DETERMINATION OF BENTHIC-INVERTEBRATE INDICES

AND WATER-QUALITY TRENDS OF SELECTED STREAMS

IN CHESTER COUNTY, PENNSYLVANIA, 1969-80

By Craig R. Moore

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FACTORS FOR CONVERTING INCH-POUND TO METRIC UNITS

Multiply Inch-Pound Unit	By	To obtain Metric Units
Square foot (ft^2)	0.2787	Square meter (m^2)
Square mile (mi^2)	2.590	Square kilometer (km^2)

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ABSTRACT

The trends of biological and chemical data collected for 12 years (1969-80) from 46 sites in Chester County were evaluated by using the seasonal Kendall test. Brillouin's diversity index was calculated and plotted against time for each site. The diversity index at 7 sites had upward trends significant at the 99-percent confidence level, the index at 9 sites had upward trends significant at the 95 to 98 percent confidence level, and the index at 11 sites had upward trends significant at the 90 to 94 percent confidence level. Although the trends were not statistically significant, 17 of the remaining sites had upward trends and 2 had downward trends.

The seasonal Kendall test was used to test the chemical data for temporal trends at eight sites having stream discharge data. Significant trends were found at one or more sites for flow-adjusted values of specific conductance, pH, total nitrate, total phosphorus, dissolved chloride, and dissolved sulfate. The chemical data for 11 sites, which were not flow adjusted, were tested for trends by plotting against time and determining a correlation coefficient. Significant trends were found at one or more sites in nitrate and chloride. Selected chemical constituents were tested by regression analysis for correlation with the diversity index. Only total dissolved solids correlated significantly with diversity index. Several suggestions are made to improve the monitoring program.

INTRODUCTION

Background

Chester County, in southeastern Pennsylvania (fig. 1), adjacent to the Philadelphia and Wilmington metropolitan areas, is undergoing transition from rural to suburban land use due to moderate population growth. The population of Chester County increased 14 percent from 1970 through 1980. Some areas of the county have undergone rapid growth. The populations of West Bradford and East Goshen Townships, for example, have increased 145 percent and 95 percent, respectively (Chester County Planning Commission, written commun., 1983). Urban growth is affecting the quality of streams in Chester County.

Interest in water-quality is centered on its effects on living organisms. Consequently, water-quality must ultimately be assessed in biological terms. Benthic invertebrates are particularly suitable for evaluating stream water-quality because their habitat preference and low motility cause them to be directly affected by substances that enter the aquatic environment.

In 1969, a study was begun using benthic invertebrates to evaluate stream water-quality. The investigation is a cooperative effort of the U.S. Geological Survey, the Chester County Water Resources Authority, and the Chester County Board of Commissioners. The project was conceived by Luna B. Leopold, former Chief Hydrologist, U.S. Geological Survey, and Robert G. Struble, former Executive Director of the Chester County Water Resources Authority (Lium, 1977, p. 6).

In late 1969 and early 1970, the project area was reconnoitered to determine the general nature of streams and of land-use practices and patterns. Water samples were collected and analyzed for background chemical data. The reconnaissance served as a guide in establishing the original water-quality network of 40 sampling sites on 13 streams.

In the fall of 1971, 10 new sites were added to the chemical sampling program to obtain background data. In 1973, these 10 additional sites were incorporated into the biological sampling program, bringing the total number of sites in the network to 50 on 14 streams. The locations of the 50 sites are shown in figure 1 and the station names and numbers are listed in table 1.

Purpose and Scope

The purposes of this report are to (1) to evaluate the chemical, biological, and field measurements and observations made on Chester County streams over a 12 year period (1969-80); (2) present a trend analysis of biological and chemical data; and (3) suggest specific modifications for improving the sampling program and network.

Samples of benthic invertebrates were collected at as many as 50 sites on 14 streams. Water samples from the streams were also collected and streamflow measurements made. The biota and water samples were analyzed statistically using the seasonal Kendall test and the diversity index.

Previous Studies

A report by Lium (1976) contains the biological and chemical data from this investigation for 1970-74. The chemical data for the 1974-81 water years has also been published in the U.S. Geological Survey's annual water resources data reports for Pennsylvania. The physical, chemical, and biological data base (1969-80) for this study are published in a companion report by Moore (in preparation) and available in the U.S. Geological Survey's computer files (WATSTORE). Lium (1977) developed a biotic index using a 10-point rating scale to determine water quality at the 50 sites of his previous report. In 1967-68, an investigation was conducted in the Pickering Creek and East Branch Brandywine Creek basins by Miller and others (1971). Their investigation examined and documented existing hydrologic conditions in these two small basins so that effects of future urbanization in the basins could be studied by comparison with their data. These two basins are among the areas studied in this investigation.

Description of Area

Chester County, in the Piedmont physiographic province of Pennsylvania, has an area of 760 mi^2 (square miles), of which 720 mi^2 are drained by the 14 streams discussed in this report. All streams sampled originate within the boundaries of the county, except short reaches in the headwaters of the West Branch Brandywine, French, and Octoraro Creeks. Octoraro Creek forms part of the western boundary of the county, and its headwaters lie in both Chester and Lancaster Counties (fig. 1).

Steepness of slope is a major factor determining urban, agricultural, and commercial land uses. Construction costs, soil erosion, soil thickness, water supply, and accessibility are all affected adversely as the slope steepens. The U.S. Soil Conservation Service does not recommend building on slopes greater than 15 percent. Using this criterion, about 52 percent of the county is suitable for most building.

Approximately 66 percent of the county is suitable for agriculture. The Chester Silt Loam and limestone soils, considered to be the most productive for crops, are mostly in southern Chester County and in the Chester Valley, which runs northeastward across the middle of the county. Major crops are hay, winter wheat, corn, garden crops, and mushrooms. Dairy and beef cattle farming are also prevalent throughout the area.

Deciduous hardwoods are the dominant type of tree and include red and black oak, tulip poplar, beech, sugar maple, and chestnut oak as the most common types. Woodland, which comprises about 19 percent of Chester County or 96,000 acres, is usually situated on steep, less productive soils (Lium, 1977).

Acknowledgments

The cooperation of the Chester County Board of Commissioners, the Chester County Water Resources Authority, and the Chester County Health Department is gratefully acknowledged. The author extends appreciation to the members and staff of the Chester County Water Resources Authority, especially David C. Yaeck, Executive Director, who has shown sincere interest throughout the investigation. In addition, many persons, particularly Richard Casson, formerly with the U.S. Environmental Protection Agency; Philip Terry, formerly with Chester County Health Department; Donald Knorr, Pennsylvania Department of Environmental Resources; and Dr. Richard McLean have been of the utmost assistance. The author is particularly indebted to Richard Alexander, Quality of Water Branch, U.S. Geological Survey, for his assistance with seasonal Kendall test.

METHODS OF DATA COLLECTION

Field Measurements

During 1970-71, samples were collected in the spring and fall to obtain data on the seasonal variation in stream biology and water quality. Since 1972, samples have been collected only once a year in the fall. Fall

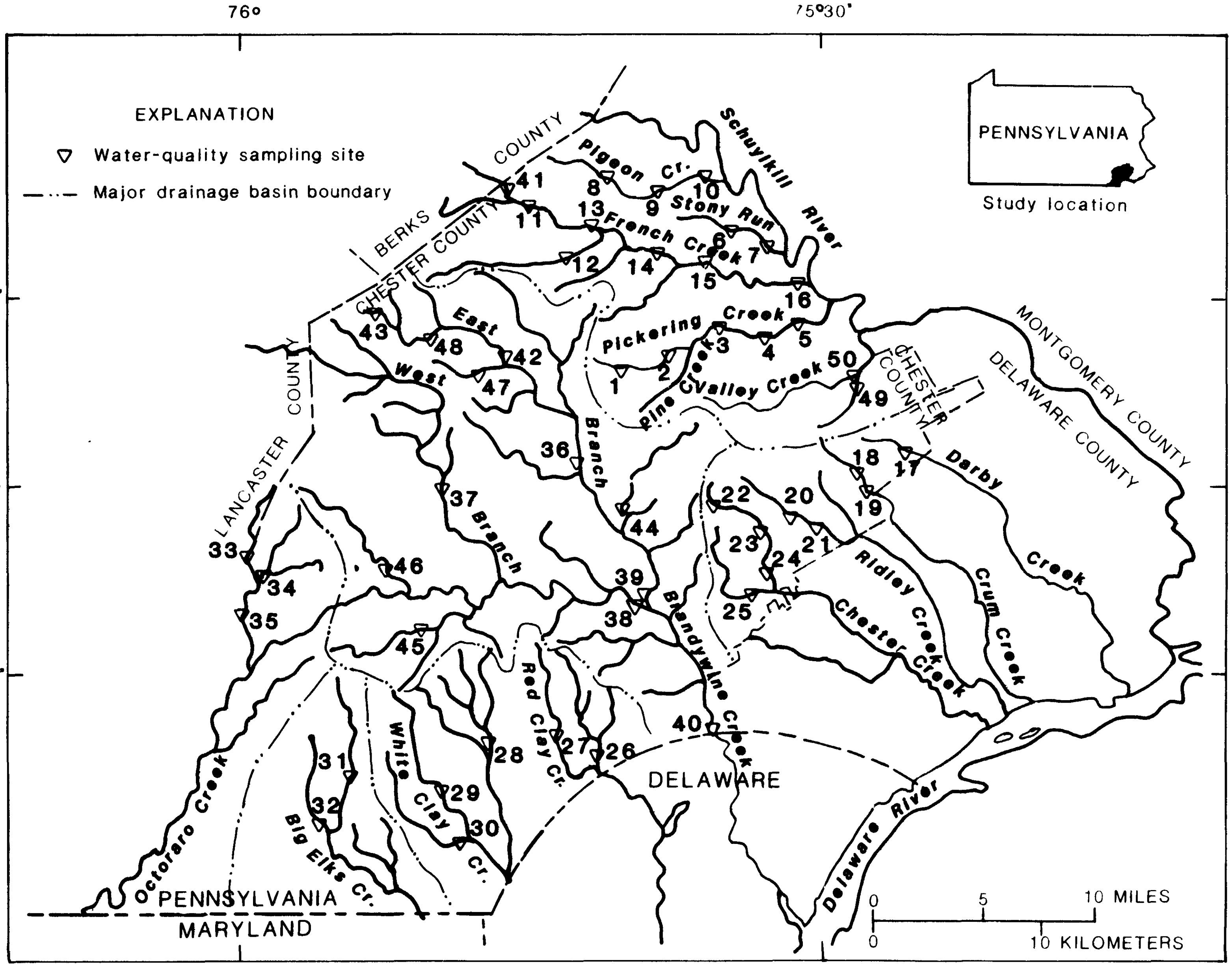

Figure 1.--Chester County, Pennsylvania, showing sampling sites and related streams. Station numbers refer to stations listed in table 1.

Table 1. —Sampling sites, station numbers, names, and drainage areas

Site Number	Station Number	Name	Drainage Area (mi2)
1	01472170	Pickering Creek near Eagle	3.09
2	01472174	Pickering Creek near Chester Springs	5.98
3	014721854	Pickering Creek at Merlin	21.2
4	014721884	Pickering Creek at Charlestown Road at Charlestown	27.5
5	01472190	Pickering Creek near Phoenixville	31.4
6	01472109	Stony Run near Spring City	2.00
7	01472110	Stony Run at Spring City	4.07
8	01472054	Pigeon Creek near Bucktown	4.20
9	01472065	Pigeon Creek at Porters Mill	6.97
10	01472080	Pigeon Creek near Parker Ford	12.0
11	01472129	French Creek near Knauertown	11.7
12	01472140	South Branch French Creek at Coventryville	12.4
13	01472138	French Creek near Coventryville	19.9
14	01472154	French Creek near Pughtown	46.1
15	01472157	French Creek near Phoenixville	59.1
16	014721612	French Creek at railroad bridge at Phoenixville	70.7
17	01475300	Darby Creek at Waterloo Mills near Devon	5.15
18	01475830	Crum Creek near Paoli	6.16
19	01475840	Crum Creek at Whitehorse	10.1
20	01476430	Ridley Creek at Goshenville	4.22
21	01476435	Ridley Creek at Dutton Mill near West Chester	9.71
22	01476790	East Branch Chester Creek at Green Hill	0.63
23	01476830	East Branch Chester Creek at Milltown	5.77
24	01476835	East Branch Chester Creek at Westtown School	10.4
25	01476840	Tributary (Goose Creek) to East Branch Chester Creek near West Chester	4.28
26	01479800	East Branch Red Clay Creek near Five Point	10.2
27	01479680	West Branch Red Clay Creek at Kennett Square	9.79
28	01478120	East Branch White Clay Creek near Avondale	11.3
29	01478190	Middle Branch White Clay Creek near Wickerton	9.94
30	01478220	West Branch White Clay Creek near Chesterville	9.92
31	01494900	East Branch Big Elk Creek at Elkview	11.1
32	01494950	West Branch Big Elk Creek near Oxford	10.0
33	01578340	East Branch Octoraro Creek at Christiana	11.8
34	01578343	Valley Creek at Atglen	10.5
35	01578345	East Branch Octoraro Creek at Steelville	32.9
36	01480700	East Branch Brandywine Creek near Downingtown	60.6
37	01480434	West Branch Brandywine Creek at Rock Run	37.3
38	01480640	West Branch Brandywine Creek at Wawaset	134.
39	01480950	East Branch Brandywine Creek at Wawaset	123.
40	01481030	Brandywine Creek near Chadds Ford	291.
41	01472126	French Creek at Trythall	5.06
42	01480653	East Branch Brandywine Creek at Glenmoore	16.5
43	01480647	East Branch Brandywine Creek near Struble Dam	4.36
44	01480903	Valley Creek at Mullsteins Meadows near Downingtown	16.1
45	01480632	Doe Run at Springdell	11.8
46	01480629	Buck Run at Doe Run	22.6
47	01480656	Indian Run near Springton	4.26
48	01480648	East Branch Brandywine Creek near Cupola	5.98
49	01473167	Little Valley Creek at Howellville	6.45
50	01473168	Valley Creek near Valley Forge	12.7

sampling was selected because it would provide the most useful biological and chemical data. Earlier biological data (1970-71) had shown that the greatest number of caddisflies (Trichoptera), stoneflies (Plecoptera), and mayflies (Ephemeroptera), which are considered pollution sensitive and provide the most useful qualitative information about water quality, were found in the fall as opposed to the spring (Lium, 1977, p. 13). This annual period of dominance in the fall is the result of the life-cycle of these particular orders of organisms.

Fall sampling provided the most useful chemical data because streamflow is normally the lowest in the fall and is composed mainly of base flow. Chemical data on base flow provide the most useful information about typical water quality in the stream. In addition, it is easier to compare water-quality data between the past and the present under base flow conditions rather than at high flows when stream discharge and chemical characteristics are changing rapidly.

During each visit to a stream site, air and water temperature, pH, specific conductance, and dissolved oxygen were measured. Through 1972, stream discharge was measured and depth-integrated suspended-sediment samples were collected. Through 1973, water samples were collected for coliform and fecal streptococcus bacteria and for chemical-oxygen-demand analyses. These samples were analyzed at the water-quality laboratory of the Chester County Health Department.

Samples for Chemical Analysis

Water samples were collected for laboratory determinations of the major nutrients (nitrite, nitrate, ammonia, organic nitrogen, total phosphorus, and orthophosphate), alkalinity, dissolved solids and major ions (calcium, potassium, sodium, magnesium, chloride, fluoride, sulfate, and silica), and trace metals (cadmium, chromium, cobalt, copper, lithium, lead, iron, manganese, nickel, and zinc). Water samples for chemical analysis were collected by taking a single "grab" sample at the approximate centroid of the flow. Brown and others (1970, p. 5) stated that, when sampling uniform stream sections on small and medium-size streams, this simplified technique may be used to obtain a homogenous stream sample that is entirely representative of the stream composition. Water samples were collected during base flow when streams were normally clear.

All chemical determinations were made from whole-water (unfiltered) samples for 1969-72 and in 1979. From 1973 through 1980, except for 1979, chemical determinations for major ions and trace metals were made from filtered water samples. Determinations of major nutrients were made from whole-water samples for all years. Constituent concentrations in whole-water samples represent the total concentrations of the water and suspended sediment; those in filtered samples represent the concentrations of the constituents in water that pass through a 0.45-micron filter and are considered to be dissolved. All water samples collected from 1969 through 1972, were analyzed at the water-quality laboratory of the Chester County Health Department. After 1972, all chemical constituents were analyzed by the U.S. Geological Survey.

Samples for Biological Analysis

A simplified method of sampling stream biota was developed to provide a cost-effective biological sampling program. The objective of the method was to collect uniform samples of the principal organisms at a site so that a biotic index could be determined and used for rating stream-water quality. Obtaining a complete description of the fauna at each site was beyond the scope of this program. In addition, the occurrence of rare species, as larger samples were collected, would not greatly change the value of a diversity index provided it was derived from information theory (Averett, 1981, p. B5).

The fact that many benthic invertebrates in shallow streams live on or beneath rocks is the basis for a sampling method involving selection of individual rocks and collecting the associated organisms (Macan, 1958; Schwoerbel, 1970). A study by Lium (1974) had shown that the maximum density and diversity of invertebrates living on rocks in a stream were found in the riffle areas and that the maximum density of organisms occurred on rocks in the 45-to 90-mm (millimeter) range. Later work (Lium, 1977, p. 14) showed that this relationship of invertebrate density to rock size held true for streams in Chester County, Pennsylvania. Lium concluded that the asymptotic diversity, that value of diversity that essentially does not change with the addition of new samples, of benthic invertebrates in streams of Chester County could be closely approximated by sampling 10 rocks, 45-to 90-mm in size, from a riffle and collecting the associated organisms. This method of sampling does bias samples but comparisons of the diversity values among samples are valid provided the method of collection is uniform (Averett, 1981, p. B5; K. V. Slack, U.S. Geological Survey, written commun., 1982).

Sample size is also an important consideration in collecting a representative biological sample. A sample size of 10 or 20 rocks is considered sufficient for faunal surveys using this method (Greeson and others, 1977, p. 164). In keeping with the objectives as an inexpensive and broad-based sampling program, sample size was limited to 10 rocks. This was considered a sufficient sample size to approximate asymptotic diversity and allowed a larger number of sites to be sampled.

Therefore, during each visit to a site, benthic invertebrates were sampled from a riffle by collecting 10 rocks, 45-to 90-mm in diameter (Lium, 1974). A specially designed sampler, called the Lium sampler (fig. 2), was used to collect the rocks. The sampler consists of a metal hood with a padded base and attached conical screen of 210-μ mesh. The sampler is described in detail by Greeson and others (1977, p. 157). The Lium sampler was designed to catch the organisms that wash off a rock as it is picked from the streambed (Lium, 1969).

Approaching a rock from the downstream side, the hood of the sampler is placed over the selected rock and pressed down to the streambed. The flexible base of the hood conforms to the streambed and forms a seal so that organisms dislodged as the rock is picked up are carried by the current into the screen behind the hood. The surrounding substrate is disturbed very little when removing the rock.

