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Abstract. Kodak Colorado Division has sponsored the collection of both macroinvertebrate and physicochemical data from the Cache la Poudre River, Colorado, from 1970 to the present. This report is a first attempt at combining the two data sets into a quantitative biotic index of eight chemical parameters. Instead of assigning organisms to qualitative tolerance categories (Beck, 1954, 1955; Chutter, 1972; Winget and Mangum, 1979; Hilsenhoff, 1977, 1982, 1988a, 1988b; and Lenat, 1991), preferred values are assigned to organisms in the same units as the chemical parameter in question. The results appear to at least initially track the trends observed in the actual chemical parameters for the period 1981 to 1991. Data on temporal and longitudinal changes in abundance, density, and diversity of taxa are presented for the years 1981 to 1991. Detrended Correspondence Analysis (DCA) is used to look at longitudinal trends associated with the macroinvertebrate populations within the reach.

Keywords. biotic index, benthic macroinvertebrates, biologically determined value, preferred value, tolerance value, pollution, Colorado

INTRODUCTION

Traditionally the health of freshwater ecosystems has been determined by direct physicochemical assessment. This is the most precise and consistent method of determining the physicochemical conditions of a system, but it requires continuous monitoring of a variety of variables; it is quite time consuming and does not give the investigator information on the effects of those conditions on the biota. More recently investigators are beginning to include a biotic component in their assessments. They have discovered that predictable changes in populations and communities within the systems also indirectly reflect the changes in physicochemical conditions and that they can save time and money in the process. Cairns and Pratt (1993) defined biological monitoring as surveillance using the responses of living organisms to determine whether the environment was favorable to living material. It is reasonable to assume that the effects of environmental alterations in an ecosystem will result in compensatory responses from the biota. Experienced aquatic ecologists have been making qualitative assessments of the conditions in freshwater systems in the field for quite some time, but they did not quantify their observations.

The concept of biological monitoring of environmental conditions originated in Europe with the idea of saprobity (the degree of pollution) (Cairns and Pratt, 1993). Saprobity has not been as widely accepted in the United States as it has in Europe and Cairns and Pratt (1993) have suggested that this may be due not only to the limited geographical distribution of many species, but to the relative lack of substantial organic pollution in the United States and the prevalent skepticism surrounding the indicator species concept in the United States. Even so, aquatic macroinvertebrates have been widely used as indicators of water quality because they have several attributes not possessed by other water quality indicators (Goodnight 1973, Hawkes 1979, Rosenberg and Resh 1993):

They are ubiquitous; therefore, they can be used to detect perturbations in a variety of aquatic systems and habitats within those systems (Rosenberg and Resh, 1993). The large numbers of species involved allows the investigator to simultaneously collect information from many "indicators" with a variety of tolerances to various environmental conditions.

Aquatic macroinvertebrates, unlike physicochemical parameters (unless continuously monitored), reflect not only present but also past and extreme environmental conditions (Patrick, 1949; Hilsenhoff, 1977). Patrick (1949) even went so far as to state that physicochemical conditions can only be used as substantiating evidence in determining the conditions for life in a stream. The life cycles of aquatic insects are generally of a duration to provide maximum information on environmental conditions. Their long life cycles allow the investigator to look at temporal aspects of environmental perturbations, both past and present. Plafkin et al. (1989) considered macroinvertebrates an essential part of a biomonitoring program because they tend to integrate water quality fluctuations between sampling periods.

Assessing the health of a reach via biotic means is less time consuming than direct physicochemical assessment. Hilsenhoff (1982) estimated that only 85 minutes would be required to calculate a biotic index value using his method. Biological monitoring in North America has come full circle since the 1960's. Monitoring programs were initially qualitative in nature, transitioned to quantitative, and are now reverting back to qualitative "rapid assessment approaches" (Resh and Jackson, 1993). Even though the rapid assessment approaches are less time consuming than the typical quantitative approach, they have their limitations and the investigator must ultimately make a choice depending on the purpose and required sensitivity of the study (Resh and Jackson, 1993).

Macroinvertebrates do not move as freely as fishes, which can immediately recolonize an area when conditions improve. This essentially sedentary nature also allows spatial analysis (e.g., downstream recovery) to be performed (Rosenberg and Resh, 1993). The investigator will never find conditions to be substantially better than they may have been in the recent past, but due to slow recolonization after a past perturbation, recovery may not be indicated until long after the system has actually recovered. An intensive physicochemical and macroinvertebrate monitoring program may be needed after a perturbation to a system to compensate for the lag time associated with the biotic measure.

Aquatic macroinvertebrates are not as difficult to identify and collect as are microorganisms. Biotic assessment can be performed by individuals without a lot of specialized training. They provide some information on water quality, even at a fairly coarse level of taxonomic resolution. Hilsenhoff (1988a) developed a biotic index based on a family level of identification. When using an EPT index the investigator is only required to identify organisms to order -- something even a person with limited expertise can do.

Given the numerous advantages of dealing with macroinvertebrates in assessing water quality one would be tempted to rely heavily on them to ensure compliance and to even maintain surveillance, but it is important to not depend solely on one component (e.g., macroinvertebrates) in assessing water quality conditions. To quote from the preface of the recent book edited by Rosenberg and Resh (1993): "Biomonitoring may have come of age with the recent adoption, by North American and European governments, of national programs of environmental monitoring and assessment that include use of aquatic biota. These programs will use a variety of 'indicators' of environmental health; benthic macroinvertebrates are one of the most promising of them." The investigator needs to be aware of the limitations of the various avenues of investigation used and develop a well-balanced monitoring program that incorporates a variety of biological, physical and chemical variables (Winget and Mangum, 1979; Rosenberg and Resh, 1993).

On the negative side, biological monitoring initially requires large databases and experienced investigators to determine the value of the taxonomic groups for use in environmental assessment. Ideally these databases should be long-term and collected over wide geographical and ecological ranges in order to gain the maximum amount of information about the responses of the individual taxa to the environment. Even with extensive long-term databases and experienced investigators, the investigator is always faced with the fact that absence of a species does not necessarily indicate the presence of intolerable conditions, and the presence of an organism only indicates that conditions have not recently become unfavorable (or at least intolerable) for its existence. The presence of an intolerant species indicates that the conditions have not exceeded its low tolerances and indicates good water quality, but the presence of a tolerant species can provide almost no information about pollution because, although they can tolerate extreme conditions, they may also occur in clean waters (Beck 1954, 1955).

Organisms have been known to enter the drift to avoid deteriorating environmental conditions, so they may be collected in a sample while avoiding an upstream perturbation (Pratt and Hall, 1981). The organisms that have entered the drift to avoid an upstream perturbation may give a false reading with the index at downstream sites.

Review of Biotic Indexes:

Patrick (1949) looked at a 474.8 square mile (1229 sq. km.) basin in Lancaster County, Pennsylvania, to examine the possibility of using organisms in streams as indicators of stream conditions particularly related to sanitary and industrial wastes. Her work concentrated on the Biochemical oxygen demand (BOD) of effluents and stream waters. She also analyzed several of the streams in the basin for other physicochemical parameters. She found that the biota provided a different and more relevant evaluation of the system than direct physicochemical assessment.

Beck (1955) proposed a very simple index to be used in the classification of Florida streams. It was based on a classification system that he proposed in 1954 (Beck, 1954). Aquatic macroinvertebrates, including aquatic insects, crustaceans, molluscs, and worms, were divided into five classes. Three of the categories were used in the index and the remaining two were a matter of convenience; they were not used directly in the development of the index. Class I organisms do not tolerate appreciable amounts of organic pollution. They are typically only found in clean waters. Class II organisms tolerate only moderate amounts of organic pollution; they do not tolerate anaerobic conditions. They too may be found in clean waters, so their presence can be interpreted to mean that the area is not heavily polluted. Class III organisms have been found to tolerate heavy organic pollution. They cannot be used to indicate either polluted or clean waters because they can survive in either of the conditions. Class IV includes organisms that are independent of dissolved oxygen; they can breathe atmospheric oxygen. Class V is the depository for all of the organisms for which not enough ecological information has been collected to place them into one of the other categories. Only the Class I and Class II organisms were used in calculating the index. He chose to error on the side of caution. If an organism was found in moderately polluted water -- even just once -- it was placed in the second category. If an organism was found in highly polluted waters, it was placed in the third category. He suggested that in the future statistical scales for classification of organisms will probably be developed in order to alleviate problems associated with placing borderline organisms into a limited number of qualitative categories.

He used a simple arithmetic formula:

$$2(n \text{ Class I}) + (n \text{ Class II}) = \text{Biotic Index}$$

The index is based solely on the relative numbers of the two subjective groups of taxa and places a selective influence on the more intolerant organisms. He suggested 10 as the lowest possible value to be indicative of clean waters. Recognizing the geographical limitations of any index he cautioned against using any generalizations made in developing the index to streams outside Florida. He also recognized that only the presence of an intolerant organism can indicate healthy stream conditions; whereas, the presence of tolerant organisms does not necessarily indicate unhealthy conditions.

Winget and Mangum (1979) developed a biotic condition index intended for use in mountain and valley streams in the western US. It uses a wide variety of organism including coelenterates, nematodes, gastropods, annelids, turbellarians, hydracarines, isopods, amphipods, decapods, cladocerans, copepods, and ostracods; however, as with most macroinvertebrate based biotic indexes it relies heavily on insects. The index was developed as a "reliable biological component" within a stream water quality and habitat management program. Environmental factors that are not strongly related to man-caused perturbation and that correlated significantly with the numbers or abundances of taxon were used. Three of the four physicochemical factors selected for use in the model were selected for their correlation to community diversity. For each of these parameters the "preferred" range for each species was determined using a "weighted average" and species were assigned to qualitative categories based on those preferred ranges. After assigning species to categories, the numbers associated with those categories were multiplied together to come up with an overall final "tolerance value" for each species.

Their index was designed around the idea that a model must be reduced to a key minimum set of structural components that are believed to be distinct in affecting the functioning of that aspect of the system that is of interest (Watson and Loucks, 1979). Four factors were selected by Winget and Mangum (1979) for their analysis as overall indicators of water quality that would be conserved from stream to stream. Sulfate was selected because it was felt that an increase in sulfate concentration was generally indicative of a decrease in natural water quality and it was found that macroinvertebrate diversity decreases with an increase in sulfate. Alkalinity was selected for its close correlation to community density, and/or biomass. They felt that the importance of alkalinity in primary production and its concomitant increase along with other elements essential to the metabolism of plants, invertebrates and vertebrates merited its inclusion in their model. Substrate was selected because it has been implicated in the structuring of stream communities (Cummins and Lauff, 1969); combinations of larger substrate particles provide more diverse microhabitats resulting in the possibility of a more diverse macroinvertebrate community. Stream gradient was selected as an index of the ability of the stream to maintain and/or recover from perturbation.

They proposed a five level management hierarchy for either maintaining existing resource quality or improving existing resources to a state nearer a desired condition. This hierarchy is based on maintaining or improving streams so that they can support high quality sport fisheries with the assumption that both a high quality habitat and macroinvertebrate community will do just that. Highest priority was given to systems with high quality habitat and a healthy macroinvertebrate community. Second priority is given to high quality habitats with only moderately healthy macroinvertebrate communities. Third priority was given to low quality habitats with higher quality macroinvertebrate communities. Systems with high to low quality habitat and low quality macroinvertebrate communities were assigned to the remaining two categories.

Hilsenhoff (1982) originally developed an index of organic pollution using 53 Wisconsin streams encompassing a wide range of sizes, currents, substrates, water chemistries, and water qualities. All samples were taken from riffles. Organisms included in the development of the index included insects, amphipods, and isopods. Organism such as Hemiptera and adult Dytiscidae, Gyrinidae, Haliplidae, and Hydrophilidae were not used because they do not rely on the stream for oxygen. "Species are assigned pollution tolerance values of 0 to 5 on the basis of previous studies (Hilsenhoff, 1977) -- a 0 value is assigned to species found only in unaltered streams of very high water quality, and a value of 5 is assigned to species known to occur is severely polluted or disturbed streams . . . Tolerance values were initially assigned to each species empirically, and adjustments were made when studies of groups of streams suggested they were necessary" (Hilsenhoff, 1982).

In Hilsenhoff (1982) several problems are discussed associated with using his index. He addressed many of the problems with later additions and modifications to the index (Hilsenhoff, 1987, 1988a, 1988b). The first of these was the need for species keys to taxa used in each index. The lack of suitable species keys becomes a problem when different species within a common genus have different tolerances to various parameters. Hilsenhoff addresses this issue by including keys modified to include only species known to occur in the area covered by the index and including relevant references for other groups. Hilsenhoff (1982) also noted that organisms can withstand lower dissolved oxygen at both higher currents and lower water temperatures. At higher currents more oxygen is transported past insects and at lower temperature not only is the metabolism of the organism lower but the amount of dissolved oxygen that the water can hold is increased. Hilsenhoff (1988b) suggested relevant seasonal modifications to increase the correspondence of his index with actual environmental conditions. Hilsenhoff (1982) also used species associations to assign tolerance values to organisms; if an organism previously thought to be intolerant was commonly associated with tolerant species it was assigned a more tolerant value, but as Beck (1954) pointed out the presence of a tolerant organism does not necessarily indicate lower water quality so this associative assignment of tolerance values may not be accurate.

Lenat (1993) developed a biotic index for use in the southeastern United States. Macroinvertebrate data included more than 2000 stream samples collected between 1983 and 1992. Samples were grouped into 5 water quality categories (bioclassifications) based on EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa richness and an earlier version of the North Carolina Biotic Index (NCBI). The emphasis of this derivation of the NCBI was to get a semi-quantitative tolerance value and to examine the general level of pollution within a reach.

OBJECTIVES OF THE CURRENT STUDY

The ultimate objective of this project is to develop an index of stream water quality based on aquatic macroinvertebrates, using a long-term data set of biotic and physicochemical variables collected at ten sampling sites along a 50 km segment of the Cache la Poudre River, Colorado. Downstream trends and site specific interannual trends elucidated by the index will be presented. In addition we (1) provide a review of existing water quality indexes based on stream macroinvertebrates, (2) examine the longitudinal and temporal changes in macroinvertebrate community composition, abundance, and diversity with corresponding changes in water quality along the study reach, and (3) assess the limitations of the biotic index, including its applicability to other Colorado streams.

STUDY AREA

Historical Background of the Cache la Poudre River

According to legend, perhaps disguised as history, sometime in November 1836 (or February 1826) a large party of trappers and support personnel of the American Fur Company under the command of William H. Ashley were en route from St. Louis, Missouri, to Green River, Wyoming, when they were stranded by a severe snow storm in Colorado. The extensive snow accumulation impaired moving the heavily loaded wagons farther. Consequently, the wagons were lightened and a cache of the materials from the wagons was established at a nearby river to be retrieved at a later date. Among the stored contents was gun powder, and from the French, Cache la Poudre (where the powder was hidden), the river acquired its name. Evans and Evans (1991) provide a more detailed account of the historical background surrounding the river.

Larimer County, Colorado, where a portion of this study was conducted, was eventually established by the territorial legislature in 1861. The remainder of this study was carried out in Weld County, Colorado, which also had its beginning during the same year.

Cities Along the River

LaPorte is the first of the larger cities along the plains segment of the Poudre River. It was officially organized in 1860 and in 1862 it was made into a stage stop. Lieutenant Colonel William O. Collins sent a group of soldiers to LaPorte to guard the stage line against Indian attack. In 1864, a "tremendous cloudburst" washed most of LaPorte and Camp Collins downstream; a new camp was set up downstream. Although the post was closed in 1867, Fort Collins presumably came into existence during its latter years and was officially established in 1872.

Six miles (9.7 kilometers) to the south of Fort Collins is the town of Timnath. It was established in 1882 after the completion of the Greeley, Salt Lake, and Pacific Railroad. It was a farming community. Around the turn of the century, Timnath became an important shipping point for livestock and other agricultural products. Today it is a small village of 700 people that uses both water and sewage facilities of Fort Collins.

Another town of significance to this study is Windsor (in Weld County), down river from Timnath. It saw early growth with the establishment of sugar beet factories, by the Great Western Sugar Company, in Loveland, Longmont, Fort Collins, Greeley, Eaton and in Windsor from 1900-1905. The Windsor plant operated from 1903-1968. Kodak established a plant in Windsor during 1970 and currently discharges treated effluent to the river. The population of Windsor was 4,277 in 1980. Until recently, the town obtained its drinking and industrial water from the Greeley-Bellvue plant. Windsor now has developed its own water treatment plant using Donnath Reservoir water. The city also returns treated wastewater to the river.

Although the study reach is upstream from the city of Greeley, this municipality has long had an impact on the upstream portion of the river. The city was established in 1870 by the Union colonists. They wasted no time in digging irrigation ditches, and water withdrawal from the Poudre prompted other irrigation projects to the north as well. Municipal and agricultural use of the river continues today and the city is expanding upstream.

Activities Impacting the River

An event that occurred early in Fort Collins' history would set the pattern of the town's growth and activity until the midpoint of the 20^{th} century. The Territorial Legislature authorized the establishment of the Agricultural College of Colorado in Fort Collins 1870. In 1957, Colorado A&M became Colorado State University with subsequent increases in faculty, students and support staff. Another event that occurred in Larimer and Weld Counties, probably related to the establishment and subsequent changes of the university, was the realization that agriculture was a more stable economic base for the new state than mining. The eastern slope of Colorado had the potential to fulfill this change in resource base, with the exception of available water, for it is a semi-arid land with minimal rainfall. To resolve this problem, a series of irrigation ditches was proposed. The first diversion taking water from the Poudre River was constructed in 1860. In 1873 the Fort Collins Irrigation Canal was constructed to provide more water to the city. Other ditches would follow. Reservoirs were also needed to store water, and in the early 1900's the North Poudre Irrigation Company constructed Fossil Creek Reservoir near Windsor with a capacity of 11,500 acre feet (14,180,000 cubic meters). This reservoir, along with others independent of it, and the ancillary irrigation ditches all impact the abiotic and biotic components of the river.

Another change that occurred in the area, important indirectly to agriculture, was the introduction of food processing plants in 1903. The construction of the Great Western beet sugar factories close to the Poudre River set a new trend for the economy that was to last some 60 years.

With the establishment of relatively stable social and industrial patterns, little population growth occurred in Fort Collins up to 1920 (8,210 people in 1910 vs. 8,755 people in 1920). The county population increased from 12,168 to 27,872 during 1910-1920. The number of people residing in the city for 1930, 1940 and 1950 was 11,489, 12,151 and 14,937, respectively. The population in the county increased from 33,127 to 43,554 during the same period.

During the 1960's more industry moved into the area (1970 census, 43,377 city vs. 89,000 county), with a significant impact on all facilities: water, air, traffic, electrical service, and education. This pattern continued into the 1970's (1973 - 55,373 city vs. 114,000 county), slowed down somewhat at the end of that decade, but growth has still continued at a significant level. The 1980 census gave Fort Collins a population of 65,092. The counties also had significant growth with Weld County having a population of 123,438 and Larimer County having 149,184 in 1980. The populations of Fort Collins and Larimer County in 1990 were 87,758 and 186,136, respectively.

The city of Fort Collins initially operated a small wastewater treatment plant and relied on county cesspools and septic tanks for much of the treatment. The city presently operates two wastewater treatment plants that are capable of discharging to the river. Mulberry Water Reclamation Facility (formerly plant #1), located at State Highway 14 and Riverside Avenue, was established in 1947. Drake Water Reclamation Facility (plant #2), located on East Drake Road, began operation in December 1968. The Drake Road facility can discharge to the Poudre River, to Fossil Creek Reservoir via Fossil Creek Ditch or to the pumping station for the Rawhide Power Plant.

To meet the demand of expanding populations and extended geographical growth, water and sanitation districts were established. The facilities associated with these districts withdraw and/or return water to the Poudre River at various locations. By the 1950's, water was taken from the Poudre River by the City of Greeley for its Bellvue drinking water treatment plant. Boxelder and South Fort Collins Sanitation Districts were introduced later.

Cache la Poudre River Basin

The main stem of the Cache la Poudre River begins at Poudre Lake near the summit of Milner Pass at 3280 meters in Rocky Mountain National Park, Colorado. The North Fork has its source at about 3200 meters near the top of Deadman Hill to the west of the Redfeather Lakes and joins the main stem at 1633 meters as the Poudre exits the foothills onto the plains. The South Fork can be traced to near the summit of Rowe Peak at almost 4000 meters in northeastern Rocky Mountain National Park and joins the main stem at about 2000 meters.

The main stem flows northeastward for about 20 miles (32 kilometers) and then eastward through the Poudre Canyon; most of this reach is in Roosevelt National Forest. It is joined by several mountain tributaries as well as diversion water from the North Platte River system through the Laramie River Tunnel at 2450 meters. Several mountain reservoirs are used to retain water from the spring snowmelt and periodic summer storms for later irrigation and other uses. Many of the smaller tributaries are dry throughout most of the year.

There are no known domestic sewage discharges above Fort Collins. However, there are two small communities located on the river several miles up the Poudre Canyon.

The greatest influx of people into the montane and foothills segments of the river is in May through September, when recreational activities such as fishing, use of summer cabins, camping, hiking and driving the paved highway along the river over the Continental Divide is moderately high. Cattle graze beside the river during summer and wildlife is abundant. Some of the Poudre River water is diverted through two state Game and Fish Department fish rearing units. The first unit is located about 80.5 kilometers up the Poudre Canyon at 2340 meters; the second unit is at Bellvue, Colorado, adjacent to Watson Lake at 1554 meters

At the lower end of the mountain segment of the Poudre River, both Fort Collins and Greeley take water for treatment as part of their drinking water supplies. The length of canyon section of river is about 65 miles (105 kilometers), and it leaves the canyon at an elevation of 1,585 meters.

What has been called the plains segment of the River is about 51 river miles (82.1 kilometers) long. It extends in a southeastward direction from 6 miles (9.7 kilometers) above the small city of LaPorte (elevation 5,061 feet; 1543 meters) to its confluence with the South Platte River, east of Greeley, at an elevation of 4,650 feet (1,418 meters). This entire area, developed historically as a major agricultural center, is dependent upon the river for its water. The average annual precipitation is about 14.5 inches (368 millimeters), but is subject to wide annual fluctuations from about 8 to 21 inches (203 to 533 millimeters). Moreover, the precipitation patterns within each year are quite uneven, with as much as one-half of the moisture occurring in very few rain or snowstorms. In both 1976 and 1977, for example, one-third of the annual moisture fell as a single storm event in July.

In the summer, Poudre River flow is augmented by a few relatively small tributaries and diverted trans-mountain Colorado River water, which is stored in Horsetooth Reservoir and Carter Lake. This plains segment of the river is part of a very complex, sophisticated, water management system. Diversions of large quantities of water at several points along the river are made to supply the needs of rightful users as they call for water, or it is stored in a large number of relatively small plains reservoirs for later use. This system of storing spring and heavy storm run-off water serves to control flooding in the valley and to provide water for irrigation. It should also be noted that the extremely large network of water transfer canals and storage reservoirs leads to large losses of water due to evaporation, as well as ground seepage in this area of high sunlight, low humidity, and normally dry soils. This highly developed technology of water management may lead to reuse of any particular portion of water several times in the 51 mile (82.1 kilometer) river reach. The intensive withdrawal of water and return downstream after use leads to a situation, particularly in the lower portion of the plains segment, in which water quality is only remotely similar to that found in the mountain canyon.

In the late 1960's when it appeared that the Cache la Poudre Valley was about to undergo dynamic changes, particularly the 30 mile (48.3 kilometer) river reach from LaPorte eastward, a program was initiated by Kodak Colorado Division in cooperation with Colorado State University to collect quantitative data that would document changes that might occur in the quality of the river. This was a time when a great deal of discussion was underway on a national effort for water pollution control. However, specific programs and clean water laws had not been promulgated, and no guidelines were available.

This stretch of the river had been primarily an agriculturally oriented, low human population density area with only higher education-oriented urban Fort Collins providing a moderate rate of growth in human pressure on the river. While the impact of agriculture on the river was considerable but relatively static, the City of Fort Collins was entering a phase of very rapid growth in small industrial and commercial developments that accompanied its extremely rapid expansion as an urban population center. A few miles east, the interstate highway attracted commercial development; Windsor, about 10 miles (16.1 kilometers) east of Interstate 25, became the location for the Kodak Colorado Division facility.

A data gathering program was initiated in 1970 for several physical, chemical, and biological parameters. This would serve as baseline data on river water quality that could be useful in determining changes to water quality as anticipated changes in population and activities took place. Four primary sampling sites were initially selected to monitor the stream. In 1980 the City of Fort Collins joined with Kodak in the monitoring program and additional sampling sites were added, bringing the total number to ten. To date these sites continue to be monitored. They are described below and are depicted on the enclosed map (Figure 1) and elevational profile (Figure 2)

Individual Site Descriptions and Locations

The numbering scheme used in this report and that used by Richard et al. (1993) do not coincide. In order to provide a consistent numbering scheme, the following conventions will be used for site numbering: Each of the ten sites analyzed will primarily be referred to by the numbering scheme or four-letter code outlined below with the individual site descriptions. When referring to site 1 and sites 4 through 10, the numbering scheme used by Richard et al. (1993) will be included in parenthesis to facilitate the use of Figures 13a-h by the reader. When referring to sites 2 and 3, site numbers in parenthesis are omitted because no analogous sites were analyzed by Richard et al. (1993). The numbering scheme used in Figures 13a-h conforms to that used by Richard et al. (1993), but all other figures will use the primary numbering or letter code scheme of this report only.

1(1). MARTINEZ PARK (MART) - This site is located at river mile 45.5 (73.2 km) and was expected to be the most pristine, since no known point sources of pollution occur above this area. The river flows between the McMurray Nature Area on the north and Martinez Park on the south. It is 0.5 mile (0.8 km) upstream from College Avenue and about 0.5 mile (0.8 km) downstream from Shields Street. The bottom is primarily cobble, gravel, and sand. The banks have been reinforced with riprap towards Shields Street, but generally the banks are made of clay and gravel. There is some erosion. The specific sampling area is near the footbridge on the bike path. This site is considered to be minimally impacted by agricultural, industrial and urban activities. One potential problem at this site is a significant gasoline contamination of the groundwater on the north side of the river, resulting from a past gasoline leakage in the area. The river classification is recreational Class 2, warm water, and agricultural. The Martinez Park site is located at 1515 meters in the N. E. 1/4 of the S. W. 1/4 of Section 2, T7N, R69W in Larimer County, Colorado.

2. MULBERRY STREET (RIVER BEND AREA) (MULB) - Located at river mile 41 (66 km), south of Mulberry Street (State Highway 14) about 1/4 mile (400 m) upstream from Riverbend Ponds and recreation area. This site is situated about one mile (1.6 km) downstream from the point where treated wastewater from the Mulberry Water Reclamation Facility is discharged into the Poudre River. The bottom is predominantly cobble, gravel and sand. The setting at this site is municipal. The Mulberry Street site is located at 1500 meters in the N. E. 1/4 of the N. E. 1/4 of S18, T7N, R68W in Larimer County, Colorado.

3. MOORE FARM (MOOR) - Located at river mile 37 (59.5 km), this site is situated downstream from the Drake Water Reclamation Facility outfall, but upstream from the outfall from the Boxelder Sanitation District. However, effluent from the water reclamation facility is not normally discharged to the Poudre River. Rather, the effluent is discharged to the Rawhide Power Plant or into Fossil Creek Ditch, which flows to Fossil Creek Reservoir. The bottom substrate is primarily composed of cobble, gravel and sand. The Moore Farm site is located at 1483 meters in the S. W. 1/4 of the N. E. 1/4 of section 28, T7N, R68W, Larimer County, Colorado.

4(2). TIMNATH (TIMN) - This sampling area is located at river mile 34.5 (55.5 km). It is about 0.3 mile (530 m) downstream from the bridge where Larimer County Road #5 crosses the Poudre River and is due south from the town of Timnath. The bottom is cobble, gravel and sand. The banks are mostly sand, gravel and clay. Some erosion is evident. The river makes a bend and deposits a lot of the heavier suspended material in this area. Upstream is the discharge from Boxelder Sanitation District Wastewater Plant and outfalls from Fort Collins' two wastewater treatment plants which treat domestic and industrial wastes. There are several gravel pit operations upstream. In 1983, the River returned to it original channel and ran down County Road 5 during runoff. The setting is a combination of municipal and agricultural. The Timnath sampling site is located at 1472 meters in the N. W. 1/4 of the N. W. 1/4 of Section 2, T6N, R68W, in Larimer County, Colorado.

5(3). 392 BRIDGE (392B) - This site is located at river mile 28.5 (45.9 km) about 0.3 miles (530 m) downstream from the Weld County road bridge. Here the river is channelized. The bottom is composed of cobble, with some sand and gravel. Silt may accumulate at this site when the river is not running full. The banks are composed of larger rocks, gravel and clay with very little erosion. About 1.2 miles (1.9 km) above this site is the confluence of the Fossil Creek Reservoir outlet ditch. Upstream of this site the river meanders and has a moderate flow. The setting is exclusively agricultural. The 392 Bridge site is located at 1457 meters in the N. W. 1/4 of the S. W. 1/4 of Section 19, T6N, R67W in Weld County, Colorado.

6(4). WINDSOR PACKING (WIND) - This sampling site is at river mile 25.5 (41.1 km) and is immediately downstream from the road that passes by the Windsor Packing Company (no longer operational). Until the road turns south, it is called County Road #66. There is a gravel mining operation about halfway between the 392 Bridge site and the Windsor Packing site. The banks of the river at this site are composed of clay and gravel, and they are highly eroded. The bottom consists of cobble, gravel, sand and silt. The river is extremely channelized in this area. At this site the river flows through the Kodak Headquarters Farm. The flow of the river is slower here than at the two previous sites. The setting is primarily agricultural. The Windsor Packing site is located at 1451 meters in the N.E. 1/4 of the N.E. 1/4 of Section 28, T6N, R67W, Weld County, Colorado.

7(5). GAUGING STATION (STAFF GAUGE) (GAGE) - This area is at river mile 22.5 (36.2 km), immediately upstream from the Windsor Sewage Plant outfall and about 1/4 mile (400 m) upstream of Kodak's effluent. There is a State of Colorado recording gauge on the river at this point. Normally the river depth is less than three feet (0.9 m), but it can increase drastically especially during spring runoff. There are high bluffs to the south. The river meanders in this region and has been channelized. The banks are riprapped but are still eroding. The land adjacent to it is a flood plain, and it is frequently under water during spring runoff. There is a drainage ditch connecting with the river to the south and a dairy farm to the west. The bottom is composed of gravel, sand and silt. The site is situated on Kodak property. The setting is primarily agricultural. The Gauging Station site is located at 1445 meters in the N. E. 1/4 of the S. W. 1/4 of Section 34, T6N, R67W, Weld County, Colorado.

8(6). LAW DITCH (LAWD) - This sampling site is at mile 21.5 (34.6 km). It is about 1,000 yards (914 m) downstream from Kodak's effluent and about 1500 yards (1,370 m) downstream from Windsor's domestic wastewater treatment plant outfall. Kodak is the only strictly industrial wastewater treatment plant in the area. Kodak's biosolids incorporation fields are between the Staff Gauge site and the Law Ditch site. Sampling is done about 100 yards (91.4 meters) downstream from the confluence of Law Ditch and the river. Nearby is a small dairy farm. There is a ford across the river downstream from the sampling site. Above the river to the north is a silage pit. The Kodak plant is north and a little bit to the west. There is moderate river flow in this area. The river is winding at this site with a bend just below the confluence of the Law Ditch. The north bank is riprapped. Automobile body parts in the banks and on the bottom of the river in this reach serve as fish habitat and help to stabilize the banks. The bottom is composed of sand and gravel with some cobble. There is some channelization. The setting is agricultural, industrial, and municipal. The Law Ditch Site is located at 1442 meters in the S. E. 1/4 of the N. W. 1/4 of Section 35, T6N, R67W, in Weld County, Colorado.

9(7). SHARK'S TOOTH (SHRK) - Situated at river mile 20 (33 km), this site is downstream from Weld County Road #23 where at one time there was a bridge. Nearby (upstream) is a large irrigation diversion dam (Jones Ditch). There is a side channel with a riprap dam that comes down from the north side of the main channel and there is an island in the middle. The bottom is composed of gravel and cobble with a small amount of sand near the sampling area. The northern bank of the river at the bend is riprapped. There are buried pipelines under the river at this point; they are water mains from the City of Greeley. Work is done periodically on these mains. The flow rate is high at this point. The banks are composed of gravel and some clay, and they are riprapped. There is significant erosion and the water is normally turbid. Irrigation return flow with its attendant soil contamination is the major addition to the river at this point. The setting is mostly agricultural. The Shark's Tooth site is located at 1439 meters in the N. W. 1/4 of the S. W. 1/4 of Section 36, T6N, R67W, in Weld County, Colorado.

10(8). FARMER'S SPUR (FARM) - This site is located at river mile 14.5 (23.3 km) near Weld County Road #31 (City of Greeley 59th Avenue). Samples are taken up to 0.25 mile (0.4 km) upstream from the bridge. There is a feedlot and dairy 0.25-0.5 mile (0.4-0.8 km) upstream. Irrigation ditches abound in the vicinity, and return flows bring agricultural chemicals and soil microbes to the river. Starting in 1983, oil or gas drilling has been carried out periodically along this stretch of the river. The City of Greeley is growing in this direction and there are small housing developments on the bluffs along the river to the south. At this site the river is winding, almost into an oxbow. For this reason there is a build-up of particulate matter with a slower rate of dilution downstream. The current is slow and the bottom is composed of both sand and silt with little or no gravel. There is also an anaerobic layer at the water-bottom interface. The river banks are composed of clay with some gravel; they are eroded badly and the rate of erosion is increasing. The setting is primarily agricultural. The Farmer's Spur site is located at 1430 meters in the S. E. 1/4 of the N. E. 1/4 of Section 33, T6N, R66W, in Weld County, Colorado.

Figure 1. Map of the study reach showing the sampling sites. Location of the Cache la Poudre River in the State of Colorado is shown (inset).

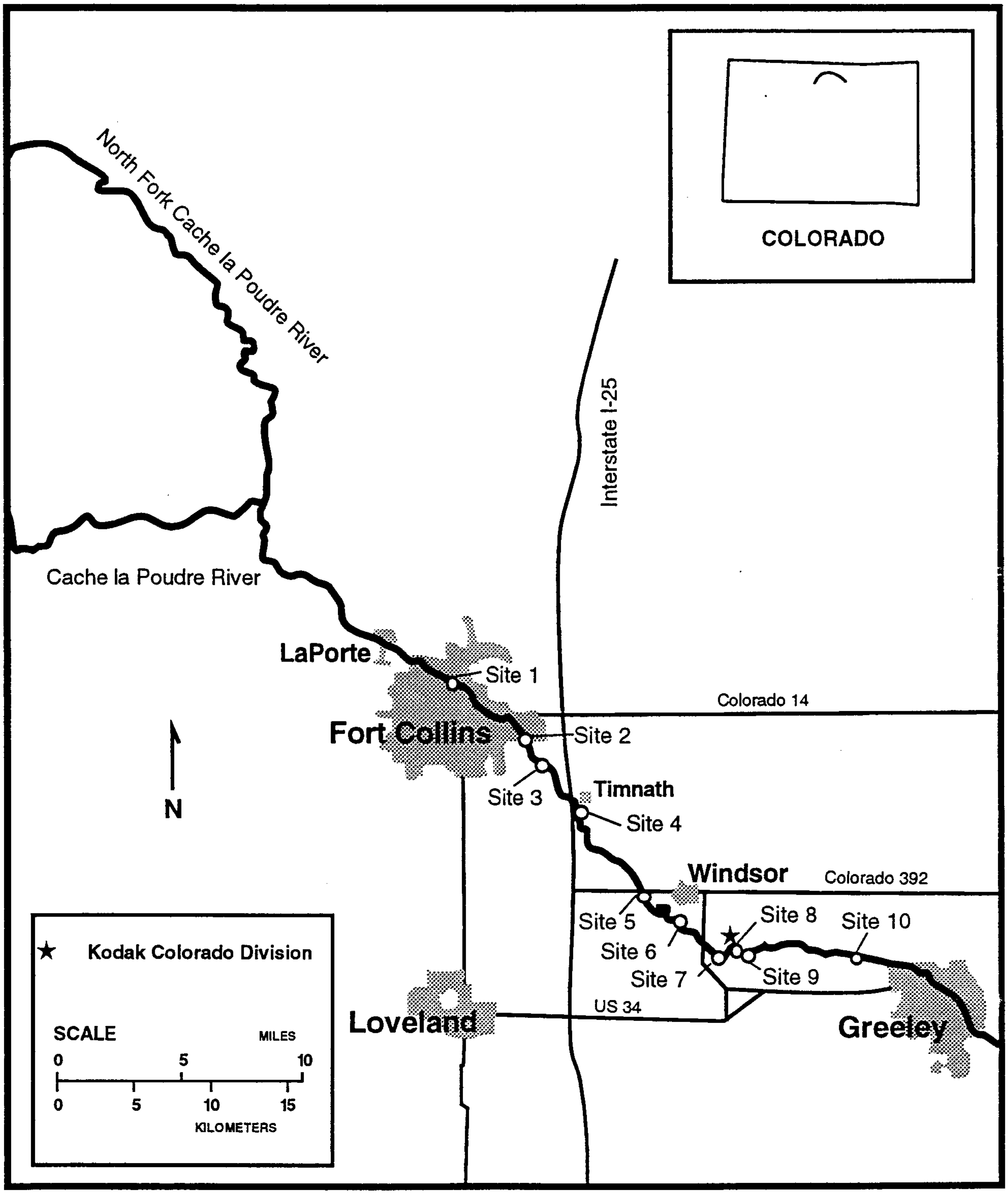
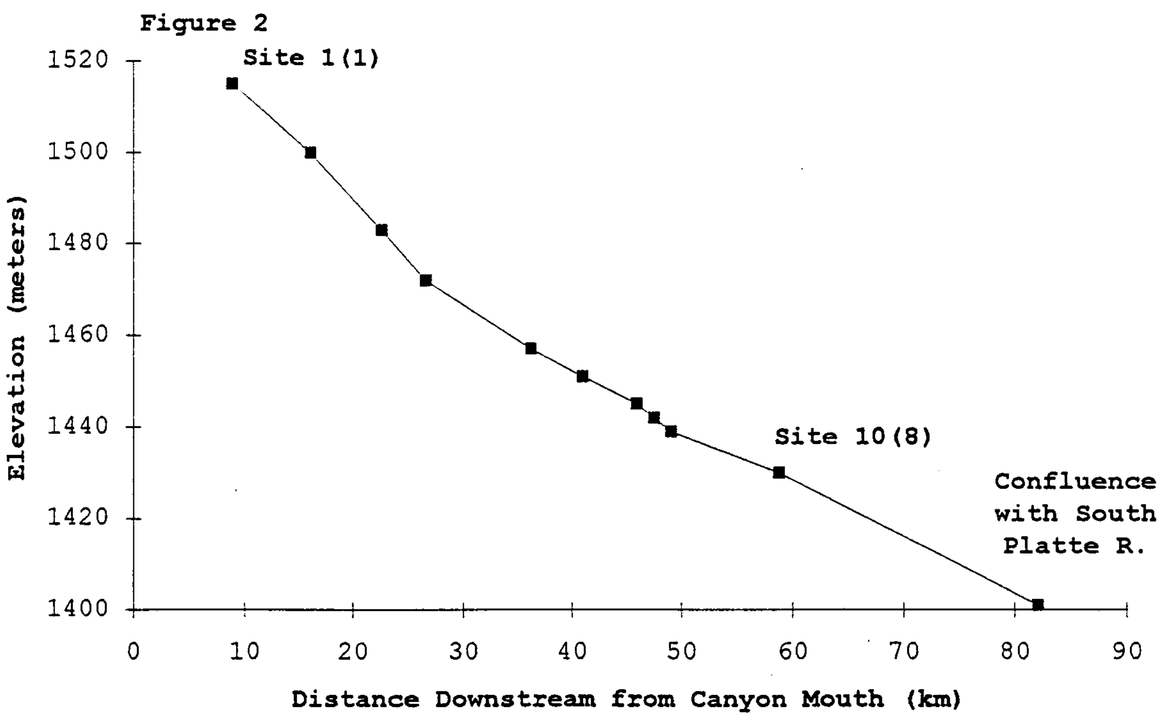


Figure 2. Elevational profile of the plains segment of the Cache la Poudre River basin from site 1 to its confluence with the South Platte River.



THE INVERTEBRATE COMMUNITY

Database

Macroinvertebrate data have been collected from the Cache la Poudre River since 1970 as part of a cooperative venture between Kodak Colorado Division and Colorado State University. Prior to 1971 only qualitative data exist and some taxonomic groups were combined. Prior to 1981, when keys to finer levels of taxonomic resolution were not available, organisms were only identified to family or order. Macroinvertebrate data were collected approximately every two weeks from August 1971-April 1975. Beginning in May 1975, samples were collected three times per year in spring, summer and autumn. Four sites were sampled regularly on the Poudre River from 1971-1980. Site 1(1), located in Martinez Park, has been used throughout the entire study. A second site was located near Moore Farm (site 3 in the 1981-1991 analysis) and was infrequently sampled. Sites 3-5 (as designated during 1970-1976) were located near the following sites: Timnath (site 4(2)), 392 Bridge (site 5(3)), and Shark's Tooth (site 9(7)), but were not in those exact locations.

Several problems exist with the 1971-1980 data. Although a Surber sampler was used to collect macroinvertebrates, it is not always clear how many samples were taken each time nor was there any documentation regarding the mesh size of the Surber sampler net. This latter information is very important because the mesh size will effect the number of organisms retained. In addition, prior to 1977 the macroinvertebrate data were presented as number of individuals per taxon with no unit area designation. We can only assume that the data were recorded as number per Surber sample (1.0 ft^2; 0.09 m^2). For these reasons the data collected prior to 1981 are not comparable to the 1981-1991 data and they will not be included in the development of the biotic index. The macroinvertebrate data collected between 1981 and 1991 were selected for inclusion in the development of the index.

Materials and Methods

A standard square foot (0.09 square meters) Surber sampler (A.P.H.A. 1981) was used to collect three samples of benthic macroinvertebrates at each site four times per year from 1981-1991 (see Table 1 for sampling dates). The Surber sampler consists of an L-shaped metal frame, with the lower portion of the frame equaling one square foot in area. Attached to the upper portion of the frame is a relatively long net. To collect macroinvertebrates, the sampler is randomly placed on the stream bottom and substrate that is enclosed in the frame is vigorously stirred. The organisms are dislodged from the substrate and are carried into the sampling net by the river current. One Surber sample was collected at each of three subsites for each biosurvey site. These subsites were approximately 100 yards (91 meters) apart. Since it is well known and documented that different benthos inhabit different stream bottoms (Hynes, 1970; Minshall, 1984; Ward 1992), each of the three subsite samples was taken from a different substrate, if possible. Considering the limitations of the Surber sampler and the selection of substrate sampled, this was considered a stratified random sampling for this survey (Weber, 1973).

Table 1. Sampling periods for the Poudre River macroinvertebrate survey 1981 to 1991.

YEAR	MONTHS	COMMENTS
1981	April, July, October, December	December sample site 6(4) - Total organisms for 3 Surbers = 38
1982	February, May, August, November	No February samples sites 2 and 3
1983	February, August, October, December	No August sample site 8(6); December sample site 9(7) - Total organisms = 25
1984	April, August, October, November	November sample site 2 - total organisms = 6
1985	February, April, August, October	May sample site 10(8); February sample site 2 - total organisms = 18
1986	February, August, October, November	
1987	February, April, August, October	
1988	February, April, July, November	
1989	February , April, August, October	
1990	February , April, August, October	
1991	February , April, August, November	

After the benthic samples were collected from the stream bottom, they were carefully transferred to wide mouth bottles, and all organisms clinging to the net were picked off and put in the bottle. The samples were then sieved through a U.S. Standard #30 sieve (A.P.H.A., 1981), washed with stream water, and observed for types, color, and other obvious features. All observations were recorded in a field notebook. The organisms in the sieve were then transferred to a large wide mouth bottle, clearly labeled, and preserved with 70% ethanol. Samples were transported to the laboratory after all collections were completed.

In the laboratory, the samples were refrigerated until time of processing. For analysis, each sample was poured from its bottle into a U.S. Standard #35 sieve (500 µm mesh) which retained all organisms and debris collected in the field on the #30 sieve. The sample was washed with tap water and transferred to a 28 x 18 x 4 cm glass pan, approximately one-third full of water. Glass pans were used so that the background color could be changed to help sort the various colored organisms from the debris. Dark organisms are more distinct against a light background and light organisms are more distinct against the dark background. Each organism was carefully sorted by hand using a low-power scanning magnifier (2.5x) when necessary. Sorting of samples containing excessively large numbers of organisms was done by Weber's method of subsampling (Weber, 1973). Subsample quantity was recorded in a laboratory workbook. All organisms picked were divided into taxonomic categories as insect orders, worms, mollusks, etc., placed in vials with 70% ethanol, and carefully labeled. The organisms from all three subsites of each biosurvey site were combined at this point, making a composite sample of the three square feet (0.27 m^2) sampled.

Each organism removed from the samples was identified using a dissecting microscope and a compound, phase-contrast microscope where needed. Pennak's key (1978) was used for all identifications. The organisms were identified to genus except for the members of the Oligochaeta and Nematoda, which were not identified further. All organisms were counted as they were identified. All taxonomic identifications and the number of organisms in each taxon were recorded in the laboratory notebook. If there were any subsamples taken due to excessively large numbers of organisms in a sample, the fractions actually sorted were used to determine numbers of organisms in each taxon for the entire sample.

Quality Control

There are a number of fundamental criteria that provide the highest possible degree of accurate, consistent, and reproducible information for benthic sampling. The sampling sites, equipment, and methods were uniform to make the data comparable among sites. The samples were handled in a consistent manner; storage, isolation, identification and counting were done carefully every time. Identifications were made from the same key for all survey samples to provide uniformity and reproducibility among samples and sampling dates. Personnel conducting the benthic surveys were experienced and well trained in field and laboratory procedures. Academic background in appropriate fields was a definite asset for the identification procedures. Complete and accurate records both in the field and in the laboratory were essential to produce accurate, reproducible results. Frequent reviews of methodology and taxonomic illustrations were done by survey personnel to promote consistency, accuracy and reproducibility in all portions of the survey. The expertise available from the faculty of Colorado State University, Department of Zoology, was periodically called upon to aid identification of unknown or questionable organisms.

A Note on Taxonomy

Although careful and consistent records and identifications were made for the benthic macroinvertebrate surveys, new identification techniques, refinement of taxonomic identification, and continued monitoring of the Poudre River resulted in changes in some of the original identifications. A conservative approach was used in including these questionable taxa in the database used in the development of the index. Organisms that were identified as taxa that probably do not exist in the region (pers. comm., B. C. Kondratieff) were not used in the development of the biotic index. This difficulty associated with using the current database only underscores the need for suitable accurate regional species keys.

Diversity Analysis

Community diversity is one of the most common ways to describe the condition of a macroinvertebrate community. Community diversity is not only dependent on the number of taxa present in a sample, but on the relative abundance of the individuals within each taxon. Diversity has two components: (1) richness, or number of taxa present and (2) evenness, or the distribution of individuals among the taxa. A community with all taxa having nearly equal number of individuals in each taxon has a higher diversity than a community in which one or a few common taxa comprise a majority of the individuals. Community diversity can be increased by increasing the number of taxa or by evening out the distribution of individuals among the taxa.

Diversity indexes are the most common method of analyzing community diversity. The Shannon-Weaver diversity index, which integrates the richness and evenness components, was used to summarize the Poudre River macroinvertebrate data. The abundance values for all taxa were used in this analysis. Larger Shannon-Weaver values are indicative of greater community diversity. Although controversy exists over which diversity index is best suited to summarizing ecological data (Washington 1984), the Shannon-Weaver diversity index has been widely applied to ecological data and continues to be used as a data analysis tool (e.g., Reiners, 1992).

Shannon-Weaver diversity is calculated using the following formula:

$$D = C/N\ (N \log_{10} N - \sum n_i \log_{10} n_i)$$

where D = $\log_2$ mean diversity

C = 3.22 (converts $\log_{10}$ to $\log_2$)

N = total number of individuals

n_i = total number of individuals of the i^{th} taxa

Equitability (also called evenness) values were also calculated to compare the actual mean diversity values from this study to a hypothetical maximum mean diversity (i.e., the maximum potential diversity) developed from the broken stick model of MacArthur (Washington, 1984). These theoretical maximum diversity values are the maximum ecological diversity attainable. In essence, this index measures the "evenness" of distribution of individuals within a community. Because a community with a few, evenly distributed taxa may have the same diversity index as one with numerous, unevenly distributed taxa, it is desirable to extract the evenness component of diversity.

The following formula was used to calculate equitability:

$$E = S^1/S$$

Where: E = equitability

S = number of taxa in the sample

S^1 = a tabulated value from Weber (1973) determined from the actual mean diversity.

Ordination Analysis

Shannon-Weaver diversity compares sites based on both presence-absence data and the abundances of taxa, but it is limited to comparing (subjectively) one number at a time. Further multi-taxa analyses between sites were conducted with ordination techniques. Such multivariate statistics are ideal for handling large data sets in contemporary biomonitoring programs (Rosenberg and Resh, 1993). Ordination is a mathematical treatment that allows samples to be organized on a graph so those that are most similar, in both taxonomic composition and relative abundance, will appear closest together. It reduces a large, multi-dimensional data set into a low-dimensional (usually two or three) space.

The controversy over which ordination technique provides the best recovery of pattern from a data set has raged for years (e.g., Curtis and McIntosh 1951, Gauch, 1982; Kent and Ballard, 1988). Some ordination methods (e.g., principal components analysis-PCA) assume that variables change linearly along underlying gradients; whereas, many ecological factors (e.g., species' distributions) may have unimodal responses. This discrepancy between the statistical and community model may explain why PCA often distorts (or does not recover) intrinsic gradient patterns (Gauch, 1982; Minchin, 1987). The often poor results obtained with PCA has been noted in aquatic studies on macroinvertebrate distributional patterns (Leland et al., 1986).

Two ordination methods that have been used extensively in ecological studies are correspondence analysis (CA) and detrended correspondence analysis (DCA). CA (also called reciprocal averaging) and DCA are similar to principal component analysis (PCA), but do not assume linear responses for the variable. DCA is a supposed improvement over both PCA and CA. There is also controversy over DCA as a useful technique and its methods for correcting the assumed faults in CA (Wartenberg et al., 1987; Peet et al., 1988). One criticism of DCA is that the computer package DECORANA (Hill 1979) does not accomplish detrending in a mathematically elegant fashion (Peet et al. 1988). Ter Braak (1988) provides an alternative (detrending-by-polynomials) in the computer package CANOCO, which was used for this study. Gauch (1982) provides a lucid discussion of the techniques that have been employed by us to examine complex spatial distribution patterns of stream macroinvertebrates (Ward and Voelz, 1990, Voelz and Ward 1989, 1991).

Because very low abundance values can influence the DCA results, all DCAs were run on abundant taxa, arbitrarily defined as those taxa with abundances greater or equal to 30/3 Surber samples for at least one sampling period. Taxa listed in Appendix I that were also used in the in the spatial (downstream) trend DCAs are indicated with an asterisk. Subsets of these taxa, using the same abundance value criterion, were used for DCAs on within site variation over time. Abundances were log transformed to reduce the effects of extreme values. Samples that have low total numbers of organisms can obscure the results of the DCAs, so a few sampling periods at some sites were omitted from the analyses. DCAs are interpreted by examining the eigenvalues and the positions of the points (sampling periods) depicted on a graph. Eigenvalues are measures of the relative variation in a data set explained by each DCA axis, with the first DCA axis always explaining the most variation, the second axis the next most, and so on. Although subjective, these values provide a guide to the relative importance of each axis and aid in the overall interpretation of the data pattern. Within the confines imposed by the interpretation of the eigenvalues, points that are in close proximity in two-dimensional space (on a DCA graph) have similar taxonomic composition and abundance.

Results and Discussion

Taxonomic Composition of the Poudre River

Over 175 taxa (primarily genera) were collected in the study reach from 1981 to 1991. The majority of macroinvertebrates collected were insects. Most taxa were considered rare, when 11-year mean number per m^2 was examined. Besides Oligochaeta (segmented worms, not identified further), a few taxa were considered abundant (100-499 individuals/m^2) or very abundant (< 500/m^2) at many or all sites. These include: *Tricorythodes* (Ephemeroptera: Tricorythidae); *Cheumatopsyche* and *Hydropsyche* (Trichoptera: Hydropsychidae); *Simulium* (Diptera: Simuliidae); and *Cricotopus* and *Orthocladius* (Diptera: Chironomidae).

Information on environmental requirements and pollution tolerances for aquatic macroinvertebrates is sparse, especially in plains streams. Beck (1977), Harris and Lawrence (1978), Hubbard and Peters (1978), and Surdick and Gaufin (1978) published manuals covering the environmental requirements and pollution tolerances of the Chironomidae, Trichoptera, Ephemeroptera, and Plecoptera respectively. Many of the common taxa found in the Poudre River generally occur in waters that have high oxygen content, low to moderate nutrient concentrations and have low to moderate organic enrichment (e.g., most of the Plecoptera, *Baetis* spp., and *Tricorythodes*).

Species List and its Rationale

Abundance data for many of the taxa collected from 1981 to 1991 were not used in the development of the index. Organisms previously identified to the generic level that were not likely to be found in the study reach (Kondratieff, pers. comm.) were removed from the species list prior to combining it with the physicochemical database. Specimens that had post-identification name changes were also not included in the data analysis. For a complete list of the taxa used in the development of the index see Appendix I.

Although the organisms collected from 1981 to 1991 at the ten sites along the Cache la Poudre River were only identified to genus, species level designations are possible in many cases using lists for Nearctic, Rocky Mountain, or Colorado species. Baumann et al. (1977) and Stark et al. (1986) were used as references for enumeration of the Plecoptera species from the generic level database. McCafferty et al. (1993) was used as a reference to enumerate the Ephemeroptera species from the generic level database. Herrmann et al. (1986) was used as a reference to enumerate the caddisfly species from the generic level database. Evans (1988) was used for the enumeration of Odonate species from the generic level database. Ward and Kondratieff (1992) was also used as a reference to determine locally common species of insects. Boris C. Kondratieff of Colorado State University was also consulted to compile the likely species list for the insects. Kenk (1976) and Pennak (1978) were used as references for the enumeration of the triclad species in the study reach. Klemm (1982) was used for the enumeration of the leeches at the species level.

The following brief ecological profiles and other information that might be considered important in any sort of qualitative evaluation of stream condition are provided at the generic or species level for the more common organisms and at higher levels of taxonomic resolution for the other groups.

PLATYHELMINTHES (flat worms)

Planarians played a certain role in the biological assessment of water quality in Europe, but no native species is common to both continents (Kenk, 1976). Some species have been found to be very sensitive to organic and inorganic pollution of their habitats while others tolerate mild degrees of pollution. In general, planarians are intolerant of heavy metal salts (Kenk, 1976). Gas exchange in flatworms occurs through the body wall and is therefore dependent on their surface to volume ratio. This inefficient system gives them little adaptability to low oxygen conditions (Kolasa, 1991). Triclads are negatively phototactic; they clearly avoid light.

Pennak (1978) and Kenk (1976) list *Dugesia dorotocephala* and *D. trigrina* as very common and widespread. Other North American members of the genus *Dugesia* occur in specific localities far outside the study reach (Pennak, 1978; Kenk, 1976), so only *D. dorotocephala* and *D. trigrina* will be included in the species list.

ANNELIDA

HIRUDINEA (leeches)

Leeches show considerable physiological plasticity and some have been known to survive for extended periods in the absence of oxygen (Davies, 1991); however they do not appear to tolerate highly acidic conditions or decomposition gases at low oxygen concentrations (Pennak, 1978). They require substrates on which they can adhere, so they are uncommon in freshwaters with pure mud or clay bottoms (Pennak, 1978). Members of the Erpobdellidae and Glossiphoniidae may be collected from swift streams and they have been shown to tolerate some degree of pollution (Pennak, 1978). Leeches have been known to disperse by temporarily attaching themselves to fish or ducks and migrating to other bodies of water (Pennak, 1978).

Erpobdellidae

Klemm (1982) lists only two species of *Erpobdella* from North America, but only *Erpobdella punctata punctata* has been reported from Colorado.

Glossiphoniidae

Glossiphonia complanata is the only member of the genus *Glossiphonia* listed by Klemm (1982) for North America.

Klemm (1982) lists a total of 6 species of *Helobdella* from North America. Only *Helobdella elongata, H. fusca, H. stagnalis* have been collected in Colorado (Klemm, 1982).

Klemm (1982) lists a total of 9 species of *Placobdella* from North America. Only *Placobdella ornata* and *P. parasitica* have been reported from Colorado (Klemm, 1982).

Hirudinidae

Klemm (1982) reports *Macrobdella decora* as the only member of the genus *Macrobdella* to be collected from Colorado.

OLIGOCHAETA (aquatic earthworms)

They are common in the mud and debris of the substrate of pools, ponds, streams, and lakes everywhere. Most of the truly aquatic species are able to thrive at low concentrations of dissolved oxygen; *Tubifex tubifex* is considered to be an indicator of organic pollution especially when the water is between 10 and 60 percent saturated with oxygen (Pennak, 1978). Taxonomy of the oligochaetes is difficult and often relies on the details of their internal anatomy so they are not identified further.

MOLLUSCA -- Subclass Pulmonata (lung-breathing snails)

Brown (1991) describes these ubiquitous snails as detritivores, feeding on the periphyton covering macrophytes or cobble. Members of the subclass Prosobranchia are common in fast flowing streams and are termed "oxy-conformers" by Brown (1991). Members of the subclass Pulmonata can withstand greater variations in dissolved oxygen than prosobranchs. Hardness and pH have been proposed as major limiting factors in the distribution of freshwater snails; approximately 45 percent of all freshwater gastropods are restricted to waters with greater than 25 mg/liter calcium, and 95 percent are restricted to waters with greater than 3 mg/liter calcium. The distribution of gastropods is also heavily determined by predation pressure; most pulmonates should occur in macrophyte beds, but the thicker-shelled *Helisoma* may be found in sandy areas.

