
CHLORIDE	18.	9.222	2.780	13.100	5.500
SILICA (SIO2)	18.	11.475	1.527	15.300	10.000
TOTAL ARSENIC*	15.	0.018	0.004	0.020	0.010
TOTAL BARIUM*	15.	0.189	0.180	0.600	0.090
TOTAL BORON*	15.	2.400	1.056	4.000	1.000
TOTAL CADMIUM*	15.	0.010	0.000	0.010	0.010
TOTAL CHROMIUM*	15.	0.025	0.011	0.050	0.020
TOTAL COPPER*	15.	0.022	0.004	0.030	0.020
TOTAL LEAD*	15.	0.118	0.043	0.200	0.090
TOTAL MANGANESE*	15.	0.743	0.606	1.900	0.330
TOTAL MERCURY*	15.	0.010	0.000	0.010	0.010
TOTAL NICKEL*	15.	0.068	0.004	0.070	0.060
TOTAL SELENIUM*	15.	0.020	0.007	0.030	0.010
TOTAL SILVER*	15.	0.013	0.005	0.020	0.010
TOTAL ZINC*	15.	0.023	0.014	0.060	0.010
FLOW (M3/SEC)	6.	0.275	0.337	0.930	0.010
TOTAL COLIFORM (#/.1 L)	18.	410.889	1024.919	4400.000	0.0
FECAL COLIFORM (#/.1 L)	16.	236.250	359.565	1200.000	0.0
FECAL STREP (#/.1 L)	17.	174.706	260.464	726.000	0.0

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 6.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	18.	13.611	5.994	21.000	3.800
DISSOLVED OXYGEN	18.	7.333	2.329	10.500	4.200
DISSOLVED OXYGEN (% SAT)	18.	67.628	14.525	79.900	46.500
FREE CARBON DIOXIDE	18.	3.683	2.237	6.000	0.0
HYDROGEN ION CONC (PH)	18.	7.778	0.412	8.600	7.400
ALKALINITY (CACO3)	18.	76.333	25.613	111.000	42.000
TOT DIS ION SOL (NACL)	18.	216.278	77.212	379.000	105.000
EDTA HARDNESS (CACO3)	18.	96.667	44.060	178.000	39.000
TURBIDITY (JTU)	18.	225.667	109.890	365.000	63.000
TOTAL PHOSPHORUS (P)	18.	0.883	0.311	1.400	0.360
SOL ORTHOPHOSPHATE (P)	18.	0.049	0.048	0.140	0.010
NITRATE (N)	18.	0.267	0.345	0.980	0.010
NITRITE (N)	18.	0.095	0.056	0.150	0.010
AMMONIA (N)	18.	0.091	0.043	0.250	0.050
ORGANIC NITROGEN (N)	18.	0.593	0.326	1.500	0.010
TOTAL NITROGEN (N)	18.	1.046	0.538	2.200	0.360
TOTAL IRON	18.	3.141	1.398	5.600	1.410
FERROUS IRON	18.	0.631	0.171	0.940	0.470
TOTAL RESIDUE (180 C)	18.	324.667	81.518	488.000	220.000
DIS RESIDUE (180 C)	18.	212.667	60.356	312.000	120.000
PART RESIDUE (180 C)	18.	112.000	55.832	224.000	32.000
SULFATE (S)	18.	13.533	6.715	25.400	6.700
CHLORIDE	18.	16.317	11.426	39.800	5.600
SILICA (SIO2)	18.	11.239	3.054	18.100	7.600
TOTAL ARSENIC*	15.	0.018	0.004	0.020	0.010
TOTAL BARIUM*	15.	0.215	0.241	0.800	0.090
TOTAL BORON*	15.	2.400	1.056	4.000	1.000
TOTAL CADMIUM*	15.	0.011	0.003	0.020	0.010
TOTAL CHROMIUM*	15.	0.026	0.009	0.050	0.020
TOTAL COPPER*	15.	0.022	0.004	0.030	0.020
TOTAL LEAD*	15.	0.118	0.043	0.200	0.090
TOTAL MANGANESE*	15.	0.660	0.258	1.140	0.380
TOTAL MERCURY*	15.	0.010	0.000	0.010	0.010
TOTAL NICKEL*	15.	0.068	0.004	0.070	0.060
TOTAL SELENIUM*	15.	0.020	0.007	0.030	0.010
TOTAL SILVER*	15.	0.014	0.005	0.020	0.010
TOTAL ZINC*	15.	0.033	0.017	0.080	0.010
FLOW (M3/SEC)	6.	1.587	2.252	5.540	0.010
TOTAL COLIFORM (#/.1 L)	17.	20.000	37.142	100.000	0.0
FECAL COLIFORM (#/.1 L)	18.	985.444	1823.636	5700.000	0.0
FECAL STREP (#/.1 L)	18.	139.556	169.527	512.000	0.0

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 7.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	18.	15.161	6.795	24.800	3.900
DISSOLVED OXYGEN	18.	8.922	2.284	11.600	4.900
DISSOLVED OXYGEN (% SAT)	18.	85.483	13.522	99.000	58.000
FREE CARBON DIOXIDE	18.	7.144	8.533	28.000	0.0
HYDROGEN ION CONC (PH)	18.	7.533	0.691	8.900	6.600
ALKALINITY (CACO3)	18.	51.889	16.984	79.000	29.000
TOT DIS ION SOL (NACL)	18.	184.722	43.524	274.000	129.000
EDTA HARDNESS (CACO3)	18.	77.000	26.357	134.000	45.000
TURBIDITY (JTU)	18.	44.889	11.045	64.000	29.000
TOTAL PHOSPHORUS (P)	18.	0.266	0.129	0.440	0.010
SOL ORTHOPHOSPHATE (P)	18.	0.017	0.013	0.050	0.010
NITRATE (N)	18.	0.084	0.104	0.320	0.010
NITRITE (N)	18.	0.047	0.032	0.090	0.010
AMMONIA (N)	18.	0.062	0.036	0.140	0.010
ORGANIC NITROGEN (N)	18.	0.341	0.183	0.740	0.130
TOTAL NITROGEN (N)	18.	0.534	0.258	1.180	0.260
TOTAL IRON	18.	1.237	0.453	1.800	0.380
FERROUS IRON	18.	0.325	0.177	0.740	0.140
TOTAL RESIDUE (180 C)	18.	223.778	61.625	340.000	140.000
DIS RESIDUE (180 C)	18.	172.889	44.680	268.000	96.000
PART RESIDUE (180 C)	18.	50.889	41.018	140.000	4.000
SULFATE (S)	18.	16.022	5.946	27.500	10.300
CHLORIDE	18.	13.978	6.110	26.000	7.900
SILICA (SIO2)	18.	9.971	2.924	13.300	4.300
TOTAL ARSENIC*	15.	0.018	0.004	0.020	0.010
TOTAL BARIUM*	15.	0.129	0.060	0.300	0.090
TOTAL BORON*	15.	2.400	1.056	4.000	1.000
TOTAL CADMIUM*	15.	0.010	0.000	0.010	0.010
TOTAL CHROMIUM*	15.	0.027	0.011	0.050	0.020
TOTAL COPPER*	15.	0.022	0.004	0.030	0.020
TOTAL LEAD*	15.	0.118	0.043	0.200	0.090
TOTAL MANGANESE*	15.	0.765	0.532	1.810	0.440
TOTAL MERCURY*	15.	0.010	0.000	0.010	0.010
TOTAL NICKEL*	15.	0.069	0.005	0.080	0.060
TOTAL SELENIUM*	15.	0.020	0.007	0.030	0.010
TOTAL SILVER*	15.	0.015	0.005	0.020	0.010
TOTAL ZINC*	15.	0.027	0.010	0.050	0.010
FLOW (M3/SEC)	6.	0.052	0.045	0.120	0.010
TOTAL COLIFORM (#/.1 L)	18.	63.556	114.970	400.000	0.0
FECAL COLIFORM (#/.1 L)	17.	98.588	132.159	500.000	0.0
FECAL STREP (#/.1 L)	17.	62.353	85.435	260.000	0.0