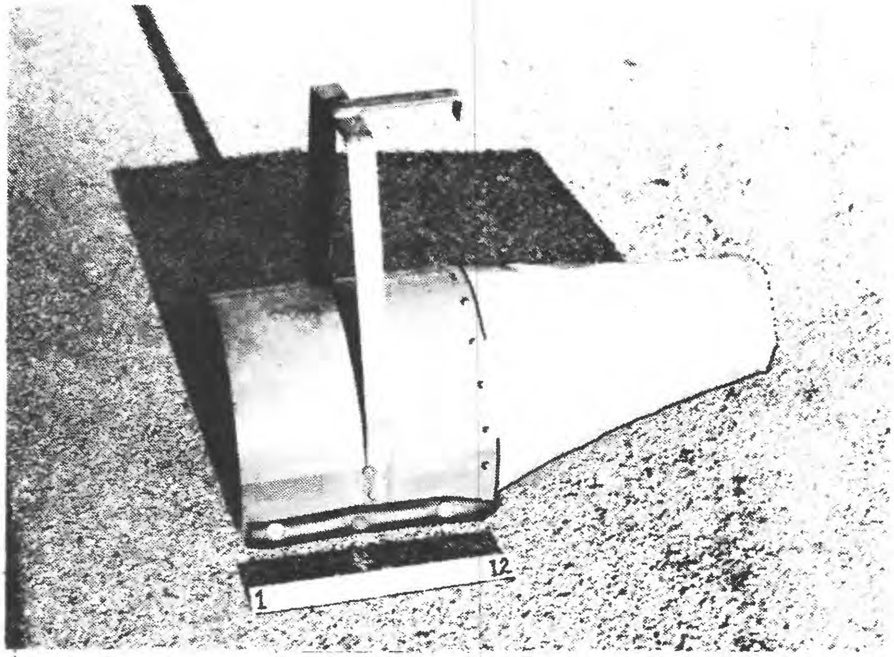

Figure 2.--Lium sampler. One-foot ruler included for scale.

Many investigators have found that three to five 1-foot-square samples, collected using a Surber sampler, are sufficient for faunal surveys in streams (Averett, 1981; Greeson and others, 1977, p. 5). Preliminary data from replicate sampling at several sites using the Lium sampler to collect 10 rocks and a Surber sampler to collect three 1-foot square samples show that the two methods are comparable.

Invertebrates are washed from the sampler onto a 210-μm mesh sieve, picked from the sieve and the rocks, and placed in a bottle containing 70-percent ethyl alcohol for later identification. Observations and field notes were made from 1970 through 1974 and in 1980 of the types and abundance of other benthic invertebrates and vertebrates and the amounts of sediment deposition on the substrate in the riffles, including the margins and in adjacent pools. Field notes were also made on the abundance of diatoms, green algae, blue-green algae, and rooted aquatics on the streambed. At sites 16, 25, 39, and 41, the regular quantitative benthic invertebrate samples were not collected. At sites 16 and 25, no organisms were found during early samplings. At sites 39 and 41, lack of suitable substrate for sampling made it impossible to collect the regular quantitative biological sample. Therefore, only qualitative biological data were collected at these sites, but observations were made and field notes taken on the types and abundance of the organisms present.

METHODS OF DATA ANALYSIS

Seasonal Kendall Test

Kendall's tau test for trend (Kendall, 1975) is a nonparametric, distribution-free statistical test for monotonic trend with time. This test has certain advantages over the classical parametric tests used in correlation and regression analysis because of its distribution-free properties. The chemical and biological data for this study are not well suited for trend analysis with parametric-correlation and regression-analysis techniques because of distributional features of the data. Organisms under natural conditions usually assume a clumped or patchy distribution (Greeson and others, 1977, p. 3). This distribution pattern has been referred to as a contagious distribution (Elliott, 1971) and is brought about by behavior and habitat requirements of the organisms. Most biological data, therefore, violate the assumptions made by parametric-correlation and regression-analysis techniques that the data are normal, independent, and identically distributed in time.

Smith and others (1982) state that most water-quality data have seasonality, are skewed, are serially correlated, and, therefore, violate the underlying assumptions of normality made by regression-analysis techniques. They also note that attempts to remove or reduce these features by altering or transforming the data are largely unsuccessful, and the degree to which these solutions work is questionable and largely unknown. They recommend using a nonparametric distribution-free statistical test such as Kendall's tau test or seasonal Kendall test, which is largely unaffected by the above-mentioned distributional characteristics, when examining water-quality data for trend. The seasonal Kendall test, a modified verison of Kendall's tau test, was chosen as the method of trend analysis for this study.

Brillouin's Diversity Index

Lium (1977) developed a 10-point rating scale for determining stream water quality that he applied to the early biological data (1970-74) from this sampling program. Briefly, a station was rated on a combination of sediment accumulation; composition, as percentages, of the major floral types; and composition, as percentages, of the major orders of benthic invertebrates. The first two elements, sediment accumulation and percent composition of major floral types, were visually estimated and, therefore, were subjective. The tabulated data on benthic invertebrate populations were quantitative but were used subjectively in the 10-point rating system. A study by R. A. McLean showed that Lium's assigned rating from the 10-point scale correlated closely with diversity index, which established the validity of Lium's ratings (R. A. McLean, written commun., 1978). However, the subjectivity of the observations makes it unlikely that other workers could use the rating system and obtain the same results. Because of this, the rating has not been widely accepted as a way of evaluating stream water quality. For this reason, diversity index, which is a widely used and accepted method of evaluating benthic invertebrate data, was used in this study. The tabulated benthic invertebrate data provide a quantitative data base that can be evaluated with this more objective method to obtain results that are reproducible.

The following discussion of diversity and its measurement is largely from a paper by K. V. Slack (U.S. Geological Survey, written commun., 1982). The relevant quantitative information about a biological community or collection consists of two things: the number of different kinds of organisms (taxa) present and their relative abundances. These two properties are commonly summed up in a descriptive statistic called a diversity index (R. C. Averett, U.S. Geological Survey, written commun., 1975; D. W. Stephens, U.S. Geological Survey, written commun., 1979). Various ways of defining and measuring diversity have been proposed (Whittaker, 1972; Peet, 1974), but all result in a single statistic in which the number of taxa and the relative abundance of individuals among the taxa are combined. In general, diversity is high if it has many taxa and their abundances are fairly even; diversity is low if the taxa are few and their abundances uneven.

Of the many measures of diversity that have been proposed, Brillouin's diversity index, which is based on information theory, is commonly used by aquatic ecologists. A diversity index based on information theory has certain advantages over other simple diversity indices: (1) they are dimensionless, so that count or biomass data can be used; (2) the importance of each species in the community is expressed as a ratio representing the contribution of each species to the total diversity; and (3) the occurrence of rare species will not greatly change the diversity (Wilhm and Dorris, 1968, p. 479; Averett, 1981, p. B5).

When all individuals of a biological collection are identified (or discriminated) and counted, the diversity of the collection may be given by Brillouin's measure of information per individual (Brillouin, 1962):

$$H = \frac{1}{N} \log_2 \left(\frac{N!}{N_1! \; N_2! \; \ldots N_s!} \right) \qquad (1)$$

where

H = the diversity,
N = the total number of individuals,
s = number of species, and
$N_i (i = 1,2,\ldots,s)$ = number of individuals in the i^{th} species.

When H is used as a measure of the diversity of a completely censused collection treated as a total community, it is free of sampling error. Brillouin's equation has not been widely used because of the necessity to compute large factorials, but it is the appropriate expression to use for most bacterial, phytoplankton, periphyton, and benthic invertebrate samples, including artificial substrate samples taken in water-quality and ecological investigations (D. W. Stephens, U.S. Geological Survey, written commun., 1979; K. V. Slack, U.S. Geological Survey, written commun., 1982).

If ecological samples are regarded as fully-censused collections, then H gives the exact diversity and not an estimate or approximation. Because it is seldom possible to define the limits of a community, especially in stream surveys, or to sample randomly from it, it is appropriate to regard a sample as only a representative population from the larger undefined community. That sample has an information content or diversity that is most appropriately given by Brillouin's equation (Pielou, 1969; Kaesler and Herricks, 1976; Zand, 1976).

Because of the ambiguous feature of diversity indices in which the number of taxa and their relative abundances are combined, it is difficult to compare or interpret the values directly. Supplementary information is needed, and two general approaches have been taken to provide this. The first involves calculation of maximum and minimum values for H, given the same s and N of the original collection. Maximum diversity exists when all individuals are distributed as uniformly as possible among the taxa; minimum diversity exists when all individuals are distributed as unevenly as possible among the taxa. Maximum diversity, H_{max}, and minimum diversity, H_{min}, were calculated using the following working equations (D. W. Stephens, U.S. Geological Survey, written commun., 1979):

$$H_{max} = \frac{C}{N}\left\{\log_{10}(N!) - s \cdot \log_{10}\left[\left(\frac{N}{s}\right)!\right]\right\} \qquad (2)$$

$$H_{min} = \frac{C}{N}\left(\log_{10}(N!) - \log_{10}\left\{\left[N - (s - 1)\right]!\right\}\right)$$

where

C = the factor 3.3219 to convert $\log_{10}$ to $\log_2$

These working equations are derived, using Pielou (1966), from theoretical equations given by Archibald (1972).

The second approach involves calculation of an index that expresses the evenness of diversity. Evenness describes the observed degree of uniformity of the distribution of individuals among the taxa in the collection. The evenness index used in this report is the one suggested by Peet (1974) in which e, relative evenness, is the ratio,

$$e = \frac{H - H_{min}}{H_{max} - H_{min}} \qquad (3)$$

Values of e between 0.5 and 1.0 are generally regarded as indicating balanced communities whereas values approaching zero indicate an imbalance.

Although species is commonly referred to in discussions of diversity, diversity can be divided hierarchically into components so that one can determine the diversity of orders, families within orders, genera within families, and species within genera. The diversity at the various levels in the hierarchy are additive and sum to the species diversity (Kaesler and Herricks, 1979).

The diversity values calculated for this study are working diversities calculated on varying hierarchial levels of identification and are not strictly generic diversities. The term "genus diversity" is applicable only when all organisms are identified and counted at the genus level. In this study, organisms were generally identified to the genus level with the exception of midges (Chironomidae) and flatworms (Planariidae), which were identified only to the family level in the early data (1970-74) because of the difficulty involved in genus-level identification. In the later data

(1975-80) the midges were identified to the genus level. To keep the working diversity values comparable, the values were calculated at the same taxonomic levels for the entire period of record. In other words, working diversities were calculated as though the midges (Chironomidae) had been identified to the family level for all samples. The true generic diversity of the samples will normally be somewhat higher than the calculated working diversity values. Comparisons between working diversity and true generic diversity in the later data (1975-80) have shown that, generally, the working diversity closely approximates the true generic diversity. Working diversity values can be used for comparative purposes when uniform procedures are used throughout a study (K. V. Slack, U.S. Geological Survey, written commun., 1982).

Benthic Invertebrates

Brillouin's diversity index (H) was calculated for each biological sample along with the supplemental calculations, maximum diversity (H_{max}), minimum diversity (H_{min}), and relative evenness (e). Brillouin's diversity index is calculated in logarithim base 2 and the unit of total diversity is expressed in bits per individual. A median and mean Brillouin's diversity index, and standard deviation and standard error of the mean were calculated for each site. Yearly values of Brillouin's diversity index were plotted against time for each site.

The seasonal Kendall test for trend was applied to Brillouin's diversity index values for each site to quantify the existence of trends statistically. A second statistical technique called the Kendall slope estimator (Thiel, 1950; Sen, 1968) was used to estimate the magnitude of trends. The Kendall slope estimator is included on the plots to show the direction and magnitude of the trends.

Kendall's tau test, seasonal Kendall test, Kendall slope estimator, and their applications are discussed in papers by Hirsch and others (1982) and Smith and others (1982). These papers used a modified form of Kendall's tau test called the seasonal Kendall test (Hirsch and others, 1982), which takes into account seasonal variation in the data. In this study, we used the seasonal Kendall test, without the modification for seasonal variation. Seasonal variation did not have to be accounted for in the data set since only data from the fall sampling were used.

Chemical Constituents

The chemical data were evaluated for trend with the seasonal Kendall test. Many chemical constituents are correlated with discharge (Langbein and Dawdy, 1964; Johnson and others, 1969; Smith and others, 1982). Therefore, the variance due to flow must be removed before the trend can be analyzed accurately. The program FAC, which computes a time series of flow-adjusted concentrations and is described in detail by Hirsch and others (1982) and Smith and others (1982), was applied to the chemical data where stream discharge data were available. Complete stream-discharge data were available only for sites 2, 7, 10, 15, 17, 36, 37, and 40. Discharges for 1973-80 for sites 2, 15, 17, 36, 37 and 40 were obtained from the records of recording stream gages either at or close to the sampling sites. Discharges for sites 7 and 10 were obtained from the daily readings of rated wire-weight gages at these sites. The flow-adjusted or residual values were then tested for trend using the seasonal Kendall test. Examination of the flow-adjusted chemical concentrations at these eight sites should detect the presence of trends that exist in the chemical characteristics that are highly flow related.

The characteristics examined for trend at these eight sites were alkalinity, specific conductance, pH, total nitrate, total ammonia, total phosphorus, dissolved chloride, and dissolved sulfate. The degree to which these chemical characteristics were flow related was evaluated by determining values of tau and probability (p) on both flow-adjusted and non-flow adjusted data. Based on comparisons of these two sets of statistics and examination of the coefficient of determination (r^2) from the flow-adjusted data, the degree to which a chemical characteristic was flow related was determined. The chemical characteristics that were not highly related to flow were evaluated for trend at additional sites where trends were suspected and streamflow data were not available. The data were evaluated for trend by plotting the chemical concentrations against time and calculating a correlation coefficient (r).

In addition to testing the water-quality data for trend, several chemical characteristics were plotted against the Brillouin's diversity index to test for correlation between chemical and biological data. The chemical characteristics tested for correlation with the biological data were alkalinity, pH, total nitrate, total ammonia, total phosphorus, methylene blue active substance (an indicator of the presence of detergents), dissolved chloride, dissolved sulfate, and total dissolved solids. For certain years, selected chemical characteristics were plotted against Brillouin's diversity index for all sites. The chemical characteristics were then tested for correlation with diversity index by linear-regression techniques. The 1980 data for nitrate, ammonia, and phosphorus were selected for correlation with diversity index because nutrient samples for that year were preserved by better techniques than those used in the previous years (R. J. Pickering, U.S. Geological Survey, written commun., 1980), and therefore the data were considered to be the more reliable. The 1980 data for pH and methylene blue active substance were selected for correlation with diversity index. The 1980 data for methylene blue active substance were chosen because they provided the most values to correlate with diversity index. Values less than the detection limit could not be used for statistically testing for correlation. The 1977 total dissolved solids data and the 1976 data for alkalinity, chloride, and sulfate were used for correlation with the diversity index. The years 1976 and 1977 were arbitrarily chosen to avoid introducing bias by testing all chemical constituents from the same year. A linear regression analysis was done and a coefficient of determination (r^2) was calculated.

BENTHIC-INVERTEBRATE DIVERSITY INDEX TRENDS

Table 2 gives Brillouin's diversity index, maximum diversity, minimum diversity, and evenness for each sample. Table 3 gives the median and mean Brillouin's diversity index, standard deviation, and standard error of the mean for each site. The values in table 3 provide an indication of the central tendency of the data over the entire period of record and the amount of variation that exists in the central value. This information is useful for examination and comparison of individual diversity values. Information from table 3 also provides an indication of the overall stability of stream conditions at a site.

The biological data are also given in graphic form in the plots of Brillouin's diversity index as a function of time for each site (figs. 3-1 to 3-46). These plots present an easily understood graphic summary of the temporal changes in diversity index at each site. Diversity can range from zero to infinity, but generally, will range from 0 to 4.0. Diversity will range from 3.0 to 4.0 in waters that do not receive organic wastes (clean water zones), from 1.0 to 3.0 in water receiving moderate levels of organic wastes, and from 0 to 1.0 in waters receiving heavy levels of organic wastes (Wilhm and Dorris, 1968; Wilhm, 1970). Diversity index measures the effect of a stress and not its cause; therefore, it is more appropriate to define these zones as measuring community stress and not pollution. Community stress may be the result of pollution, but this must be determined from the data. Time plots of diversity index are not given for sites 16, 25, 39, and 41 due to the lack of quantitative biological data. Only qualitative biological data regarding the types and abundances of organisms present were collected at these sites. In figures 3-1 through 3-46, some data points for 1975 and 1978 are missing. Missing data points for 1975 are due to improper preservation of the biological samples. Out of the 46 biological samples collected that year, data are available for only 19 samples. The 1978 data were omitted from the time plots and trend analysis because a variation in the sampling procedure made it inappropriate to compare these data with the other data.

Magnitude of trend in the data was determined by the Kendall slope estimator, which is shown on each figure. The slope estimator is not a substitute for visual examination of the plots and actual quantitative taxonomic data, but is a useful tool to aid in evaluating the data. However, where the data are considerably skewed, visual examination of the plots alone may be somewhat misleading. This is due to the tendency of the reader to concentrate on the extreme values of a series rather than the more subtle but regular trends in the bulk of the values closer to the median. The Kendall

Table 3.--Median, mean, standard deviation, and standard error values of Brillouin's diversity index, by site

Site Number	Station Number	Number of Samples	Median	Mean	Standard Deviation	Standard Error
1	01472170	8	2.3	2.1	0.65	0.23
2	01472174	9	2.1	2.3	.77	.26
3	014721854	9	2.3	2.4	.40	.13
4	014721884	7	2.3	2.2	.60	.23
5	01472190	9	2.4	2.4	.80	.27
6	01472109	9	1.7	1.6	.74	.25
7	01472110	9	2.1	2.3	1.17	.39
8	01472054	8	2.0	2.2	.45	.16
9	01472065	9	2.2	2.2	.43	.14
10	01472080	8	2.5	2.4	.57	.20
11	01472129	7	2.8	2.7	.45	.17
12	01472140	9	2.7	2.6	.36	.12
13	01472138	9	2.3	2.8	.66	.22
14	01472154	9	2.8	2.6	.56	.19
15	01472157	10	2.6	2.6	.68	.21
17	01475300	9	2.4	2.2	.74	.25
18	01475830	8	2.2	2.4	.64	.23
19	01475840	9	2.7	2.5	.57	.19
20	01476430	9	2.5	2.2	.75	.25
21	01476435	9	2.2	2.3	.71	.24
22	01476790	9	2.3	2.1	.44	.15
23	01476830	9	1.9	1.7	.51	.17
24	01476835	8	2.0	1.8	.85	.30
26	01479800	8	1.1	1.0	.57	.20
27	01479680	9	1.2	1.2	.59	.20
28	01478120	8	2.5	2.4	.79	.28
29	01478190	9	1.7	1.6	.57	.19
30	01478220	8	2.2	2.1	.60	.21
31	01494900	8	2.1	2.1	1.18	.42
32	01494950	7	2.1	2.1	.60	.23
33	01578340	8	2.0	2.0	.40	.14
34	01578343	8	1.8	1.8	.75	.26
35	01578345	9	2.1	2.0	.42	.14
36	01480700	10	2.1	2.1	.63	.20
37	01480434	10	2.2	2.1	.77	.24
38	01480640	8	1.6	1.4	.70	.25
40	01481030	8	1.9	2.1	.59	.21
42	01480653	6	2.5	2.6	.34	.14
43	01480647	6	1.7	1.8	.57	.23
44	01480903	7	2.5	2.4	.59	.22
45	01480632	7	2.5	2.3	.72	.27
46	01480629	7	1.4	1.6	.45	.17
47	01480656	6	3.0	3.1	.30	.12
48	01480648	7	2.9	2.8	.27	.10
49	01473167	7	2.3	1.7	1.13	.43
50	01473168	7	1.7	1.6	.75	.28

slope estimator is resistant to the effects of extreme values and gives more weight to the bulk of the values closer to the median value and, therefore, will more closely approximate the trend (Hirsch and others, 1982).