The following is a list of the genera used in the development of the index along with their family designations:

Physa sp. (Gastropoda: Physidae)

Ferrissia sp. (Gastropoda: Ancylidae)

Lymnaea sp. (Gastropoda: Lymnaeidae)

Gyraulus sp. (Gastropoda: Planorbidae)

Helisoma sp. (Gastropoda: Planorbidae)

CRUSTACEA -- superorder Peracarida

Most amphipods (scuds) and isopods (aquatic sowbugs) are restricted to relatively constant, cold waters where they avoid bright light, by moving into the current and into crevices or under leaves and roots (Covich and Thorp, 1991). Amphipods and isopods generally remain in the same locality for extended periods and have limited ability to move upstream against the current, but have been known to drift downstream under specific ecological conditions. This characteristic of amphipods and isopods may give them a utility as an indicator of the maximum downstream reach of low frequency environmental perturbations. Calcification of the carapace immediately following molting is sensitive to low pH and there is evidence that lotic species have a narrower range of tolerance to low pH; low pH habitats may exclude them. Groundwater habitats have also been considered not only as refugia from environmental extremes, but a possible avenue to circumnavigate migration barriers such as swift current or intermittent streams (Stanford and Ward, 1988; Covich and Thorp, 1991). Isopods are often characteristic of organically polluted waters (Brown, 1976).

Isopoda

Asellus communis (Isopoda: Asellidae) is the only member of the genus *Asellus* to be reported from Colorado (Williams, 1976). The genus *Asellus* has recently been changed to *Caecidotea.*

Amphipoda

Gammarus lacustris (Amphipoda: Gammaridae) is the only member of the Gammaridae to occur in the study reach (Holsinger, 1976).

Hyalella azteca (Amphipoda: Hyalellidae) is the only species of *Hyalella* known to occur in the study reach, but is present from Canada to South America in the littoral zone of glacial lakes, small ponds, and streams; *Hyalella azteca* has also been collected from warm springs (Covich and Thorp, 1991).

PLECOPTERA (stoneflies)

Baumann (1979) feels that the Plecoptera are perhaps the best indicators of environmental quality at the generic level. No Plecoptera were collected beyond site 6(4) and most were not collected beyond site 2. Most Plecoptera occur in cold lotic habitats (Baumann, 1979; Ward and Kondratieff, 1992), but many Capniidae, Taeniopterygidae and Perlidae show a tendency toward tolerance of warmer lotic habitats (Baumann, 1979).

Taeniopterygidae

Taenionema nigripenne and *T. pacificum* have both been collected from Larimer County, Colorado (Baumann et al., 1977), but Kondratieff (pers. comm.) has said that *Taenionema nigripenne* and *T. pallidum* are the two species of *Taenionema* likely to occur within the study reach. All three species have been collected from Colorado streams (Baumann et al., 1977; Stark et al., 1986).

Capniidae

Capnia barbata, C. confusa, and *C. decepta* have all been collected from Larimer County, Colorado (Baumann et al., 1977), but Kondratieff (pers. comm.) has said that *Capnia confusa* and *C. gracilaria* are the two species of *Capnia* most likely to occur within the study reach. *Capnia confusa* has been collected from the Cache la Poudre River (Stark et al., 1973a). All four species have been collected from Colorado (Baumann et al., 1977; Stark et al., 1986).

Perlidae

Claassenia sabulosa is the only species within the genus *Claassenia* that is known to occur in the Nearctic. It has been collected from Colorado (Stark et al., 1986) and Larimer County, Colorado (Baumann et al., 1977).

Hesperoperla pacifica is the only member of the genus *Hesperoperla* to be collected from Colorado (Stark et al., 1986) and it has been reported from Larimer County, Colorado (Baumann et al., 1977).

Perlodidae

Cultus aestivalis is listed by Stark et al. (1986) as the only member of the genus to be collected in Colorado. Baumann et al. (1977) do not list *C. aestivalis* as an inhabitant of Larimer County, Colorado, but they do list *C. pilatus* as an additional member of the Colorado fauna that was collected from Larimer County.

Skwala americana is listed as *Skwala parallela* by Baumann et al. (1977) and is the only member of the genus to be reported from Colorado (Baumann et al., 1977; Stark et al., 1986).

Isoperla bilineata, I. fulva, I. jewetti, I. longiseta, I. mormona, I. petersoni, I. phalarata, I. pinta, I. quinquepunctata, and *I. sobria* have all been collected within Colorado (Baumann et al., 1977; Stark et al., 1986), but *Isoperla fulva* and *I. quinquepunctata* are the only members of the genus documented as collected from Larimer County, Colorado (Baumann et al., 1977). Kondratieff (pers. comm.) has said that *Isoperla fulva* and *I. quinquepunctata* are the only members of the genus likely to occur within the study reach.

Chloroperlidae

Alloperla pilosa and *A. severa* are the only members of the genus collected from Colorado (Baumann et al., 1977; Stark et al., 1986), but *Alloperla pilosa* is the only member of the genus collected from Larimer County, Colorado (Baumann et al., 1977) and that is likely to occur within the study reach (Kondratieff, pers. comm.).

EPHEMEROPTERA (mayflies)

Siphlonuridae

Although *Ameletus aequivocus, A. celer, A. sparsatus, A. subnotatus, A. validus,* and *A. velox* have all been collected within Larimer County, Colorado, only *A. subnotatus* has been collected from within the Cache la Poudre River (McCafferty et al., 1993) and is said to be the only likely species to occur within the study reach (Kondratieff, pers, comm.).

Baetidae

Although *Baetis bicaudatus, B. flavistriga, B. magnus,* and *B. tricaudatus* have all been collected in Larimer County, Colorado (McCafferty et al., 1993), *B. flavistriga* and *B. tricaudatus* are said to be the only species likely to occur within the study reach (Kondratieff, pers. comm.). Merritt and Cummins (1984) describe the widespread genus *Baetis* (Ephemeroptera: Baetidae) as swimmers, climbers and clingers inhabiting both erosional and depositional lotic reaches. Trophically they are collector-gatherers, consuming detritus and diatoms, or scrapers. Collectively *Baetis* occupies an extremely wide range of lotic habitats (Ward and Kondratieff, 1992).

Heptageniidae

The genus *Epeorus,* also known as the genus *Iron,* contains three Colorado species: *Epeorus albertae, E. deceptivus* and *E. longimanus* all of which have been reported from Larimer County, Colorado (McCafferty et al., 1993). *Epeorus deceptivus* and *E. longimanus* are the only species likely to occur within the study reach (Kondratieff, pers. comm.).

Although *Heptagenia diabasia, H. elegantula, H. solitaria* have all been collected within Larimer County, Colorado (McCafferty et al., 1993), *H. diabasia* and *H. elongata* are the only species likely to occur within the study reach (Kondratieff, pers. comm.).

Rhithrogena hageni, R. robusta, and *R. undulata* have all been collected from within Larimer County, Colorado (McCafferty et al., 1993), but *Rhithrogena hageni* is the only species likely to be collected from within the study reach (Kondratieff, pers. comm.). *Rhithrogena hageni* was identified by Nelson and Roline (1993) as an organisms that was intolerant of conditions caused by mine drainage in the Arkansas River, Colorado.

Ephemerellidae

Although *Drunella coloradensis, D. doddsi,* and *D. grandis* have all been collected within Larimer County, Colorado (McCafferty et al., 1993), only *Drunella doddsi* and *D. grandis* are likely to occur within the study reach (Kondratieff, pers. comm.). Environmental profiles of both *D. doddsi* (Mangum and Winget, 1991) and *D. grandis* (Mangum and Winget, 1993) have recently been published.

Although *Ephemerella inermis* and *Ephemerella infrequens* have both been said to be collected from Colorado and Larimer County, they are difficult to distinguish and the accuracy of the identification of specimens collected in the past is in doubt (McCafferty et al., 1993). B. C. Kondratieff (pers. comm.) has said that *Ephemerella inermis* is the only species likely to be collected within the study reach. Merritt and Cummins (1984) describe the widespread genus *Ephemerella* as primarily a clinging genus with a few swimmers inhabiting both erosional and depositional lotic reaches. Trophically, members of the genus are collector-gatherers and scrapers.

Tricorythidae

Tricorythodes minutus is the only species within the family Tricorythidae known to occur within the study reach (McCafferty et al., 1993). Winget and Mangum (1991) published an environmental profile of *Tricorythodes minutus*. Merritt and Cummins (1984) describe the widespread genus *Tricorythodes* as sprawlers and clingers inhabiting the depositional reaches of lotic habitats. Trophically they are collector-gatherers. They are associated with beds of aquatic plants or other habitats were silt tends to accumulate with their opercular gills protecting the remaining gills from silt deposition (Ward and Kondratieff, 1992).

Leptophlebiidae

Choroterpes inornata is the only species in the genus *Choroterpes* known to occur within the study reach (McCafferty et al., 1993).

Leptophlebia cupida is the only species in the genus *Leptophlebia* known to occur within the study reach (McCafferty et al., 1993).

Paraleptophlebia heteronea and *P. debilis* have both been collected within Larimer County, Colorado, (McCafferty et al., 1993), but *Paraleptophlebia heteronea* is the only species likely to occur within the study reach (Kondratieff, pers. comm.).

Polymitarcyidae

Ephoron album is the only species in the family Polymitarcyidae known to occur within the study reach (McCafferty et al., 1993).

TRICHOPTERA (caddisflies)

The attainment of oxygen by caddisflies is limited to what can be absorbed through the body wall or gills and these are usually covered by some sort of a case, consequently they are typically only found in habitats with a good supply of oxygen. The larvae often undulate inside their cases to increase the flow of water and dissolved oxygen over their bodies.

Psychomyiidae

Psychomyia flavida is the only species in the family Psychomyiidae to be collected in Colorado (Herrmann et al., 1986).

Polycentropodidae

Polycentropus cinereus is the only species in the genus *Polycentropus* reported from Larimer County, Colorado (Herrmann et al., 1986).

Hydropsychidae

Arctopsyche grandis is the only species in the genus *Arctopsyche* to be collected in Colorado; it has only been documented in Larimer County, but not Weld County (Herrmann et al., 1986).

Although *Cheumatopsyche gracilis* was originally collected in Fort Collins by Banks in 1899, it is not common in Colorado. *C. pettiti* is the only other species of *Cheumatopsyche* that has been found in Larimer or Weld County, Colorado (Herrmann et al., 1986). Merritt and Cummins (1984) describe the widespread genus *Cheumatopsyche* as net-spinning clingers that build nets and fixed retreats attached to surfaces in riffles. They are said to prefer running water and riffles especially in warmer streams and rivers. Trophically they are collectors, filtering the water for algae, detritus, and small animals.

Hydropsyche cockerelli, H. occidentalis and *H. oslari* have been collected in Larimer County, but only *Hydropsyche occidentalis* has been collected in both Larimer and Weld Counties (Herrmann et al., 1986). Merritt and Cummins (1984) describe the widespread genus *Hydropsyche* (Trichoptera: Hydropsychidae) as net-spinning clingers that build nets and fixed retreats attached to surfaces in riffles. They are said to prefer running water and riffles especially in warmer streams and rivers. Trophically they are collectors, filtering the water for diatoms, algae, detritus, and animals.

Rhyacophilidae

Although *Rhyacophila angelita, R. brunnea, R. coloradensis, R. hyalinata, R. pellisa,* and *R. rotunda* have all been reported from Larimer County, Colorado (Herrmann et al., 1986), B. C. Kondratieff (pers. comm.) has said that only *Rhyacophila brunnea* and *R. coloradensis* are likely to occur within the study reach.

Hydroptilidae

Although *Hydroptila arctia, H. consimilis, H. icona, H. pecos, H. rono* have all been collected in Larimer County, Colorado (Herrmann et al., 1986), B. C. Kondratieff (pers. comm.) has said that *Hydroptila pecos* is the only species of *Hydroptila* to occur within the study reach.

Brachycentridae

Brachycentrus americanus and *B. occidentalis* are the only species of *Brachycentrus* collected from Colorado and both have also been collected in Larimer County, Colorado (Herrmann et al., 1986).

Lepidostomatidae

Although *Lepidostoma ormea, L. pluviale, L. roafi, L. unicolor,* and *L. veleda* have all been collected in Larimer County, Colorado (Herrmann et al., 1986), B. C. Kondratieff (pers. comm.) has said that *L. ormea* is the only species of *Lepidostoma* likely to occur in the study reach.

Limnephilidae

Although *Hesperophylax designatus, H. magnus,* and *H. occidentalis* have all been collected in Larimer County, Colorado (Herrmann et al., 1986), *H. occidentalis* is the only species of *Hesperophylax* likely to occur in the study reach (B. C. Kondratieff, pers. comm.).

Helicopsychidae

Helicopsyche borealis is the only species in the family Helicopsychidae known to occur in Colorado (Herrmann et al., 1986).

Leptoceridae

Although *Nectopsyche lahontanensis* and *N. stigmatica* have both been collected in Larimer County, Colorado, *N. stigmatica* is the only species of *Nectopsyche* likely to occur within the study reach (Kondratieff, pers. comm.). Merritt and Cummins (1984) describe the widespread genus *Nectopsyche* as adapted for living on vascular hydrophytes or detrital debris with modification for moving vertically on stem-type surfaces. Their case is usually long and slender, constructed of mineral and vegetation pieces, and may have balance sticks. They are said to be found in both lentic and lotic habitats, but in both cases they are associated with vascular hydrophytes. They are found in both erosional and depositional reaches of streams. Trophically, they are shredders, consuming live macrophyte tissue and coarse organic detritus. Members have also been shown to be predators, engulfing whole animals or parts. They are warm adapted and normally only occur in the slow-flowing lower reaches of mountain streams, and are often associated with beds of aquatic plants (Ward and Kondratieff, 1992).

COLEOPTERA (water beetles)

Dytiscidae

The presence of clean substrate and aquatic vegetation seem to be a requirement of the dytiscids; few species occur on muddy bottoms or in rapid water (Pennak, 1978). Dytiscids are independent of the dissolved oxygen in the stream; they renew the oxygen in their tracheae and subelytral chamber with atmospheric oxygen, but they are included in the development of the index, if not for the dissolved oxygen determination, than for the other parameters.

Agabus is the only genus in the family likely to be found in the study reach (B. C. Kondratieff, pers. comm.).

Elmidae

Most adult elmids, once they return to the water, will never again emerge into the air; they will spend the rest of their lives under water (Brown, 1976). These beetles, unlike other atmospheric oxygen breathing forms, should be included in the development of an index.

Heterlimnius corpulentus is the only species in the genus *Heterlimnius* found in Colorado (Ward and Kondratieff, 1992; Brown, 1976).

Optioservus castanipennis, O. divergens, O. quadrimaculatus, O. seriatus are the only *Optioservus* species listed by White (1978) to occur in the study area.

Zaitzevia parvula is the only species in the genus *Zaitzevia* found in Colorado (Ward and Kondratieff, 1992).

LEPIDOPTERA (aquatic moths)

Pyralidae

Petrophila avernalis is a common inhabitant of the Cache la Poudre river and its larger tributaries (Ward and Kondratieff, 1992). The larvae can be found under their silk canopies on the surface of rocks from which they are feeding in rapid sections of streams.

HEMIPTERA (water bugs)

Members of the order Hemiptera can live independent of the dissolved oxygen in the water, so they are not typically included in the development of biotic indexes, but the Corixidae, unlike some of the surface dwelling Hemiptera, spend a large portion of their lives in the water, so they are included here.

Corixidae

Although they are primarily lentic forms, *Sigara alternata* and *S. grossolineata*, are also able to reside in lotic habitats (Ward and Kondratieff, 1992).

No local species distributional information was found for species of *Trichocorixa*.

ODONATA (dragonflies)

Gomphidae

Larvae in the Gomphidae, being wholly aquatic and having life cycles spanning 2-4 years, may act as excellent integrators of long-term change/stability in a system.

Ophiogomphus severus is the only member of the genus to be reported from Colorado (Evans, 1988). Ward and Kondratieff (1992) describe *Ophiogomphus severus* as the only member of the order Odonata known to occur in high-gradient mountain streams of Colorado, but additional members of the order can be found in riverine reaches and in special habitats such as springbrooks (Ward and Kondratieff, 1992).

Coenagrionidae

Argia vivida is the only species in the genus *Argia* to be reported from Larimer County, Colorado, but *Argia sedula, A. violacea,* and *Argia vivida* have been reported from Weld County, Colorado (Evans, 1988).

DIPTERA (two-winged flies)

Tipulidae (crane flies)

No suitable species keys are available for larval tipulids (Ward and Kondratieff (1992).

Antocha is one of the few genera in the Tipulidae that is considered truly aquatic since it lacks spiracles (Merritt and Cummins, 1984). It is found clinging in a silk tube to rocks or logs in fast water (Merritt and Cummins, 1984). Merritt and Cummins (1984) also list this organism as preferring well oxygenated water.

Hexatoma is described by Merritt and Cummins (1984) to be an inhabitant of the sand and gravel near the margins of clear, cool brooks and stream.

Tipula is trophically considered a shredder and is found burrowing in the detritus in both erosional and depositional reaches of streams (Merritt and Cummins, 1984)

Simuliidae (black flies)

Simulium articum and *S. vittatum* are the two species in the genus Simulium likely to be found in the study reach (Kondratieff, pers. comm.) Merritt and Cummins (1984) describe the widespread genus *Simulium* (Diptera: Simuliidae) as adapted for attachment to surfaces in stream riffles. Trophically they are collectors, filtering suspended fine particulate organic matter from the water column. In Colorado, *Prosimulium* extends to higher elevations than *Simulium*; *Simulium* is more common in streams at middle to lower elevations (Ward and Kondratieff, 1992).

Chironomidae (midges)

Chironomids, as stated in Merritt and Cummins (1984), occupy "almost the complete range of gradients of temperature, pH, salinity, oxygen concentration, current velocity, depth, productivity, altitude, latitude. . ." Identification of chironomid larvae, even to the genus level, is difficult to say the least, so they will only be included in the index at that level.

Chironomus sp. -- Merritt and Cummins (1984) describe the widespread genus *Chironomus* as tube building burrowers inhabiting the depositional reaches of streams. As collectors, they consume detritus from surfaces or filter it from the water column. As shredders they consume living macrophytes.

Cricotopus sp. -- Merritt and Cummins (1984) describe the widespread genus *Cricotopus* as tube building clingers or burrowers. Some of the first instars may be planktonic. They can be found in both the erosional and depositional reaches of streams. Trophically they are either shredders or collectors, burrowing into live plants and consuming coarse organic detritus or gathering detritus and algae from the water column.

Eukiefferiella sp. -- Merritt and Cummins (1984) describe the widespread genus *Eukiefferiella* as sprawlers, inhabiting erosional reaches of streams. Trophically they are collectors, but have been known to prey on chironomid eggs and larvae.

Orthocladius sp. -- Merritt and Cummins (1984) describe the widespread genus *Orthocladius* as sprawlers, inhabiting the surface of the floating leaves of vascular leaves of vascular hydrophytes or fine sediments or burrowers, inhabiting the fine sediments of pools in streams. The are found in the erosional reaches of streams. Trophically they are collectors, gathering detritus, diatoms, and filamentous algae.

Polypedilum sp. -- Merritt and Cummins (1984) describe the widespread genus *Polypedilum* as climbers or clingers that inhabit lentic waters living among the vascular hydrophytes. Trophically the genus is very diverse with shredders, collectors and predators being known.

Tanytarsus sp. -- Merritt and Cummins (1984) describe the widespread genus *Tanytarsus* as tube building climbers or clingers that inhabit the erosional reaches of lotic habitats with some of the first instar larvae being planktonic. Trophically they typically are collectors, filtering and gathering fine particulate organic matter as food, but some members of the genus are also scrapers.

Stratiomyidae (soldier flies)

Odontomyia is the only genus likely to occur within the study reach and no suitable species keys exist (Ward and Kondratieff, 1992)

Athericidae

Atherix pachypus is the only species in the family known in the West and in Colorado (Ward and Kondratieff, 1992).

Muscidae

Limnophora aequifrons is the only member of the family known to occur in Colorado mountain streams (Ward and Kondratieff, 1992) and is the only species likely to be found within the study reach (B. C. Kondratieff, pers. comm.)

Responses of Common Taxa

Average yearly abundances of the most common taxa that were also used in the development of the biotic index are shown in Figure 3a-f. Brief profiles of these taxa are included below:

Abundances of the mayfly *Tricorythodes* (Ephemeroptera: Tricorythidae) were generally highest in 1981-1982 and during the latter part of this study at sites 2 through 7(5) (Figure 3a). Low abundances of *Tricorythodes* were observed in 1983-1984 at all sites, corresponding to the high flow events that occurred during those years. *Tricorythodes* is relatively common in plains sections of Colorado streams (e.g. Ward, 1986) and is apparently well adapted for streams that can have large sediment loads, because their first pair of respiratory gills are enlarged and provide a protective covering for their other gills (Gammon 1970, Gray and Ward 1982). This presumably shields the gills from fouling by sediments. However, they are not well adapted for current and may be adversely affected by large flows. Densities of *Tricorythodes* were greatly diminished by flood events in a desert stream (Gray, 1981).

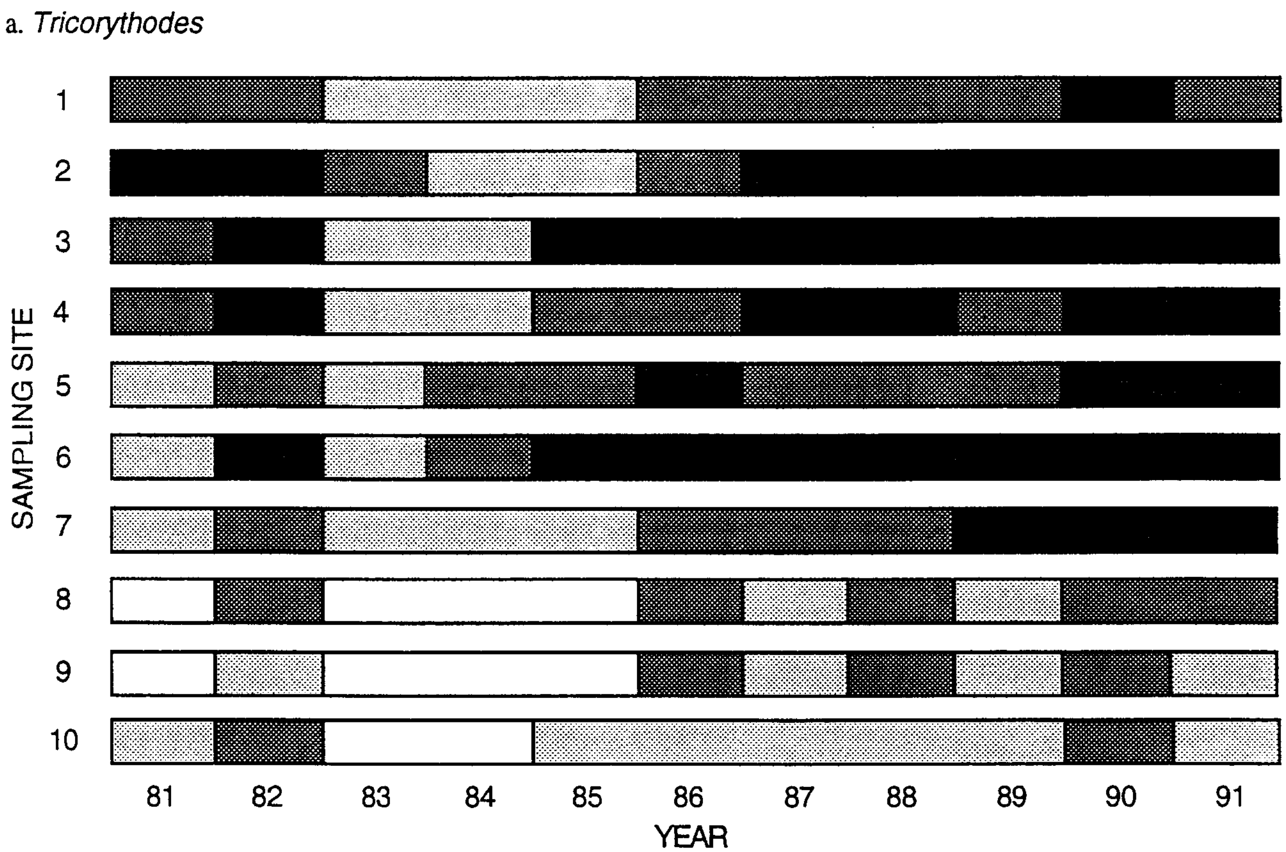
Densities of the filter-feeding caddisfly *Cheumatopsyche* (Trichoptera: Hydropsychidae) were often highest at sites 5(3)-9(7) and usually low across sites in 1983 and 1984 (Figure 3b). *Hydropsyche* (Trichoptera: Hydropsychidae), which is closely related to *Cheumatopsyche*, exhibited a different abundance pattern during the study. Highest densities were observed primarily in the middle years with noticeable declines in 1988 and/or 1989 (Figure 3c). *Hydropsyche* abundances were usually low at site 10(8). Neither *Cheumatopsyche* nor *Hydropsyche* were found at site 2 in 1991. These caddisflies build fixed retreats of organic and mineral fragments, which are firmly affixed to various hard substrates found in streams and presumably shelter them from the adverse affects of high flows. *Cheumatopsyche* densities were low at some (but not all) sites during 1983-1984, indicating either a differential susceptibility to the high flows (perhaps due to among site substrate differences) or a normal population cycle minimum.

The abundances of filter-feeding black flies, *Simulium* (Diptera: Simuliidae), were high in most years (except 1983-1984) at sites 3-10(8) (Figure 3d). Overall lowest densities were observed at sites 1(1) and 2. *Simulium* use a combination of hooks and silk for attachment to stream substrate. They are typically found in areas of high current.

The chironomids, *Cricotopus* and *Orthocladius* (Diptera: Chironomidae) exhibited a variety of density patterns during 1981 to 1991. *Cricotopus* was consistently the most abundant taxon at many sites, particularly in the latter part of the study (Figure 3e). The densities of *Orthocladius* were relatively high during 1985 to 1991, except at site 3, where the lowest abundances were often observed from 1981 to 1991 (Figure 3f). The chironomids are a difficult taxonomic group and relatively little is known of their ecology. In general, most chironomids live among the stream bottom sediments where they are well protected from the dislodging influence of current (Merritt and Cummins, 1984).

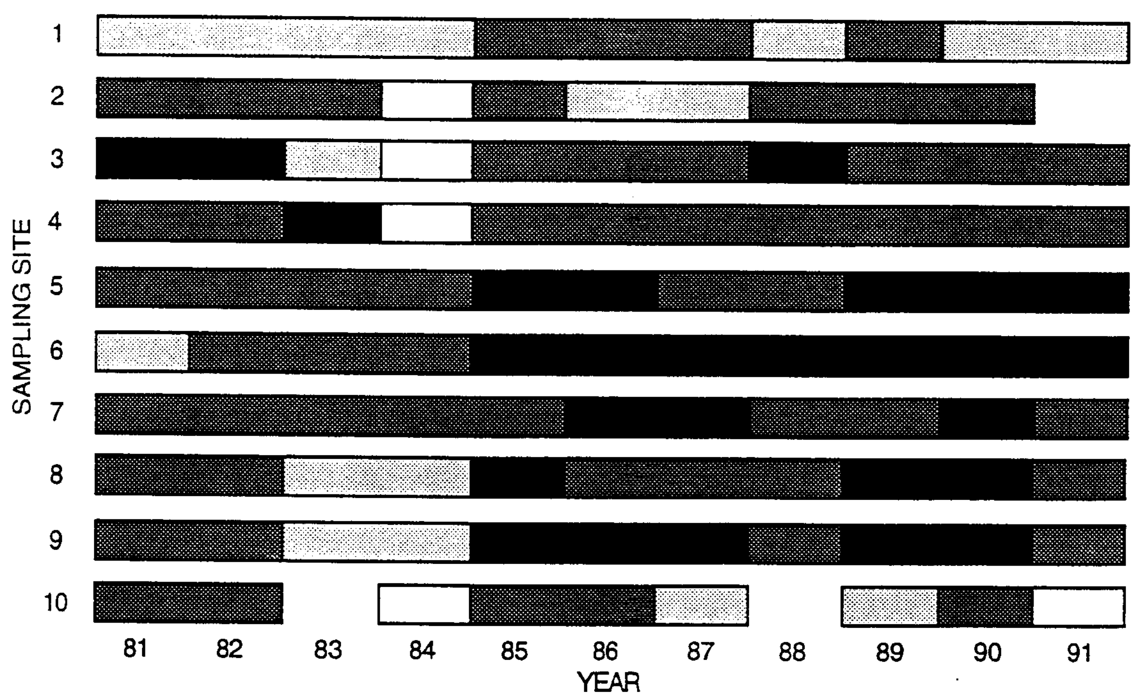
Many taxa were absent from site 2 during some years. Five of the eight predominant taxa were not observed at site 2 during 1991. All of these taxa were present in the new 1992 data; however, this is a trend that should be closely monitored. At the other sites, the predominant taxa exhibited a variety of abundance patterns, but no clear density declines were observed other than in 1983-1984. That many of these taxa were found at similar (or greater) numbers at the beginning and end of the study suggests that the water quality of the river has not changed drastically.

Figure 3a. Average yearly abundances for *Tricorythodes* at all sites on the Cache la Poudre River. Abundance codes are ▭ ≤ 10; ▭ 11-99; ▩ 100-499; ■ ≥ 500 per m^2. Blank spaces indicate no individuals of that taxon were found.

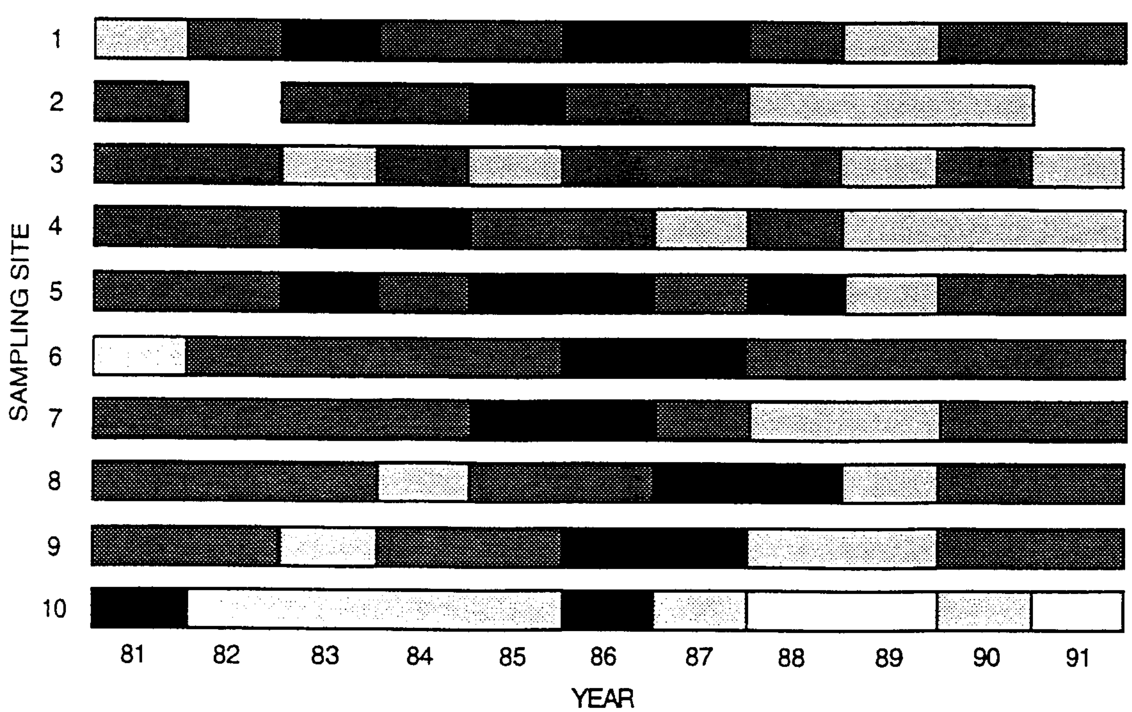


Figures 3b and 3c. Average yearly abundances for *Cheumatopsyche* and *Hydropsyche* at all sites on the Cache la Poudre River. Abundance codes are ☐ ≤ 10; ▒ 11-99; ▓ 100-499; ■ ≥ 500 per m^2. Blank spaces indicate no individuals of that taxon were found.

b. *Cheumatopsyche*

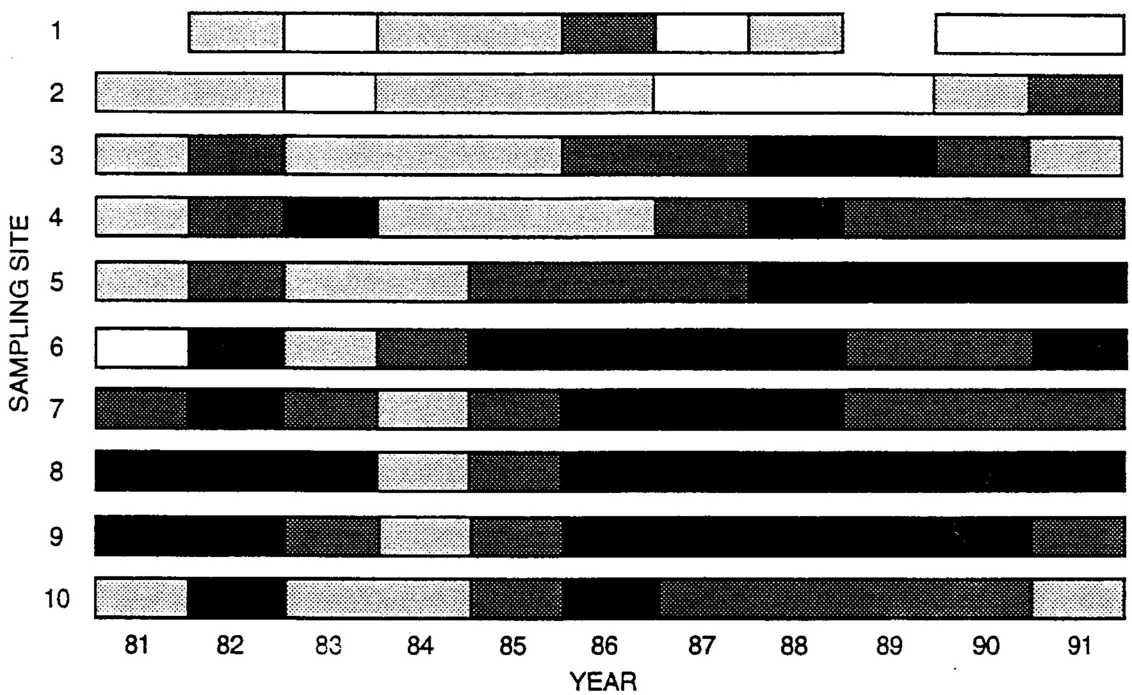


c. *Hydropsyche*



Figures 3d and 3e. Average yearly abundances for *Simulium* and *Cricotopus* at all sites on the Cache la Poudre River. Abundance codes are ☐ ≤ 10; ☐ 11-99; ▒ 100-499; ■ ≥ 500 per m^2. Blank spaces indicate no individuals of that taxon were found.

d. *Simulium*



e. *Cricotopus*

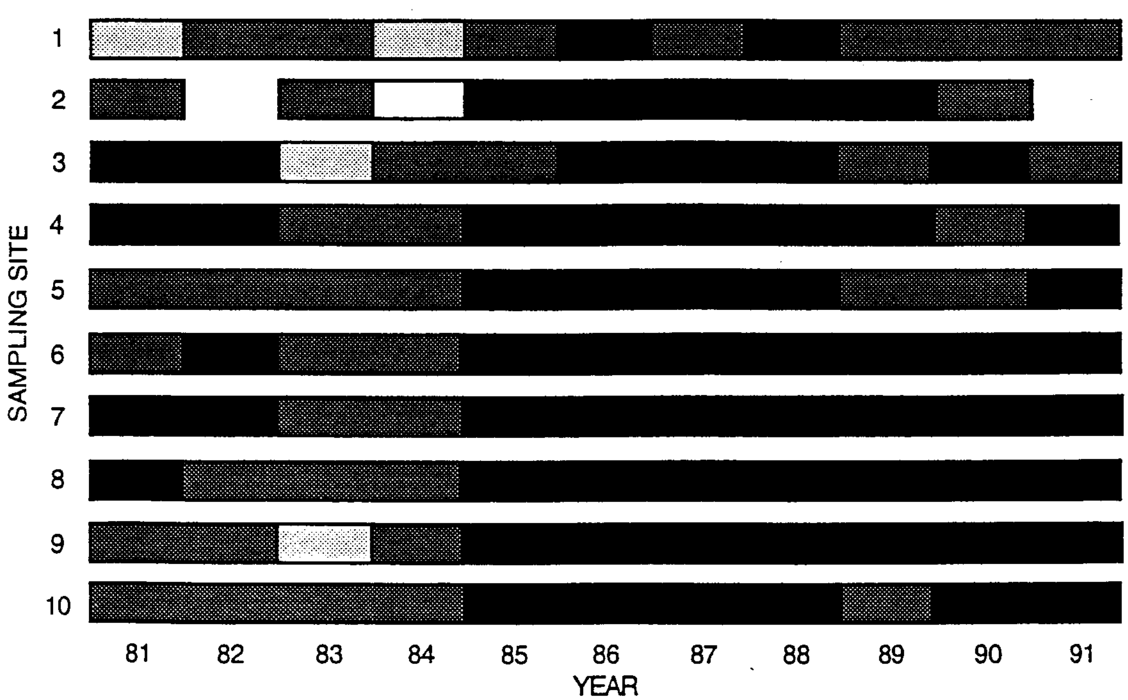
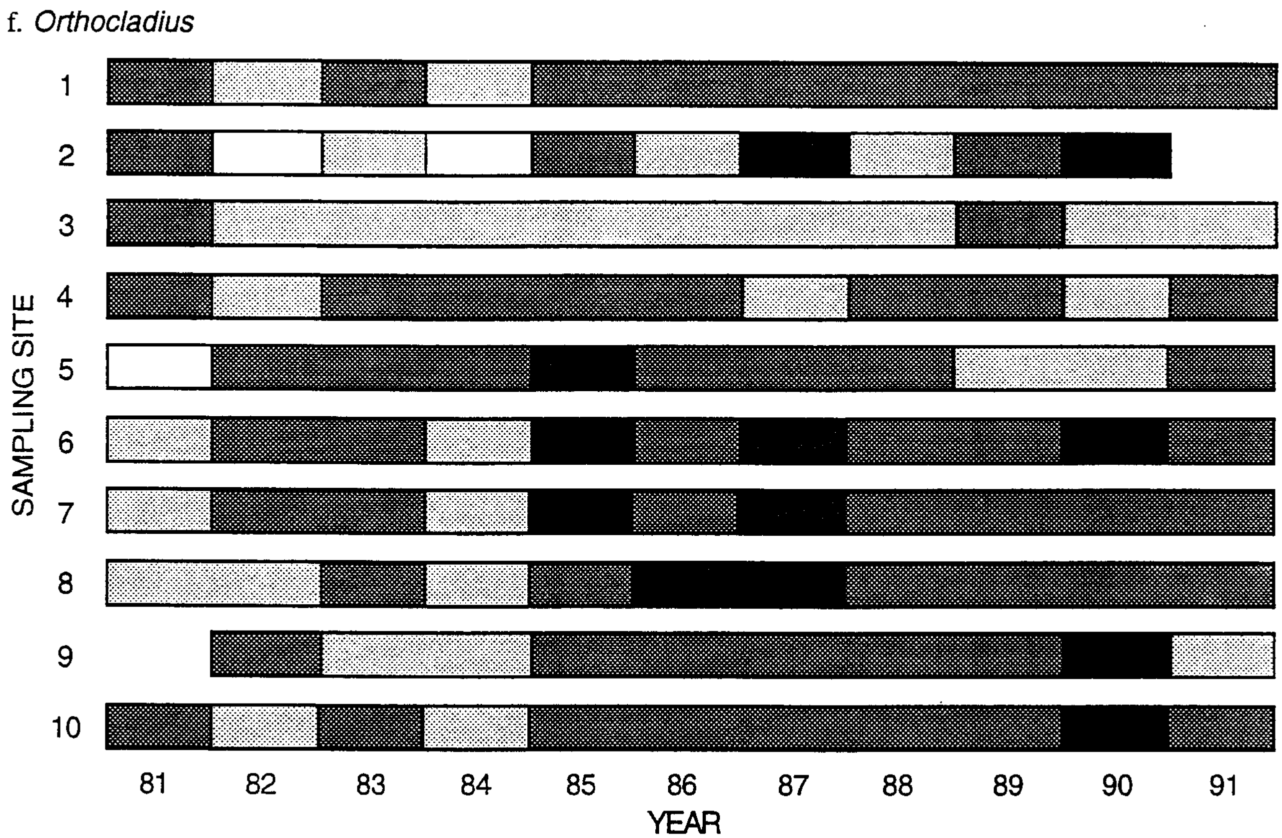


Figure 3f. Average yearly abundances for *Orthocladius* at all sites on the Cache la Poudre River. Abundance codes are ☐ ≤ 10; ▒ 11-99; ▓ 100-499; ■ ≥ 500 per m^2. Blank spaces indicate no individuals of that taxon were found.



Longitudinal Trends 1981-1991

An examination of longitudinal patterns among years is needed to understand the overall changes observed in the river. Mean number of taxa generally showed a steep decline between sites 1(1) and 2 for all years (Figures 4a-c), then increased at site 3 (though remaining lower than observed at site 1(1)). Downstream of site 3, the mean number of taxa either decreased slightly in some years or remained at levels similar to those at site 3. The overall pattern is similar among years.

The long-term longitudinal trends for mean number of individuals (Figures 5a-c) were less consistent than those for mean number of taxa. From 1981-1984 and 1989-1991, there was a general increase in total numbers downstream, except for a precipitous decline between sites 2 and 3 in 1983. In 1985-1988, there was an increase in total numbers from sites 1(1)-6(4), with a decrease farther downstream.

Median Shannon-Weaver diversity generally declined downstream (Figures 6a-c), except in 1983 and 1984 when diversity values declined from sites 1(1)-4(2), then increased slightly downstream from site 4(2). There was always a distinct drop in diversity between sites 1(1) and 2. Median diversity values were lowest in 1981 across sites. However the overall longitudinal diversity pattern fluctuated within similar limits for the 11-year period.

In order to facilitate the interpretation of the detrended correspondence analysis (DCA) on the longitudinal (downstream) distribution of macroinvertebrates in the Poudre River, we present the results from another study where a clear longitudinal change in macroinvertebrates occurred. Figure 7 represents a DCA from a study that was conducted on the Colorado River below Granby Reservoir (Voelz and Ward, 1991). In this regulated stretch of the Colorado River, a distinct downstream recovery pattern was observed corresponding to changes in environmental conditions with distance downstream from the deep-release dam. Several items are important for interpreting this type of analysis. First, each point on the graph (Figure 7) represents a synthetic value that was derived from the monthly abundance values of 28 predominant macroinvertebrate taxa that occurred in the study area. For example, one point integrates all the abundance values for the predominant taxa at site C1 during November 1984. Thus, a great deal of information has been distilled into a simpler form. Second, points on the graph that are in close proximity have similar macroinvertebrate composition and abundance values. However, the precipitous drop in eigenvalue between axis 1 and 2 (Figure 7) suggests that the interpretation of the second axis may be superfluous. In this study, site C1 was located 250 m below the dam. The remaining sites were established using approximately a geometric progression (500 m, 1200 m, etc.), with site C6 located 12 kilometers downstream from the reservoir. In Figure 7 three patterns are evident: 1) Sites are sequentially arrayed along the primary axis, 2) Points representing macroinvertebrate data from individual sites are often close together, and 3) A change in macroinvertebrate composition and/or abundance can be observed from the site nearest the dam (C1) to the farthest downstream site (C6), with noticeable overlap between some adjacent sites.

Results from the detrended correspondence analysis (DCA) for the plains segment of the Cache la Poudre River indicated that this stretch of the river exhibited little longitudinal change beyond site 2 (Figure 8). In general, the sites are not sequentially arrayed along the primary axis as they were for the Colorado River DCA (compare Figures 7 and 8). Also note that the eigenvalues for the first and second axes are relatively similar (i.e., explain a similar amount of variation in the data). Although in this case no clear two-dimensional interpretation is evident, it does mean that points in close proximity in the two-dimensional DCA space have very similar taxa composition and abundance. Site 1(1) was the most distinct site, but had many taxa common to all sites. Although there was some faunal change indicated between sites 1(1)-2, the amount of overlap between sites is striking. Taken as a whole, this analysis indicates that the downstream pattern of macroinvertebrate communities changed very little from 1981-1991.

It is not surprising that there was little longitudinal change in this section of the Poudre River. Overall environmental conditions (e.g., temperature, substrate) were similar at these sites and there was relatively little elevational gradient. The somewhat distinct nature of site 1(1) probably occurred for several reasons. First, it was the least impacted site and some taxa that occurred there may not be able to tolerate conditions that occurred in the downstream reaches. Second, some of the taxa found at site 1(1) are commonly found in the montane sections of the river and are probably existing at the lower portion of their distributional range. Nonetheless, the results from these longitudinal distribution analyses suggest that comparisons among sites, with regard to long-term changes, are plausible because confounding factors such as rapid change in elevation (with its concomitant change in numerous environmental parameters) does not occur in this stretch of river. In addition, these results suggest that the macroinvertebrate community dynamics at site 1(1) are relatively natural and provide a good monitor of natural interannual variability.

Figure 4a and 4b. Longitudinal trends for mean number of taxa at each site for 1981 to 1984 and 1985 to 1988.

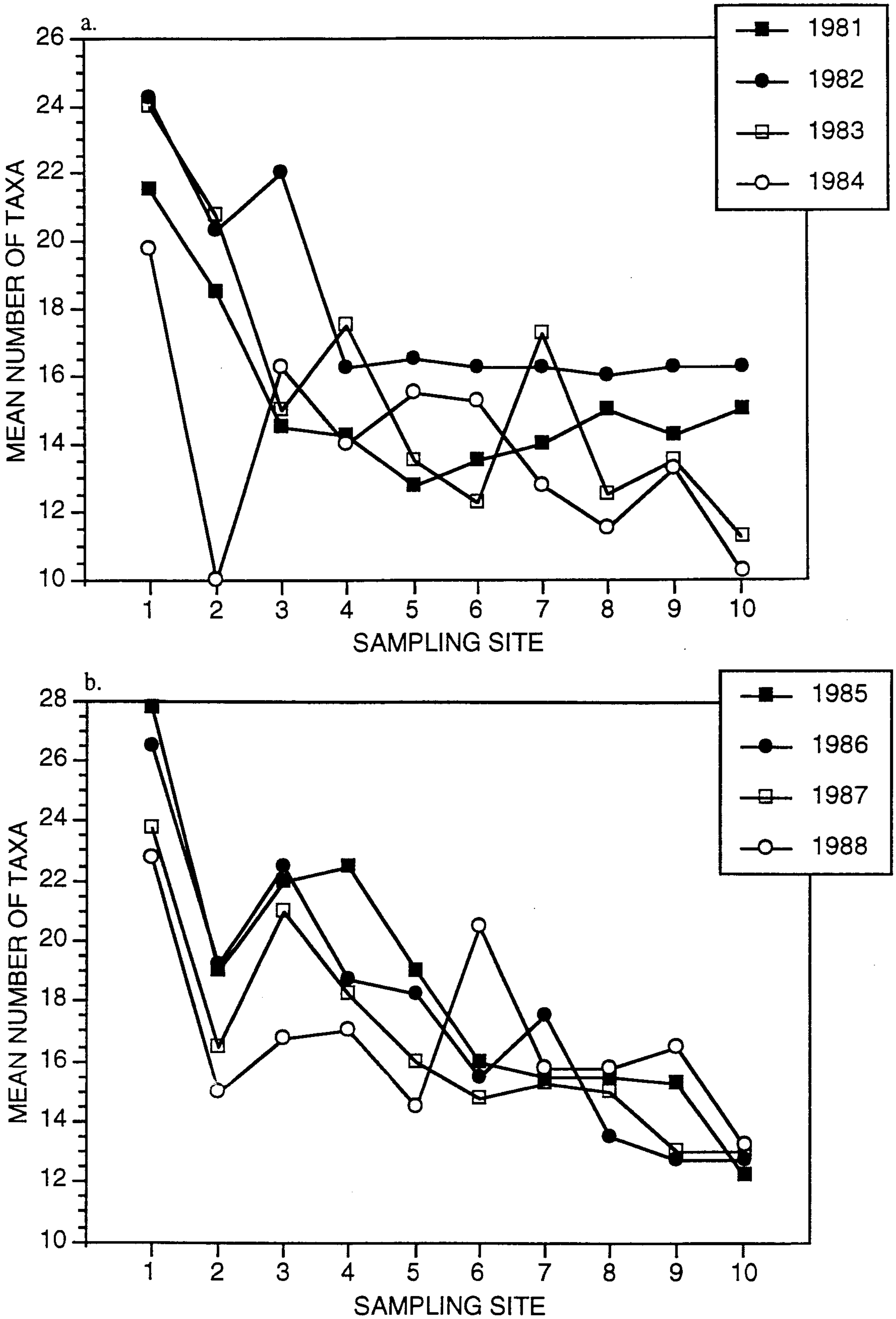
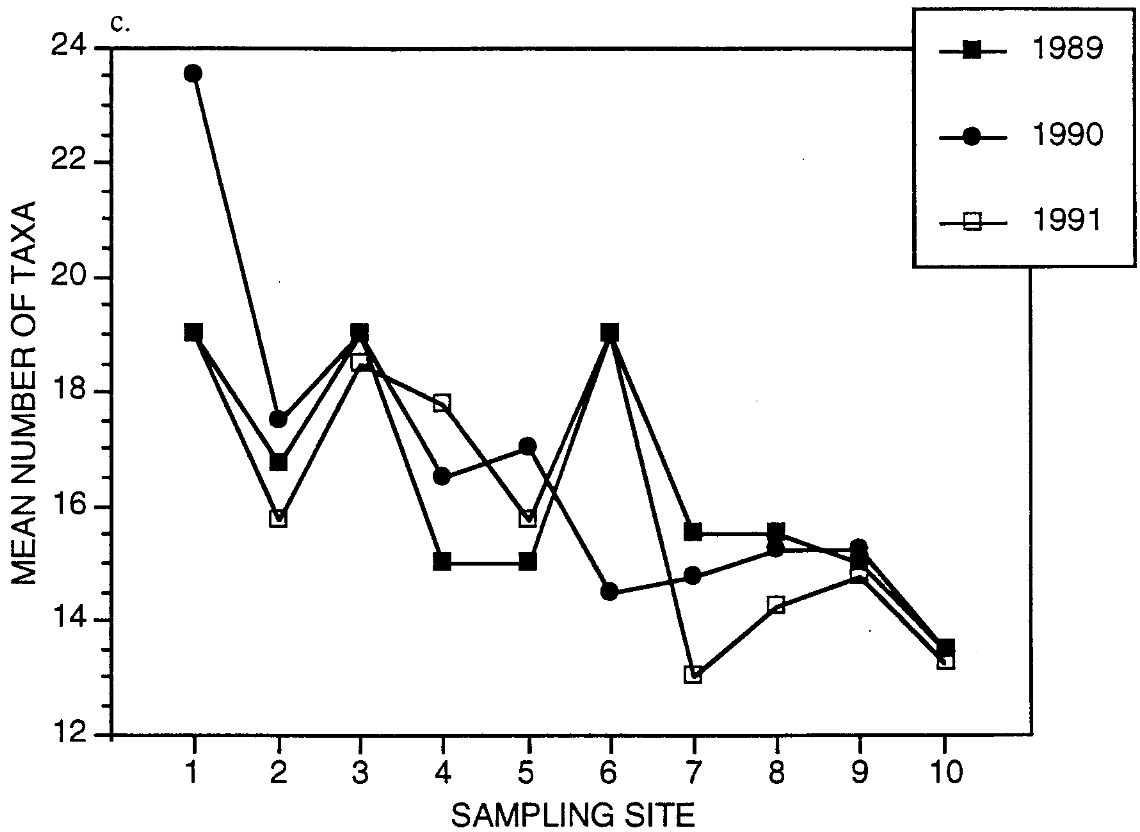


Figure 4c. Longitudinal trends for mean number of taxa at each site for 1989 to 1991.



Figures 5a and 5b. Longitudinal trends for annual mean number of individuals per 3 Surber samples at each site for 1981 to 1984 and 1985 to 1888.