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 8.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	18.	16.461	6.547	25.600	5.000
DISSOLVED OXYGEN	18.	10.956	2.076	15.000	8.300
DISSOLVED OXYGEN (% SAT)	18.	112.044	31.355	172.000	68.800
FREE CARBON DIOXIDE	18.	1.094	1.044	3.100	0.0
HYDROGEN ION CONC (PH)	18.	8.200	0.751	9.700	7.500
ALKALINITY (CACO3)	18.	35.000	9.443	45.000	18.000
TOT DIS ION SOL (NACL)	18.	164.944	21.757	199.000	135.000
EDTA HARDNESS (CACO3)	18.	59.833	8.361	74.000	48.000
TURBIDITY (JTU)	18.	77.778	84.628	265.000	12.500
TOTAL PHOSPHORUS (P)	18.	0.414	0.237	0.810	0.150
SOL ORTHOPHOSPHATE (P)	18.	0.023	0.020	0.060	0.010
NITRATE (N)	18.	0.746	0.645	1.860	0.030
NITRITE (N)	18.	0.106	0.075	0.200	0.010
AMMONIA (N)	18.	0.083	0.048	0.190	0.030
ORGANIC NITROGEN (N)	18.	0.606	0.508	1.630	0.070
TOTAL NITROGEN (N)	18.	1.541	0.946	2.840	0.400
TOTAL IRON	18.	1.447	1.258	4.200	0.270
FERROUS IRON	18.	0.296	0.084	0.420	0.130
TOTAL RESIDUE (180 C)	18.	224.000	50.764	340.000	160.000
DIS RESIDUE (180 C)	18.	149.333	54.015	232.000	56.000
PART RESIDUE (180 C)	18.	74.667	57.181	216.000	12.000
SULFATE (S)	18.	17.372	6.126	29.900	10.500
CHLORIDE	18.	14.122	5.698	25.200	7.800
SILICA (SIO2)	18.	8.814	4.027	13.500	1.300
TOTAL ARSENIC*	15.	0.018	0.004	0.020	0.010
TOTAL BARIUM*	15.	0.129	0.060	0.300	0.090
TOTAL BORON*	15.	2.400	1.056	4.000	1.000
TOTAL CADMIUM*	15.	0.010	0.000	0.010	0.010
TOTAL CHROMIUM*	15.	0.032	0.021	0.090	0.020
TOTAL COPPER*	15.	0.023	0.005	0.030	0.020
TOTAL LEAD*	15.	0.118	0.043	0.200	0.090
TOTAL MANGANESE*	15.	0.399	0.196	0.580	0.050
TOTAL MERCURY*	15.	0.010	0.000	0.010	0.010
TOTAL NICKEL*	15.	0.068	0.004	0.070	0.060
TOTAL SELENIUM*	15.	0.020	0.007	0.030	0.010
TOTAL SILVER*	15.	0.013	0.005	0.020	0.010
TOTAL ZINC*	15.	0.030	0.013	0.050	0.010
FLOW (M3/SEC)	6.	0.652	1.363	3.430	0.010
TOTAL COLIFORM (#/.1 L)	15.	7.467	16.008	50.000	0.0
FECAL COLIFORM (#/.1 L)	15.	683.200	1357.600	4700.000	0.0
FECAL STREP (#/.1 L)	15.	155.200	291.109	734.000	0.0

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 9.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	18.	13.878	5.521	21.800	4.500
DISSOLVED OXYGEN	18.	5.156	2.160	8.500	1.000
DISSOLVED OXYGEN (% SAT)	18.	47.622	16.165	65.600	10.900
FREE CARBON DIOXIDE	18.	18.617	16.160	50.000	2.900
HYDROGEN ION CONC (PH)	18.	7.022	0.389	7.600	6.300
ALKALINITY (CACO3)	18.	61.722	24.058	108.000	42.000
TOT DIS ION SOL (NACL)	18.	168.556	66.565	289.000	101.000
EDTA HARDNESS (CACO3)	18.	78.667	54.383	195.000	30.000
TURBIDITY (JTU)	18.	211.389	134.461	410.000	30.000
TOTAL PHOSPHORUS (P)	18.	1.121	0.329	1.740	0.570
SOL ORTHOPHOSPHATE (P)	18.	0.053	0.039	0.130	0.010
NITRATE (N)	18.	0.199	0.364	1.000	0.010
NITRITE (N)	18.	0.071	0.066	0.170	0.010
AMMONIA (N)	18.	0.163	0.088	0.450	0.050
ORGANIC NITROGEN (N)	18.	0.839	0.480	1.820	0.150
TOTAL NITROGEN (N)	18.	1.272	0.785	3.170	0.440
TOTAL IRON	18.	3.166	1.709	6.000	0.990
FERROUS IRON	18.	0.767	0.327	1.300	0.320
TOTAL RESIDUE (180 C)	18.	261.556	44.672	368.000	208.000
DIS RESIDUE (180 C)	18.	154.667	30.277	228.000	104.000
PART RESIDUE (180 C)	18.	106.889	50.500	212.000	12.000
SULFATE (S)	18.	7.567	3.803	15.200	2.500
CHLORIDE	18.	9.039	2.585	13.600	6.400
SILICA (SIO2)	18.	12.379	3.455	18.800	8.200
TOTAL ARSENIC*	15.	0.018	0.004	0.020	0.010
TOTAL BARIUM*	15.	0.149	0.099	0.400	0.090
TOTAL BORON*	15.	2.400	1.056	4.000	1.000
TOTAL CADMIUM*	15.	0.010	0.000	0.010	0.010
TOTAL CHROMIUM*	15.	0.027	0.010	0.050	0.020
TOTAL COPPER*	15.	0.023	0.006	0.040	0.020
TOTAL LEAD*	15.	0.118	0.043	0.200	0.090
TOTAL MANGANESE*	15.	0.943	0.764	2.380	0.160
TOTAL MERCURY*	15.	0.010	0.000	0.010	0.010
TOTAL NICKEL*	15.	0.068	0.004	0.070	0.060
TOTAL SELENIUM*	15.	0.020	0.007	0.030	0.010
TOTAL SILVER*	15.	0.013	0.005	0.020	0.010
TOTAL ZINC*	15.	0.035	0.015	0.060	0.010
FLOW (M3/SEC)	6.	1.312	1.874	4.050	0.020
TOTAL COLIFORM (#/.1 L)	18.	45.889	86.123	250.000	0.0
FECAL COLIFORM (#/.1 L)	18.	1792.889	4204.277	15200.000	0.0
FECAL STREP (#/.1 L)	18.	230.333	412.593	1158.000	4.000