The diversity indices were evaluated for trend using the seasonal Kendall test for trend. The degree of correlation is measured by tau and the significance of the trend is measured by p. The level of confidence of the trend is determined from the p value.

Generally, the more scatter in the points about the slope estimator, the greater the variability in the data, the lower the correlation (signified by a low tau value), and the higher the probability of error (signified by a high p value). As the tau value approaches either positive or negative 1, the degree of correlation increases. As the p value approaches 1, the probability of error increases, indicating that the trend is less significant. Generally, high tau values will be associated with low p values indicating significant trends with a low probability of error, or low tau values will be associated with high p values, indicating poorly correlated trends with a high probability of error.

The level at which trend is significant is determined by the alpha (α) value. The α value is defined as the p value at which the trend is considered significant. The most commonly accepted levels of confidence are the 99 percent level of confidence (α=0.01) and the 95 percent level of confidence (α=0.05). Occasionally, the 90 percent level of confidence (α=0.10) is considered acceptable (Smith and others, 1982). When the number of observations in the data set is less than 10, the normal approximation used in the seasonal Kendall test (Hirsch and others, 1982, p. 108) will give inaccurate values of p. Consequently, for data sets containing less than 10 observations, the level of statistical significance was determined from a probability distribution table in Bradley (1968, p. 364). The exact level of confidence could not be determined for sites with less than 10 observations where alpha values were less than 0.10 because of the limitations of the table.

Upward trends in biological conditions were found at 44 sites and downward trends, indicating degraded water quality, were found at two sites using the Kendall slope estimator. The upward trends were significant at the 99 percent confidence level at seven sites, 95 to 98 percent confidence level at nine sites, and 90 to 94 percent confidence level at 11 sites (table 4). The diversity index trends at the remaining sites were not statistically significant; however, data from these sites may not be altogether inconclusive. Characteristics of the data other than variability may interfere with or invalidate the statistical analysis for trend. Thus, caution must be used when evaluating data with statistical methods. The seasonal Kendall test for trend is not a substitute for visual examination of the plots and associated data, but rather a useful statistical tool for evaluating the data.

The seasonal Kendall test and the Kendall slope estimator are suitable procedures where water-quality characteristics appear to be changing monotonically over time (Hirsch and others, 1982). Streams are dynamic systems; consequently, water-quality data and biological data are quite variable and will not always show trend in only one direction. For example, at site 20 (fig. 3-19) diversity index initially increases and then beginning in 1976

Table 4.--Values of tau, p, and level of confidence from seasonal Kendall test of diversity index

Site Number	Station Number	Tau	p	Level of confidence of significant trends (percent) 1/
1	01472170	0.43	0.10 2/	90
2	01472174	.33	.25	-
3	014721854	- .17	.60	-
4	014721884	.52	.10 2/	90
5	01472190	.28	.35	-
6	01472109	.69	.01	99
7	01472110	.36	.21	-
8	01472054	.11	.80	-
9	01472065	.44	.10 2/	90
10	01472080	.43	.10 2/	90
11	01472129	.62	.05 2/	95
12	01472140	.39	.10 2/	90
13	01472138	.69	.01	99
14	01472154	.44	.10 2/	90
15	01472157	.40	.10 2/	90
17	01475300	.78	.01	99

Table 4.—Values of tau, p, and level of confidence from seasonal Kendall test of diversity index—continued

Site Number	Station Number	Tau	P	Level of confidence of significant trends (percent)
18	01475830	0.36	0.27	-
19	01475840	.64	.02	98
20	01476430	.39	.18	-
21	01476435	.33	.25	-
22	01476790	.25	.40	-
23	01476830	.28	.35	-
24	01476835	.86	.00	99
26	01479800	.00	1.00	-
27	01479680	.25	.40	-
28	01478120	.79	.01	99
29	01478190	.39	.10[2/]	90
30	01478220	.64	.04	96
31	01494900	.64	.04	96
32	01494950	.62	.05[2/]	95
33	01578340	.50	.10	90
34	01578343	.14	.71	-
35	01578345	.44	.10[2/]	90

Table 4.--Values of tau, p, and level of confidence from seasonal Kendall test of diversity index--continued

Site Number	Station Number	Tau	p	Level of confidence of significant trends (percent)
36	01480700	0.51	0.05	95
37	01480434	.33	.21	-
38	01480640	.71	.01[2/]	99
40	01481030	.71	.01[2/]	99
42	01480653	.20	.71	-
43	01480647	.60	.10[2/]	90
44	01480903	.62	.05[2/]	95
45	01480632	.62	.05[2/]	95
46	01480629	.43	.23	-
47	01480656	.47	.26	-
48	01480648	.14	.76	-
49	01473167	.24	.55	-
50	01473168	.71	.04	96

1/ A dash indicates trend not statistically significant

2/ Alpha values from table XI in Bradley (1968) for data sets with less than 10 observations.

decreases as a result of development in the basin. The seasonal Kendall test for trend will not work when the data have multiple trends. This may be the case at several sites and may be responsible for the insignificant statistical correlation of diversity index trends at sites 1, 2, 20, 26, 27, and 49. Due to the limited number of data points in the data base, the data cannot be split into segments and each trend analyzed separately. However, the addition of more data points may make it possible to do this in the future.

The seasonal Kendall test for trend treats all data in the same manner regardless of the magnitude of the slope of the trend. However, because of the method of calculation used in the normal approximation of the seasonal Kendall test, the amount of variance in the data becomes more important in determining the significance of the trend in the case of trends with slopes of low magnitude. Consequently, trends with slopes of low magnitude need an extremely small variance and large sample size in order to be statistically significant (R. B. Alexander, U.S. Geological Survey, oral commun., 1983).

The trends in diversity index at sites 3, 22, 23, 42, 46, 47, and 48 were statistically insignificant and had high p values due to the low magnitude of the slope of the trends. These low magnitude trends represent a stable unchanging condition or small degrees of change that could not be measured by the seasonal Kendall test due to the limited number of observations. However, given the low degree of variability in the data at these sites, it should be possible eventually to statistically validate many of these low magnitude trends given a larger number of observations.

The trends in diversity index at sites 5, 7, 8, 18, 21, 34, and 37 were not statistically significant as a result of the low degree of correlation and large degree of variability in the data. It is highly unlikely, due to the large degree of variability in the data, that sites 7, 8, 18, and 34 will exhibit any significant trends. Some sites (5, 21, and 37) show some possibility of yielding a significant trend given a larger number of observations.

Sites 3 and 26 (figs. 3-3 and 3-24) are of particular interest because there appears to be a downward trend to the data. Although these downward trends could not be statistically validated, they may represent a deterioration in water quality. The decreasing trend in the diversity index at site 3, on Pickering Creek, is probably the result of urbanization in the Pine Creek basin. Pine Creek is a major tributary which enters Pickering Creek between sites 2 and 3. The development and subsequent deterioration in water quality, which began in 1968 in the Pine Creek basin, was first noted by Miller and others (1971). From the data, it appears that the development in the Pine Creek basin is having an impact on Pickering Creek. The trend in diversity index at sites 1 and 2 on Pickering Creek above the confluence with Pine Creek is upward. At site 3, just below the confluence of Pine Creek and Pickering Creek, the trend in diversity is downward. Farther downstream at site 4, the trend is stable or unchanging. At site 5 the upward trend in diversity index is resumed.

The diversity index at site 26 in the Red Clay Creek basin also had a downward trend that was especially apparent in the later data (1976-80). The downward trend is most likely due to increased levels of pesticides in the basin. Recent sampling by Pennsylvania Department of Environmental Resources, Pennsylvania Fish Commission, and the U.S. Fish and Wildlife Service have shown moderate to low levels of pesticides in fish flesh, sediments, and water from Red Clay Creek (D. F. Knorr, Pennsylvania Department of Environmental Resources, written commun., 1983). The biological data for site 27, also in the Red Clay Creek basin, were too inconclusive to make a determination of trend although diversity indices were generally quite low.

Benthic-invertebrate sampling is an effective method of evaluating water quality. The diversity indices at 27 sites had an upward trend that was statistically significant at the 90 percent or greater level of confidence and 16 of these were significant at the 95 percent or greater level of confidence. These increases are not due to variations in the sampling procedure. The biological data, for these sites, show that pollution-sensitive organisms such as the stoneflies (Plecoptera), mayflies (Ephemeroptera), and caddisflies (Trichoptera) increased in frequency of occurrence, diversity of taxa, and total number of individuals. The increase in diversity index and pollution-sensitive organisms over time is an indication of improved water quality at these sites.

WATER-QUALITY TRENDS

The chemical data from eight sites (2, 7, 10, 15, 17, 36, 37, and 40) were analyzed for trend using the seasonal Kendall test. The results of the analyses are summarized in table 5. These sites were the only sites having complete streams-discharge records, which were used to flow adjust the chemical concentrations before trend analysis to remove the variance due to streamflow. The water-quality characteristics tested for trend at these sites were specific conductance, pH, alkalinity, dissolved sulfate, dissolved chloride, total nitrate, total ammonia, and total phosphorus. These particular water-quality characteristics were selected because of their importance in exercising control over the biological community and the possibility that they might correlate with the biological data. Other investigations (Miller and others, 1971; Murphy and others, 1982) showed that many of these water-quality parameters were exhibiting trends in Chester County. Miller and others (1971, p. A20) showed a marked increase in sulfate, nitrate, chloride, and dissolved solids as a result of urbanization.

The specific conductance was increasing at six of the eight sites (2, 10, 15, 17, 36, and 40), and decreasing at two sites (7 and 37). The decreasing trend in specific conductance at sites 7 and 37 is the result of a decreasing level of ions in the water. The increasing trend at sites 2, 10, 17, and 36 was statistically significant; sites 2 and 36 were significant at the 98 percent level of confidence, site 10 at the 95 percent level of confidence, and site 17 at the 94 percent level of confidence. The p values at the other sites (7, 15, 37, and 40) ranged from 0.15 to 0.71.

The pH was decreasing at five sites (2, 15, 17, 36, and 40), and increasing at three sites (7, 10, and 37). Only the decreasing trend at site 2 was statistically significant with a confidence level of 96 percent. The p values at the other sites ranged from 0.11 to 1.0.

Table 5.—Summary of results of seasonal Kendall test for trend of streamflow-adjusted chemical concentrations

Constituent or Property	Increasing (+) or decreasing (-) trend at site							
	2	7	10	15	17	36	37	40
Specific Conductance	+*	-	+*	+	+*	+*	-	+
pH	-*	+	+	-	-	-	+	-
Alkalinity	-	-	-	-	+	-	-	-
Dissolved chloride	+	+	+	+	+	-	+	+*
Dissolved sulfate	+	+	+*	+	+	-	-	-
Total nitrate as nitrogen	-	-	-	+	-*	+	-	-
Total ammonia as nitrogen	+	+	+	+	-	-	+	+
Total phosphorus as phosphorus	-	-	-*	+	-*	+	+	-

*Trend significant at the 90 percent level of confidence or greater. All other trends are not statistically significant.

Alkalinity was decreasing at seven sites (2, 7, 10, 15, 36, 37, and 40), and increasing only at site 17. None of the sites showed a statistically significant trend as p values ranged from 0.23 to 1.0.

Dissolved chloride concentrations were increasing at seven sites (2, 7, 10, 15, 17, 37, and 40), and decreasing only at site 36. Only the increasing trend at site 40 was statistically significant with a confidence level of 99 percent. The p values at the other sites ranged from 0.12 to 1.0.

Dissolved sulfate concentrations were increasing at five sites (2, 7, 10, 15, and 17), and decreasing at three sites (36, 37, and 40). Only the increasing trend at site 10 was statistically significant with a 94 percent level of confidence. The p values at the other sites ranged from 0.12 to 1.0.

Total nitrate concentrations were decreasing at six sites (2, 7, 10, 17, 37 and 40), and increasing at two sites (15 and 36). Only the decreasing trend at site 17 was statistically significant with a confidence level of 96 percent. The p values at the other sites ranged from 0.21 to 1.0.

Total ammonia concentrations were increasing at six sites (2, 7, 10, 15, 37, and 40), and decreasing at the two sites (17 and 36). None of the trends were statistically significant as the p values ranged from 0.25 to 0.86.

Total phosphorus concentrations were decreasing at five sites (2, 7, 10, 17 and 40), and increasing at three sites (15, 36, and 37). Only the decreasing trends at sites 10 and 17 were statistically significant, having confidence levels of 97 percent and 96 percent, respectively. The p values for the other sites ranged from 0.12 to 0.88.

Three significant trends were detected at site 17 on Darby Creek. Results of the seasonal Kendall test show a significant increasing trend in specific conductance and significant decreasing trends in nitrate and total phosphorous concentrations. The decreasing trends in nitrate and phosphorous probably result from the elimination of a small sewage treatment plant which discharged into the stream. A decreasing trend in ammonia concentrations was also observed but was not statistically significant. The statistically significant increasing trend in specific conductance is indicative of increasing levels of ions in the water. Increasing trends in chloride and sulfate concentrations were observed, but were not statistically significant. The source of these increasing ion concentrations could not be determined.

The chemical data were also tested for trend at 13 sites (6, 20, 21, 22, 23, 24, 26, 27, 38, 44, 46, 49, and 50) where stream discharge data were not available to flow adjust the chemical concentrations. Trends in the chemical data were suspected at these sites because of trends in diversity index. In addition, changes in land use in many of the basins could have produced a trend in the chemical data. Since the chemical constituents could not be flow adjusted, constituents that had shown little degree of relationship with stream discharge, based on earlier r^2 statistics, were selected. The constituents analyzed for trend were total nitrate, dissolved chloride, and dissolved sulfate. The results of the analyses are summarized in table 6.

Table 6.--Summary of results of trend analysis of chemical concentrations not adjusted for streamflow

Constituent	Increasing (+) or decreasing (-) trend at site												
	6	20	21	22	23	24	26	27	38	44	46	49	50
Total nitrate as nitrogen	+	-	-	+*	-	+*	-	+	-	-	+	-*	-
Dissolved chloride	+	+	+*	+*	+*	+*	+	-	-	+	+	-	+*
Dissolved sulfate	+	+	-	-	-	+	+	-	-	+	+	-	+

*Trend significant at r equal to or greater than 0.60.
All other trends are not statistically significant.

The data were analyzed for trend by plotting the chemical constituents against time and calculating a correlation coefficient (r). The values of r range from 0 to 1 or to -1 with 0 being no correlation and 1 or -1 being a perfect correlation. The value of r will be positive (+) if the trend is increasing and negative (-) if the trend is decreasing. Generally, an r greater than 0.60 was considered significant.

Total nitrate was tested for trend at the 13 sites. No significant trends were found at 10 sites (6, 20, 21, 23, 26, 27, 38, 44, 46, and 50); r at these sites ranged from 0 to 0.56. Statistically significant trends were found at three sites (22, 24, and 49) that had r values greater than 0.60. An increasing trend in nitrate concentrations was found at sites 22 and 24; the r values were 0.69 and 0.66, respectively. The increases in nitrate concentrations at these two sites in the Chester Creek basin are probably due to intense urbanization. The number of housing developments in this basin has greatly increased since the beginning of this project. A decreasing trend in nitrate concentrations was found at site 49 where the r was -0.60. The decrease in nitrate concentrations at this site is probably due to the elimination of point-source discharges from several small sewage-treatment plants, when the large Valley Forge regional sewage-treatment system came on line in 1977. Site 50, in the Valley Creek basin, did not show a statistically significant downward trend.

Dissolved chloride was tested for trend at the 13 sites. No significant trends were found at eight sites (6, 20, 26, 27, 38, 44, 46, and 49). The values of r ranged from 0.20 to 0.53. Significant increasing trends were found at five sites (21, 22, 23, 24, and 50). The trend at site 21 in the Ridley Creek basin had an r of 0.73. Chloride concentrations at site 20 in the Ridley Creek basin also appeared to be increasing. However, this was not statistically significant because of an outlier in the data; r was 0.40. The increasing trend in chloride concentrations at sites 20 and 21 is probably caused by large scale development in the west branch of the Ridley Creek basin. Sites 22, 23, and 24 in the Chester Creek basin each had an increasing trend; the r values were 0.66, 0.73, and 0.72, respectively. The increasing trends in chloride concentration are probably caused by the intense urbanization in the basin. The trend at site 50 in the Valley Creek basin had an r of 0.69. As with other sites, the increasing trend in chloride concentrations is probably caused by increasing development.

Sulfate was tested for trend at 13 sites (6, 20, 21, 22, 23, 24, 26, 27, 38, 44, 46, 49, and 50). The values of r ranged from 0 to 0.53. There were no statistically significant trends in sulfate concentrations at the 13 sites.

CORRELATION OF DIVERSITY INDICES AND WATER QUALITY

Data on total nitrate, total phosphorus, total ammonia, pH, and methylene blue active substance for 1980 were tested by linear regression for correlation with diversity index. A coefficient of determination (r^2) was calculated to determine the degree of correlation. No statistically significant correlations were found. The values of r^2 for the parameters were 0.09, 0.08, 0.07, 0, and 0.05, respectively. Total-alkalinity, dissolved-chloride, and dissolved-sulfate data for 1976 were tested by linear regression for correlation with diversity index. No statistically significant correlation was found. The r^2 values were 0.04, 0.04, and 0.07, respectively.

Total dissolved-solids data for 1977 were tested by linear regression for correlation with diversity index. A statistically significant correlation was found; the r^2 value was 0.27. The correlation indicates that as the concentration of dissolved solids increases, the diversity index decreases. This relationship was observed by Lium (1977, p. 13) who showed a correlation between the decrease in his 10-point biotic index ratings and the increased dissolved-solids concentrations.

The results of the correlation analysis of chemical data with diversity index are generally in agreement with those by Lium (1977, p. 32) who showed that, with the exception of dissolved solids, no other correlations were established between the chemical constituents and biological conditions.