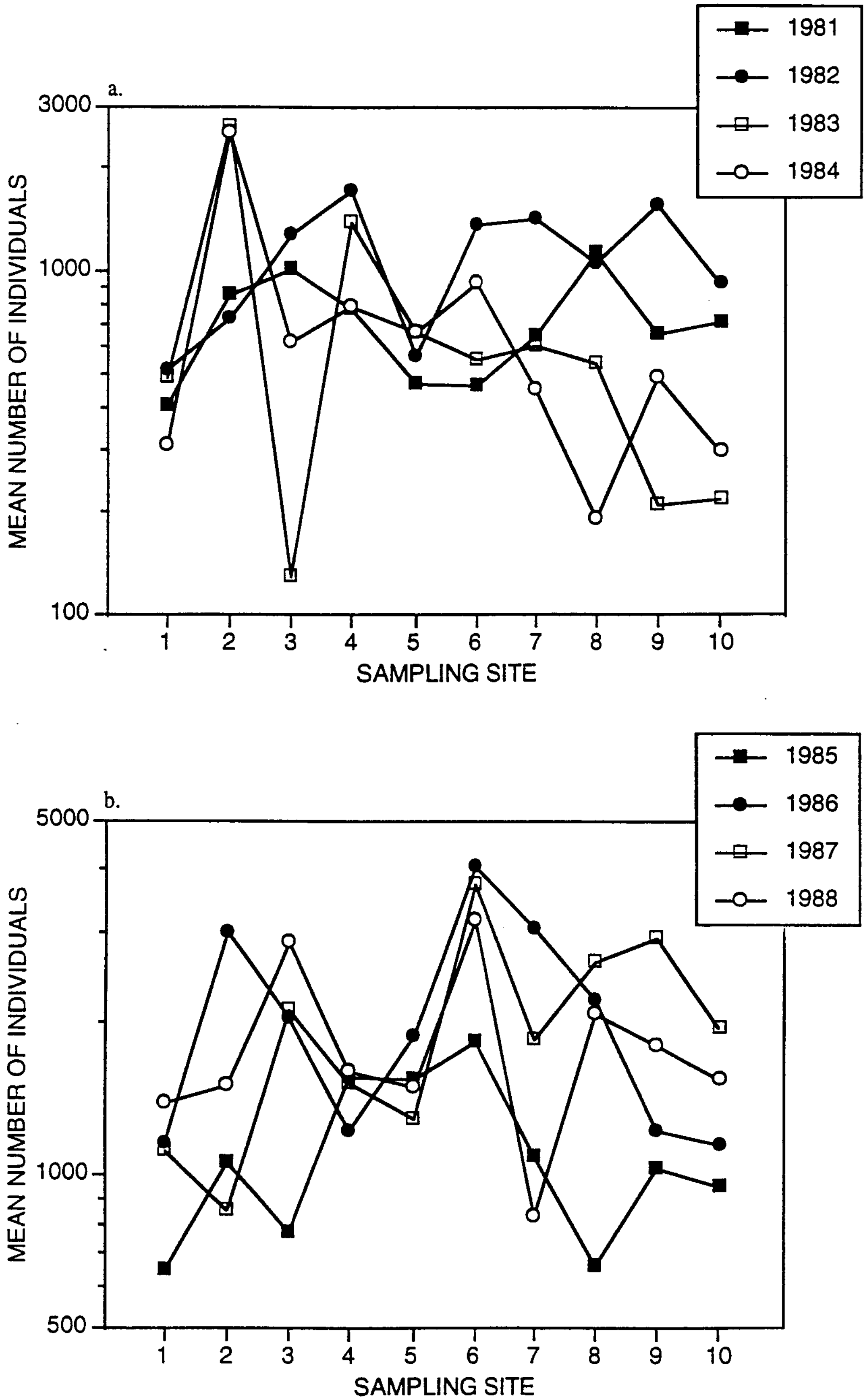
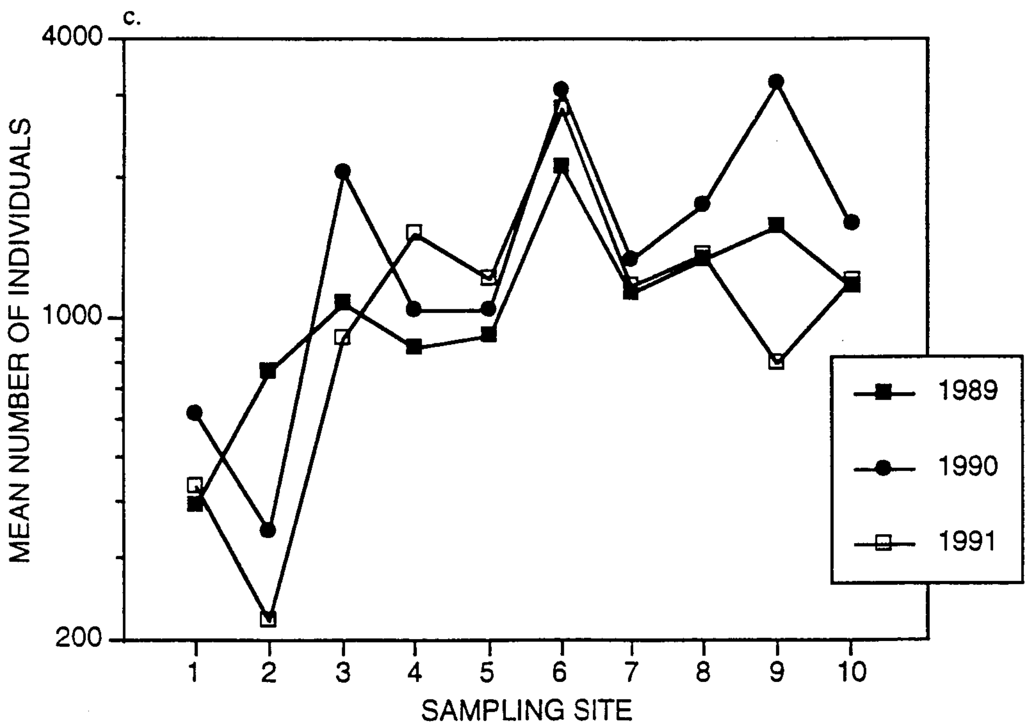
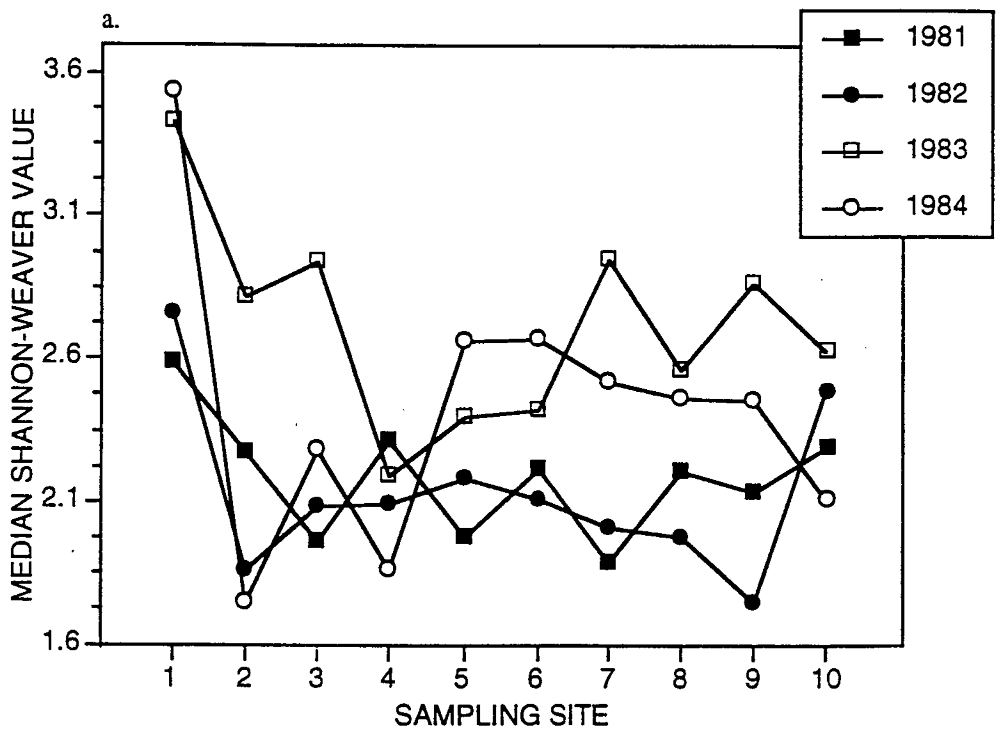
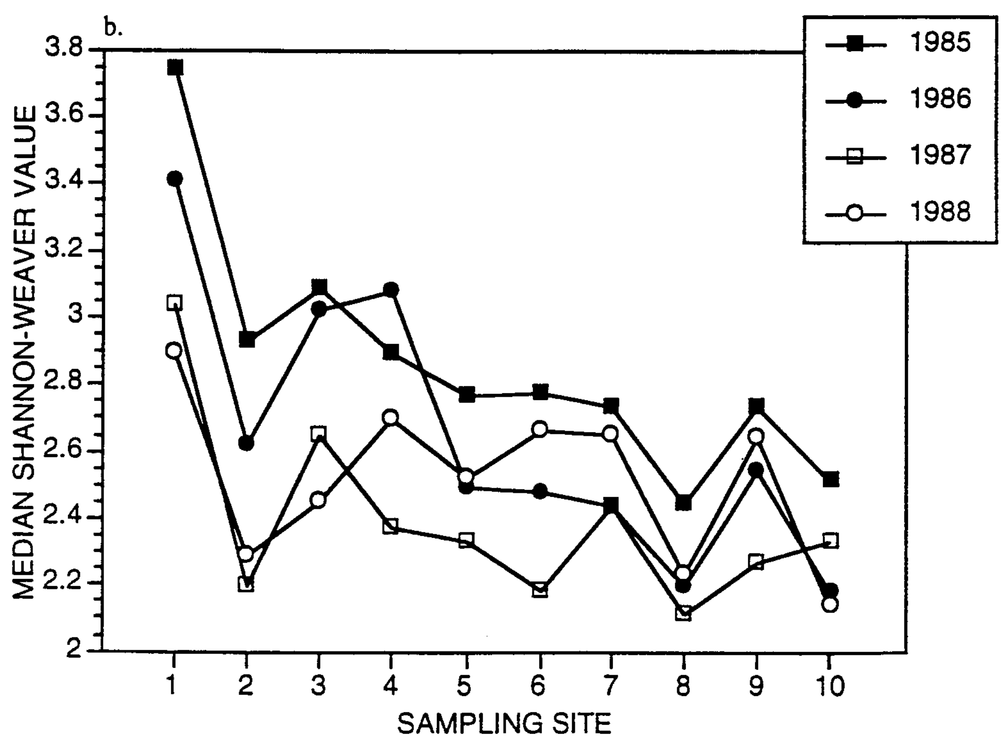


Figure 5c. Longitudinal trends for annual mean number of individuals per 3 Surber samples at each site for 1989 to 1991.



Figures 6a and 6b. Longitudinal trends of median Shannon-Weaver values for each site from 1981 to 1984 and 1985 to 1988.





Figures 6c. Longitudinal trends of median Shannon-Weaver values for each site from 1989 to 1991.

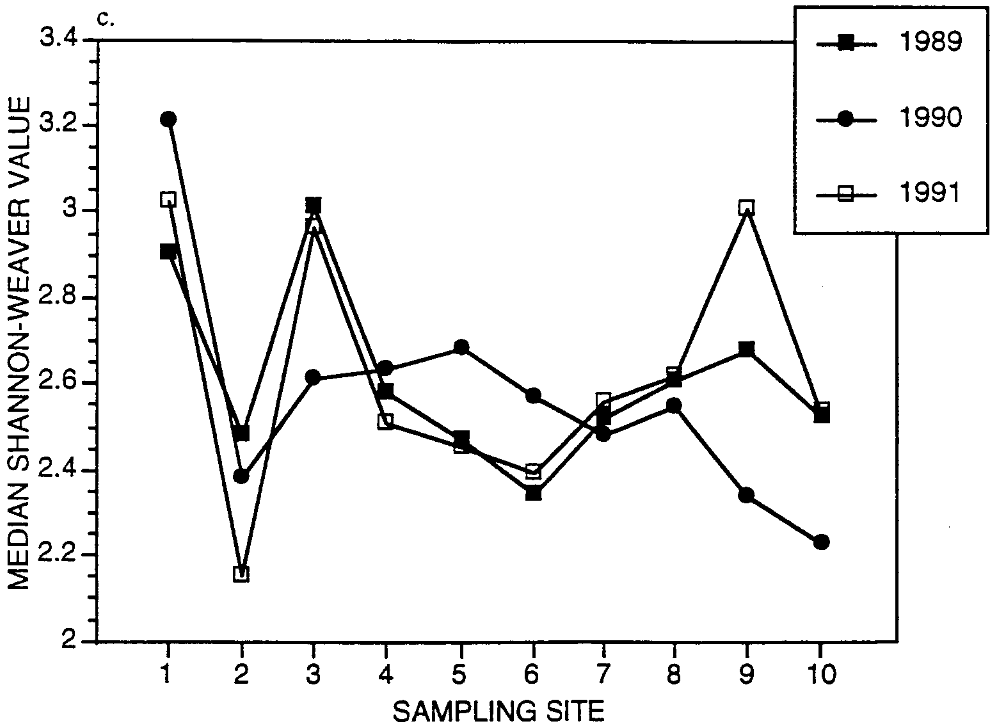


Figure 7. An example of a detrended correspondence analysis (DCA) showing a clear downstream change in macroinvertebrate community structure (from Voelz and Ward, 1991). C1-C6 are sites increasingly distant from Granby Dam on the Colorado River. Symbols plot monthly samples at each site. Eigenvalues for the first 3 DCA axes are 0.277, 0.040, and 0.027 respectively.

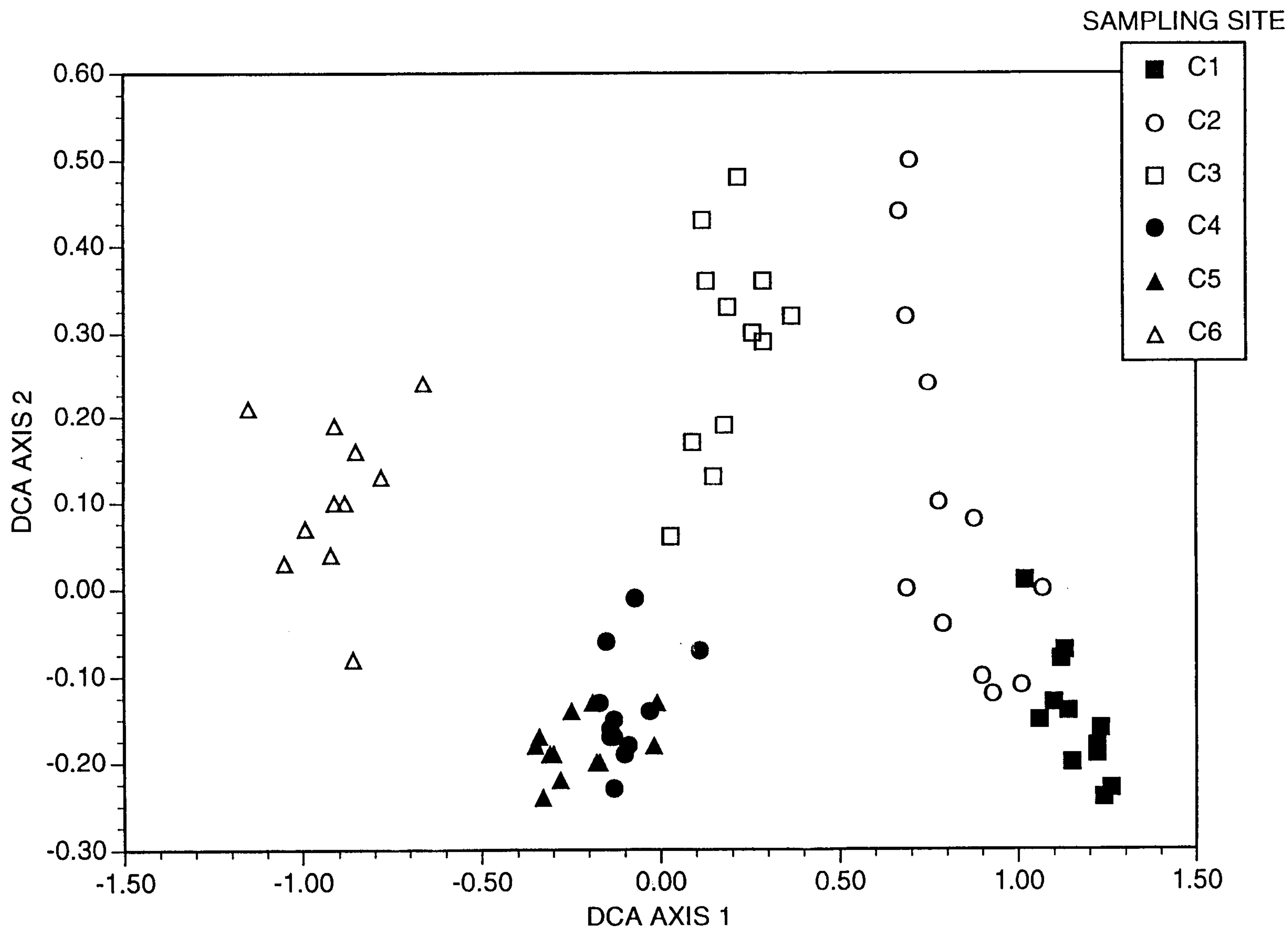
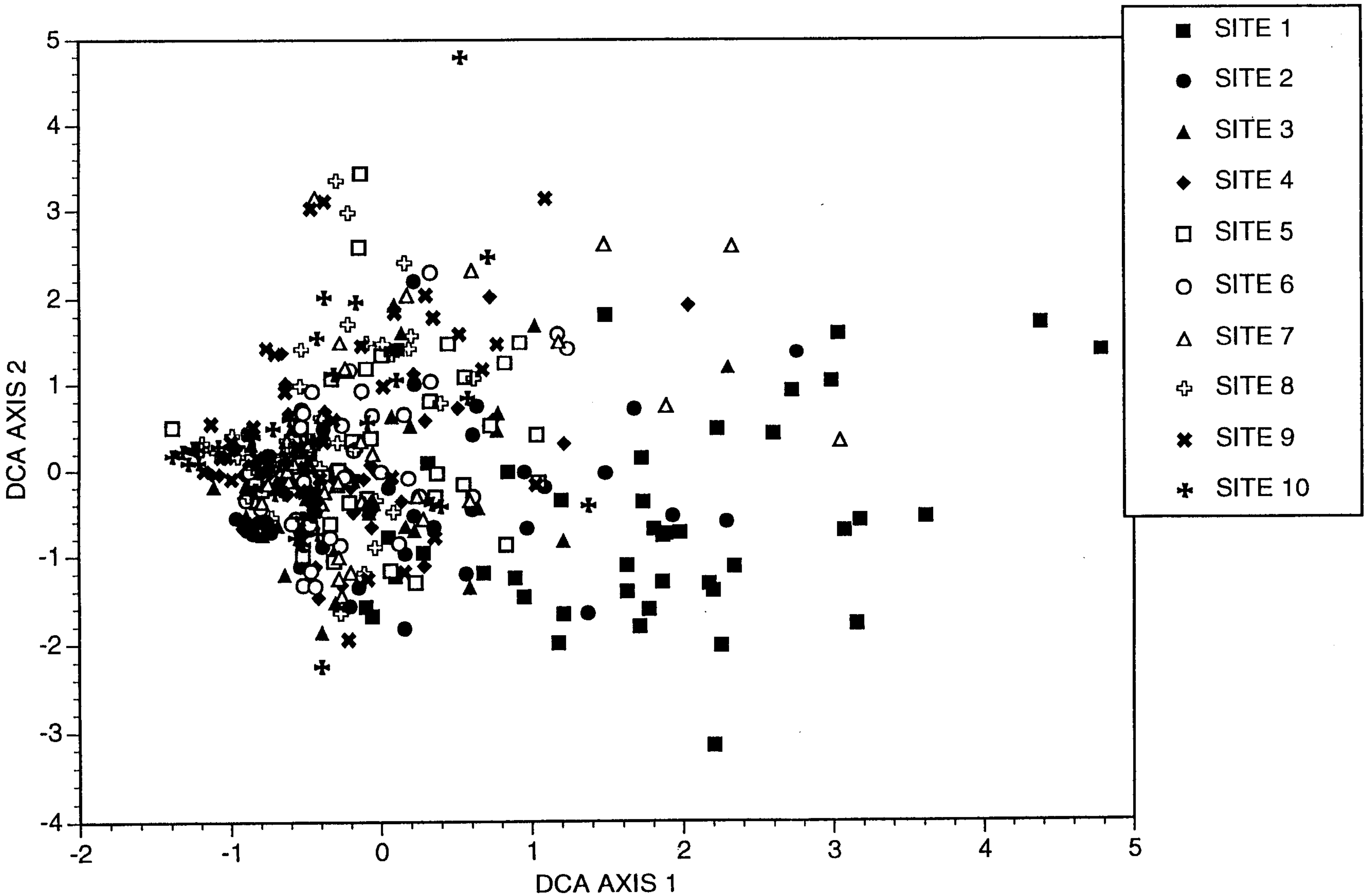


Figure 8. Detrended correspondence analysis (DCA) on all sites for 1981 to 1991. Each point indicates one sampling date at a given site. Eigenvalues for the first 3 DCA axes are 0.235, 0.175, and 0.147 respectively. Samples for August 1983 (site 10), December 1983 (sites 3 and 9), October/November 1984, and February 1985 (site 2) were omitted from the analysis due to extremely low macroinvertebrate abundances. All samples for 1991 at site 2 were also omitted because the unduly influenced the analysis.



Temporal Patterns within Sites 1981-1991

There was a decline in total number of taxa at most sites during 1983-1984 (discussed below), but otherwise there were not discernible temporal patterns within sites and fluctuations were within similar limits across sites (Figures 9a-j). The pattern may be described as "white noise" (static). Thus, there appeared to be no long-term change in the number of taxa. Although species replacement could occur without changes in the number of taxa, examination of the data confirmed that no relatively abundant taxa appeared or disappeared from 1981-1991. The maximum number of taxa recorded at site 1(1) was slightly higher than the number recorded at any other site and was considerably higher than peak numbers at some sites. The minimum number of taxa at site 1(1) was higher than the lowest number observed at all sites except site 3. The minimum at site 2 (late 1984) was the lowest recorded at any site. Because site 1(1) also exhibited marked year-to-year differences in the number of taxa, with no discernible pattern, one cannot attribute interannual variations to changes in water quality.

Macroinvertebrate density declined sharply in late 1983 through 1984 at most sites, then increased to (or surpassed) pre-1983 levels from 1985-1991, remaining relatively constant and primarily exhibiting seasonal trends (Figures 10a-j). This density decline corresponded with the highest discharge in 75 years (1983) and a prolonged, heavy spring runoff in 1984 (Figure 14). At several sites, including site 1(1), there appeared to be a delayed density decline after the 1983 record flow (Figure 14). This is difficult to explain, since the effects of high discharge on macroinvertebrate density should be immediate. Perhaps the record flow disrupted the resource base (e.g., amount of food), which might produce the lag in density decline. Maximum density was similar across sites. Site 2 exhibited the lowest minimum abundance values during 1981-1991.

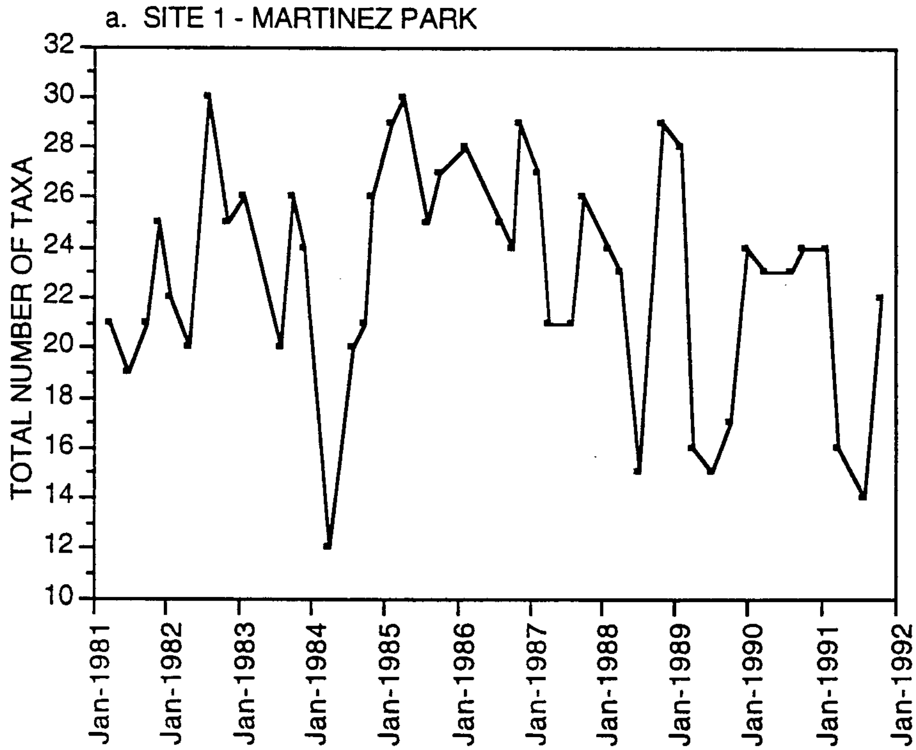
Many of the sites exhibited relatively constant diversity values, or increased slightly through time, when extreme values are ignored (Figures 11a-j). These extreme diversity values were isolated instances and did not appear to follow any particular pattern. Most sites had highest diversity values in 1985. Site 1(1) attained the highest maximum diversity values and the minimum value at that site exceeded minimum values at all other sites. The lowest minimum Shannon-Weaver diversity value was at site 8(6). Wilhm (1970) has calculated Shannon-Weaver values from aquatic macroinvertebrate data collected by numerous investigators who used a variety of collecting techniques and sampled a variety of habitats. Almost invariably, macroinvertebrate communities of unpolluted waters exhibited Shannon-Weaver values between 3.0-4.0; whereas, values from polluted streams were generally less than 1.0. Most values for Rocky Mountain streams generally approach or exceed 3.0 (Platts et al., 1983). Although there are no comparable data for plains streams, the values obtained for this study are primarily greater than 2.0. Only a few, isolated values were below 1.0 (at sites 2, 5(3), 7(5) and 8(6)). Shannon-Weaver values recorded during the latter part of this study, at all sites, approached or exceeded 3.0. This indicates that water quality has not declined and may have increased slightly during the course of the study.

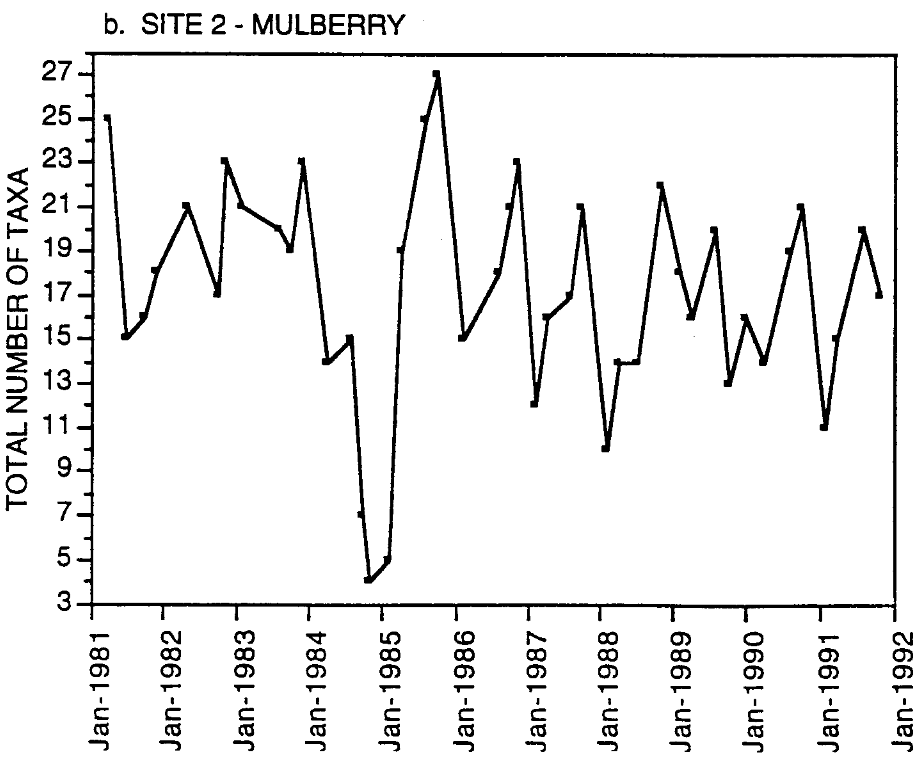
Overall long-term trends for equitability within individual sites were not as conclusive as those for Shannon-Weaver diversity. Equitability exhibited mostly random fluctuations. Most sites had very high equitability values at some time, particularly in 1983-1984. These high values were often a result of extremely low macroinvertebrate density, where a few individuals were distributed evenly over a few taxa. Thus, they are artificially high and should be interpreted cautiously. Maximum and minimum equitability values were similar across sites. In unpolluted streams in the southeastern United States, equitability normally ranges from 0.6-0.8; whereas, even mild levels of organic wastes generally depress equitability values below 0.3. In the

Poudre River values were primarily greater than 0.4. This suggests that the water quality of the river over the long-term has not declined and perhaps has increased.

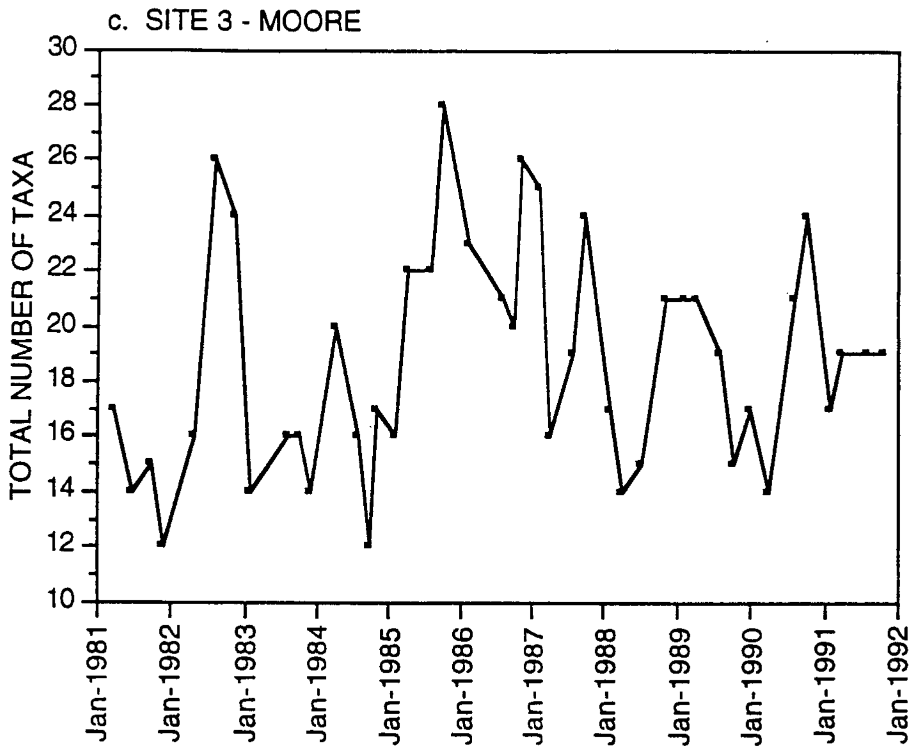
Results from detrended correspondence analyses (DCA) on individual sites are shown in Figures 12a-j. Eigenvalues and samples omitted from the analyses are presented in Table 2. The eigenvalues for the second axis (for all sites) are relatively high, suggesting a two-dimensional interpretation of the graphs (compare with example DCA, Figure 7). The samples omitted had very low total number of organisms or low abundances of predominant taxa and unduly influenced the analyses. The results from the DCAs on individual sites suggested a similar community structure through time. At most sites (including site 1(1)) over half of the sampling periods exhibited close proximity in DCA space, indicating similar macroinvertebrate composition and abundance. Most of the outlying points, those having progressively lower affinity with the main cluster of points, at most sites were from sampling periods during 1981-1983. This indicates that there has potentially been some change in macroinvertebrate composition from the early years of the study. In addition, at sites 2, 4(2)-6(4), and 8(6)-10(8), a few outlying points were from 1989-1991. However, highest densities and diversity of taxa was greater than at other sampling periods. Thus, these outliers were often a result of somewhat different and diverse taxa combinations, and not the result of low diversity or declining macroinvertebrate populations.

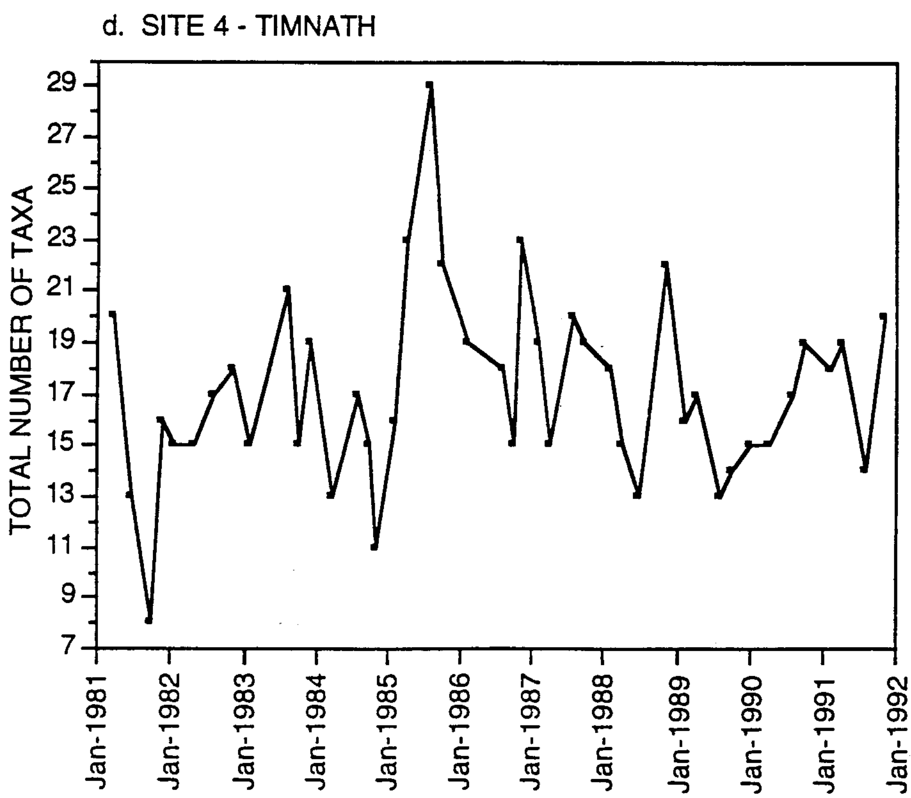
Figures 9a and 9b. Total number of taxa at sites 1(1) and 2 from 1981 to 1991.



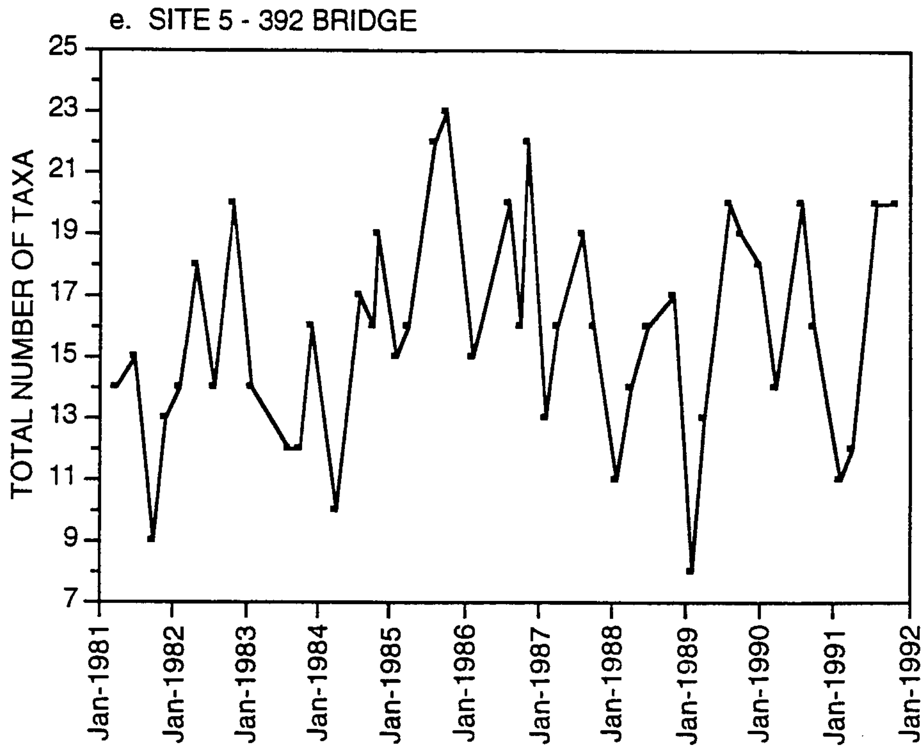


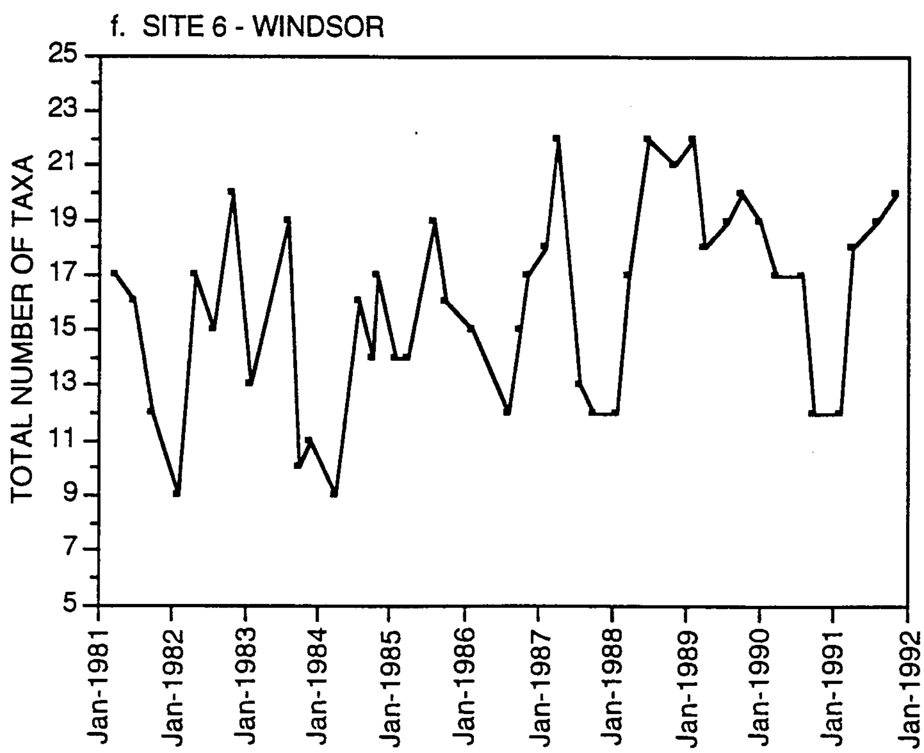
Figures 9c and 9d. Total number of taxa at sites 3 and 4(2) from 1981 to 1991.



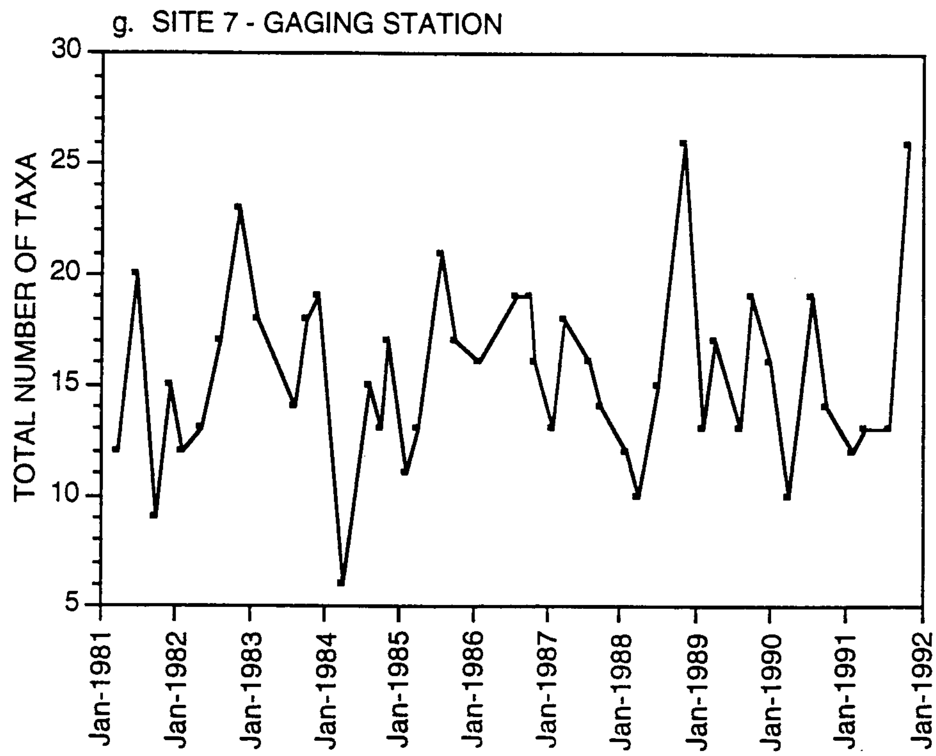


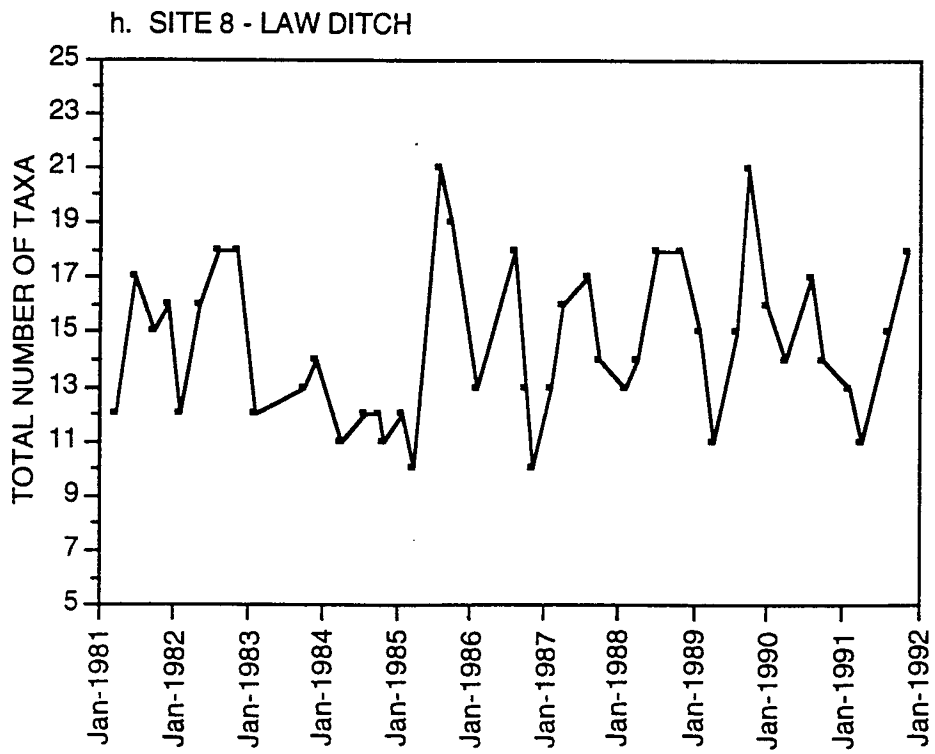
Figures 9e and 9f. Total number of taxa at sites 5(3) and 6(4) from 1981 to 1991.



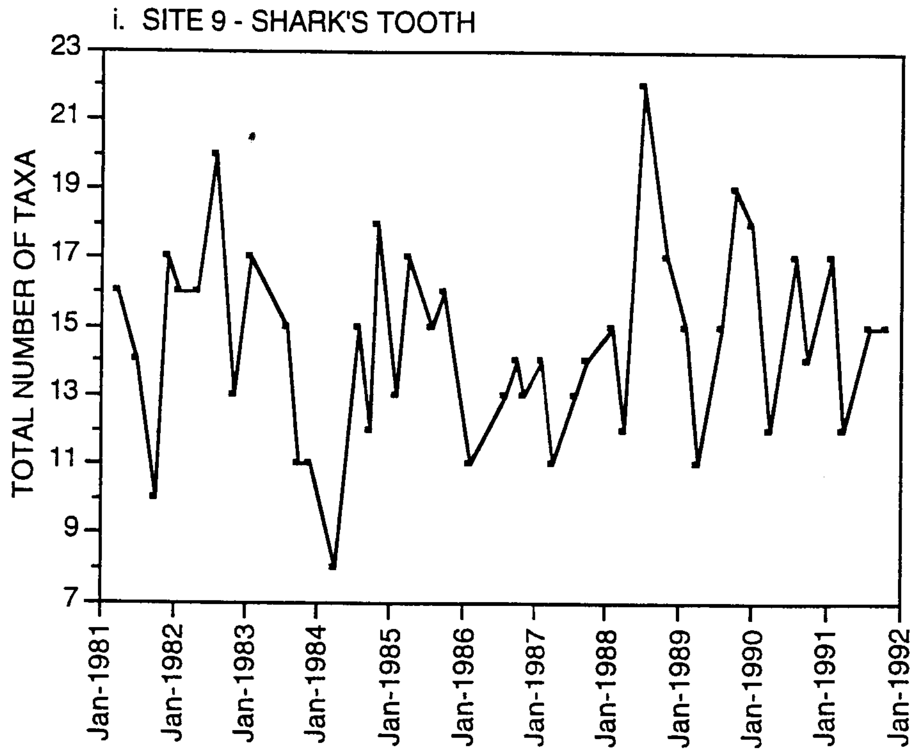


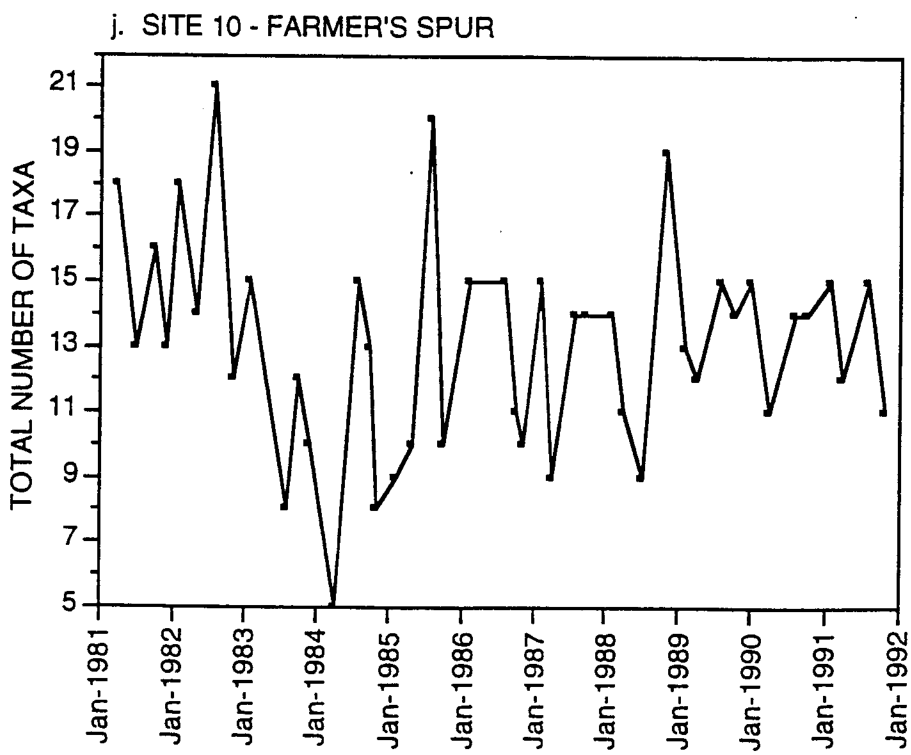
Figures 9g and 9h. Total number of taxa at sites 7(5) and 8(6) from 1981 to 1991.



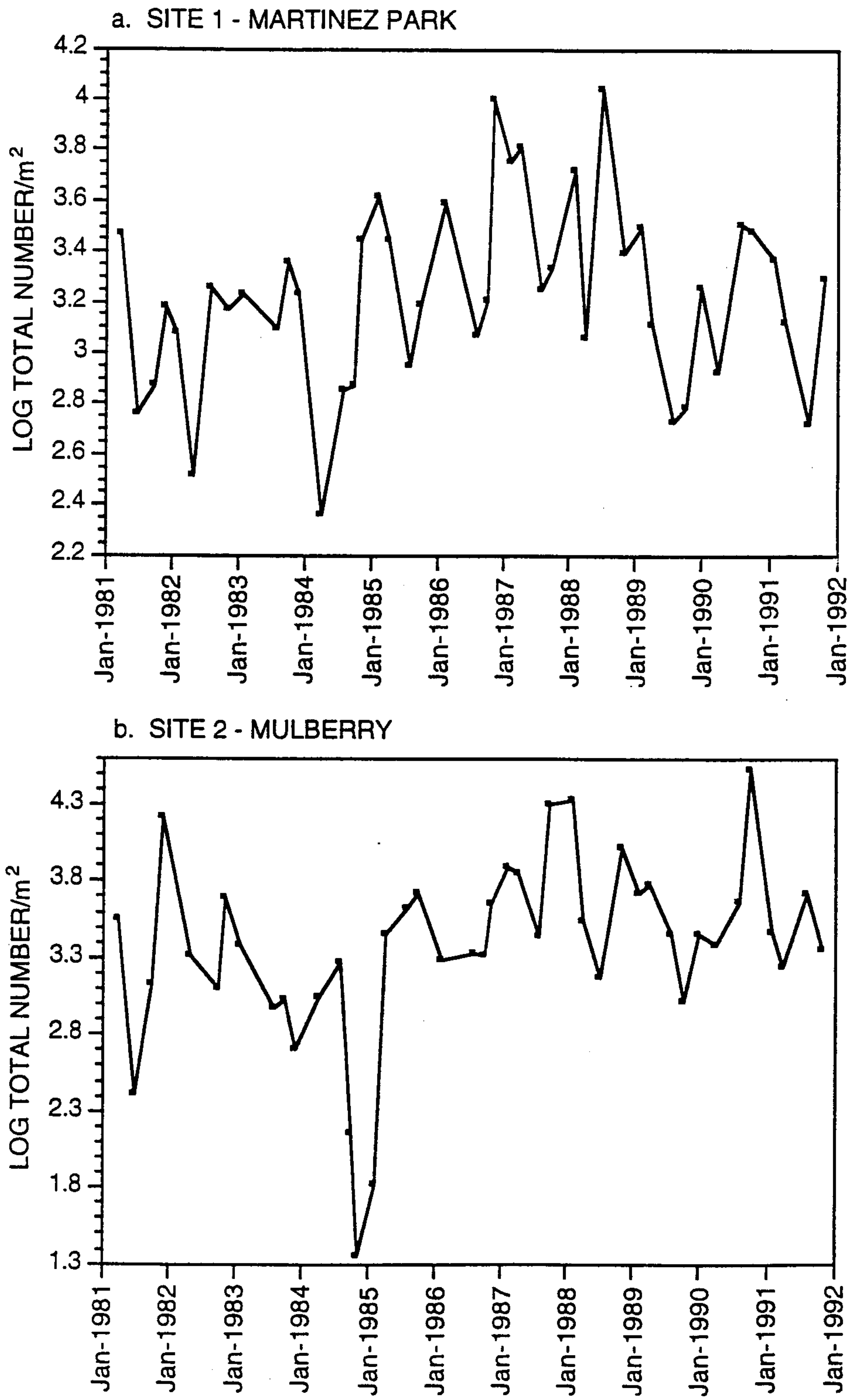


Figures 9i and 9j. Total number of taxa at sites 9(7) and 10(8) from 1981 to 1991.

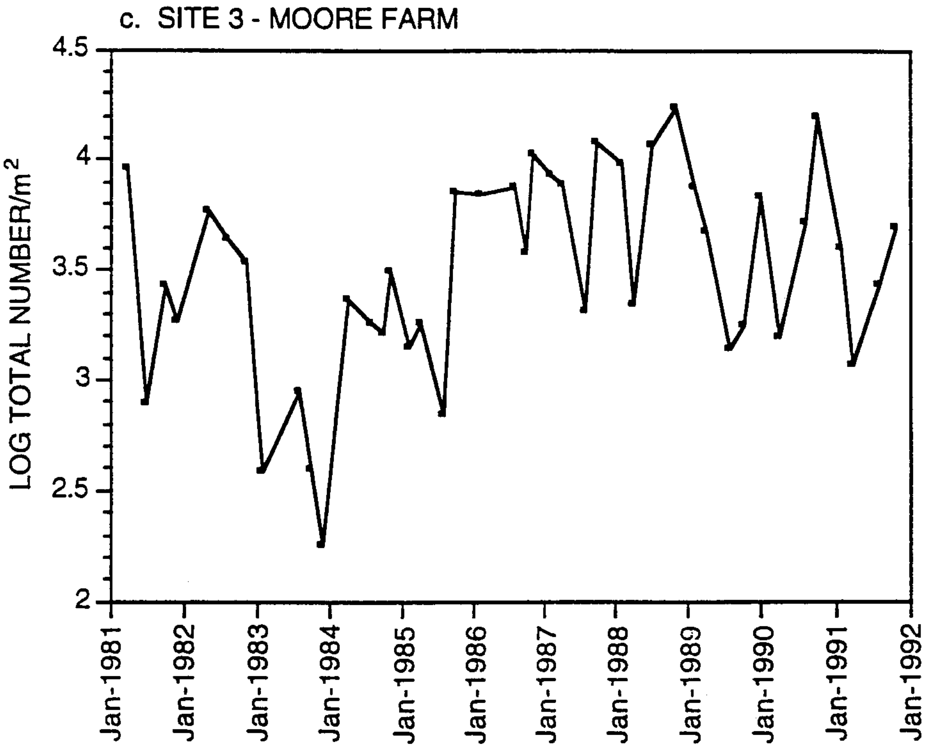


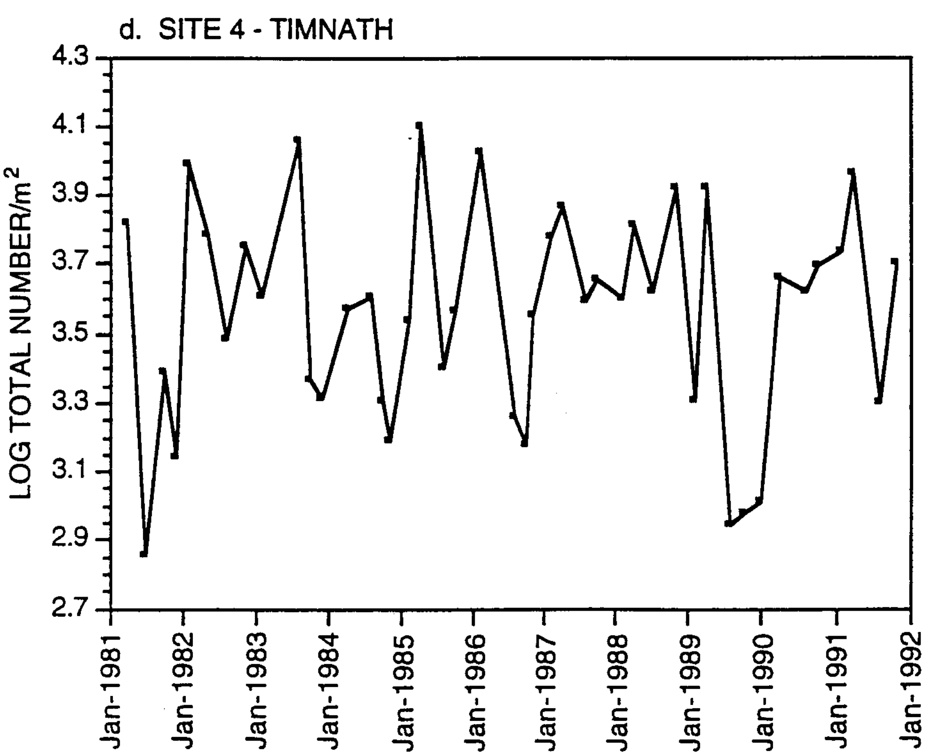


Figures 10a and 10b. Total abundances at sites 1(1) and 2 from 1981 to 1991.

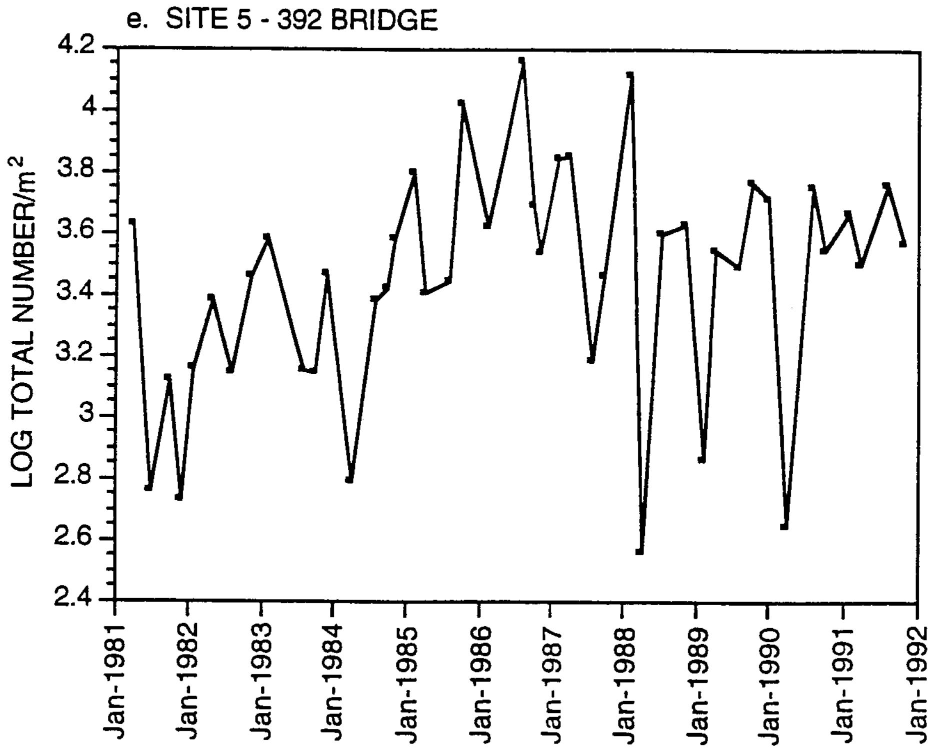


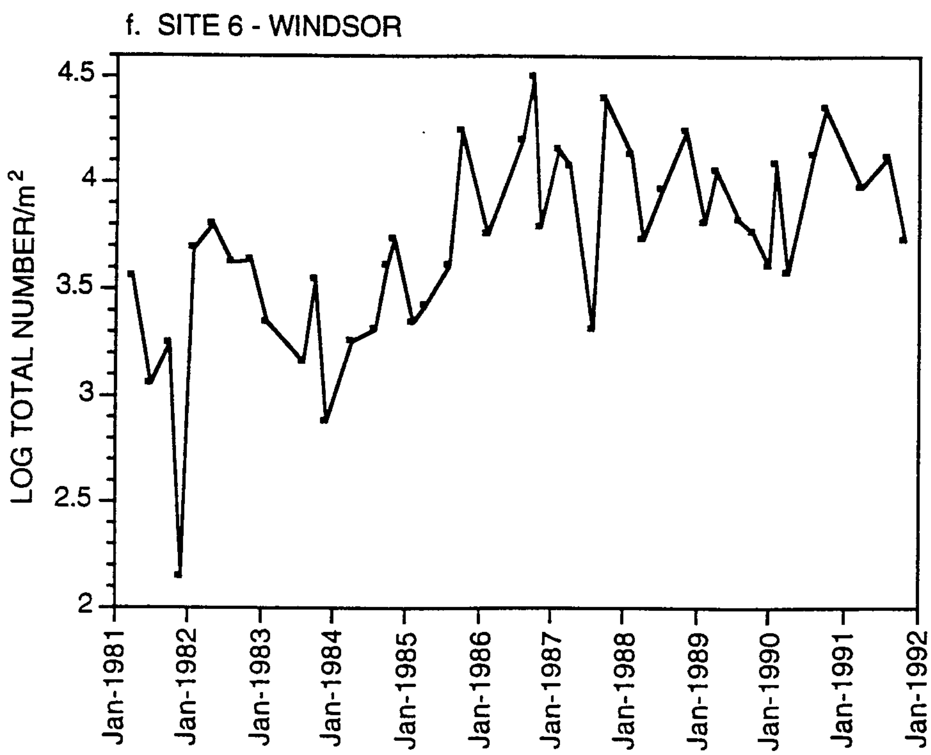
Figures 10c and 10d. Total abundances at sites 3 and 4(2) from 1981 to 1991.