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 10.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	18.	15.828	6.566	25.800	5.500
DISSOLVED OXYGEN	18.	8.067	1.510	10.000	5.800
DISSOLVED OXYGEN (% SAT)	18.	79.400	10.706	102.000	64.400
FREE CARBON DIOXIDE	18.	9.167	8.944	28.000	2.000
HYDROGEN ION CONC (PH)	18.	7.244	0.326	7.700	6.800
ALKALINITY (CACO3)	18.	58.444	26.210	87.000	18.000
TOT DIS ION SOL (NACL)	18.	173.500	24.305	199.000	137.000
EDTA HARDNESS (CACO3)	18.	74.944	16.257	95.000	53.000
TURBIDITY (JTU)	18.	277.278	86.704	425.000	125.000
TOTAL PHOSPHORUS (P)	18.	1.107	0.371	1.760	0.660
SOL ORTHOPHOSPHATE (P)	18.	0.019	0.010	0.040	0.010
NITRATE (N)	18.	0.924	0.688	1.810	0.050
NITRITE (N)	18.	0.103	0.076	0.240	0.010
AMMONIA (N)	18.	0.084	0.056	0.230	0.010
ORGANIC NITROGEN (N)	18.	0.638	0.512	2.030	0.010
TOTAL NITROGEN (N)	18.	1.748	1.131	3.940	0.340
TOTAL IRON	18.	3.647	1.785	7.000	1.380
FERROUS IRON	18.	0.974	0.594	2.400	0.300
TOTAL RESIDUE (180 C)	18.	289.556	82.389	428.000	172.000
DIS RESIDUE (180 C)	18.	157.333	56.000	260.000	80.000
PART RESIDUE (180 C)	18.	132.222	86.255	276.000	16.000
SULFATE (S)	18.	11.083	1.831	14.400	8.300
CHLORIDE	18.	10.333	2.704	15.300	6.600
SILICA (SIO2)	18.	15.022	4.497	21.800	8.500
TOTAL ARSENIC*	15.	0.018	0.004	0.020	0.010
TOTAL BARIUM*	15.	0.169	0.149	0.600	0.090
TOTAL BORON*	15.	2.400	1.056	4.000	1.000
TOTAL CADMIUM*	15.	0.010	0.000	0.010	0.010
TOTAL CHROMIUM*	15.	0.029	0.011	0.060	0.020
TOTAL COPPER*	15.	0.024	0.005	0.030	0.020
TOTAL LEAD*	15.	0.118	0.043	0.200	0.090
TOTAL MANGANESE*	15.	0.695	0.165	0.890	0.400
TOTAL MERCURY*	15.	0.010	0.000	0.010	0.010
TOTAL NICKEL*	15.	0.068	0.004	0.070	0.060
TOTAL SELENIUM*	15.	0.020	0.007	0.030	0.010
TOTAL SILVER*	15.	0.013	0.005	0.020	0.010
TOTAL ZINC*	15.	0.037	0.009	0.050	0.020
FLOW (M3/SEC)	6.	0.740	0.815	2.330	0.120
TOTAL COLIFORM (#/.1 L)	15.	3.467	7.386	20.000	0.0
FECAL COLIFORM (#/.1 L)	18.	396.889	442.230	1700.000	0.0
FECAL STREP (#/.1 L)	17.	278.824	319.279	926.000	12.000

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 11.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	12.	21.050	5.459	29.500	14.800
DISSOLVED OXYGEN	12.	9.525	1.559	11.400	6.800
DISSOLVED OXYGEN (% SAT)	12.	103.675	11.349	126.400	81.900
FREE CARBON DIOXIDE	12.	1.625	1.037	2.900	0.0
HYDROGEN ION CONC (PH)	12.	8.117	0.319	8.400	7.600
ALKALINITY (CACO3)	12.	147.000	61.921	187.000	45.000
TOT DIS ION SOL (MACL)	12.	286.333	35.163	345.000	251.000
EDTA HARDNESS (CACO3)	12.	185.167	14.801	204.000	164.000
TURBIDITY (JTU)	12.	49.583	17.532	89.000	25.000
TOTAL PHOSPHORUS (P)	12.	0.360	0.077	0.470	0.240
SOL ORTHOPHOSPHATE (P)	12.	0.033	0.042	0.110	0.010
NITRATE (N)	12.	0.205	0.148	0.370	0.030
NITRITE (N)	12.	0.053	0.031	0.100	0.010
AMMONIA (N)	12.	0.042	0.039	0.160	0.010
ORGANIC NITROGEN (N)	12.	0.309	0.235	0.860	0.040
TOTAL NITROGEN (N)	12.	0.609	0.345	1.270	0.240
TOTAL IRON	12.	1.082	0.438	2.100	0.580
FERROUS IRON	12.	0.258	0.126	0.470	0.130
TOTAL RESIDUE (180 C)	12.	335.000	46.244	380.000	256.000
DIS RESIDUE (180 C)	12.	270.000	48.015	336.000	196.000
PART RESIDUE (180 C)	12.	65.000	61.759	184.000	4.000
SULFATE (S)	12.	13.933	7.928	27.900	7.700
CHLORIDE	12.	9.508	2.409	12.000	5.800
SILICA (SIO2)	12.	15.387	1.206	17.000	13.100
TOTAL ARSENIC*	0.	---	---	---	---
TOTAL BARIUM*	0.	---	---	---	---
TOTAL BORON*	0.	---	---	---	---
TOTAL CADMIUM*	0.	---	---	---	---
TOTAL CHROMIUM*	0.	---	---	---	---
TOTAL COPPER*	0.	---	---	---	---
TOTAL LEAD*	0.	---	---	---	---
TOTAL MANGANESE*	0.	---	---	---	---
TOTAL MERCURY*	0.	---	---	---	---
TOTAL NICKEL*	0.	---	---	---	---
TOTAL SELENIUM*	0.	---	---	---	---
TOTAL SILVER*	0.	---	---	---	---
TOTAL ZINC*	0.	---	---	---	---
FLOW (M3/SEC)	4.	0.035	0.026	0.070	0.010
TOTAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL STREP (#/.1 L)	0.	---	---	---	---