The lack of significant correlations between the chemical and physical constituents and the diversity index can be explained in part. The range of values for the chemical and physical characteristics is limited at most stations and seldom exceeds the extreme tolerance limits for many of the more tolerant species of organisms. If the chemical and physical conditions varied over a much wider range, a better correlation with the diversity index would be observed. By nature of its derivation, diversity index, especially above the species level, will not exhibit a great deal of sensitivity to minor degrees of disturbance, but can detect significant levels of disturbance (Benke and others, 1981). Diversity index is an all-encompassing measure of biological conditions that includes many tolerant species as well as the intolerant species. Minor degrees of disturbance can probably better be measured by qualitative and statistical analysis of the pollution-intolerant genera and species of organisms in the community because of their greater sensitivity (Benke and others, 1981). Also, the large degree of variability intrinsically present in chemical and biological data often obscures the relationships of the various constituents. This is especially true when working with a limited number of observations. Generally, as the number of observations increases, the variability in the data is more easily explained.

In many cases, it is not certain what variables are responsible for a trend in the biological data. Due to the limitations of the data base, only a small number of statistically significant trends were found in the chemical data as opposed to the larger number of significant trends in the biological data. Only 18 out of 103 possible trends in the chemical data were statistically significant. It is very difficult to define the cause of a trend in the biological data when a trend in the chemical data cannot be defined because of the variability in the data or a limited number of observations. Trends in the biological data may also be caused by variables that are not even being measured, such as pesticides. Additionally, water-chemistry constituents, due to their variability, may not be sensitive enough to detect subtle degrees of change in water quality that can cause a shift in stream biota. Benke and others (1981) point out that standard water-chemistry constituents showed little relation to the degree of urbanization measured by the biological data, and furthermore did not indicate any major degree of pollution. Little correlation was shown between trends in diversity index and trends in the chemical constituents. Therefore, although once a year (fall), chemical sampling showed some trends; it did not appear to be as effective as the biological sampling as a means of evaluating water quality in this study.

SUGGESTED MODIFICATIONS TO THE SAMPLING PROGRAM

Several changes might be made to improve the biological sampling program. Taxonomic identification of the benthic invertebrates should be done to the species level when possible. Although species-level identification is more difficult, the resulting data are more useful because of their greater sensitivity. Many investigators using benthic invertebrates and diversity indices to evaluate water quality determined diversity at the species level (Wilhm and Dorris, 1966; Wilhm, 1970; Hilsenhoff, 1977). Additionally, species-level identification would also enable a more detailed qualitative analysis of the biological data. Most published data about water quality requirements of benthic invertebrates are based on species-level identification (Weber, 1973; Roback, 1974). Qualitative information for genera is much more general than for individual species. The tolerance values for a genus are only equal to values of its most pollution tolerant species (Hilsenhoff, 1977). The tolerance range for the individual species is much more restricted and therefore provides more useful information about water-quality conditions.

Information is needed to validate the 10-rock sample as an acceptable sample size. It should be determined how many samples (rocks) must be collected from a riffle before asymptotic diversity is reached. Asymptotic diversity is that value of diversity that essentially does not change with the addition of new samples. Additional data also are needed to compare the Lium sampling method to the Surber sampling method. The Surber sampler is a widely accepted method of sampling benthic invertebrates. A favorable statistical comparison of the Lium method with the Surber method would help to establish a greater acceptance of the Lium sampling method.

A number of changes could be made to improve the water-quality sampling program. In order to use chemical data to detect water-quality trends, a much larger data base is necessary (Harned, 1980; Smith and others, 1982). A more comprehensive monthly or quarterly sampling program would be required to generate this larger data base, and to explain variation caused by seasonal variation, rainfall runoff, and storms. This would increase the cost of the sampling program considerably and is not within the scope of the present program. If a program for using chemical data to determining trends is desired, an independent water-quality sampling program could be designed and developed to meet those objectives. Otherwise, the sampling frequency should remain at once a year to provide a limited chemical data base to supplement interpretation of trends in the biological data. Additionally, the sampling can be tailored for the water-quality conditions at each site so that the most useful information for interpreting the biological data will be collected. This will reduce the overall chemical sampling program by eliminating unnecessary sample collection at some sites. It will also give the program more flexibility by allowing a more thorough sampling of additional constituents, such as pesticides, at those sites where it is needed.

Measurements of stream discharge are needed at all sites where water-quality samples are collected. Concentrations of many constituents are directly related to flow and must be adjusted for flow before they can be evaluated or tested for trend. The lack of streamflow data hampered the analysis of the water-quality data.

Nutrient sampling should be continued. Nutrient determinations provide some of the most useful and inexpensive information about water quality, and are useful in interpreting the biological data. The program, however, could be improved by determining dissolved nitrate, nitrite, and ammonia instead of total nitrate, nitrite, and ammonia because they represent the forms that are most readily available for uptake by the biological community. Nutrients associated with the sediments may be tied up in forms that are not readily available to the biological community. In addition, analytical techniques for the determination of dissolved nitrate, nitrite, and ammonia give more reliable results than those for total nitrate, nitrite, and ammonia. Dissolved nitrate, nitrite, and ammonia are more stable than total nitrate, nitrite, and ammonia samples due to better preservation techniques (L. R. Larson, U.S. Geological Survey, written commun., 1980).

Analysis for common ions, or at least chloride and sulfate, should continue. Measurement of these constituents provide useful and inexpensive data about water-quality conditions for interpreting the biological data.

Repeated sampling for dissolved and total trace metals has shown that trace metals either are not present or are present at extremely low levels in the water column at most sites in the network. High diversity index values at these sites indicate that levels of trace metals sufficient to cause acute or chronic toxicity to benthic-invertebrate communities are not present. Trace-metal analysis could be dropped from the routine sampling program, except at sites 16, 24, 25, 26, 27, 31, 32, 34, 38, 39, 49, and 50 where there have been either significant levels of trace-metal contamination or there is possibility of future trace-metal contamination from nearby industrial and municipal sources. Because of high toxicity of trace metals to fish and invertebrates, even at low concentrations, dissolved trace metals and trace metals in sediments should be sampled at any site where the diversity index falls below 1.0. Trace-metal concentrations may then be compared to the historical data for a site to determine if the levels have changed enough to affect the diversity index. The addition of a dissolved aluminum determination at all sites is suggested because high concentrations of aluminum are toxic to fish and invertebrates. One of the possible effects of acid rain is increased aluminum concentrations in water due to increased leaching from soils. Because of widespread acid precipitation in Pennsylvania (D. R. DeWalle, Pennsylvania State University, written commun., 1982) and the possible effect it may have on stream ecosystems in Chester County, Pennsylvania (S. J. Zlotowski, Williams College Center for Environmental Studies, written commun., 1982), analyses of dissolved aluminum might help to understand the effects of this potential problem.

Analysis for pesticides may be warranted at a site where the diversity index falls below 1.0. A diversity index below 1.0 is indicative of toxic pollution conditions, and pesticides may be a major cause of toxicity. Pesticide sampling should be tailored to each basin on the basis of possible sources and types of pesticides used within the basin. Sites 26 and 27 on Red Clay Creek are candidates for pesticide sampling. Both stations have shown a decreasing trend in diversity index over the past several years. The diversity index for 1980 was below 1.0 at both stations. The mushroom industry may be a potential source of pesticides. Pesticides commonly used in the mushroom industry are the organochlorine insecticides (chlorodane, endrin, lindane, methoxychlor, and toxaphene), the organophosphorous insecticides (DDVP, diazinon, dibrom, malathion, methyl parathion, parathion, ronnel), and the pyrethrin-based insecticides. Other compounds, such as the phenols, pentachlorophenols, and formaldehyde, are used as sterilizing agents and wood preservatives.

A large number of pesticides are used in crop and dairy farming in Chester County. If diversity values drop below 1.0 in areas where crop farming is the dominant land use, samples should be analyzed for the organchlorine insecticides, organophosphorous insecticides, chlorophenoxy acid herbicides, (2,4-D, 2,4-DP, 2,4,5-T and silvex), triazine herbicides (atrazine, cyanazine, propazine, and simazine), and amide herbicides (alachlor and metalachlor). In areas where dairy farms are dominant, when necessary, samples should be analyzed for the pyrethrin-based insecticides, which are used for pest control around dairy barns and feed lots.

Although the organochlorine pesticide DDT has been banned from use since 1971, recent sampling by the Pennsylvania Department of Environmental Resources has shown that DDT and its components and degradation products, DDD and DDE, are still persistent in the Red Clay Creek basin in moderate to low levels (D. F. Knorr, Pennsylvania Department of Environmental Resources, oral commun., 1983). For this reason, pesticide analysis should include a determination for DDT, DDD, and DDE.

Many pesticides and trace metals are persistent and have a tendency to accumulate in the sediments of a stream under normal flow conditions. Studies have shown that fine sediments (silt and clay) act as long-term integrators of trace metals and organic compounds such as pesticides because of their hydrophobic properties (J. D. Schornick, U.S. Geological Survey, written commun., 1983). Therefore, during base flows, sampling of the stream sediments would be more useful than sampling the water column for trace metals and pesticides.

The sampling network could be modified in several ways to improve its effectiveness. The collection of only qualitative and not quantitative biological data at some sites should be discontinued. In the past only qualitative biological data has been collected at sites 16, 25, 39, and 41. Sites 16 and 39 should be kept in the network, but should be sampled with the same procedure used for all other sites in order to make the data comparable in the future.

Site 25 on Goose Creek should be discontinued and replaced with a better sampling site. The site is presently located 1.9 miles below the West Chester Goose Creek sewage treatment plant and 1.3 miles below the West Goshen sewage treatment plant. This site falls within the septic zone below the discharge from these sewage treatment plants and provides very little useful biological information. More useful information could be gained by replacing site 25 with a new site on East Branch Chester Creek below the confluence with Goose Creek. A sampling site at this location would still provide adequate data about the water quality from Goose Creek and would also provide information about the impact of Goose Creek on the biology of East Branch Chester Creek.

Site 41 should be dropped from the network. This site was established on a first order stream in a woodland setting that is not comparable to the environmental setting of the other sites in the network. Diversity index at this site is naturally low because of the increased effect of shading, restricted nutritional base, and the heterotrophic nature of first-order woodland streams (Vannote and others, 1980). Useful information is already provided by other sites (11 and 13) farther downstream.

The biological data collected at sites 7 and 8 have been inconclusive because of the large degree of variability in the data (figs. 3-7 and 3-8). For this reason, these sites can be dropped from the network. Sites 9, 11, 18, 35, and 43 can also be discontinued. The biological data collected at these sites duplicates the data collected at an upstream or downstream site.

Site 34 on Valley Creek in the Octoraro Creek basin could be moved to an upstream site with better substrate. Data analysis at this site was inconclusive because of the large amount of variability in the data (fig. 3-32). This variability may be due to the scarcity of available substrate suitable for colonization by the benthic invertebrates. Valley Creek is an important tributary to East Branch Octoraro Creek. Octoraro Creek is designated as a "High Quality Stream" by the Pennsylvania Department of Environmental Resources (Pennsylvania Department of Environmental Resources, written commun., 1982). Valley Creek is the only tributary to East Branch Octoraro Creek that has undergone significant development within the basin. Several industries discharge waste water into Valley Creek. The water quality of the Valley Creek basin should continue to be observed closely because of its potential effect on Octoraro Creek.

Site 21 on the main stem of Ridley Creek could be moved upstream to a new site on the east branch of Ridley Creek. The high diversity indices are indicative of high water quality at site 21, but they have been inconclusive in indicating trend due to the large amount of variability (fig. 3-20). Site 21 is on the main stem of Ridley Creek just below the confluence of the east and west branches. Site 20 is on the west branch of Ridley Creek just above the confluence, and the east branch of Ridley Creek is not sampled in the current network. The Hershey Mill complex, a major development, currently being constructed in the west branch basin, has caused a gradual downward trend in the diversity index since 1976 at site 20 (fig. 3-19). At the present time, the east branch basin is still relatively undeveloped. A sampling site on the east branch of Ridley Creek would provide useful information on the effects of future development in this basin.

The establishment of a new sampling site on Pine Creek at Chester Springs (USGS station 01472183) would enable observations of changes in a basin undergoing rapid development, the most notable of which is the Pickering Creek Industrial Park. The effects of this major shift in land use were noted and documented as early 1969 by Miller and others (1971). The impact of this development on the Pickering Creek basin is shown by the downward trend in diversity index at site 3 (fig. 3-3) and should be observed more closely.

A sampling site is needed on the lower reaches of East Branch White Clay Creek. Site 28 on the upper reaches of East Branch White Clay Creek covers only the area above Avondale where data indicate the water quality is good (fig. 3-26). The lower East Branch White Clay Creek flows through Avondale and an area below Avondale, dominated by the mushroom industry, before joining with the other branches. For this reason, East Branch White Clay Creek needs another sampling site on its lower reaches. This would also enable a comparison of the data from the two sites to determine the degree of impact on water quality at the lower site.

A sampling site is needed on the upper West Branch Brandywine Creek above Icedale Lake at the stream gage near Honeybrook (USGS station 01480300). The area of the West Branch above site 37 is too large to be adequately covered by one sampling site.

The establishment of new sampling sites at the continuous water-quality monitors at East Branch Brandywine Creek below Downingtown (USGS station 01480870), and West Branch Brandywine Creek at Modena (USGS station 01480617) would take advantage of the continuous record of temperature, pH, specific conductance, and dissolved oxygen, as well as the historical water-quality data available at these stations. The continuous record of temperature, pH, specific conductance and dissolved oxygen would provide the data base necessary for establishing trends in the water-quality data (Murphy and others, 1982). Biological data could be compared to and possibly correlated with trends in water-quality data at these sites. These sites would also provide the sampling program with some insight into the overall water-quality trends in the East Branch and West Branch Brandywine Creek.

Chester County could be more completely covered by adding sites in several basins such as Little Elk Creek, that are not presently included in the sampling network. The Little Elk Creek basin is the only sub-major drainage basin in the county that is not included in the network. The divisions of the county's watersheds into drainage basins is given in a report by Chester County Planning Commission (1963, p. 11). Other minor drainage basins that might be included in the sampling network are Northeast Creek in the Elk Creek basin and Trout Creek in the Schuylkill River basin.

Several minor basins Beaver, Broad, and Pocopson, in the Brandywine Creek basin, are undergoing varying degrees of development that could have an impact on Brandywine Creek. Sampling sites on these creeks might enable observation of this impact.

Additional sampling sites are needed in the Octoraro Creek basin to assure adequate coverage of this "High Quality Stream". Sampling sites on Knight Run and Muddy Run would provide complete coverage of all three minor basins draining into the East Branch Octoraro Creek. These streams are presently sampled as part of the Chester County Health Department water-quality network and sampling should be done at the same sites in order to take advantage of the historical chemical data base. An additional sampling site could be established on the lower part of East Branch Octoraro Creek below Muddy Run and above the Pine Grove reservoir.

The above proposed modifications will help to increase the efficiency and the areal coverage of the current sampling network and enable better observation of the water quality of Chester County.

SUMMARY AND CONCLUSIONS

Biological and chemical data collected for 12 years (1969-80) at 46 sites in Chester County were evaluated for temporal trends. The results show that benthic-invertebrate sampling is an effective method of evaluating water quality. The present method of biological sampling appears to be adequate, but some improvements are suggested to make the program more effective. On the other hand, only 18 of 103 possible trends in the chemical data were statistically significant. Little correlation was shown between trends in diversity index and trends in the chemical constituents. Therefore, although once a year (fall) chemical sampling showed some trends, it did not appear to be as effective as biological sampling as a means of evaluating water quality in this study.

Brillouin's diversity index was calculated for all biological samples. Diversity index was plotted against time for each site and tested for trend using the seasonal Kendall test. Upward trends in biological conditions, indicating improved water quality, were found at 44 sites and downward trends, indicating degraded water quality, were found at two sites using the Kendall slope estimator. The upward trends were significant at the 99 percent confidence level at 7 sites, were significant at the 95 to 98 percent confidence level at 9 sites, and were significant at the 90 to 94 percent confidence level at 11 sites. Trends were not significant at the remaining 19 sites.

Selected chemical data from 21 sites were evaluated for trend using various statistical methods. The seasonal Kendall test for trend was used at eight sites that had stream-discharge data. Chemical data at these sites were adjusted for flow before trend analysis. Specific conductance had a statistically significant increasing trend at four sites. At one site pH had a significant decreasing trend. Dissolved chloride had a significant increasing trend at one site and dissolved sulfate had a significant increasing trend at another site. Total nitrate at one site had a significant decreasing trend. Total phosphorus at two sites showed a significantly decreasing trend. No significant trends were found in alkalinity and total ammonia.

For 11 sites that could not be adjusted for flow, the chemical data were tested for trend by plotting against time and determining a correlation coefficient. Total nitrate had a significant increasing trend at two sites and a significant decreasing trend at one site. Dissolved chloride had a significant increasing trend at five sites. No significant trends in dissolved sulfate were found.

Alkalinity, pH, methylene blue active substance, total nitrate, total phosphorus, total ammonia, dissolved chloride, dissolved sulfate, and total dissolved solids were tested for correlation with diversity index. These constituents were plotted against diversity index and a coefficient of determination was determined by linear regression. The only significant correlation was between total dissolved solids and diversity index.

Based on the results of this study, several suggestions are made to improve the sampling program. Biological sampling would be improved by identifying organisms to the species level where possible and by doing additional work to validate the 10-rock sample size and the Lium sampling method. Chemical sampling would be improved by measuring stream discharge when chemical samples are collected and by determining dissolved aluminum concentrations at all sites. Routine sampling of dissolved nutrients and major ions should be continued at all sites. Routine sampling of trace metals can be discontinued at all but 12 sites. Pesticide analysis could be done at sites 26 and 27 in the Red Clay Creek basin and also at any site where the diversity index falls below 1.0 in the future. The sampling network would be improved by dropping eight sites from the network and adding 14 new sites. These new sites would provide the sampling network with more complete coverage of Chester County.

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BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 1-4

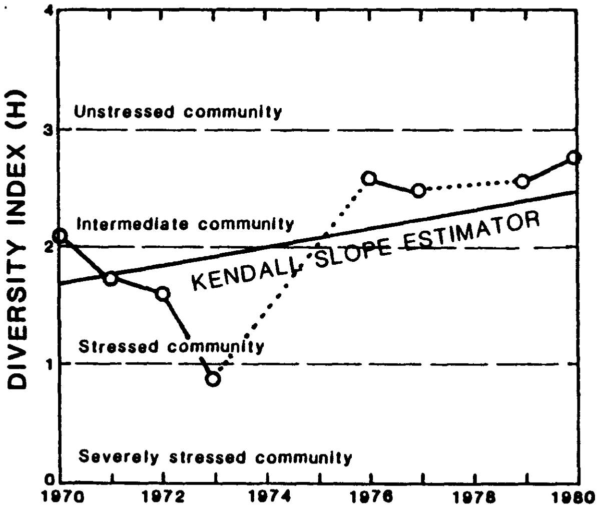

Figure 3-1.--Site 1 Pickering Creek near Eagle, station number 01472170.