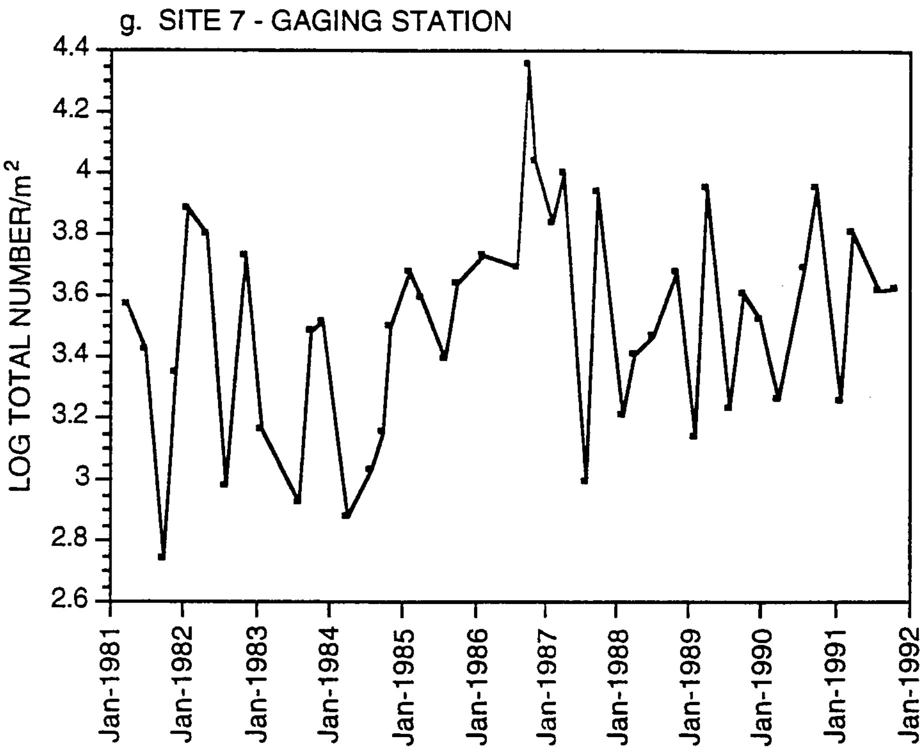


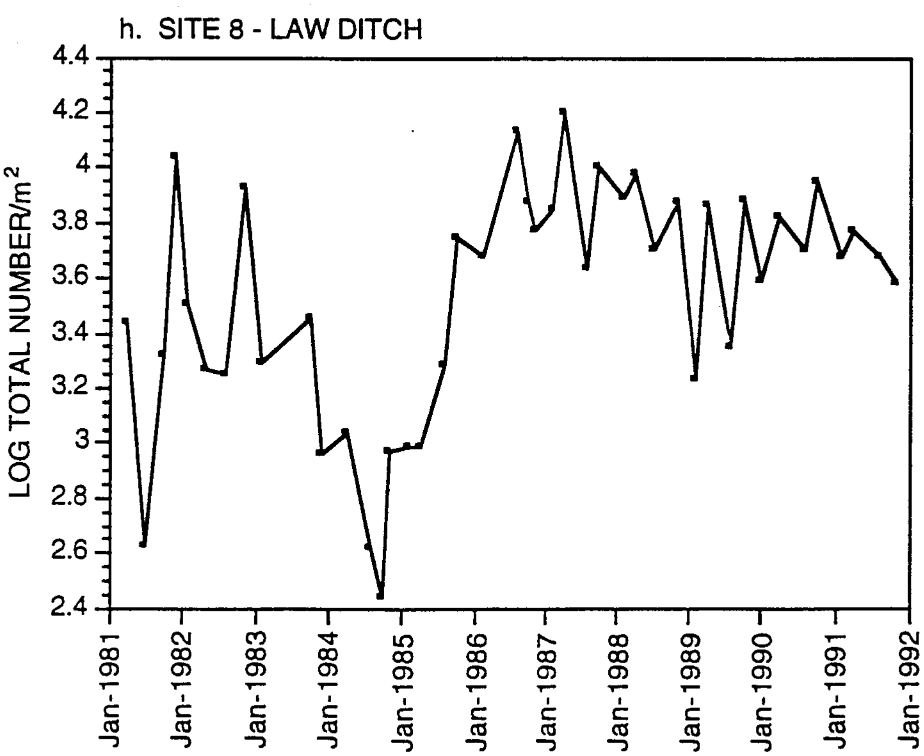
Figures 10e and 10f. Total abundances at sites 5(3) and 6(4) from 1981 to 1991.



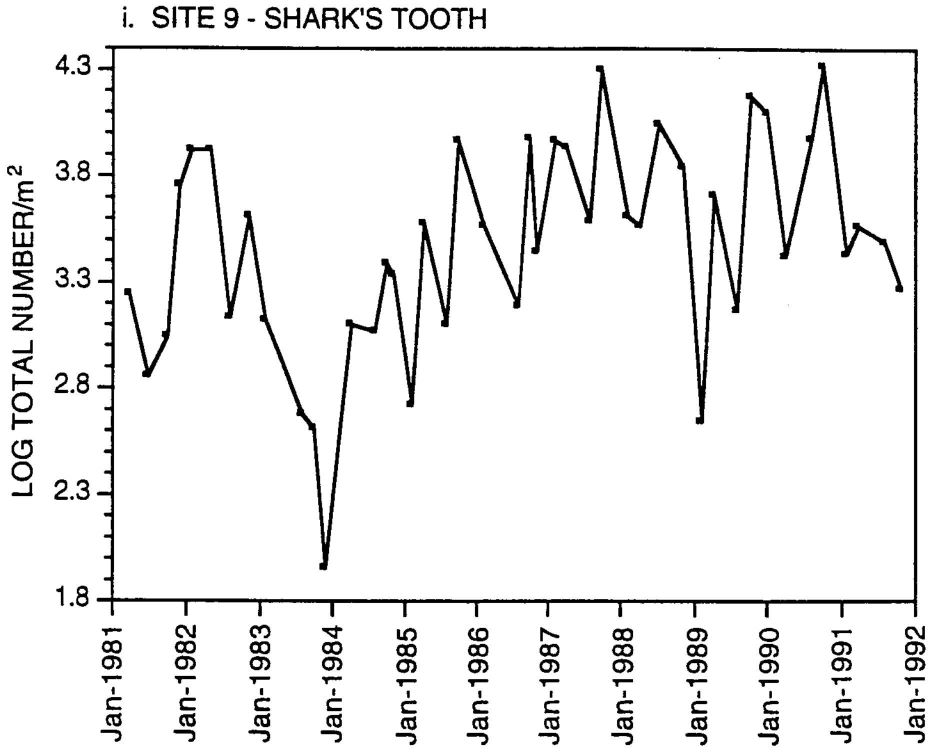


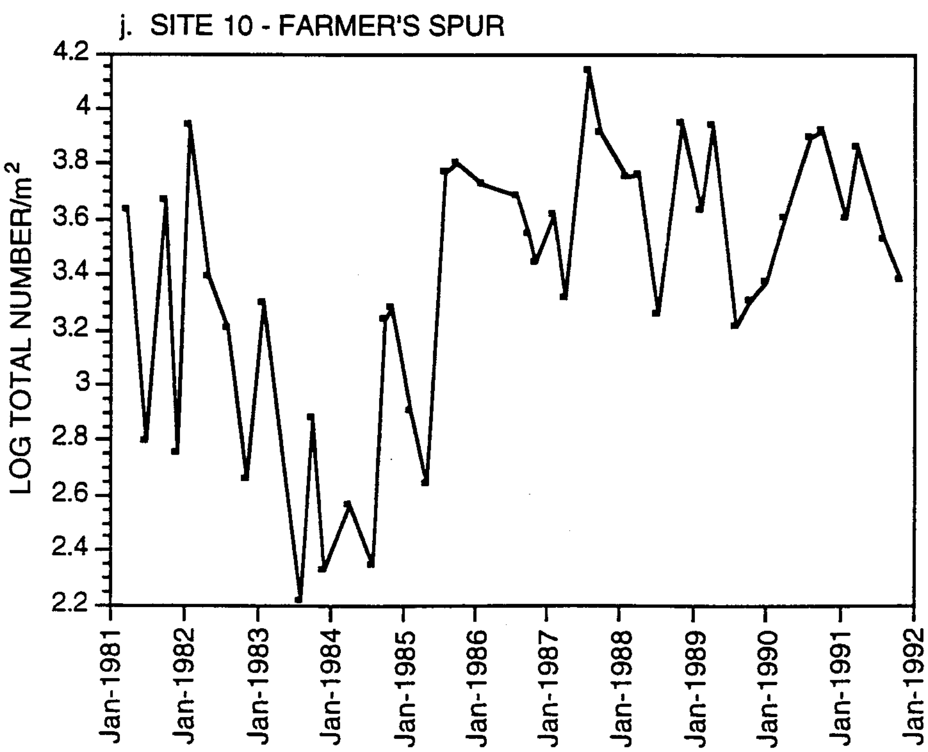
Figures 10g and 10h. Total abundances at sites 7(5) and 8(6) from 1981 to 1991.



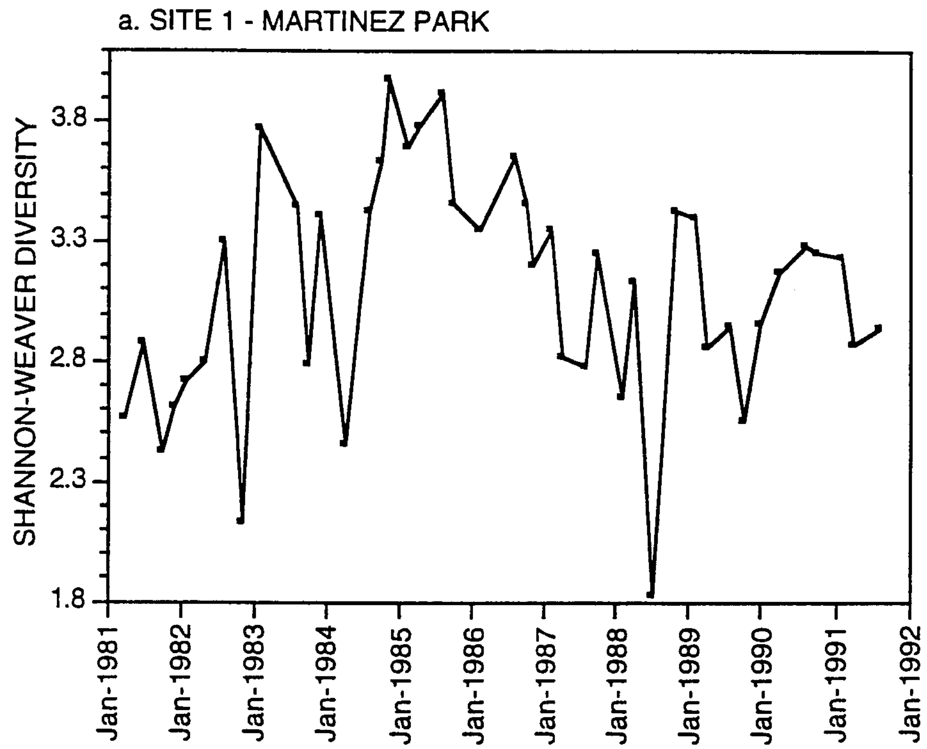


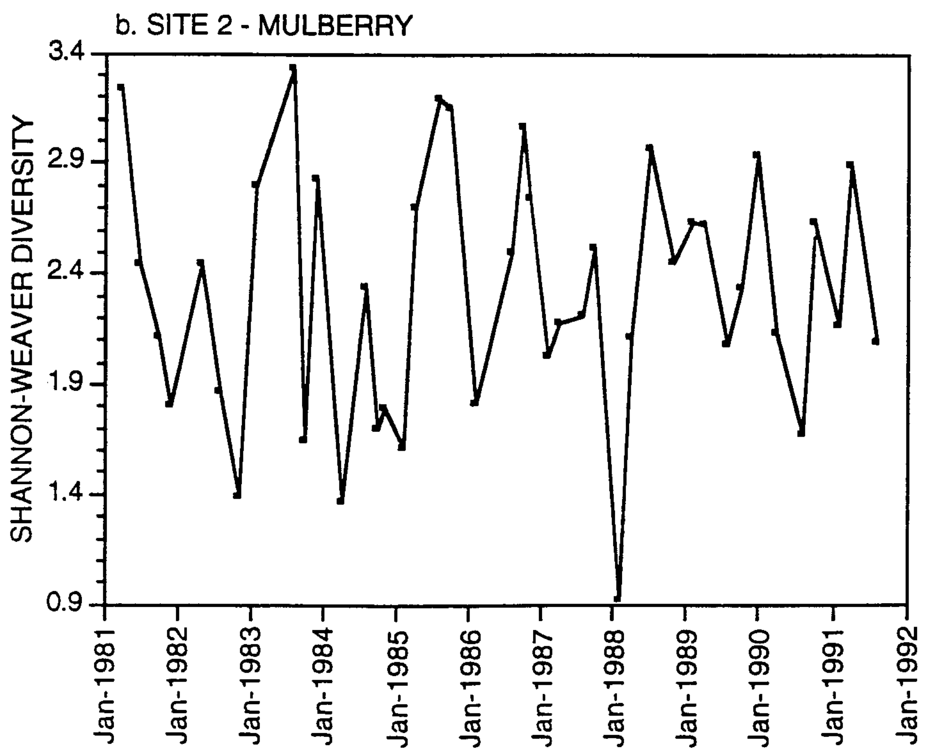
Figures 10i and 10j. Total abundances at sites 9(7) and 10(8) from 1981 to 1991.





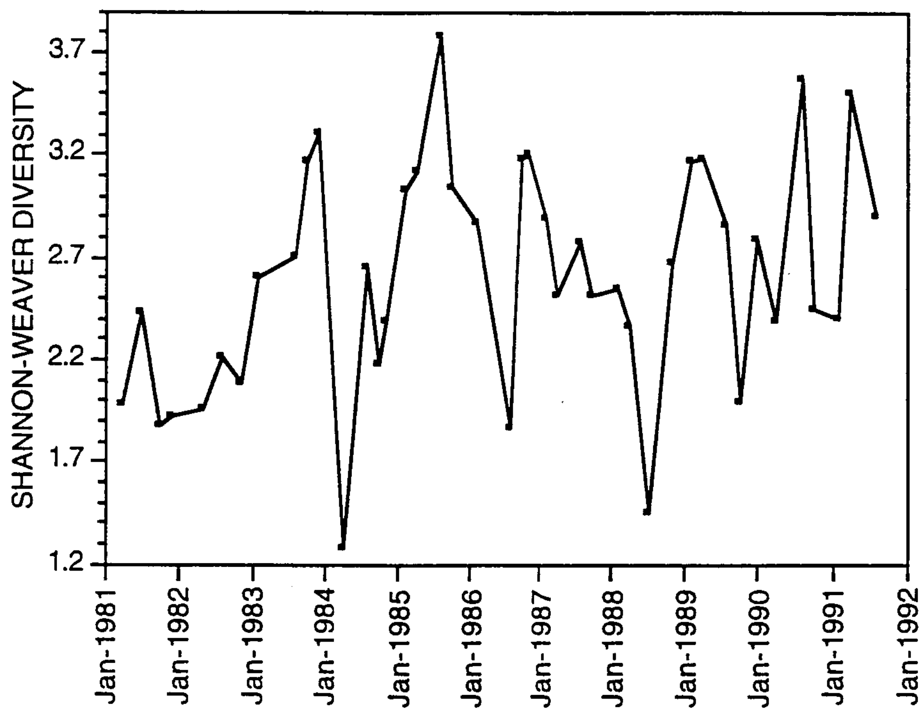
Figures 11a and 11b. Shannon-Weaver diversity values at sites 1(1) and 2 from 1981 to 1991.



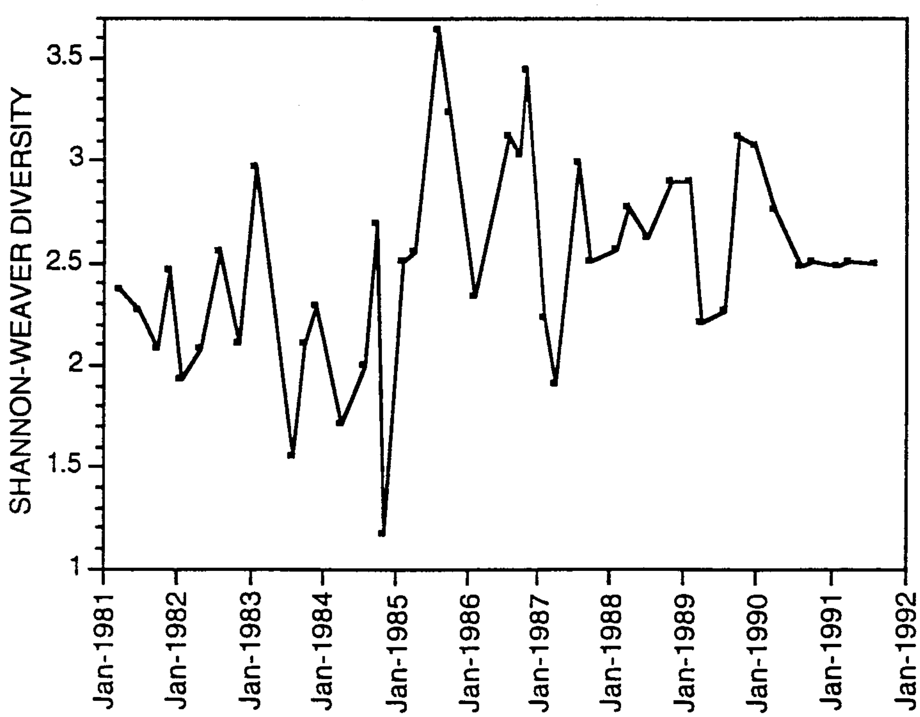


Figures 11c and 11d. Shannon-Weaver diversity values at sites 3 and 4(2) from 1981 to 1991.

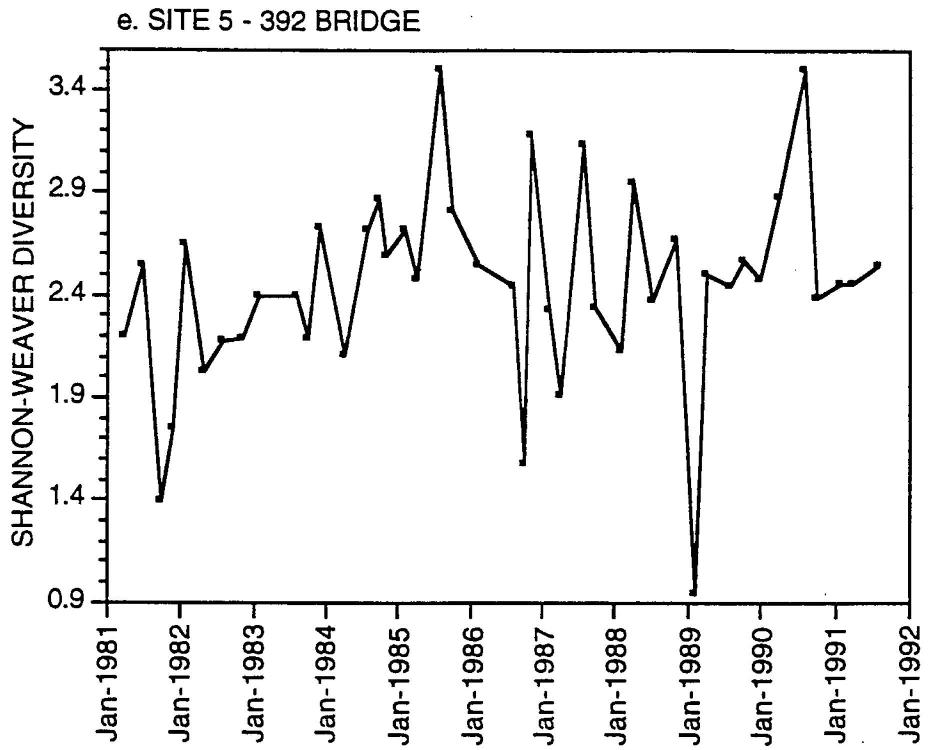
c. SITE 3 - MOORE FARM

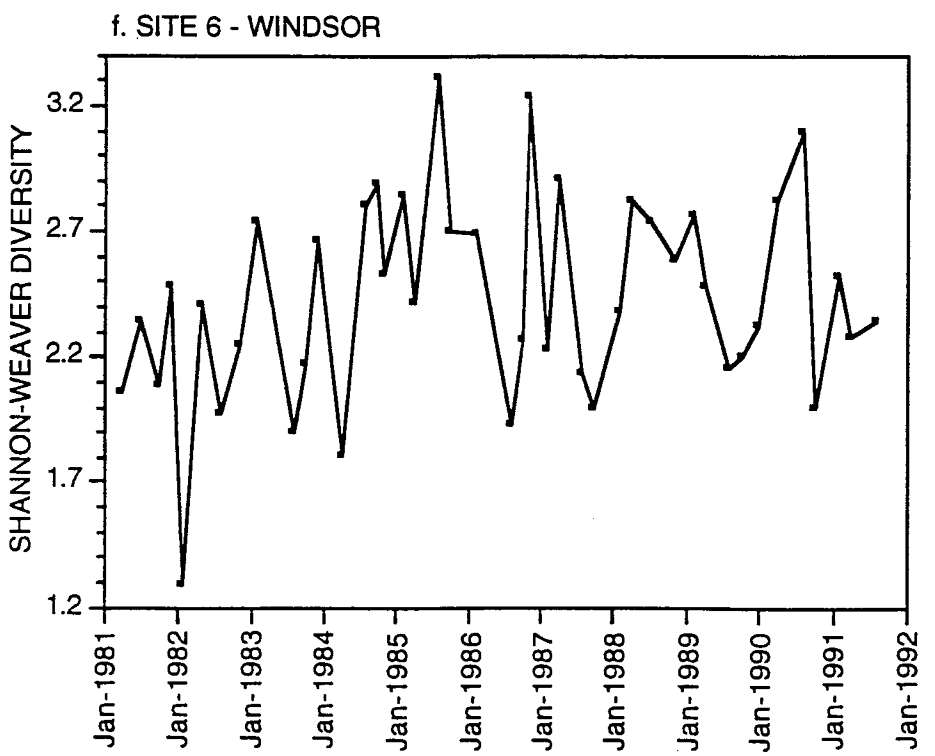


d. SITE 4 - TIMNATH

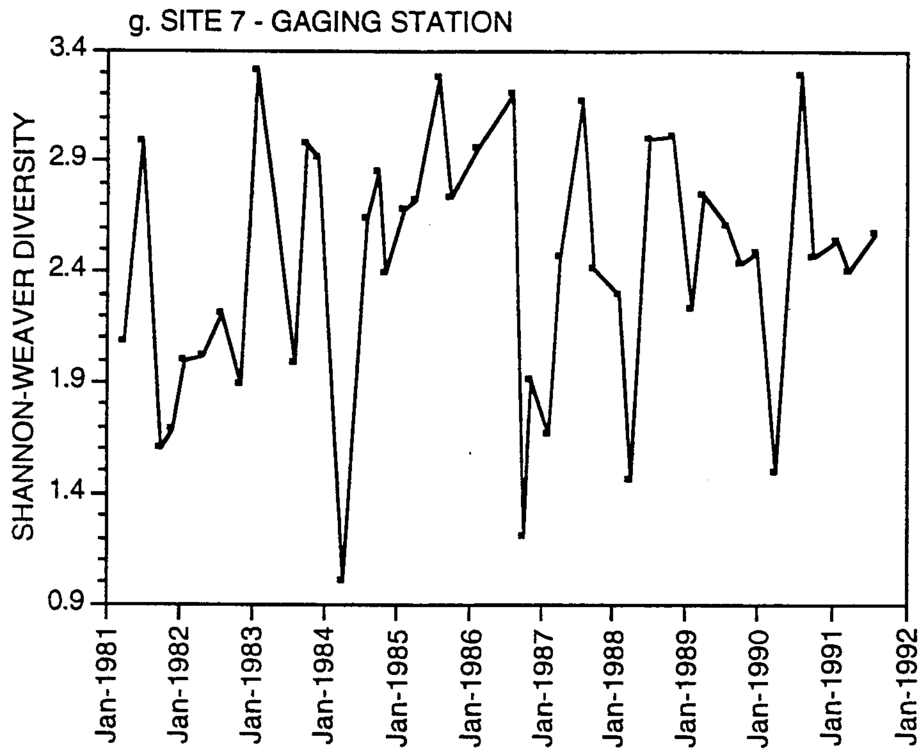


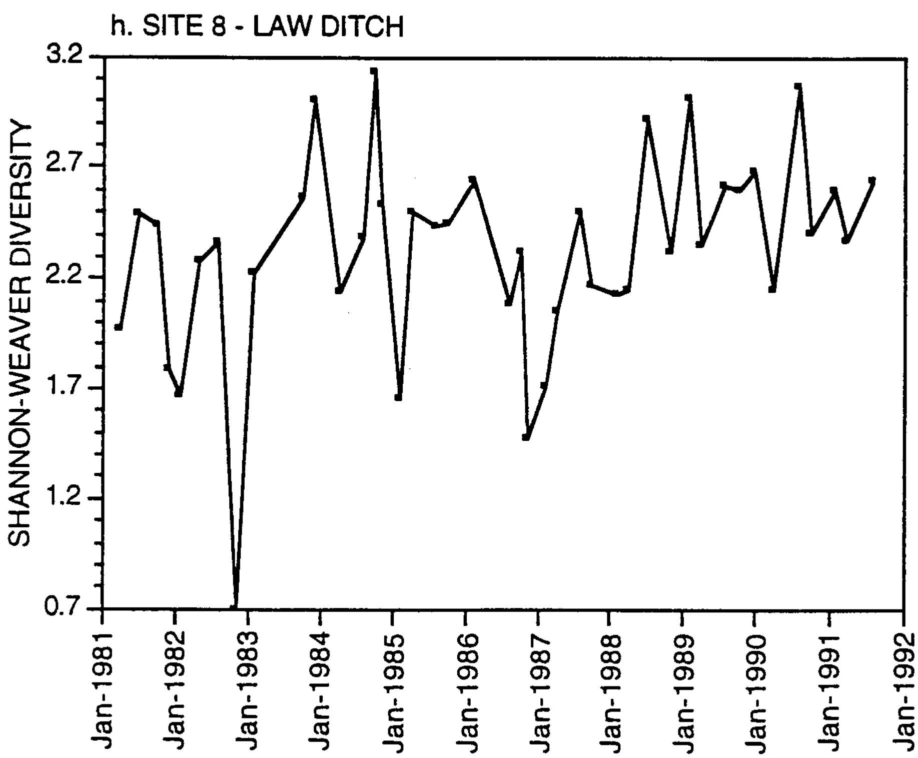
Figures 11e and 11f. Shannon-Weaver diversity values at sites 5(3) and 6(4) from 1981 to 1991.



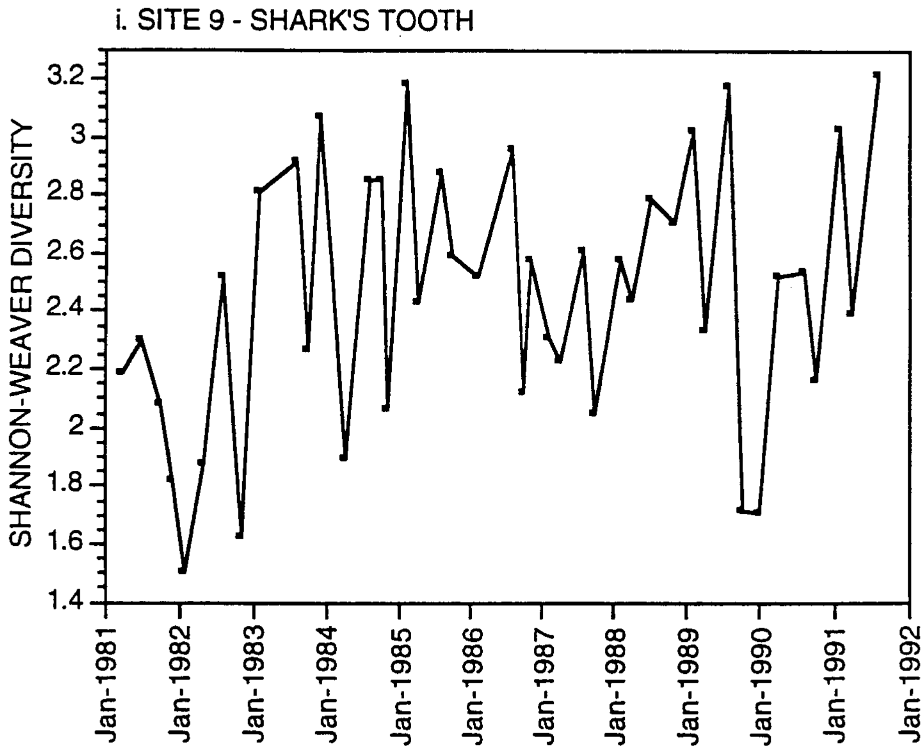


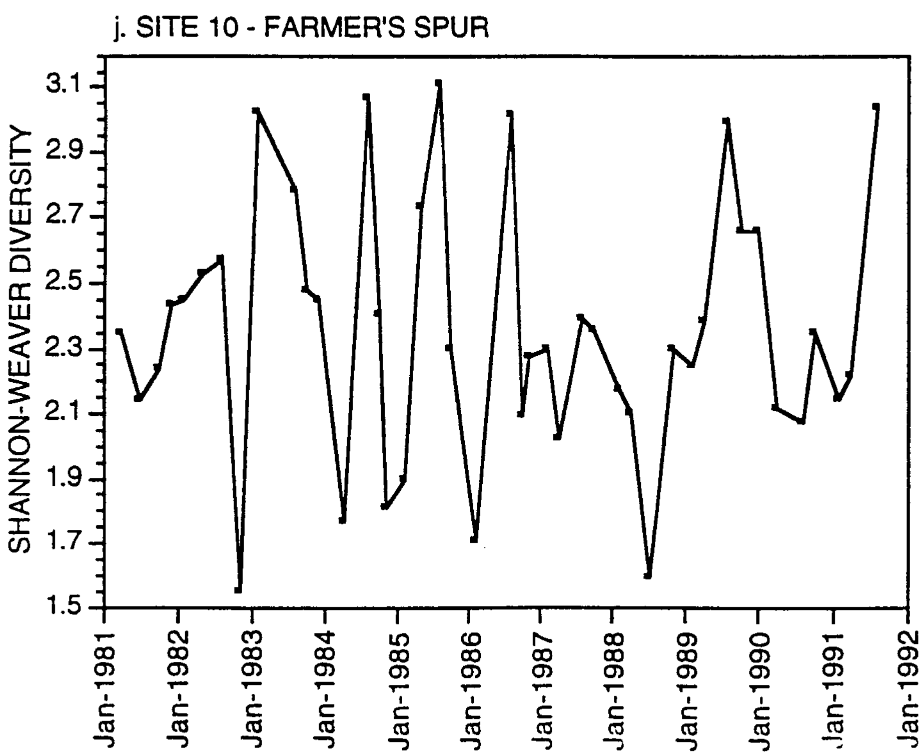
Figures 11g and 11h. Shannon-Weaver diversity values at sites 7(5) and 8(6) from 1981 to 1991.



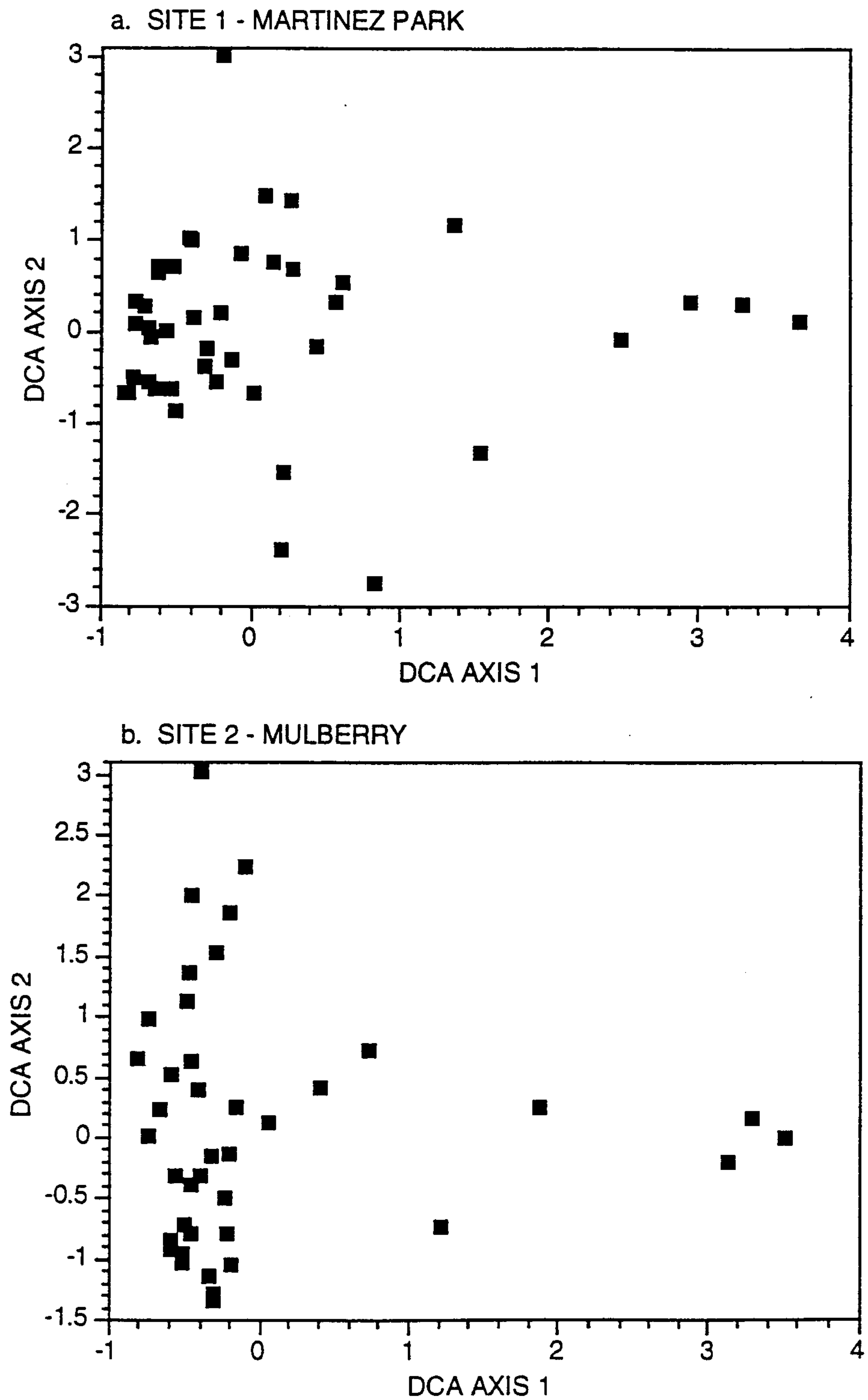


Figures 11i and 11j. Shannon-Weaver diversity values at sites 9(7) and 10(8) from 1981 to 1991.

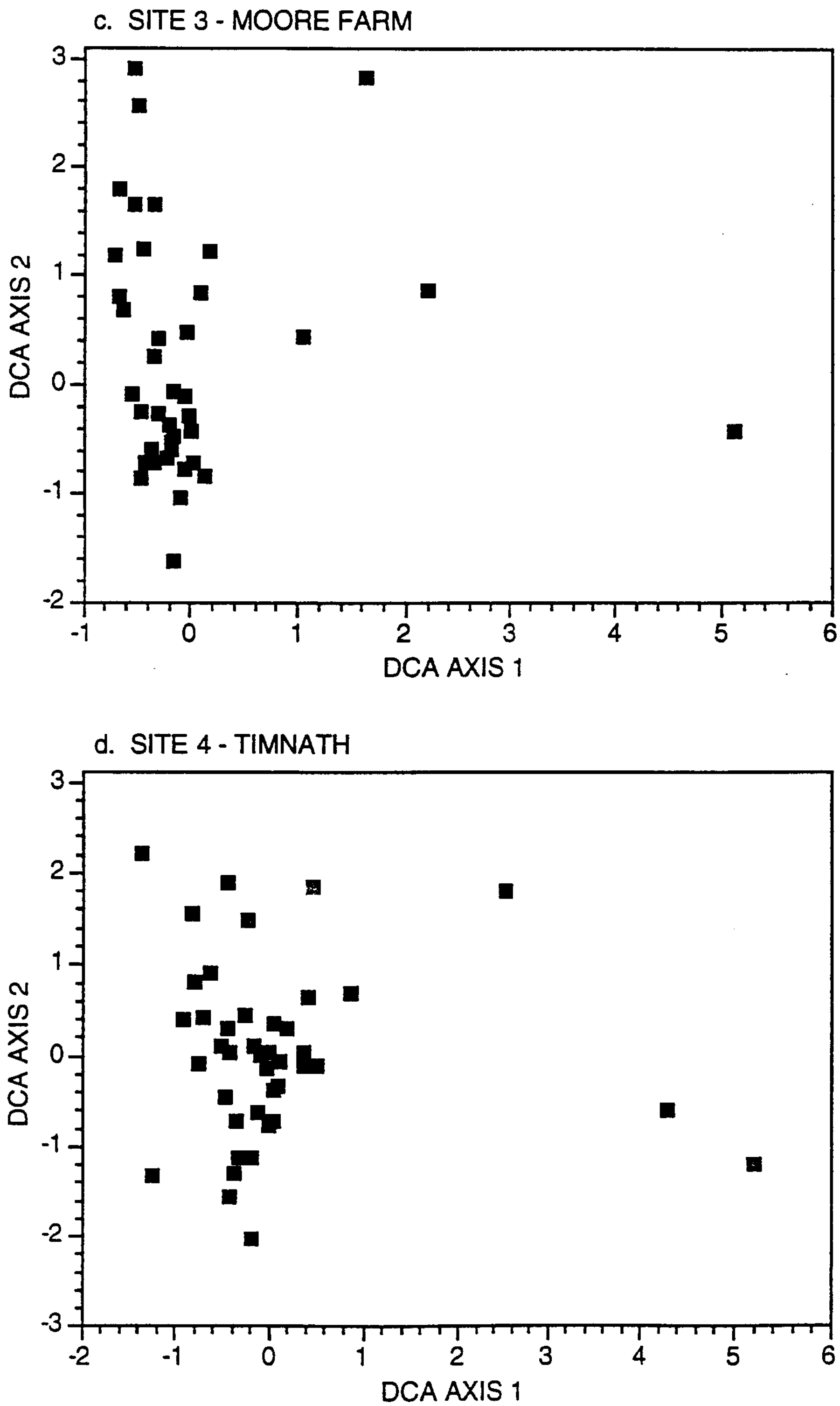




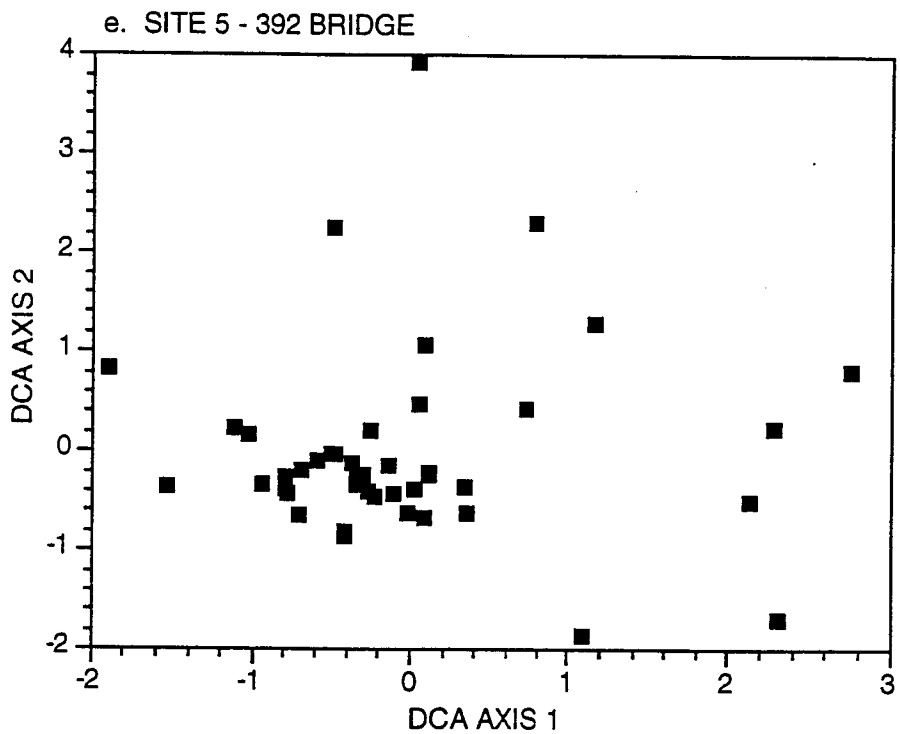
Figures 12a and 12b. Detrended correspondence analysis (DCA) for sites 1(1) and 2 from 1981 to 1991. Each point indicates one sampling date at a given sites. Dates (month/year) are indicated for the outliers.

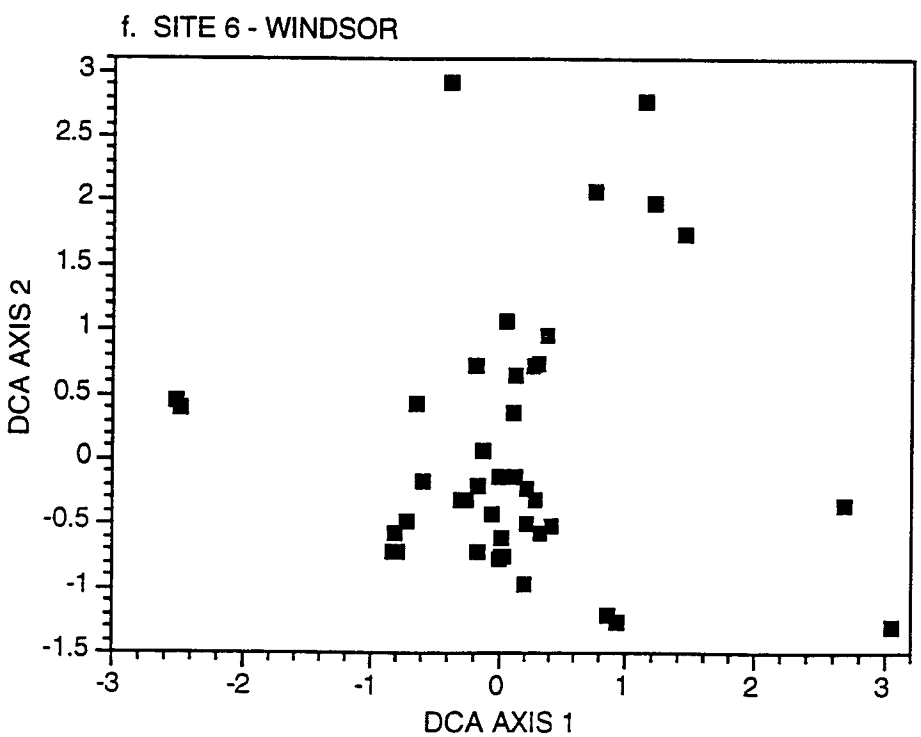


Figures 12c and 12d. Detrended correspondence analysis (DCA) for sites 3 and 4(2) from 1981 to 1991. Each point indicates one sampling date at a given sites. Dates (month/year) are indicated for the outliers.



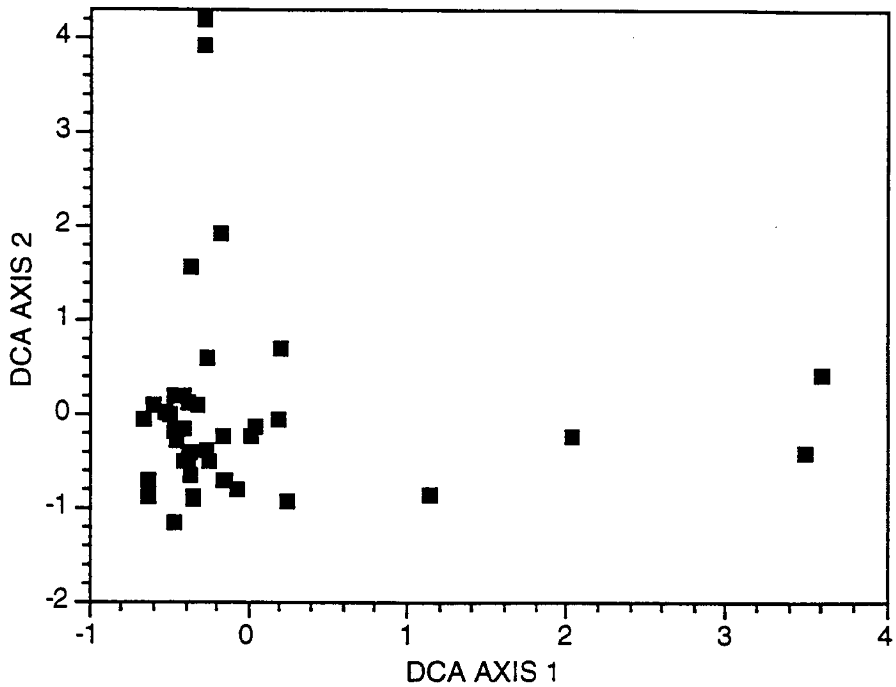
Figures 12e and 12f. Detrended correspondence analysis (DCA) for sites 5(3) and 6(4) from 1981 to 1991. Each point indicates one sampling date at a given sites. Dates (month/year) are indicated for the outliers.



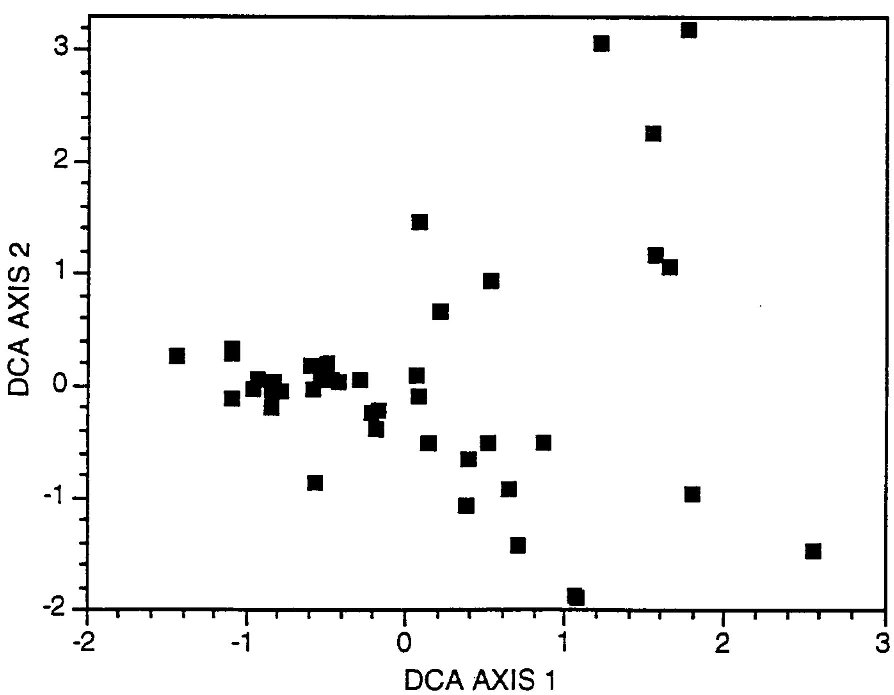


Figures 12g and 12h. Detrended correspondence analysis (DCA) for sites 7(5) and 8(6) from 1981 to 1991. Each point indicates one sampling date at a given sites. Dates (month/year) are indicated for the outliers.

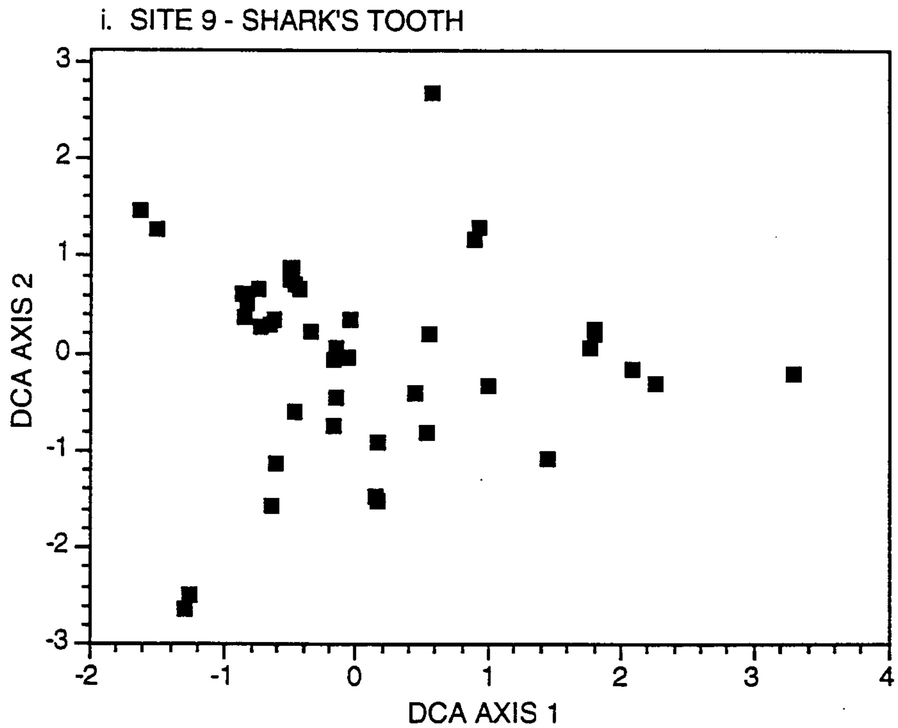
g. SITE 7 - GAGING STATION



h. SITE 8 - LAW DITCH



Figures 12i and 12j. Detrended correspondence analysis (DCA) for sites 9(7) and 10(8) from 1981 to 1991. Each point indicates one sampling date at a given sites. Dates (month/year) are indicated for the outliers.



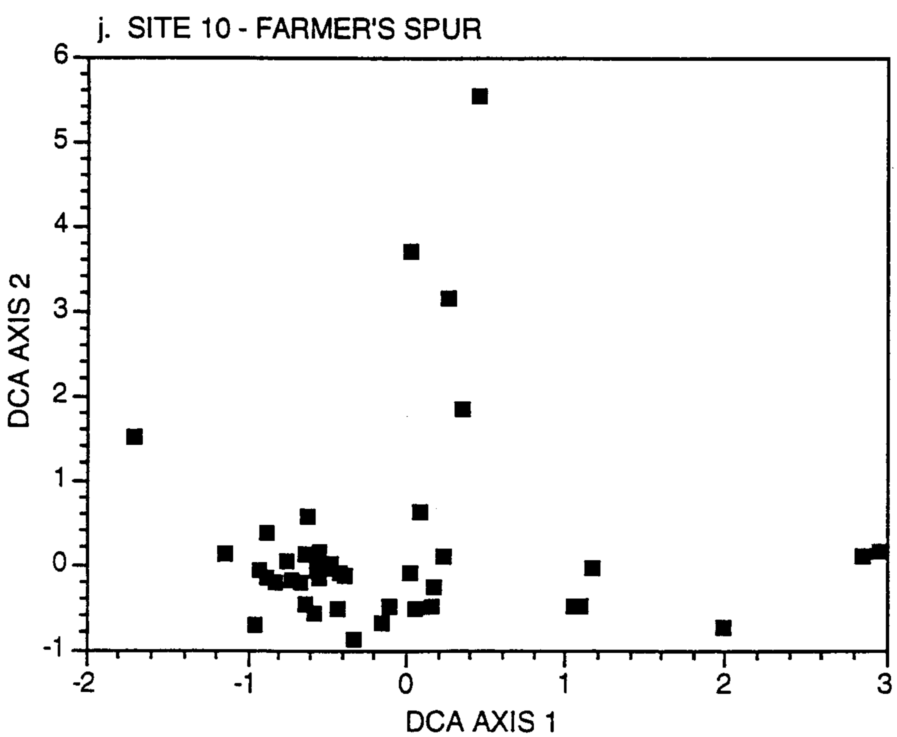


Table 2. Eigenvalues for axes 1-3 and samples omitted from individual site detrended correspondence analyses (DCAs)

Sampling Site	**Eigenvalues for DCA Axes 1-3**	**Sampling Periods Omitted**
1(1)	0.255, 0.189, 0.159	None
2	0.471, 0.278, 0.211	October and November 1984, February 1985
3	0.245, 0.207, 0.162	December 1983
4(2)	0.245, 0.185, 0.144	None
5(3)	0.214, 0.185, 0.153	None
6(4)	0.252, 0.175, 0.147	October 1981
7(5)	0.403, 0.207, 0.155	October 1981
8(6)	0.216, 0.200, 0.144	None
9(7)	0.275, 0.213, 0.168	December 1983
10(8)	0.293, 0.222, 0.187	August 1983

PHYSICOCHEMICAL DATA

Kodak Colorado Division contacted RBD Engineering Consultants in 1992 to compile and analyze the physicochemical data for the entire 22 year period of the study (1970-1992). They were asked to do the following:

1. Compile water quality data for eight sites (sites 1(1) and 4(2) through 10(8)) for the entire period of record (1970-1992) and review these data at each sampling site for errors and accuracy.
2. Prepare summary statistic characterizations of these water quality data at each sampling site.
3. Identify significant trends in water quality parameters at each site for recent (last 5 years of record) and long-term (last 10 - 22 years of record) time periods.
4. Compare the last 3 years of data at each site to instream state water quality standards and identify any areas of noncompliance or concern.
5. Recommend changes to the sampling program either in sites sampled, parameters sampled or frequency of sampling.

The complete results of this analysis are presented in Richard et al., (1993). Only those trends associated with the development of the index will be included here. Graphical depiction of the downstream trends from 1980 to 1992 are presented in Figures 13a-h. Physicochemical data at sites not analyzed by Richard et al. (1993) were obtained from Dr. Keith Elmond with the City of Fort Collins. The analysis by RBD Engineering only covered sites 1(1) and 4(2)-10(8). Figures 13a-h were obtained from Richard et al. (1993), a report compiled by RBD Engineering for Kodak Colorado Division, and use their numbering convention only. The data obtained from the City of Fort Collins covered sites 2 and 3. Although no trend or other analyses were performed on these data, it was used in the development of the index.

Significant seasonal variation in the physicochemical character of the plains segment of the Cache la Poudre River occurs between spring runoff and the remainder of the year. Certain reaches below the Fort Collins receive no native flow during the summer and winter periods. During spring runoff, the entire reach receives native flow; flows are cold with low mineral and high suspended solids concentration. During the remainder of the year, the flows in the plains segment reflect air temperatures and can be as high as 25°C. During the winter period, river temperatures are low, usually near 0°C. High mineral and hardness values are normal in the plains segment for all non-runoff periods.

Changes in Water Quality Going Downriver Since 1980

RBD Engineering (Richard et al., 1993) cautions that investigations involving water quality in the main channel may not reflect the changes in the water quality of the native flow; the numerous inflows and outflows may be the cause of the changes in water quality. Water quality trends were not examined prior to 1980 because in the mid to late 1970's significant changes in water quality occurred due to changes in wastewater treatment along the river.

The median dissolved oxygen concentration remained relatively consistent in a range of about 6 to 12 mg/l at all sites (Figure 13d). Many of the parameters showed a marked increase after site 1(1). The pH increased from 7.8 to 8.0 between sites 1(1) and 5(3) (Figure 13g). The pattern of alkalinity basically paralleled that of pH, but increased between sites 1(1) and 4(2) and then leveled off downstream (Figure 13a). Conductivity showed a marked increase at site 4(2) and continued to gradually increase thereafter (Figure 13c). This marked increase is explained by diversion of much of the native flow between sites 1(1) and 4(2) and its replacement with irrigation return flows, treated wastewater effluents, and groundwater seepage. BOD5 and unionized ammonia nitrogen showed increases at sites 4(2) and 8(6) with little change at the other sites or even declines between these sites (Figures 13b adn 13f). These increases would be expected in municipal and industrial wastewater effluents. Site 4(2) receives treated effluents from Fort Collins' two treatment plants and site 8(6) receives effluent from the town of Windsor and the Kodak industrial facility. Turbidity remained somewhat low at site 1(1) through 6(4), increasing somewhat at site 7(5), and remaining high thereafter (Figure 13h). Dissolved lead was highest at site 1(1) and generally declined thereafter (Figure 13e). The relatively high dissolved lead values add support to the belief that groundwater contributions from the leaded gasoline spill near site 1(1) are entering the channel.

Areas of Concern -- Meeting Current Water Quality Standards

Richard et al. (1993) checked the data for exceedances of the current aquatic life or agricultural water quality standards for the last three years of record (usually 1990, 1991, and 1992). The study area spans a reach of the river that has been classified differently as to their acceptable in-stream water quality. Segment 11 spans the Cache la Poudre River from Shields Street in Fort Collins to immediately above the confluence with Boxelder Creek, sites 1(1) and 2. Segment 12 includes waters immediately above the confluence with Boxelder Creek to the Confluence with the South Platte River: sites 3 through 10(8). Agricultural standards are fixed values and are the same for both segments. The aquatic life standards are given as either fixed values or as variable table value standards (TVS). Water quality standards are considered to be met if the value does not exceed the standard more than once in three years.

Dissolved oxygen was found to exceed the aquatic life standard more than once in the three year period; DO was less than 5.0 (3.16, 4.50) twice at site 4(2). Although the two occurrences appear to be isolated, concern is warranted. Unionized ammonia as nitrogen was found to exceed the standard once at sites 5(3), 6(4), 7(5), 8(6), and 10(8). It was also found to exceed the standard more than three times at site 9(7). RBD Engineering considered sporadic elevations of unionized ammonia nitrogen as an area of concern starting at site 3 and continuing downriver. Unionized ammonia nitrogen appeared to have its source in treated wastewater effluent from its increase below known wastewater discharges, so it has been singled out as an area of concern. Dissolved lead was found to exceed the aquatic life standard twice at site 1(1) and both of these exceedances occurred within a three year period in May of each year.

Trends in Physicochemical Parameters

RBD Engineering did a trend analysis covering the entire period of record and for the last five years of record for all of the physicochemical parameters analyzed. In their detailed report they included trends all with a significance of $p=0.20$ or better and noted whether or not the trend resulted in a change of more than 1% per year on average. They also performed a visual trend analysis of the box and whisker plots (Figures 13a-h) and reported any significant trends that were merely a result of outlying high or low values. Physicochemical trends considered not significant after the visual analysis for parameters analyzed in this report are as follows: 5 year BOD5 at site 5(3) and the 20 year alkalinity at site 7(5).

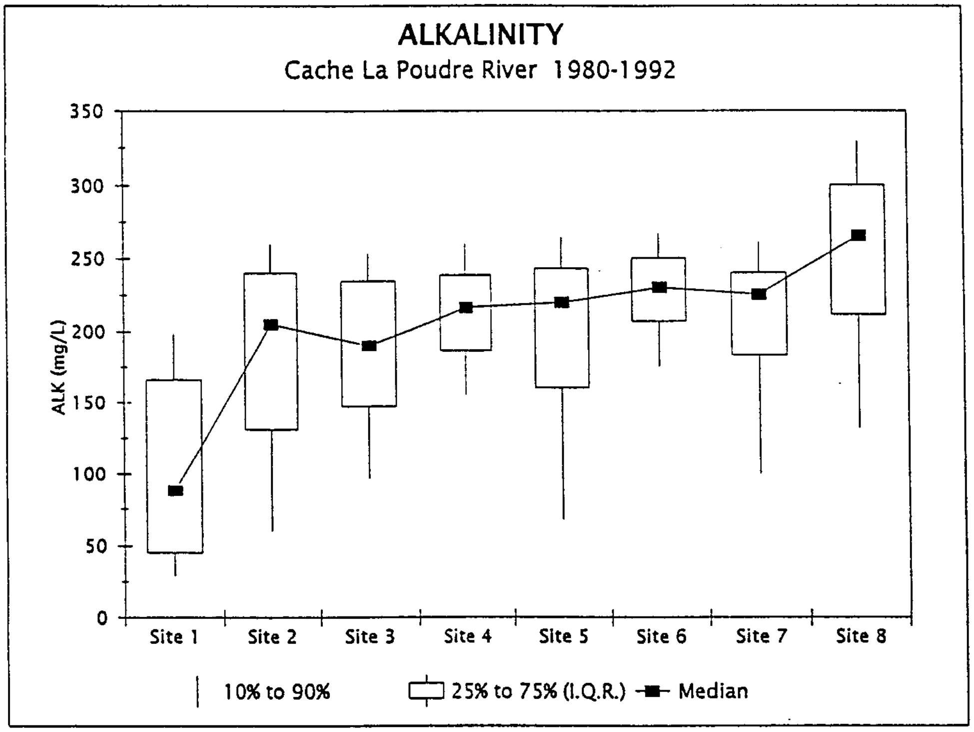
Several of the trends were only apparent at one isolated site, but trends present in at least two adjacent site were considered to be more significant than when taken in isolation as they may have more of a biological impact on the stream. Conductivity showed a long-term increasing trend at site 1(1) and 4(2) through 9(7) (sites 2 and 3 are not included in the RBD report). Unionized Ammonia showed a long-term increasing trend at sites 6(4) and 7(5) and an increasing recent trend at sites 9(7) and 10(8). Dissolved oxygen showed a decreasing long-term trend at sites 6(4) and 7(5). BOD5 showed a decreasing long-term trend at sites 4(2) and 5(3), but it showed an increasing recent trend at sites 8(6) and 9(7).