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 12.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	12.	19.300	4.475	25.500	13.700
DISSOLVED OXYGEN	12.	10.467	0.656	11.800	9.500
DISSOLVED OXYGEN (% SAT)	12.	112.333	9.952	132.600	101.000
FREE CARBON DIOXIDE	12.	1.708	1.165	3.400	0.0
HYDROGEN ION CONC (PH)	12.	8.050	0.373	8.400	7.400
ALKALINITY (CACO3)	12.	118.750	46.761	151.000	41.000
TOT DIS ION SOL (NACL)	12.	242.167	27.967	282.000	201.000
EDTA HARDNESS (CACO3)	12.	152.750	14.967	178.000	140.000
TURBIDITY (JTU)	12.	12.083	1.490	15.000	10.000
TOTAL PHOSPHORUS (P)	12.	0.206	0.091	0.380	0.070
SOL ORTHOPHOSPHATE (P)	12.	0.017	0.012	0.040	0.010
NITRATE (N)	12.	0.054	0.044	0.140	0.010
NITRITE (N)	12.	0.013	0.007	0.030	0.010
AMMONIA (N)	12.	0.018	0.010	0.040	0.010
ORGANIC NITROGEN (N)	12.	0.332	0.270	0.990	0.160
TOTAL NITROGEN (N)	12.	0.417	0.278	1.030	0.220
TOTAL IRON	12.	0.263	0.075	0.440	0.160
FERROUS IRON	12.	0.122	0.104	0.340	0.010
TOTAL RESIDUE (180 C)	12.	257.333	45.522	328.000	188.000
DIS RESIDUE (180 C)	12.	201.333	49.414	280.000	136.000
PART RESIDUE (180 C)	12.	56.000	34.662	120.000	8.000
SULFATE (S)	12.	11.542	5.768	23.500	7.500
CHLORIDE	12.	8.575	2.360	12.100	5.800
SILICA (SIO2)	12.	11.063	0.766	12.100	10.000
TOTAL ARSENIC*	0.	---	---	---	---
TOTAL BARIUM*	0.	---	---	---	---
TOTAL BORON*	0.	---	---	---	---
TOTAL CADMIUM*	0.	---	---	---	---
TOTAL CHROMIUM*	0.	---	---	---	---
TOTAL COPPER*	0.	---	---	---	---
TOTAL LEAD*	0.	---	---	---	---
TOTAL MANGANESE*	0.	---	---	---	---
TOTAL MERCURY*	0.	---	---	---	---
TOTAL NICKEL*	0.	---	---	---	---
TOTAL SELENIUM*	0.	---	---	---	---
TOTAL SILVER*	0.	---	---	---	---
TOTAL ZINC*	0.	---	---	---	---
FLOW (M3/SEC)	4.	0.058	0.061	0.120	0.001
TOTAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL STREP (#/.1 L)	0.	---	---	---	---

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 13.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	12.	18.350	2.363	21.000	15.000
DISSOLVED OXYGEN	12.	8.092	1.525	9.700	5.600
DISSOLVED OXYGEN (% SAT)	12.	84.975	15.350	105.200	62.100
FREE CARBON DIOXIDE	12.	5.067	2.016	8.200	2.100
HYDROGEN ION CONC (PH)	12.	7.650	0.145	7.800	7.400
ALKALINITY (CACO3)	12.	119.000	46.863	150.000	41.000
TOT DIS ION SOL (NACL)	12.	321.833	72.532	450.000	261.000
EDTA HARDNESS (CACO3)	12.	168.000	18.360	190.000	143.000
TURBIDITY (JTU)	12.	97.917	29.497	150.000	50.000
TOTAL PHOSPHORUS (P)	12.	1.633	0.562	2.580	1.100
SOL ORTHOPHOSPHATE (P)	12.	0.406	0.314	0.770	0.100
NITRATE (N)	12.	1.311	0.517	2.020	0.700
NITRITE (N)	12.	0.128	0.019	0.160	0.110
AMMONIA (N)	12.	0.079	0.030	0.140	0.030
ORGANIC NITROGEN (N)	12.	0.529	0.148	0.830	0.360
TOTAL NITROGEN (N)	12.	2.047	0.628	3.030	1.230
TOTAL IRON	12.	2.142	0.549	3.110	1.200
FERROUS IRON	12.	0.295	0.167	0.560	0.110
TOTAL RESIDUE (180 C)	12.	374.667	60.958	436.000	268.000
DIS RESIDUE (180 C)	12.	252.333	74.803	380.000	120.000
PART RESIDUE (180 C)	12.	122.333	54.164	184.000	20.000
SULFATE (S)	12.	16.983	4.895	26.000	12.000
CHLORIDE	12.	30.467	17.649	60.100	15.500
SILICA (SIO2)	12.	12.811	1.830	15.000	9.600
TOTAL ARSENIC*	0.	---	---	---	---
TOTAL BARIUM*	0.	---	---	---	---
TOTAL BORON*	0.	---	---	---	---
TOTAL CADMIUM*	0.	---	---	---	---
TOTAL CHROMIUM*	0.	---	---	---	---
TOTAL COPPER*	0.	---	---	---	---
TOTAL LEAD*	0.	---	---	---	---
TOTAL MANGANESE*	0.	---	---	---	---
TOTAL MERCURY*	0.	---	---	---	---
TOTAL NICKEL*	0.	---	---	---	---
TOTAL SELENIUM*	0.	---	---	---	---
TOTAL SILVER*	0.	---	---	---	---
TOTAL ZINC*	0.	---	---	---	---
FLOW (M3/SEC)	4.	0.602	0.705	1.600	0.010
TOTAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL STREP (#/.1 L)	0.	---	---	---	---