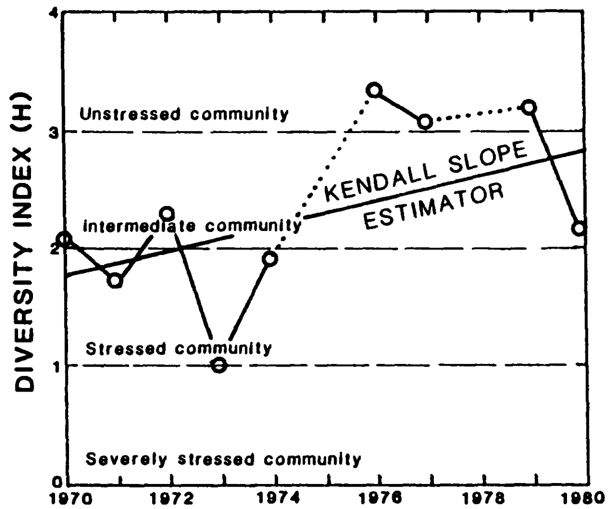

Figure 3-2.--Site 2 Pickering Creek near Chester Springs, station number 01472174.

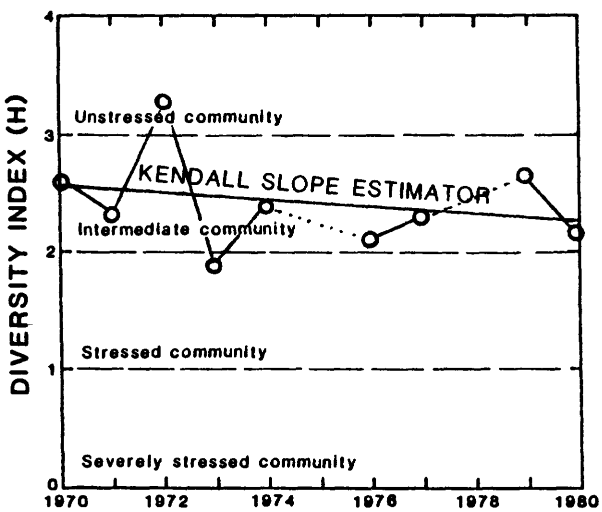

Figure 3-3.--Site 3 Pickering Creek at Merlin, station number 014721854.

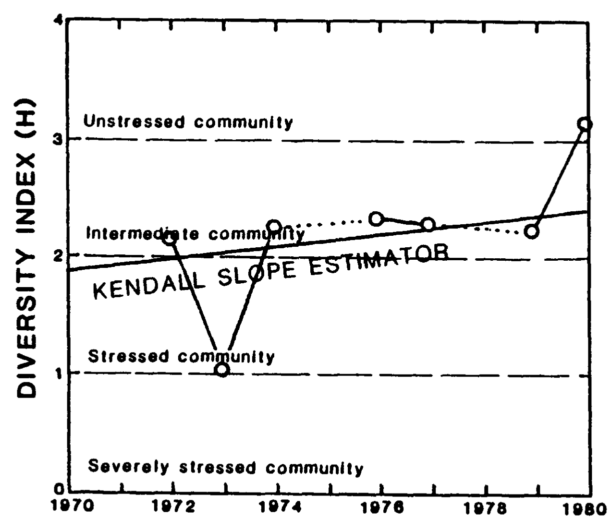

Figure 3-4.--Site 4 Pickering Creek at Charlestown Road at Charlestown, station number 014721884.

BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 5-8

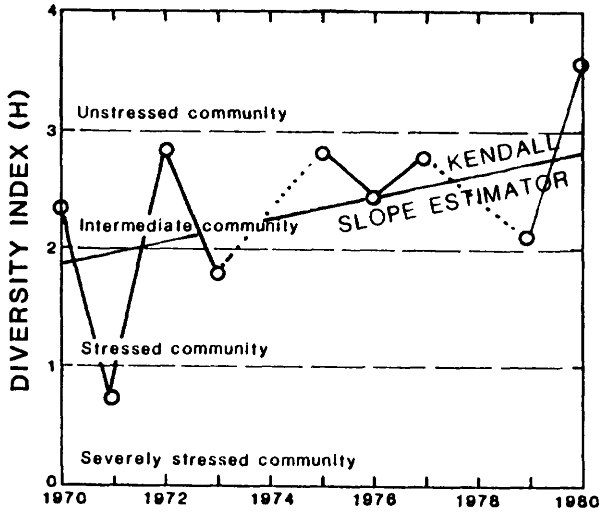

Figure 3-5.--Site 5 Pickering Creek near Phoenixville, station number 01472190.

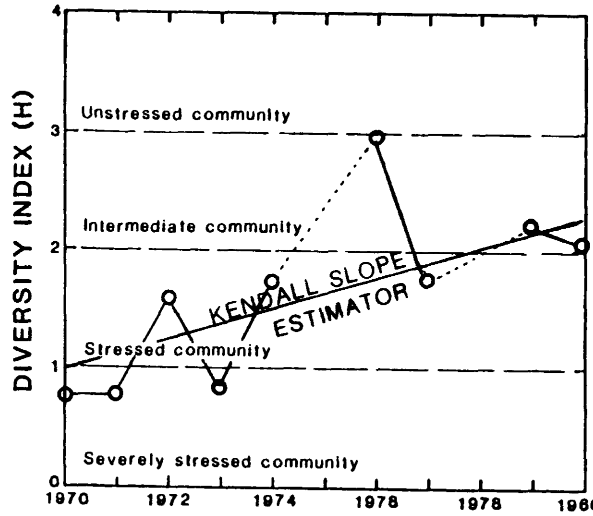

Figure 3-6.--Site 6 Stony Run near Spring City, station number 01472109.

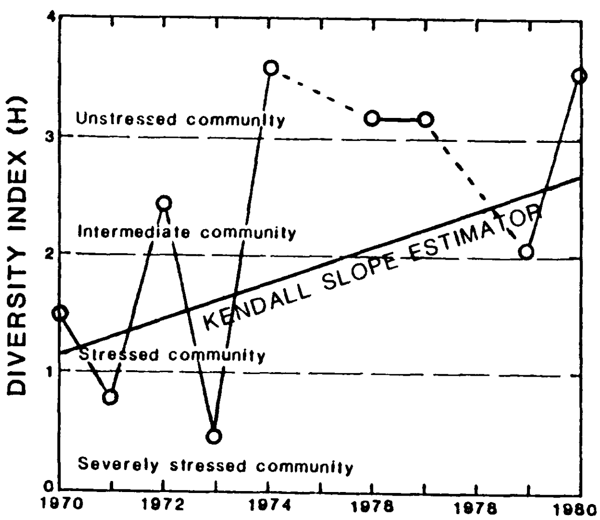

Figure 3-7.--Site 7 Stony Run at Spring City, station number 01472110.

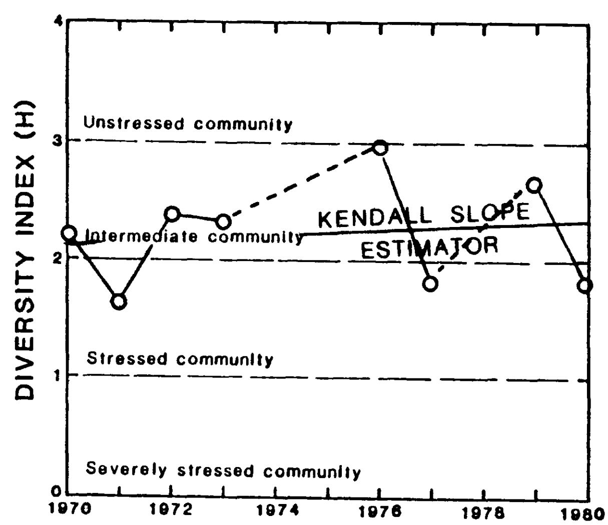

Figure 3-8.--Site 8 Pigeon Creek near Bucktown, station number 01472054.

BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 9-12

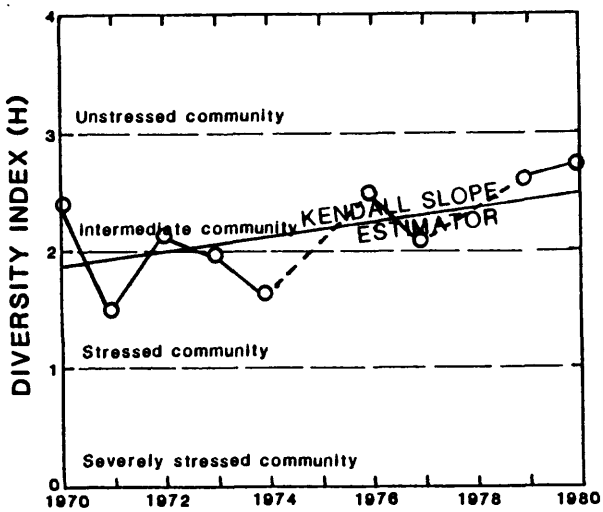

Figure 3-9.--Site 9 Pigeon Creek at Porters Mill, station number 01472065.

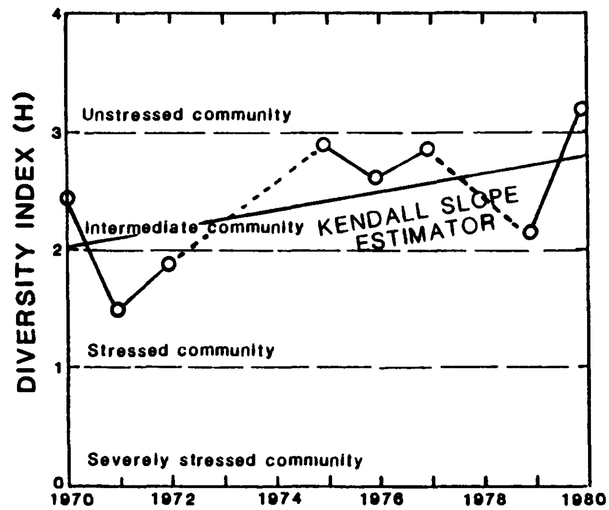

Figure 3-10.--Site 10 Pigeon Creek near Parker Ford, station number 01472080.

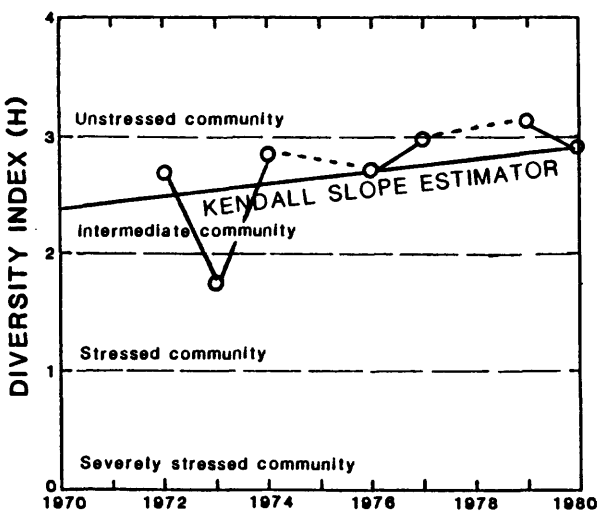

Figure 3-11.--Site 11 French Creek near Knauertown, station number 01472129.

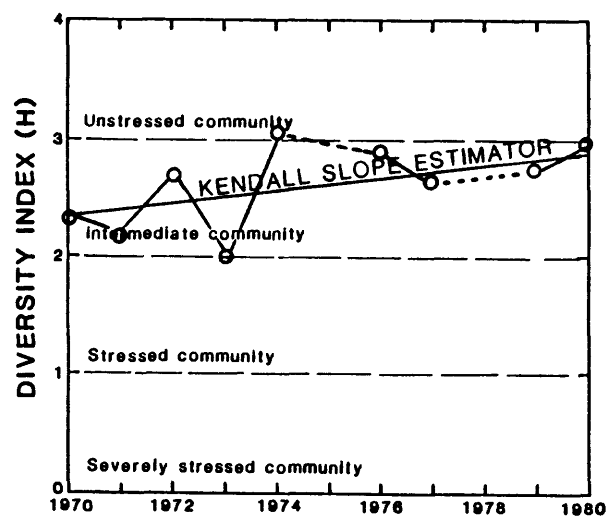

Figure 3-12.--Site 12 South Branch French Creek at Coventryville, station number 01472140

BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 13-15, 17

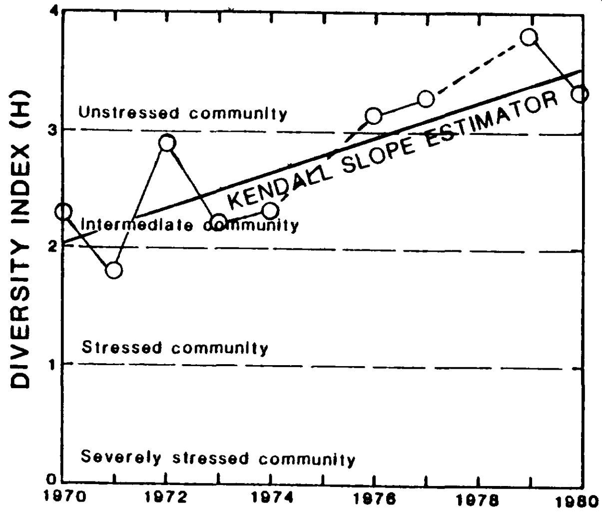

Figure 3-13.--Site 13 French Creek near Coventryville, station number 01472138.

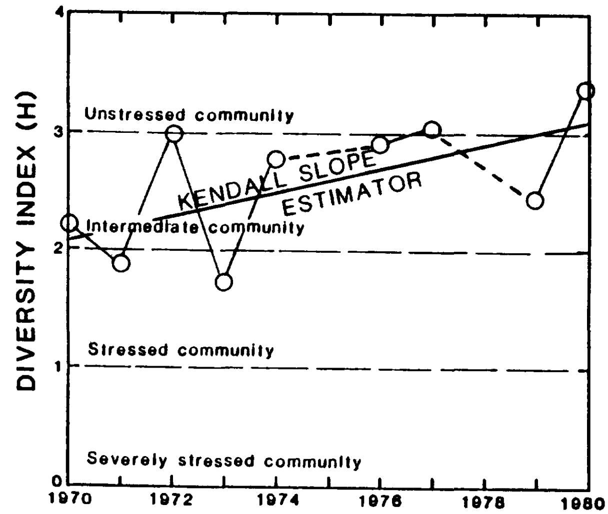

Figure 3-14.--Site 14 French Creek near Pughtown, station number 01472154.

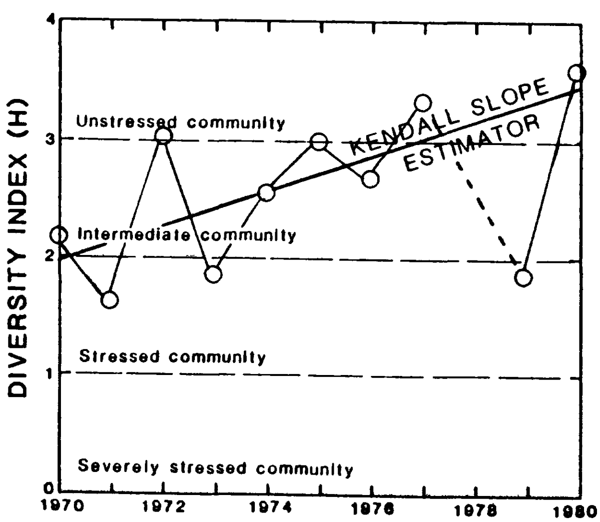

Figure 3-15.--Site 15 French Creek near Phoenixville, station number 01472157.

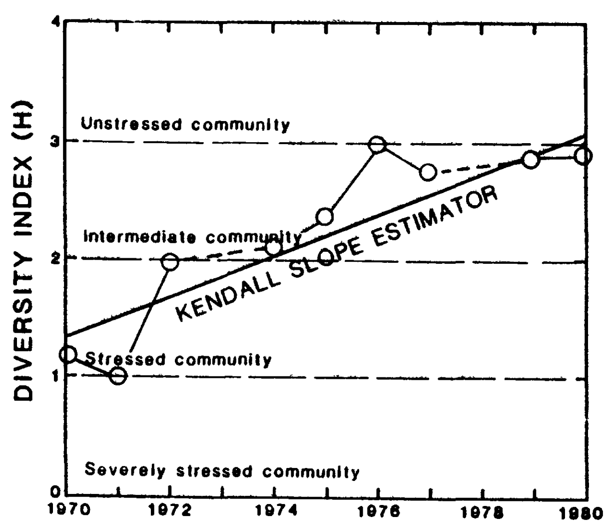

Figure 3-16.--Site 17 Darby Creek at Waterloo Mills near Devon, station number 01475300.

BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 18-20

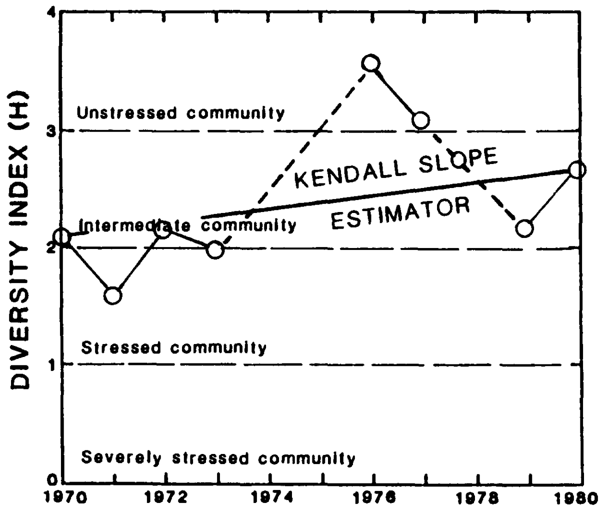

Figure 3-17.--Site 18 Crum Creek near Paoli, station number 01475830.

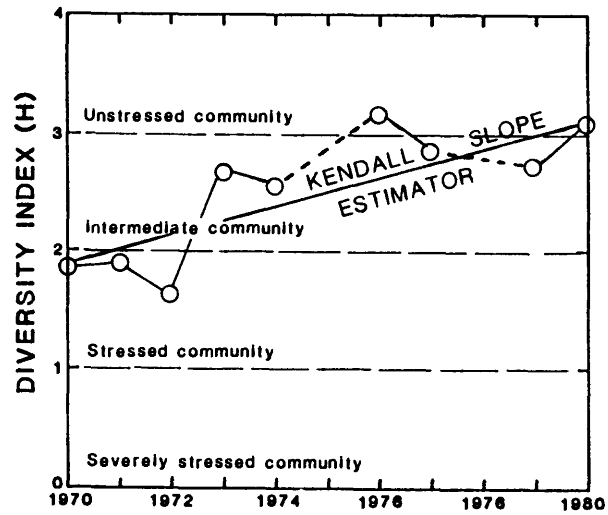

Figure 3-18.--Site 19 Crum Creek at Whitehorse, station number 01475840.

