Big South Fork/Bear Creek Nonpoint Source Interstate Demonstration Project

Final Report

Kentucky Division of Water
Water Quality Branch
Nonpoint Source Section
August, 1999

Natural Resources and Environmental
Protection Cabinet

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Kentucky Department for Environmental Protection
Division of Water
Water Quality Branch
Nonpoint Source Section
Frankfort, Kentucky

Technical Report No. 3
August, 1999

This report has been approved for release:

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

EXECUTIVE SUMMARY

The Big South Fork/Bear Creek Nonpoint Source Interstate Demonstration Project was an acid mine drainage (AMD) project originally coordinated with the state of Tennessee. The original intent of the project was to collect biological and physicochemical data from Bear Creek near the mouth before and after AMD treatment in Tennessee. Part of the original goals of the study was to collect macroinvertebrates from Bear Creek and compare the data to similar collections made in a relatively undisturbed section of Rock Creek. Both creeks were direct tributaries to the South Fork Cumberland River (SFCR).

The nonpoint source pollution impacts to Bear Creek begin outside the Big South Fork National River and Recreation Area (BSFNRRA) in Tennessee. The lower portion of Bear Creek lies in Kentucky, mostly within the BSFNRRA. The National Park Service was concerned about: (1) the impacts of the Bear Creek drainage on state and federally listed endangered species, (2) high concentrations of metals in surface and underground water sources, and (3) the related public health problems with domestic and recreational use of these waters. The National Park Service encouraged the state of Tennessee's involvement with reclamation of lands outside the National River and Recreation Area boundaries within the Bear Creek watershed.

Since this was an interstate demonstration project, and to ensure that biological data from the two states were comparable, Tennessee Standard Operating Procedures for quantitative and qualitative macroinvertebrate sampling were followed. One-square-foot Surber samplers were used for quantitative sampling. All available habitat was sampled with kick nets for qualitative sampling. Fishes were collected at each station during the fall and spring with a seine in all available habitats. Physicochemical data was collected at both stations with several methods, depending on rainfall amounts and flow conditions.

A total of 517 macroinvertebrates representing 81 taxa were collected from Bear Creek and 4,658 individuals representing 143 taxa were collected from Rock Creek. The low Taxa Richness and Total Number of Individuals (TNI) values observed from Bear Creek indicated an impacted system. The average Ephemeroptera-Plecoptera-Trichoptera (EPT) value for the Bear Creek collections was 4.9, and the percentage of Chironomidae was significantly greater than the percentage of EPT (t=3.06, α=0.05). The average Hilsenhoff Biotic Index (HBI) score for the nine Bear Creek collections was 5.93, and the average Shannon-Wiener Index value was 2.53, both of which also indicated an impacted system.

The average Taxa Richness value for Rock Creek was 53.4, and the average TNI value was 584.25. These Taxa Richness and TNI values indicated that, at the present sampling station, Rock Creek was not affected by AMD and was therefore characteristic of a natural, unaffected system. The average EPT value for Rock Creek was 25, and in contrast to the data from Bear Creek, the percentage of EPT was significantly higher than the percentage of Chironomidae (t=4.25, α=0.05). This indicated a system that was not being impacted by AMD and supported a diverse EPT fauna. The average HBI score for Rock Creek was 3.53, and the average Shannon-Wiener Index value was 2.88, both of which indicated the stream had not been impacted.

Taxa Richness (t=9.78, α=0.05) and Total Number of Individuals (t=5.26, α=0.05) for Rock Creek were significantly greater than those for Bear Creek. Significant differences were also observed between EPT (t=14.14, α=0.05), percent EPT (t=4.70, α=0.05), percent Chironomidae (t=2.17, α=0.05), and HBI values (t=3.85, α=0.05). These data clearly showed the inability of the AMD-impacted Bear Creek to support a diverse, pollution intolerant macroinvertebrate fauna. The CC_J and Percent Community Similarity (PS_C) values between the Bear Creek and Rock Creek collections indicated a large dissimilarity between the two streams.

Attempts were made to collect fish at the Bear Creek station on five occasions, yielding only one fish, which was most likely a transient. The resultant Index of Biotic Integrity values for Bear Creek were 0, with the exception of the one collection (IBI of 36). However, this was based on a single intolerant insectivore and should be considered an anomaly, since in all likelihood that individual was either washed down from a tributary that was not impacted, or was an upstream migrant from the South Fork Cumberland River.

In contrast to the collections from Bear Creek, the five collections of fish from Rock Creek yielded a total of 1,265 individuals. IBI values for Rock Creek ranged from 38 to 46, and averaged 42.8, indicating an overall water quality rating of "Fair."

Of the 25 physicochemical parameters examined, 11 exhibited significant differences between Bear Creek and Rock Creek. Calcium, conductivity, hardness, magnesium, manganese, nickel, potassium, sodium, sulfate, and zinc levels were all significantly higher (α=.05) in Bear Creek; alkalinity levels in Bear Creek were significantly lower (α=.05) than those observed in Rock Creek. The manganese and sulfate values for Bear Creek indicated that it was an AMD-impacted stream.

Reclamation occurred at three sites in the Tennessee portion of the Bear Creek watershed during 1991 and 1992. Results from a study conducted by the Tennessee Department of Health indicated that some slight improvements in water quality have occurred in the larger (3^{rd} order) streams in the Tennessee portion of the Bear Creek watershed. However, these slight improvements were not observed at the Kentucky monitoring site at the mouth of Bear Creek.

INTRODUCTION

The Big South Fork/Bear Creek Nonpoint Source Interstate Demonstration Project was an acid mine drainage (AMD) project originally coordinated with the state of Tennessee, since the Bear Creek watershed drains portions of both states. Part of the original goals of the study was to collect macroinvertebrates from Bear Creek and compare the data to similar collections made in a relatively undisturbed section of Rock Creek, both of which were direct tributaries to the South Fork Cumberland River (SFCR).

The nonpoint source pollution impacts to Bear Creek begin outside of the Big South Fork National River and Recreation Area (BSFNRRA) in Tennessee. The lower portion of Bear Creek lies in Kentucky, mostly within the BSFNRRA. The National Park Service was concerned about: (1) the impacts of the Bear Creek drainage on state and federally listed endangered species, (2) high concentrations of metals in surface and underground water sources, and (3) the related public health problems with domestic and recreational use of these waters. The National Park Service encouraged the state of Tennessee's involvement with reclamation of the lands outside the National River and Recreation Area boundaries within the Bear Creek watershed.

The Tennessee portion of Bear Creek is the segment most impacted by nonpoint source pollution. The impacted portion of Bear Creek is affected by unreclaimed strip mines; numerous uncased, unmapped and abandoned oil and gas wells; agricultural activities; and suspected illegal industrial dumpsites. An abandoned surface coal mine of approximately 28 hectares, characterized by heavily eroding spoil banks and acid mine drainage, is an example of several nonpoint source pollution problems in the upper Bear Creek watershed. Located in north central Scott County, Tennessee, on the Winfield 7.5 minute topographic quadrangle, this mine was mined for coal in 1973 and remined in 1977. Minimal reclamation efforts were implemented after mining because it occurred prior to passage of the Surface Mine Control and Reclamation Act. Intensive water quality problems still exist from nonpoint source runoff.

Water quality impairments included increased heavy metals, increased acidity, increased sedimentation, decreased dissolved oxygen and color changes. In addition, some 100 families in the study area used groundwater for their drinking water supply. Testing, other than for coliforms, was practically non-existent. There was a high potential for the existence of health hazards associated with contaminated groundwater sources in this watershed.

The Kentucky Division of Water's Ecological Support Section and Nonpoint Source Pollution Control Program assisted Tennessee agencies in their efforts to assess water quality and remediate nonpoint source pollution impacts in the Bear Creek drainage. The Ecological Support Section conducted an intensive survey of the Kentucky portion of the South Fork Cumberland River drainage during the fall of 1990. This pre-BMP water quality assessment was conducted in order to determine legitimate stream uses and assess current conditions of the South Fork Cumberland River within the Wild River corridor. Physicochemical, sediment, and biological monitoring were conducted as part of this survey.

STUDY AREA DESCRIPTION

A large portion of the South Fork Cumberland River watershed is classified and operated by the U.S. Department of the Interior, National Park Service, as the Big South Fork National River and Recreation Area (BSFNRRA) (Figure 1). The waterways feeding the South Fork Cumberland River vary in their degree of water quality. The tributaries of the South Fork Cumberland River are impacted by agriculture, coal mining, oil and gas exploration, sewage discharge, and silviculture (Rikard *et al*. 1986). The major constituents of concern in these tributaries are dissolved sulfate, suspended sediments, and most other major ions (Evaldi and Garcia 1991). Bear Creek is the most severely impacted of the 16 acid mine drainage (AMD) polluted streams that flow into the South Fork Cumberland River (Stucki 1995).

Bear Creek flows into the South Fork Cumberland River just upstream from a freshwater mussel bed that contains 22 species (Bakaletz 1991). Six of these taxa (*Alasmidonta atropurpurea*, *Epioblasma brevidens*, *Lampsilis ovata*, *Pegias fabula*, *Ptychobranchus subtentum*, and *Villosa trabalis*) are considered threatened or endangered on either the federal and/or state level. In addition, one other (*Epioblasma florentina walkeri*) is now believed extirpated from Kentucky (Kentucky State Nature Preserves Commission [KSNPC] 1996). The *P. fabula* population in this mussel bed may be the largest in the world, according to the U.S. Fish and Wildlife Service. Waters from Bear Creek do not fully mix with the mainstem at the bed's location. The west side, where Bear Creek mixing is not complete, is inhabited by the freshwater mussel species. The mussels would reasonably be expected to occupy habitat on the river's east side, which is currently barren, if the water quality from the Bear Creek drainage were improved (Bakaletz 1991).

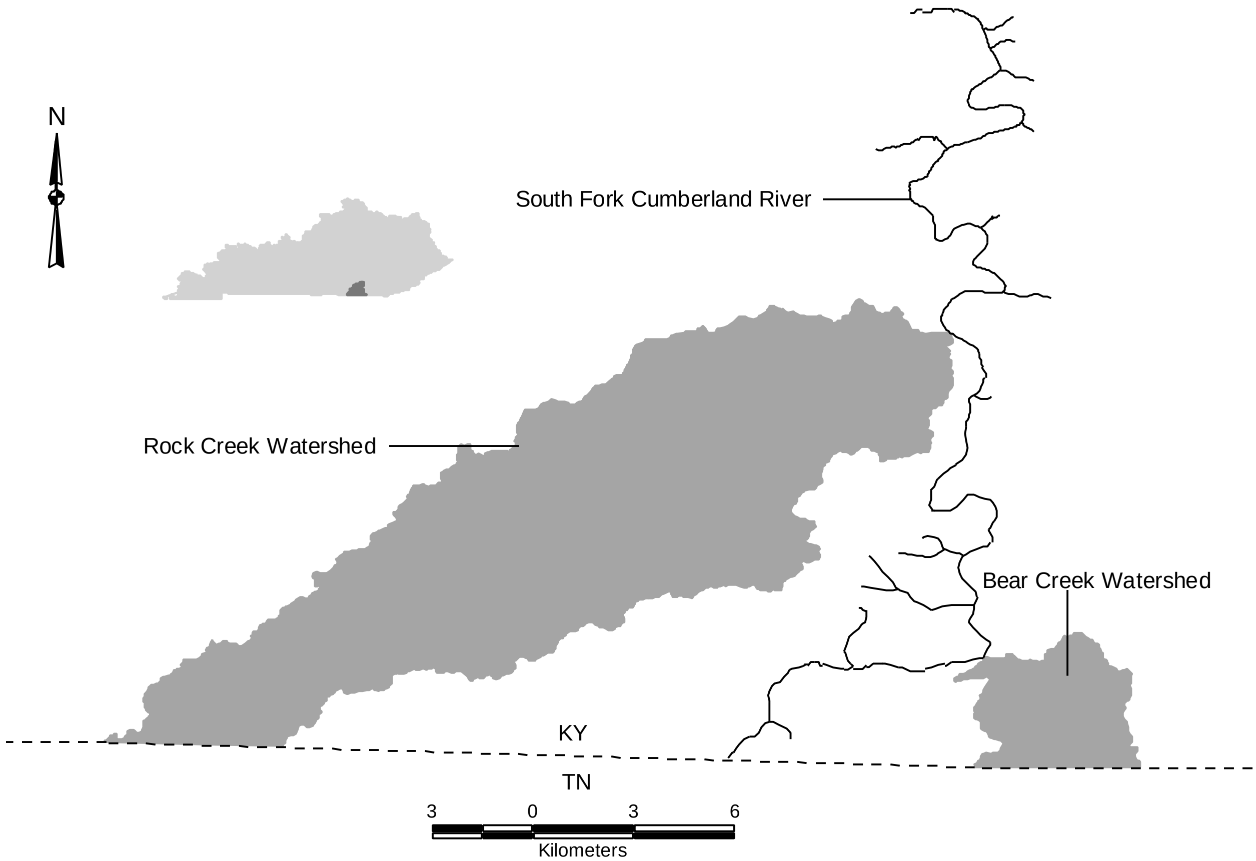

Figure 1. Location of the Bear and Rock Creek watersheds. Inset shows the location of McCreary County in Kentucky

In addition to the freshwater mussel species inhabiting South Fork Cumberland River, 44 species of fishes are known from the river (Rikard *et al*. 1986). Six species (*Etheostoma cinereum*, *E. maculatum*, *E. sagitta*, *Ichthyomyzon greeleyi*, *Notropis albizonatus*, and *Percina squamata*) are considered either threatened or endangered on the federal and/or state level (KSNPC 1996).

The two forks of Bear Creek (East and West Forks) originate near the town of Oneida in Scott County, Tennessee, and flow in a northerly direction. The two forks join together to form Bear Creek mainstem approximately 1.6 km south of the Kentucky/Tennessee state line in northern Scott County, Tennessee. From the Kentucky/Tennessee state line, Bear Creek flows in a northwesterly direction until its confluence with the South Fork Cumberland River at river mile 50.6 (Stucki 1995, Alexander and Robison 1997) (Figure 2). The Bear Creek watershed is approximately 60.5 km^2 in size (Bower and Jackson 1981) and includes portions of Scott County, Tennessee, and McCreary County, Kentucky (Stucki 1995, Alexander and Robison 1997).

Bear Creek is the most severely AMD-impacted stream in the upper Cumberland River basin (Rikard *et al*. 1986). The extraction of minerals within the headwaters of Bear Creek began in the late 1800s. These operations continued sporadically throughout this century but were non-existent during passage of the Surface Mining Reclamation and Control Act in 1977 (Alexander and Robison 1997). High conductivity levels can be found throughout Bear Creek (Stucki 1995); and low pH, sediments, and other pollutants are also prevalent (United States Department of Agriculture [USDA] 1991). Approximately 33 sites (USDA 1991) encompassing 310 ha of abandoned mine lands (AML) and reclaimed lands (Alexander and Robison 1997) existed in the watershed. It is estimated that the average cost for remediation in the watershed is $10,700 per ha (USDA 1991).

The majority of land within the Bear Creek watershed is forested (81% or 2,833 ha). The remaining land uses are: mining (7%); grassland (8%); and urban, including roads (3%). Due to

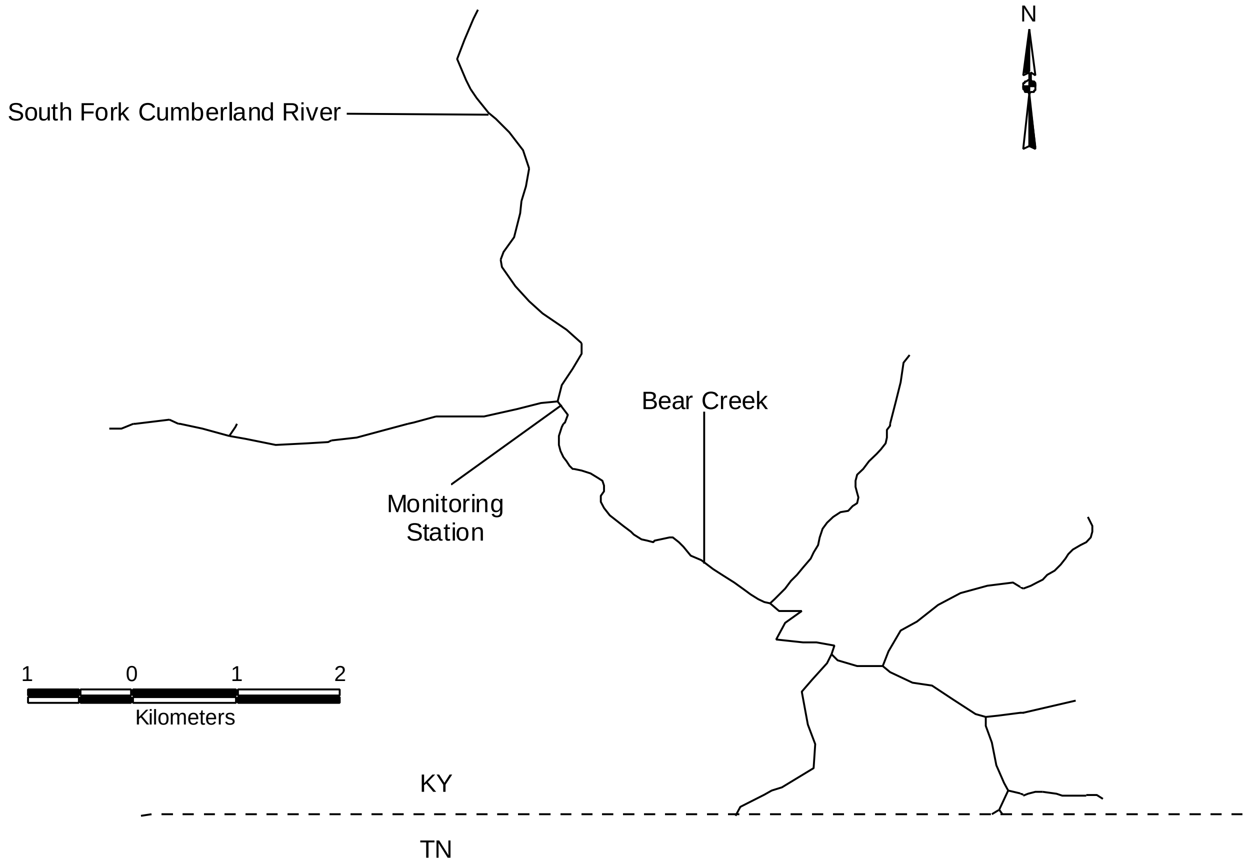

Figure 2. Location of the Bear Creek monitoring station

the topography of the area, cropland makes up only a small percentage of the land use in the watershed (1%) (USDA 1991).