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 14.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	12.	17.975	2.743	21.200	13.800
DISSOLVED OXYGEN	12.	8.492	2.250	11.200	5.000
DISSOLVED OXYGEN (% SAT)	12.	87.983	20.627	115.500	55.800
FREE CARBON DIOXIDE	12.	2.658	2.418	5.700	0.0
HYDROGEN ION CONC (PH)	12.	8.033	0.202	8.400	7.800
ALKALINITY (CACO3)	12.	192.833	102.580	273.000	26.000
TOT DIS ION SOL (NACL)	12.	314.167	54.954	373.000	226.000
EDTA HARDNESS (CACO3)	12.	198.500	52.995	242.000	109.000
TURBIDITY (JTU)	12.	84.333	47.227	165.000	45.000
TOTAL PHOSPHORUS (P)	12.	0.687	0.610	1.720	0.200
SOL ORTHOPHOSPHATE (P)	12.	0.019	0.017	0.060	0.010
NITRATE (N)	12.	0.368	0.284	0.830	0.030
NITRITE (N)	12.	0.148	0.193	0.480	0.010
AMMONIA (N)	12.	0.448	0.472	1.270	0.020
ORGANIC NITROGEN (N)	12.	1.519	1.701	4.300	0.010
TOTAL NITROGEN (N)	12.	2.484	1.898	4.760	0.610
TOTAL IRON	12.	2.006	1.260	4.200	0.800
FERROUS IRON	12.	0.386	0.407	1.300	0.050
TOTAL RESIDUE (180 C)	12.	346.000	85.221	468.000	248.000
DIS RESIDUE (180 C)	12.	235.333	67.513	356.000	124.000
PART RESIDUE (180 C)	12.	110.667	65.867	268.000	24.000
SULFATE (S)	12.	13.108	10.265	30.800	4.100
CHLORIDE	12.	11.933	2.136	15.100	9.100
SILICA (SIO2)	12.	10.833	5.914	15.600	0.880
TOTAL ARSENIC*	0.	---	---	---	---
TOTAL BARIUM*	0.	---	---	---	---
TOTAL BORON*	0.	---	---	---	---
TOTAL CADMIUM*	0.	---	---	---	---
TOTAL CHROMIUM*	0.	---	---	---	---
TOTAL COPPER*	0.	---	---	---	---
TOTAL LEAD*	0.	---	---	---	---
TOTAL MANGANESE*	0.	---	---	---	---
TOTAL MERCURY*	0.	---	---	---	---
TOTAL NICKEL*	0.	---	---	---	---
TOTAL SELENIUM*	0.	---	---	---	---
TOTAL SILVER*	0.	---	---	---	---
TOTAL ZINC*	0.	---	---	---	---
FLOW (M3/SEC)	4.	0.007	0.005	0.010	0.0
TOTAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL STREP (#/.1 L)	0.	---	---	---	---

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 15.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	12.	16.108	3.781	20.200	11.000
DISSOLVED OXYGEN	12.	6.158	2.264	9.000	3.200
DISSOLVED OXYGEN (% SAT)	12.	60.625	19.383	86.500	34.900
FREE CARBON DIOXIDE	12.	5.792	3.224	12.500	3.000
HYDROGEN ION CONC (PH)	12.	7.408	0.235	7.800	7.100
ALKALINITY (CACO3)	12.	65.833	28.524	96.000	22.000
TOT DIS ION SOL (NACL)	12.	169.667	24.574	206.000	133.000
EDTA HARDNESS (CACO3)	12.	71.000	20.329	98.000	41.000
TURBIDITY (JTU)	12.	266.333	399.581	960.000	22.000
TOTAL PHOSPHORUS (P)	12.	0.598	0.533	1.630	0.200
SOL ORTHOPHOSPHATE (P)	12.	0.032	0.038	0.110	0.010
NITRATE (N)	12.	0.442	0.448	1.170	0.030
NITRITE (N)	12.	0.058	0.037	0.110	0.010
AMMONIA (N)	12.	0.145	0.072	0.220	0.030
ORGANIC NITROGEN (N)	12.	0.630	0.388	1.550	0.280
TOTAL NITROGEN (N)	12.	1.275	0.865	2.970	0.540
TOTAL IRON	12.	2.635	2.098	6.100	0.980
FERROUS IRON	12.	0.412	0.134	0.750	0.230
TOTAL RESIDUE (180 C)	12.	273.667	193.708	736.000	120.000
DIS RESIDUE (180 C)	12.	129.333	19.621	164.000	104.000
PART RESIDUE (180 C)	12.	144.333	177.608	572.000	12.000
SULFATE (S)	12.	8.333	3.375	13.900	3.900
CHLORIDE	12.	15.233	2.411	19.300	13.400
SILICA (SIO2)	12.	8.579	3.311	11.400	3.000
TOTAL ARSENIC*	0.	---	---	---	---
TOTAL BARIUM*	0.	---	---	---	---
TOTAL BORON*	0.	---	---	---	---
TOTAL CADMIUM*	0.	---	---	---	---
TOTAL CHROMIUM*	0.	---	---	---	---
TOTAL COPPER*	0.	---	---	---	---
TOTAL LEAD*	0.	---	---	---	---
TOTAL MANGANESE*	0.	---	---	---	---
TOTAL MERCURY*	0.	---	---	---	---
TOTAL NICKEL*	0.	---	---	---	---
TOTAL SELENIUM*	0.	---	---	---	---
TOTAL SILVER*	0.	---	---	---	---
TOTAL ZINC*	0.	---	---	---	---
FLOW (M3/SEC)	4.	0.032	0.036	0.080	0.0
TOTAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL STREP (#/.1 L)	0.	---	---	---	---

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 16.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	12.	16.842	3.467	20.100	11.200
DISSOLVED OXYGEN	12.	6.742	3.459	9.900	1.200
DISSOLVED OXYGEN (% SAT)	12.	67.658	33.471	94.800	12.800
FREE CARBON DIOXIDE	12.	10.158	11.122	28.000	1.400
HYDROGEN ION CONC (PH)	12.	6.850	0.523	7.400	6.100
ALKALINITY (CACO3)	12.	18.383	1.929	21.000	16.000
TOT DIS ION SOL (NACL)	12.	95.750	34.780	157.000	70.000
EDTA HARDNESS (CACO3)	12.	29.083	22.342	67.000	12.000
TURBIDITY (JTU)	12.	25.250	13.130	60.000	16.000
TOTAL PHOSPHORUS (P)	12.	0.361	0.221	0.770	0.170
SOL ORTHOPHOSPHATE (P)	12.	0.034	0.054	0.190	0.010
NITRATE (N)	12.	0.670	0.661	1.370	0.020
NITRITE (N)	12.	0.055	0.037	0.110	0.010
AMMONIA (N)	12.	0.107	0.116	0.320	0.020
ORGANIC NITROGEN (N)	12.	0.243	0.144	0.620	0.130
TOTAL NITROGEN (N)	12.	1.075	0.610	1.680	0.300
TOTAL IRON	12.	0.972	0.570	2.000	0.540
FERROUS IRON	12.	0.297	0.368	0.990	0.040
TOTAL RESIDUE (180 C)	12.	157.667	35.755	212.000	108.000
DIS RESIDUE (180 C)	12.	88.333	23.227	124.000	52.000
PART RESIDUE (180 C)	12.	69.333	39.976	132.000	12.000
SULFATE (S)	12.	5.533	2.398	9.100	1.700
CHLORIDE	12.	6.092	1.502	8.400	4.100
SILICA (SIO2)	12.	12.996	2.122	14.930	9.400
TOTAL ARSENIC*	0.	---	---	---	---
TOTAL BARIUM*	0.	---	---	---	---
TOTAL BORON*	0.	---	---	---	---
TOTAL CADMIUM*	0.	---	---	---	---
TOTAL CHROMIUM*	0.	---	---	---	---
TOTAL COPPER*	0.	---	---	---	---
TOTAL LEAD*	0.	---	---	---	---
TOTAL MANGANESE*	0.	---	---	---	---
TOTAL MERCURY*	0.	---	---	---	---
TOTAL NICKEL*	0.	---	---	---	---
TOTAL SELENIUM*	0.	---	---	---	---
TOTAL SILVER*	0.	---	---	---	---
TOTAL ZINC*	0.	---	---	---	---
FLOW (M3/SEC)	4.	0.075	0.099	0.220	0.0
TOTAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL STREP (#/.1 L)	0.	---	---	---	---