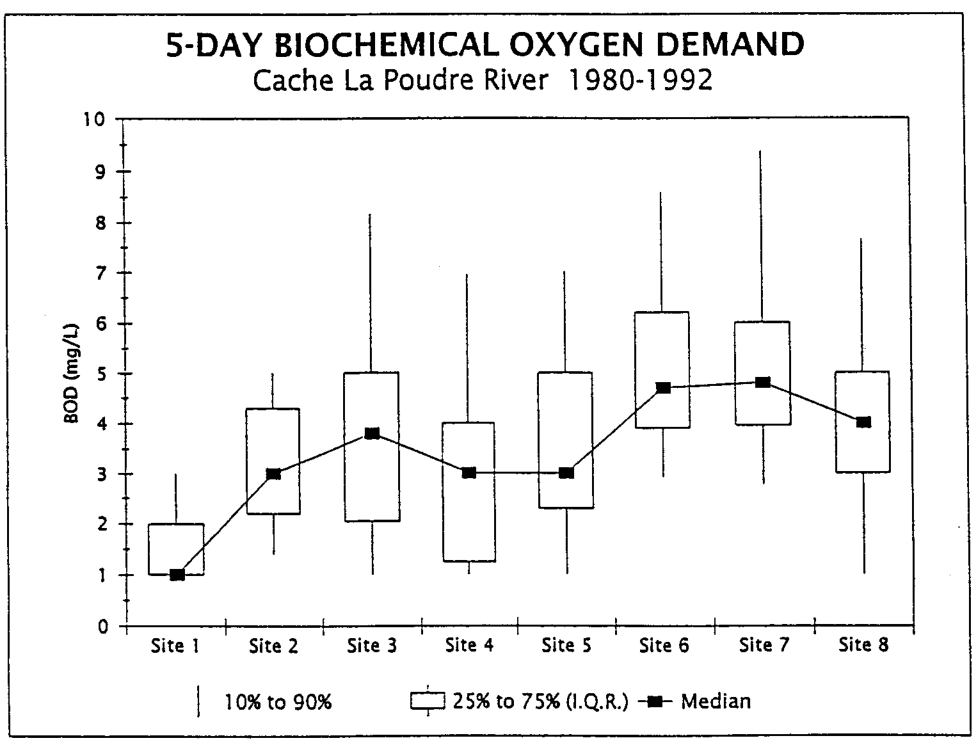
Trends in parameters having a significance of p=0.10 or better, and that are changing at greater than 1% per year are as follows: (1) Dissolved oxygen showed a decreasing 20 year trend at sites 6(4) and 7(5) and also showed a decreasing 5 year trend at site 9(7). (2) BOD5 showed a decreasing 20 year trend at sites 4(2) and 5(3), but showed both an increasing 5 and 20 year trend at site 8(6) and an increasing 5 year trend at site 9(7). (3) Turbidity showed an increasing 20 year trend at site 9(7). (4) Conductivity showed increasing 20 year trends at sites 1(1), 4(2), 5(3), 6(4), 7(5), 8(6), and 9(7). (5) Unionized ammonia nitrogen showed increasing 20 year trends at site 1(1), 6(4), 7(5), and 10(8) with increasing 5 year trends at sites 5(3), 9(7), and 10(8).

Flow Patterns

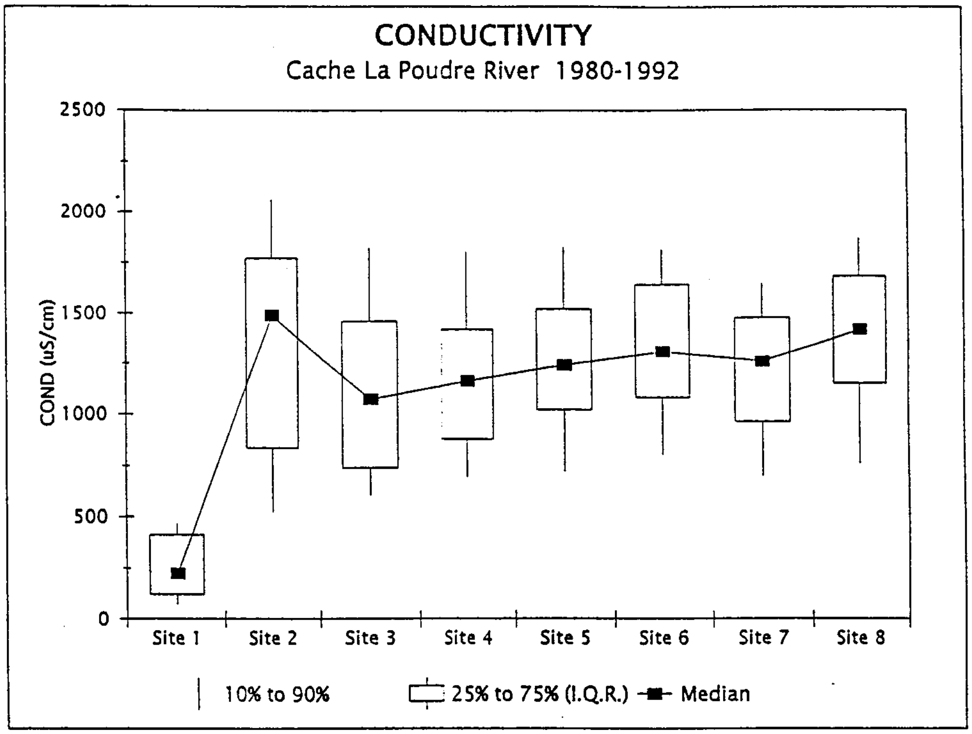
It is beyond the scope of this report to examine all the physical and chemical parameters measured during this study and relate them to the effects on the macroinvertebrate communities. However, flow (discharge) has been shown to play a major role in structuring lotic communities (Hynes, 1970; Poff and Ward, 1989; Ward 1992) and we believe it should be discussed in the context of the long-term changes of macroinvertebrates observed in the Poudre River. Figure 14 shows the flow pattern for the Poudre River at Fort Collins from May 1975-September 1991. The timing of the high flow events was influenced by spring snowmelt. In 1983, the highest flows observed in the Poudre River during the past ca. 75 years were recorded. Flow was again high in 1984 and 1986.

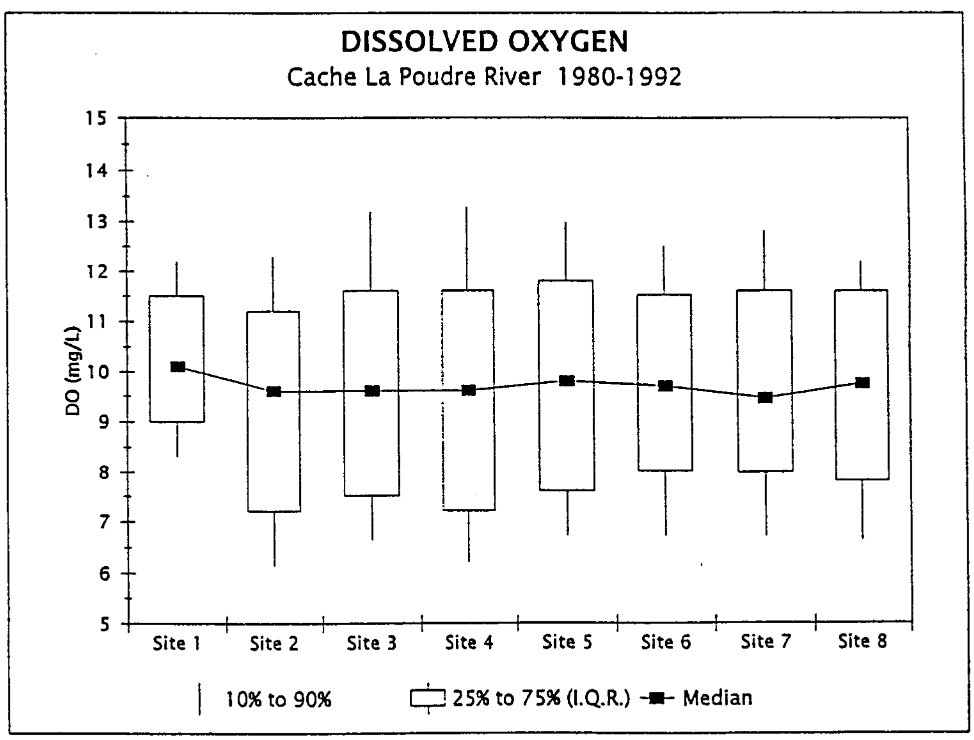
Figures 13a and 13b. Downstream trends in alkalinity and BOD5 as found by Richard et al. (1993) for 1980 to 1992 for sites 1(1) to 10(8). Data from sites 2 and 3 was not analyzed by Richard et al. (1993).



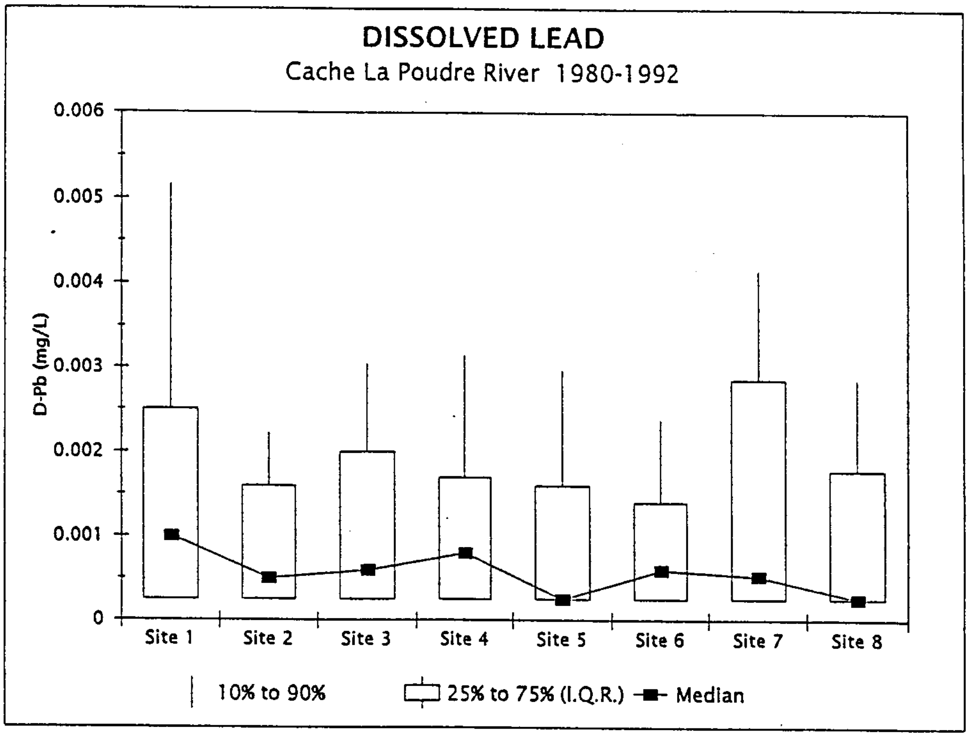


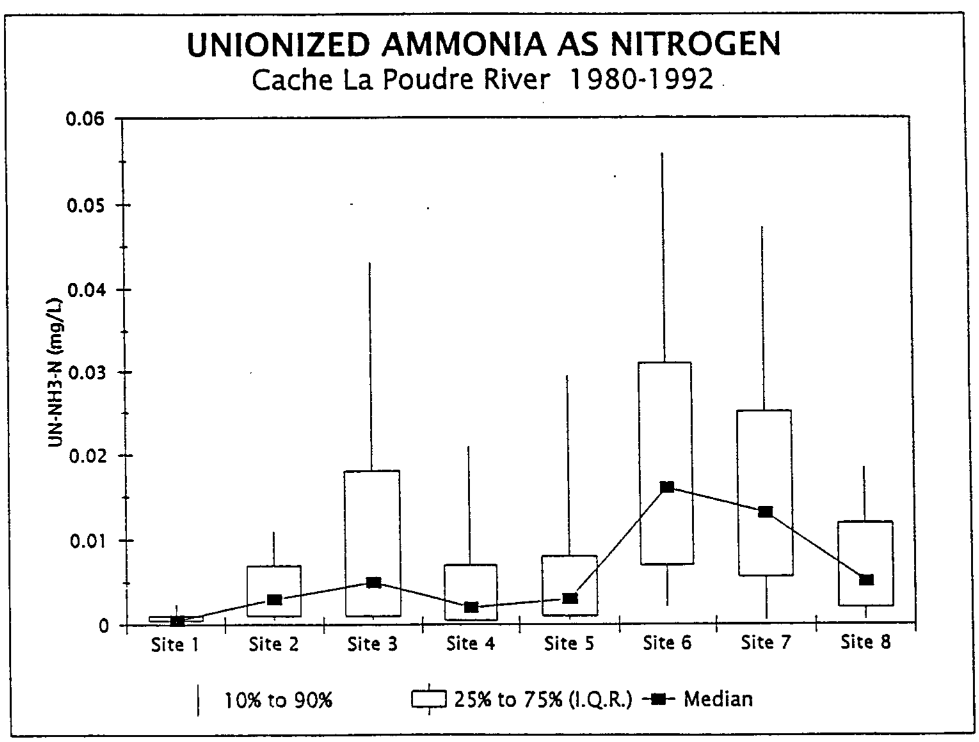
Figures 13c and 13d. Downstream trends in conductivity and dissolved oxygen as found by Richard et al. (1993) for 1980 to 1992 for sites 1(1) to 10(8). Data from sites 2 and 3 was not analyzed by Richard et al. (1993).



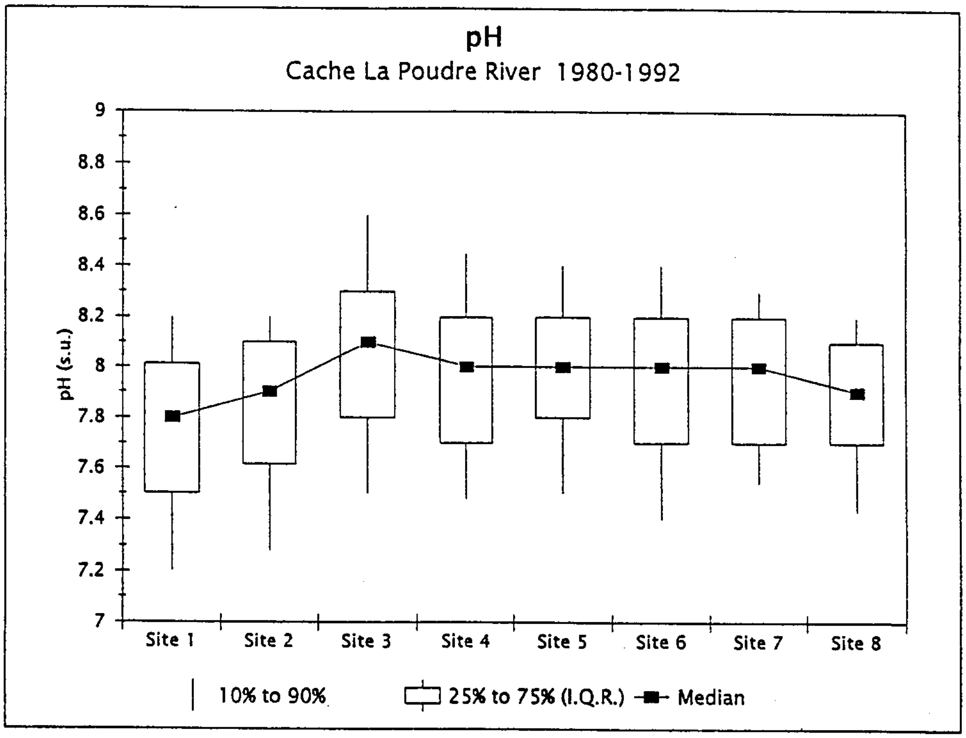


Figures 13e and 13f. Downstream trends in dissolved lead and unionized ammonia nitrogen as found by Richard et al. (1993) for 1980 to 1992 for sites 1(1) to 10(8). Data from sites 2 and 3 was not analyzed by Richard et al. (1993).





Figures 13g and 13h. Downstream trends in pH and turbidity as found by Richard et al. (1993) for 1980 to 1992 for sites 1(1) to 10(8). Data from sites 2 and 3 was not analyzed by Richard et al. (1993).



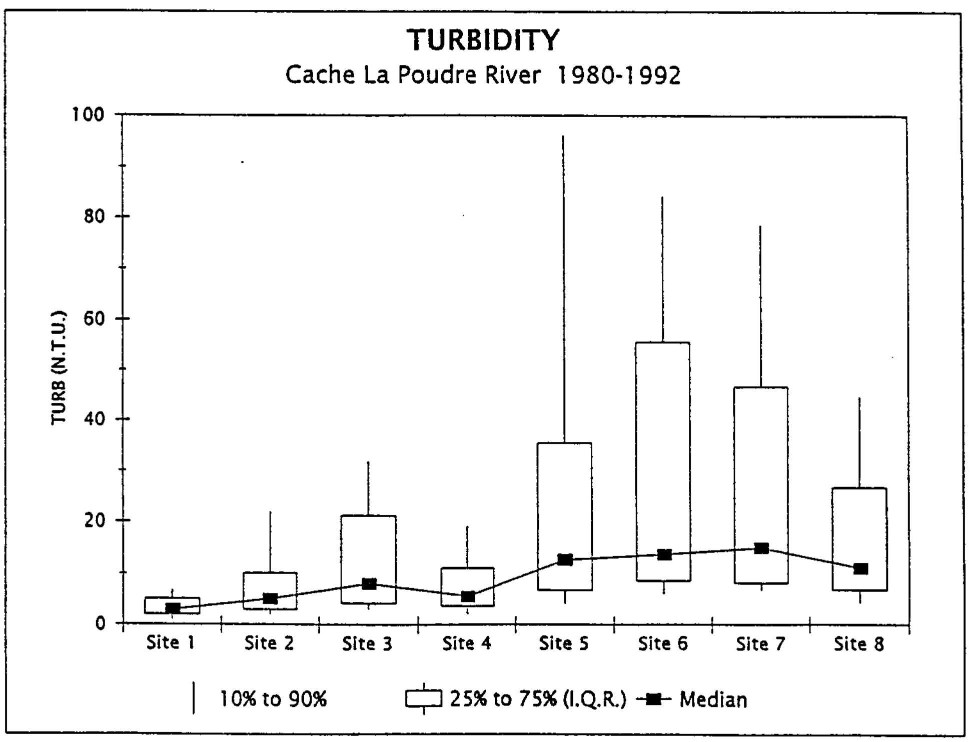
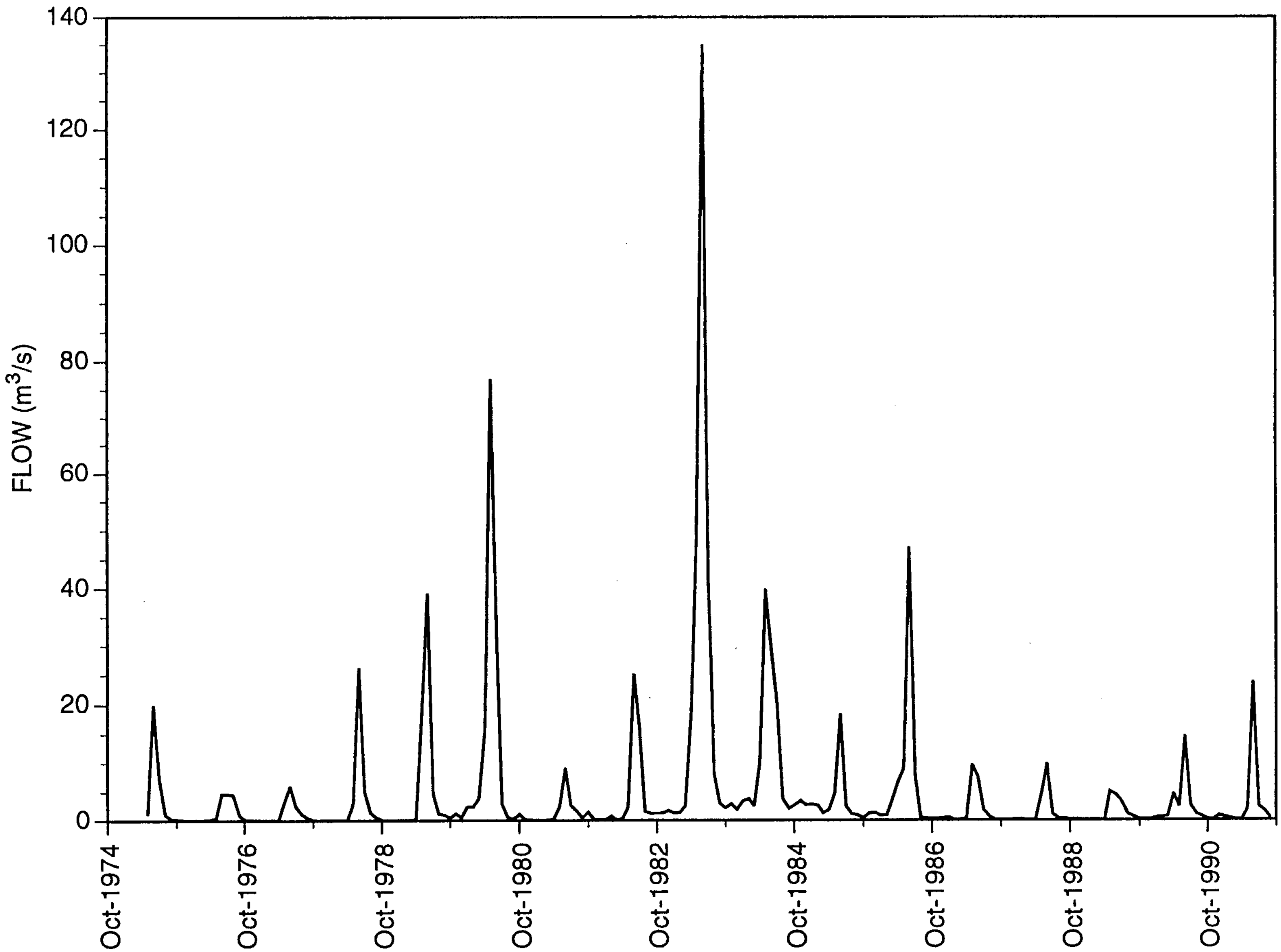


Figure 14. Average monthly flow for the Cache la Poudre River at Fort Collins.



DEVELOPMENT OF THE BIOTIC INDEX

Areas of Emphasis

Biotic indexes use macroinvertebrates (or other biota) to evaluate ecosystem health. Ideally, a biotic index should use the macroinvertebrate tolerances to look at physicochemical as well as biological/ecological characteristics of the system. Winget and Mangum (1979) termed these factors "habitat, water quality, and biotic relationships." Metcalfe (1989) termed these factors "physical, chemical and biological characteristics." Regardless of the terminology, we need to look at where they live, what they live in, who their neighbors are, and how they interact with them to get an accurate picture of the system.

Physical Habitat

Substrate composition has been shown to be an important variable in structuring aquatic communities (Cummins and Lauff, 1969; Minshall, 1984; Ward, 1992), but analysis of biotic trends with respect to substrate was not performed for the following reasons: (1) data from all three of the Surbers was combined in the final presentation of the data; (2) an effort was made to sample over a variety of substrate types; and (3) data on substrate composition at each site is also qualitative at best.

Biological/Ecological

Qualitative descriptions of habitat preference and ecology of the dominant species in the system are included in "Species List and its Rationale" and in "Responses of Common Taxa," as added information for the reader, but are not directly included in the quantitative analysis. Merritt and Cummins (1984) provide a wealth of qualitative information about the ecology of the North American aquatic insects.

Chemical

The majority of the biotic index focuses on temporal and longitudinal patterns that emerge after examining taxonomic abundance in relation to selected chemical variables. Since 1970 quite a variety of physicochemical parameters have been monitored in the plains section of the Cache la Poudre River. Inclusion of all of these data in the development of this index would be a complex and probably superfluous undertaking, so only selected parameters were chosen to be included in the analysis: total alkalinity, biochemical oxygen demand (BOD5), conductance, dissolved oxygen, dissolved lead, unionized ammonia nitrogen, pH, and turbidity. Total alkalinity was chosen because Winget and Mangum (1979) found it to be correlated with density and biomass in the development of their index. Five-day biochemical oxygen demand (BOD5) was chosen due to its correlation with organic loading in a stream and because of its common use in the development of other indexes (Chutter, 1972; Hilsenhoff, 1977, 1982, 1987, 1988a, 1988b). Conductance was chosen as an overall index of the amount of dissolved solids (TDS) in the water column. Dissolved oxygen was chosen for its well known importance in the structuring of aquatic communities. Dissolved lead was chosen because Richard et al. (1993) highlighted it as a possible area of concern in their report. There was a leaded gasoline spill to the north of the river at site 1(1) and water released from Horsetooth Reservoir into the river has been shown to contain elevated lead concentrations (Richard et al., 1993). The combination of these factors may have resulted in the exceedance of the aquatic life standard at site 1(1) (Richard et al., 1993). Unionized ammonia nitrogen was chosen because sporadic elevations in this parameter caused Richard et al. (1993) to highlight it as an area of concern. pH was chosen because of its traditional inclusion in aquatic analysis and because macroinvertebrates have been shown to respond to changes in pH (Pratt and Hall, 1981). pH has also been implicated in the ability/inability of gastropods to properly calcify and thicken their shells (Brown, 1991). Turbidity was chosen because of its impacts on primary production and the ability of stream insect to respire.

The Biotic Index

In the development of the index it was decided to emphasize the predominant view that taxa will show unimodal abundance distributions along environmental gradients (Winget and Mangum, 1979). Physicochemical and macroinvertebrate data collected from 1981 to 1991 were combined from 10 sites along the Cache la Poudre River. The physicochemical conditions present at each site at the time of collection for each of the macroinvertebrate samples was determined. Initially an attempt was made to divide the observed ranges for each of the selected parameters into qualitative categories based on relevant biological/ecological information about species' tolerances to those parameters (Winget and Mangum, 1979). The preferred range for each taxon was determined qualitatively by discerning the category in which taxa were found in greatest abundance; however, due to the lack of substantial physicochemical diversity within the study reach, qualitative separation of the taxa in this manner could not reliably be accomplished.

In order to circumvent this apparent impasse, a more quantitative approach had to be used. An organism should show a unimodal abundance distribution along an environmental gradient (Winget and Mangum, 1979), with its maximum abundance at its preferred value for existence within the gradient. A weighted average, using numerical abundance as "weights", was calculated for the selected parameters (Table 3 and Figure 15). Only data on selected parameters collected coincidentally with the macroinvertebrate data are used in the calculation. This value was used as the "preferred value" (PV) for the species. The preferred value is the point along an environmental gradient at which the organism most commonly occured.

The following formula was used to calculate preferred values (PV) for each of the taxon used in the development of the index:

$$PV = \sum n_i EP_i / N$$

PV = preferred value for the i^{th} taxon

n_i = abundance of the i^{th} taxon at time of collection of the environmental parameter

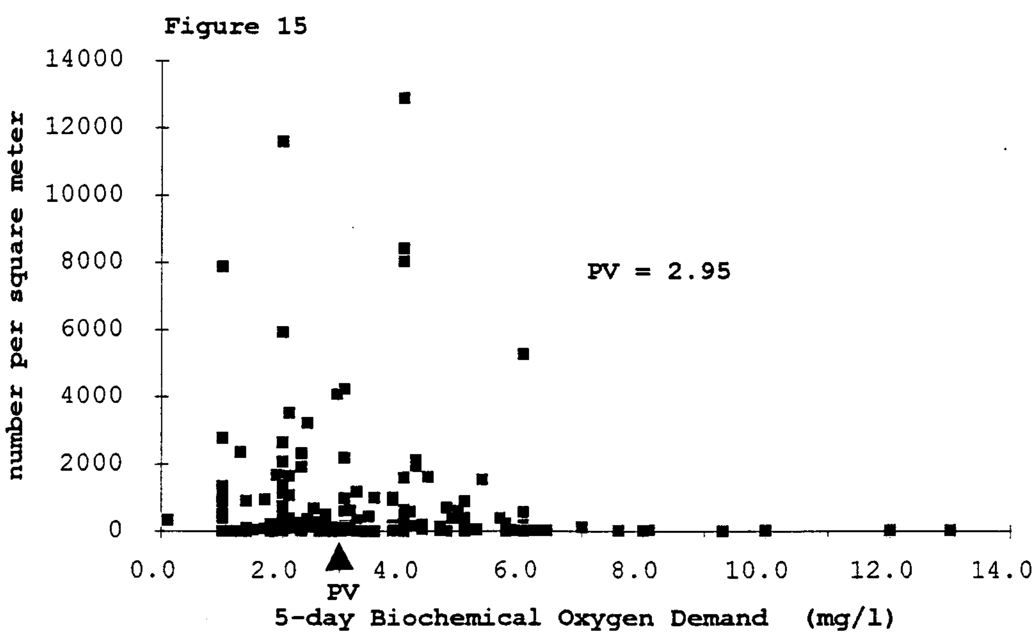
EP_i = value of the environmental parameter at time of collection of the i^{th} taxon

$N = \sum n_i$

Table 3. Portion of the combined macroinvertebrate/physicochemical database to provide a sample calculation of the preferred 5-day biochemical oxygen demand (BOD5) for *Paraleptophlebia* (Ephemeroptera: Leptophlebiidae). The numbers were taken directly from the combined database and are rounded to one decimal place. The preferred BOD5 for *Paraleptophlebia* is found by dividing the sum of the products of the environmental parameter and the organisms respective abundance by the sum of the respective abundance: 10824.6/2225.8 = 4.9

Genus	Date	Site	EP_i	n_i	EP_i*n_i
Paraleptophlebia	08/20/86	MART	2.0	28.7	57.4
Paraleptophlebia	08/20/86	TIMN	4.8	21.5	103.4
Paraleptophlebia	10/14/87	MART	1.0	93.3	93.3
Paraleptophlebia	08/31/83	MULB	2.0	3.6	7.2
Paraleptophlebia	08/14/91	392B	5.6	922.6	5166.7
Paraleptophlebia	08/20/86	MOOR	6.0	710.8	4264.9
Paraleptophlebia	10/10/90	MART	2.0	129.2	258.5
Paraleptophlebia	02/27/85	MART	3.0	14.4	43.1
Paraleptophlebia	08/20/86	GAGE	2.4	3.6	8.6
Paraleptophlebia	08/20/86	SHRK	4.0	132.8	531.3
Paraleptophlebia	02/23/83	SHRK	2.8	3.6	10.1
Paraleptophlebia	07/06/88	MOOR	4.0	7.2	28.7
Paraleptophlebia	11/13/91	MART	2.0	39.5	79.0
Paraleptophlebia	10/16/86	MART	1.0	3.6	3.6
Paraleptophlebia	11/16/88	MART	1.0	82.6	82.6
Paraleptophlebia	02/25/86	MART	3.0	28.7	86.2
		SUM =		2225.8	10824.6

Figure 15. Distribution of *Tricorythodes* (Ephemeroptera: Tricorythidae) along a BOD5 gradient. *Tricorythodes* is used because the large sample size is conducive to visual depiction of the preferred value. BOD5 is shown on the X-axis and the abundance in each individual sample is shown on the Y-axis. The preferred value for BOD5 is indicated on the X-axis and in the body of the graph as "PV".



These preferred values were then used to discover what the taxa were indicating about the conditions present in the reach. A weighted average, again using numerical abundance as "weights," of the preferred values for the organisms was calculated (Table 4 and Figure 16). Only the preferred values of the taxa collected at the site(s) or time(s) to be evaluated are used in this calculation. The value obtained is the "biologically determined value" (BDV) of the selected parameter of the site(s) or time(s) analyzed. The BDV is the physicochemical condition of the site(s) or time(s) under consideration as defined by the preferred values of the organisms collected at the same site(s) and time(s). The BDV is in the same units as the actual parameter being evaluated.

The following formula was used to calculate the BDV for each of the 8 chemical parameters analyzed for both the entire 11 year period and for each of the individual years at each site:

$$BDV = \sum n_i PV_i / N$$

BDV = biologically determined value of the selected parameter at the selected site(s) and/or time(s).

n_i = abundance of the i^{th} taxon collected at the selected site(s) and/or time(s)

PV_i = preferred value for the i^{th} taxon

$N = \sum n_i$

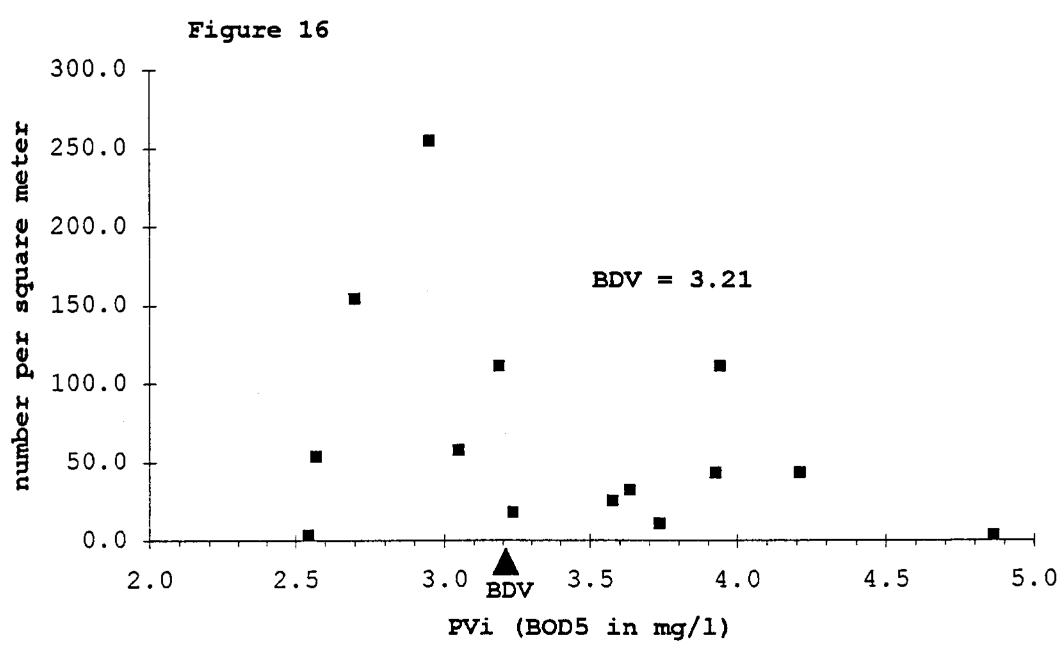
Ideally, having a different spatial distribution along each physicochemical gradient, each species would have a different preferred value (PV); as the physicochemical parameters change on either a temporal or spatial scale, so should the abundance of each taxon and the overall community composition. Each site with a "biologically significant" difference physicochemically should have a different community composition and BDV. The BDV should reflect the trend in the actual physicochemical condition of the reach.

The BDV was calculated as an average for the entire 11 year period of analysis and at each site (Figures 17a-h). These calculations were done to get an overall average picture of the downstream water quality trends for the period. The BDV was also calculated for each individual site by year from 1981 to 1991 (Figures 18a-o and Figures 19a-p). These calculations were performed to examine the detailed longitudinal and temporal trends in the BDVs.

Table 4. Portion of the combined macroinvertebrate/physicochemical database showing the results of a BDV calculation for site 2 (MULB) on 08/31/83. The numbers were taken directly from the combined database and are rounded to one decimal place. All of the macroinvertebrates collected on that date, their respective abundance, and their preferred values are used in the calculation. The biologically determined BOD5 (BDV) for the site is found by dividing the sum of the products of the preferred value and the organisms respective abundance by the sum of the respective abundance: 2959.1/922.6 = 3.21

Group	Family	Genus	Date	Site	n_i	PV_i	$PV_i * n_i$
TRICHOPTERA	BRACHYCENTRIDAE	*Brachycentrus*	08/31/83	MULB	3.6	2.5	9.1
EPHEMEROPTERA	LEPTOPHLEBIIDAE	*Paraleptophlebia*	08/31/83	MULB	3.6	4.9	17.5
EPHEMEROPTERA	HEPTAGENIIDAE	*Heptagenia*	08/31/83	MULB	10.8	3.7	40.2
DIPTERA	CHIRONOMIDAE	*Eukiefferiella*	08/31/83	MULB	18.0	3.2	58.1
TRICHOPTERA	HYDROPSYCHIDAE	*Hydropsyche*	08/31/83	MULB	25.1	3.6	89.9
DIPTERA	TIPULIDAE	*Tipula*	08/31/83	MULB	32.3	3.6	117.4
TRICHOPTERA	HYDROPSYCHIDAE	*Cheumatopsyche*	08/31/83	MULB	43.1	4.2	181.5
DIPTERA	CHIRONOMIDAE	*Orthocladius*	08/31/83	MULB	43.1	3.9	169.2
EPHEMEROPTERA	SIPHLONURIDAE	*Ameletus*	08/31/83	MULB	53.9	2.6	138.4
EPHEMEROPTERA	EPHEMERELLIDAE	*Ephemerella*	08/31/83	MULB	57.4	3.0	175.1
DIPTERA	CHIRONOMIDAE	*Cricotopus*	08/31/83	MULB	111.3	3.9	438.8
DIPTERA	CHIRONOMIDAE	*Polypedilum*	08/31/83	MULB	111.3	3.2	354.8
PLECOPTERA	CHLOROPERLIDAE	*Alloperla*	08/31/83	MULB	154.4	2.7	416.9
EPHEMEROPTERA	TRICORYTHIDAE	*Tricorythodes*	08/31/83	MULB	254.9	3.0	752.3
			SUM =		922.6		2959.1

Figure 16. Distribution of the preferred values for all of the organisms collected from site 2 (MULB) on August 31, 1983. The abundances, in number per m^2, are shown on the Y-axis and their respective preferred values (PVs) are shown on the X-axis. The biologically determined BOD5 (the BDV for BOD5) is indicated along the X-axis and in the body of the graph as "BDV".



Results

The trends in the BDV appear to at least qualitatively correspond to the trends in the actual physicochemical conditions of the sites. For many of the parameters a dramatic change was indicated circa 1983, when the highest flows observed on the Cache la Poudre River in the last 75 years were recorded (Figure 14). Biologically determined dissolved oxygen is the only case where the trend seems to differ from that of the actual physicochemical data. Significant changes in the BDV of any of the sites along the river should be viewed with caution and investigated further; they may be an indication of past or present perturbation to the system.

The results of the BDV calculations are displayed graphically in Figures 17a-h, Figures 18a-o, and Figures 19a-p. Figures 17a-h compare the results of the BDV calculations using a genus level of resolution, a family level of resolution, and an order or higher level of resolution. The "order or higher level" of resolution will be referred to as the "group level" of resolution in the discussion of the results for the individual parameters. Figures 18a-o compare downstream changes in the genus level biologically determined value (BDV) within a given year. Figures 19a-p compare interannual changes in the genus level BDV for individual sites. These trends, as well as others that appeared in the analysis, are discussed by parameter in relation to those found by Richard et al. (1993):

Alkalinity

When calculated for the entire 11 year period, the long-term average biologically determined alkalinity of the river shows a consistent increase between sites 1(1) and 4(2) and between sites 6(4) and 8(6) (Figure 17a). It shows a decrease in the BDV between sites 4(2) and 6(4) with a relatively flat response between sites 8(6) and 10(8) (Figure 17a). This pattern holds for the genus, family and group levels of resolution, but trends are noticeably less at the group level (Figure 17a).

When comparing adjacent sites, alkalinity was found by Richard et al. (1993) to increase significantly between sites 1(1) and 4(2) and to remain relatively constant thereafter (Figure 13a). For each of the 11 years examined using the index, biologically determined alkalinity also increase from site 1(1) to 4(2) (Figure 18a and 18b). In all years for which data are present, except 1984, the index also showed an increase between sites 1(1) and 2 and between sites 3 and 4(2) (Figure 18a and 18b). Between sites 2 and 3, an increase in biologically determined alkalinity was indicated for all years of record except 1986 (Figure 18a and 18b).

In the analysis of the individual sites, alkalinity showed no significant increasing recent or long-term trends at any individual sites (Richard et al., 1993). With the exception of sites 1(1), 6(4), and 7(5), biologically determined alkalinity also showed no noticeable increasing or decreasing trends from 1981 to 1991 (Figures 19a and 19b). Biologically determined alkalinity was found to decrease at site 1(1) for the years 1981 to 1984 and then return to its 1981 value from 1984 to 1988, remaining relatively constant thereafter (Figure 19a). This trend might be explained, not as a result of an actual change in the alkalinity, but as a result of the faunal recovery patterns associated with the abnormally high flow events surrounding the period (Figure 14). At sites 6(4) and 7(5) the biologically determined alkalinity remained relatively constant except for a substantial decrease that occurred in 1983 (Figure 19b). This decrease is again probably explained by the faunistic changes associated with the exceedingly high flows that occurred during that year (Figure 14).

A summary of the preferred alkalinity values and those tolerated by the taxa used in the development of the index is provided in Appendix IIIa.

Five-day Biochemical Oxygen Demand (BOD5)

When calculated over the entire 11 year period of analysis, the long-term average BOD5 increased between sites 1(1) and 2, sites 3 and 4(2), and sites 6(4) and 8(6), but showed an overall decrease between the remaining sites (Figure 17b). The only apparent significant separation between the genus, family and groups level calculations of BDV's were at sites 1(1) and 2; the biologically determined BOD5 increased with decreasing taxonomic resolution (Figure 17b).

When comparing adjacent sites, BOD5 was found to show a significant increase at sites 4(2) and 8(6) (Richard, et al., 1993). Biologically determined BOD5 also showed an increase at sites 4(2) and 8(6) for all years analyzed (Figure 18c and 18d). The increase from site 1(1) to 4(2) noted by Richard et al. (1993) also occurred in biologically determined BOD5 between sites 1(1) and 2 and between sites 3 and 4(2), but trend analysis between sites 2 and 3 is difficult due to the lack of data (Figure 18c and 18d).

In the analysis of the individual sites, Richard et al. (1993) found and increasing long-term trend in 5-day biochemical oxygen demand (BOD5) at site 8(6), a decreasing long-term trend at sites 4(2) and 5(3), and an increasing recent trend at sites 8(6) and 9(7) for BOD5. The decreasing long-term trends were not obvious in the analysis of the biologically determined BOD5 for sites 4(2) and 5(3), but a slight recent increasing trend is indicated in the biologically determined BOD5 for sites 8(6) and 9(7) (Figure 19c and 19d). Additionally a decreasing recent trend in biologically determined BOD5 for site 6(4) was indicated by the present analysis (Figure 19d).

A summary of the preferred BOD5 values and those tolerated by the taxa used in the development of the index is provided in Appendix IIIb.

Conductivity

When calculated over the entire 11 year period of analysis, the biologically determined conductance again mirrors the patterns found by Richard et al. (1993); biologically determined conductance increases dramatically after site 1(1) and gradually increases downstream with only the minor deviation in the pattern at site 3 that was documented by both Richard et al. (1993) and was picked up by the index (Figure 17c). The genus and family level long-term average biologically determined conductivities are almost identical, but the group level value is again slightly higher at site 1(1) when compared to the genus and family level values (Figure 17c).

When comparing adjacent sites, conductivity was found to increase dramatically at site 4(2) when compared to site 1(1) and continue to gradually increase downstream (Figure 13c) (Richard et al., 1993). Biologically determined conductance also showed a parallel pattern for the 11 years of analysis (Figures 18e and 18f). Only site 6(4) showed a deviation from the pattern with an indication of a sharp reduction in biologically determined conductance in 1984.

In the analysis of the individual sites, Richard et al. (1993) found increasing long-term trends in conductance at sites 4(2), 5(3), 7(5), 8(6), and 9(7); no other significant recent or long-term trends were found in their analysis. Biologically determined conductance shows an overall increase at all sites for the 11 years of analysis (Figures 19e and 19f), but again the trend analysis seems to have been impacted by the abnormal flow events that occurred in the early 1980's (Figure 14).

A summary of the preferred conductivity values and those tolerated by the taxa used in the development of the index is provided in Appendix IIIc.

Dissolved Oxygen

When calculated over the entire 11 year period of analysis, the biologically determined dissolved oxygen again shows an overall increasing downstream trend, but declines between sites 1(1) and 3, between sites 4(2) and 6(4), and between sites 8(6) and 10(8) (Figure 17d). Sharp increased are indicated between sites 3 and 4(2) and between sites 6(4) and 8(6) (Figure 17d). The patterns at the genus, family and group level are quite similar.

When comparing adjacent sites, Richard et al. (1993) found no significant changes; the median dissolved oxygen concentration remained in a consistent range over all eight sites analyzed. Biologically determined dissolved oxygen showed a slight increasing downstream trend for all sites (Figures 18g and 18h). Since this is contrary to what one would expect to find in the plains section of a front range river, some concern is warranted in relying on the dissolved oxygen portion of the index.

In the analysis of individual sites, Richard et al. (1993) found an increasing long-term trend in dissolved oxygen at site 6(4), a decreasing long-term trend at site 7(5), and a decreasing recent trend at site 9(7). Biologically determined dissolved oxygen shows a recent decreasing trend at sites 3, 6(4), and 7(5) (Figure 19g and 19h). Biologically determined dissolved oxygen also declines dramatically in 1983 for sites 6(4) and 7(5) and is again depressed in 1984 for site 6(4) (Figure 19h).

A summary of the preferred dissolved oxygen values and those tolerated by the taxa used in the development of the index is provided in Appendix IIId.

Dissolved Lead

When calculated over the 5 year period of analysis, the biologically determined dissolved lead decreases between sites 1(1) and 2, sites 5(3) and 6(4), and again between sites 9(7) and 10(8), but shows either an increasing or flat trend between the remaining sites (Figure 17e). The patterns at both the genus and family levels mimic each other closely, but the group level value again tends to flatten out the downstream trends (Figure 17e).

When comparing adjacent sites, Richard et al. (1993) found that dissolved lead was generally highest at site 1(1) and decreased downstream, but found no other significant trends between sites. Biologically determined dissolved lead definitely declines downstream from site 1(1), but fluctuates around an overall increasing trend downstream from site 1(1) (Figure 18i). The pattern of biologically determined dissolved lead seems to at least qualitatively mimic the trend in the upper ends of the ranges of dissolved lead shown in Figure 13e.

In the analysis of individual sites, Richard et al. (1993) found no significant recent or long-term increasing or decreasing trends, but clearly more data need to be collected. In Richard et al. (1993) and in this report only a maximum of 4 years of dissolved lead data were analyzed for any given site (Figures 19i and 19j).

A summary of the preferred dissolved lead values and those tolerated by the taxa used in the development of the index is provided in Appendix IIIe.

Unionized Ammonia Nitrogen

When calculated over the entire 11 year period, the index shows a consistent increase in alkalinity between sites 2 and 4(2), between sites 6(4) and 8(6), and between sites 9(7) and 10(8), with the parameter decreasing between remaining sites. This pattern holds for the genus, family and group levels of resolution (Figure 17f).

When comparing adjacent sites, Richard et al. (1993) noted significant increases in unionized ammonia nitrogen at sites 4(2) and 8(6). In many cases unionized ammonia nitrogen was declining slightly upstream, but increased at site 4(2) and 8(6). For the period 1981 to 1991 the index also showed an increase in biologically determined unionized ammonia nitrogen between sites 1(1) and 4(2); for years in which data were collected this can also be said for the difference between sites 1(1) and 3 (Figures 18j and 18k).

In the analysis of individual sites, Richard et al. (1993) found unionized ammonia nitrogen to show increasing long-term trends at site 1(1), 6(4), 7(5) and 10(8). At site 1(1), the index showed a decrease from 1981 to 1984, but an overall increase from 1984 to 1991 (Figure 19k). At site 6(4), the index shows a decreasing recent trend (Figure 19l). At site 7(5), the index again shows a decreasing recent trend (Figure 19l). At site 10(8), the index shows an increasing trend (Figure 19l). RBD Engineering (Richard et al., 1993) also mention an increasing recent trend in unionized ammonia nitrogen at site 9(7), but no such trend is obvious in from the index (Figure 19l).

A summary of the preferred unionized ammonia nitrogen values and those tolerated by the taxa used in the development of the index is provided in Appendix IIIf.

pH

When calculated over the entire 11 year period, the long-term average biologically determined pH showed an increase between sites 1(1) and 3, leveling off downstream. The genus level BDV as well and the family level BDV were quite similar, but again the group level BDV tended to reduce the magnitude of changes between sites (Figure 17g).

When comparing adjacent sites, Richard et al. (1993) found no significant downstream trends. The index showed an increase in the biologically determined pH between sites 1(1) and 3 leveling to a relatively constant plateau downstream from site 3 (Figure 18l and 18m). Calculation of biologically determined pH was impacted by the high flow event of 1983 (Figure 14).

In the analysis of individual sites, Richard et al. (1993) found no increasing recent or long-term trends for any of the eight sites in their analysis. Other than the apparent impacts of the high flow events that occurred in 1983, 1984 and 1986, no apparent trends in the biologically determined pH at individual sites were noted either (Figures 19m and 19n). The determination of the BDV at sites 1(1), 5(3) and 6(4) seems to have been most severely impacted by the high flow events.

A summary of the preferred pH values and those tolerated by the taxa used in the development of the index is provided in Appendix IIIg.

Turbidity

When calculated over the entire 11 year period, the long-term average biologically determined turbidity increases from sites 1(1) to 4(2), levels off, and the increases again after site 9(7). The genus and family level calculations of BDV mimic one another and the group level BDV tends to reduce any apparent trend (Figure 17h).

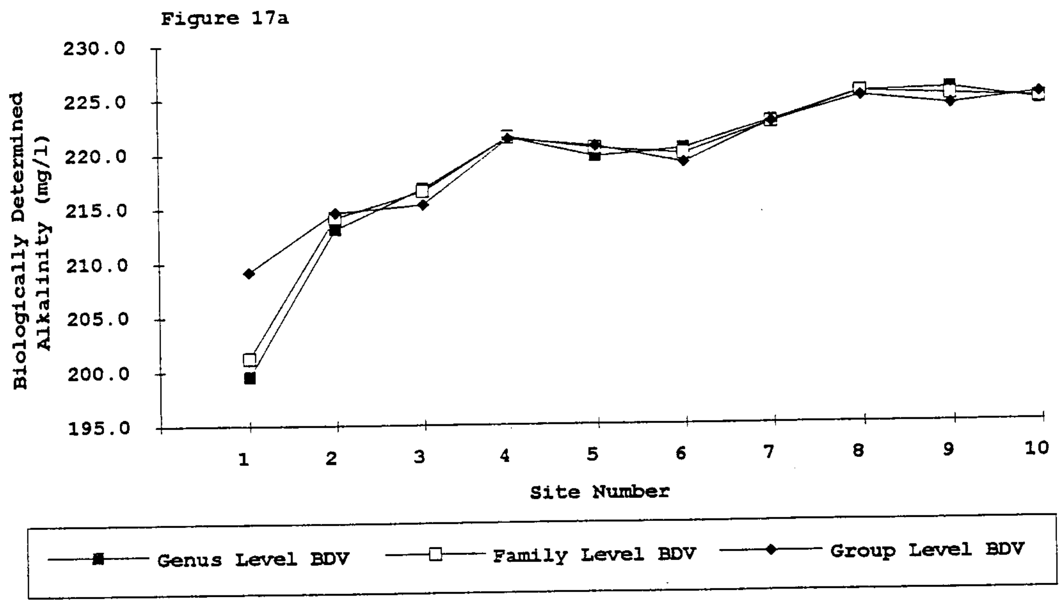
When comparing adjacent sites, Richard et al. (1993) found that turbidity was relatively low at sites 1(1) through 6(4), increased at site 5(3), and remained relatively constant thereafter (Figure 13h). Turbidity data were not collected at site 2 and 3 during the period of this analysis, but the biologically determined turbidity increased between sites 1(1) and 4(2).

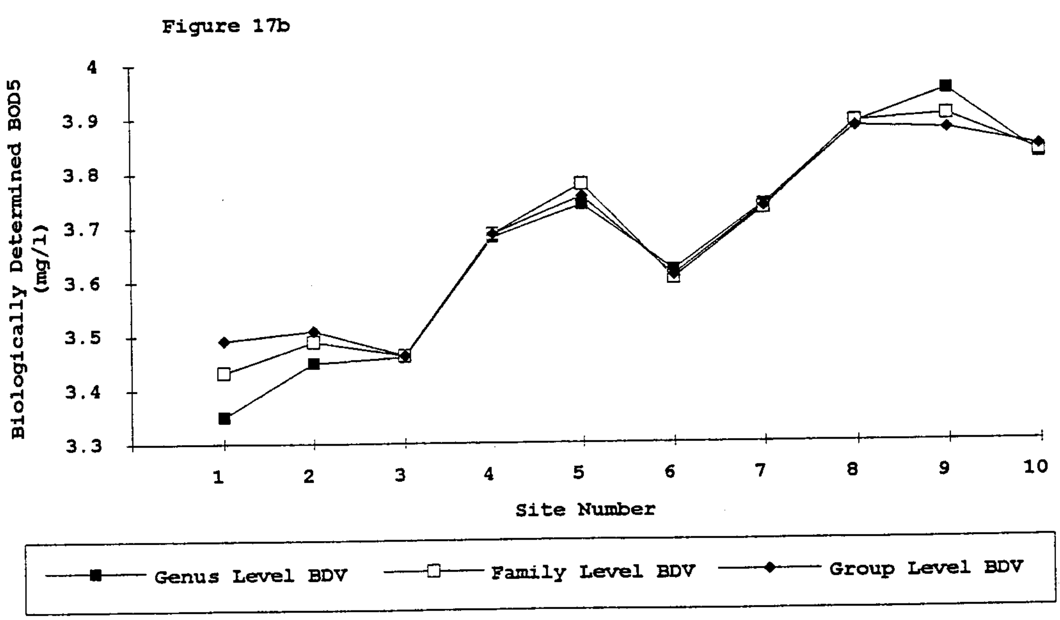
leveled off, and then increased again downstream from site 9(7), especially in the recent past (Figures 18n and 18o). Again, the high flow event of 1983 seems to have impacted the calculation of biologically determined turbidity in 1983.

In the analysis of individual sites, Richard et al. (1993) found an increasing long-term trend for turbidity at site 9(7), but no other significant recent or long-term trends were noted in their report. No apparent trends in biologically determined turbidity were revealed by the index for individual sites (Figures 19o and 19p). The high flow events of 1983 and 1984 seem to have impacted the calculation of the BDV for turbidity at all sites.

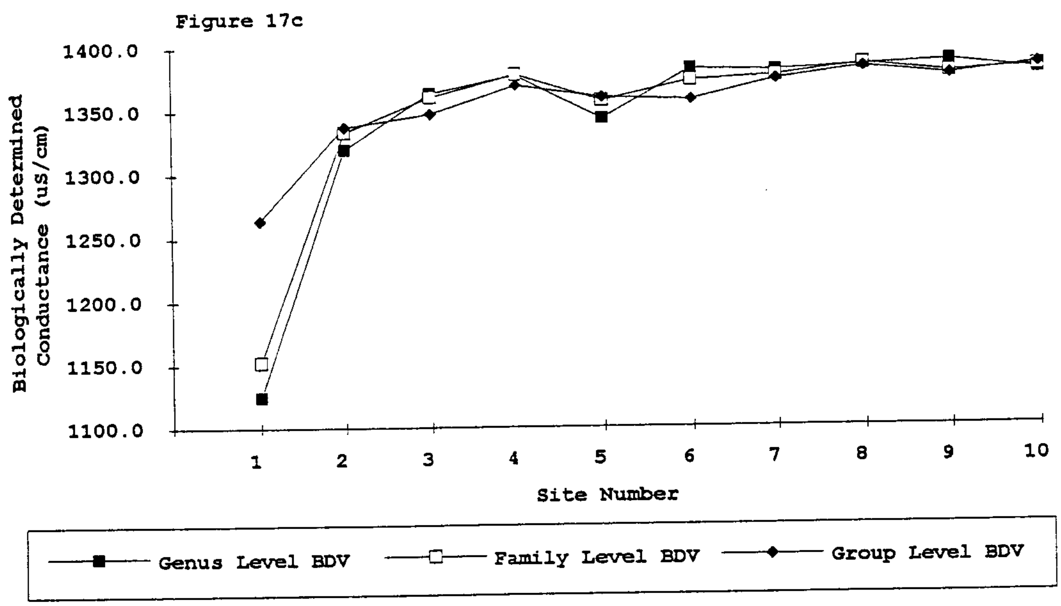
A summary of the preferred turbidity values and those tolerated by the taxa used in the development of the index is provided in Appendix IIIh.