In Tennessee, the majority of the Bear Creek watershed is located within the Ramsey-Muskingum soil association. The loamy soils in this association are usually well drained, and soil depth ranges from shallow to moderately deep. The terrain in this soil association is steep, with slopes ranging from 20% to 60%, and erosion potential is moderate to high (USDA 1991).

In Kentucky, the Bear Creek watershed is located within the Tate-Trappist soil association. This association is characterized by ridgetops with strongly sloping soils, and side slopes along narrow drainageways with steep soils. Commonly, the side slopes in this association are crossed by sandstone cliffs that range from 12 to 18 m in height. In fact, the hilly ridgetops in this association are approximately 240 m higher than the narrow valley floors. This association is underlain by sandstone and acid shale, the beds of which are approximately equally thick. This association is comprised of Tate (60%), Trappist (25%), and four minor (15%) soils. The primary soils in this association are deep to moderately deep, very strongly acid, and have either a loamy (Tate) or Clayey (Trappist) subsoil. In this association, the Tate soils occur on side slopes, in coves, and are generally found below sandstone cliffs; the Trappist soils occur on the upper side slopes and on benches, noses, and ridgetops. Three of the minor soils in this association are found on the ridgetops (Wellston, Dekalb, and Clymer), and the fourth (Shelocta) occurs on the lower side slopes (Byrne *et al*. 1970).

A control station was established on Rock Creek which originates in Fentress County, Tennessee, and flows northeastward through Pickett and Scott counties, Tennessee, and then into McCreary County, Kentucky. The stream continues in a northeasterly direction until it flows into the South Fork Cumberland River (SFCR) at Yamacraw, Kentucky (SFCR mile 40.9) (Harker *et al*. 1979, 1980; Layzer and Anderson 1992) (Figure 3). The Rock Creek watershed is approximately 162.2 km^2 in size, with only 30% of the watershed (49.2 km^2) in Tennessee (Bower and Jackson 1981).

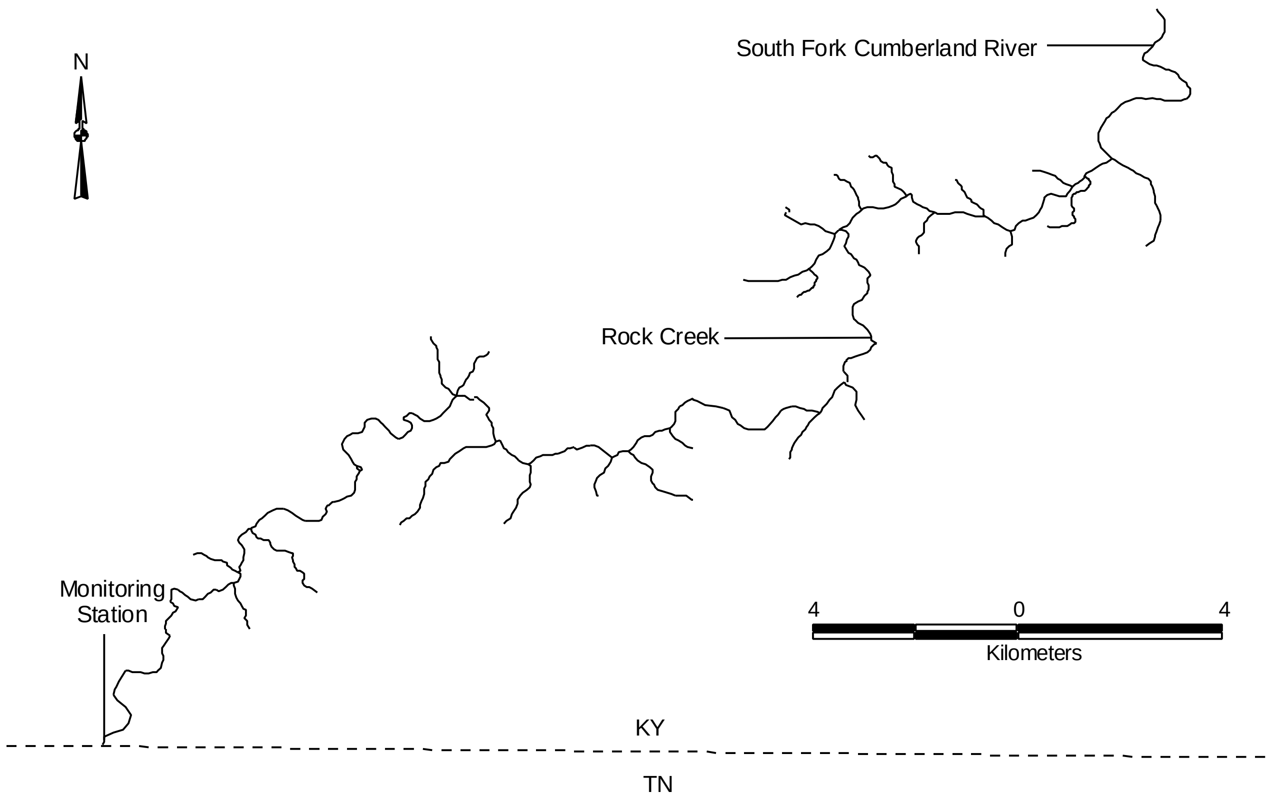

Figure 3. Location of the Rock Creek monitoring station

In Kentucky, Rock Creek is almost entirely located within the Daniel Boone National Forest (Harker *et al*. 1979, 1980), and the watershed is approximately 95% forested (Harker *et al*. 1980, KDOW [no date]). The upper Rock Creek watershed is rugged, as the stream meanders through a steep, narrow gorge with vertical sandstone bluffs (Harker *et al*. 1980). Until the confluence with White Oak Creek, Rock Creek is a clean, sandstone-influenced stream, with stable pH levels (Rikard *et al*. 1986).

From the Kentucky/Tennessee state line (mile 21.9) to the confluence with White Oak Creek (White Oak Junction, Rock Creek mile 3.9), Rock Creek has been a designated Wild River since 1972 (Miller, Wihry, and Lee, Inc. 1980). However, below this confluence Rock Creek is an extremely polluted stream, severely impacted by AMD from White Oak Creek (Rikard *et al*. 1986, Layzer and Anderson 1992).

In the Wild River segment, Rock Creek has an average width of approximately 6.1 m, and an average depth of approximately 0.5 m. The stream has an average gradient of approximately 17 feet per mile (KDOW [no date]; Miller, Wihry, and Lee, Inc. 1980). The headwaters of Rock Creek, in Fentress County, Tennessee, are at an elevation of 488 meters (Harker *et al*. 1980). The substrate of the stream is composed mainly of gravel and cobble, with some sections containing large boulders (KDOW [no date]).

Approximately 93% of the land within the Rock Creek Wild River segment watershed is in public ownership (U.S. Forest Service) (KDOW [no date]; Miller, Wihry, and Lee, Inc. 1980). Only a small amount of land in the watershed is devoted to agriculture. The principal mineral resources in the watershed are coal, oil, and gas (KDOW [no date]). In the Kentucky portion, there are four soil associations present in the Rock Creek Watershed: Tate-Shelocta, Atkins-Pope-Tate, Tate-Clymer-Dekalb, and Tate-Trappist. The first two associations are found in the floodplain of Rock Creek, and the latter two make up the remainder of the watershed. The majority of the soils in the watershed are in the Tate-Trappist and Tate-Clymer-Dekalb associations (Byrne *et al*. 1970).

The soils in the Tate-Shelocta association are underlain by limestone and calcareous shales, and stones and boulders cover 3% to 20% of the surface in most places. The Atkins-Pope-Tate association occurs in only a small portion of the Rock Creek floodplain, extending in a narrow band from the mouth of Watts Branch upstream approximately 5.5 km. The Tate-Clymer-Dekalb association occurs to the west of Rock Creek mainstem and is characterized by deep valleys rimmed by high sandstone cliffs (the average height of ridgetops is approximately 137 m) with narrow ridges and steep side slopes. The Tate-Trappist association is the largest, and occurs east of Rock Creek mainstem. This association is characterized by ridgetops with strongly sloping soils and side slopes along narrow drainageways with steep soils. Commonly, the side slopes in this association are crossed by sandstone cliffs that range from 12 to 18 m in height. The hilly ridgetops in this association are approximately 240 m higher than the narrow valley floors. This association is underlain by sandstone and acid shale, the beds of which are approximately equally thick (Byrne *et al*. 1970).

Both Bear and Rock Creeks are located within the Cumberland Plateau Section of the Central Appalachian Ecoregion (Burr and Warren 1986, KDOW 1997). The Cumberland Plateau Section is located in the southern portion of the Appalachian Plateaus Physiographic Province. This section is bordered by the Unglaciated Allegheny Plateau (north), Tennessee (south), the Cumberland Mountains (east), and the Pottsville Escarpment (west). Due to the base leveling of streams, the topography of this section is extremely rugged, with elevations between 366 and 549 meters. Streams in this section usually have moderate to high gradients, with poorly developed floodplains (Burr and Warren 1986). The Central Appalachian Ecoregion is drained by several high-gradient streams that form the headwaters of four major river basins (the Big Sandy, Cumberland, Kentucky, and Licking River basins). The region is heavily forested and is underlain by Pennsylvanian age strata (KDOW 1997).

MATERIALS AND METHODS

Tennessee Standard Operating Procedures (SOPs) for quantitative and qualitative macroinvertebrate sampling were followed for this interstate demonstration project to ensure that biological data from the two states were comparable. One-square-foot Surber samplers were used for quantitative sampling, with three replicates in comparable substrate at each station to avoid bias. All substrate within the Surber frame was washed down into the tail of the net. When the substrate was sufficiently washed, the collection was removed from the end of the Surber sampler and preserved in 70% ethanol. The three replicate samples were kept in separate containers (Stucki 1995). For qualitative sampling, all available habitat (banks, pool rocks, riffle rocks, sediments, leaf packs, and moss) was sampled with kick nets. Three standard efforts were performed in each habitat to avoid bias between stations. Samples from each habitat present were preserved in 70% ethanol in separate collecting jars. Location information for the two sampling stations is presented in Table 1.

Fishes were collected at each station during the fall and spring following methods outlined in Kentucky Division of Water (KDOW) (1995). Each station was sampled intensively for 0.5 to 1.0 hr with a common sense minnow seine. Each habitat type present at the stations was sampled in order to effectively assess the fish communities at each site. Fish were preserved initially in 10% formalin and later transferred to 70% ethanol in the laboratory.

Physicochemical data was collected at both stations with several methods, depending on rainfall amounts and flow conditions. Temperature, pH, dissolved oxygen, specific conductance, and turbidity were measured *in-situ* with appropriate field meters. Water samples for the

Table 1. Big South Fork/Bear Creek NPS Demonstration Project Sampling Stations

Site ID	02009007	02008007
Stream	Bear Creek	Rock Creek
Mile Point	0.10	21.90
Order	4	3
Ecoregion	Central Appalachian	
Basin	Upper Cumberland	
U.S.G.S. Topographic Map	Barthell	Barthell S.W.
Latitude	36-37-32	36-36-10
Longitude	084-31-58	084-44-26
Location	Above mouth	KY/TN State Line

remaining 31 parameters were collected with either grab or depth-integrated samples, following protocols outlined in KDOW (1995), or with an automated sampler, depending on flow conditions. Water samples for physicochemical analysis were placed into containers with appropriate preservative if necessary (i.e., H_2SO_4) and kept on ice until delivered to the analyzing laboratory. Stream velocity was measured with a Marsh-McBirney flowmeter, and supplemental stream-flow information was obtained from the U.S. Geological Survey's Big South Fork/Bear Creek gaging station. Daily precipitation records were maintained by the National Park Service. The physicochemical parameters measured are listed in Table 2.

Data evaluation included the analysis and interpretation of the biological, physicochemical, and land use data. Macroinvertebrate biological indices which describe community structure and community health were used to document differences in water quality between the reference (Rock Creek) and impacted (Bear Creek) streams. The Index of Biotic Integrity (IBI) was used to compare the collections of fishes from the two stations. The IBI was originally developed by Karr (1981), but has since been modified by KDOW (1997) to compensate for differences between stations in headwater/wading situations and ecoregion. Since a large enough database did not exist for an accurate IBI calculation of sites in the Central Appalachian Ecoregion (KDOW 1997), the original method proposed by Karr (1981) described in KDOW (1993) was used to calculate IBIs. The IBI is composed of 12 equally weighted metrics separated into 3 categories, and is used to determine the biotic integrity and community composition of fish samples (KDOW 1995).

Several biological indices or metrics were used to analyze the macroinvertebrate data and make comparisons between the two stations: Taxa Richness, Total Number of Individuals, modified Hilsenhoff Biotic Index, Ephemeroptera-Plecoptera-Trichoptera (EPT), Community Similarity Index, Jaccard's Coefficient of Community Similarity, Shannon-Wiener Diversity Index, and Shannon-Wiener Evenness.

Taxa Richness is simply the number of distinct taxa present in the sample. Total Number of Individuals (TNI) is a measure of the total number of organisms present in the sample. It is

Table 2. Physicochemical Parameters Analyzed from Bear Creek and Rock Creek. All in mg/L unless noted otherwise. *In situ* field parameters are noted with an asterisk.

Alkalinity	Dissolved Oxygen*	Sodium
Aluminum	Fluoride	Sulfate
Ammonia-Nitrogen	Hardness, total	Temperature (^{o}C)*
Arsenic	Iron	Total Dissolved Phosphorous
Barium	Lead	Total Dissolved Solids
Cadmium	Magnesium	Total Kjeldahl Nitrogen
Calcium	Manganese	Total Phosphorous
Chloride	Mercury	Total Solids
Chromium	Nickel	Total Suspended Solids
Cobalt	Nitrate	Total Volatile Solids
Conductivity (µmho/cm)*	pH (SU)*	Turbidity (NTU)*
Copper	Potassium	Zinc

reasonably expected that the values for these two metrics will increase as water quality improves (KDOW 1993). The Hilsenhoff Biotic Index (HBI) is a measure of the overall organic pollution tolerance of a stream arthropod community. This metric uses macroinvertebrate tolerance values that have been modified for streams of the southeastern United States (Lenat 1993, KDOW unpublished data) to assess impacts from organic pollution. The Ephemeroptera-Plecoptera-Trichoptera (EPT) Index is a simple measure of the distinct taxa from these generally pollution-intolerant insect orders (Mayflies, Stoneflies, and Caddisflies). It is expected that this value will increase with increasing water quality (KDOW 1993).

The Community Similarity Index, or Percent Community Similarity (PS_c), is a useful measure for comparing the community structure (similarity) between impacted stations and suitable reference stations in watersheds with minimal impacts (KDOW 1993). Jaccard's Coefficient of Community Similarity uses taxon presence or absence to measure the taxonomic similarity between two samples or stations. Values increase from 0 to 1.0 as similarity increases (KDOW 1993). The Shannon-Wiener Index (H') is a diversity index that is more sensitive to changes in the rare species present in the samples (Krebs 1989, Brower *et al*. 1990). Shannon-Wiener Evenness (J) is a measure of the evenness of the distribution of individuals among the various species. Evenness can also be used as a measure of dominance (Brower *et al*. 1990). The first four metrics and the last two were used to establish the water quality of the impacted and reference streams at the monitoring stations. The remaining metrics were used to make comparisons between the impacted (Bear Creek) and reference (Rock Creek) streams. The *t*-test was used to examine differences between the metric values for the two streams.