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is continued on the next page

Appendix 4 (continued). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Station 17.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	12.	17.392	3.543	20.000	11.500
DISSOLVED OXYGEN	12.	7.458	2.583	10.200	3.500
DISSOLVED OXYGEN (% SAT)	12.	76.033	23.807	96.800	37.900
FREE CARBON DIOXIDE	12.	3.033	1.312	5.000	1.300
HYDROGEN ION CONC (PH)	12.	7.175	0.270	7.600	6.800
ALKALINITY (CACO3)	12.	19.083	3.801	24.000	13.000
TOT DIS ION SOL (NACL)	12.	80.833	13.617	103.000	65.000
EDTA HARDNESS (CACO3)	12.	22.333	11.211	40.000	12.000
TURBIDITY (JTU)	12.	21.000	23.108	85.000	4.000
TOTAL PHOSPHORUS (P)	12.	0.361	0.290	1.010	0.100
SOL ORTHOPHOSPHATE (P)	12.	0.022	0.021	0.070	0.010
NITRATE (N)	12.	0.475	0.481	1.130	0.010
NITRITE (N)	12.	0.058	0.040	0.120	0.010
AMMONIA (N)	12.	0.048	0.022	0.100	0.020
ORGANIC NITROGEN (N)	12.	0.160	0.033	0.240	0.100
TOTAL NITROGEN (N)	12.	0.742	0.505	1.450	0.220
TOTAL IRON	12.	0.975	0.897	2.500	0.290
FERROUS IRON	12.	0.186	0.099	0.390	0.010
TOTAL RESIDUE (180 C)	12.	158.000	48.617	232.000	72.000
DIS RESIDUE (180 C)	12.	74.333	42.622	124.000	8.000
PART RESIDUE (180 C)	12.	83.667	48.914	176.000	12.000
SULFATE (S)	12.	3.327	1.923	4.800	0.0
CHLORIDE	12.	5.267	1.330	7.800	3.900
SILICA (SIO2)	12.	11.978	0.941	13.100	10.200
TOTAL ARSENIC*	0.	---	---	---	---
TOTAL BARIUM*	0.	---	---	---	---
TOTAL BORON*	0.	---	---	---	---
TOTAL CADMIUM*	0.	---	---	---	---
TOTAL CHROMIUM*	0.	---	---	---	---
TOTAL COPPER*	0.	---	---	---	---
TOTAL LEAD*	0.	---	---	---	---
TOTAL MANGANESE*	0.	---	---	---	---
TOTAL MERCURY*	0.	---	---	---	---
TOTAL NICKEL*	0.	---	---	---	---
TOTAL SELENIUM*	0.	---	---	---	---
TOTAL SILVER*	0.	---	---	---	---
TOTAL ZINC*	0.	---	---	---	---
FLOW (M3/SEC)	4.	0.155	0.216	0.470	0.0
TOTAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL COLIFORM (#/.1 L)	0.	---	---	---	---
FECAL STREP (#/.1 L)	0.	---	---	---	---

*Denotes detection limit variance of spectrophotometer between sampling periods.

Appendix 4 is concluded on the next page

Appendix 4 (concluded). Summaries, by station, of measured water quality parameters, including maximum, mimimum, mean, standard deviation, and number of observations from water samples collected in the Cache River basin, southern Illinois, 1975 through 1977.

Final summary for all stations.

PARAMETER	N	MEAN	STAND. DEV.	MAX	MIN
WATER TEMPERATURE (C)	264.	15.511	6.196	29.500	0.200
DISSOLVED OXYGEN	264.	8.430	2.723	15.000	1.000
DISSOLVED OXYGEN (% SAT)	264.	82.274	25.045	172.000	10.900
FREE CARBON DIOXIDE	264.	6.114	7.584	50.000	0.0
HYDROGEN ION CONC (PH)	264.	7.621	0.546	9.700	6.100
ALKALINITY (CACO3)	264.	87.470	55.740	273.000	13.000
TOT DIS ION SOL (NACL)	264.	218.197	88.038	583.000	65.000
EDTA HARDNESS (CACO3)	264.	106.220	55.096	242.000	12.000
TURBIDITY (JTU)	264.	101.610	131.720	960.000	4.000
TOTAL PHOSPHORUS (P)	264.	0.736	0.756	6.300	0.010
SOL ORTHOPHOSPHATE (P)	264.	0.095	0.228	1.540	0.010
NITRATE (N)	264.	0.467	0.568	2.120	0.010
NITRITE (N)	264.	0.086	0.076	0.480	0.010
AMMONIA (N)	264.	0.102	0.141	1.270	0.010
ORGANIC NITROGEN (N)	264.	0.526	0.583	4.300	0.010
TOTAL NITROGEN (N)	264.	1.181	0.958	4.760	0.220
TOTAL IRON	264.	1.744	1.390	7.000	0.160
FERROUS IRON	264.	0.387	0.328	2.400	0.010
TOTAL RESIDUE (180 C)	264.	288.242	108.037	736.000	72.000
DIS RESIDUE (180 C)	264.	198.788	88.238	596.000	8.000
PART RESIDUE (180 C)	264.	89.455	71.841	572.000	4.000
SULFATE (S)	264.	13.897	11.810	111.000	0.0
CHLORIDE	264.	13.825	10.359	60.100	3.900
SILICA (SIO2)	264.	11.821	3.329	21.800	0.880
TOTAL ARSENIC*	150.	0.018	0.004	0.020	0.010
TOTAL BARIUM*	150.	0.177	0.177	1.100	0.090
TOTAL BORON*	150.	2.400	1.023	4.000	1.000
TOTAL CADMIUM*	150.	0.010	0.001	0.020	0.010
TOTAL CHROMIUM*	150.	0.027	0.016	0.160	0.020
TOTAL COPPER*	150.	0.023	0.005	0.040	0.020
TOTAL LEAD*	150.	0.118	0.041	0.200	0.090
TOTAL MANGANESE*	150.	0.599	0.419	2.380	0.050
TOTAL MERCURY*	150.	0.010	0.000	0.010	0.010
TOTAL NICKEL*	150.	0.068	0.004	0.080	0.060
TOTAL SELENIUM*	147.	0.020	0.006	0.030	0.010
TOTAL SILVER*	150.	0.013	0.005	0.020	0.010
TOTAL ZINC*	150.	0.028	0.014	0.080	0.010
FLOW (M3/SEC)	88.	0.421	0.954	5.540	0.0
TOTAL COLIFORM (#/.1 L)	173.	278.231	1355.309	14000.000	0.0
FECAL COLIFORM (#/.1 L)	173.	500.717	1594.764	15200.000	0.0
FECAL STREP (#/.1 L)	171.	157.064	238.807	1158.000	0.0