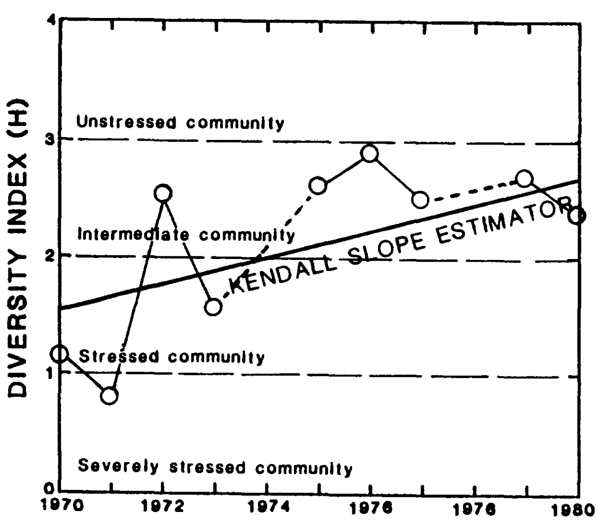

Figure 3-19.--Site 20 Ridley Creek at Goshenville, station number 01476430.

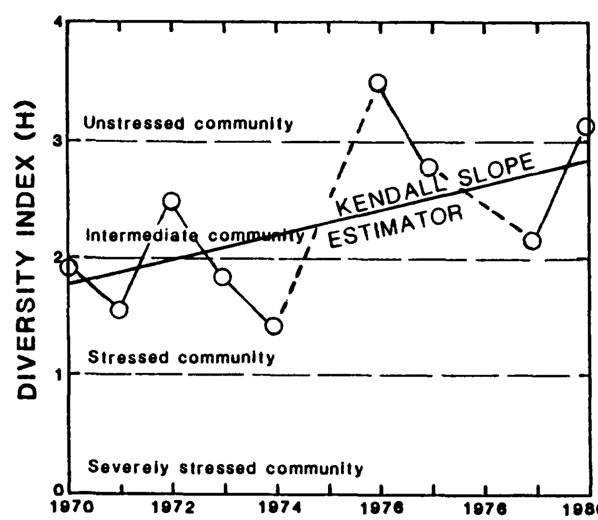

Figure 3-20.--Site 21 Ridley Creek at Dutton Mill near West Chester, station number 01476435.

BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 22-24, 26

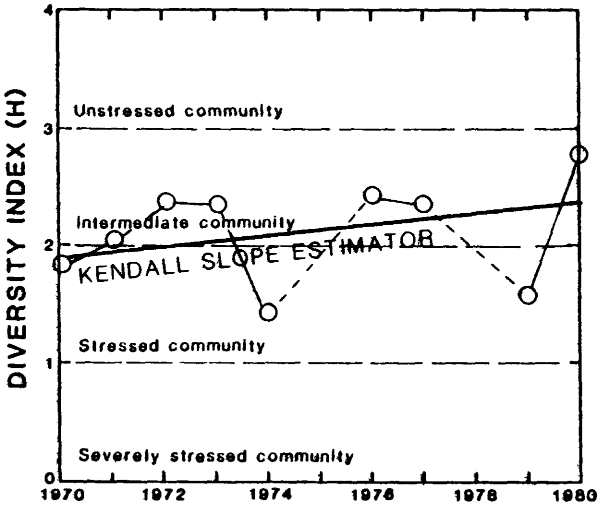

Figure 3-21.--Site 22 East Branch Chester Creek at Green Hill, station number 01476790.

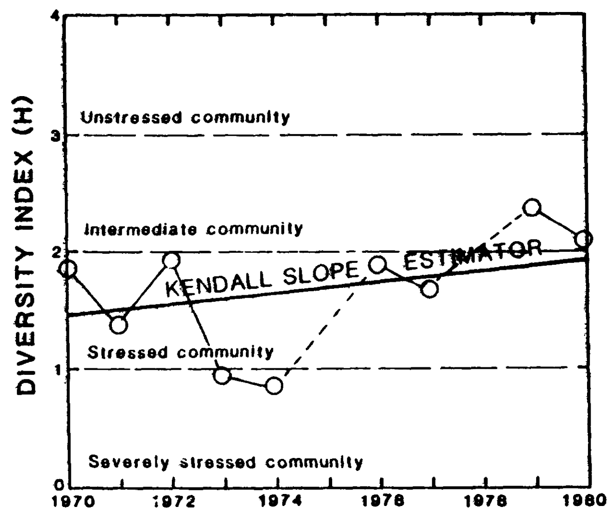

Figure 3-22.--Site 23 East Branch Chester Creek at Milltown, station number 01476830.

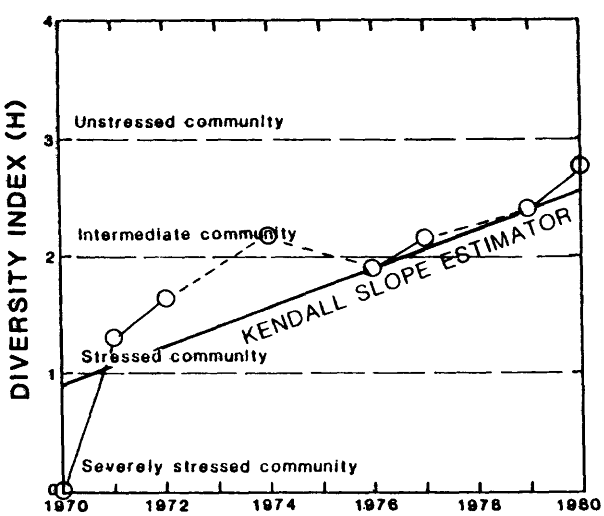

Figure 3-23.--Site 24 East Branch Chester Creek at Westtown School, station number 01476835.

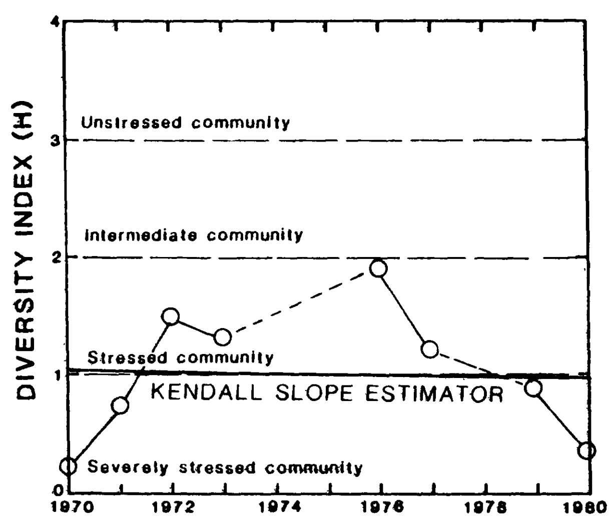

Figure 3-24.--Site 26 East Branch Red Clay Creek near Five Point, station number 01479800.

BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 27-30

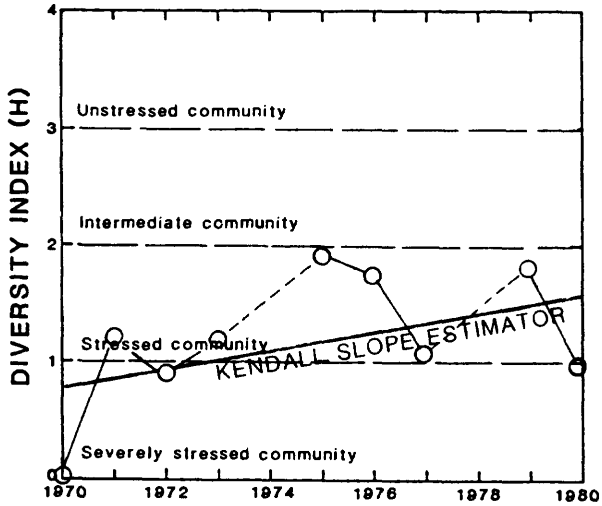

Figure 3-25.--Site 27 West Branch Red Clay Creek at Kennett Square, station number 01479680.

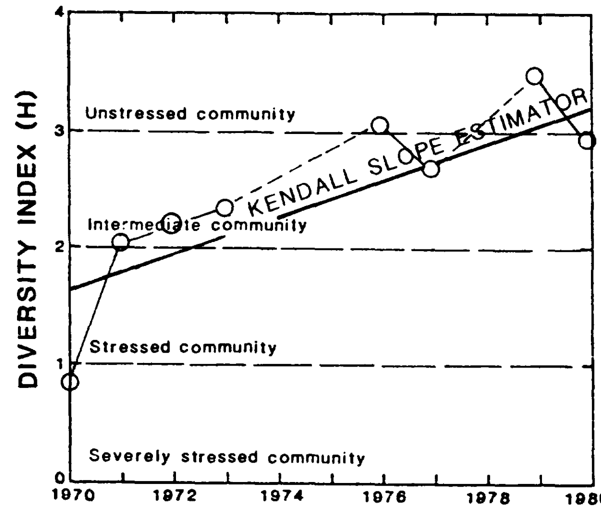

Figure 3-26.--Site 28 East Branch White Clay Creek near Avondale, station number 01478120.

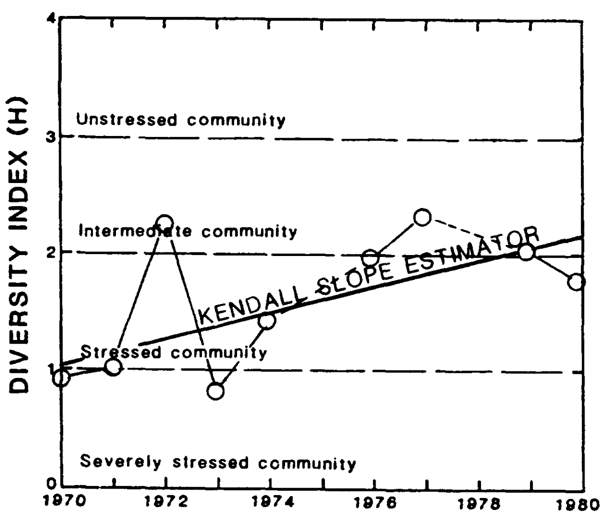

Figure 3-27.--Site 29 Middle Branch White Clay Creek near Wickerton, station number 01478190.

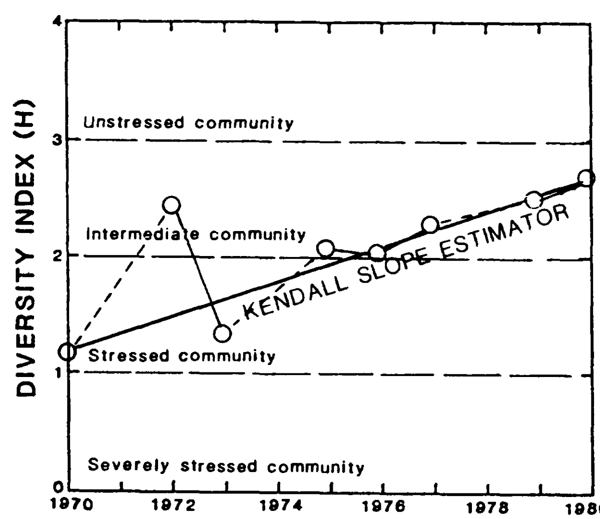

Figure 3-28.--Site 30 West Branch White Clay Creek near Chesterville, station number 01478220.

BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 31-34

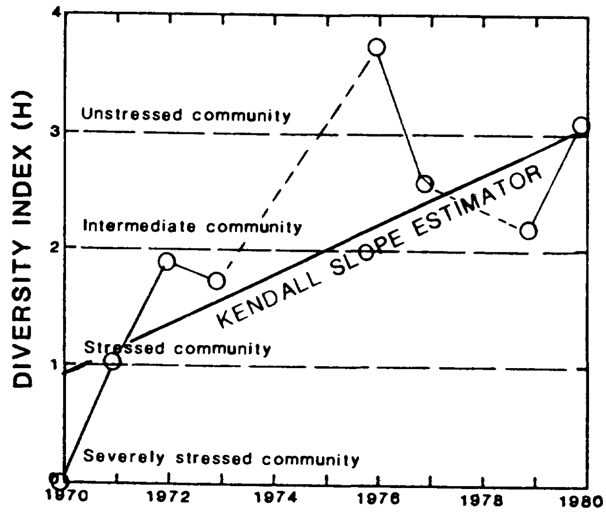

Figure 3-29.--Site 31 East Branch Big Elk Creek at Elkview, station number 01494900.

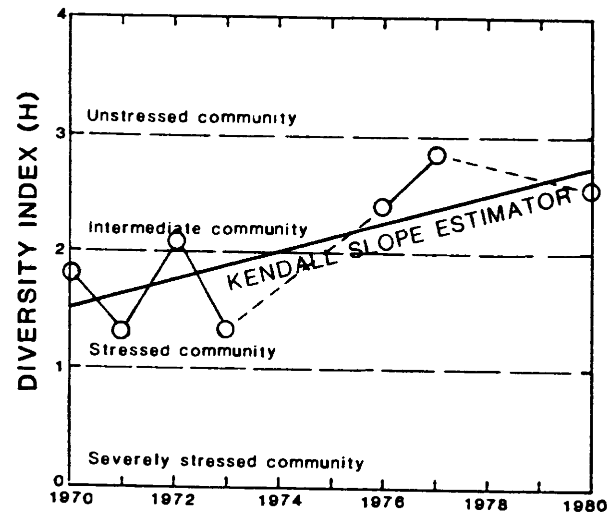

Figure 3-30.--Site 32 West Branch Big Elk Creek near Oxford, station number 01494950.

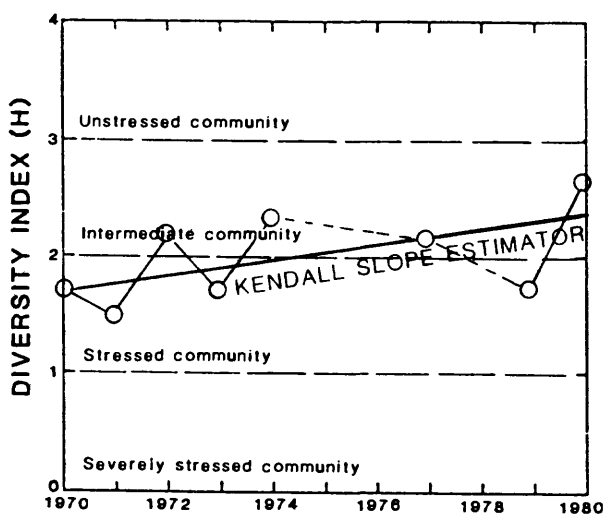

Figure 3-31.--Site 33 East Branch Octoraro Creek at Christiana, station number 01578340.

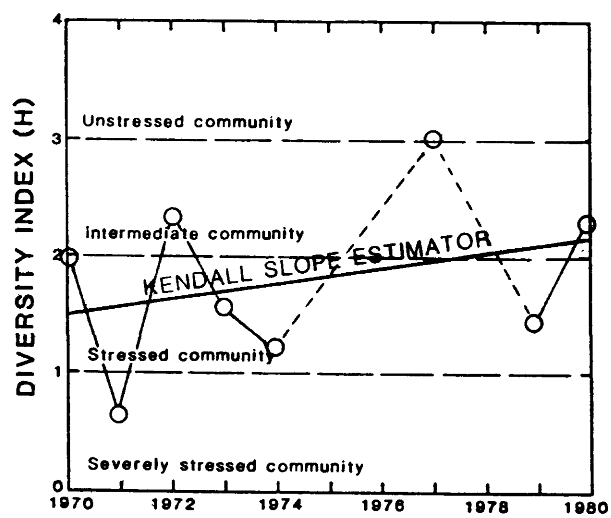

Figure 3-32.--Site 34 Valley Creek at Atglen, station number 01578343.

BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 35-38

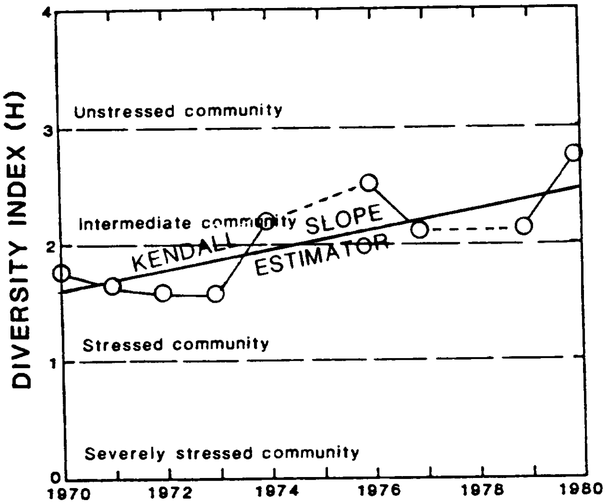

Figure 3-33.--Site 35 East Branch Octoraro Creek at Steelville, station number 01578345.

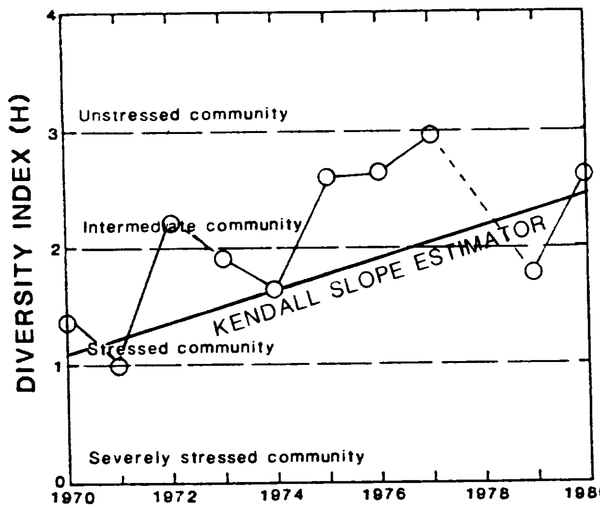

Figure 3-34.--Site 36 East Branch Brandywine Creek near Dowingtown, station number 01480700.

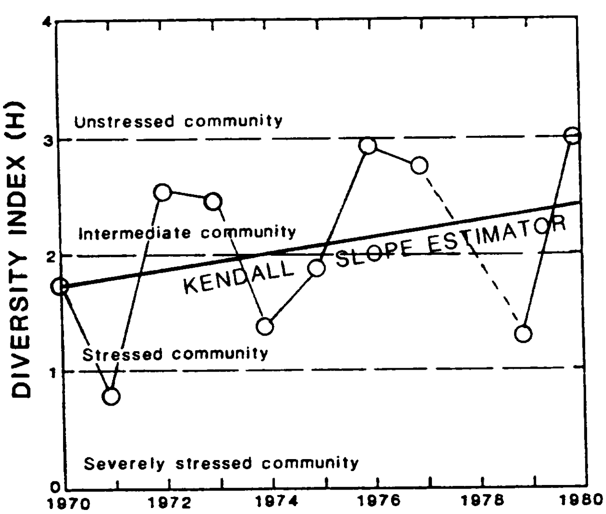

Figure 3-35.--Site 37 West Branch Brandywine Creek at Rock Run, station number 01480434.