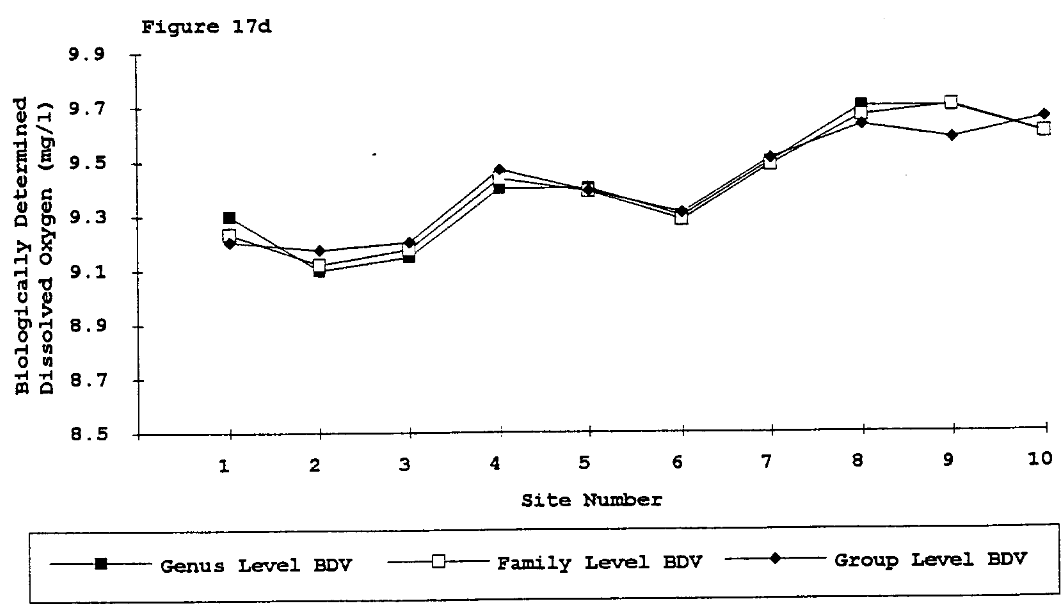
Figures 17a and 17b. Comparison of the genus level, family level and group level BDVs for alkalinity and BOD5 calculated over the entire 11-year period of analysis. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.



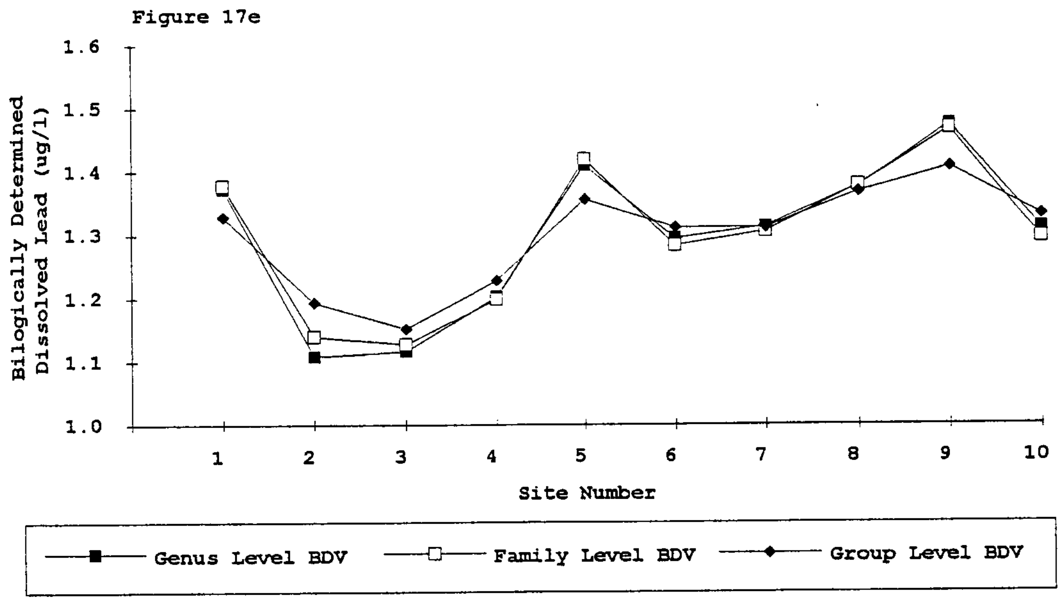


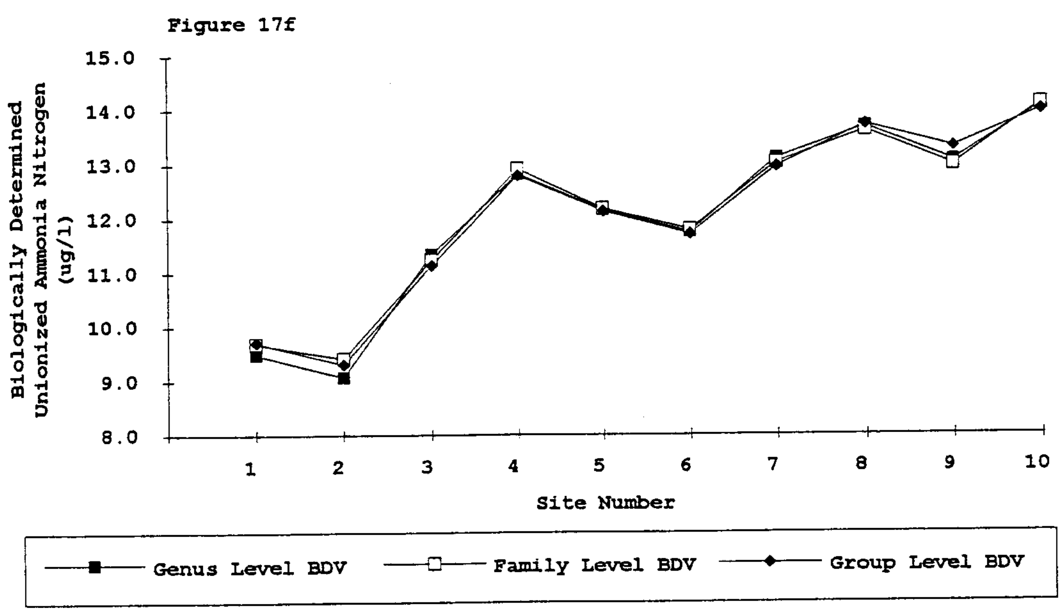
Figures 17c and 17d. Comparison of the genus level, family level and group level BDVs for conductance and dissolved oxygen calculated over the entire 11-year period of analysis. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.





Figures 17e and 17f. Comparison of the genus level, family level and group level BDVs for dissolved lead and uionized ammonia nitrogen calculated over the entire 11-year period of analysis. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.





Figures 17g and 17h. Comparison of the genus level, family level and group level BDVs for pH and turbidity calculated over the entire 11-year period of analysis. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.

Figure 17g

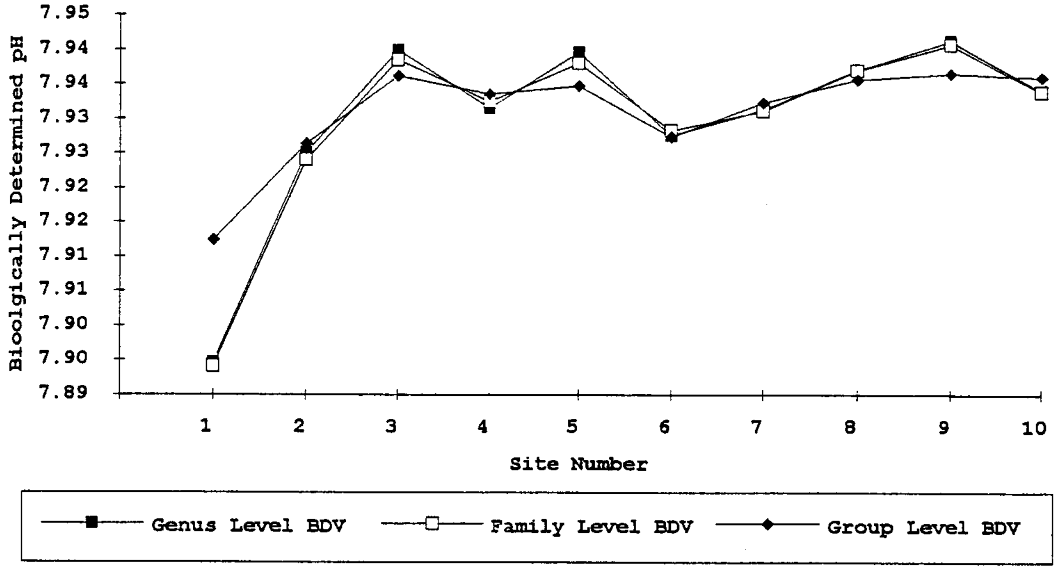
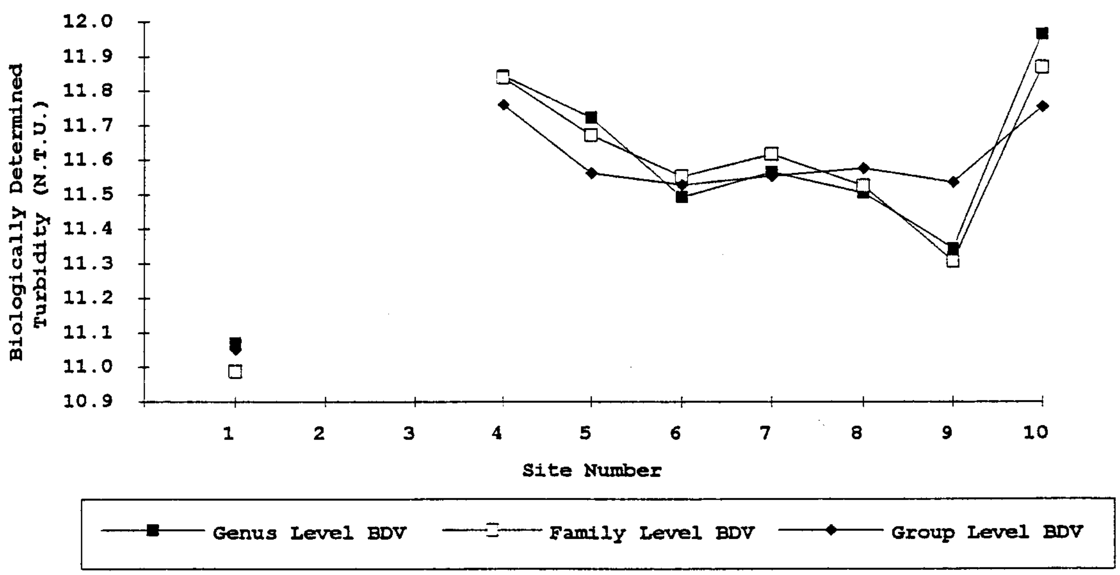
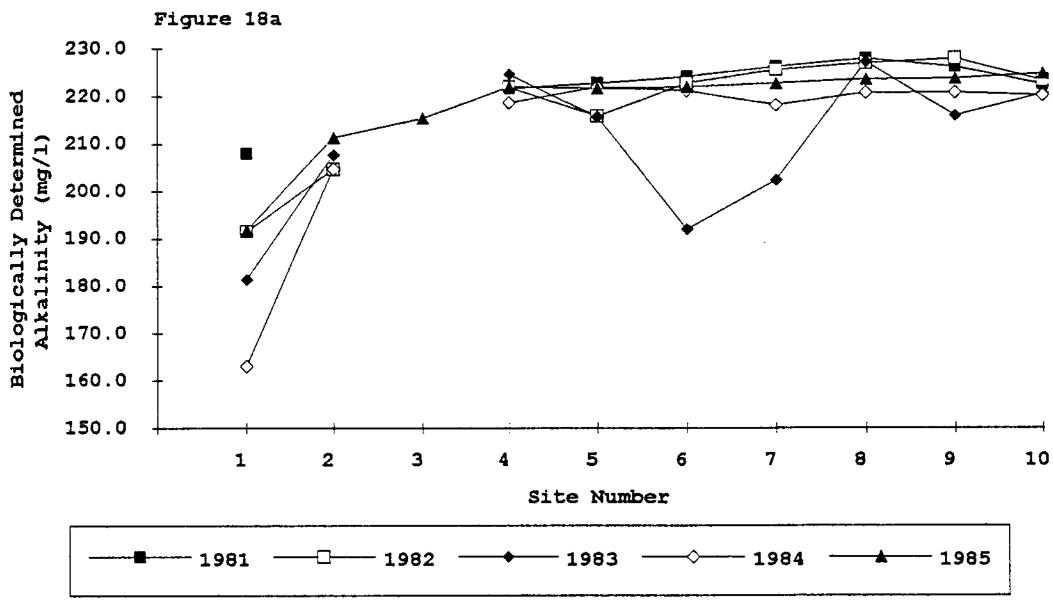
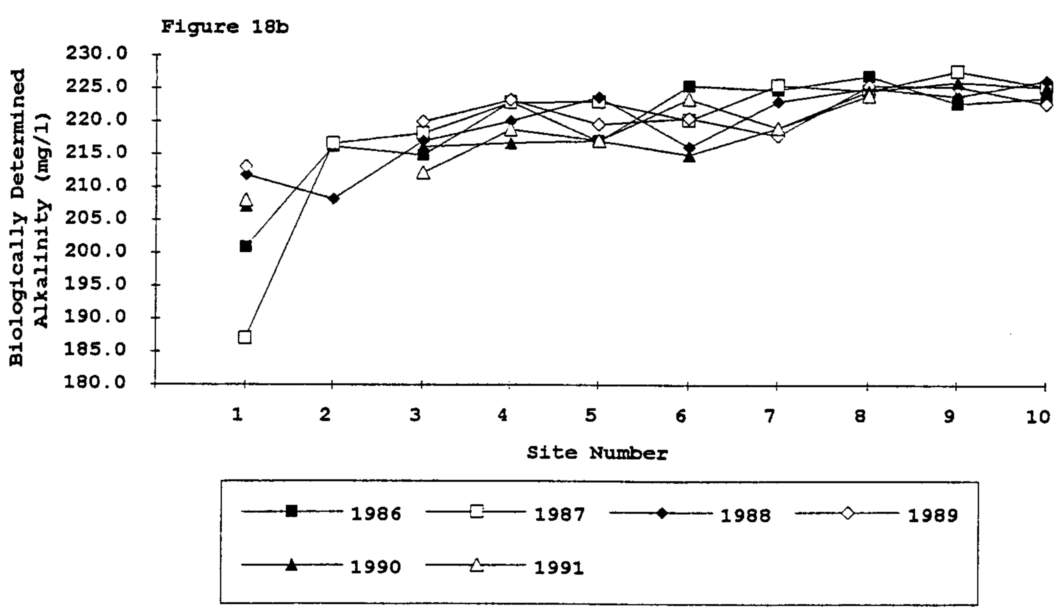


Figure 17h



Figures 18a and 18b. Downstream trends in the BDV for alkalinty by year. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.





Figures 18c and 18d. Downstream trends in the BDV for BOD5 by year. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.

Figure 18c

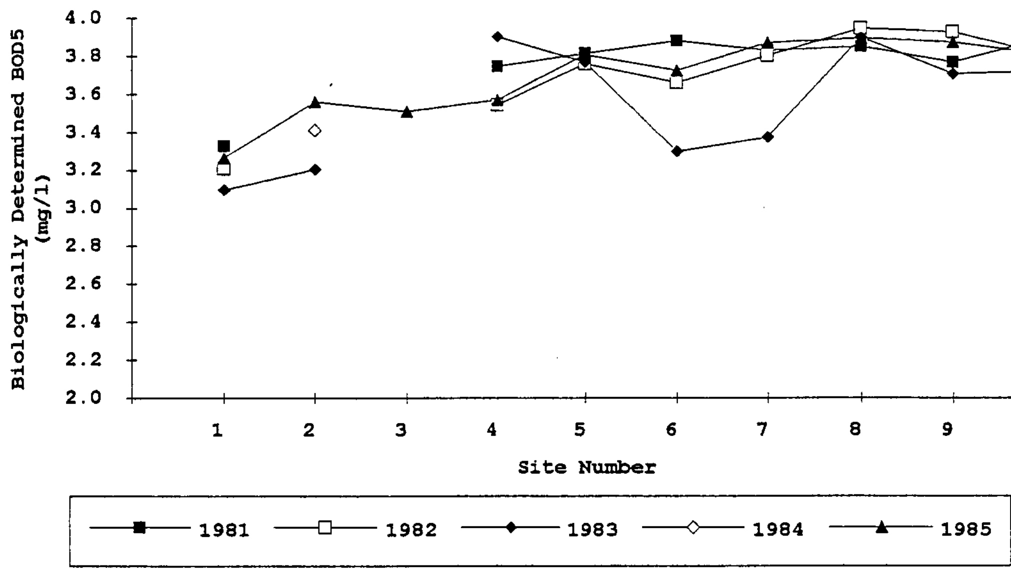
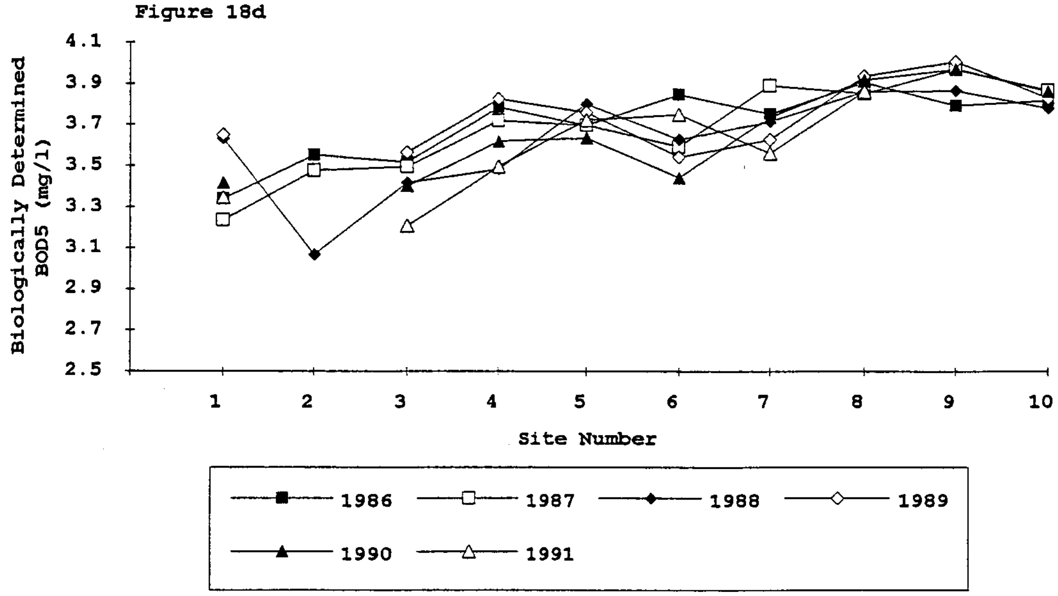
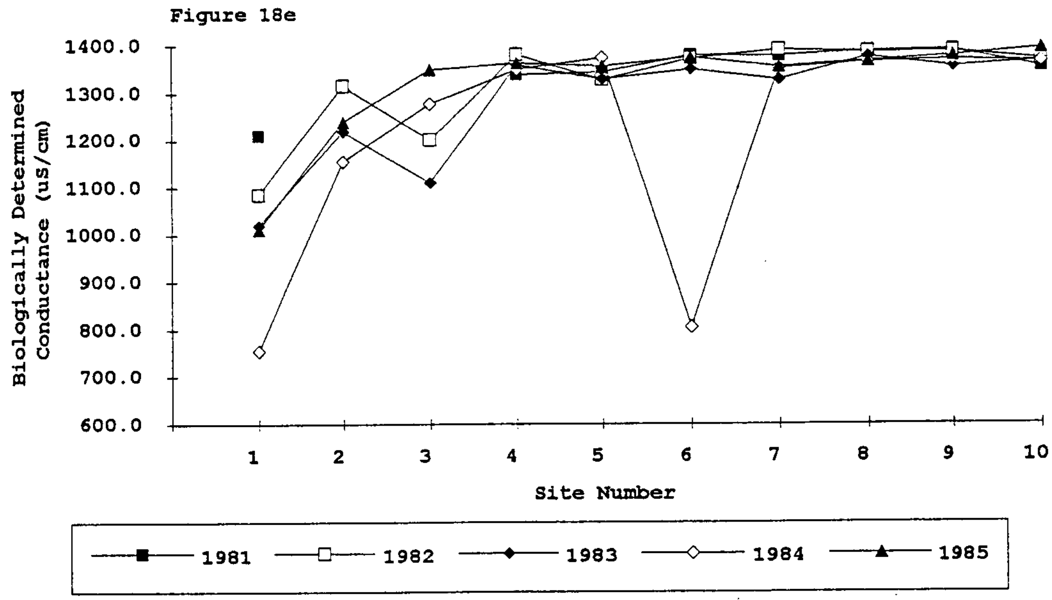
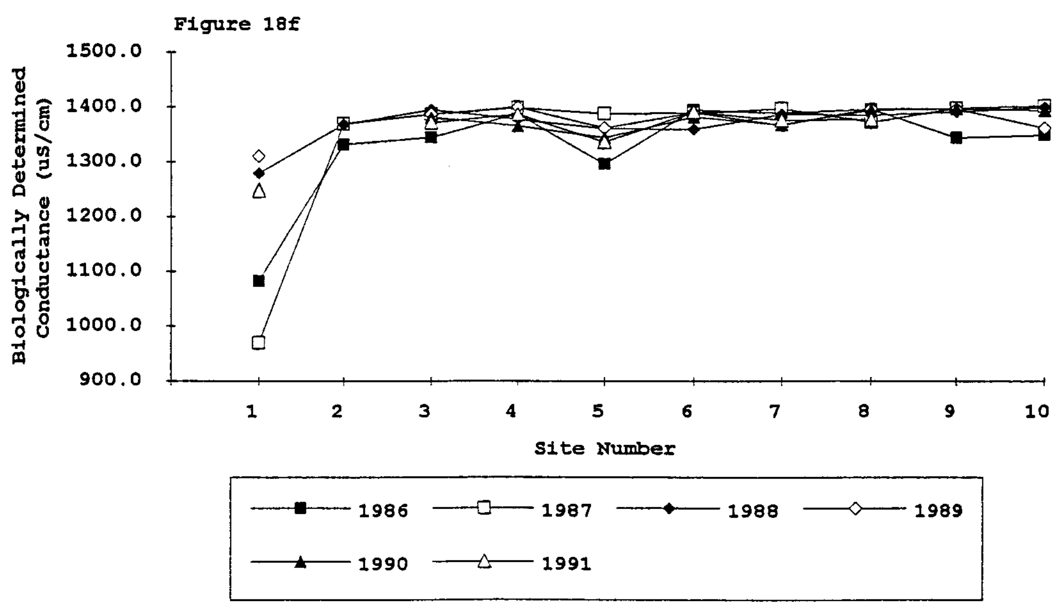


Figure 18d

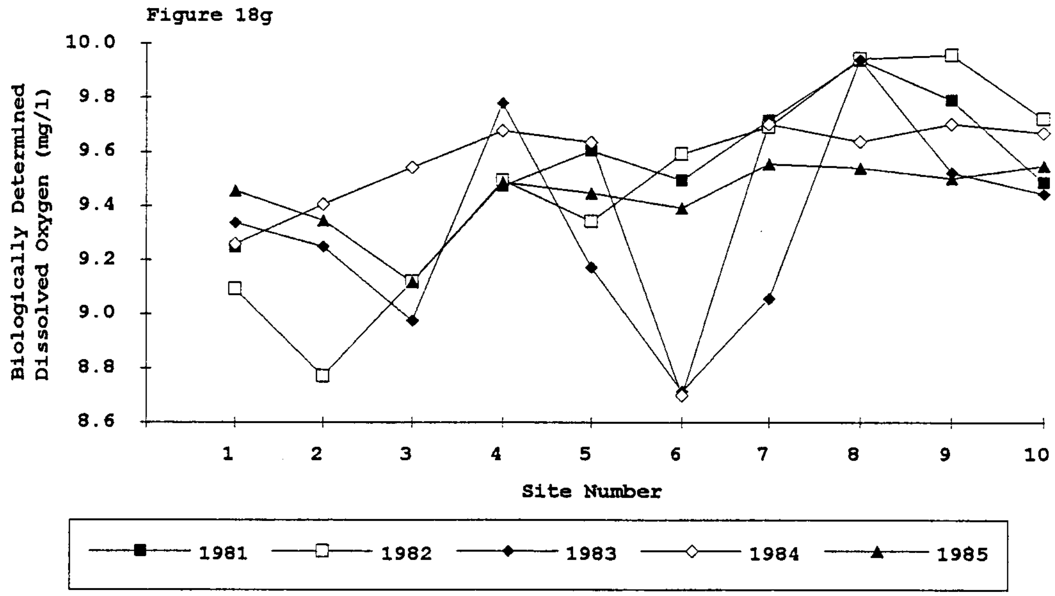


Figures 18e and 18f. Downstream trends in the BDV for conductance by year. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.





Figures 18g and 18h. Downstream trends in the BDV for dissolved oxygen by year. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.



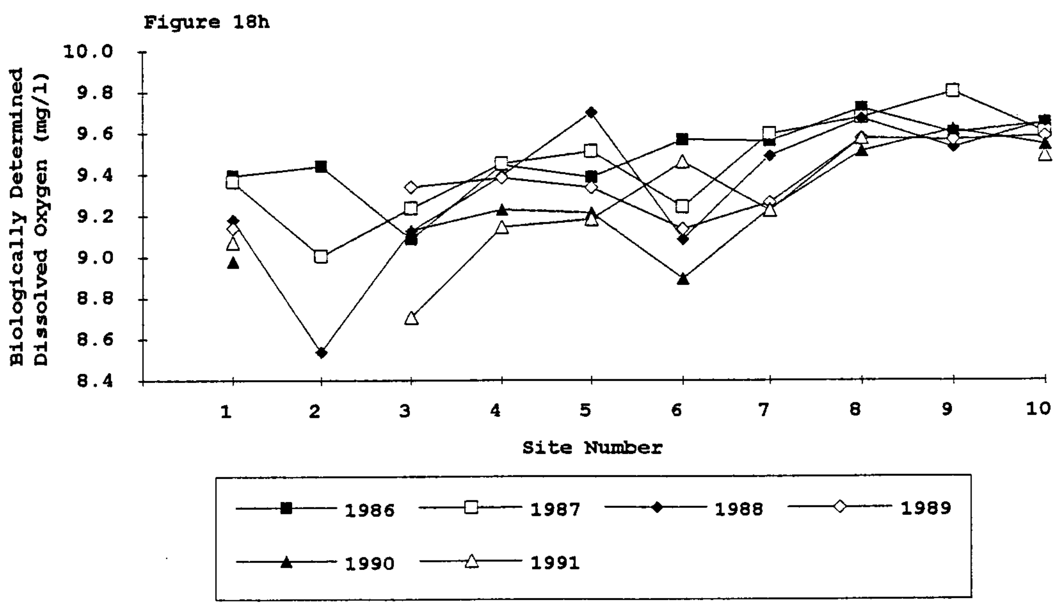
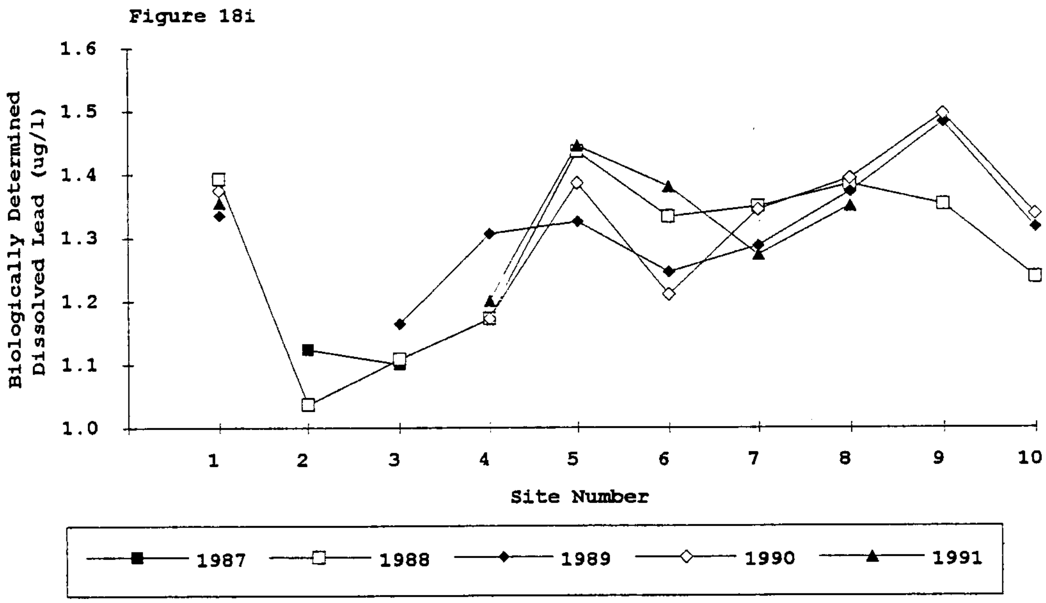
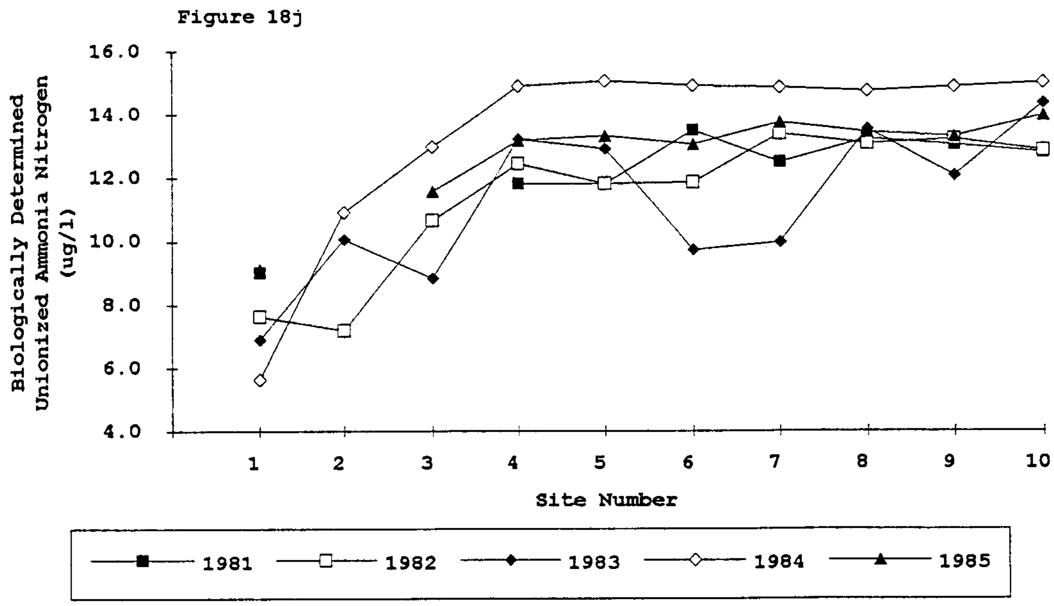
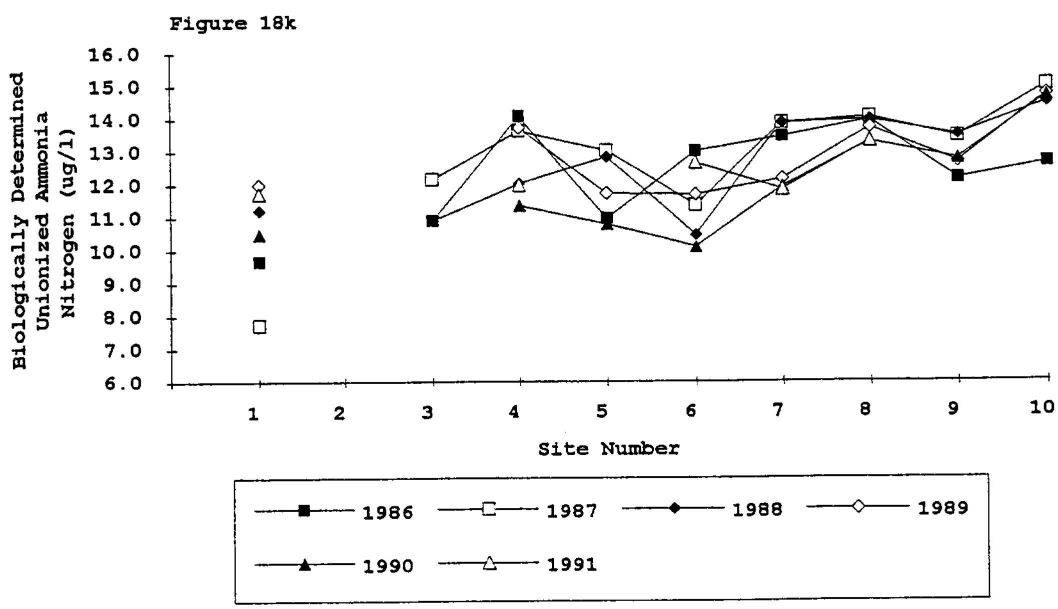


Figure 18i. Downstream trends in the BDV for dissolved lead by year. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.



Figures 18j and 18k. Downstream trends in the BDV for unionized ammonia nitrogen by year. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.





Figures 181 and 18m. Downstream trends in the BDV for pH by year. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.

Figure 181

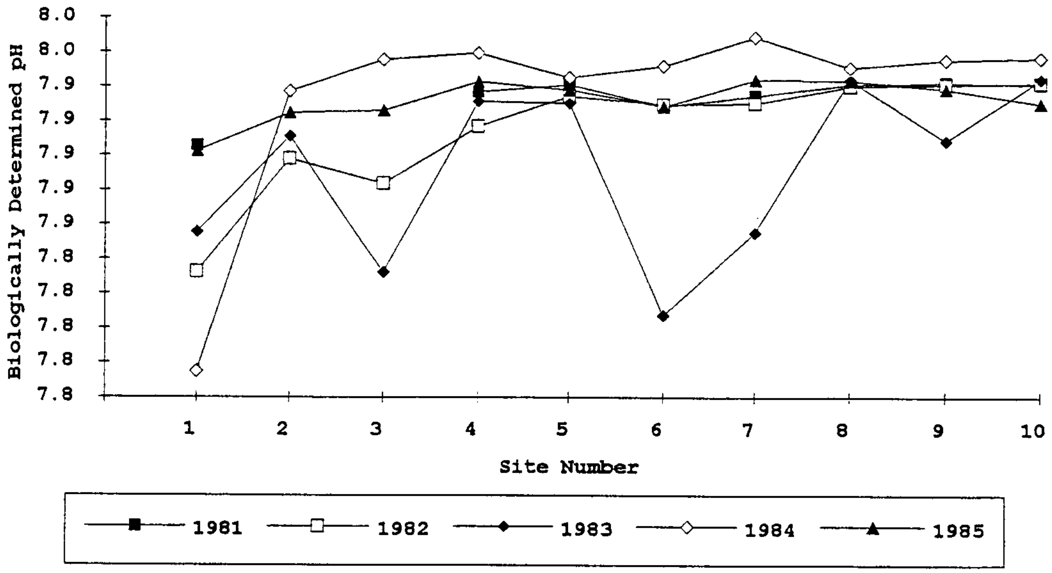
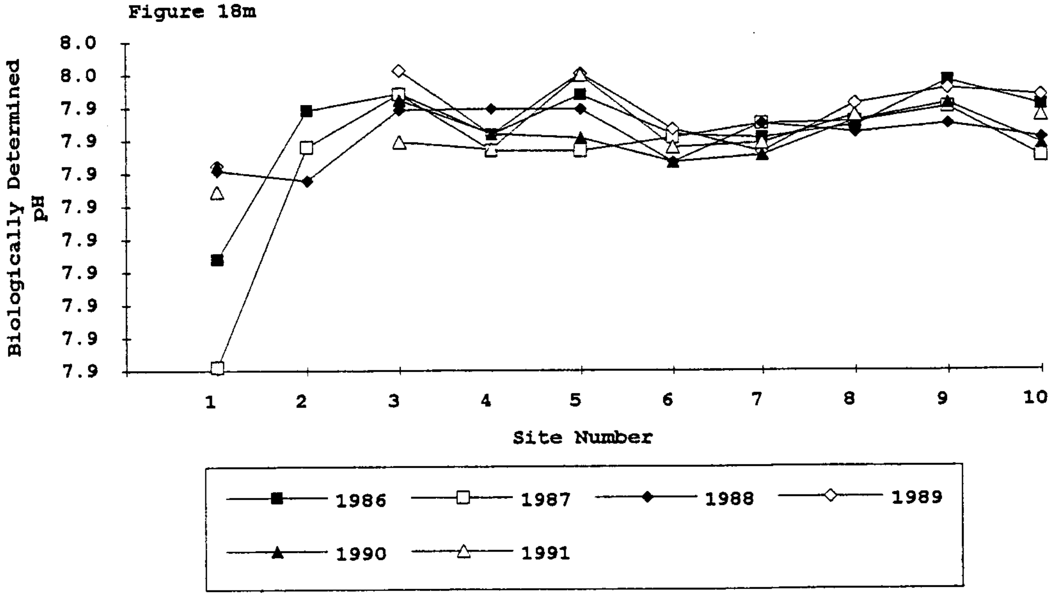
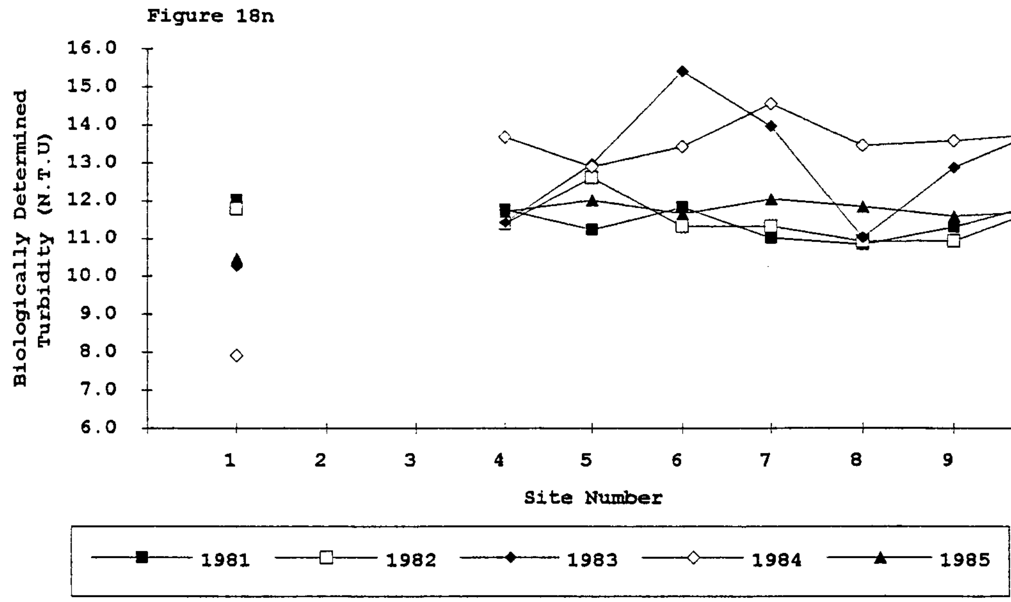
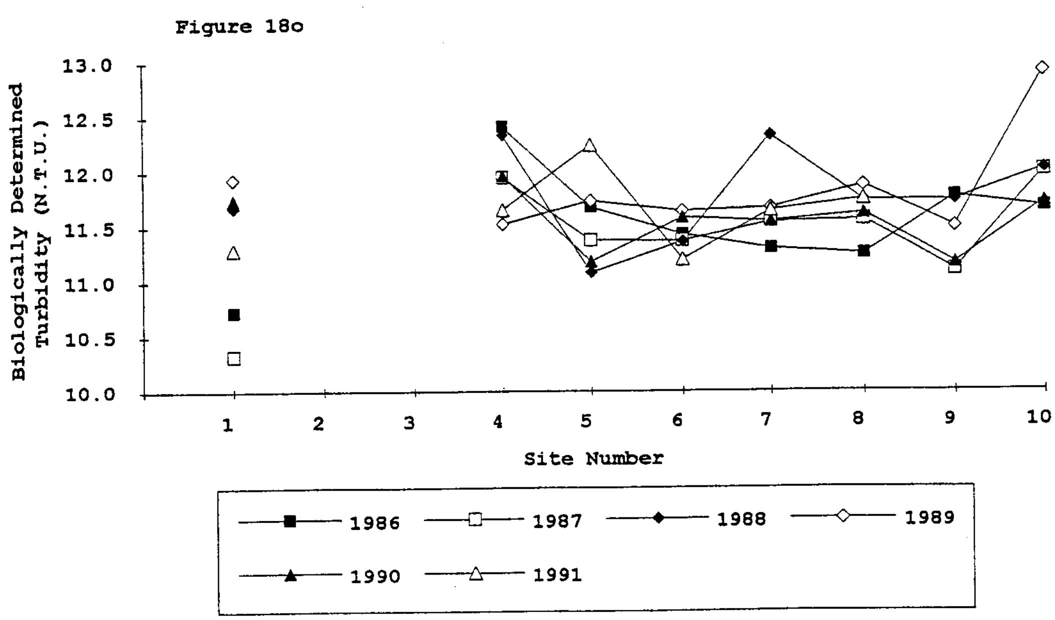


Figure 18m

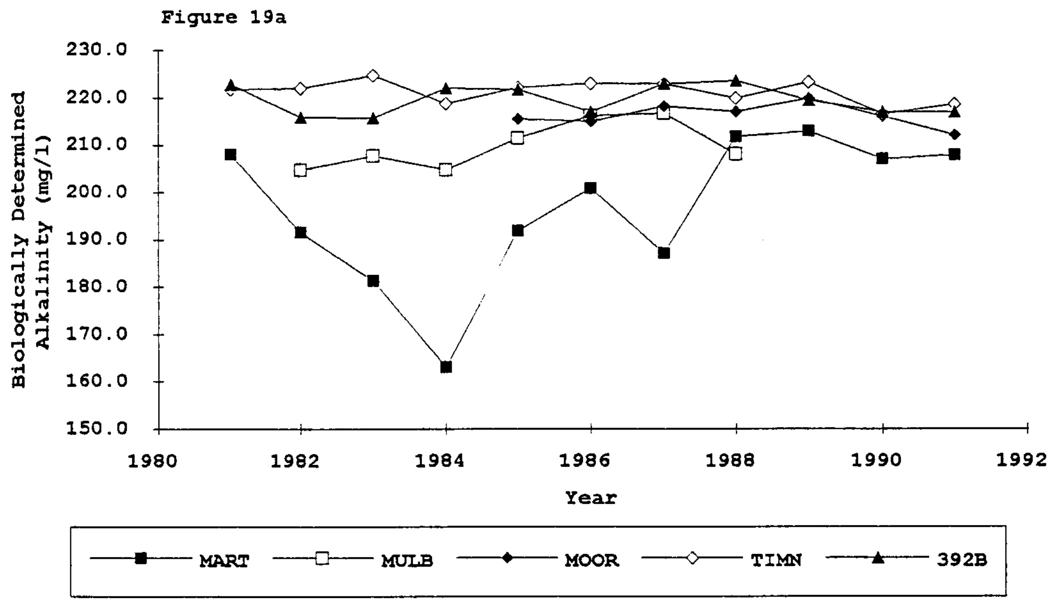


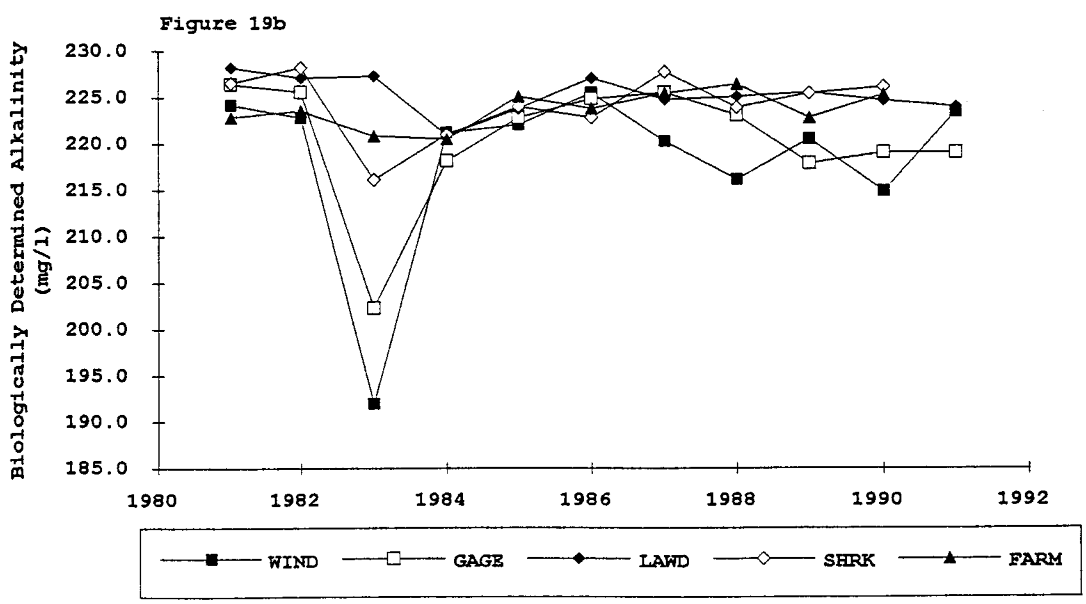
Figures 18n and 18o. Downstream trends in the BDV for turbidity by year. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.



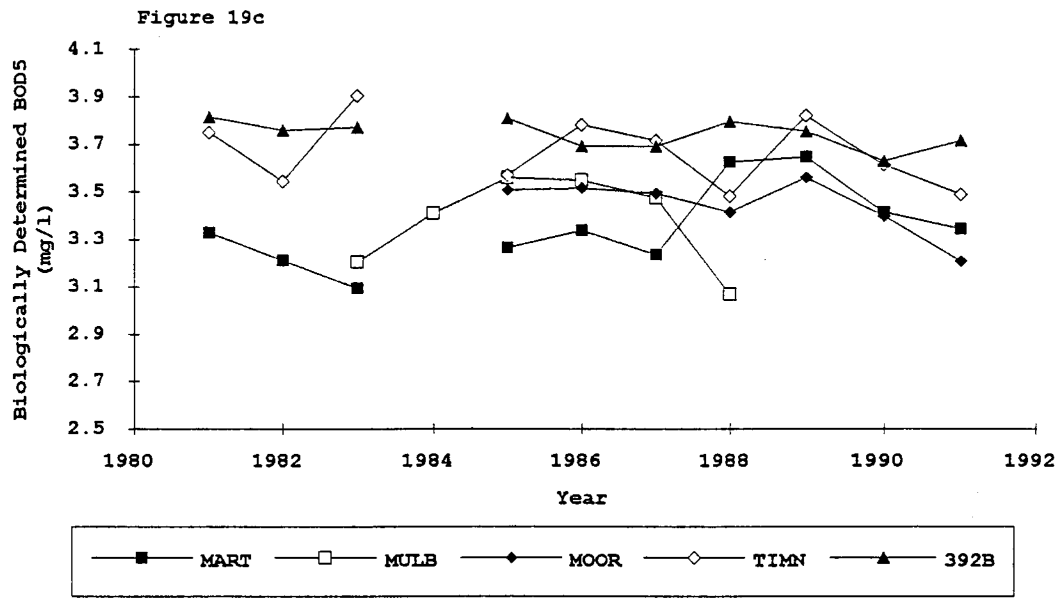


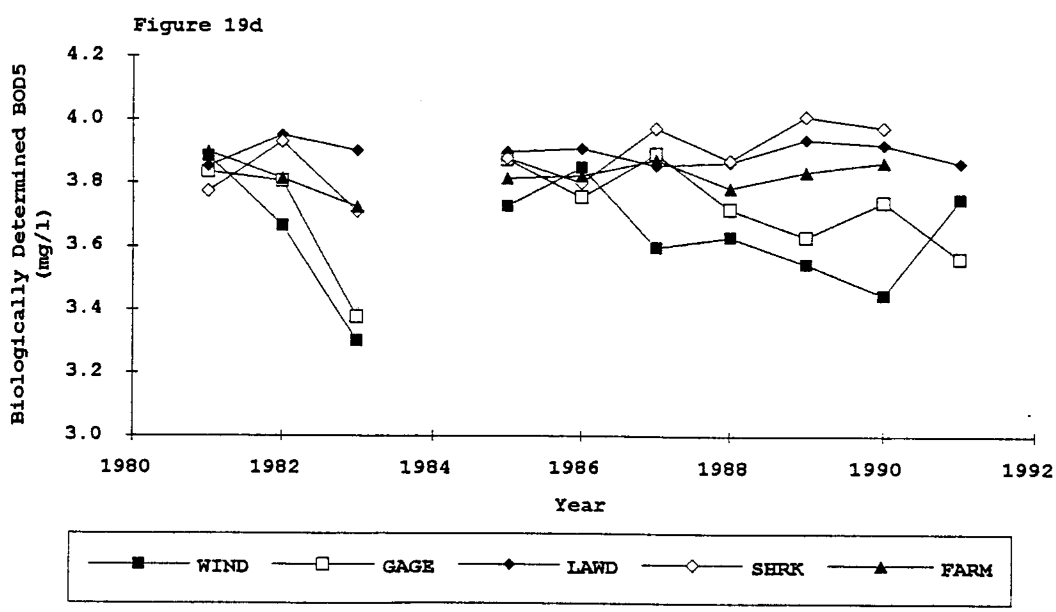
Figures 19a and 19b. Interannual trends in the BDV for alkalinty by site. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.



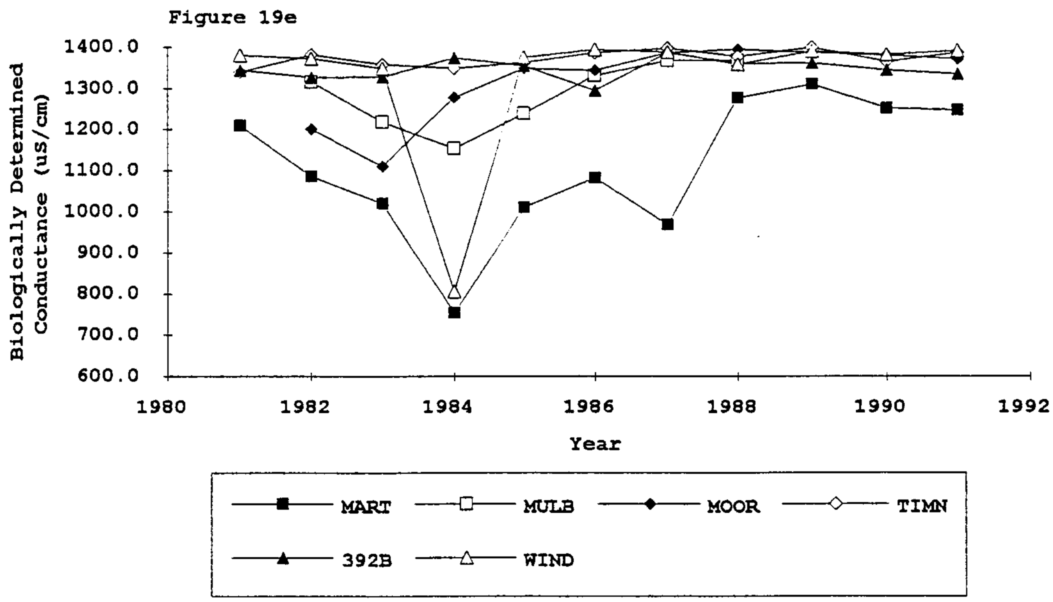


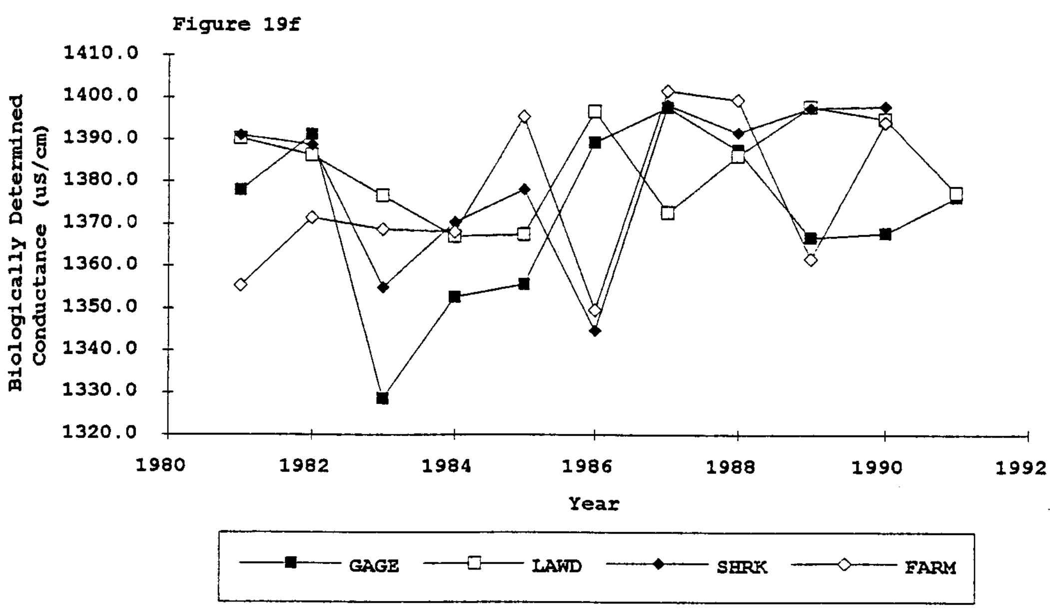
Figures 19c and 19d. Interannual trends in the BDV for BOD5 by site. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.



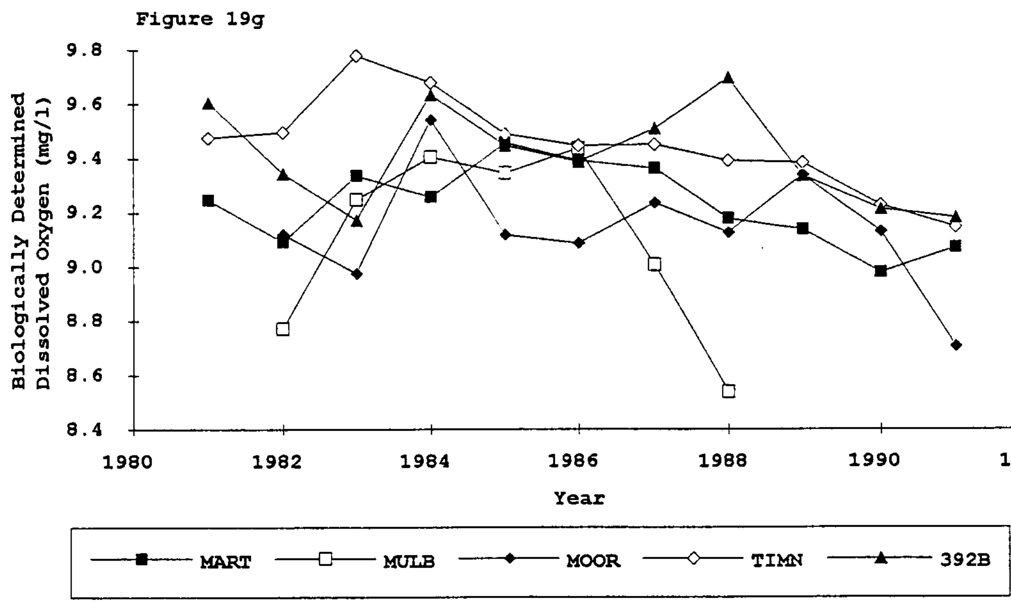


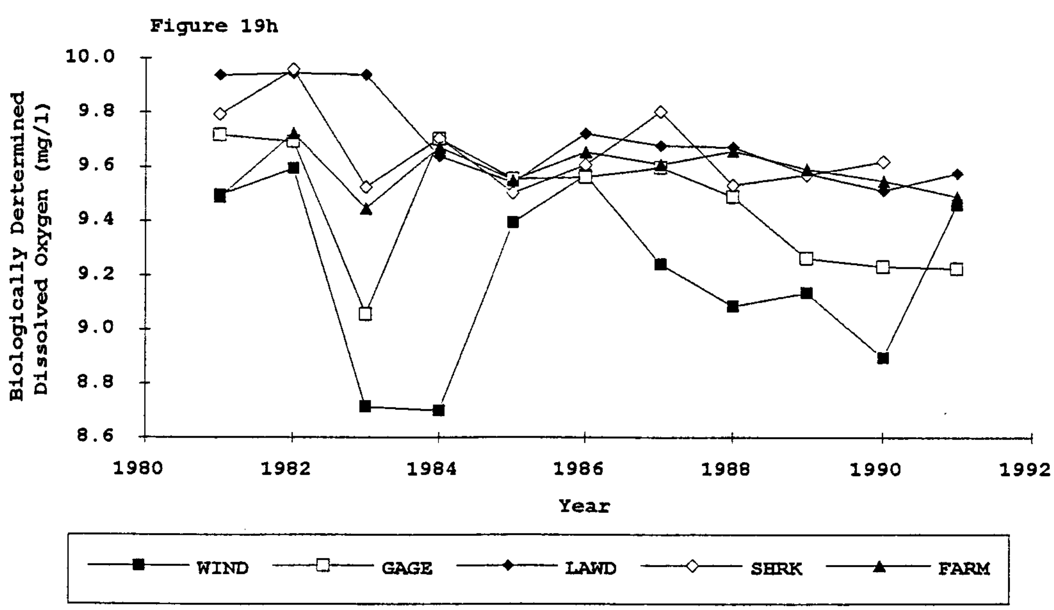
Figures 19e and 19f. Interannual trends in the BDV for conductance by site. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.





Figures 19g and 19h. Interannual trends in the BDV for dissolved oxygen by site. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.





Figures 19i and 19j. Interannual trends in the BDV for dissolved lead by site. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.