*Denotes detection limit variance of spectrophotometer between sampling periods.

RESUME OF MARK J. WETZEL

Mr. Wetzel was born in Morrison, Whiteside County, Illinois on 30 January 1950. Elementary and high school education was in the Champaign and Urbana public school systems, with a high school diploma awarded in June 1968. Undergraduate studies were conducted at Blackburn College, Parkland College, and the University of Illinois. Graduate studies were conducted in part at the University of Illinois and completed at Eastern Illinois University. He has been employed at the Illinois Natural History Survey (INHS) since February 1972 and presently holds the rank of Technical Assistant. Mr. Wetzel's area of interest is freshwater benthos, with taxonomic expertise in freshwater Annelida. Mr. Wetzel is currently compiling distributional and ecological data for Oligochaeta and Hirudinea occurring in Illinois and Kansas watersheds.

EDUCATION

Blackburn College: Major in Chemistry and Biology -- 1968-1970.

Parkland College: Major in Biology -- 1970-1971. Received Associate of Science Degree, June 1971.

University of Illinois: Major in Biology with minors in Chemistry and Physics -- 1971-1973. Received Bachelor of Science Degree, February 1973.

University of Illinois: Graduate College, Major in Zoology -- 1973-1975.

Eastern Illinois University: 1975-1977. Candidate for Master of Science Degree, December 1981. Thesis title: The distribution and relative abundance of aquatic Oligochaeta in the Cache River system, southern Illinois, in relation to water quality.

PROFESSIONAL SOCIETIES

American Fisheries Society

American Society of Limnology and Oceanography

Freshwater Biological Association

North American Benthological Society

Societas Internationalis Limnologiae

HONORARY SOCIETIES

Phi Sigma Society

RESEARCH EXPERIENCE

1966-Summer Lab assistant to Dr. Lowell P. Hager, Chairman, Department of Biochemistry, University of Illinois.

1969-Summer Lab technician to Dr. Harry P. Broquist, Department of Dairy Science, University of Illinois.

1972-1975 Research assistant to Dr. R. Weldon Larimore, INHS -- Collection and coordination of benthos and fish.

1975-1976 Technical assistant to Dr. Warren U. Brigham, INHS -- Collection and coordination of benthos and fish.

1976-present Sole proprietor of Invertaxon -- specializing in taxonomy and ecology of aquatic Annelida.

1976-1978 Technical assistant to Dr. Allison R. Brigham, INHS -- Collection and coordination of benthos; water chemistry analysis; literature reviews.

1978-present Technical assistant to Dr. Warren U. Brigham, INHS -- Collection and coordination of benthos and fish; literature reviews; water chemistry analysis; economic impact statements; endangered species studies.

1979-1981 Technical assistant and Coinvestigator under Dr. Robert Gorden, INHS -- Collection, coordination and analysis of benthos: efficacy of a hybrid carp for aquatic weed control.

1981-present Technical assistant under Dr. D. Homer Buck, INHS -- Collection, coordination, and analysis of benthos: aquaculture studies.

RESEARCH INTERESTS

Benthos; freshwater annelid systematics and ecology; preservation, restoration and management of watersheds.

CONFERENCES ATTENDED

American Fisheries Society, Illinois Chapter
1974 -- Edwardsville, IL
1980 -- Chicago, IL

First International Symposium on Aquatic Oligochaeta
1979 -- Sidney, British Columbia

North American Benthological Society
1973 -- East Lansing, MI
1974 -- Cincinnati, OH
1975 -- Springfield, IL
1976 -- LaCrosse, WI
1977 -- Roanoke, VA
1978 -- Winnipeg, Manitoba, Canada
1979 -- Erie, PA
1980 -- Savannah, GA
1981 -- Provo, UT

GRANTS AND CONTRACTS

Mr. Wetzel served in the capacity of either a Research Assistant or Technical Assistant for the following projects:

Water Quality Investigation for Lake Shelbyville, Army Corps of Engineers (ACE); 1972-1975.

Environmental contamination by lead and other heavy metals, an NSF grant to the Institute for Environmental Studies, University of Illinois; 1972-1975.

Annual sulfur cycle and effects upon benthic macroinvertebrates in Lake Shelbyville, Illinois. University of Illinois Water Resources Center; July 1972.

Water quality investigations for Lake Carlysle (ACE); 1974-1975.

Aquatic limnetic monitoring of Lake Sangchris. Commonwealth Edison Company. 1974-1975.

Faunistic assessment of Mill Creek watershed, Clark and Edgar Counties, Illinois, U.S.D.A., Soil Conservation Service; July 1975.

Faunistic and water quality assessment of Long Point Slough, Logan, Macon, and Sangamon Counties, Illinois. U.S.D.A., Soil Conservation Service; July 1975.

GRANTS AND CONTRACTS (continued)

Faunistic and water quality assessment of the Upper Cache watershed, Johnson, Massac, Pope, Pulaski, and Union Counties, Illinois. U.S.D.A., Soil Conservation Service; July 1975.

Illinois coastal zone management development program: Component study of biological communities. Illinois Department of Transportation; July 1975.

Faunistic and water quality assessment of the North Fork Embarras River watershed, Clark, Coles, Crawford, Cumberland, Edgar, and Jasper Counties, Illinois. U.S.D.A., Soil Conservation Service; May 1976.

An assessment of the water quality of the Illinois Rock River basin derived from a biological investigation. Illinois Environmental Protection Agency (IEPA) March 1977.

An assessment of the water quality of the Illinois Wabash River basin derived from a biological investigation. IEPA, March 1977.

An assessment of the water quality of the Cache River basin derived from a biological investigation, IEPA, March 1977.