Comparison of constituent concentrations was more appropriate than an in-depth analysis of constituent loading because physicochemical parameters were collected intermittently for both the reference and impacted stations. For statistical analyses, samples where data existed for only one of the two stations were deleted. The Wilcoxon Rank Sum Test, a non-parametric alternative to the commonly used *t*-test (Ott 1993), was used to examine differences between the two stations.

In order to have a complete watershed monitoring plan for this interstate project, the Kentucky Nonpoint Source Pollution Control Program (KY-NPS) conducted pre-, during-, and post-BMP installation monitoring for the Kentucky portion of Bear Creek. Kentucky Nonpoint Source On-site Planning Field Teams (KY-NPS Field Teams) supplemented Tennessee's monitoring activities by establishing a sampling station at the mouth of Bear Creek in Kentucky (RMI 0.2). An automated water sampler was purchased, installed, and operated at the station. Kentucky's parametric coverage for water sample analysis was identical to Tennessee's parametric coverage and included acid mine drainage pollutants and other inorganic, organic, and general physicochemical water quality parameters (see Table 2).

Sampling frequency at the Kentucky Bear Creek site also attempted to coincide with Tennessee's sampling frequency. Water sample collection by KY-NPS was coordinated with Tennessee water quality monitoring activities including activities conducted by the Tennessee Department of Health and Environment, Nonpoint Source Program (TDHE-NPS), Tennessee Department of Conservation (TDOC), and the National Park Service. Water quality sampling efforts by Kentucky began February, 1991. Water samples were also collected and analyzed at the Kentucky site during each biological sample collection effort by TDHE-NPS staff. The KY-NPS Field Teams monitored water quality for pre-BMP implementation. Biological samples were collected once each quarter from second quarter FY91 through first quarter FY92. BMP implementation began in the spring of 1991.

RESULTS AND DISCUSSION

Macroinvertebrate Data

Macroinvertebrate sampling was conducted during all four seasons at both sites. A total of nine collections were conducted at the Bear Creek site: four during 1991, four during 1992, and one during 1994. Collections at the Rock Creek site corresponded to those at Bear Creek, except that no collection was conducted during 1994. A total of 517 individuals representing 81 taxa were collected from Bear Creek and 4,658 individuals representing 143 taxa were collected from Rock Creek throughout the course of the study. A synoptic qualitative list of the macroinvertebrate taxa collected from Bear Creek is presented in Table 3, and the metrics calculated are presented in Table 4. Complete macroinvertebrate data from the Bear Creek station during each collection period can be found in Appendix A.

During 1991 at the Bear Creek site, macroinvertebrate Taxa Richness increased as summer progressed, peaking in July, and started to decline again during the fall (October). During 1992, Taxa Richness continued this downward trend, reaching a low of 10 during the summer (August). Taxa Richness had started to rise during the fall (October) 1992 collection. During the single 1994 collection (October), Taxa Richness approximated the fall 1992 value. Total Number of Individuals (TNI) in the Bear Creek collections tended to follow a pattern similar to that of Taxa Richness. The total individuals present in the samples increased from the winter 1991 collection, peaked during the summer, and started to decline during the fall collection. This decline was still in progress during the early part of 1992 and continued through the summer collection. In the fall 1992 collection, TNI was again beginning to rise. The single collection from 1994 mimicked this pattern. These fluctuations observed in Taxa Richness and

Table 3: Bear Creek Qualitative Macroinvertebrate List

Enchytraeus sp.
Lumbriculus sp.
Sphaerium sp.
Crangonyx sp.
Cambarus distans
Orconectes placidus
Unidentified Baetidae
Ephemerella sp.
Hexagenia sp.
Eurylophella sp.
Epeorus sp.
Stenacron interpunctatum
Boyeria sp.
Calopteryx sp.
Cordulegaster sp.
Helocordulia sp.
Neurocordulia sp.
Gomphus sp.
Stylogomphus albistylus
Libellula sp.
Didymops sp.
Macromia sp.
Leuctra sp.
Acroneuria sp.
Eccoptura xanthenes
Belostoma sp.
Unidentified Corixidae
Sigara sp.

Unidentified Corixidae
Unidentified Gerridae
Rhuematobates sp.
Microvelia sp.
Corydalus cornutus
Nigronia sp.
N. serricornis
Sialis sp.
Unidentified Hydropsychidae
Ceratopsyche sparna
Cheumatopsche sp.
Diplectrona modesta
Hydropsyche betteni
Lepidostoma sp.
Oecetis sp.
Pycnopsyche sp.
Cernotina sp.
Polycentropus sp.
Rhyacophila sp.
Unidentified Curculionidae
Helichus sp.
H. basalis
Dytiscus sp.
Hydroporus sp.
Laccophilus sp.
Neoporus sp.
Uvarus sp.
Oulimnius sp.

Stenelmis sp.
Psephenus herricki
Unidentified Ceratopogonidae
Unidentified Chironomidae
Ablablesmyia sp.
Corynoneura sp.
Cricotopus sp.
Cryptochironomus sp.
Micropsectra sp.
Parametriocnemus sp.
Pentaneura sp.
Phaenopsectra sp.
Polypedilum sp.
Procladius sp.
Rheotanytarsus sp.
Saetheria sp.
Stenochironomus sp.
Tanytarsus sp.
Thienemanniella sp
Thienemannimyia gr.
Zavrelimyia sp.
Ephydra sp.
Prosimulium sp.
Simulium sp.
Chrysops sp.
Limnophila sp.
Tipula sp.

Table 4: Bear Creek Metrics

	Collection Dates								
METRICS	Feb 91	Apr 91	Jul 91	Oct 91	Feb 92	Apr 92	Aug 92	Oct 92	Oct 94
N	16	21	182	106	41	42	29	42	40
s	10	14	39	38	22	17	10	17	16
EPT	1	2	5	12	4	5	3	8	4
%EPT	6.2	14.2	7.1	16.9	14.6	33.3	10.3	59.5	20
%CHIR	43.8	9.5	41.8	31.1	39	14.3	72.4	2.4	7.5
HBI	5.46	7.01	4.04	6.47	6.61	5.96	5.87	4.56	7.39
H'	1.98	2.58	2.81	3.1	2.91	2.64	1.91	2.45	2.37
J	0.71	0.84	0.54	0.66	0.78	0.7	0.57	0.66	0.64

N = Total Number of Individuals
s = Taxa Richness
EPT = Number of Ephemeroptera, Plecoptera, Trichoptera
%EPT = Percentage of sample represented by EPT
%CHIR = Percentage of sample represented by midges (Chironomidae)
HBI = Modified Hilsenhoff Biotic Index
H' = Shannon-Wiener Index
J = Shannon-Wiener Evenness

TNI are most likely due to the natural phenologies of aquatic macroinvertebrates and should be considered normal. However, the low Taxa Richness and TNI values observed from all of the Bear Creek collections indicate an impacted system. Comparisons with collections from another AMD-impacted stream in close proximity to Bear Creek support this (KDOW unpublished data). Reductions in the number of taxa (Taxa Richness) and individuals (TNI) are common impacts of AMD on aquatic macroinvertebrate communities (Cairns *et al*. 1971, Branson *et al*. 1984, Stucki 1995, Courtney and Clements 1998).

The average EPT value for the Bear Creek collections was 4.9, and values ranged from a low of 1 during the winter 1991 collection to a high of 12 during the fall 1991 collection. For the most part, the percentage of the samples collected from Bear Creek represented by EPT taxa remained relatively low as well. With the exception of the spring 1992 (33.3%) and the fall 1992 (59.5%) collections, the percentage of the samples represented by EPT taxa was below 25%. When the percentage of EPT taxa was low, the percentage of chironomid (midge) taxa was relatively high (Figure 4). In fact, the percentage of Chironomidae was significantly greater than the percentage of EPT for the Bear Creek samples (t=3.06, α=0.05). While this does not necessarily indicate a replacement of the pollution-intolerant EPT taxa with the usually more pollution-tolerant taxa found in the family Chironomidae, it does indicate an impaired system that cannot support a diverse EPT fauna.

The average HBI score for the nine Bear Creek collections was 5.93. The lowest HBI observed was 4.04, during summer 1991. The majority of the HBI values for the Bear Creek collections fell into either the "Fair" or "Fairly Poor" water quality designations. This indicated fairly significant to significant pollution impacts (Hilsenhoff 1987). Even though the HBI was originally formulated to assess impacts from organic enrichment, several states, including Kentucky, have had success in using the HBI to assess impacts from other sources (KDOW 1993). However, in the present case, the HBI does not appear to be as valuable in terms of AMD as other more commonly used metrics. Even though the HBI values for the Bear Creek collections indicated only fair to fairly poor water quality designations, Taxa Richness, TNI and EPT values indicated an extremely impacted system.

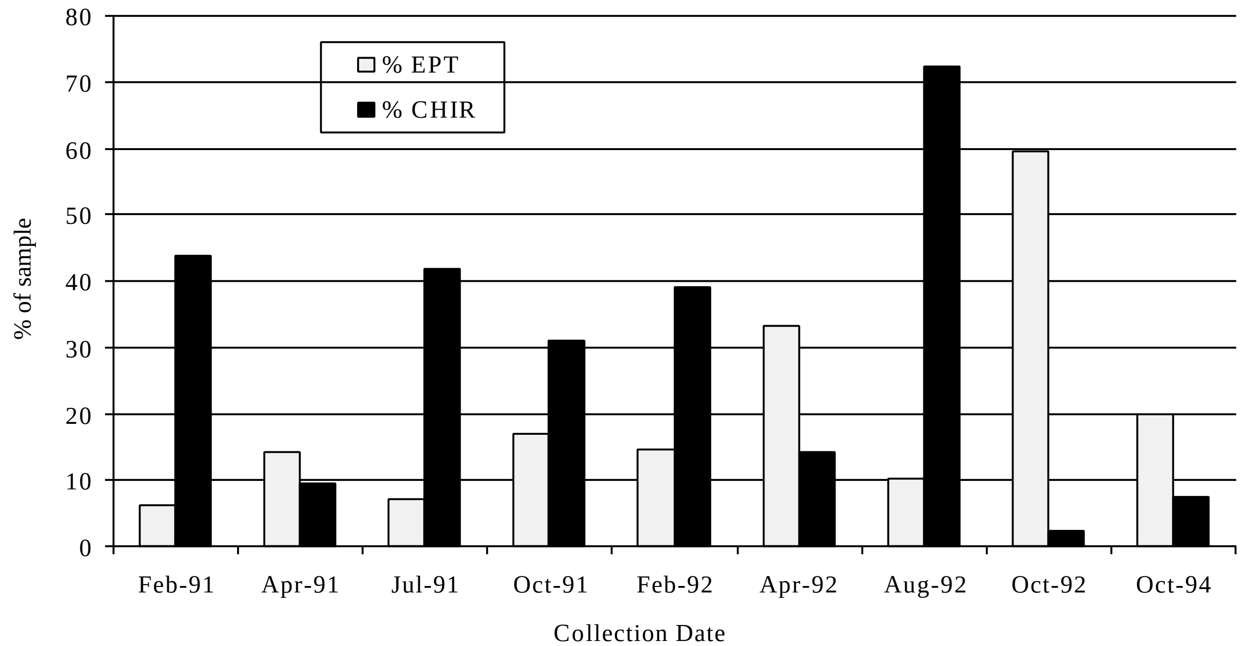

Figure 4. Comparison of Percentage Ephemeroptera-Plecoptera-Trichoptera (%EPT) and Percentage Chironomidae (% CHIR) in Bear Creek Macroinvertebrate Samples

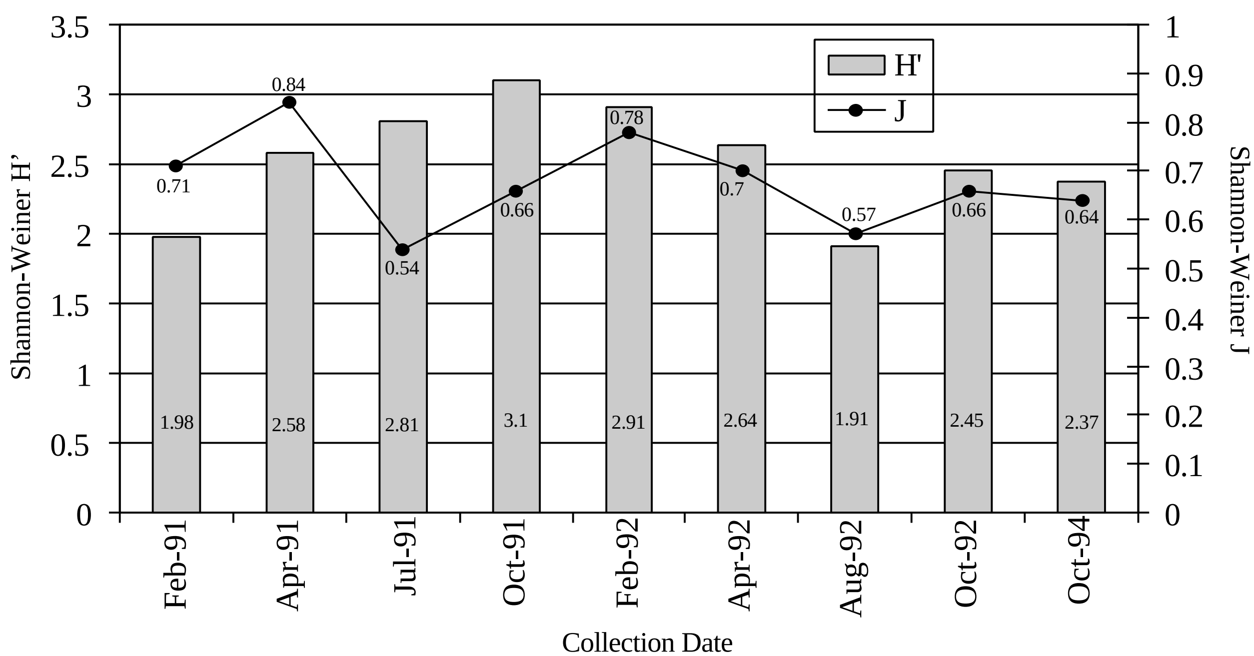

Figure 5. Bear Creek Macroinvertebrate Shannon-Wiener Index (H') and Evenness (J) Values

The average Shannon-Wiener Index value for the Bear Creek collections was 2.53. There was no distinct trend evidenced by the index values. There was also no trend in the evenness values, except that the lowest values occurred during the winter collections of 1991 and 1992 (February) (Figure 5). Even though Shannon-Wiener is more commonly used as a diversity index, it can also be used to determine if the data is representative of an impacted or high-quality station (Wilhm 1970). Based on Shannon-Wiener Index values, the Bear Creek data was not representative of clean water (Wilhm 1970).

A synoptic, qualitative list of the macroinvertebrate taxa collected from Rock Creek is presented in Table 5, and the metrics calculated from the data are presented in Table 6. Complete macroinvertebrate data from the Rock Creek station during each collection period can be found in Appendix B.

Rock Creek Taxa Richness also fluctuated and, as with the Bear Creek collections, should be considered natural. The average Taxa Richness value for Rock Creek was 53.4. From winter 1991, macroinvertebrate Taxa Richness increased to 77 during the summer 1991 collection and then decreased to a low of 37 during winter 1992. From there, the total number of taxa present in the samples from Rock Creek again followed the same pattern. The average TNI for the eight Rock Creek samples was 584.25. The lowest TNI for the Rock Creek samples was observed during the winter and summer collections of 1992. The highest was observed during the summer 1991 collection (1084 individuals). These Taxa Richness and TNI values indicated that at this sampling station Rock Creek was not affected by AMD and therefore was characteristic of a system that has not been affected by AMD.