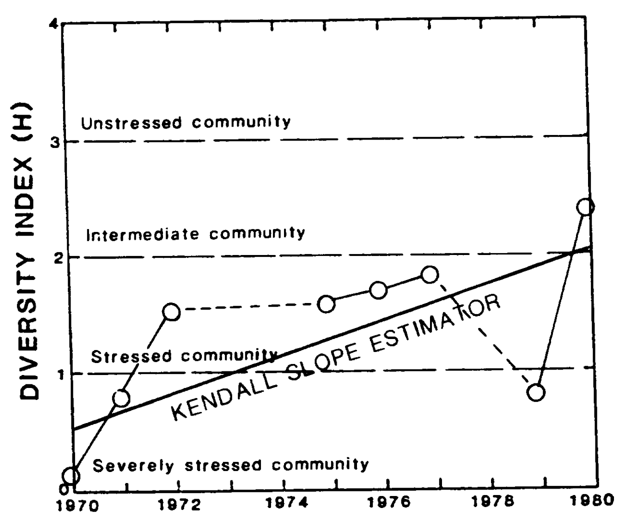

Figure 3-36.--Site 38 West Branch Brandywine Creek at Wawaset, station number 01480640.

BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 40, 42-44

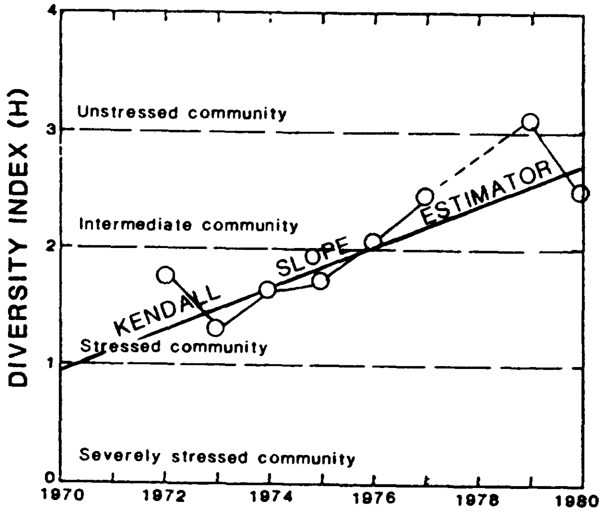

Figure 3-37.--Site 40 Brandywine Creek near Chadds Ford, station number 01481030.

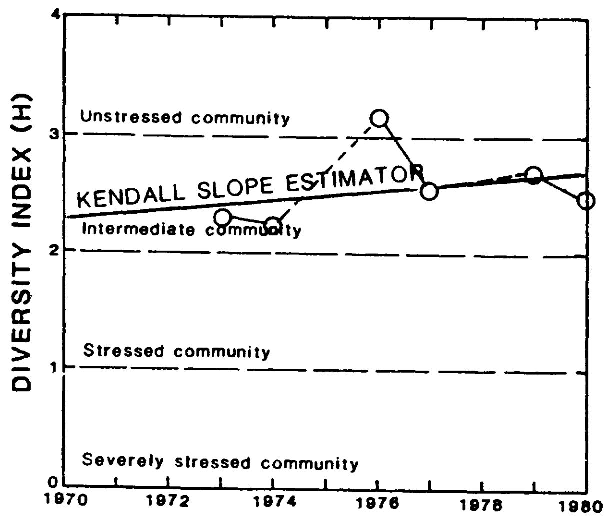

Figure 3-38.--Site 42 East Branch Brandywine Creek at Glenmoore, station number 01480653.

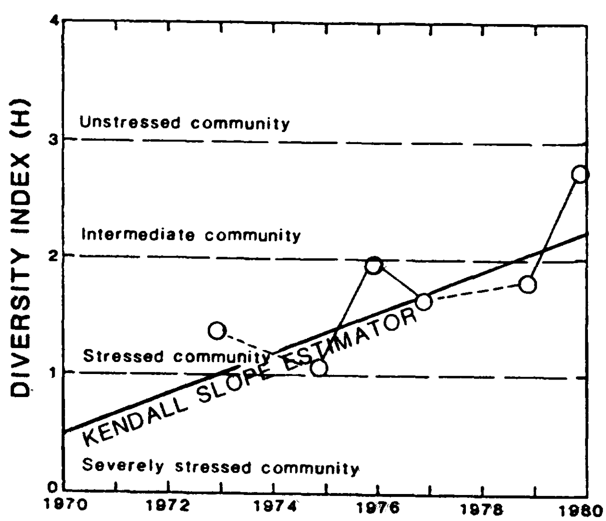

Figure 3-39.--Site 43 East Branch Brandywine Creek near Struble Dam, station number 01480647.

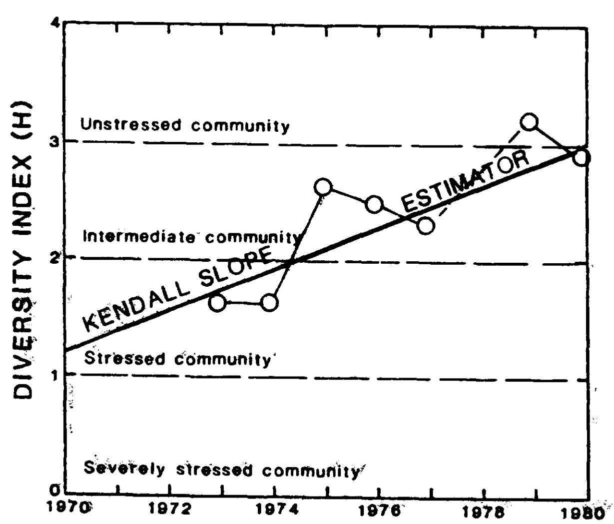

Figure 3-40.--Site 44 Valley Creek at Mullsteins Meadows near Downingtown, station number 01480903.

BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 45-48

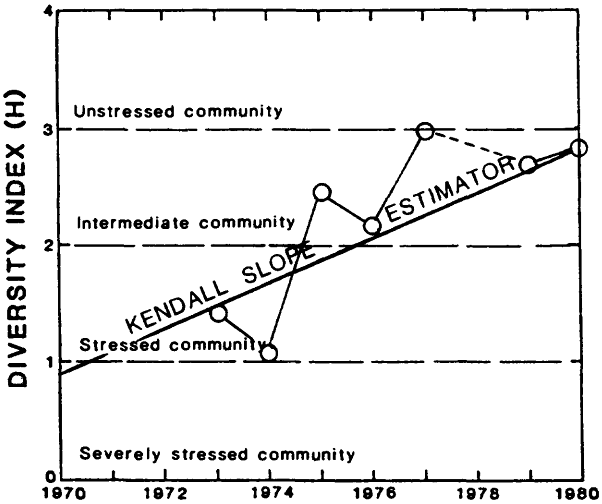

Figure 3-41.--Site 45 Doe Run at Springdell, station number 01480632.

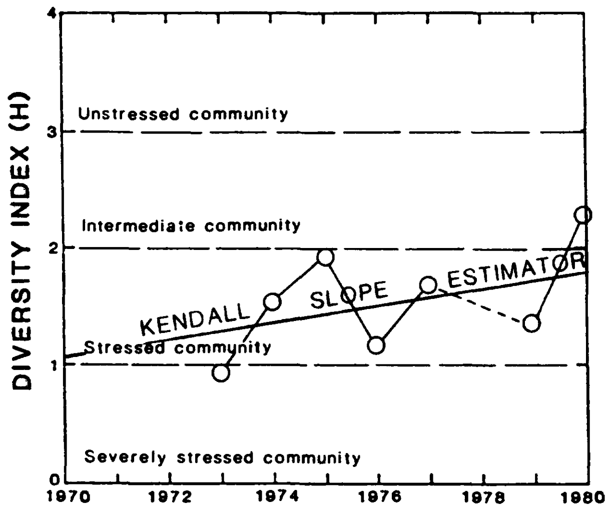

Figure 3-42.--Site 46 Buck Run at Doe Run, station number 01480629.

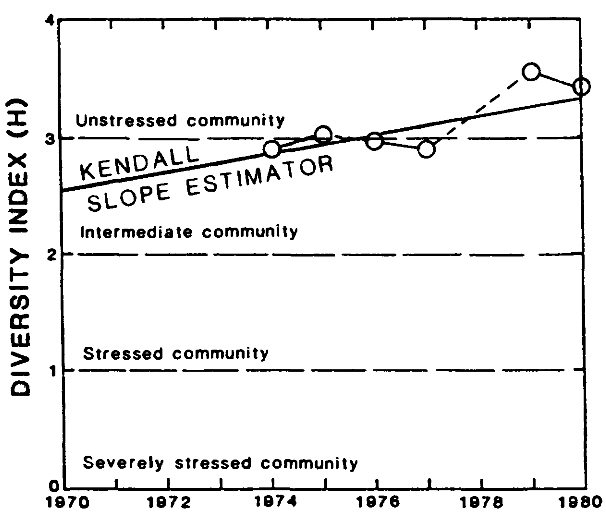

Figure 3-43.--Site 47 Indian Run near Springton, station number 01480656.

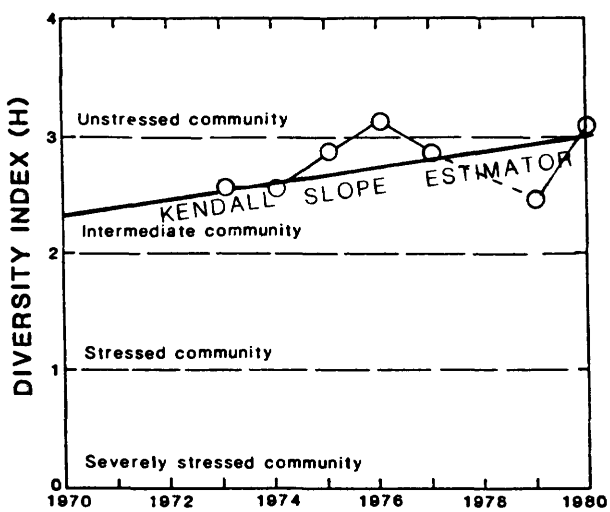

Figure 3-44.--Site 48 East Branch Brandywine Creek near Cupola, station number 01480648.

BRILLOUIN'S DIVERSITY INDEX (H) OF BENTHIC MACROINVERTEBRATES VERSUS TIME, SITES 49, 50

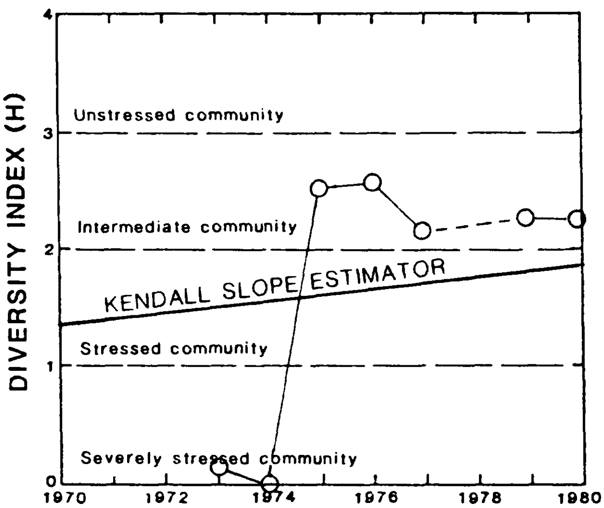

Figure 3-45.--Site 49 Little Valley Creek, at Howellville, station number 01473167

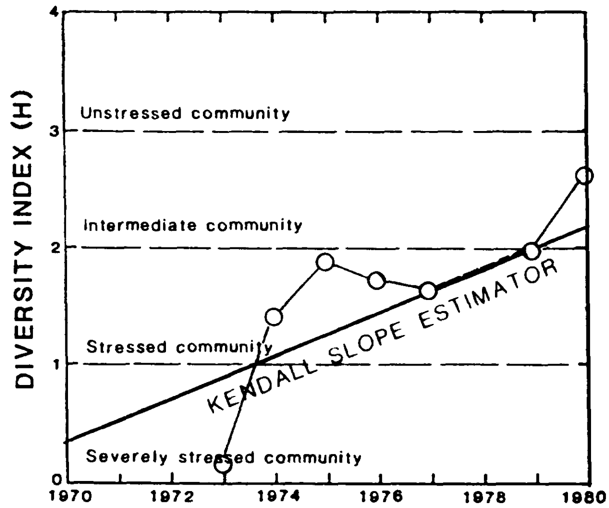

Figure 3-46.--Site 50 Valley Creek near Valley Forge, station number 01473168.

Table 2.—Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site

[A dash indicates no data]

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 1 (station 01472170) Pickering Creek near Eagle						
1970	161	5	2.10	2.27	0.18	0.92
1971	37	4	1.71	1.88	.42	.89
1972	743	14	1.58	3.74	.17	.40
1973	173	6	0.87	2.62	.21	.27
1974	-	-	-	-	-	-
1975	-	-	-	-	-	-
1976	820	23	2.60	4.52	.26	.55
1977	1121	22	2.49	4.49	.19	.54
1979	94	11	2.56	3.37	.69	.70
1980	242	16	2.76	3.84	.49	.68
Site 2 (station 01472174) Pickering Creek near Chester Springs						
1970	84	7	2.07	2.60	.45	.75
1971	29	4	1.72	1.85	.50	.90
1972	413	17	2.29	4.01	.34	.53
1973	629	20	1.01	4.28	.28	.18
1974	173	13	1.89	3.58	.51	.45
1975	-	-	-	-	-	-
1976	531	35	3.34	4.97	.58	.63
1977	190	17	3.07	3.89	.63	.75
1979	83	19	3.19	3.94	1.35	.71
1980	132	7	2.13	2.85	.32	.72
Site 3 (station 014721854) Pickering Creek at Merlin						
1970	79	10	2.60	3.36	.71	.71
1971	71	7	2.30	2.62	.52	.85
1972	119	24	3.26	4.57	1.31	.60
1973	560	21	1.87	4.38	.33	.38
1974	128	14	2.37	3.57	.70	.58
1975	-	-	-	-	-	-
1976	1660	27	2.09	4.74	.17	.42
1977	547	23	2.27	4.53	.36	.46
1979	47	13	2.62	3.48	1.37	.59
1980	1334	28	2.14	4.80	.21	.42

Table 2.--Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site--continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 4 (station 014721844) Pickering Creek at Charlestown Road at Charlestown						
1970	-	-	-	-	-	-
1971	-	-	-	-	-	-
1972	483	16	2.16	3.92	0.28	0.52
1973	103	9	1.07	3.08	.52	.21
1974	415	17	2.27	4.03	.33	.52
1975	-	-	-	-	-	-
1976	740	26	2.34	4.66	.32	.47
1977	862	22	2.29	4.39	.24	.49
1979	232	19	2.22	4.08	.61	.47
1980	2864	22	3.13	4.43	.08	.70
Site 5 (station 01472190) Pickering Creek near Phoenixville						
1970	127	10	2.34	3.31	.49	.65
1971	7	2	.73	1.02	.40	.54
1972	241	17	2.82	3.93	.52	.68
1973	156	11	1.76	3.31	.46	.46
1974	-	-	-	-	-	-
1975	375	17	2.80	3.95	.36	.68
1976	906	29	2.41	4.78	.30	.47
1977	316	23	2.78	4.51	.57	.56
1979	85	12	2.10	3.28	.82	.52
1980	520	20	3.56	4.19	.33	.84
Site 6 (station 01472109) Stony Run near Spring City						
1970	124	2	.79	.97	.06	.81
1971	30	2	.79	.91	.16	.85
1972	508	12	1.58	3.54	.19	.41
1973	391	6	.85	2.55	.11	.31
1974	177	8	1.72	2.89	.29	.55
1975	-	-	-	-	-	-
1976	285	23	2.97	4.40	.63	.62
1977	34	8	1.74	2.68	1.02	.43
1979	132	11	2.20	3.24	.53	.62
1980	272	15	2.05	3.77	.41	.49

Table 2.--Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site--continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 7 (station 01472110) Stony Run at Spring City						
1970	93	6	1.50	2.55	0.35	0.52
1971	47	3	.80	1.63	.24	.41
1972	109	11	2.44	3.50	.62	.63
1973	13	2	.48	1.04	.28	.26
1974	146	19	3.59	4.18	.88	.82
1975	-	-	-	-	-	-
1976	495	21	3.17	4.36	.36	.70
1977	200	24	3.17	4.39	.87	.65
1979	124	11	2.05	3.31	.56	.54
1980	850	29	3.54	4.79	.32	.72
Site 8 (station 01472054) Pigeon Creek near Bucktown						
1970	94	6	2.23	2.59	.35	.84
1971	26	4	1.65	1.94	.54	.79
1972	288	15	2.39	3.79	.40	.59
1973	486	20	2.32	4.24	.35	.51
1974	-	-	-	-	-	-
1975	-	-	-	-	-	-
1976	554	21	2.97	4.33	.33	.66
1977	125	12	1.83	3.47	1.61	.43
1979	117	14	2.67	3.64	.75	.66
1980	440	9	1.83	3.20	.16	.55
Site 9 (station 01472065) Pigeon Creek at Porters Mill						
1970	132	7	2.41	2.85	.32	.83
1971	37	4	1.51	1.88	.42	.75
1972	125	9	2.16	3.22	.44	.62
1973	361	15	1.99	3.78	.33	.48
1974	131	11	1.65	3.51	.53	.38
1975	-	-	-	-	-	-
1976	579	21	2.51	4.37	.32	.54
1977	42	7	2.11	2.46	.76	.79
1979	290	21	2.63	4.40	.56	.54
1980	254	11	2.75	3.34	.31	.80

Table 2.--Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site--continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 10 (station 01472080) Pigeon Creek near Parker Ford						
1970	104	8	2.45	2.80	0.45	0.85
1971	24	4	1.50	1.71	.57	.81
1972	548	15	1.88	3.89	.23	.45
1973	-	-	-	-	-	-
1974	-	-	-	-	-	-
1975	767	19	2.90	4.21	.22	.67
1976	880	26	2.62	4.72	.28	.53
1977	344	27	2.87	4.74	.63	.55
1979	32	10	2.15	2.87	1.35	.53
1980	620	19	3.19	4.24	.27	.74
Site 11 (station 01472129) French Creek near Knauertown						
1970	-	-	-	-	-	-
1971	-	-	-	-	-	-
1972	64	11	2.68	3.44	.92	.70
1973	343	16	1.75	3.94	.37	.39
1974	166	18	2.85	3.96	.75	.65
1975	-	-	-	-	-	-
1976	136	15	2.70	3.64	.72	.68
1977	491	27	2.97	4.62	.47	.60
1979	151	18	3.12	4.00	.81	.72
1980	1088	21	2.90	4.41	.19	.64
Site 12 (station 01472140) South Branch French Creek at Coventryville						
1970	118	7	2.32	2.86	.35	.79
1971	36	7	2.17	2.49	.84	.81
1972	1053	19	2.69	4.22	.17	.62
1973	288	20	2.00	4.22	.54	.40
1974	271	20	3.06	4.26	.56	.68
1975	-	-	-	-	-	-
1976	972	28	2.88	4.81	.28	.57
1977	942	22	2.61	4.48	.22	.56
1979	137	16	2.71	3.90	.77	.62
1980	1499	27	2.94	4.74	.18	.61