Figure 19i

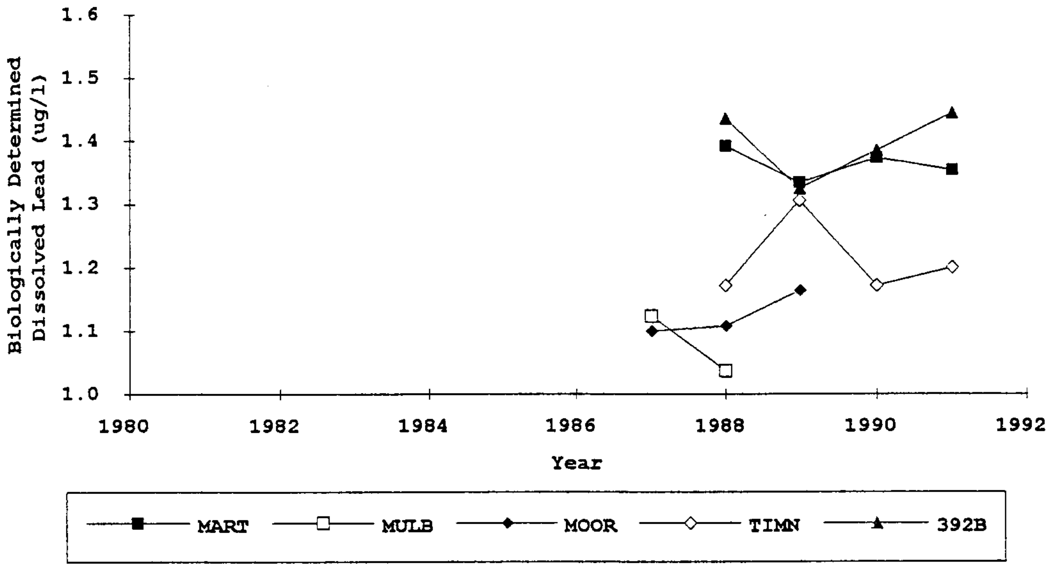
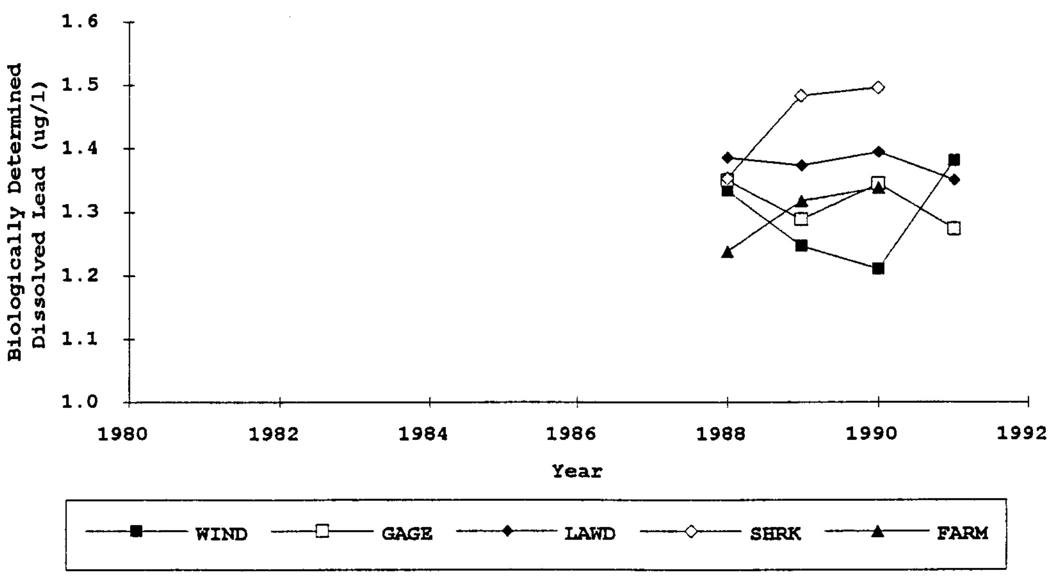
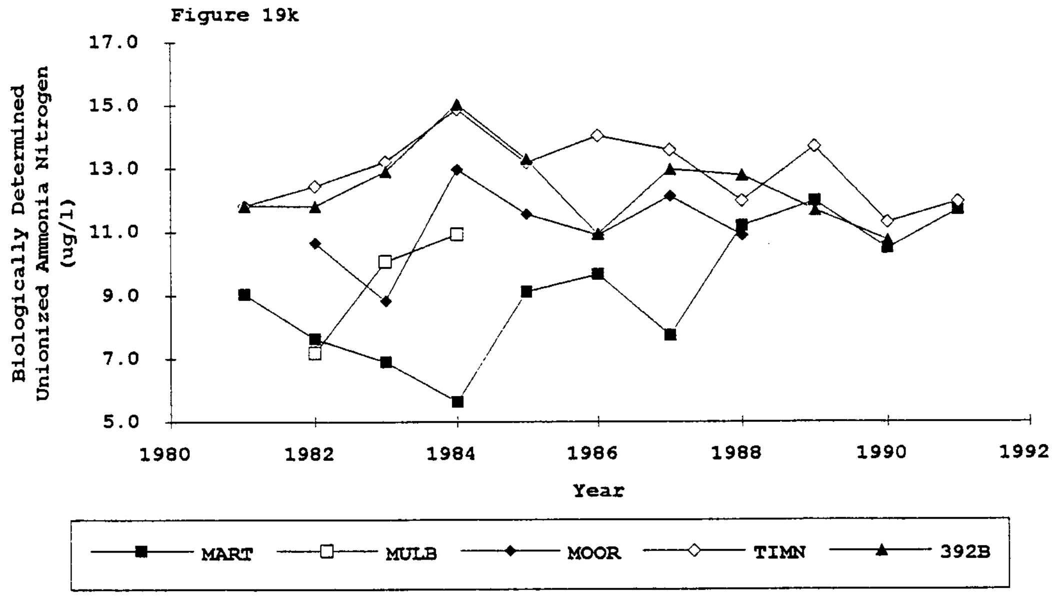
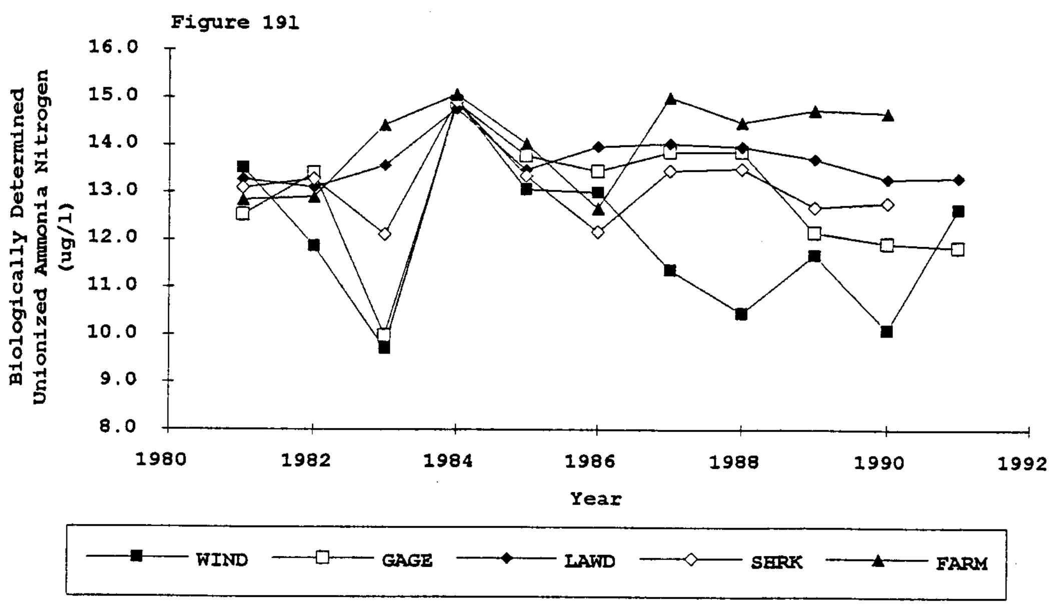


Figure 19j

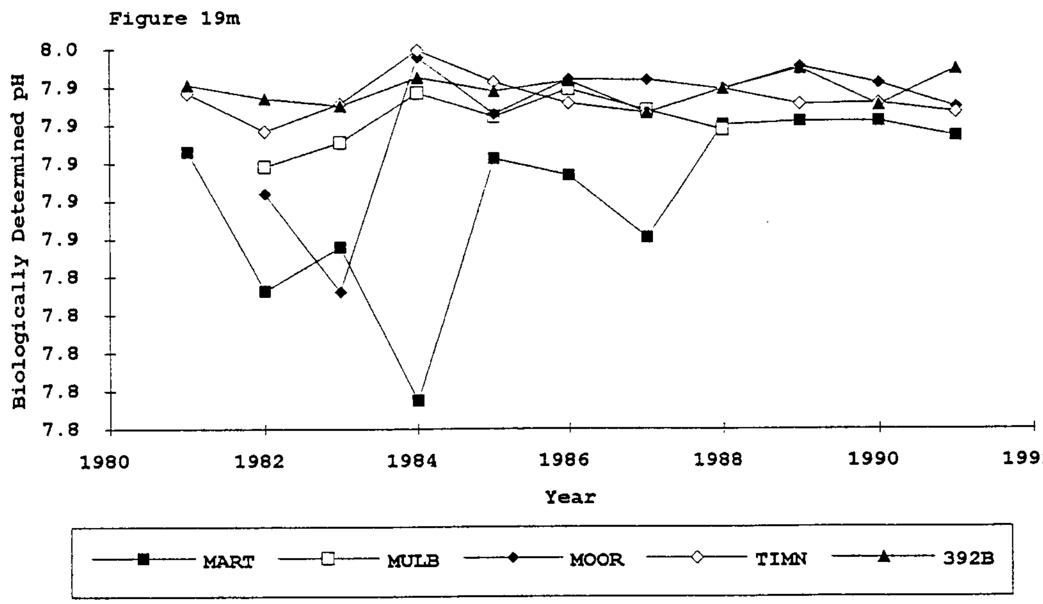


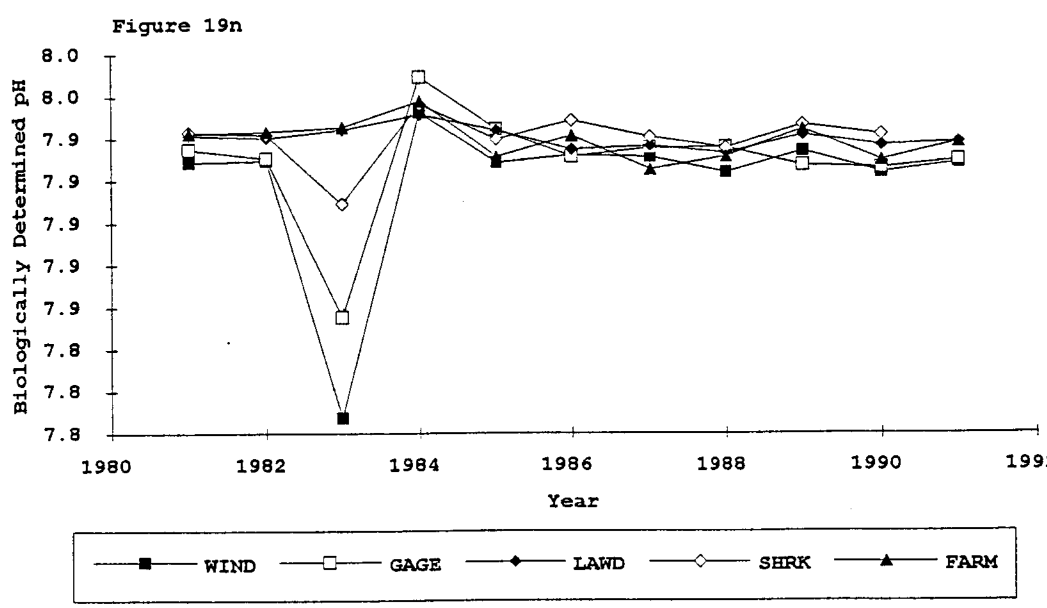
Figures 19k and 19l. Interannual trends in the BDV for unionized ammonia nitrogen by site. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.



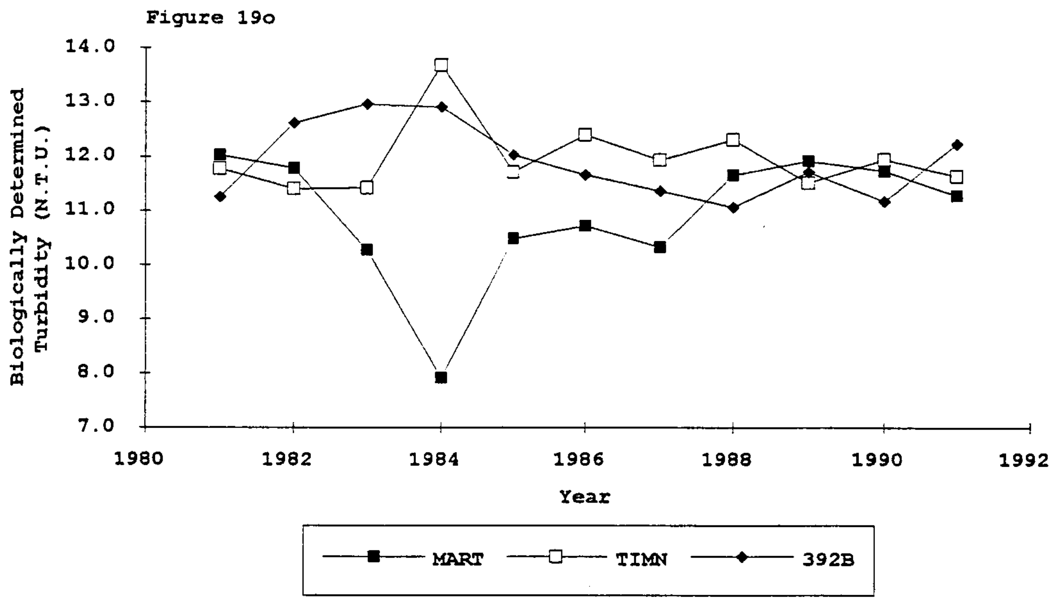


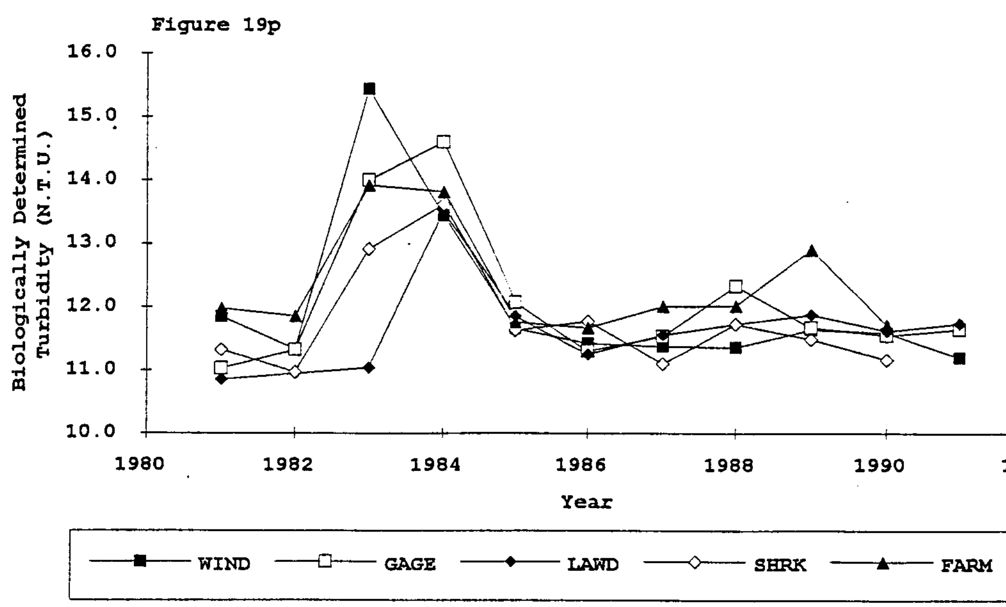
Figures 19m and 19n. Interannual trends in the BDV for pH by site. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.





Figures 19o and 19p. Interannual trends in the BDV for turbidity by site. The Y-axis is not the actual chemical parameter, but is the BDV of the parameter plotted in the same units.





Problems and Limitations

"Tolerance/Preferred Value" Assignment

The "preferred value" for an organism is a point in a continuum that may or may not describe the actual preferred range of the organism. "Tolerance" is a term that appears in the development of many indexes (Patrick, 1949; Beck, 1954, 1955; Hilsenhoff, 1977, 1982, 1987, 1988a, 1988b), but what is the proper use of the term in the development of tolerance values? Defining "tolerance" seems to be one of the most difficult problems associated with assigning qualitatively or quantitatively derived numbers to organisms. Should "tolerance" be defined as the ability to withstand a wide range of physicochemical conditions or a narrow range at either of the extremes. Surely both situations describe some sort of tolerance, but what is the biological/ecological relevance of this tolerance and can it provide us with valuable information about the health of the system?

Physicochemical parameters can be seen as either toxic (e.g. lead) or essential (e.g. dissolved oxygen). In the case of toxic parameters, the maximum value that an organism can withstand would need to be incorporated into the calculation of a preferred/tolerance value. In the case of essential parameters, the minimum amount that can support the taxa in question may need to be incorporated into the calculation of the preferred/tolerance value. If neither of these extremes is reached in the system of study, then the concept of cumulative abundance (Lenat, 1991) as well as the concept of a mean preferred value may not achieve the desired separation along the selected environmental gradient. Laboratory studies may be needed to examine the extremes, so that the final preferred/tolerance values can be either qualitatively or quantitatively modified.

Winget and Mangum (1979) tended toward a semi-quantitative approach; they calculated preferred values and then assigned organisms to qualitative categories along the entire significant range of the parameter. Additional organisms for which quantitative data were not available were assigned to categories based on their coexistence with other taxa in the category. Hilsenhoff (1982) assigned organisms to categories based on experience and revised them as needed according to associations. The idea of assigning "tolerance values" based on associations seems inherently flawed, especially when the reason(s) for the association(s) is unknown.

Beck (1954, 1955), although he did assign all taxa to some sort of category, felt that it was unnecessary and in fact undesirable to include "tolerant" species in his biotic index. He felt that they did not add any relevant information due to the fact that they would tolerate anaerobic conditions and that many of them could breathe atmospheric oxygen. The presence of a tolerant organism tells the investigator nothing, but the presence of an intolerant organism at least lets the investigator know that the condition are within the acceptable stringent requirements of that organism.

Abundance weighted averages seem to remove some of the important information at the tails of the distribution. Plecoptera, although they seem to prefer average levels of dissolved oxygen that are similar to many of the other organism, were not found at levels as low as most of the other organisms. The plecopterans also did not withstand higher biochemical oxygen demands; whereas, many of the other groups were collected at much higher levels.

Continued collection of both macroinvertebrate and physicochemical data in the future will allow investigators to determine more accurately the "preferred values" for each of the species considered in this biotic index. A little bit of qualitative manipulation of these quantitative "preferred values" might be in order. Additionally, the variances around those values as well as the tolerable extremes may also be helpful in the final assignment of some sort of semi-quantitative tolerance/preferred value.

Geographic

Macroinvertebrate samples were only collected from one reach of a single river with little elevational change (Figure 2). The well known biotic indexes (Hilsenhoff, 1982; Hilsenhoff, 1987; Lenat, 1993; Winget and Mangum, 1979) all rely on databases collected from a large number of streams. Collections taken from a single stream reach have the advantage of controlling for factors associated with geographic diversity of species tolerances, but has the limitation of not giving the investigator a broad picture of the species' tolerances to a variety of conditions not experienced within the single reach. The "preferred values" calculated from the Poudre River data may be artificial in that the preferred or possible range for existence of a given species may not exist within the study reach; the organisms may merely tolerate the existing conditions within the reach. These problems could possibly be overcome by increasing the altitudinal range of the sample sites along the reach, or by increasing the diversity and number of streams types with the given altitude range studied.

Temporal

Macroinvertebrates were only collected a minimum of 4 times per year; whereas, physicochemical data was collected many times per year. To compound this problem, the time of collection for macroinvertebrate and physicochemical data did not always exactly coincide. Most physicochemical and macroinvertebrate collections coincided temporally, but only physicochemical data collected within a two week time window of the macroinvertebrate collections were included in the analysis.

Seasonal influences on the macroinvertebrate population have been documented by several authors (Hilsenhoff, 1982; Lenat, 1993) and no effort was made in the current analysis to separate the seasonal dynamics. Hilsenhoff discussed the impact of season on his biotic index values (Hilsenhoff, 1977; Hilsenhoff, 1982; Hilsenhoff, 1988b). The seasonal dynamics that Hilsenhoff (1988b) found to have the most profound impact on the biotic index were current and temperature related changes in realized dissolved oxygen levels. Some stream macroinvertebrates are dependent on current to enhance oxygen uptake and may succumb in low current situations even at fairly high levels of dissolved oxygen (Ward, 1992). Hilsenhoff (1988b) suggested sampling only in the spring and fall months to avoid thermal or current induced dissolved oxygen reduction. The reasoning for avoiding the summer period was that organisms may enter a diapause state during the summer months to avoid the oxygen stress. The Poudre River has a substantial seasonal flow variation, especially in the plains section. This variation is due to the dominance of snowmelt runoff coupled with agricultural usage of the water and will have an impact on the faunal dynamics over time.

In the plains sections of front range streams, diel changes in the values of physicochemical parameters may become important. As the water velocity slows and the turbulence of the water is reduced, the natural mixing and equalization of the water column is reduced and the diel dynamics may approach those of a lentic environment. Diel measurements may be necessary in order to assess actual maxima and minima of physicochemical variables, especially those closely linked to the metabolism of the system (e.g. dissolved oxygen and BOD5).

Roback (1974) discussed the use of indicator assemblages to reduce the problems associated with the astatic nature of the macroinvertebrate community and the possible temporary natural absence of particular species. It is important to remember that the absence of a species does not necessarily indicate that the current or past conditions are or were intolerable. Only the presence of a species can indicate tolerance to present or past conditions that occurred within the non-diapausal portions of their life cycles. Data collected at finer temporal scales and statistically analyzed for seasonal impacts (i.e. life cycles of the organisms) should minimized these problems.

Spatial

The macroinvertebrate data were only collected from riffles. Riffles and pools have been shown to contain different faunal groupings. Since three Surbers were collected from each site and an effort was made to include a diversity of substrate types at the site there is an averaging of community structure over a wider range of substrates, making it difficult to use substrate as a variable in the biotic index. Substrate, at least qualitatively, also shows little variation along the reach.

The data were collected from a stream reach with little longitudinal variation in faunal characteristics or physicochemical conditions. Site 1(1), the reference site, is the only site that is consistently significantly different in its physicochemical or macroinvertebrate character from the remaining nine downstream sites. Many of the "sensitive" organisms collected from the study reach were only collected at site 1(1) and then only very rarely downstream. The physicochemical conditions of the study reach might not provide an adequate range to reliably construct the "unimodal" species distributions on which this index relies -- the proper environmental gradients may not exist in the majority of the study reach.

Compatibility with Existing Indexes

Hilsenhoff (1977, 1982) used a "weighted mean" to determine the biotic index value once the tolerance value is obtained. The current index uses a "preferred value" (PV) as the "tolerance value" (TV) with the "biotic index" being the "biologically determined value" (BDV); a weighted average of the preferred values with taxonomic abundances as "weights" was used to determine the biologically determined value (BDV) of the selected parameter at each site. The use of quantitative preferred values for a specific chemical parameter contrasts to the use of qualitative tolerance values to organic pollution for each species. The attainment of a biologically determined value for a parameter in the same units as the parameter in question contrasts to the attainment of a unitless number on a scale of 1-5 or 1-10.

A similar method to Winget and Mangum (1979) was used to develop the "preferred values," but no effort was made to establish statistical significance for correlation between the parameters selected and any indicator of diversity, community health, or biomass. No effort was made to assign the species to categories based on their preferred values. In the Poudre River index, those parameters thought to be of biological significance (Winget and Mangum, 1979), those that may vary as a result of anthropogenic impacts or those highlighted by Richard et al. (1993) were selected for inclusion.

Lenat (1993) assigned organisms to qualitative categories based on their cumulative mean abundance. The organism was assigned to the highest tolerance category below which at least 75 percent of the total number of taxa had been collected. The current index assigns a quantitative preferred value to each taxon based on an abundance weighted average of the physicochemical conditions present at the time of their collection -- in essence organisms are being assigned to the 50^{th} percentile.

ASSESSING REACH HEALTH USING BIOLOGICAL/PHYSICOCHEMICAL CONDITIONS

The quality of running waters should be assessed on the basis of physicochemical and biological characters (Metcalfe, 1989). Reach health cannot be reliably determined using either physicochemical or macroinvertebrate samples in isolation; both methods must be used together in order to obtain a more complete picture of reach health. It may be possible after long-term regular monitoring of both physicochemical and macroinvertebrate conditions to discontinue data collection of either, but until significant and reliable information about both have been well established, both physicochemical and biological data need to be collected in order to determine the health of aquatic systems.

Physicochemical parameters can vary on temporal scales not detected even by a systematic regular sampling regime and even with such a regime the data provide the investigator with no real biological information about the system. Macroinvertebrate communities should be good indicators of reach "health" because they integrate the effects of the altered environment over time (Cairns and Pratt, 1993). The long-term effects of a supposedly insignificant increase in a parameter of concern may have a greater impact on a population than a short term sublethal impact. "Faunistic changes in streams are always very meaningful, although it is not always clear if altered water quality is the cause" (Cairns and Pratt, 1993) Changes in macroinvertebrate communities will remain evident for extended periods of time after a disturbance, so although the frequency of sampling is not as critical it is still important in monitoring the health of the reach.

If extreme conditions are detected, the investigator can only guess about the impacts of the present conditions on the long or short term health of the community present in the reach, but without biological samples it is impossible to determine the actual "health" of the reach. If the biotic data indicate a past extreme environmental perturbation, it will be important to have the relevant historical physicochemical record to find the source of the problem so that the appropriate solutions or correction can be implemented.

A biotic assessment will not always correspond with the existing environmental conditions; they will tend to integrate the condition of the system over time. The time frame for recovery after a lethal pulse will depend of the life histories and phenologies of the impacted organisms. The only safe assumption would be that the organisms in the system are not intolerant of the present conditions; the environment may be substantially better than the biota may lead the investigator to believe. Typically a biotic assessment will at least reflect a long-term average of the environmental conditions present in the reach on at least a seasonal scale. Given the current limited database on the deleterious effects of environmental conditions on macroinvertebrates, the effects of long-term sublethal stresses on organisms will only be detected by sampling of the biota within a stream and by examining changes at both the population and community level.

APPLICABILITY TO OTHER COLORADO STREAMS

The applicability of this index or any other biotic index to other Colorado streams would be limited or experimental at best. Every biotic index that is developed is essentially regional in its applicability. Variations in the tolerance of individuals to environmental variables may exist within a single species (Hilsenhoff, 1982) and species may vary in their regional character as well (Winget and Mangum, 1991). Caution should be used in using the database for analysis of other reaches outside of the Northeastern Colorado Plains.

Most of the biotic indexes developed to date have been created from databases collected over short time periods from a diverse grouping of streams over larger geographical areas than the current index (Hilsenhoff, 1982; Winget and Mangum, 1979; Lenat, 1993). The biotic index developed from the Cache la Poudre River data came from a long-term database collected in a very limited geographical area.

Pristine cannot be universally defined by a specific species assemblage. The long-term cumulative effects of seasonally variable physicochemical parameters in one reach may result in a totally different community than a similarly pristine reach in another locality. As Winget and Mangum (1979) stated: "what is natural for one stream is not necessarily natural for another," so caution should be taken in trying to apply biotic indexes on a regional level.

Past environmental perturbations that resulted in the local eradication of selected species may still show up in healthy reaches that have not yet biologically recovered via recolonization or other anthropogenic mitigation (i.e. if the species isn't present it does not necessarily mean that the system is not healthy). The Cache la Poudre River has seen reduced anthropogenic impact in the recent past (Richard et al., 1993). The faunal assemblage used in the development of the index may in fact be more tolerant or have different preferred values than the current conditions may lead one to believe. Given their current probable immigration/emigration to or from their current ranges, future data collection may yield altered preferred values for the taxa as they recolonize recovering habitats.

Species for which "preferred values" were determined probably have ranges that extend much beyond the study reach, so a realistic picture of their preferred physicochemical environment may not have been obtained from the current data set. The index is based on the assumption that each species will show a normalized unimodal distribution along the environmental parameters within the study area. Environmental extremes for the species in the study area were probably not crossed with the exception of a few of the rare forms collected only from the upper sites. In the case of these rare forms, they were probably collected from within the tails of their unimodal distributions. It is important to include both tails of the distribution in order to more accurately determine the "preferred value." *Tricorythodes minutus*, one of the more commonly collected species in the reach, has been described as one of the most ubiquitous mayflies in North America (McCafferty et al., 1993). The physicochemical parameters that this organism is exposed to in the plains section of the Cache la Poudre River probably do not begin to describe the tolerable range for *Tricorythodes minutus*. Nelson and Roline (1993) ran into difficulty finding species that were common throughout their study range; most of the species were only common at either the upstream or downstream sites. They found 4 of 70 species to be common at reference sites and distributed throughout the range. This gave them the ability to examine broad range environmental tolerances of these organisms. In the Cache la Poudre River data set most of the organisms are common throughout the study reach with the exception of a few rare specimens that were only collected from the upper reference site, so their distributions along environmental gradients may not have been fully elucidated. Other Colorado streams evaluated with this index should have ranges of values for physicochemical characters similar to those in the study reach for the Cache la Poudre index to be of use. The simple combining of data sets to increase the range of environmental parameters or the species list should be done with caution so as to avoid any possible geographical differences in intraspecific tolerance ranges and to avoid any possible inconsistencies in the protocols used in the collection of the physicochemical or macroinvertebrate database.

The entire data set used in developing the current version of the index was collected for a 42.7 km reach of the Cache la Poudre River. The total elevational change encompassed by the sampling sites is only about 85 meters (Figure 2). Site 1(1) is at an elevation of 1515 meters; site 10(8) is at an elevation 1430 meters. At the confluence with the South Platte River, 23.3 kilometers below site 10(8) the elevation is 1,418 meters. In order for this index to be reliably applied to other Front Range Colorado streams the current database would have to be expanded to include a broader elevational gradient so as to include a broader range of physicochemical conditions and a wider range of species.

All ten sites are primarily in an urban/agricultural setting. The report issued by RBD Engineering for Kodak Colorado Division, Windsor, Colorado, lists five waste water treatment plants along the study reach. Three of them are located between site 1(1), at Martinez Park, and Site 3, at Moore Farm. A total of 26 inlets and outlets are also listed in the report between sites 1(1) and 10(8). Seventeen of these are inflows and the remaining 9 are diversions. This reach is far from having a lack of anthropogenic impacts. As long as streams analyzed with the current system have that type of setting the index should work fine.

Although the flow in the Cache la Poudre River is regulated, it does experience substantial seasonal flow fluctuations because there are not an abundance of large water storage facilities along its course (Figure 14). The plains segments of other front range Colorado rivers, such as the South Plate experience less seasonal fluctuation in flow and the biota is consequently less seasonally stressed with regard to flow. Lower temperatures and higher flows have been suggested to allow stream macroinvertebrates to survive in lower absolute dissolved oxygen environments, by reducing their metabolisms and increasing the perceived dissolved oxygen content of the water (Hilsenhoff, 1982). Conversely, higher temperatures and lower flows can have a negative impact on the ability of organisms to withstand oxygen stress. Hilsenhoff (1988b) recommended that currents below 0.3 m/sec. be avoided when collecting samples to be used with his biotic index.

FUTURE RESEARCH NEEDS

Databases in the future should be constructed in a format that is conducive to looking at correlation between macroinvertebrate populations/community data and the physicochemical conditions present at the time of collection. A wide variety of levels of taxonomic resolution should be included in the database to increase the possibilities for future analysis. Databases are often accumulated in a format that is conducive to its visual presentation or publication. They should be put in a common format so that combining of data in the future can be done more easily.

The following is a suggested format that is conducive to sorting and statistical analysis:

species 1 - date - site - abundance - physicochemical parameters . .

species 2 - date - site - abundance - physicochemical parameters . .

species 3 . . .

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If species keys are not available, then the specimens should be reliably identified to genus so that regional faunal list can be used on the complete generic level list to come up with a reliable possible species list for future reference. These databases should be combined into regional and broad-range geographical species distributions for use by future investigators in the determination of water quality on broader scales.

Biotic databases are also often accumulated in isolation from corresponding physicochemical databases collected from the same reach. In order to further the development of accurate, inexpensive, and less time consuming biotic indexes, these databases need to be combined and/or collected at the same time. The physicochemical and macroinvertebrate data used in the present analysis were collected by separate groups working toward one goal, but the temporal and spatial aspects of the sampling scheme were not always fully compatible. Physicochemical and macroinvertebrate data need to be collected in conjunction with one another in order to elucidate correlations between the two.

Detection limits vary from test to test and year to year. As stated by RBD Engineering, "data values are often reported as "non-detect". Future "non-detect" values should be reported as "less than" the actual detection limit used at the time of sampling."

A site or sites should be added upstream from site 1(1). Most of the significant changes occur between site 1(1) and 2. Some sort of determination needs to be made as to whether these sudden changes are the result of decreasing water quality downstream from the site or whether site 1(1) is at the edge of an ecotone and these changes are the result of some sort of natural process. The addition of a site above site 1(1) would also add more reference data for the determination of preferred ranges for common species within the range and allow the investigators the get the rest of the picture for the species that were only collected from site 1(1).

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APPENDIX I

Genera included in the development of the Cache la Poudre biotic index and the associated likely species within the corresponding genera (*indicates taxa used in the downstream DCA analysis, [1]combined proportionately into *Cheumatopsyche* and *Hydropsyche*)

Platyhelminthes (flatworms)
*Dugesia dorotocephala**
*tigrina**

Hirudinea (leeches)
*Erpobdella punctata punctata**
Glossiphonia complanata
Placobdella ornata
parasitica
*Helobdella elongata**
*fusca**
*stagnalis**
Macrobdella decora

Oligochaeta (aquatic earthworms)

Isopoda (aquatic sow-bugs)
*Asellus communis**

Amphipoda (scuds)
Gammarus lacustris
*Hyalella azteca**

Gastropoda (snails)
Aplexa
*Ferrissea**
*Lymnaea**
*Physa**
Gyraulus
Helisoma

Plecoptera (stoneflies)
Taenionema nigripenne
pallidum
Capnia confusa
gracilaria
Claassenia sabulosa
Hesperoperla pacifica
Cultus aestivalis
pilatus
Skwala americana (S. parallela)
*Isoperla fulva**
*quinquepunctata**
*Alloperla pilosa**

APPENDIX I (cont.)

Ephemeroptera (mayflies)
Ameletus subnotatus[*]
Baetis flavistriga[*]
tricaudatus[*]
Epeorus deceptivus
longimanus
Heptagenia diabasia[*]
elongata[*]
Rithrogena hageni[*]
Drunella doddsi
grandis
Ephemerella inermis[*]
Tricorythodes minutus[*]
Choroterpes inornata
Leptophlebia cupida
Paraleptophlebia heteronea[*]
Ephoron album

Trichoptera (caddisflies)
Psychomyia flavida[*]
Polycentropus cinereus
Arctopsyche grandis[*1]
Cheumatopsyche pettiti[*]
Hydropsyche cockerelli[*]
occidentalis[*]
oslari[*]
Rhyacophila brunnea
coloradensis
Hydroptila pecos[*]
Brachycentrus americanus[*]
occidentalis[*]
Lepidostoma ormeum
Hesperophylax occidentalis
Helicopsyche borealis[*]
Nectopsyche stigmatica[*]

Coleoptera (water beetles)
Agabus sp.
Heterlimnius corpulentus
Optioservus castanipennis
divergens
quadrimacualtus
seriatus
Zaitzevia parvula

Lepidoptera (aquatic moths)
Petrophila avernalis

Hemiptera (water bugs)
Sigara alternata
grossolineata
Trichocorixa sp.

APPENDIX I (cont.)

Odonata (dragonflies)
Ophiogomphus severus
Argia sedula
violacea
vivida

Diptera (two-winged flies)
*Antocha** *sp.*
*Hexatoma** *sp.*
*Tipula** *sp.*
*Simulium articum**
*vittatum**
*Chironomus** *sp.*
*Cricotopus** *sp.*
*Eukiefferiella** *sp.*
*Orthocladius** *sp.*
*Polypedilum** *sp.*
*Tanytarsus** *sp.*
Odontomyia sp.
Atherix pachypus
Limnophora aequifrons

Appendix II

Group	Taxa	Hilsenhoff (1982) (1-5)	Hilsenhoff (1987) (1-10)	Hilsenhoff (1988) (1-10)	Winget and Mangum (1979) (2-128)	Lenat (1993) (1-10)
Platyhelminthes						
	Tricladida	-	-	-	-	-
	Dugesia	-	-	-	-	7.8
Hirudinea		-	-	-	108.0	-
	Erpobdellidae					
	Erpobdella	-	-	-	-	7.8
	Glossiphoniidae					
	Glossiphonia	-	-	-	-	-
	Helobdella	-	-	-	-	-
	Placobdella	-	-	-	-	-
	Hirudinidae					
	Macrobdella	-	-	-	-	-
Oligochaeta		-	-	-	108.0	-
Isopoda						
	Asellidae	-	-	8.0	108.0	-
	Asellus	-	-	-	108.0	9.4
Amphipoda						
	Gammaridae	-	-	4.0	108.0	-
	Gammarus	-	-	-	-	-

Appendix II. Tolerance values assigned by other authors to the taxa used in the development of the Cache la Poudre biotic index. The possible range of values is indicated in parentheses at the top of each of the columns. Although the Cache la Poudre index only assigns preferred values at the genus level, levels of resolution beyond genus are included if a selected authors(s) specifically assigned tolerance values to the indicated taxa at that level. Refer to Appendix I for a complete species list.

Appendix II

Group	Taxa	Hilsenhoff (1982) (1-5)	Hilsenhoff (1987) (1-10)	Hilsenhoff (1988) (1-10)	Winget and Mangum (1979) (2-128)	Lenat (1993) (1-10)
Amphipoda (cont.)						
	Hyalellidae	-	-	8.0	-	
	Hyalella	-	-	-	-	
	H. azteca	4.0	8.0	-	108.0	7.9
Plecoptera						1.8
	Taeniopterygidae	-	-	2.0	48.0	-
	Taenionema	-	-	-	48.0	-
	Capniidae	-	-	1.0	32.0	-
	Capnia	-	-	-	32.0	-
	Perlidae	-	-	1.0	24.0	-
	Claassenia	-	-	-	-	-
	C. sabulosa	-	-	-	6.0	-
	Hesperoperla	-	-	-	-	-
	H. pacifica	-	-	-	18.0	-
	Perlodidae	-	-	2.0	48.0	-
	Cultus	-	-	-	-	1.6
	C. aestivalis	-	-	-	12.0	-
	Skwala	-	-	-	-	-
	S. americana	-	-	-	18.0	-
	Isoperla	-	-	-	48.0	-
	I. fulva	-	-	-	48.0	-
	I. quinquepunctata	-	-	-	48.0	-

Appendix II

Group	Taxa	Hilsenhoff (1982) (1-5)	Hilsenhoff (1987) (1-10)	Hilsenhoff (1988) (1-10)	Winget and Mangum (1979) (2-128)	Lenat (1993) (1-10)
Plecoptera (cont.)						
	Chloroperlidae	-	-	1.0	24.0	-
	Alloperla	0.0	0.0	-	-	1.4
Ephemeroptera						2.7
	Siphlonuridae	-	-	7.0	72.0	-
	Ameletus	0.0	0.0	-	48.0	-
	Baetidae	-	-	4.0	72.0	-
	Baetis	-	-	-	72.0	-
	B. flavistriga	2.0	4.0	-	-	7.2
	B. tricaudatus	-	-	-	-	1.8
	Heptageniidae	-	-	4.0	48.0	-
	Epeorus	-	-	-	21.0	1.2
	Heptagenia	-	-	-	48.0	2.8
	H. diabasia	-	3.0	-	-	-
	Rhithrogena	0.0	0.0	-	21.0	0.4
	Ephemerellidae	-	-	1.0	48.0	-
	Drunella	0.0	-	-	-	-
	D. doddsi	-	-	-	4.0	-
	D. grandis	-	-	-	24.0	-
	Ephemerella	-	-	-	48.0	-
	E. inermis	-	1.0	-	48.0	-
	Tricorythidae	-	-	4.0	108.0	-
	Tricorythodes	2.0	4.0	-	108.0	5.4

Appendix II

Group	Taxa	Hilsenhoff (1982) (1-5)	Hilsenhoff (1987) (1-10)	Hilsenhoff (1988) (1-10)	Winget and Mangum (1979) (2-128)	Lenat (1993) (1-10)
Ephemeroptera (cont.)						
	Leptophlebiidae	-	-	2.0	36.0	-
	Choroterpes	-	-	-	36.0	-
	Leptophlebia	2.0	4.0	-	24.0	6.4
	Paraleptophlebia	1.0	1.0	-	24.0	1.2
	Polymitarcyidae	-	-	2.0	48.0	-
	Ephoron	-	2.0	-	48.0	-
Trichoptera						2.3
	Psychomyiidae	-	-	2.0	108.0	-
	Psychomyia	-	-	-	108.0	-
	P. flavida	2.0	2.0	-	-	3.3
	Polycentropodidae	-	-	6.0	72.0	-
	Polycentropus	2.0	6.0	-	72.0	3.5
	Hydropsychidae	-	-	4.0	108.0	-
	Cheumatopsyche	3.0	5.0	-	108.0	6.6
	Hydropsyche	-	-	-	108.0	-
	Rhyacophilidae	-	-	0.0	18.0	-
	Rhyacophila	0.0	-	-	18.0	-
	R. brunnea	-	0.0	-	-	-
	Hydroptilidae	-	-	4.0	108.0	-
	Hydroptila	3.0	6.0	-	108.0	6.2

Appendix II

Group	Taxa	Hilsenhoff (1982) (1-5)	Hilsenhoff (1987) (1-10)	Hilsenhoff (1988) (1-10)	Winget and Mangum (1979) (2-128)	Lenat (1993) (1-10)
Tricoptera (cont.)						
	Brachycentridae	-	-	1.0	24.0	-
	Brachycentrus	-	-	-	24.0	-
	B. americanus	0.0	1.0	-	-	-
	B occidentalis	1.0	1.0	-	-	-
	Lepidostomatidae	-	-	1.0	18.0	-
	Lepidostoma	1.0	1.0	-	18.0	1.0
	Limnephilidae	-	-	4.0	108.0	-
	Hesperophylax	-	-	-	108.0	-
	Helicopsychidae	-	-	3.0	18.0	-
	Helicopsyche	-	-	-	-	-
	H. borealis	2.0	3.0	-	18.0	0.0
	Leptoceridae	-	-	4.0	54.0	-
	Nectopsyche	2.0	3.0	-	-	-
Diptera						6.4
	Tipulidae	-	-	3.0	72.0	
	Antocha	2.0	3.0	-		4.6
	Hexatoma	3.0	2.0	-	36.0	4.7
	Tipula	2.0	4.0	-	36.0	7.7
	Simuliidae	-	-	6.0	108.0	-
	Simulium	-	-	-	-	4.4
	S. vittatum	4.0	7.0	-	-	8.7

Appendix II

Group	Taxa	Hilsenhoff (1982) (1-5)	Hilsenhoff (1987) (1-10)	Hilsenhoff (1988) (1-10)	Winget and Mangum (1979) (2-128)	Lenat (1993) (1-10)
Diptera (cont.)						
	Chironomidae	-	-	6.0	108.0	5.7
	Chironomus	5.0	10.0	-	-	9.8
	Cricotopus	4.0	7.0	-	-	-
	Eukiefferiella	2.0	8.0	-	-	-
	Orthocladius	3.0	6.0	-	-	-
	Polypedilum	3.0	6.0	-	-	-
	Tanytarsus	3.0	6.0	-	-	6.7
	Stratiomyidae	-	-	-	108.0	-
	Odontomyia	-	-	-	-	-
	Athericidae	-	-	-	24.0	-
	Atherix	-	-	-	-	-
	A. pachypus	-	-	-	24.0	-
	Muscidae	-	-	-	-	-
	Limnophora	-	-	-	-	7.0
Odonata						6.9
	Gomphidae	-	-	1.0	108.0	-
	Ophiogomphus	1.0	1.0	-	-	6.2
	O. severus	-	-	-	108.0	-
	Coenagrionidae	-	-	9.0	108.0	-
	Argia	-	-	-	108.0	-

Appendix II

Group	Taxa	Hilsenhoff (1982) (1-5)	Hilsenhoff (1987) (1-10)	Hilsenhoff (1988) (1-10)	Winget and Mangum (1979) (2-128)	Lenat (1993) (1-10)
Hemiptera						-
	Corixidae	-	-	-	108.0	9.0
	Sigara	-	-	-	108.0	-
	Trichocorixa	-	-	-	108.0	-
Lepidoptera						
	Pyralidae	-	-	5.0	72.0	-
	Petrophila	1.0	5.0	-	-	1.8
Coleoptera						5.7
	Dytiscidae	-	-	-	72.0	-
	Agabus	-	-	-	72.0	-
	Elmidae	-	-	4.0	108.0	-
	Heterlimnius	-	-	-	-	-
	Optioservus	-	-	-	108.0	2.7
	Zaitzevia	-	-	-	-	-
Mollusca						6.1
	Ancylidae	-	-	-	-	-
	Ferrissea	-	-	-	-	6.9
	Lymnaidae	-	-	-	108.0	-
	Lymnaea	-	-	-	108.0	-
	Physidae	-	-	-	108.0	-
	Physa	-	-	-	108.0	-

Appendix II

Group	Taxa	Hilsenhoff (1982) (1-5)	Hilsenhoff (1987) (1-10)	Hilsenhoff (1988) (1-10)	Winget and Mangum (1979) (2-128)	Lenat (1993) (1-10)
Mollusca (cont.)						
	Planorbidae	-	-	-	108.0	-
	Helisoma	-	-	-	-	-
	Gyraulus	-	-	-	-	-

Appendix III. Summary of the chemical conditions present at the time of collection of each of the taxon used in the development of the Cache la Poudre biotic index along with their respective preferred values (PVs). To reduce the length of the list, levels of resolution beyond genus are included only if they are referred to in Appendix II. For a complete species list refer to Appendix I. Minima and maxima are the lowest and highest values for the parameter observed at the time of collection and are provided to give the reader an idea of the total indicated tolerable range for each of the taxa. Next lowest and highest values are given to provide the reader with the ability to qualitatively determine a reasonable tolerable range by removing obvious outliers. Sample size is the total number of samples used in the compilation of the table. Values are given for higher taxonomic categories only if data were available for at least two lower taxonomic levels. The genera listed are the members of their respective families known to occur in the Cache la Poudre River, so the values associated with them can be transferred to their respective families when examining the plains segment of the Cache la Poudre River. Values were not assigned at the species level, but they can be transferred to that level (at the readers discretion) for genera in which only one species was identified in the reach.

Appendix IIIa

Group	Taxa	ALKALINITY (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Platyhelminthes							
	Tricladida						
	Dugesia	29.0	45.0	198.6	254.0	262.0	72.0
Hirudinea		29.0	77.0	209.6	284.0	340.0	115.0
	Erpobdellidae						
	Erpobdella	77.0	84.0	212.5	284.0	340.0	81.0
	Glossiphoniidae	29.0	77.0	194.0	259.0	265.0	33.0
	Glossiphonia	77.0	179.0	172.2	254.0	259.0	8.0
	Helobdella	29.0	77.0	149.1	235.0	247.0	10.0
	Placobdella	28.0	167.0	227.7	253.0	265.0	15.0
	Hirudinidae						
	Macrobdella	166.0	166.0	166.0	166.0	166.0	1.0
Oligochaeta		46.0	47.0	216.6	350.0	382.0	321.0
Isopoda							
	Asellidae						
	Asellus	77.0	84.0	217.0	284.0	340.0	65.0
Amphipoda		40.0	77.0	224.6	287.0	330.0	115.0
	Gammaridae						
	Gammarus	129.0	199.0	249.6	280.0	287.0	9.0
	Hyalellidae						
	Hyalella	40.0	77.0	222.9	287.0	330.0	106.0
	H. azteca						
Plecoptera		45.0	48.0	140.5	207.0	238.0	60.0
	Taeniopterygidae						
	Taenionema	100.0	238.0	192.0	100.0	238.0	2.0
	Capniidae						
	Capnia	88.0	88.0	88.0	88.0	88.0	1.0
	Perlidae	48.0	77.0	162.6	204.0	207.0	14.0
	Claassenia	77.0	88.0	160.1	204.0	207.0	11.0
	C. sabulosa						
	Hesperoperla	48.0	177.0	167.6	177.0	196.0	3.0
	H. pacifica						

Appendix IIIa

Group	Taxa	ALKALINITY (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Plecoptera (cont.)							
	Perlodidae	45.0	50.0	138.8	204.0	207.0	28.0
	Cultus	115.0	115.0	115.0	115.0	115.0	1.0
	C. aestivalis						
	Skwala	115.0	192.0	127.8	115.0	192.0	2.0
	S. americana						
	Isoperla	45.0	50.0	139.2	204.0	207.0	25.0
	I. fulva						
	I. quinquepunctata						
	Chloroperlidae						
	Alloperla	77.0	84.0	139.8	204.0	207.0	15.0
Ephemeroptera		28.0	40.0	199.8	350.0	360.0	676.0
	Siphlonuridae						
	Ameletus	40.0	46.0	143.4	260.0	350.0	45.0
	Baetidae						
	Baetis	40.0	45.0	177.4	304.0	326.0	148.0
	B. flavistriga						
	B. tricaudatus						
	Heptageniidae	46.0	47.0	145.1	207.0	239.0	73.0
	Epeorus	77.0	100.0	148.2	165.0	207.0	7.0
	Heptagenia	48.0	50.0	139.3	207.0	239.0	52.0
	H. diabasia						
	Rhithrogena	46.0	47.0	150.0	194.0	196.0	14.0
	Ephemerellidae	28.0	45.0	166.4	284.0	287.0	75.0
	Drunella	196.0	196.0	196.0	196.0	196.0	1.0
	D. doddsi						
	D. grandis						
	Ephemerella	28.0	45.0	166.4	284.0	287.0	74.0
	E. inermis						
	Tricorythidae						
	Tricorythodes	28.0	40.0	205.3	350.0	360.0	288.0
	Leptophlebiidae	28.0	40.0	164.7	245.0	262.0	45.0
	Choroterpes	46.0	193.0	64.9	193.0	228.0	3.0
	Leptophlebia	29.0	48.0	125.6	245.0	262.0	16.0
	Paraleptophlebia	40.0	45.0	171.0	227.0	230.0	26.0

Appendix IIIa

Group	Taxa	ALKALINITY (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Ephemeroptera (cont.)							
	Polymitarcyidae						
	Ephoron	56.0	248.0	152.0	56.0	248.0	2.0
Trichoptera		40.0	45.0	219.2	350.0	482.0	782.0
	Psychomyiidae						
	Psychomyia	190.0	220.0	234.4	240.0	260.0	4.0
	P. flavida						
	Polycentropodidae						
	Polycentropus	237.0	237.0	237.0	237.0	237.0	1.0
	Hydropsychidae	40.0	45.0	219.8	350.0	482.0	609.0
	Cheumatopsyche	40.0	45.0	224.9	350.0	482.0	310.0
	Hydropsyche	40.0	45.0	211.6	350.0	482.0	299.0
	Rhyacophilidae						
	Rhyacophila	500.0	200.0	140.8	217.0	265.0	4.0
	R. brunnea						
	Hydroptilidae						
	Hydroptila	45.0	77.0	220.9	287.0	326.0	72.0
	Brachycentridae						
	Brachycentrus	45.0	46.0	108.0	238.0	253.0	34.0
	B. americanus						
	B occidentalis						
	Lepidostomatidae						
	Lepidostoma	47.0	102.0	114.5	102.0	232.0	3.0
	Limnephilidae						
	Hesperophylax	47.0	102.0	88.3	47.0	102.0	2.0
	Helicopsychidae						
	Helicopsyche	52.0	115.0	114.4	126.0	241.0	4.0
	H. borealis						
	Leptoceridae						
	Nectopsyche	45.0	48.0	177.0	269.0	272.0	49.0

Appendix IIIa

Group	Taxa	ALKALINITY (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Diptera		28.0	40.0	228.4	380.0	482.0	1306.0
	Tipulidae	46.0	47.0	193.0	278.0	380.0	124.0
	Antocha	46.0	48.0	211.8	240.0	269.0	16.0
	Hexatoma	46.0	47.0	169.1	253.0	254.0	26.0
	Tipula	55.0	77.0	202.7	278.0	380.0	82.0
	Simuliidae						
	Simulium	28.0	45.0	231.2	360.0	482.0	280.0
	S. vittatum						
	Chironomidae	28.0	40.0	227.4	350.0	482.0	844.0
	Chironomus	28.0	140.0	228.7	350.0	360.0	119.0
	Cricotopus	28.0	40.0	228.4	360.0	482.0	318.0
	Eukiefferiella	56.0	84.0	242.3	280.0	482.0	31.0
	Orthocladius	28.0	40.0	223.1	326.0	482.0	219.0
	Polypedilum	47.0	48.0	199.8	340.0	350.0	58.0
	Tanytarsus	47.0	84.0	226.6	287.0	326.0	99.0
	Stratiomyidae						
	Odontomyia	225.0	225.0	225.0	225.0	225.0	1.0
	Athericidae						
	Atherix	45.0	48.0	202.7	246.0	248.0	34.0
	A. pachypus						
	Muscidae						
	Limnophora	77.0	84.0	206.1	272.0	284.0	23.0
Odonata		55.0	77.0	197.0	282.0	326.0	45.0
	Gomphidae						
	Ophiogomphus	55.0	77.0	196.1	282.0	326.0	43.0
	O. severus						
	Coenagrionidae						
	Argia	247.0	253.0	250.0	247.0	253.0	2.0
Hemiptera							
	Corixidae	183.0	190.0	240.7	256.0	265.0	18.0
	Sigara	183.0	190.0	240.3	253.0	265.0	11.0
	Trichocorixa	225.0	240.0	246.8	248.0	256.0	7.0
Lepidoptera							
	Pyralidae						
	Petrophila	151.0	175.0	166.4	175.0	204.0	3.0

Appendix IIIa

Group	Taxa	ALKALINITY (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Coleoptera		46.0	47.0	158.1	225.0	243.0	9.0
	Dytiscidae						
	Agabus	46.0	47.0	95.8	47.0	243.0	3.0
	Elmidae	142.0	179.0	165.4	222.0	225.0	6.0
	Heterlimnius	-	-	-	-	-	-
	Optioservus	187.0	222.0	198.8	187.0	222.0	2.0
	Zaitzevia	142.0	179.0	158.3	187.0	225.0	4.0
Mollusca		40.0	46.0	219.4	326.0	360.0	207.0
	Ancylidae						
	Ferrissea	119.0	132.0	218.3	265.0	287.0	63.0
	Lymnaidae						
	Lymnaea	40.0	77.0	226.6	260.0	262.0	30.0
	Physidae						
	Physa	46.0	48.0	219.2	326.0	360.0	107.0
	Planorbidae	199.0	213.0	220.6	227.0	247.0	7.0
	Helisoma	199.0	199.0	199.0	199.0	199.0	1.0
	Gyraulus	213.0	215.0	224.5	227.0	247.0	6.0

Appendix IIIb

Group	Taxa	BOD5 (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Platyhelminthes							
	Tricladida						
	Dugesia	0.0	1.0	2.7	5.6	13.0	53.0
Hirudinea		1.0	1.2	2.9	8.1	9.3	79.0
	Erpobdellidae						
	Erpobdella	1.0	1.2	2.9	8.1	9.3	57.0
	Glossiphoniidae	1.0	1.7	2.9	4.2	4.7	21.0
	Glossiphonia	1.3	2.0	3.0	4.0	4.2	7.0
	Helobdella	1.7	3.0	2.8	3.8	4.0	4.0
	Placobdella	1.0	1.7	2.3	4.2	4.7	10.0
	Hirudinidae						
	Macrobdella	4.3	4.3	4.3	4.3	4.3	1.0
Oligochaeta		0.1	1.0	3.5	12.0	13.0	191.0
Isopoda				2.6			
	Asellidae						
	Asellus	1.0	1.3	2.6	7.0	7.6	44.0
Amphipoda		1.0	1.3	3.2	7.0	8.1	76.0
	Gammaridae						
	Gammarus	1.0	2.3	3.8	5.0	7.0	8.0
	Hyalellidae						
	Hyalella	1.0	1.3	3.1	7.1	8.1	68.0
	H. azteca						
Plecoptera		1.0	1.2	2.6	4.0	5.0	57.0
	Taeniopterygidae						
	Taenionema	-	-	-	-	-	-
	Capniidae						
	Capnia	-	-	-	-	-	-
	Perlidae	1.0	2.0	2.1	3.0	3.9	12.0
	Claassenia	1.0	2.0	2.2	3.0	3.9	9.0
	C. sabulosa						
	Hesperoperla	1.0	2.0	1.8	1.0	2.0	3.0
	H. pacifica						