Ephemeroptera-Plecoptera-Trichoptera (EPT) values for Rock Creek varied from 18 to 33. The average EPT value for the Rock Creek collections was 25. The percentage of the samples collected from Rock Creek represented by EPT taxa also remained high. With the exception of the winter 1991 (13.9%) collection, the percent EPT of all the Rock Creek samples was well above 25%. As in the Bear Creek samples, when the percentage of EPT taxa was low, the percentage of chironomid (midge) taxa was relatively high (Figure 6). However, this

Table 5: Rock Creek Qualitative Macroinvertebrate List

Enchytraeus sp.
Lumbriculus sp.
Unidentified Naididae
Unidentified Tubificidae
Ferrissia sp.
Physella sp.
Elimia sp.
Helisoma sp.
Cambarus cumberlandensis
Cambarus distans
Orconectes placidus
Unidentified Baetidae
Acentrella sp.
Baetis sp.
Centroptilum sp.
Baetisca sp.
Brachycerus sp.
Caenis sp.
Cercobrachys sp.
Ephemerella sp.
Eurylophella sp.
Unidentified Ephemeridae
Ephemera sp.
Unidentified Heptageniidae
Cinygmula subaequalis
Epeorus sp.
Heptagenia sp.
Leucrocuta sp.
Stenonema sp.
S. femoratum
S. mediopunctatum
S. vicarium
Stenacron interpunctatum
Isonychia sp.
Unidentified Leptophlebiidae
Leptophlebia sp.
Paraleptophlebia sp.
Neoephemera sp.
Boyeria sp.
Calopteryx sp.
Argia sp.
Unidentified Corduliidae
Unidentified Gomphidae
Hagenius sp.
Lanthus sp.
Ophiogomphus sp.
Stylogomphus albistylus
Unidentified Macromiidae
Didymops sp.
Unidentified Chloroperlidae
Alloperla sp.
Haploperla sp.
Leuctra sp.
Unidentified Nemouridae
Amphinemura sp.
Peltoperla sp.
Acroneuria sp.
Eccoptura xanthenes
Paragnetina sp.
Perlesta sp.
Cultus sp.
Isoperla sp.
Pteronarcys biloba
Unidentified Taeniopterygidae
Strophopteryx sp.
Taeniopteryx sp.
Limnoporus sp.
Trepobates sp.
Microvelia sp.
Rhagovelia sp.
Corydalus cornutus
Sialis sp.
Micrasema sp.
Heteroplectron americanum
Glossosoma sp.
Goera sp.
Helicopsyche borealis
Ceratopsyche sparna
C. ventura
Cheumatopsche sp.
Diplectrona modesta
Lepidostoma sp.
Unidentified Leptoceridae
Oecetis sp.
Pycnopsyche sp.
Chimarra sp.
Dolophilodes distinctus
Wormaldia sp.
Paranyctiophylax sp.
Polycentropus sp.
Rhyacophila sp.
Helichus basalis
Hydroporus sp.
Neoporus sp.
Dubiraphia sp.
Macronychus glabratus
Optioservus sp.
Oulimnius latiusculus
Promeresia sp.
Stenelmis sp.
Sperchopsis sp.
Tropisternus sp.
Psephenus herricki
Atherix variegata
Unidentified Ceratopogonidae
Unidentified Chironomidae
Brillia sp.
Cladotanytarsus sp.
Corynoneura sp.
Cricotopus sp.
Cryptochironomus sp.
Endochironomus sp.

Table 5: Rock Creek Qualitative Macroinvertebrate List, continued

Eukiefferiella sp.	*Polypedilum* sp.	*Hemerodromia* sp.
Glyptotendipes sp.	*Procladius* sp.	Unidentified Simuliidae
Micropsectra sp.	*Rheocricotopus* sp.	*Prosimulium* sp.
Microtendipes sp.	*Rheotanytarsus* sp.	*Simulium* sp.
Nanocladius sp.	*Stempellina* sp.	*Chrysops* sp.
Omisus sp.	*Stempellinella* sp.	*Protoplasa fitchii*
Orthocladinae sp.	*Stenochironomus* sp.	*Antocha* sp.
Parakeifferiella sp.	*Tanytarsus* sp.	*Dicranota* sp.
Parametriocnemus sp.	*Thienemannimyia* gr.	*Hexatoma* sp.
Phaenopsectra sp.	*Zavrelimyia* sp.	*Limnophila* sp.
		Tipula sp.

Table 6: Rock Creek Metrics

	DATES							
METRICS	Feb 91	Apr 91	Jul 91	Oct 91	Feb 92	Apr 92	Aug 92	Oct 92
N	691	333	1084	1057	288	446	310	465
s	37	46	77	70	37	65	46	49
EPT	21	27	30	33	20	27	18	24
%EPT	13.9	82.6	47.4	68.8	49	65	45.8	65.6
%CHIR	18.2	6.6	39.6	14.8	6.2	13.2	11.3	8
HBI	4.14	2.01	4.34	3.61	3.64	3	3.69	3.81
H'	1.83	2.79	3.38	3.06	2.69	3.44	2.78	3.08
J	0.28	0.48	0.48	0.44	0.48	0.56	0.48	0.5

N = Total Number of Individuals
s = Taxa Richness
EPT = Number of Ephemeroptera, Plecoptera, Trichoptera
%EPT = Percentage of sample represented by EPT
%CHIR = Percentage of sample represented by midges (Chironomidae)
HBI = Modified Hilsenhoff Biotic Index
H' = Shannon-Wiener Index
J = Shannon-Wiener Evenness

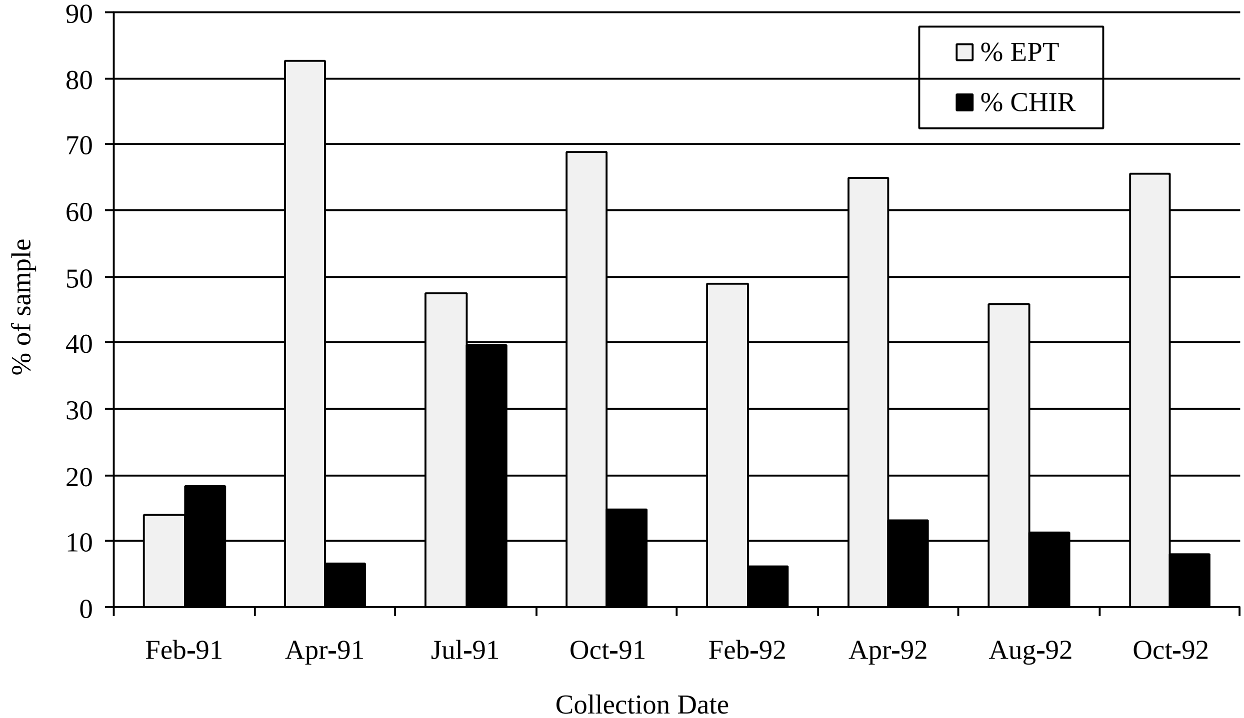

Figure 6. Comparison of Percentage Ephemeroptera-Plecoptera-Trichoptera (% EPT) and Percentage Chironomidae (% CHIR) in Rock Creek Macroinvertebrate Samples

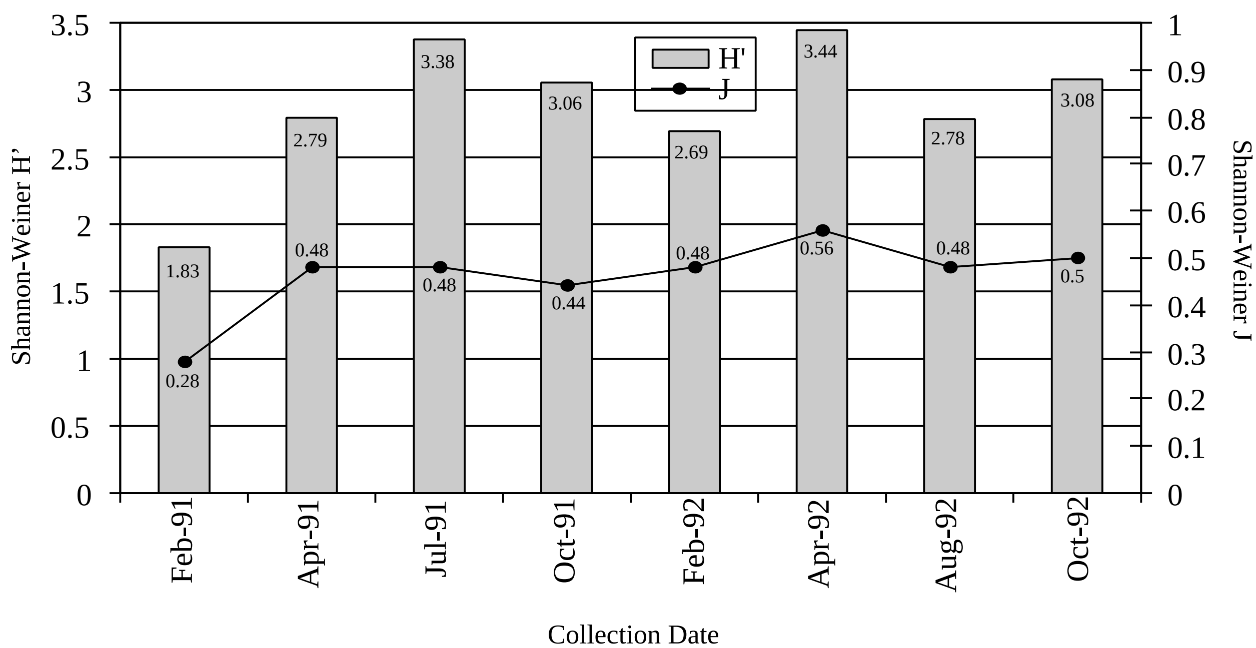

Figure 7. Rock Creek Macroinvertebrate Shannon-Wiener Index (H') and Evenness (J) Values

occurred only once (February 1991). In contrast to the Bear Creek collections, the percentage of the Rock Creek samples represented by EPT taxa was significantly higher than that represented by Chironomidae (t=4.25, α=0.05). This indicated a system that was not being impacted by AMD and supported a diverse EPT fauna.

The average HBI score for the eight Rock Creek collections was 3.53. The lowest HBI observed was 2.01 during spring 1991. The majority of the HBI values for the Rock Creek collections fell into the "Very Good" water quality designation. Two of the collections, during the spring of both years (1991 HBI = 2.01; 1992 HBI = 3.00), were in the "Excellent" category. This indicated no apparent to possible slight pollution impacts (Hilsenhoff 1987). The HBI was originally formulated to assess impacts from organic enrichment (KDOW 1993), and at this site, Rock Creek appears to be only slightly, if at all, impacted by organic pollution.

The average Shannon-Wiener Index value for the Rock Creek collections was 2.88. With the exception of the winter 1991 collection, all of the Rock Creek index values were above 2.60. There was no real trend exhibited by the evenness values, except that the lowest values occurred during the winter collections of 1991 and 1992 (February) (Figure 7). Based on Shannon-Wiener Index values, with the exception of the winter 1991 collection, Rock Creek was representative of clean water (Wilhm 1970).

Taxa Richness values for Rock Creek exceeded Bear Creek values (Figure 8). The greatest difference was during the summer and fall 1991 and the fall 1992 collections. These values for Rock Creek were significantly greater than those for Bear Creek (t=9.78, α=0.05). Total Number of Individuals values were also significantly different between the two study streams (t=5.26, α=0.05). The greatest difference in TNI was during the summer and fall 1991 collections (difference of 902 and 951 individuals, respectively) (Figure 9). These differences may indicate, among other things, the impacts of acidification on the Bear Creek macroinvertebrate fauna (Courtney and Clements 1998). Significant differences were also observed between EPT values (t=14.14, α=0.05), percent EPT values (t=4.70, α=0.05) and percent Chironomidae values (t=2.17, α=0.05) (Figures 10 and 11). The greatest difference

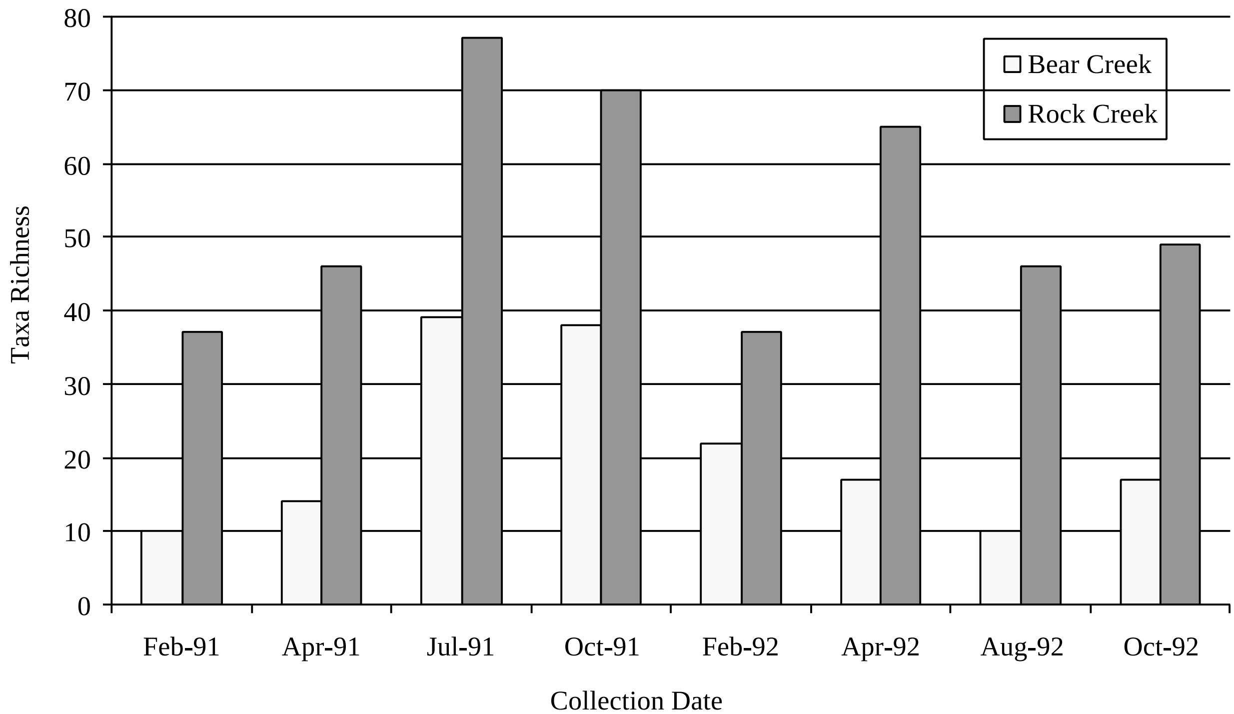

Figure 8. Comparison of Taxa Richness Values from Bear Creek and Rock Creek

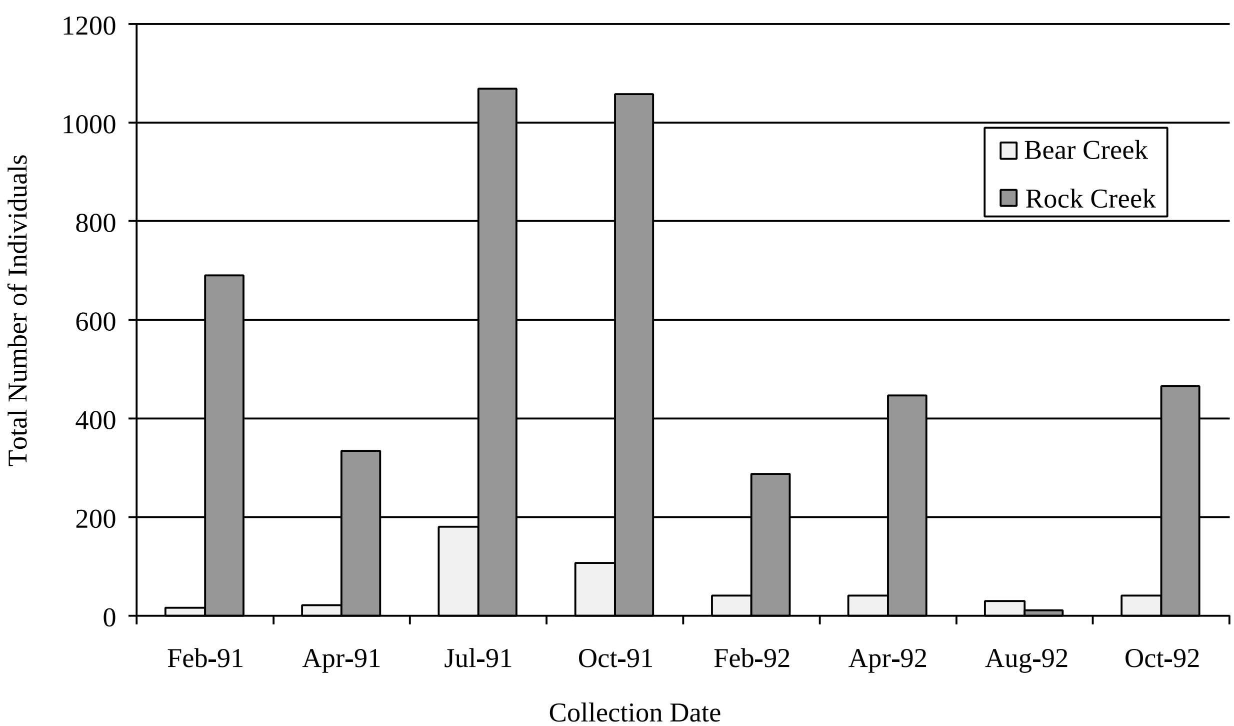

Figure 9. Comparison of Total Number of Individuals Collected from Bear Creek and Rock Creek