Table 2.—Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site—continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 13 (station 01472138) French Creek near Coventryville						
1970	58	8	2.30	2.79	0.70	0.77
1971	23	5	1.80	2.24	.77	.70
1972	272	23	2.89	4.53	.65	.58
1973	101	14	2.21	3.56	.85	.50
1974	31	8	2.30	2.97	1.08	.64
1975	-	-	-	-	-	-
1976	160	18	3.12	4.19	.77	.69
1977	380	22	3.27	4.34	.47	.72
1979	163	29	3.80	4.71	1.24	.74
1980	694	21	3.31	4.29	.27	.76
Site 14 (station 01472154) French Creek near Pughtown						
1970	58	8	2.23	2.79	.70	.73
1971	34	6	1.88	2.54	.74	.63
1972	643	27	3.00	4.77	.38	.60
1973	225	15	1.73	3.71	.48	.39
1974	189	16	2.79	4.01	.60	.64
1975	-	-	-	-	-	-
1976	362	27	2.91	4.65	.61	.57
1977	747	27	3.04	4.74	.33	.61
1979	96	16	2.44	3.61	1.01	.55
1980	615	26	3.37	4.68	.38	.70
Site 15 (station 01472157) French Creek near Phoenixville						
1970	56	7	2.20	2.53	.62	.83
1971	24	6	1.64	2.15	.93	.58
1972	324	19	3.05	4.08	.46	.72
1973	96	11	1.86	3.44	.68	.43
1974	85	14	2.58	3.46	.96	.65
1975	232	21	3.02	4.15	.67	.67
1976	277	22	2.70	4.40	.61	.55
1977	645	31	3.34	4.96	.43	.64
1979	174	10	1.86	3.25	.38	.51
1980	629	27	3.60	4.67	.38	.75

Table 2.--Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site--continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 17 (station 01475300) Darby Creek at Waterloo Mills near Devon						
1970	46	3	1.20	1.54	0.24	0.74
1971	8	3	1.02	1.54	.73	.36
1972	155	10	1.98	3.27	.42	.55
1973	-	-	-	-	-	-
1974	239	11	2.11	3.47	.33	.57
1975	690	15	2.36	3.83	.19	.60
1976	473	21	2.99	4.35	.37	.66
1977	555	18	2.75	4.19	.28	.63
1979	362	18	2.87	4.04	.40	.68
1980	468	15	2.90	3.83	.26	.74
Site 18 (station 01475830) Crum Creek near Paoli						
1970	125	8	2.08	2.99	.39	.65
1971	28	4	1.59	1.74	.51	.87
1972	129	11	2.18	3.45	.54	.56
1973	132	12	1.97	3.34	.58	.50
1974	-	-	-	-	-	-
1975	-	-	-	-	-	-
1976	212	23	3.55	4.31	.79	.78
1977	221	25	3.08	4.64	.84	.59
1979	22	9	2.14	2.77	1.53	.49
1980	46	13	2.61	3.44	1.39	.59
Site 19 (station 01475840) Crum Creek at Whitehorse						
1970	88	9	1.87	3.18	.58	.50
1971	45	6	1.90	2.50	.60	.68
1972	219	8	1.64	2.95	.25	.51
1973	120	17	2.66	3.76	.91	.61
1974	67	14	2.55	3.73	1.15	.54
1975	-	-	-	-	-	-
1976	363	25	3.16	4.57	.56	.65
1977	835	27	2.85	4.79	.30	.57
1979	131	12	2.72	3.63	.59	.70
1980	417	16	3.16	3.88	.31	.80

Table 2.—Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site—continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 20 (station 01476430) Ridley Creek at Goshenville						
1970	116	5	1.20	2.25	0.24	0.48
1971	15	2	.84	1.04	.26	.74
1972	158	14	2.56	3.66	.60	.64
1973	246	13	1.59	3.75	.39	.36
1974	-	-	-	-	-	-
1975	788	20	2.64	4.28	.23	.59
1976	420	17	2.92	4.09	.33	.69
1977	349	15	2.52	3.82	.34	.63
1979	84	14	2.71	3.42	.97	.71
1980	202	18	2.39	3.99	.64	.52
Site 21 (station 01476435) Ridley Creek at Dutton Mill near West Chester						
1970	172	9	1.94	3.04	.34	.59
1971	32	5	1.56	2.19	.62	.60
1972	189	12	2.49	3.59	.44	.65
1973	63	8	1.85	3.04	.66	.50
1974	165	8	1.43	2.99	.31	.42
1975	-	-	-	-	-	-
1976	470	25	3.50	4.65	.45	.72
1977	105	17	2.78	3.78	1.01	.64
1979	236	15	2.15	3.90	.47	.49
1980	1144	21	3.12	4.37	.18	.70
Site 22 (station 01476790) East Branch Chester Creek at Green Hill						
1970	59	5	1.83	2.37	.40	.73
1971	43	7	2.04	2.53	.74	.73
1972	520	17	2.36	4.07	.28	.55
1973	144	11	2.34	3.28	.49	.66
1974	13	4	1.42	1.71	.83	.67
1975	-	-	-	-	-	-
1976	703	21	2.41	4.36	.27	.52
1977	162	12	2.34	3.52	.50	.61
1979	179	10	1.57	3.37	.37	.40
1980	247	16	2.77	3.92	.48	.67

Table 2.--Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site--continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 23 (station 01476830) East Branch Chester Creek at Milltown						
1970	83	4	1.87	2.04	0.23	0.90
1971	24	4	1.39	1.71	.57	.72
1972	299	10	1.93	3.36	.25	.54
1973	234	5	.97	2.35	.13	.38
1974	73	6	.88	2.44	.42	.23
1975	-	-	-	-	-	-
1976	244	19	1.90	4.26	.58	.36
1977	338	14	1.69	3.70	.32	.40
1979	490	19	2.38	4.26	.33	.52
1980	102	8	2.10	3.01	.45	.64
Site 24 (station 01476835) East Branch Chester Creek at Westtown School						
1970	55	1	0	0	0	0
1971	156	5	1.32	2.26	.19	.54
1972	901	11	1.64	3.48	.11	.45
1973	-	-	-	-	-	-
1974	1333	13	2.18	3.69	.09	.58
1975	-	-	-	-	-	-
1976	860	18	1.90	4.18	.19	.43
1977	1094	21	2.16	4.33	.18	.48
1979	49	10	2.41	3.32	1.01	.61
1980	2721	19	2.75	4.23	.08	.64
Site 26 (station 01479800) East Branch Red Clay Creek near Five Point						
1970	61	2	.25	1.03	.10	.16
1971	7	3	.77	1.33	.77	0
1972	181	5	1.52	2.27	.17	.64
1973	473	12	1.34	3.55	.21	.34
1974	-	-	-	-	-	-
1975	-	-	-	-	-	-
1976	826	12	1.90	3.60	.13	.51
1977	1463	13	1.23	3.70	.09	.32
1979	239	4	.90	2.02	.10	.41
1980	468	4	.35	1.97	.06	.15

Table 2.—Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site—continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 27 (station 01479780) West Branch Red Clay Creek at Kennett Square						
1970	182	1	0	0	0	0
1971	30	4	1.19	1.95	0.49	0.48
1972	177	5	.90	2.30	.17	.35
1973	108	6	1.19	2.44	.31	.41
1974	-	-	-	-	-	-
1975	60	9	1.91	3.11	.78	.48
1976	172	12	1.75	3.48	.47	.43
1977	70	5	1.10	2.15	.35	.41
1979	29	8	1.83	2.83	1.13	.41
1980	556	3	1.01	1.58	.03	.63
Site 28 (station 01478120) East Branch White Clay Creek near Avondale						
1970	76	4	.87	1.88	.25	.38
1971	26	6	2.04	2.34	.88	.79
1972	202	10	2.18	3.22	.34	.64
1973	293	10	2.34	3.26	.25	.70
1974	-	-	-	-	-	-
1975	-	-	-	-	-	-
1976	820	18	3.05	4.16	.20	.72
1977	935	23	2.65	4.52	.23	.56
1979	855	27	3.45	4.75	.30	.71
1980	1188	17	2.91	4.11	.14	.70
Site 29 (station 01478190) Middle Branch White Clay Creek near Wickerton						
1970	61	6	.95	2.42	.48	.24
1971	13	3	1.05	1.44	.56	.55
1972	677	15	2.25	3.84	.19	.56
1973	290	6	.85	2.56	.14	.29
1974	156	6	1.44	2.48	.23	.54
1975	-	-	-	-	-	-
1976	174	12	1.97	3.52	.47	.49
1977	283	12	2.32	3.56	.32	.62
1979	84	13	2.03	3.53	.90	.43
1980	1376	14	1.77	3.78	.10	.45

Table 2.--Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site--continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 30 (station 01478220) West Branch White Clay Creek near Chesterville						
1970	42	4	0.97	1.97	0.38	0.37
1971	-	-	-	-	-	-
1972	367	15	2.44	3.86	.32	.60
1973	259	7	1.36	2.72	.19	.46
1974	-	-	-	-	-	-
1975	669	14	2.09	3.82	.18	.52
1976	391	19	2.04	4.21	.39	.43
1977	823	17	2.30	4.06	.19	.55
1979	80	10	2.53	3.02	.70	.79
1980	908	14	2.72	3.83	.14	.70
Site 31 (station 01494900) East Branch Big Elk Creek at Elkview						
1970	69	1	0	0	0	0
1971	6	3	1.08	1.08	.82	1.0
1972	325	14	1.92	3.71	.33	.47
1973	43	6	1.76	2.36	.62	.65
1974	-	-	-	-	-	-
1975	-	-	-	-	-	-
1976	199	19	3.77	4.14	.68	.89
1977	1005	20	2.60	4.27	.19	.59
1979	37	9	2.21	2.76	1.09	.67
1980	972	18	3.12	4.10	.17	.75
Site 32 (station 01494950) West Branch Big Elk Creek near Oxford						
1970	104	4	1.83	1.90	.19	.96
1971	15	4	1.34	1.99	.76	.47
1972	921	17	2.11	4.04	.17	.50
1973	441	11	1.36	3.38	.20	.37
1974	-	-	-	-	-	-
1975	-	-	-	-	-	-
1976	256	20	2.42	4.33	.59	.49
1977	758	22	2.87	4.42	.26	.63
1979	-	-	-	-	-	-
1980	1304	15	2.59	3.93	.11	.65

Table 2.—Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site--continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 33 (station 01578340) East Branch Octoraro Creek at Christiana						
1970	76	4	1.72	1.88	0.25	0.91
1971	63	5	1.50	2.31	.38	.58
1972	705	13	2.17	3.66	.16	.57
1973	385	12	1.72	3.49	.24	.45
1974	172	11	2.34	3.44	.43	.63
1975	-	-	-	-	-	-
1976	-	-	-	-	-	-
1977	1125	23	2.17	4.55	.20	.45
1979	141	7	1.74	2.70	.30	.60
1980	476	11	2.67	3.41	.19	.77
Site 34 (station 01578343) Valley Creek at Atglen						
1970	77	5	2.01	2.27	.32	.87
1971	5	2	.66	.98	.46	.39
1972	334	14	2.37	3.84	.33	.58
1973	136	7	1.59	2.76	.31	.52
1974	130	7	1.25	2.79	.32	.38
1975	-	-	-	-	-	-
1976	-	-	-	-	-	-
1977	768	19	3.04	4.21	.22	.71
1979	13	6	1.48	2.04	1.33	.22
1980	1288	12	2.33	3.57	.09	.64
Site 35 (station 01578345) East Branch Octoraro Creek at Steelville						
1970	102	5	1.78	2.28	.26	.75
1971	43	4	1.65	2.05	.38	.76
1972	858	14	1.60	3.77	.15	.40
1973	138	6	1.59	2.46	.26	.60
1974	140	12	2.20	3.56	.56	.55
1975	-	-	-	-	-	-
1976	182	13	2.52	3.50	.49	.67
1977	1174	17	2.12	4.03	.14	.51
1979	79	10	2.14	3.36	.71	.54
1980	1048	11	2.76	3.44	.10	.80

Table 2.--Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site--continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 36 (station 01480700) East Branch Brandywine Creek near Downingtown						
1970	86	7	1.39	2.69	0.45	0.42
1971	38	5	1.03	2.29	.55	.28
1972	127	14	2.22	3.55	.71	.53
1973	201	13	1.93	3.63	.45	.46
1974	147	14	1.67	3.72	.63	.34
1975	357	21	2.61	4.21	.47	.57
1976	685	29	2.66	4.83	.38	.51
1977	325	24	2.97	4.52	.59	.61
1979	55	10	1.80	3.16	.93	.39
1980	3840	14	2.64	3.80	.04	.69
Site 37 (station 01480434) West Branch Brandywine Creek at Rock Run						
1970	66	7	1.75	2.71	.54	.55
1971	20	2	.81	.87	.22	.90
1972	128	14	2.56	3.57	.70	.65
1973	117	16	2.48	3.79	.87	.55
1974	113	7	1.40	2.68	.36	.45
1975	40	7	1.89	2.77	.78	.56
1976	266	20	2.96	4.19	.57	.66
1977	221	15	2.79	3.90	.49	.67
1979	77	9	1.33	3.09	.64	.28
1980	468	19	3.01	4.23	.34	.68
Site 38 (station 01480640) West Branch Brandywine Creek at Wawaset						
1970	58	2	.18	.94	.10	.10
1971	26	2	.83	.90	.18	.91
1972	507	11	1.55	3.39	.18	.43
1973	-	-	-	-	-	-
1974	-	-	-	-	-	-
1975	277	11	1.60	3.37	.29	.42
1976	196	10	1.71	3.30	.35	.46
1977	52	10	1.83	3.01	.97	.42
1979	52	4	.85	1.84	.33	.35
1980	464	13	2.40	3.70	.23	.63

Table 2.--Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site--continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 40 (station 01481030) Brandywine Creek near Chadds Ford						
1970	-	-	-	-	-	-
1971	-	-	-	-	-	-
1972	133	8	1.77	2.99	0.37	0.53
1973	653	11	1.34	3.43	.14	.36
1974	246	10	1.66	3.31	.29	.46
1975	717	16	1.74	4.02	.20	.40
1976	460	13	2.08	3.66	.23	.54
1977	103	15	2.48	3.91	.90	.53
1979	132	18	3.13	3.96	.90	.73
1980	549	10	2.53	3.35	.15	.74
Site 42 (station 01480653) East Branch Brandywine Creek at Glenmoore						
1973	134	14	2.29	3.73	.68	.53
1974	113	17	2.20	3.99	.95	.41
1975	-	-	-	-	-	-
1976	424	24	3.16	4.56	.47	.66
1977	120	16	2.55	3.80	.85	.56
1979	305	14	2.71	3.82	.35	.68
1980	444	18	2.49	4.16	.34	.56
Site 43 (station 01480647) East Branch Brandywine Creek near Struble Dam						
1973	191	8	1.38	3.04	.28	.40
1974	-	-	-	-	-	-
1975	228	8	1.07	2.98	.24	.30
1976	295	15	1.95	3.89	.39	.44
1977	12	6	1.64	1.90	1.38	.50
1979	130	10	1.80	3.11	.48	.50
1980	188	19	2.75	4.27	.72	.57

Table 2.--Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site--continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 44 (station 01480903) Valley Creek at Mullsteins Meadows near Downingtown						
1973	770	16	1.65	3.94	0.19	0.39
1974	949	16	1.66	3.97	.16	.39
1975	997	18	2.64	4.14	.17	.62
1976	630	20	2.50	4.29	.28	.55
1977	433	18	2.33	4.04	.34	.54
1979	381	14	3.21	3.72	.29	.85
1980	1596	12	2.91	3.55	.07	.82
Site 45 (station 01480632) Doe Run at Springdell						
1973	15	7	1.45	2.22	1.45	0
1974	147	7	1.12	2.67	.29	.35
1975	575	18	2.48	4.21	.27	.56
1976	836	22	2.19	4.36	.24	.47
1977	665	16	3.00	3.99	.21	.74
1979	150	15	2.71	3.64	.67	.69
1980	628	14	2.86	3.83	.19	.73
Site 46 (station 01480629) Buck Run at Doe Run						
1973	346	8	.97	2.95	.17	.29
1974	54	5	1.56	2.37	.42	.58
1975	790	16	1.94	3.97	.18	.46
1976	218	9	1.20	3.09	.28	.33
1977	795	18	1.70	4.11	.21	.38
1979	5	5	1.38	1.38	1.38	1.00
1980	420	10	2.30	3.24	.19	.69

Table 2.--Brillouin's diversity index, maximum diversity, minimum diversity, and relative evenness, by site--continued

Year	Total number of organisms	Total number of taxa	Brillouin's diversity index (H)	Maximum diversity (H_{max})	Minimum diversity (H_{min})	Evenness (E)
Site 47 (station 01480656) Indian Run near Springton						
1973	-	-	-	-	-	-
1974	188	21	2.89	4.43	0.80	0.58
1975	446	28	3.02	4.84	.53	.58
1976	135	18	2.97	4.03	.88	.66
1977	42	15	2.90	3.69	1.71	.60
1979	185	28	3.57	4.68	1.08	.69
1980	622	28	3.44	4.70	.40	.71
Site 48 (station 01480648) East Branch Brandywine Creek near Cupola						
1973	218	14	2.59	3.76	.46	.65
1974	188	17	2.58	3.86	.64	.60
1975	749	28	2.89	4.81	.34	.57
1976	518	23	3.15	4.48	.38	.67
1977	583	21	2.88	4.40	.31	.63
1979	166	21	2.47	4.41	.88	.45
1980	624	16	3.10	3.91	.22	.78
Site 49 (station 01473167) Little Valley Creek at Howellville						
1973	29	2	.17	1.04	.17	0
1974	0	0	0	0	0	0
1975	988	12	2.54	3.56	.11	.70
1976	449	12	2.59	3.55	.22	.71
1977	279	13	2.18	3.65	.35	.56
1979	222	14	2.25	3.84	.45	.54
1980	1983	15	2.26	3.88	.08	.57
Site 50 (station 01473168) Valley Creek near Valley Forge						
1973	25	2	0.19	1.04	0.19	0
1974	153	8	1.42	2.88	.33	.43
1975	534	10	1.89	3.30	.15	.55
1976	849	14	1.73	3.81	.15	.43
1977	1003	13	1.65	3.66	.12	.43
1979	263	9	1.98	3.10	.24	.61
1980	1412	12	2.64	3.59	.08	.73