The watersheds of northeastern Illinois: Quality of the aquatic environment based upon water quality and fishery data. Northern Illinois Planning Commission; July 1977.

The proposed change in the water quality standard for copper in Illinois waters. Illinois Institute of Environmental Quality. November 1977.

Aquisition of baseline data from Dutchman Creek, Johnson County, Illinois. U.S.D.A., Soil Conservation Service; November 1977.

Selected aquatic invertebrates of the Kankakee River basin, Illinois, with emphasis upon the effects of sedimentation and the reach of the river between the Indiana state line and Momence. Illinois Institute of Environmental Quality; Summer 1978.

Economic impact of the proposed amendment to the Illinois water quality standards for fluoride. Illinois Institute of Natural Resources; January 1979.

Economic impact of the proposed amendment to the Illinois water quality standards for chloride and total dissolved solids. Illinois Institute of Natural Resources; April 1979.

GRANTS AND CONTRACTS (concluded)

Aquatic invertebrates and fishes of the Kankakee River basin, Illinois, with emphasis upon the effects of sedimentation and the reach of the river between the Indiana state line and Momence. Phase Two. Illinois Institute of Environmental Quality; October 1979.

A comparative study of the effects of hybrid carp and a chemical method of controlling aquatic vegetation. Illinois Department of Conservation, Dingle-Johnson funds; November 1979.
Kinmundy 1980, 1981 benthic studies: Efficacy of prawn and carp production in swine waste ponds.

Mississippi River ACE monitoring: biweekly monitoring of water quality at four stations on the Misissippi River.

Illinois Department of Transporation: numerous contracts to assess the potential for impact on Illinois threatened or endangered species or their habitats resulting from new or reconstruction of highways.

REPRESENTATIVE PUBLICATIONS

REPORTS:

1975. Whitley, L. S., and M. J. Wetzel. Aquatic Oligochaeta, in W. U. Brigham, ed. Illinois Coastal Zone Management; Component study of biological communities. An Illinois Natural History Survey publication for the Illinois Coastal Zone Management Program.

1978. Brigham, W. U., D. A. McCormick, and M. J. Wetzel. The watersheds of northeastern Illinois: Quality of the aquatic environment based upon water quality and fishery data. Northeastern Illinois Planning Commission Staff paper No. 31. 251 pp.

1979. Brigham, A. R., and M. J. Wetzel. Economic impact of changing the copper effluent standard, R76-21. Illinois Institute of Natural Resources Document No. 79/12. Chicago. vii + 123 pp.

1980. Brigham, W. U., D. A. McCormick, and M. J. Wetzel. Economic impact of a suspension of Rule 203 as it applies to an unnamed tributary of the Vermilion River, Vermilion County, Illinois. Illinois Institute of Natural Resources Document No. 80/05. ix + 90 pp.

1981. Wetzel, M. J., and M. J. Wiley. Benthos, pp. 110-119. *In*: R. W. Gorden, S. W. Waite, and M. J. Wiley, eds. Effects of Using hybrid carp to control aquatic vegetation. First annual report, Federal Aid Project F-37-R1, to the Illinois Dept. Conservation.

BIBLIOGRAPHIES

1979. Whitley, L. S. and M. Wetzel. Aquatic Oligochaeta and Polychaeta. Pp. 7-10, *In*: D. W. Webb, ed. Current and selected bibliographies on benthic biology. North American Benthological Soc., Springfield, IL.

1980. Whitley, L. S., and M. Wetzel. Oligochaeta and Polychaeta, pp. 9-14. *In*: D. W. Webb, ed. Current and selected bibliographies on benthic biology. North American Benthological Soc., Springfield, IL.

1981. Wetzel, M. J., and L. S. Whitley. Annelida, pp. 9-17. *In:* D. W. Webb, ed. Current and selected bibliographics on benthic biology. North American Benthological Society, Springfield, IL.

1982. Wetzel, M. J., and L. S. Whitley. Aquatic Annelida, exclusive of the Hirudinea. *In*: D. W. Webb, ed. Current and selected bibliographies on benthic biology. North American Benthological Soc., Springfield, IL. *in prep.*

JOURNAL ARTICLES:

1977. McNurney, J. M., R. W. Larimore, and M. J. Wetzel. Distribution of lead in the sediments and fauna of a small midwestern stream, pp. 167-177. *In*: Biological implications of metals in the environment. Energy Research and Development Administration, Symposium Series 42. Proceedings of the Fifteenth Annual Hanford Life Sciences Symposium, Richland, Washington, 29 September through 1 October 1975.

1979. Klemm, D. J., D. G. Huggins, and M. J. Wetzel. Kansas leeches, (Annelida: Hirudinea) with notes on distribution and ecology. Tech. Publ. State Biol. Surv. Kansas. 8:38-46.

1980. Wetzel, M. J. *Limnodrilus rubripenis* Loden and *Psammoryctides californianus* Brinkhurst, two new aquatic worms (Annelida: Oligochaeta: Tubificidae) new to Illinois. Trans. Illinois St. Acad. Sci. 73(3):36-38.

1981. Wetzel, M. J., F. C. Gilbert, and M. B. DuBois. Introduction to the non-arthropod group, pp. 4-8. *In*: Guide to the freshwater invertebrates of the Midwest. Tech. Publ. St. Biol. Surv. Kansas No. 11.

1981. Wetzel, M. J., and F. C. Gilbert. Hirudinea (leeches), pp. 9-14. *In*: Guide to the freshwater invertebrates of the Midwest. Tech. Pub. St. Biol. Surv. Kansas No. 11.

1981. Wetzel, M. J., and F. C. Gilbert. 1981. Oligochaeta (earthworms), pp. 15-22. *In*: Guide to the freshwater invertebrates of the Midwest. Tech. Publ. St. Biol. Surv. Kansas No. 11.

Papers in preparation

1982. Seagle, H. H., Jr., and M. J. Wetzel. A comparison of processing techniques for benthic samples from large alluvial rivers.

1982. Wetzel, M. J. A preliminary checklist of the aquatic Annelida (Oligochaeta and Hirudinea) of Utah, with notes on their distribution and biology.

1982. Wetzel, M. J. The distribution and relative abundance of aquatic Oligochaeta in the Cache River system, southern Illinois.

1982. Wetzel, M. J. A review of oligochaete research in Illinois, with a preliminary checklist of species known to occur in the State.

1982. Wetzel, M. J. A new species of the genus *Limnodrilus* (Annelida: Oligochaeta: Tubificidae).

1982. Wetzel, M. J. A note on the morphological variation of setae due to a sporidian infection in *Branchiura sowerbyi* (Annelida: Oligochaeta: Tubificidae).

1983. Brinkhurst, R. O., and M. J. Wetzel. A review of aquatic oligochaete research since 1970 [literature review, list of new species and recent revisions]. *in prep.*