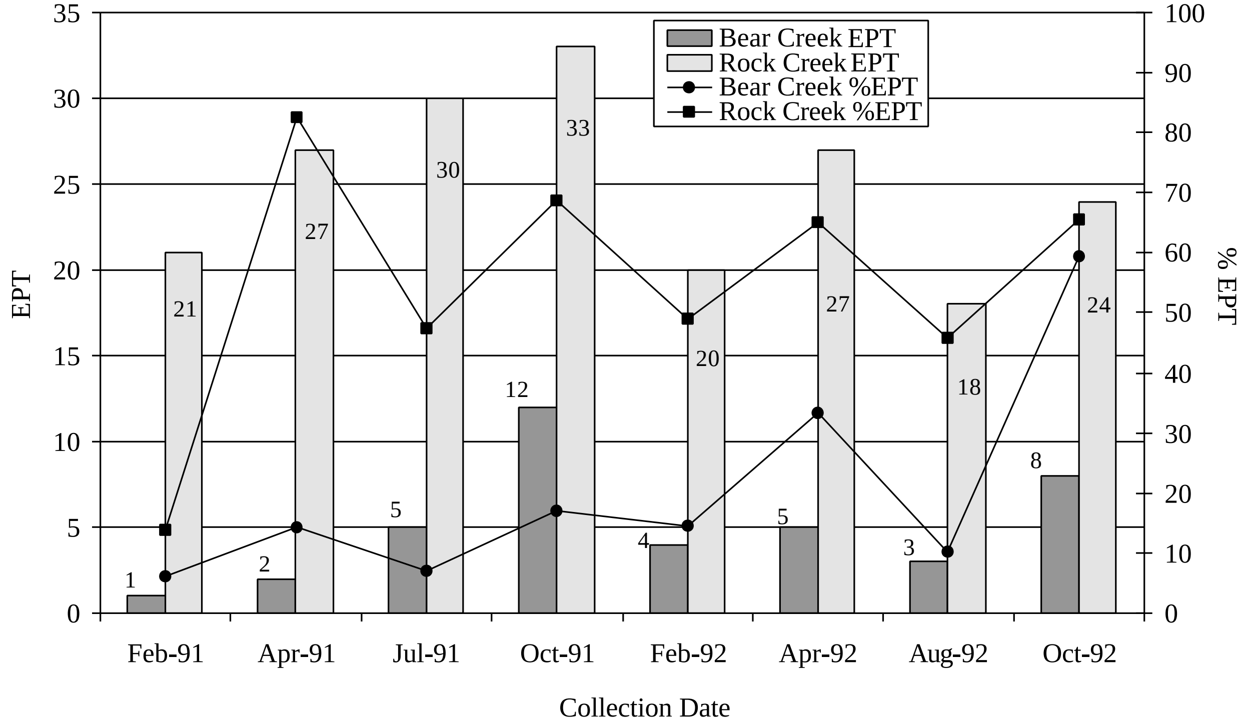

Figure 10. Comparison of Bear Creek and Rock Creek Ephemeroptera-Plecoptera-Trichoptera (EPT) and Percent EPT (% EPT) Values

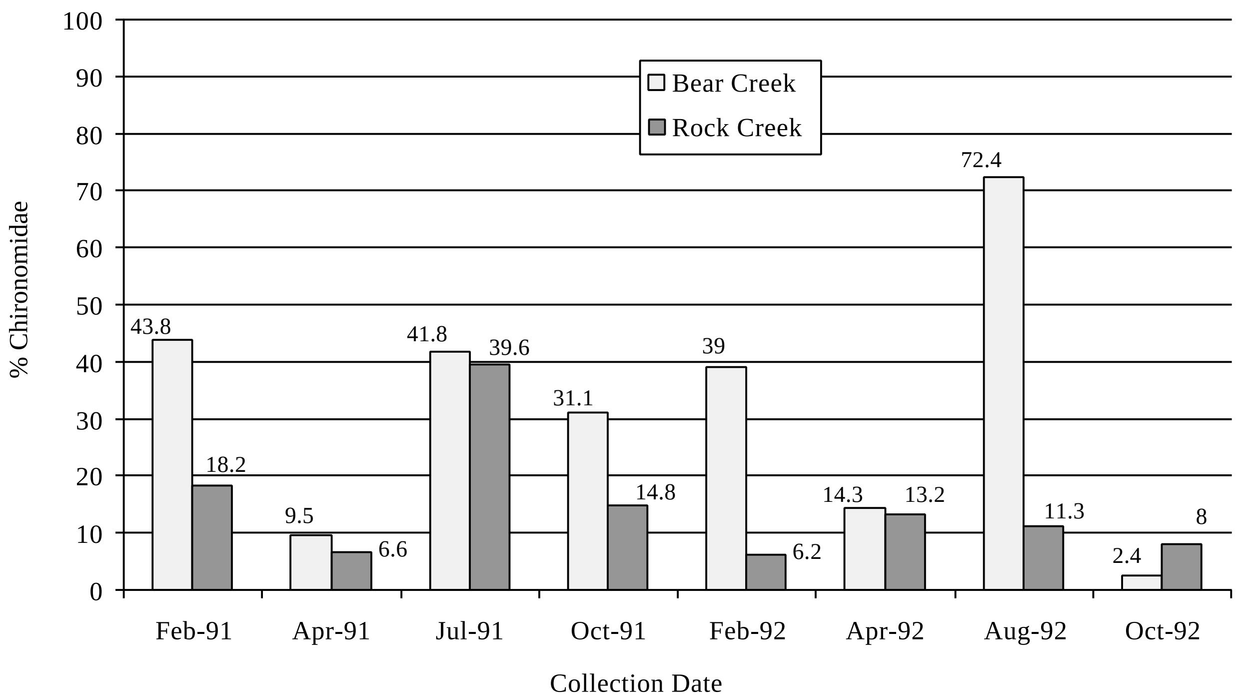

Figure 11. Comparison of Bear Creek and Rock Creek Percent (%) Chironomidae Values

in EPT values was observed during the spring and summer 1991 collections (difference of 25 each), in percent EPT values during the spring and fall 1991 collections (difference of 68.4% and 51.9%, respectively), and in percent Chironomidae values during the winter and summer 1992 collections (difference of 32.8% and 61.1%, respectively). Even though midges (Chironomidae) are generally considered to be pollution tolerant, they are an integral part of the macroinvertebrate community in most situations (Merritt and Cummins 1996). However, the percentage of EPT, which are generally considered to be pollution intolerant (Merritt and Cummins 1996), are not comparatively higher in the Bear Creek collections. These data showed the inability of the AMD-impacted Bear Creek to support a diverse, pollution intolerant fauna of mayflies, stoneflies, and caddisflies.

Hilsenhoff Biotic Index (HBI) values were also significantly different between the Bear Creek and Rock Creek collections (t=3.85, α=0.05). The largest differences were observed during the fall 1991 and winter and spring 1992 collections (Figure 12). These periods also represented the highest HBI scores for Bear Creek. The greatest difference was during the winter 1992 collection, where the HBI score for Bear Creek was 6.61 and the HBI score for Rock Creek was 3.64 (difference of 2.97). As stated previously, the HBI was originally developed to measure the impacts of organic pollution on aquatic systems. Since Bear Creek is an AMD-impacted stream, the majority of pollutants of concern are inorganic in nature. This means that while the HBI scores for Bear Creek were relatively high (decreased water quality), the impacts may be more intense than the use of the HBI suggests.

The previous metrics allowed for a determination of the water quality of the impacted and reference streams (Bear Creek and Rock Creek, respectively) and comparisons of those values. Jaccard Coefficient of Community Similarity (CC_J) is a useful measure of the taxonomic similarity between two collections. Values for CC_J range from 0 to 1.0 with increasing water quality (KDOW 1993). The CC_J values for the comparisons between the Bear Creek and Rock Creek collections indicated a large dissimilarity between the two stations (Figure 13). The highest CC_J value observed, and hence the collection exhibiting the most similarity, was during the fall of 1991 (CC_J=0.19). If these two streams were more taxonomically similar, then CC_J

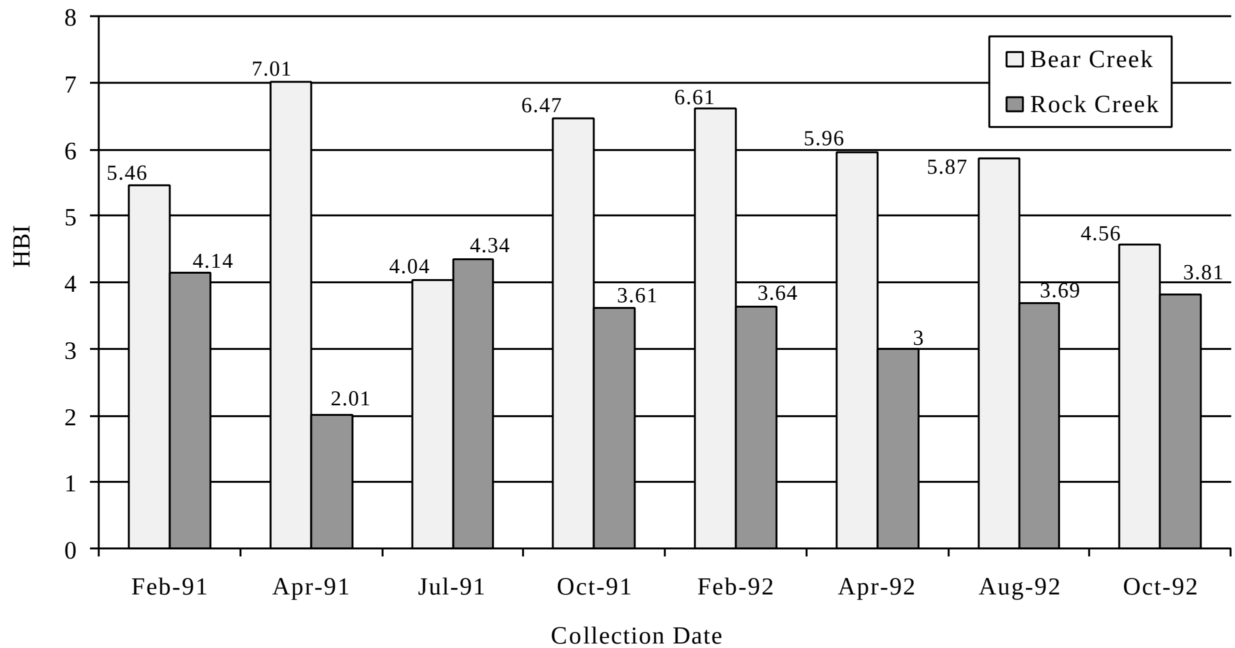

Figure 12. Comparison of Hilsenhoff Biotic Index Values from Bear Creek and Rock Creek

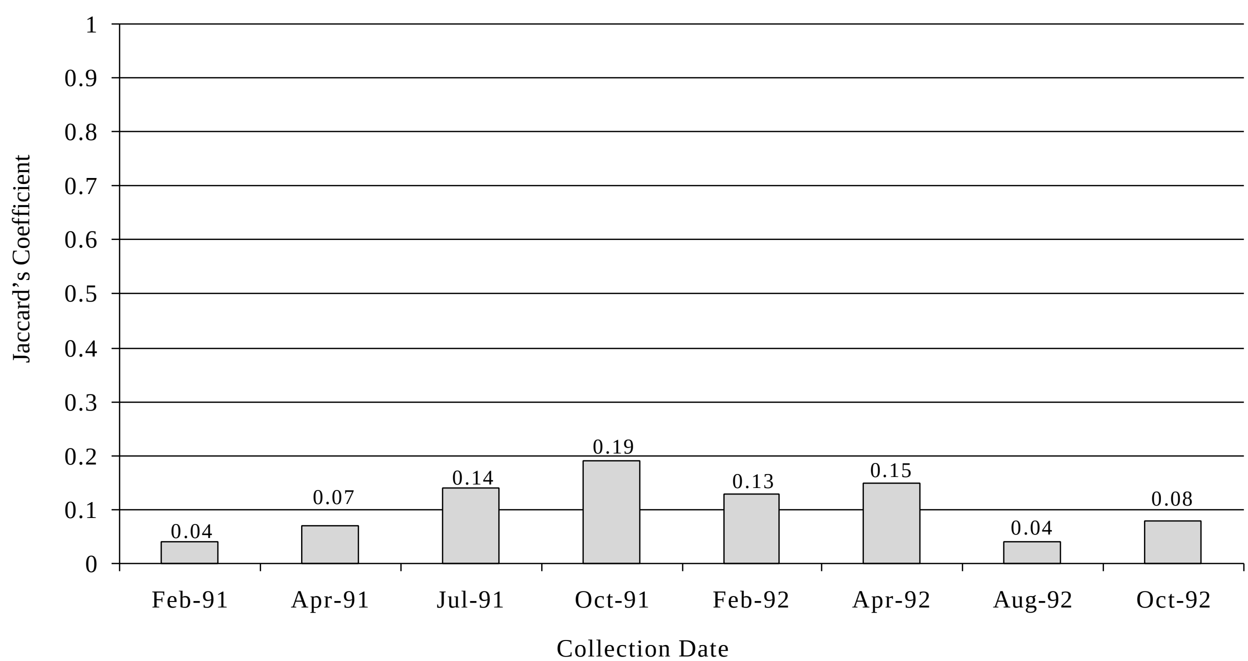

Figure 13. Jaccard Coefficient Values for Bear Creek and Rock Creek Macroinvertebrates

values closer to, and approaching, 1.0 would be observed. Bear Creek is more taxonomically similar to the AMD-impacted portion of Rock Creek (KDOW unpublished data) than to that portion of Rock Creek that is not impacted by AMD. This is also demonstrated by the Percent Community Similarity (PS_C) values between the two streams (Table 7). Based on the close proximity of the streams to each other, and the fact that they are located within the same ecoregion, it would be expected that the PS_C values would more closely approximate 75%.

Fish Data

Attempts were made to collect fish at the Bear Creek station on five occasions (Table 8) during the spring and fall of 1991 and 1992, and again during the fall of 1994. Of these five collections, only one yielded any fish, and the single individual collected was most likely a transient. The resultant Index of Biotic Integrity values for all of the collections was 0, with the exception of the Fall 1991 collection (IBI of 36). The IBI score for the Fall 1991 collection represented a water quality rating of "Poor to Fair" (KDOW 1993). However, this rating was based on a single intolerant insectivore (KDOW 1997), hence the elevated IBI value. This value should be considered an anomaly, since in all likelihood this individual was either washed down from a tributary stream that was not impacted or was an upstream migrant from the South Fork Cumberland River, because the pH levels of Bear Creek were consistently outside the range of pH tolerance of minnow (Cyprinidae) species (Heard *et al*. 1997). The loss of fish species can be directly attributed to the impacts caused by surface mining in the Bear Creek watershed (Branson *et al*. 1984, Heard *et al*. 1997).

In contrast to the collections from Bear Creek, the five collections of fish from Rock Creek yielded a total of 1,265 individuals (Table 9). These individuals represented six families and 19 species. Index of Biotic Integrity values for Rock Creek ranged from a low of 38 ("Poor to Fair" water quality) during spring 1992 to a high of 46 ("Fair to Good" water quality) during spring 1991 (KDOW 1993). The average IBI value for the five collections was 42.8, indicating an overall water quality rating of "Fair" (KDOW 1993). Even though the IBI-based water quality

Table 7. Macroinvertebrate Percent Community Similarity (PS_C) Between Bear Creek and Rock Creek for Nine Sampling Periods and for All Samples Pooled

	Collection Date									
	1991				1992				‘94*	
	Feb	Apr	Jul	Oct	Feb	Apr	Aug	Oct	Oct	Pooled
PS_C	1.2	11.0	18.7	9.2	9.4	7.8	5.7	6.7	3.6	18.9

*The October 1994 Bear Creek sample was compared with the Rock Creek October 1992 sample since there was no Rock Creek sample taken in 1994

Table 8. Fish species collected, and the corresponding IBI values, for Bear Creek at the mouth during Spring and Fall 1991 and 1992 and Fall 1994

Taxa	Collection Date				
	Spring 1991	Fall 1991	Spring 1992	Fall 1992	Fall 1994
Cyprinidae:					
Cyprinella galacturus		1			
Totals:	NO FISH	1	NO FISH	NO FISH	NO FISH
IBI:	0	36	0	0	0

Table 9. Fish species collected, and the corresponding IBI values, for Rock Creek at the KY/TN state line during Spring and Fall 1991 and 1992 and Fall 1994

Taxa	Collection Date				
	Spring 1991	Fall 1991	Spring 1992	Fall 1992	Fall 1994
Petromyzontidae:					
Lamprey ammocoete larvae	1			1	
Cyprinidae:					
Campostoma anomalum		3	3	6	3
Cyprinella spiloptera			1		
Lythrurus fasciolaris	21	27		2	48
Notropis amblops	6		45	30	7
Notropis ariommus			115		
Notropis galacturus	1			7	
Notropis telescopus	34	78	81	91	84
Notropis volucellus		70	214	20	177
Semotilus atromaculatus			5		5
Catostomidae:					
Hypentelium nigricans		1			1
Moxostoma duquesnei					1
Ictaluridae:					
Noturus flavus				1	1
Centrarchidae:					
Micropterus salmoides	1				1
Percidae:					
Etheostoma blennioides		3	3	1	2
Etheostoma caeruleum	1	5	5	12	22
Etheostoma camurum				3	4
Etheostoma obeyense	4	1	2	1	2
Etheostoma sanguifluum	1				
Totals:	70	188	474	175	358
IBI:	46	44	38	42	44

water quality ratings for Rock Creek do not at present indicate excellent water quality, even a cursory comparison of the data between the two study streams shows drastic differences in water quality.