Appendix IIIb

Group	Taxa	BOD5 (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Plecoptera (cont.)							
	Perlodidae	1.0	1.2	2.4	4.0	5.0	20.0
	Cultus	3.0	3.0	3.0	3.0	3.0	1.0
	C. aestivalis						
	Skwala	3.0	3.0	3.0	3.0	3.0	1.0
	S. americana						
	Isoperla	1.0	1.2	2.3	4.0	5.0	18.0
	I. fulva						
	I. quinquepunctata						
	Chloroperlidae						
	Alloperla	1.0	2.0	2.7	3.9	5.0	25.0
Ephemeroptera		0.1	1.0	3.0	12.0	13.0	420.0
	Siphlonuridae						
	Ameletus	1.0	1.2	2.6	4.0	5.6	25.0
	Baetidae						
	Baetis	0.1	1.0	2.8	8.0	10.0	93.0
	B. flavistriga						
	B. tricaudatus						
	Heptageniidae	1.0	1.4	2.5	3.0	5.6	48.0
	Epeorus	1.0	2.0	2.0	3.0	3.9	5.0
	Heptagenia	1.0	1.4	3.7	3.0	5.6	32.0
	H. diabasia						
	Rhithrogena	1.0	1.5	1.7	2.9	3.0	11.0
	Ephemerellidae	1.0	1.2	3.0	8.1	9.3	51.0
	Drunella	4.0	4.0	4.0	4.0	4.0	1.0
	D. doddsi						
	D. grandis						
	Ephemerella	1.0	1.2	3.0	8.1	9.3	50.0
	E. inermis						
	Tricorythidae						
	Tricorythodes	0.1	1.0	3.0	12.0	13.0	174.0
	Leptophlebiidae	1.0	2.0	4.7	5.6	9.3	28.0
	Choroterpes	1.0	7.0	2.0	1.0	7.0	2.0
	Leptophlebia	1.4	2.0	4.1	4.6	9.3	10.0
	Paraleptophlebia	1.0	2.0	4.9	5.6	6.0	16.0

Appendix IIIb

Group	Taxa	BOD5 (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Ephemeroptera (cont.)							
	Polymitarcyidae						
	Ephoron	8.0	8.0	8.0	8.0	8.0	1.0
Trichoptera		0.1	1.2	4.0	12.0	13.0	473.0
	Psychomyiidae						
	Psychomyia	-	-	-	-	-	-
	P. flavida						
	Polycentropodidae						
	Polycentropus	-	-	-	-	-	-
	Hydropsychidae	0.1	1.0	4.0	12.0	13.0	362.0
	Cheumatopsyche	0.1	1.0	4.2	12.0	13.0	185.0
	Hydropsyche	0.1	1.0	3.6	12.0	13.0	177.0
	Rhyacophilidae						
	Rhyacophila	3.0	3.0	3.0	3.0	3.0	1.0
	R. brunnea						
	Hydroptilidae						
	Hydroptila	1.0	1.2	3.7	6.0	8.0	47.0
	Brachycentridae						
	Brachycentrus	1.0	1.2	2.5	6.0	7.0	21.0
	B. americanus						
	B occidentalis						
	Lepidostomatidae						
	Lepidostoma	2.0	5.0	4.4	2.0	5.0	2.0
	Limnephilidae						
	Hesperophylax	2.0	5.0	4.3	2.0	5.0	2.0
	Helicopsychidae						
	Helicopsyche	1.0	2.4	2.9	2.4	3.0	3.0
	H. borealis						
	Leptoceridae						
	Nectopsyche	1.0	1.2	2.5	6.0	7.0	35.0

Appendix IIIb

Group	Taxa	BOD5 (mg/l)					
		minimum	next lowest	PV	next highest	maximum	sample size
Diptera		0.1	1.0	3.9	12.0	13.0	833.0
	Tipulidae	1.0	1.2	3.2	12.0	13.0	84.0
	Antocha	1.0	1.2	3.1	3.9	5.0	9.0
	Hexatoma	1.0	1.2	2.4	5.0	7.0	21.0
	Tipula	1.0	1.2	3.6	12.0	13.0	54.0
	Simuliidae						
	Simulium	0.1	1.0	4.0	12.0	13.0	169.0
	S. vittatum						
	Chironomidae	0.1	1.0	3.9	12.0	13.0	543.0
	Chironomus	1.0	1.7	3.5	9.3	10.0	77.0
	Cricotopus	0.1	1.0	3.9	12.0	13.0	193.0
	Eukiefferiella	1.4	2.0	3.2	5.0	6.0	18.0
	Orthocladius	0.1	1.0	3.9	12.0	13.0	148.0
	Polypedilum	1.0	1.4	3.2	8.0	10.0	33.0
	Tanytarsus	1.0	1.2	3.7	12.0	13.0	74.0
	Stratiomyidae						
	Odontomyia	2.0	2.0	2.0	2.0	2.0	1.0
	Athericidae						
	Atherix	1.0	2.0	3.1	6.0	7.0	23.0
	A. pachypus						
	Muscidae						
	Limnophora	1.0	2.0	3.0	4.2	5.0	13.0
Odonata		1.0	1.2	2.9	7.0	10.0	27.0
	Gomphidae						
	Ophiogomphus	1.0	1.2	2.9	7.0	10.0	25.0
	O. severus						
	Coenagrionidae						
	Argia	2.1	3.8	3.0	2.1	3.8	2.0
Hemiptera							
	Corixidae	1.0	1.8	4.0	5.0	13.0	13.0
	Sigara	1.0	2.1	4.3	5.0	13.0	9.0
	Trichocorixa	1.0	1.8	1.3	1.8	2.0	4.0
Lepidoptera							
	Pyralidae						
	Petrophila	1.0	2.0	1.5	1.0	2.0	2.0

Appendix IIIb

Group	Taxa	BOD5 (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Coleoptera		1.0	2.0	2.2	2.0	2.9	9.0
	Dytiscidae						
	Agabus	1.5	2.0	2.0	2.0	2.3	3.0
	Elmidae	1.0	2.0	2.4	2.0	2.9	6.0
	Heterlimnius	-	-	-	-	-	-
	Optioservus	2.0	2.0	2.3	2.0	3.0	2.0
	Zaitzevia	1.0	2.0	2.5	2.0	2.9	4.0
Mollusca		0.1	1.0	2.7	9.3	13.0	136.0
	Ancylidae						
	Ferrissea	1.0	1.4	4.1	7.0	8.0	37.0
	Lymnaidae						
	Lymnaea	1.3	1.4	4.4	7.6	9.3	23.0
	Physidae						
	Physa	0.1	1.0	2.6	9.3	13.0	71.0
	Planorbidae	2.3	2.4	3.1	4.0	4.2	5.0
	Helisoma	4.0	4.0	4.0	4.0	4.0	1.0
	Gyraulus	2.3	2.4	2.8	3.4	4.2	4.0

Appendix IIIc

Group	Taxa	CONDUCTANCE (uS/cm) minimum	next lowest	PV	next highest	maximum	sample size
Platyhelminthes							
	Tricladida						
	Dugesia	70.0	103.0	1179.0	2218.0	2219.0	73.0
Hirudinea		70.0	180.0	1321.2	2175.0	2213.0	114.0
	Erpobdellidae						
	Erpobdella	180.0	190.0	1339.0	2175.0	2213.0	81.0
	Glossiphoniidae	70.0	180.0	1234.1	2000.0	2213.0	32.0
	Glossiphonia	389.0	1110.0	1246.0	1935.0	2000.0	8.0
	Helobdella	70.0	180.0	795.0	1600.0	1730.0	9.0
	Placobdella	70.0	343.0	1379.0	1850.0	2213.0	15.0
	Hirudinidae						
	Macrobdella	427.0	427.0	427.0	427.0	427.0	1.0
Oligochaeta		96.0	103.0	1341.0	2307.0	2330.0	325.0
Isopoda							
	Asellidae						
	Asellus	180.0	190.0	1300.0	2080.0	2307.0	70.0
Amphipoda		130.0	180.0	1339.8	2307.0	2330.0	118.0
	Gammaridae						
	Gammarus	343.0	461.0	1303.0	1850.0	2060.0	9.0
	Hyalellidae						
	Hyalella	130.0	180.0	1342.0	2307.0	2330.0	109.0
	H. azteca						
Plecoptera		92.0	107.0	392.9	1600.0	1732.0	64.0
	Taeniopterygidae						
	Taenionema	420.0	1600.0	1207.0	420.0	1600.0	2.0
	Capniidae						
	Capnia	249.0	249.0	249.0	249.0	249.0	1.0
	Perlidae	92.0	149.0	361.4	559.0	948.0	15.0
	Claassenia	162.0	149.0	388.0	559.0	948.0	11.0
	C. sabulosa						
	Hesperoperla	92.0	285.0	315.0	390.0	502.0	4.0
	H. pacifica						

Appendix IIIc

Group	Taxa	CONDUCTANCE (uS/cm) minimum	next lowest	PV	next highest	maximum	sample size
Plecoptera (cont.)							
	Perlodidae	107.0	130.0	391.4	1210.0	1732.0	30.0
	Cultus	250.0	250.0	250.0	250.0	250.0	1.0
	C. aestivalis						
	Skwala	250.0	1070.0	387.0	250.0	1070.0	2.0
	S. americana						
	Isoperla	107.0	130.0	39.0	1210.0	1732.0	27.0
	I. fulva						
	I. quinquepunctata						
	Chloroperlidae						
	Alloperla	162.0	202.0	393.0	666.0	717.0	16.0
Ephemeroptera		70.0	96.0	1286.8	2290.0	2330.0	701.0
	Siphlonuridae						
	Ameletus	130.0	146.0	678.0	1500.0	2030.0	41.0
	Baetidae						
	Baetis	96.0	103.0	806.0	2240.0	2290.0	156.0
	B. flavistriga						
	B. tricaudatus						
	Heptageniidae	96.0	103.0	444.8	1820.0	1930.0	77.0
	Epeorus	162.0	250.0	422.0	559.0	948.0	7.0
	Heptagenia	96.0	103.0	626.0	1820.0	1930.0	53.0
	H. diabasia						
	Rhithrogena	96.0	103.0	289.0	439.0	445.0	17.0
	Ephemerellidae	70.0	96.0	779.3	2060.0	2240.0	80.0
	Drunella	718.0	718.0	718.0	718.0	718.0	1.0
	D. doddsi						
	D. grandis						
	Ephemerella	70.0	96.0	779.0	2060.0	2240.0	79.0
	E. inermis						
	Tricorythidae						
	Tricorythodes	70.0	96.0	1375.0	2307.0	2330.0	293.0
	Leptophlebiidae	70.0	96.0	759.4	1680.0	1690.0	52.0
	Choroterpes	146.0	310.0	265.0	873.0	1100.0	6.0
	Leptophlebia	70.0	96.0	574.9	1680.0	1690.0	16.0
	Paraleptophlebia	107.0	120.0	793.0	1470.0	1530.0	30.0

Appendix IIIc

Group	Taxa	CONDUCTANCE (uS/cm) minimum	next lowest	PV	next highest	maximum	sample size
Ephemeroptera (cont.)							
	Polymitarcyidae						
	Ephoron	220.0	1510.0	865.0	220.0	1510.0	2.0
Trichoptera		96.0	103.0	1323.6	2307.0	2330.0	798.0
	Psychomyiidae						
	Psychomyia	312.0	960.0	1047.0	1080.0	2219.0	5.0
	P. flavida						
	Polycentropodidae						
	Polycentropus	1930.0	1930.0	1930.0	1930.0	1930.0	1.0
	Hydropsychidae	96.0	103.0	1330.5	2307.0	2330.0	619.0
	Cheumatopsyche	96.0	103.0	1419.0	2307.0	2330.0	313.0
	Hydropsyche	96.0	107.0	1188.0	2307.0	2330.0	306.0
	Rhyacophilidae						
	Rhyacophila	150.0	900.0	925.0	1600.0	2007.0	4.0
	R. brunnea						
	Hydroptilidae						
	Hydroptila	107.0	162.0	1337.0	2007.0	2307.0	73.0
	Brachycentridae						
	Brachycentrus	96.0	107.0	378.0	1920.0	2307.0	36.0
	B. americanus						
	B occidentalis						
	Lepidostomatidae						
	Lepidostoma	120.0	307.0	507.0	497.0	1600.0	5.0
	Limnephilidae						
	Hesperophylax	120.0	497.0	403.0	120.0	497.0	2.0
	Helicopsychidae						
	Helicopsyche	250.0	500.0	303.0	500.0	2080.0	3.0
	H. borealis						
	Leptoceridae						
	Nectopsyche	96.0	107.0	678.0	2000.0	2307.0	50.0

Appendix IIIc

Group	Taxa	CONDUCTANCE (uS/cm) minimum	next lowest	PV	next highest	maximum	sample size
Diptera		70.0	96.0	1406.3	2290.0	2330.0	1344.0
	Tipulidae	103.0	120.0	1019.5	2218.0	2290.0	134.0
	Antocha	103.0	132.0	1229.0	1700.0	1770.0	17.0
	Hexatoma	120.0	130.0	906.0	1690.0	1700.0	32.0
	Tipula	130.0	150.0	1049.0	2218.0	2290.0	85.0
	Simuliidae						
	Simulium	70.0	107.0	1407.0	2307.0	2330.0	285.0
	S. vittatum						
	Chironomidae	70.0	96.0	1408.2	2307.0	2330.0	864.0
	Chironomus	70.0	150.0	1302.0	2218.0	2240.0	127.0
	Cricotopus	107.0	120.0	1430.0	2307.0	230.0	324.0
	Eukiefferiella	130.0	202.0	1282.0	1800.0	1860.0	31.0
	Orthocladius	70.0	96.0	1355.0	2290.0	2330.0	222.0
	Polypedilum	96.0	120.0	1107.0	2080.0	2307.0	53.0
	Tanytarsus	120.0	130.0	1446.0	2284.0	2307.0	107.0
	Stratiomyidae						
	Odontomyia	1759.0	1759.0	1759.0	1759.0	1759.0	1.0
	Athericidae						
	Atherix	96.0	107.0	1331.0	2044.0	2330.0	36.0
	A. pachypus						
	Muscidae						
	Limnophora	150.0	190.0	1228.0	2195.0	2307.0	24.0
Odonata		150.0	162.0	922.6	1960.0	2044.0	45.0
	Gomphidae						
	Ophiogomphus	150.0	162.0	908.0	1960.0	2044.0	43.0
	O. severus						
	Coenagrionidae						
	Argia	1740.0	1810.0	1775.0	1740.0	1810.0	2.0
Hemiptera							
	Corixidae	900.0	1110.0	1638.6	2007.0	2307.0	19.0
	Sigara	900.0	1250.0	1654.0	2007.0	2307.0	11.0
	Trichocorixa	1110.0	1240.0	1436.0	1680.0	1820.0	8.0
Lepidoptera							
	Pyralidae						
	Petrophila	343.0	373.0	380.0	373.0	439.0	3.0

Appendix IIIc

Group	Taxa	CONDUCTANCE (uS/cm) minimum	next lowest	PV	next highest	maximum	sample size
Coleoptera		120.0	146.0	712.0	2219.0	2307.0	16.0
	Dytiscidae						
	Agabus	120.0	146.0	529.0	440.0	1820.0	4.0
	Elmidae	307.0	429.0	732.4	2219.0	2307.0	12.0
	Heterlimnius	307.0	307.0	307.0	307.0	307.0	1.0
	Optioservus	466.0	2219.0	1242.0	2219.0	2307.0	3.0
	Zaitzevia	429.0	466.0	654.0	1307.0	2219.0	8.0
Mollusca		103.0	130.0	1555.2	2307.0	2330.0	209.0
	Ancylidae						
	Ferrissea	362.0	552.0	1288.0	2080.0	2307.0	63.0
	Lymnaidae						
	Lymnaea	130.0	389.0	1564.0	2080.0	2213.0	30.0
	Physidae						
	Physa	103.0	132.0	1578.0	2240.0	2330.0	109.0
	Planorbidae	1050.0	1561.0	1648.7	1949.0	2307.0	7.0
	Helisoma	1690.0	1690.0	1690.0	1690.0	1690.0	1.0
	Gyraulus	1050.0	1561.0	1641.0	1949.0	2307.0	6.0

Appendix IIId

Group	Taxa	DISSOLVED OXYGEN (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Platyhelminthes							
	Tricladida						
	Dugesia	3.7	4.5	8.0	12.8	13.0	77.0
Hirudinea		3.7	4.5	8.4	16.4	17.5	118.0
	Erpobdellidae						
	Erpobdella	3.7	4.5	8.2	16.4	17.5	84.0
	Glossiphoniidae	5.7	6.2	9.3	13.6	16.4	33.0
	Glossiphonia	5.7	6.4	8.3	9.4	9.9	8.0
	Helobdella	6.2	6.4	9.6	13.6	16.4	10.0
	Placobdella	7.7	8.4	10.1	13.0	13.1	15.0
	Hirudinidae						
	Macrobdella	7.1	7.1	7.1	7.1	7.1	1.0
Oligochaeta		3.7	4.5	9.7	17.5	26.4	339.0
Isopoda							
	Asellidae						
	Asellus	3.7	5.4	9.8	13.9	16.4	71.0
Amphipoda		5.5	5.7	9.9	16.4	26.4	122.0
	Gammaridae						
	Gammarus	6.1	9.3	11.5	13.0	26.4	9.0
	Hyalellidae						
	Hyalella	5.5	5.7	9.8	16.4	26.4	113.0
	H. azteca						
Plecoptera		5.5	7.2	10.1	12.3	12.6	66.0
	Taeniopterygidae						
	Taenionema	8.6	9.6	9.3	8.6	9.6	2.0
	Capniidae						
	Capnia	10.7	10.7	10.7	10.7	10.7	1.0
	Perlidae	8.1	8.4	9.9	12.3	12.6	15.0
	Claassenia	8.1	8.4	9.7	12.3	12.6	11.0
	C. sabulosa						
	Hesperoperla	8.4	10.3	10.3	10.3	11.7	4.0
	H. pacifica						

Appendix IIId

Group	Taxa	DISSOLVED OXYGEN (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Plecoptera (cont.)							
	Perlodidae	5.5	7.2	10.2	12.3	12.6	32.0
	Cultus	12.3	12.3	12.3	12.3	12.3	1.0
	C. aestivalis						
	Skwala	5.5	12.3	11.2	6.5	12.3	2.0
	S. americana						
	Isoperla	6.1	7.2	10.2	12.3	12.6	29.0
	I. fulva						
	I. quinquepunctata						
	Chloroperlidae						
	Alloperla	7.1	7.9	10.1	12.3	12.6	16.0
Ephemeroptera		3.7	4.5	8.4	17.5	26.4	732.0
	Siphlonuridae						
	Ameletus	5.0	6.2	8.0	12.8	16.4	50.0
	Baetidae						
	Baetis	4.5	5.4	8.7	16.8	26.4	159.0
	B. flavistriga						
	B. tricaudatus						
	Heptageniidae	5.0	6.1	9.3	12.1	12.3	79.0
	Epeorus	8.1	8.4	9.2	12.1	12.3	7.0
	Heptagenia	5.0	6.1	8.3	11.7	12.3	55.0
	H. diabasia						
	Rhithrogena	6.4	6.9	10.1	11.7	12.3	17.0
	Ephemerellidae	5.0	5.8	9.3	15.9	16.4	82.0
	Drunella	7.0	7.0	7.0	7.0	7.0	1.0
	D. doddsi						
	D. grandis						
	Ephemerella	5.0	5.8	9.3	15.9	16.4	81.0
	E. inermis						
	Tricorythidae						
	Tricorythodes	3.7	4.5	8.3	17.5	26.4	307.0
	Leptophlebiidae	6.2	6.3	7.7	11.7	12.3	53.0
	Choroterpes	6.3	6.9	8.4	8.9	9.8	6.0
	Leptophlebia	6.4	7.1	9.0	11.0	12.1	17.0
	Paraleptophlebia	6.2	6.3	7.6	11.7	12.3	30.0

Appendix IIId

Group	Taxa	DISSOLVED OXYGEN (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Ephemeroptera (cont.)							
	Polymitarcyidae						
	Ephoron	7.5	8.4	8.0	7.5	8.4	2.0
Trichoptera		3.7	4.5	9.3	17.5	26.4	824.0
	Psychomyiidae						
	Psychomyia	9.8	10.0	14.6	13.9	15.8	5.0
	P. flavida						
	Polycentropodidae						
	Polycentropus	9.0	9.0	9.0	9.0	9.0	1.0
	Hydropsychidae	3.7	4.5	9.3	17.5	26.4	640.0
	Cheumatopsyche	3.7	4.5	9.1	17.5	26.4	323.0
	Hydropsyche	3.7	4.5	9.5	16.4	17.5	317.0
	Rhyacophilidae						
	Rhyacophila	7.7	8.2	8.4	9.4	10.0	4.0
	R. brunnea						
	Hydroptilidae						
	Hydroptila	5.5	5.8	8.8	14.1	26.4	74.0
	Brachycentridae						
	Brachycentrus	5.0	6.2	9.2	12.8	16.4	38.0
	B. americanus						
	B occidentalis						
	Lepidostomatidae						
	Lepidostoma	7.2	9.1	9.6	10.6	10.8	5.0
	Limnephilidae						
	Hesperophylax	7.2	9.1	7.7	7.2	9.1	2.0
	Helicopsychidae						
	Helicopsyche	8.7	9.6	11.9	11.1	12.3	4.0
	H. borealis						
	Leptoceridae						
	Nectopsyche	3.7	5.6	9.6	12.6	26.4	51.0

Appendix IIId

Group	Taxa	DISSOLVED OXYGEN (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Diptera		1.7	3.7	9.8	17.5	26.4	1400.0
	Tipulidae	4.5	6.1	9.4	13.1	13.2	135.0
	Antocha	6.1	7.1	11.1	12.1	12.7	17.0
	Hexatoma	4.5	6.3	8.3	12.6	14.0	32.0
	Tipula	5.4	6.1	9.7	13.1	13.2	86.0
	Simuliidae						
	Simulium	3.7	5.0	10.2	16.4	17.5	298.0
	S. vittatum						
	Chironomidae	1.7	3.7	9.6	17.5	26.4	903.0
	Chironomus	3.7	5.5	9.7	15.8	17.5	131.0
	Cricotopus	1.7	3.7	9.7	17.5	26.4	336.0
	Eukiefferiella	1.7	5.0	10.9	15.9	16.4	33.0
	Orthocladius	1.7	3.7	9.1	16.4	17.5	232.0
	Polypedilum	5.0	6.2	8.7	15.9	16.4	61.0
	Tanytarsus	3.7	5.4	8.9	16.4	26.4	110.0
	Stratiomyidae						
	Odontomyia	10.4	10.4	10.4	10.4	10.4	1.0
	Athericidae						
	Atherix	6.0	6.2	9.1	12.6	13.0	36.0
	A. pachypus						
	Muscidae						
	Limnophora	5.6	6.4	8.7	12.6	13.4	27.0
Odonata		3.7	5.5	9.3	12.8	16.4	48.0
	Gomphidae						
	Ophiogomphus	3.7	5.5	9.3	12.8	16.4	46.0
	O. severus						
	Coenagrionidae						
	Argia	10.0	11.3	10.7	10.0	11.3	2.0
Hemiptera							
	Corixidae	6.4	7.1	9.0	12.2	13.0	19.0
	Sigara	6.4	7.1	8.8	9.4	10.0	11.0
	Trichocorixa	10.2	10.4	11.6	12.2	13.0	8.0
Lepidoptera							
	Pyralidae						
	Petrophila	9.8	11.4	10.5	11.4	11.6	3.0

Appendix IIId

Group	Taxa	DISSOLVED OXYGEN (mg/l) minimum	next lowest	PV	next highest	maximum	sample size
Coleoptera		7.1	9.1	10.1	11.8	12.8	16.0
	Dytiscidae						
	Agabus	8.9	9.1	10.1	10.8	12.8	4.0
	Elmidae	7.1	9.8	10.1	11.8	12.0	12.0
	Heterlimnius	10.2	10.2	10.2	10.2	10.2	1.0
	Optioservus	7.1	9.8	9.2	9.8	10.1	3.0
	Zaitzevia	9.5	9.8	10.2	11.8	12.0	8.0
Mollusca		3.7	5.4	9.0	16.4	26.4	212.0
	Ancylidae						
	Ferrissea	5.4	5.5	8.9	13.3	13.8	64.0
	Lymnaidae						
	Lymnaea	5.4	5.7	7.8	12.8	13.8	30.0
	Physidae						
	Physa	3.7	5.4	9.1	16.4	26.4	111.0
	Planorbidae	5.4	6.4	8.0	10.4	11.6	7.0
	Helisoma	6.4	6.4	6.4	6.4	6.4	1.0
	Gyraulus	5.4	7.1	8.3	10.4	11.6	6.0

Appendix IIIe

Group	Taxa	DISSOLVED LEAD (ug/l) minimum	next lowest	PV	next highest	maximum	sample size
Platyhelminthes							
	Tricladida						
	Dugesia	0.0	0.3	0.9	6.1	29.8	43.0
Hirudinea		0.0	0.3	1.7	6.1	29.8	62.0
	Erpobdellidae						
	Erpobdella	0.0	0.3	1.8	6.1	29.8	47.0
	Glossiphoniidae	0.0	0.3	1.0	3.7	6.1	14.0
	Glossiphonia	0.0	0.3	1.1	2.1	6.1	5.0
	Helobdella	0.0	1.0	0.5	0.0	1.0	2.0
	Placobdella	0.0	0.3	0.9	1.0	3.7	7.0
	Hirudinidae						
	Macrobdella	0.3	0.3	0.3	0.3	0.3	1.0
Oligochaeta		0.0	0.3	0.9	5.3	29.8	98.0
Isopoda							
	Asellidae						
	Asellus	0.0	0.3	0.6	6.1	29.8	30.0
Amphipoda		0.0	0.3	1.6	4.2	6.1	47.0
	Gammaridae						
	Gammarus	0.0	0.3	0.5	1.0	2.0	5.0
	Hyalellidae						
	Hyalella	0.0	0.3	1.6	4.2	6.1	42.0
	H. azteca						
Plecoptera		0.0	0.5	2.0	2.8	2.9	13.0
	Taeniopterygidae						
	Taenionema	-	-	-	-	-	-
	Capniidae						
	Capnia	-	-	-	-	-	-
	Perlidae						
	Claassenia	1.0	2.2	2.4	2.2	2.9	3.0
	C. sabulosa						
	Hesperoperla	-	-	-	-	-	-
	H. pacifica						

Appendix IIIe

Group	Taxa	DISSOLVED LEAD (ug/l) minimum	next lowest	PV	next highest	maximum	sample size
Plecoptera (cont.)							
	Perlodidae						
	Cultus	-	-	-	-	-	-
	C. aestivalis						
	Skwala	-	-	-	-	-	-
	S. americana						
	Isoperla	0.0	2.0	2.3	2.8	2.9	5.0
	I. fulva						
	I. quinquepunctata						
	Chloroperlidae						
	Alloperla	0.5	1.0	1.5	2.1	2.2	5.0
Ephemeroptera		0.0	0.3	1.1	6.1	29.8	196.0
	Siphlonuridae						
	Ameletus	1.0	2.7	5.1	2.7	29.8	3.0
	Baetidae						
	Baetis	0.0	0.3	1.8	3.1	29.8	46.0
	B. flavistriga						
	B. tricaudatus						
	Heptageniidae	0.3	0.5	3.1	2.9	29.8	16.0
	Epeorus	2.2	2.9	2.8	2.2	2.9	2.0
	Heptagenia	0.3	0.5	3.8	2.9	29.8	11.0
	H. diabasia						
	Rhithrogena	1.3	2.0	1.5	2.0	2.1	3.0
	Ephemerellidae	0.0	0.3	1.9	5.3	6.1	19.0
	Drunella	0.0	0.0	0.0	0.0	0.0	1.0
	D. doddsi						
	D. grandis						
	Ephemerella	0.0	0.3	1.9	5.3	6.1	18.0
	E. inermis						
	Tricorythidae						
	Tricorythodes	0.0	0.3	1.0	6.1	29.8	100.0
	Leptophlebiidae	0.0	0.3	2.6	5.3	29.8	12.0
	Choroterpes	-	-	-	-	-	-
	Leptophlebia	0.0	0.3	3.6	5.3	29.8	6.0
	Paraleptophlebia	0.0	0.5	2.5	2.8	2.9	6.0

Appendix IIIe

Group	Taxa	DISSOLVED LEAD (ug/l) minimum	next lowest	PV	next highest	maximum	sample size
Ephemeroptera (cont.)							
	Polymitarcyidae						
	Ephoron	-	-	-	-	-	-
Trichoptera		0.0	0.3	1.6	6.1	29.8	226.0
	Psychomyiidae						
	Psychomyia	-	-	-	-	-	-
	P. flavida						
	Polycentropodidae						
	Polycentropus	-	-	-	-	-	-
	Hydropsychidae	0.0	0.3	1.6	6.1	29.8	185.0
	Cheumatopsyche	0.0	0.3	1.6	6.1	29.8	100.0
	Hydropsyche	0.0	0.3	1.5	5.3	29.8	85.0
	Rhyacophilidae						
	Rhyacophila	-	-	-	-	-	-
	R. brunnea						
	Hydroptilidae						
	Hydroptila	0.0	0.3	2.1	3.0	29.8	23.0
	Brachycentridae						
	Brachycentrus	0.3	2.8	8.0	3.2	29.8	4.0
	B. americanus						
	B occidentalis						
	Lepidostomatidae						
	Lepidostoma	-	-	-	-	-	-
	Limnephilidae						
	Hesperophylax	-	-	-	-	-	-
	Helicopsychidae						
	Helicopsyche	0.5	0.5	0.5	0.5	0.5	1.0
	H. borealis						
	Leptoceridae						
	Nectopsyche	0.0	0.3	1.2	2.8	2.9	13.0

Appendix IIIe

Group	Taxa	DISSOLVED LEAD (ug/l) minimum	next lowest	PV	next highest	maximum	sample size
Diptera		0.0	0.3	1.4	6.1	29.8	398.0
	Tipulidae	0.0	0.3	1.2	3.1	3.2	36.0
	Antocha	0.3	1.3	1.7	2.1	2.2	6.0
	Hexatoma	0.0	0.5	1.3	1.6	2.0	5.0
	Tipula	0.0	0.3	1.2	3.1	3.2	25.0
	Simuliidae						
	Simulium	0.0	0.3	1.6	5.6	6.1	92.0
	S. vittatum						
	Chironomidae	0.0	0.3	1.3	6.1	29.8	251.0
	Chironomus	0.0	0.3	1.1	4.4	5.3	36.0
	Cricotopus	0.0	0.3	1.4	6.1	29.8	97.0
	Eukiefferiella	0.5	0.5	0.5	0.5	0.5	1.0
	Orthocladius	0.0	0.3	1.3	6.1	29.8	74.0
	Polypedilum	0.3	0.6	0.7	0.6	2.2	3.0
	Tanytarsus	0.0	0.3	0.8	5.3	29.8	40.0
	Stratiomyidae						
	Odontomyia	0.0	0.0	0.0	0.0	0.0	1.0
	Athericidae						
	Atherix	0.0	0.3	1.2	2.8	3.7	14.0
	A. pachypus						
	Muscidae						
	Limnophora	0.0	1.7	0.9	1.7	2.0	4.0
Odonata		0.0	0.3	1.8	2.2	2.9	14.0
	Gomphidae						
	Ophiogomphus	0.0	0.5	1.9	2.2	2.9	12.0
	O. severus						
	Coenagrionidae						
	Argia	0.3	0.5	0.4	0.3	0.5	2.0
Hemiptera							
	Corixidae	0.0	0.3	0.5	1.2	2.0	8.0
	Sigara	0.0	0.3	0.3	0.3	0.5	3.0
	Trichocorixa	0.0	1.0	1.6	1.2	2.0	5.0
Lepidoptera							
	Pyralidae						
	Petrophila	1.0	2.0	1.5	1.0	2.0	2.0

Appendix IIIe

Group	Taxa	DISSOLVED LEAD (ug/l) minimum	next lowest	PV	next highest	maximum	sample size
Coleoptera		0.0	0.3	0.4	0.3	0.5	5.0
	Dytiscidae						
	Agabus	0.5	0.5	0.5	0.5	0.5	1.0
	Elmidae	0.0	0.3	0.4	0.3	0.5	4.0
	Heterlimnius	-	-	-	-	-	-
	Optioservus	0.5	0.5	0.5	0.5	0.5	1.0
	Zaitzevia	0.0	0.3	0.4	0.3	0.5	3.0
Mollusca		0.0	0.3	0.4	5.3	6.1	89.0
	Ancylidae						
	Ferrissea	0.0	0.3	1.6	2.7	3.0	15.0
	Lymnaidae						
	Lymnaea	0.0	0.3	1.4	5.3	6.1	20.0
	Physidae						
	Physa	0.0	0.3	0.3	5.3	6.1	50.0
	Planorbidae						
	Helisoma	-	-	-	-	-	-
	Gyraulus	0.0	0.3	0.7	0.3	1.8	4.0

Appendix IIIf

Group	Taxa	UNIONIZED AMMONIA NITROGEN (ug/l) minimum	next lowest	PV	next highest	maximum	sample size
Platyhelminthes							
	Tricladida						
	Dugesia	0.0	0.1	3.0	24.0	53.0	58.0
Hirudinea		0.0	0.1	10.7	110.0	253.0	98.0
	Erpobdellidae						
	Erpobdella	0.0	0.1	11.0	110.0	253.0	67.0
	Glossiphoniidae	0.0	0.1	9.0	71.0	253.0	30.0
	Glossiphonia	0.0	0.1	2.1	1.0	3.0	6.0
	Helobdella	0.0	0.1	5.4	19.0	31.0	10.0
	Placobdella	0.1	0.1	13.1	71.0	253.0	14.0
	Hirudinidae						
	Macrobdella	1.0	1.0	1.0	1.0	1.0	1.0
Oligochaeta		0.0	0.1	14.7	340.0	342.0	306.0
Isopoda							
	Asellidae						
	Asellus	0.0	0.1	3.0	48.0	53.0	60.0
Amphipoda		0.0	0.1	16.0	259.0	342.0	108.0
	Gammaridae						
	Gammarus	0.0	0.1	8.0	16.0	25.0	8.0
	Hyalellidae						
	Hyalella	0.0	0.1	16.5	259.0	342.0	100.0
	H. azteca						
Plecoptera		0.0	0.1	1.5	25.3	41.3	58.0
	Taeniopterygidae						
	Taenionema	0.1	7.0	4.7	0.1	7.0	2.0
	Capniidae						
	Capnia	4.0	4.0	4.0	4.0	4.0	1.0
	Perlidae	0.1	0.1	2.5	9.0	22.0	14.0
	Claassenia	0.1	0.1	3.2	9.0	22.0	10.0
	C. sabulosa						
	Hesperoperla	0.1	1.0	1.2	3.0	4.0	4.0
	H. pacifica						

Appendix IIIf

Group	Taxa	UNIONIZED AMMONIA NITROGEN (ug/l) minimum	next lowest	PV	next highest	maximum	sample size
Plecoptera (cont.)							
	Perlodidae	0.0	0.1	2.6	25.3	41.3	29.0
	Cultus	0.1	0.1	0.1	0.1	0.1	1.0
	C. aestivalis						
	Skwala	0.1	2.0	0.4	0.1	2.0	2.0
	S. americana						
	Isoperla	0.0	0.1	2.7	25.3	41.3	26.0
	I. fulva						
	I. quinquepunctata						
	Chloroperlidae						
	Alloperla	0.1	0.1	1.0	2.8	9.0	12.0
Ephemeroptera		0.0	0.1	6.1	259.0	340.0	658.0
	Siphlonuridae						
	Ameletus	0.0	0.5	1.2	18.0	31.0	49.0
	Baetidae						
	Baetis	0.0	0.5	7.4	86.0	110.0	142.0
	B. flavistriga						
	B. tricaudatus						
	Heptageniidae	0.0	0.1	6.1	60.0	110.0	67.0
	Epeorus	0.1	1.0	6.1	9.0	22.0	6.0
	Heptagenia	0.0	0.1	11.6	60.0	110.0	46.0
	H. diabasia						
	Rhithrogena	0.1	1.0	1.9	4.0	8.0	15.0
	Ephemerellidae						
	Drunella	-	-	-	-	-	-
	D. doddsi						
	D. grandis						
	Ephemerella	0.0	0.1	2.7	41.3	42.0	76.0
	E. inermis						
	Tricorythidae						
	Tricorythodes	0.0	0.1	6.3	259.0	340.0	273.0
	Leptophlebiidae	0.0	0.1	6.7	22.0	24.0	49.0
	Choroterpes	0.0	0.1	0.7	2.2	13.0	5.0
	Leptophlebia	0.0	0.1	4.1	14.0	21.0	16.0
	Paraleptophlebia	0.0	0.1	7.3	22.0	24.0	28.0

Appendix IIIf

Group	Taxa	minimum	next lowest	PV	next highest	maximum	sample size
		UNIONIZED AMMONIA NITROGEN (ug/l)					
Ephemeroptera (cont.)							
	Polymitarcyidae						
	Ephoron	2.4	53.0	27.2	2.4	53.0	2.0
Trichoptera		0.0	0.1	10.2	340.0	342.0	742.0
	Psychomyiidae						
	Psychomyia	5.0	11.0	6.5	11.0	35.0	4.0
	P. flavida						
	Polycentropodidae						
	Polycentropus	6.0	6.0	6.0	6.0	6.0	1.0
	Hydropsychidae	0.0	0.1	10.3	340.0	342.0	583.0
	Cheumatopsyche	0.0	0.1	10.9	340.0	342.0	293.0
	Hydropsyche	0.0	0.1	9.2	304.0	340.0	290.0
	Rhyacophilidae						
	Rhyacophila	0.0	0.3	3.1	5.0	14.0	4.0
	R. brunnea						
	Hydroptilidae						
	Hydroptila	0.0	0.1	12.0	74.0	110.0	68.0
	Brachycentridae						
	Brachycentrus	0.0	0.1	2.3	32.0	34.0	33.0
	B. americanus						
	B occidentalis						
	Lepidostomatidae						
	Lepidostoma	0.1	2.2	2.2	2.2	2.8	4.0
	Limnephilidae						
	Hesperophylax	0.1	0.1	0.1	0.1	0.1	1.0
	Helicopsychidae						
	Helicopsyche	0.1	0.3	2.2	1.0	9.4	4.0
	H. borealis						
	Leptoceridae						
	Nectopsyche	0.0	0.1	2.2	22.0	30.0	40.0

Appendix IIIf

Group	Taxa	UNIONIZED AMMONIA NITROGEN (ug/l) minimum	next lowest	PV	next highest	maximum	sample size
Diptera		0.0	0.1	14.8	340.0	342.0	1265.0
	Tipulidae	0.0	0.1	31.5	259.0	340.0	123.0
	Antocha	0.1	0.1	4.3	9.0	10.0	14.0
	Hexatoma	0.0	0.1	5.9	25.3	32.0	27.0
	Tipula	0.0	0.1	45.6	259.0	340.0	82.0
	Simuliidae						
	Simulium	0.0	0.1	13.6	340.0	342.0	271.0
	S. vittatum						
	Chironomidae	0.0	0.1	15.2	340.0	342.0	818.0
	Chironomus	0.0	0.1	9.7	86.0	342.0	118.0
	Cricotopus	0.0	0.1	14.9	340.0	342.0	308.0
	Eukiefferiella	0.0	0.3	9.1	41.0	83.0	31.0
	Orthocladius	0.0	0.1	18.3	340.0	342.0	207.0
	Polypedilum	0.0	0.1	5.2	53.0	110.0	59.0
	Tanytarsus	0.0	0.1	21.4	304.0	342.0	95.0
	Stratiomyidae						
	Odontomyia	-	-	-	-	-	-
	Athericidae						
	Atherix	0.1	0.1	12.7	74.0	253.0	33.0
	A. pachypus						
	Muscidae						
	Limnophora	0.0	0.1	9.7	30.0	53.0	20.0
Odonata		0.0	0.1	8.3	60.0	86.0	43.0
	Gomphidae						
	Ophiogomphus	0.0	0.1	8.3	60.0	86.0	41.0
	O. severus						
	Coenagrionidae						
	Argia	2.0	18.0	10.0	2.0	18.0	2.0
Hemiptera							
	Corixidae	0.0	2.0	4.3	18.0	53.0	16.0
	Sigara	0.0	2.0	4.1	14.0	16.0	10.0
	Trichocorixa	2.0	4.0	7.4	18.0	53.0	6.0
Lepidoptera							
	Pyralidae						
	Petrophila	0.1	0.1	0.1	0.1	0.1	3.0

Appendix IIIf

Group	Taxa	UNIONIZED AMMONIA NITROGEN (ug/l) minimum	next lowest	PV	next highest	maximum	sample size
Coleoptera		0.1	0.1	3.0	2.8	3.4	10.0
	Dytiscidae						
	Agabus	0.1	2.0	1.0	2.0	2.8	4.0
	Elmidae	0.1	1.0	3.3	18.0	58.0	6.0
	Heterlimnius	-	-	-	-	-	-
	Optioservus	3.4	3.4	3.4	3.4	3.4	1.0
	Zaitzevia	0.1	1.0	3.4	18.0	58.0	5.0
Mollusca		0.0	0.1	9.5	253.0	340.0	186.0
	Ancylidae						
	Ferrissea	0.1	0.1	11.8	53.0	110.0	58.0
	Lymnaidae						
	Lymnaea	0.1	0.1	7.4	21.0	86.0	27.0
	Physidae						
	Physa	0.0	0.1	9.4	253.0	340.0	94.0
	Planorbidae	0.0	1.0	3.1	3.4	8.0	7.0
	Helisoma	8.0	8.0	8.0	8.0	8.0	1.0
	Gyraulus	0.0	1.0	2.2	3.0	3.4	6.0

Appendix IIIg

Group	Taxa	pH minimum	pH next lowest	pH PV	pH next highest	pH maximum	pH sample size
Platyhelminthes							
	Tricladida						
	Dugesia	6.7	6.9	7.9	8.5	9.2	76.0
Hirudinea		6.9	7.2	7.9	9.2	9.4	103.0
	Erpobdellidae						
	Erpobdella	6.9	7.2	7.9	8.9	9.2	83.0
	Glossiphoniidae	7.4	7.5	8.1	8.5	8.6	19.0
	Glossiphonia	7.5	7.6	8.0	8.3	8.4	8.0
	Helobdella	7.4	7.6	8.0	8.4	8.6	10.0
	Placobdella	7.7	7.8	8.1	8.5	8.6	1.0
	Hirudinidae						
	Macrobdella	7.4	7.4	7.4	7.4	7.4	1.0
Oligochaeta		6.7	6.8	8.0	8.9	9.2	339.0
Isopoda							
	Asellidae						
	Asellus	7.2	7.3	8.0	8.3	8.5	71.0
Amphipoda		7.2	7.3	8.0	8.5	8.6	121.0
	Gammaridae						
	Gammarus	7.8	7.9	8.1	8.3	8.4	9.0
	Hyalellidae						
	Hyalella	7.2	7.3	8.0	8.5	8.6	112.0
	H. azteca						
Plecoptera		6.7	6.9	7.8	8.3	8.4	65.0
	Taeniopterygidae						
	Taenionema	7.6	8.0	7.9	7.6	8.0	1.0
	Capniidae						
	Capnia	8.0	8.0	8.0	8.0	8.0	1.0
	Perlidae	7.5	7.7	7.7	8.2	8.4	15.0
	Claassenia	7.5	7.7	7.7	8.2	8.4	11.0
	C. sabulosa						
	Hesperoperla	7.6	7.7	7.7	7.7	8.2	4.0
	H. pacifica						

Appendix IIIg

Group	Taxa	pH minimum	next lowest	PV	next highest	maximum	sample size
Plecoptera (cont.)							
	Perlodidae	6.7	6.9	7.8	8.3	8.4	32.0
	Cultus	8.4	8.4	8.4	8.4	8.4	1.0
	C. aestivalis						
	Skwala	7.9	8.4	8.3	7.9	8.4	2.0
	S. americana						
	Isoperla	6.7	6.9	7.8	8.3	8.4	29.0
	I. fulva						
	I. quinquepunctata						
	Chloroperlidae						
	Alloperla	7.4	7.5	7.8	7.9	8.4	16.0
Ephemeroptera		6.7	6.8	7.9	8.9	9.2	730.0
	Siphlonuridae						
	Ameletus	6.7	6.8	7.6	8.5	8.6	49.0
	Baetidae						
	Baetis	6.7	6.8	7.9	8.9	9.2	159.0
	B. flavistriga						
	B. tricaudatus						
	Heptageniidae	6.7	7.3	7.8	8.9	9.2	79.0
	Epeorus	7.5	7.6	7.8	8.2	8.4	7.0
	Heptagenia	6.7	7.3	7.9	8.9	9.2	55.0
	H. diabasia						
	Rhithrogena	7.5	7.6	7.7	8.2	8.4	17.0
	Ephemerellidae	6.7	6.9	7.8	8.4	8.5	82.0
	Drunella	8.5	8.5	8.5	8.5	8.5	1.0
	D. doddsi						
	D. grandis						
	Ephemerella	6.7	6.9	7.8	8.4	8.5	81.0
	E. inermis						
	Tricorythidae						
	Tricorythodes	6.7	6.8	7.9	8.9	9.2	306.0
	Leptophlebiidae	6.7	6.9	8.2	8.6	9.2	53.0
	Choroterpes	7.5	7.7	7.5	8.1	8.3	6.0
	Leptophlebia	6.7	6.9	7.6	8.1	8.2	17.0
	Paraleptophlebia	7.3	7.4	8.3	8.6	9.2	30.0

Appendix IIIg

Group	Taxa	pH minimum	next lowest	PV	next highest	maximum	sample size
Ephemeroptera (cont.)							
	Polymitarcyidae						
	Ephoron	7.7	8.0	7.9	7.7	8.0	2.0
Trichoptera		6.7	6.8	8.0	8.9	9.2	824.0
	Psychomyiidae						
	Psychomyia	8.1	8.2	8.2	8.2	8.3	5.0
	P. flavida						
	Polycentropodidae						
	Polycentropus	8.2	8.2	8.2	8.2	8.2	1.0
	Hydropsychidae	6.7	6.8	8.0	8.9	9.2	640.0
	Cheumatopsyche	6.7	6.8	8.0	8.9	9.2	323.0
	Hydropsyche	6.7	6.8	8.0	8.9	9.2	317.0
	Rhyacophilidae						
	Rhyacophila	6.7	8.0	7.5	8.1	8.3	4.0
	R. brunnea						
	Hydroptilidae						
	Hydroptila	6.8	6.9	8.0	8.9	9.2	74.0
	Brachycentridae						
	Brachycentrus	6.7	6.9	7.6	8.3	8.4	38.0
	B. americanus						
	B occidentalis						
	Lepidostomatidae						
	Lepidostoma	7.4	7.5	7.7	8.0	8.3	5.0
	Limnephilidae						
	Hesperophylax	7.4	7.5	7.5	7.4	7.5	2.0
	Helicopsychidae						
	Helicopsyche	7.5	7.6	8.3	7.9	8.4	4.0
	H. borealis						
	Leptoceridae						
	Nectopsyche	6.7	7.0	7.8	8.4	8.5	51.0

Appendix IIIg

Group	Taxa	pH minimum	pH next lowest	pH PV	pH next highest	pH maximum	sample size
Diptera		6.7	6.8	7.9	8.9	9.2	1395.0
	Tipulidae	6.7	7.1	7.9	8.5	8.6	135.0
	Antocha	6.7	7.3	7.5	8.2	8.3	17.0
	Hexatoma	7.4	7.5	7.8	8.3	8.5	32.0
	Tipula	7.1	7.2	8.0	8.5	8.6	86.0
	Simuliidae						
	Simulium	6.8	6.9	7.9	8.7	9.2	297.0
	S. vittatum						
	Chironomidae	6.7	6.8	7.9	8.9	9.2	900.0
	Chironomus	7.1	7.2	8.0	8.6	9.2	130.0
	Cricotopus	6.7	6.8	7.9	8.9	9.2	336.0
	Eukiefferiella	7.3	7.4	8.0	8.5	8.6	32.0
	Orthocladius	6.8	6.9	8.0	8.9	9.2	232.0
	Polypedilum	6.7	6.8	7.8	8.7	8.9	61.0
	Tanytarsus	6.7	6.9	7.9	8.5	8.6	109.0
	Stratiomyidae						
	Odontomyia	8.3	8.3	8.3	8.3	8.3	1.0
	Athericidae						
	Atherix	6.7	6.8	7.9	8.6	9.2	36.0
	A. pachypus						
	Muscidae						
	Limnophora	7.1	7.2	7.9	8.4	8.5	26.0
Odonata		6.7	6.8	7.9	8.4	8.5	48.0
	Gomphidae						
	Ophiogomphus	6.7	6.8	7.9	8.4	8.5	46.0
	O. severus						
	Coenagrionidae						
	Argia	7.8	8.0	7.9	7.8	8.0	2.0
Hemiptera							
	Corixidae	7.7	7.9	8.1	8.4	8.5	19.0
	Sigara	7.7	7.9	8.1	8.3	8.4	11.0
	Trichocorixa	7.8	7.9	8.0	8.4	8.5	8.0
Lepidoptera							
	Pyralidae						
	Petrophila	7.8	7.9	7.8	7.8	7.9	3.0

Appendix IIIg

Group	Taxa	pH minimum	next lowest	PV	next highest	maximum	sample size
Coleoptera		7.4	7.5	7.8	8.2	8.5	16.0
	Dytiscidae						
	Agabus	7.5	7.5	7.6	7.7	8.1	4.0
	Elmidae	7.4	7.7	7.8	8.2	8.5	12.0
	Heterlimnius	8.0	8.0	8.0	8.0	8.0	1.0
	Optioservus	7.4	8.1	7.7	8.1	8.2	3.0
	Zaitzevia	7.4	7.7	7.8	8.2	8.5	8.0
Mollusca		6.7	6.8	8.1	8.9	9.2	210.0
	Ancylidae						
	Ferrissea	6.7	6.8	8.0	8.9	9.2	63.0
	Lymnaidae						
	Lymnaea	7.2	7.2	7.6	8.3	8.4	30.0
	Physidae						
	Physa	6.9	7.1	8.1	8.6	9.2	110.0
	Planorbidae	7.5	7.7	7.9	8.2	8.3	7.0
	Helisoma	7.9	7.9	7.9	7.9	7.9	1.0
	Gyraulus	7.5	7.7	7.9	8.2	8.3	6.0

Appendix IIIh

Group	Taxa	TURBIDITY (N.T.U.) minimum	next lowest	PV	next highest	maximum	sample size
Platyhelminthes							
	Tricladida						
	Dugesia	1.0	1.5	5.5	41.0	49.7	46.0
Hirudinea		1.0	1.5	12.3	51.0	74.2	87.0
	Erpobdellidae						
	Erpobdella	1.0	1.5	13.2	51.0	74.2	60.0
	Glossiphoniidae	1.6	2.0	8.0	25.0	46.0	26.0
	Glossiphonia	1.6	2.4	13.6	14.7	25.0	6.0
	Helobdella	2.0	3.0	11.2	21.0	46.0	8.0
	Placobdella	2.0	2.8	4.6	11.0	11.9	12.0
	Hirudinidae						
	Macrobdella	1.6	1.6	1.6	1.6	1.6	1.0
Oligochaeta		1.0	1.3	15.1	160.0	190.0	263.0
Isopoda							
	Asellidae						
	Asellus	1.0	1.3	7.6	66.0	84.0	45.0
Amphipoda		1.0	1.6	11.7	94.0	115.0	90.0
	Gammaridae						
	Gammarus	2.8	3.3	6.9	5.0	94.0	6.0
	Hyalellidae						
	Hyalella	1.0	1.6	12.0	94.0	115.0	84.0
	H. azteca						
Plecoptera		1.0	1.6	6.0	20.0	41.0	49.0
	Taeniopterygidae						
	Taenionema	2.0	20.0	4.0	2.0	20.0	2.0
	Capniidae						
	Capnia	-	-	-	-	-	-
	Perlidae	1.0	1.6	4.8	9.0	41.0	12.0
	Claassenia	1.0	1.6	5.4	9.0	41.0	9.0
	C. sabulosa						
	Hesperoperla	1.0	4.0	3.0	3.0	4.0	3.0
	H. pacifica						

Appendix IIIh

Group	Taxa	TURBIDITY (N.T.U.) minimum	next lowest	PV	next highest	maximum	sample size
Plecoptera (cont.)							
	Perlodidae	1.0	1.6	3.4	9.0	12.0	23.0
	Cultus	1.0	1.0	1.0	1.0	1.0	1.0
	C. aestivalis						
	Skwala	1.0	5.0	1.7	1.0	5.0	2.0
	S. americana						
	Isoperla	1.0	1.6	3.5	9.0	12.0	20.0
	I. fulva						
	I. quinquepunctata						
	Chloroperlidae						
	Alloperla	1.0	2.0	6.9	9.0	41.0	12.0
Ephemeroptera		1.0	1.3	11.7	160.0	190.0	547.0
	Siphlonuridae						
	Ameletus	1.0	1.5	19.3	95.0	115.0	42.0
	Baetidae						
	Baetis	1.0	1.3	11.9	128.0	160.0	112.0
	B. flavistriga						
	B. tricaudatus						
	Heptageniidae	1.0	1.6	9.0	95.0	190.0	57.0
	Epeorus	1.0	1.6	4.9	6.0	41.0	6.0
	Heptagenia	1.0	2.0	19.7	95.0	190.0	38.0
	H. diabasia						
	Rhithrogena	1.0	2.0	2.8	7.0	9.0	13.0
	Ephemerellidae						
	Drunella	-	-	-	-	-	-
	D. doddsi						
	D. grandis						
	Ephemerella	1.0	1.5	7.6	32.0	64.0	66.0
	E. inermis						
	Tricorythidae						
	Tricorythodes	1.0	1.3	11.3	160.0	190.0	234.0
	Leptophlebiidae	1.0	1.5	22.4	128.0	160.0	36.0
	Choroterpes	3.0	7.0	3.1	3.0	7.0	2.0
	Leptophlebia	1.5	1.6	16.8	41.0	160.0	11.0
	Paraleptophlebia	1.0	1.6	23.6	68.0	128.0	23.0

Appendix IIIh

Group	Taxa	TURBIDITY (N.T.U.) minimum	next lowest	PV	next highest	maximum	sample size
Ephemeroptera (cont.)							
	Polymitarcyidae						
	Ephoron	-	-	-	-	-	-
Trichoptera		1.0	1.3	11.5	160.0	190.0	620.0
	Psychomyiidae						
	Psychomyia	1.0	4.0	4.5	8.0	9.0	4.0
	P. flavida						
	Polycentropodidae						
	Polycentropus	5.0	5.0	5.0	5.0	5.0	1.0
	Hydropsychidae	1.0	1.3	11.4	160.0	190.0	503.0
	Cheumatopsyche	1.0	1.3	11.4	160.0	190.0	256.0
	Hydropsyche	1.0	1.3	11.6	160.0	190.0	247.0
	Rhyacophilidae						
	Rhyacophila	2.0	4.0	4.3	4.0	6.0	3.0
	R. brunnea						
	Hydroptilidae						
	Hydroptila	1.0	1.5	27.0	84.0	190.0	51.0
	Brachycentridae						
	Brachycentrus	1.0	1.5	5.0	22.0	25.0	23.0
	B. americanus						
	B occidentalis						
	Lepidostomatidae						
	Lepidostoma	3.0	4.0	3.5	3.0	4.0	2.0
	Limnephilidae						
	Hesperophylax	3.0	3.0	3.0	3.0	3.0	1.0
	Helicopsychidae						
	Helicopsyche	1.0	2.3	3.9	6.0	22.0	4.0
	H. borealis						
	Leptoceridae						
	Nectopsyche	1.0	1.6	6.9	42.3	64.0	28.0

Appendix IIIh

Group	Taxa	TURBIDITY (N.T.U.) minimum	next lowest	PV	next highest	maximum	sample size
Diptera		1.0	1.3	11.3	160.0	190.0	1086.0
	Tipulidae	1.0	1.3	6.6	25.0	41.0	101.0
	Antocha	1.0	3.0	5.3	12.0	41.0	16.0
	Hexatoma	1.0	2.0	4.5	9.0	25.0	19.0
	Tipula	1.0	1.3	7.7	25.0	41.0	66.0
	Simuliidae						
	Simulium	1.0	1.3	10.4	115.0	128.0	241.0
	S. vittatum						
	Chironomidae	1.0	1.3	11.7	160.0	190.0	701.0
	Chironomus	1.0	1.6	13.1	95.0	190.0	101.0
	Cricotopus	1.0	1.3	10.9	160.0	190.0	267.0
	Eukiefferiella	1.0	2.0	8.2	36.0	66.0	27.0
	Orthocladius	1.0	1.3	14.0	128.0	190.0	185.0
	Polypedilum	1.0	2.0	17.9	95.0	115.0	43.0
	Tanytarsus	1.0	1.5	16.1	64.0	160.0	78.0
	Stratiomyidae						
	Odontomyia	-	-	-	-	-	-
	Athericidae						
	Atherix	1.0	3.0	9.7	30.3	70.0	26.0
	A. pachypus						
	Muscidae						
	Limnophora	2.0	3.0	16.1	44.4	66.0	17.0
Odonata		1.0	1.6	14.7	84.0	160.0	35.0
	Gomphidae						
	Ophiogomphus	1.0	1.6	14.8	84.0	160.0	33.0
	O. severus						
	Coenagrionidae						
	Argia	4.8	10.7	7.8	2.0	10.7	2.0
Hemiptera							
	Corixidae	2.0	2.6	3.4	6.0	36.6	12.0
	Sigara	2.0	4.0	3.0	5.0	6.0	6.0
	Trichocorixa	2.6	5.0	10.6	5.5	36.6	5.0
Lepidoptera							
	Pyralidae						
	Petrophila	4.6	6.0	5.9	6.0	7.0	3.0

Appendix IIIh

Group	Taxa	TURBIDITY (N.T.U.) minimum	next lowest	PV	next highest	maximum	sample size
Coleoptera		1.0	2.1	5.9	9.0	36.6	10.0
	Dytiscidae						
	Agabus	3.0	6.8	4.0	3.0	6.8	3.0
	Elmidae	1.0	2.1	6.1	9.0	36.6	7.0
	Heterlimnius	-	-	-	-	-	-
	Optioservus	2.1	2.1	2.1	2.1	2.1	1.0
	Zaitzevia	1.0	2.1	6.5	9.0	36.6	6.0
Mollusca		1.0	1.3	9.9	94.0	160.0	158.0
	Ancylidae						
	Ferrissea	1.0	2.0	16.3	94.0	160.0	49.0
	Lymnaidae						
	Lymnaea	1.3	1.5	12.4	67.0	74.2	26.0
	Physidae						
	Physa	1.0	1.6	7.2	74.2	94.0	80.0
	Planorbidae						
	Helisoma	-	-	-	-	-	-
	Gyraulus	6.0	7.9	9.0	7.9	10.3	3.0