Physicochemical Data

Results of the physicochemical analyses for Bear Creek are presented in Appendix C, and those for Rock Creek in Appendix D. Eleven of the physicochemical parameters listed in Table 2 were not statistically analyzed due to: 1) a majority of the observations being "not detected" at a given test level, 2) the samples not being analyzed for that particular parameter on several occasions (i.e., "NA" values), or 3) the parameter being analyzed for only one of the study streams (i.e., total dissolved solids and total solids were only analyzed for two of the Bear Creek samples). The Wilcoxon Rank Sum Test was used to determine if there were any significant differences between these 25 values.

Eleven of the parameters examined were found to exhibit significant differences between the Bear Creek and Rock Creek samples. Calcium, conductivity, hardness, magnesium, manganese, nickel, potassium, sodium, sulfate, and zinc were all significantly higher (α=.05) in Bear Creek. Alkalinity levels in Bear Creek were significantly lower (α=.05) than those observed in Rock Creek. No significant differences were observed between the aluminum, barium, chloride, chromium, cobalt, copper, dissolved oxygen, iron, mercury, pH, temperature, total suspended solids, total volatile solids, and turbidity levels. The between-station comparisons for these parameters are also presented graphically in Appendix E.

There are several physicochemical parameters that can be used to indicate coal mining impacts. These include increases in the levels of aluminum, calcium, copper, iron, magnesium, manganese, sodium, specific conductance, and sulfates (KDOW 1981, Branson *et al*. 1984, Becker *et al*. 1986, Rikard *et al*. 1986) and decreased pH and alkalinity levels (KDOW 1981, Branson *et al*. 1984). Total dissolved solids is another parameter that can be used to indicate impacts that are the result of coal mining; however, increases in this parameter have been shown to not be associated with watersheds in which mining has not occurred in some time (Becker *et al*. 1986), as was the case with the Bear Creek watershed.

Even though there was no statistically significant difference in pH between the two study streams, Bear Creek pH levels exceeded Kentucky Water Quality Standards (KDOW 1994) for the protection of aquatic life on 11 occasions. The pH level of a stream is commonly believed to be the most reliable indicator of acid mine drainage. However, because of the presence of carbonates and alkaline soils which raise the alkalinity in some streams, there may not be a relationship between pH and sulfate levels. When this occurs, pH levels are more buffered and do not reflect the actual level of impact in the system (Rikard *et al*. 1986). For these reasons, sulfate and manganese are more reliable indicators of AMD (Branson *et al*. 1984, Rikard *et al*. 1986), and the Bear Creek values for these two parameters indicated that it was an AMD-impacted stream.

SUMMARY AND CONCLUSIONS

Taxa Richness, Total Number of Individuals, EPT, and HBI values for Bear Creek at the mouth are indicative of an impacted system. The values for these same metrics from Rock Creek near the Kentucky/Tennessee state line are characteristic of a natural, unaffected system. Significant differences were observed between all of the macroinvertebrate metrics calculated from the stations in the two study streams. Percent Community Similarity and CC_J values between the two study streams indicated a large dissimilarity between the two stations. These data clearly show the inability of the AMD-impacted Bear Creek to support a diverse, pollution-intolerant, macroinvertebrate fauna.

Attempts were made to collect fish at the Bear Creek station on five occasions, yielding only one fish, which was likely a transient. The IBI values for these collections were 0, with the exception of the collection of the single fish (IBI of 36). However, this is based on a single intolerant insectivore and should be considered an anomaly. In contrast to this, the five collections of fish from Rock Creek had IBI values ranging from 38 to 46, with an average value of 42.8, indicating an overall water quality rating of “Fair.”

Eleven of the 25 parameters examined exhibited significant differences between the two study streams. Alkalinity, calcium, conductivity, hardness, magnesium, manganese, nickel, potassium, sodium, sulfate, and zinc values from the two streams were significantly (α=.05) different. No significant differences were observed between the aluminum, barium, chloride, chromium, cobalt, copper, dissolved oxygen, iron, mercury, pH, temperature, total suspended solids, total volatile solids, and turbidity levels.

Reclamation occurred at three sites in the Tennessee portion of the Bear Creek watershed during 1991 and 1992 (Stucki 1995). Results from a study conducted by the Tennessee Department of Health indicated that some slight improvements in water quality have occurred in the larger (3^{rd} order) streams in the Tennessee portion of the Bear Creek watershed (Stucki 1995). However, these slight improvements were not observed at the Kentucky monitoring site at the mouth of Bear Creek.

Attempts are still being made by several state and federal agencies to abate AMD in the Bear Creek watershed. The state of Kentucky will continue to monitor Bear Creek under the Kentucky Watershed Management Approach. Additionally, approval was recently granted for a proposal to acquire funding for reclamation under the Watershed Protection and Flood Prevention Act (Public Law 83-566) (NRCS 1997).

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Appendix A

Macroinvertebrate Data from Bear Creek near the Mouth (Mile Point 0.1)

	COLLECTION DATES									
	1991				1992				1994	
TAXA	Feb-13	Apr-10	Jul-1	Oct-16	Feb-5	Apr-6	Aug-14	Oct-29	Oct-28	Totals
Annelida										
Oligochaeta										
Enchytraeidae:										
Enchytraeus sp.	3	2	37	7	4	6	4	3	3	69
Lumbriculidae:										
Lumbriculus sp.				1						1
Mollusca										
Sphaeriidae:										
Sphaerium sp.			1							1
Arthropoda										
Crustacea										
Crangonyctidae:										
Crangonyx sp.					1					1
Decapoda										
Cambaridae:										
Cambarus distans		2	2	4	1	4		4	13	30
Orconectes placidus				1				1		2
Insecta										
Ephemeroptera										
Baetidae			2	1						3
Ephemerellidae:										
Ephemerella sp.				1		2				3
Hexagenia sp.				1		3				4
Eurylophella sp.			1					1		2
Heptageniidae:										
Epeorus sp.		2								2

	1991				1992				1994	
TAXA	Feb-13	Apr-10	Jul-1	Oct-16	Feb-5	Apr-6	Aug-14	Oct-29	Oct-28	Totals
Stenacron interpunctatum				4						4
Odonata										
Aeshnidae:										
Boyeria sp.			1							1
Calopterygidae:										
Calopteryx sp.		1				4				5
Cordulegastridae:										
Cordulegaster sp.			1	2	3					6
Corduliidae:										
Helocordulia sp.		1						1		2
Neurocordulia sp.			2							2
Gomphidae:										
Gomphus sp.			1		2					3
Stylogomphus albistylus			1							1
Libellulidae:										
Libellula sp.				3		2				5
Macromiidae:										
Didymops sp.				1		1			1	3
Macromia sp.			3							3
Plecoptera										
Leuctridae:										
Leuctra sp.			2	1	1		1	1	1	7
Perlidae:										
Acroneuria sp.			3	2		6		1		12
Eccoptura xanthenes				1					1	2
Heteroptera										
Belostomatidae:										

	1991				1992				1994	
TAXA	Feb-13	Apr-10	Jul-1	Oct-16	Feb-5	Apr-6	Aug-14	Oct-29	Oct-28	Totals
Belostoma sp.				1						1
Corixidae:		1	1							2
Sigara sp.				12						12
Gerridae:		1								1
Rhuematobates sp.			1							1
Veliidae:										
Microvelia sp.				2					1	3
Megaloptera										
Corydalidae:										
Corydalus cornutus					1				1	2
Nigronia sp.				3				1		4
Nigronia serricornis			2					3		5
Sialidae:										
Sialis sp.			7	1	1				3	12
Trichoptera										
Hydropsychidae:							1			1
Ceratopsyche sparna								11		11
Cheumatopsche sp.				2		1	1			4
Diplectrona modesta			5	1	1			6	3	16
Hydropsyche betteni					3			1	3	7
Lepidostomidae:										
Lepidostoma sp.				2						2
Leptoceridae:										
Oecetis sp.		1		1						2
Limnephilidae:										
Pycnopsyche sp.	1					2		3		6
Polycentropodidae:										

	1991				1992				1994	
TAXA	Feb-13	Apr-10	Jul-1	Oct-16	Feb-5	Apr-6	Aug-14	Oct-29	Oct-28	Totals
Cernotina sp.								1		1
Polycentropus sp.				1						1
Rhyacophilidae:										
Rhyacophila sp.					1					1
Coleoptera										
Curculionidae	1			3						4
Dryopidae:										
Helichus sp.		2						1		3
Helichus basalis		2		1						3
Dytiscidae:										
Dytiscus sp.			11							11
Hydroporus sp.			8			2			2	12
Laccophilus sp.		2	1	7					3	13
Neoporus sp.				2						2
Uvarus sp.		2								2
Elmidae:										
Oulimnius sp.			2							2
Stenelmis sp.	1									1
Psephenidae:										
Psephenus herricki			2		1	1				4
Diptera										
Ceratopogonidae			4	5	1					10
Chironomidae:					3					3
Ablablesmyia sp.			2							
Corynoneura sp.			1	1						2
Cricotopus sp.			8	2	3	2	3			18
Cryptochironomus sp.			2				1			3

	1991				1992				1994	
TAXA	Feb-13	Apr-10	Jul-1	Oct-16	Feb-5	Apr-6	Aug-14	Oct-29	Oct-28	Totals
Micropsectra sp.				1					1	2
Parametriocnemus sp.			2	1		1	9			13
Pentaneura sp.			1							1
Phaenopsectra sp.	5	1	45	22	5	3	7	1	1	90
Polypedilum sp.			2				1			3
Procladius sp.									1	1
Rheotanytarsus sp.					1					1
Saetheria sp.			3							3
Stenochironomus sp.				1						1
Tanytarsus sp.		1	7							8
Thienemanniella sp	1		3							4
Thienemannimyia gr.					1					1
Zavrelimyia sp.	1				3					4
Ephydridae:										
Ephydra sp.			1							1
Simuliidae:										
Prosimulium sp.					1					1
Simulium sp.						1				1
Tabanidae:										
Chrysops sp.			1	1		1				3
Tipulidae:										
Limnophila sp.	1		2	1	1		1			6
Tipula sp.	2		1	2	2			2	2	11
SITE TOTALS:	16	21	182	106	41	42	29	42	40	517
TAXA RICHNESS:	10	14	39	38	22	17	10	17	16	81

Appendix B

Macroinvertebrate Data from Rock Creek at the KY/TN State Line (Mile Point 21.9)

	COLLECTION DATES								
	1991				1992				
TAXA	Feb-13	Apr-10	Jul-2	Oct-17	Feb-5	Apr-7	Aug-14	Oct-30	Totals
Annelida									
Oligochaeta									
Enchytraeidae:									
Enchytraeus sp.	4								4
Lumbriculidae:									
Lumbriculus sp.	4	1	1	8	1	3	2	3	23
Naididae			1						1
Tubificidae			3						3
Mollusca									
Ancylidae:									
Ferrissia sp.			1		1				2
Physidae:									
Physella sp.			14	2					16
Pleuroceridae:									
Elimia sp.	30			8					38
Planorbidae:									
Helisoma sp.			7		1				8
Arthropoda									
Crustacea									
Decapoda									
Cambaridae:									
Cambarus cumberlandensis		1		2				1	4
Cambarus distans		2	1	12		3	1	4	23
Orconectes placidus		1				3			4
Insecta									
Ephemeroptera									

	1991				1992				
TAXA	Feb-13	Apr-10	Jul-2	Oct-17	Feb-5	Apr-7	Aug-14	Oct-30	Totals
Baetidae:			4						4
Acentrella sp.	1	18	6	6	7		21	8	67
Baetis sp.				3				11	14
Centroptilum sp.			13	3			13		29
Baetiscidae:									
Baetisca sp.				4	6	2	1	2	15
Caenidae:									
Brachycercus sp.							1	1	2
Caenis sp.	1		1						2
Cercobrachys sp.					1				1
Ephemerellidae:									
Ephemerella sp.	26	99	17	2	37	69		10	260
Eurylophella sp.	2			15	1	3			21
Ephemeridae:				4					4
Ephemera sp.		2							2
Heptageniidae:			74			5			79
Cinygmula subaequalis	1	47	6			16			70
Epeorus sp.	8	32	1	6	19	39	7	1	113
Heptagenia sp.	1		8				3	19	31
Leucrocuta sp.				13			2		15
Stenonema sp.	9	9	36	221	15	25	30		345
Stenonema femoratum		14		15	12	1			42
Stenonema mediopunctatum			4						4
Stenonema vicarium	2	2	127	80		18	15	109	353
Stenacron interpunctatum		1		1		12			14
Isonychidae:									
Isonychia sp.	4		56	26	6	17	7	42	158

	1991				1992				
TAXA	Feb-13	Apr-10	Jul-2	Oct-17	Feb-5	Apr-7	Aug-14	Oct-30	Totals
Leptophlebiidae:			4	1			1		6
Leptophlebia sp.								2	2
Paraleptophlebia sp.		1	25	1		1			28
Neoephemeridae:									
Neoephemera sp.		3	12	3		2	1	3	24
Odonata									
Aeshnidae:									
Boyeria sp.		2	4					1	7
Calopterygidae:									
Calopteryx sp.		2	1			1	1	1	6
Coenagrionidae:									
Argia sp.				5					5
Corduliidae			1						1
Gomphidae:		7	24	2	2	3	1		39
Hagenius sp.							2		2
Lanthus sp.						5			5
Ophiogomphus sp.				14		4	1	1	20
Stylogomphus albistylus		2		6		1	2	11	22
Macromiidae:					1				1
Didymops sp.							1		1
Plecoptera									
Chloroperlidae:		1				4			5
Alloperla sp.		4		2				6	12
Haploperla sp.			31						31
Leuctridae:									
Leuctra sp.			7		2		18		27
Nemouridae:	1								1

	1991				1992				
TAXA	Feb-13	Apr-10	Jul-2	Oct-17	Feb-5	Apr-7	Aug-14	Oct-30	Totals
Amphinemura sp.		3			1				4
Peltoperlidae:									
Peltoperla sp.						1	1		2
Perlidae:									
Acroneuria sp.	3	4	14	95	1	28	3	29	177
Eccoptura xanthenes				1					1
Paragnetina sp.								1	1
Perlesta sp.			23						23
Perlodidae:									
Cultus sp.		1							1
Isoperla sp.		4				17			21
Pteronarcyidae:									
Pteronarcys biloba	1	2		1		1		2	7
Taeniopterygidae:				6					6
Strophopteryx sp.	11			1	13				25
Taeniopteryx sp.	4	1		15				5	25
Heteroptera									
Gerridae:									
Limnoporus sp.				1					1
Trepobates sp.			2						2
Veliidae:									
Microvelia sp.			3	3		1			7
Rhagovelia sp.			1	2				4	7
Megaloptera									
Corydalidae:									
Corydalus cornutus	4	3	6	22		3		9	47
Sialidae:									

	1991				1992				
TAXA	Feb-13	Apr-10	Jul-2	Oct-17	Feb-5	Apr-7	Aug-14	Oct-30	Totals
Sialis sp.						1	1		2
Trichoptera									
Brachycentridae:									
Micrasema sp.			7	1					8
Calamoceratidae:									
Heteroplectron americanum						1			1
Glossosomatidae:									
Glossosoma sp.	2	3	1		2	2	2	9	21
Goeridae:									
Goera sp.	1								1
Helicopsychidae:									
Helicopsyhce borealis			2		11	3			16
Hydropsychidae:									
Ceratopsyche sparna	5	5	4	5			11	15	45
Ceratopsyche ventura		3				2			5
Cheumatopsche sp.	4			16	2	10		7	39
Diplectrona modesta		8		9		1		1	19
Lepidostomidae:									
Lepidostoma sp.		3							3
Leptoceridae:			2						2
Oecetis sp.			1						1
Limnephilidae:									
Pycnopsyche sp.		1	1		2				4
Philopotamidae:									
Chimarra sp.	8	2	10	156	1	7	5	16	205
Dolophilodes distinctus				1				2	3
Wormaldia sp.				1				3	4

	1991				1992				
TAXA	Feb-13	Apr-10	Jul-2	Oct-17	Feb-5	Apr-7	Aug-14	Oct-30	Totals
Polycentropodidae:									
Nyctiophylax sp.					1				1
Polycentropus sp.		2	1	7		1			11
Rhyacophilidae:									
Rhyacophila sp.	1			6	1	1		1	10
Coleoptera									
Dryopidae:									
Helichus basalis	1	3	3	2		1	6		16
Dytiscidae:									
Hydroporus sp.			7			2			9
Neoporus sp.			1	1		1	1		4
Elmidae:									
Dubiraphia sp.			6			2			8
Macronychus glabratus			1					1	2
Optioservus sp.	3	1	29		6	3	7	28	77
Oulimnius latiusculus				7			2		9
Promeresia sp.				9				11	20
Stenelmis sp.		1	2					1	4
Hydrophilidae:									
Sperchopsis sp.						2			2
Tropisternus sp.						1		1	2
Psephenidae:									
Psephenus herricki	2	3	5	7	3	6		4	30
Diptera									
Athericidae:									
Atherix variegata				2	1		1	6	10
Ceratopogonidae:			2			5	1		8

	1991				1992				
TAXA	Feb-13	Apr-10	Jul-2	Oct-17	Feb-5	Apr-7	Aug-14	Oct-30	Totals
Chironomidae:				3		2			5
Brillia sp.			8	85	2			6	101
Cladotanytarsus sp.			35	6			1		42
Corynoneura sp.				2	1		1		4
Cricotopus sp.	11		16		8			8	43
Cryptochironomus sp.			17						17
Endochironomus sp.							3	1	4
Eukiefferiella sp.						2			2
Glyptotendipes sp.			1						1
Micropsectra sp.		3	10	4	4	18	19		58
Microtendipes sp.			6	4			2	6	18
Nanocladius sp.			1						1
Omisus sp.			2						2
Orthocladinae sp.		13				1	1		15
Parakeifferiella sp.	24		5						29
Parametriocnemus sp.	55		4	1		8			68
Phaenopsectra sp.			82		2	2			86
Polypedilum sp.		6	169	34		9	7	16	241
Procladius sp.			1	3		13			17
Rheocricotopus sp.			1			3	1		5
Rheotanytarsus sp.	18		19	4		1	1		43
Stempellina sp.				8					8
Stempellinella sp.								1	1
Stenochironomus sp.			12	2					14
Tanytarsus sp.	12		29	1	1				43
Thienemannimyia gr.	6		11						17
Zavrelimyia sp.			1						1

	1991				1992				
TAXA	Feb-13	Apr-10	Jul-2	Oct-17	Feb-5	Apr-7	Aug-14	Oct-30	Totals
Empididae:									
Hemerodromia sp.						1			1
Simuliidae:					69				69
Prosimulium sp.	416	3		3	43	23			488
Simulium sp.			10	40		6	98	31	185
Tabanidae:									
Chrysops sp.						1			1
Tanyderidae:									
Protoplasa fitchii			2			2	1		5
Tipulidae:									
Antocha sp.	1			3		2	1		7
Dicranota sp.		1					2		3
Hexatoma sp.		3	1	6		3			13
Limnophila sp.			1		1			1	3
Tipula sp.	4			6		9		3	22
SITE TOTALS:	691	333	1068	1057	288	446	310	465	4658
TAXA RICHNESS:	37	46	77	70	37	65	46	49	143

Appendix C

Physicochemical Data from Bear Creek near the Mouth (Mile Point 0.1)

Parameters	Collection Date						
	2/13/91	4/10/91	7/1/91	9/26/91	10/15/91	10/16/91	11/7/91
Alkalinity (mg/L)	2.0	NA	ND@0.1	1.8	2.5	2.3	1.0
Aluminum (mg/L)	0.037	0.829	0.008	0.205	0.183	0.334	0.263
Ammonia-Nitrogen (mg/L)	<0.03	NA	ND@0.05	NA	NA	NA	NA
Arsenic (mg/L)	ND@0.001	ND@0.001	ND@0.002	0.002	ND@0.002	ND@0.002	ND@0.002
Barium (mg/L)	NA	0.022	0.062	0.030	0.041	0.043	0.061
Cadmium (mg/L)	ND@0.001	ND@0.001	ND@0.001	0.002	ND@0.001	ND@0.001	ND@0.001
Calcium (mg/L)	7.32	8.9	8.3	14.7	11.4	11.5	18.2
Chloride (mg/L)	4.0	2.2	1.5	2.8	5.2	6.0	5.3
Chromium (mg/L)	ND@0.001	ND@0.001	0.001	0.003	ND@0.001	0.001	ND@0.001
Cobalt (mg/L)	NA	0.017	ND@0.025	ND@0.025	ND@0.025	ND@0.025	ND@0.023
Conductivity (umho/cm)	145	122	121	197	210	210	NA
Copper (mg/L)	0.005	0.005	0.004	0.001	0.003	0.005	0.004
Dissolved Oxygen (mg/L)	11.5	10.0	8.0	10.1	9.8	9.8	NA
Fluoride (mg/L)	ND@0.10	ND@0.10	0.1	ND@0.10	ND@0.10	0.11	ND@0.10
Hardness, total (mg/L)	48.7	39.8	45.4	63.5	62.4	69.1	91.6
Iron (mg/L)	0.14	0.11	0.32	0.27	0.27	0.28	0.050
Lead (mg/L)	ND@0.002	ND@0.002	0.002	ND@0.002	ND@0.002	ND@0.002	ND@0.002
Magnesium (mg/L)	6.61	5.44	6.12	8.26	7.10	8.22	11.9
Manganese (mg/L)	2.15	1.47	1.52	1.51	0.85	1.14	1.96
Mercury (mg/L)	ND@0.0001	NA	0.0002	NA	0.0001	0.0001	ND@0.0001
Nickel (mg/L)	0.042	0.026	0.029	0.014	0.010	0.016	0.025
Nitrate (mg/L)	<0.1	NA	0.105	NA	NA	NA	NA
pH (SU)	4.3	4.8	4.9	7.0	7.1	7.1	8.2
Potassium (mg/L)	1.02	0.77	0.990	1.64	1.67	1.68	2.27
Sodium (mg/L)	1.93	ND@3.5	ND@0.1	4.0	4.9	6.2	5.00
Sulfate (mg/L)	62.1	42.5	42.7	65.2	61.6	71.4	83.8
Temperature (deg. C)	5.4	13.3	25	13.0	10.7	10.7	5.7
Total Dissolved Phosphorous (mg/L)	0.031	NA	NA	NA	NA	NA	NA
Total Dissolved Solids (mg/L)	NA	NA	NA	NA	NA	NA	NA
Total Kjeldahl Nitrogen (mg/L)	0.235	ND@0.05	0.182	NA	NA	NA	NA
Total Phosphorous (mg/L)	NA	NA	ND@0.005	NA	NA	NA	NA
Total Solids (mg/L)	NA	NA	NA	NA	NA	NA	185

	Collection Date						
Parameters	2/13/91	4/10/91	7/1/91	9/26/91	10/15/91	10/16/91	11/7/91
Total Suspended Solids (mg/L)	1.0	5	3	ND@1	2	ND@1	NA
Total Volatile Solids (mg/L)	29	2	40	ND@1	ND@1	ND@1	162
Turbidity (NTU)	1.42	4.3	2.3	6.3	2.4	2.4	0.6
Zinc (mg/L)	0.088	0.065	0.038	0.026	0.046	0.078	0.079
ND = Not detected at the level indicated; NA = Parameter not analyzed							

	Collection Date						
Parameters	11/20-25/91	1/27/92	2/5/92	2/15/92	4/6/92	6/3/92	8/13/92
Alkalinity (mg/L)	1.7	ND@0.10	ND@0.10	11.4	ND@0.10	ND@0.10	ND@0.10
Aluminum (mg/L)	0.068	1.11	1.48	1.78	0.925	0.807	1.54
Ammonia-Nitrogen (mg/L)	NA	NA	NA	NA	NA	NA	NA
Arsenic (mg/L)	ND@0.002	ND@0.002	ND@0.002	ND@0.002	ND@0.002	ND@0.002	ND@0.002
Barium (mg/L)	0.064	0.004	0.018	0.031	0.022	0.028	0.038
Cadmium (mg/L)	ND@0.001	ND@0.001	ND@0.001	ND@0.001	ND@0.001	0.003	0.001
Calcium (mg/L)	18.2	7.76	9.29	11.9	6.67	9.57	11.1
Chloride (mg/L)	5.9	1.13	1.20	1.52	0.63	0.5	ND@1.0
Chromium (mg/L)	0.002	ND@0.001	0.003	0.005	0.009	0.003	0.001
Cobalt (mg/L)	ND@0.023	ND@0.023	ND@0.024	0.032	0.022	0.025	0.019
Conductivity (umho/cm)	NA	139	192	NA	118	148	171
Copper (mg/L)	0.009	0.002	0.002	0.004	ND@0.001	0.002	0.002
Dissolved Oxygen (mg/L)	NA	13.1	NA	NA	11.0	NA	8.9
Fluoride (mg/L)	ND@0.10	ND@0.10	ND@0.10	NA	ND@0.10	0.070	ND@0.10
Hardness, total (mg/L)	89.0	NA	55.2	71.2	42.4	41.9	57.8
Iron (mg/L)	ND@0.01	0.244	0.105	0.408	0.150	0.111	2.71
Lead (mg/L)	0.002	ND@0.002	ND@0.002	ND@0.002	ND@0.002	0.002	0.002
Magnesium (mg/L)	12.3	6.62	8.75	10.9	6.02	7.69	7.59
Manganese (mg/L)	1.62	1.69	2.29	3.02	1.56	2.10	2.16
Mercury (mg/L)	0.0002	ND@0.0001	ND@0.0001	ND@0.0001	ND@0.0001	ND@0.0001	ND@0.0001
Nickel (mg/L)	0.023	0.029	ND@0.002	0.053	0.028	0.057	0.035
Nitrate (mg/L)	NA	NA	NA	NA	NA	NA	NA
pH (SU)	NA	4.8	5.2	NA	4.87	NA	5.2

Parameters	Collection Date						
	11/20-25/91	1/27/92	2/5/92	2/15/92	4/6/92	6/3/92	8/13/92
Potassium (mg/L)	2.09	1.04	1.13	1.44	1.08	1.56	1.78
Sodium (mg/L)	7.2	1.44	1.98	2.09	1.32	1.98	1.93
Sulfate (mg/L)	30.8	55.8	70.7	79.3	46.8	54.6	45.4
Temperature (deg. C)	NA	3.7	1.0	NA	6.87	NA	20.4
Total Dissolved Phosphorous (mg/L)	NA	NA	NA	NA	NA	NA	NA
Total Dissolved Solids (mg/L)	NA	136	NA	NA	NA	114	NA
Total Kjeldahl Nitrogen (mg/L)	NA	NA	NA	NA	NA	NA	NA
Total Phosphorous (mg/L)	NA	NA	NA	NA	NA	NA	NA
Total Solids (mg/L)	NA	NA	NA	NA	NA	126	NA
Total Suspended Solids (mg/L)	2	NA	2	7	ND@1.0	8	33
Total Volatile Solids (mg/L)	34	1	12	34	32	NA	25.6
Turbidity (NTU)	NA	1.05	8.0	NA	NA	NA	50
Zinc (mg/L)	0.252	0.041	0.056	0.068	0.036	0.058	0.070
ND = Not detected at the level indicated; NA = Parameter not analyzed							

Parameters	Collection Date			
	10/29/92	4/5/93	10/11/94	10/28/94
Alkalinity (mg/L)	1.82	ND@0.10	NA	2.1
Aluminum (mg/L)	0.131	0.962	0.198	0.493
Ammonia-Nitrogen (mg/L)	ND@0.05	NA	ND@0.05	NA
Arsenic (mg/L)	ND@0.001	ND@0.002	ND@0.002	ND@0.002
Barium (mg/L)	0.039	0.024	0.044	0.041
Cadmium (mg/L)	ND@0.001	ND@0.001	ND@0.001	ND@0.001
Calcium (mg/L)	13.3	5.74	13.4	17.5
Chloride (mg/L)	ND@1.0	2.4	4.6	ND@1.0
Chromium (mg/L)	0.007	0.001	ND@0.001	ND@0.001
Cobalt (mg/L)	0.018	0.020	0.006	0.009
Conductivity (umho/cm)	191	122	234	280
Copper (mg/L)	0.002	0.001	ND@0.001	ND@0.002
Dissolved Oxygen (mg/L)	NA	12.1	10.4	7.7
Fluoride (mg/L)	ND@0.10	ND@0.10	ND@0.10	ND@0.10

	Collection Date			
Parameters	10/29/92	4/5/93	10/11/94	10/28/94
Hardness, total (mg/L)	22.5	36.4	74.4	95.1
Iron (mg/L)	0.112	0.588	0.135	0.102
Lead (mg/L)	ND@0.002	ND@0.002	ND@0.002	ND@0.002
Magnesium (mg/L)	9.34	5.33	8.93	12.1
Manganese (mg/L)	2.20	1.36	1.62	2.46
Mercury (mg/L)	ND@0.0001	ND@0.0001	ND@0.0001	ND@0.0001
Nickel (mg/L)	0.018	0.020	0.027	0.016
Nitrate (mg/L)	0.041	NA	0.019	NA
pH (SU)	5.7	4.2	5.1	5.8
Potassium (mg/L)	1.89	1.03	2.20	2.52
Sodium (mg/L)	3.38	1.10	NA	4.63
Sulfate (mg/L)	NA	37.1	NA	104
Temperature (deg. C)	NA	8.9	10.8	10.1
Total Dissolved Phosphorous (mg/L)	NA	NA	NA	NA
Total Dissolved Solids (mg/L)	NA	NA	NA	NA
Total Kjeldahl Nitrogen (mg/L)	0.137	NA	ND@0.05	NA
Total Phosphorous (mg/L)	ND@0.005	NA	ND@0.005	NA
Total Solids (mg/L)	NA	NA	NA	NA
Total Suspended Solids (mg/L)	1	13	1	11
Total Volatile Solids (mg/L)	16	NA	34	31
Turbidity (NTU)	NA	17	4.7	0.9
Zinc (mg/L)	0.030	0.035	NA	0.043
ND = Not detected at the level indicated; NA = Parameter not analyzed				

Appendix D

Physicochemical Data from Rock Creek at the KY/TN State Line (Mile Point 21.9)

Parameters	Collection Date						
	2/13/91	4/10/91	7/2/91	10/17/91	2/5/92	4/7/92	8/13/92
Alkalinity (mg/L)	18.0	NA	16.4	14.1	6.33	6.38	8.24
Aluminum (mg/L)	0.012	0.078	ND@0.001	0.235	ND@0.023	0.049	0.175
Ammonia-Nitrogen (mg/L)	<0.03	NA	ND@0.05	NA	NA	NA	NA
Arsenic (mg/L)	ND@0.001	ND@0.001	ND@0.002	ND@0.002	ND@0.002	ND@0.002	ND@0.002
Barium (mg/L)	NA	0.035	0.048	0.024	0.004	0.027	0.021
Cadmium (mg/L)	ND@0.001	ND@0.001	ND@0.001	ND@0.001	ND@0.001	ND@0.001	0.001
Calcium (mg/L)	6.14	4.4	4.2	4.1	2.96	2.87	3.5
Chloride (mg/L)	2.0	2.4	0.8	1.7	1.13	ND@0.5	ND@1.0
Chromium (mg/L)	0.002	ND@0.001	0.001	0.003	0.001	0.008	0.001
Cobalt (mg/L)	NA	0.005	ND@0.025	ND@0.025	ND@0.023	ND@0.006	0.006
Conductivity (umho/cm)	62	39	50	42	33.1	38	39
Copper (mg/L)	0.001	0.018	0.003	0.007	ND@0.001	0.001	0.001
Dissolved Oxygen (mg/L)	11.3	9.8	8.1	10.8	NA	11.9	9.3
Fluoride (mg/L)	ND@0.10	ND@0.10	ND@0.10	ND@0.10	ND@0.10	ND@0.10	ND@0.10
Hardness, total (mg/L)	25.1	10.7	16.1	15.2	8.42	10.8	9.36
Iron (mg/L)	0.12	0.004	0.23	0.31	0.044	0.040	0.323
Lead (mg/L)	ND@0.002	ND@0.002	0.002	ND@0.002	ND@0.002	ND@0.002	0.002
Magnesium (mg/L)	1.97	1.04	1.43	1.05	0.95	0.980	0.958
Manganese (mg/L)	0.03	ND@0.01	0.01	ND@0.01	ND@0.019	0.005	0.020
Mercury (mg/L)	ND@0.0001	NA	0.0002	0.0001	0.0001	ND@0.0001	ND@0.0001
Nickel (mg/L)	0.004	ND@0.002	0.004	ND@0.002	ND@0.002	ND@0.002	ND@0.002
Nitrate (mg/L)	<0.10	NA	0.088	NA	NA	NA	NA
pH (SU)	6.1	6.9	7.1	7.1	7.5	8.1	6.8
Potassium (mg/L)	0.60	0.43	0.53	0.71	0.43	0.531	0.524
Sodium (mg/L)	1.43	ND@3.5	ND@0.10	0.50	0.98	0.749	0.748
Sulfate (mg/L)	13.8	5.89	ND@2.0	3.13	NA	8.71	5.0
Temperature (deg. C)	6.0	15.0	23	7.6	1.0	7.1	18.6
Total Dissolved Phosphorous (mg/L)	0.031	NA	NA	NA	NA	NA	NA
Total Kjeldahl Nitrogen (mg/L)	0.425	ND@0.005	0.231	NA	NA	NA	NA
Total Phosphorous (mg/L)	NA	NA	ND@0.005	NA	NA	NA	NA
Total Suspended Solids (mg/L)	1.0	2.0	0.0	ND@1.0	2	ND@1.0	3
Total Volatile Solids (mg/L)	12	ND@1.0	21	ND@1.0	2	8	3.5

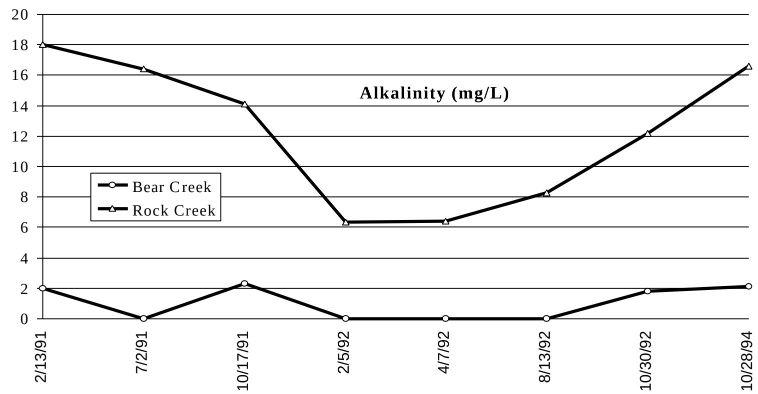
	Collection Date						
Parameters	2/13/91	4/10/91	7/2/91	10/17/91	2/5/92	4/7/92	8/13/92
Turbidity (NTU)	3.88	1.6	1.8	1.2	0.77	1.2	8.0
Zinc (mg/L)	0.013	0.065	0.014	0.025	ND@0.015	ND@0.003	0.005
ND = Not detected at the level indicated; NA = Parameter not analyzed							

Parameters	Collection Date	
	10/30/92	10/28/94
Alkalinity (mg/L)	12.2	16.6
Aluminum (mg/L)	ND@0.023	ND@0.056
Ammonia-Nitrogen (mg/L)	NA	NA
Arsenic (mg/L)	ND@0.001	ND@0.002
Barium (mg/L)	0.021	0.018
Cadmium (mg/L)	ND@0.001	ND@0.001
Calcium (mg/L)	3.93	4.34
Chloride (mg/L)	1.7	1.2
Chromium (mg/L)	0.002	ND@0.001
Cobalt (mg/L)	ND@0.002	ND@0.002
Conductivity (umho/cm)	39.6	55
Copper (mg/L)	0.001	ND@0.002
Dissolved Oxygen (mg/L)	NA	9.8
Fluoride (mg/L)	ND@0.10	ND@0.10
Hardness, total (mg/L)	15.0	14.5
Iron (mg/L)	0.140	0.233
Lead (mg/L)	ND@0.002	ND@0.002
Magnesium (mg/L)	0.992	0.990
Manganese (mg/L)	0.008	0.008
Mercury (mg/L)	ND@0.0001	ND@0.0001
Nickel (mg/L)	ND@0.002	ND@0.002
Nitrate (mg/L)	NA	NA
pH (SU)	6.5	6.9
Potassium (mg/L)	0.632	0.710
Sodium (mg/L)	0.976	0.960

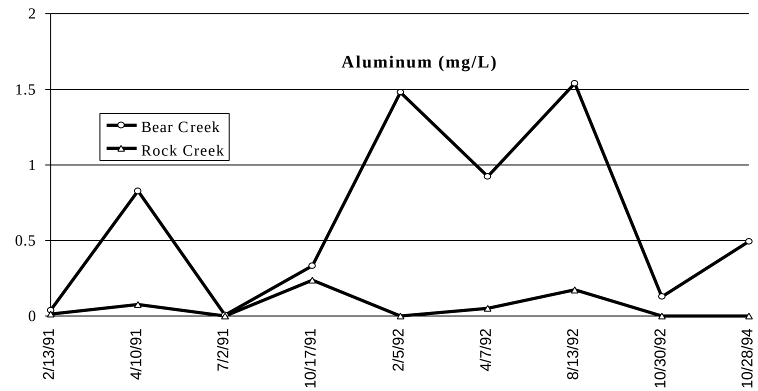
Parameters	Collection Date	
	10/30/92	10/28/94
Sulfate (mg/L)	NA	5.3
Temperature (deg. C)	NA	6.4
Total Dissolved Phosphorous (mg/L)	NA	NA
Total Kjeldahl Nitrogen (mg/L)	NA	NA
Total Phosphorous (mg/L)	NA	NA
Total Suspended Solids (mg/L)	8	6
Total Volatile Solids (mg/L)	10	23
Turbidity (NTU)	NA	0.8
Zinc (mg/L)	ND@0.003	0.004
ND = Not detected at the level indicated; NA = Parameter not analyzed		

Appendix E

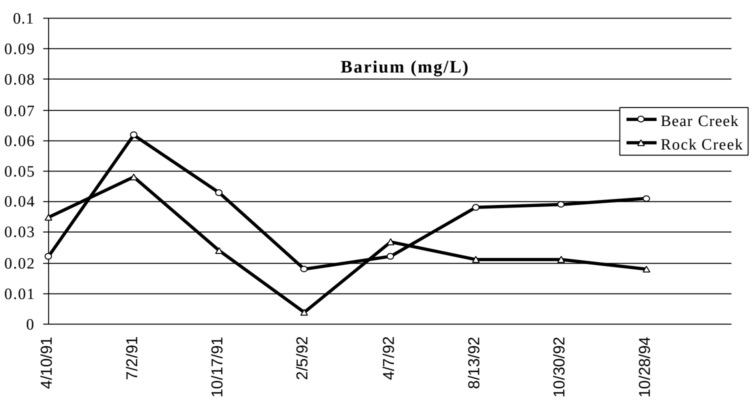
Comparisons of Selected Physicochemical Parameters from Bear Creek near the Mouth (Mile Point 0.1) and Rock Creek at the KY/TN State Line (Mile Point 21.9)



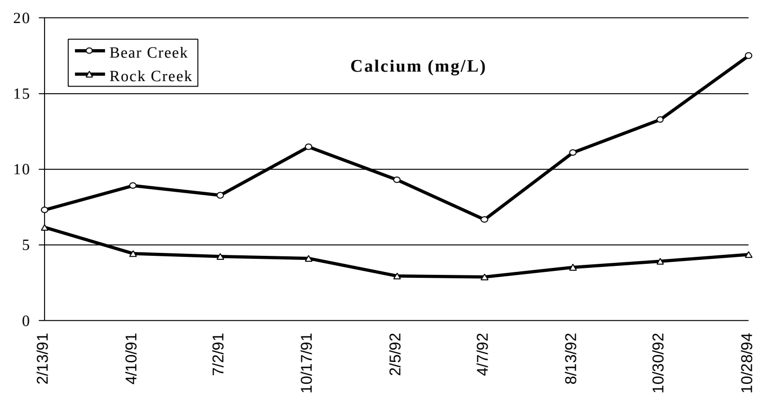
Alkalinity (mg/L)
Bear Creek
Rock Creek
20
18
16
14
12
10
8
6
4
2
0
2/13/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94



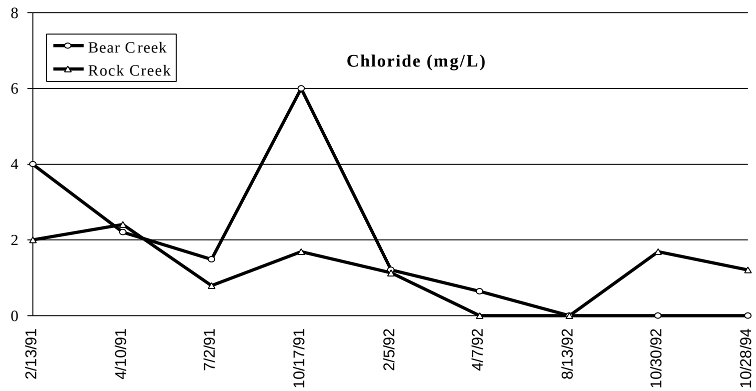
Aluminum (mg/L)
Bear Creek
Rock Creek
2
1.5
1
0.5
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

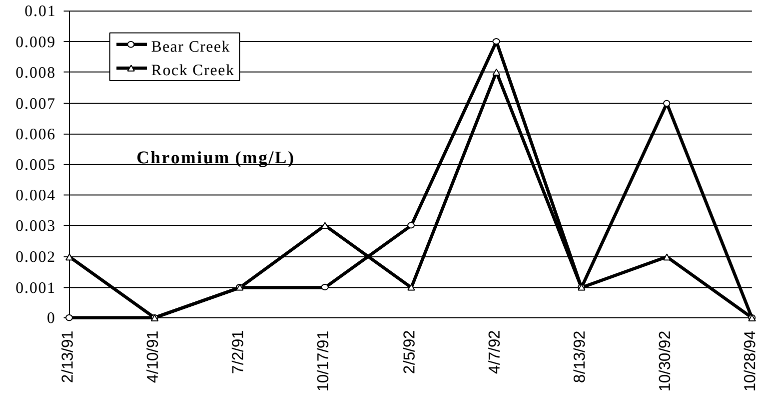


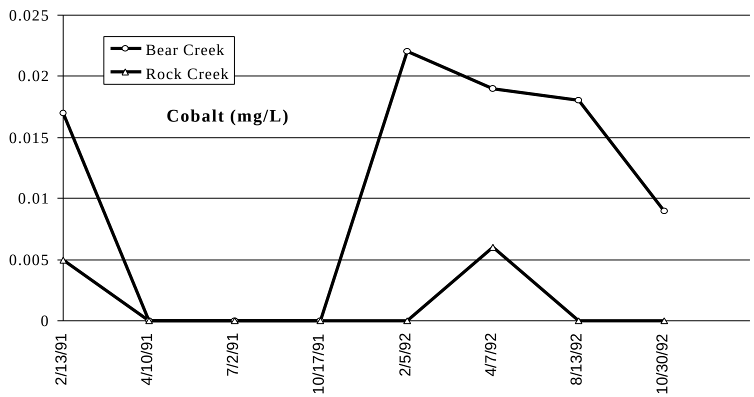
Barium (mg/L)
Bear Creek
Rock Creek
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

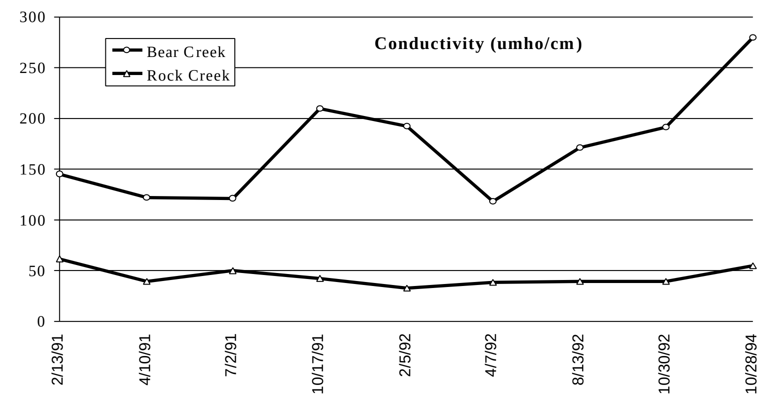


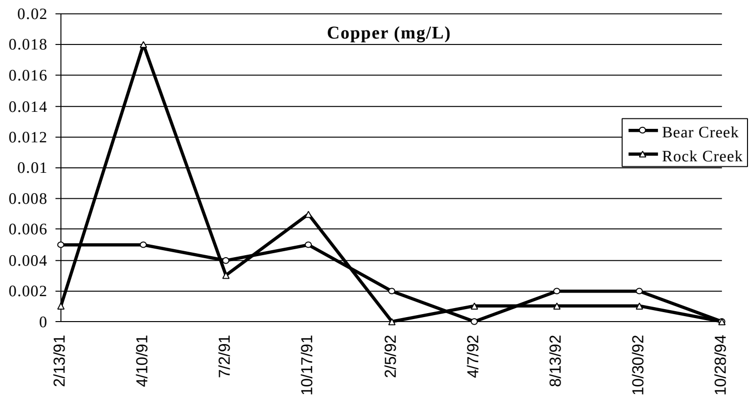
Calcium (mg/L)
Bear Creek
Rock Creek
20
15
10
5
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94


Chloride (mg/L)
Bear Creek
Rock Creek
8
6
4
2
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

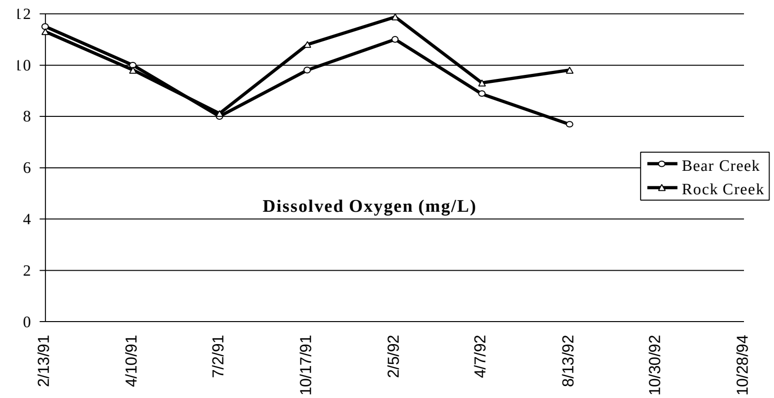

Chromium (mg/L)
Bear Creek
Rock Creek
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94


Cobalt (mg/L)
Bear Creek
Rock Creek
0.025
0.02
0.015
0.01
0.005
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92

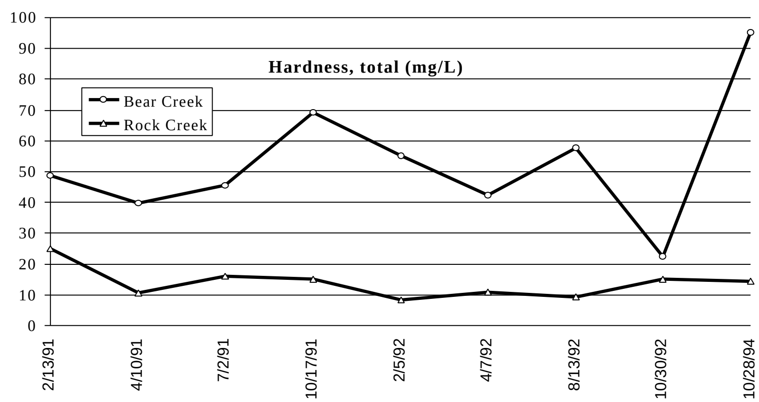

Conductivity (umho/cm)
Bear Creek
Rock Creek
300
250
200
150
100
50
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94



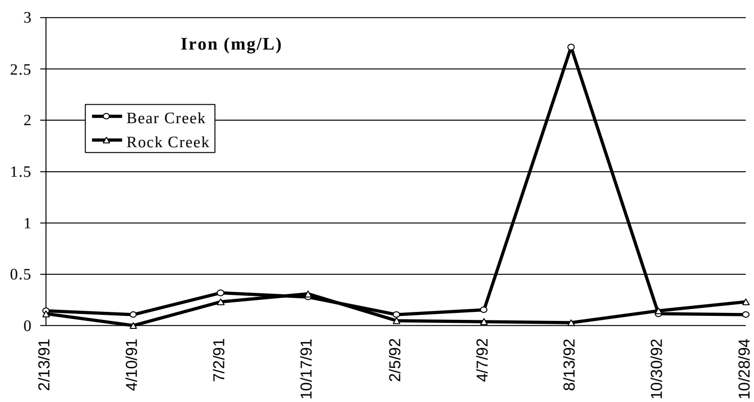
Copper (mg/L)
Bear Creek
Rock Creek
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94



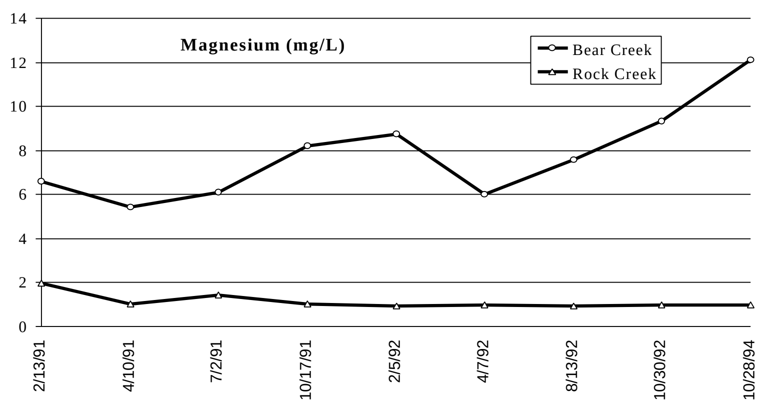
Dissolved Oxygen (mg/L)
Bear Creek
Rock Creek
12
10
8
6
4
2
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

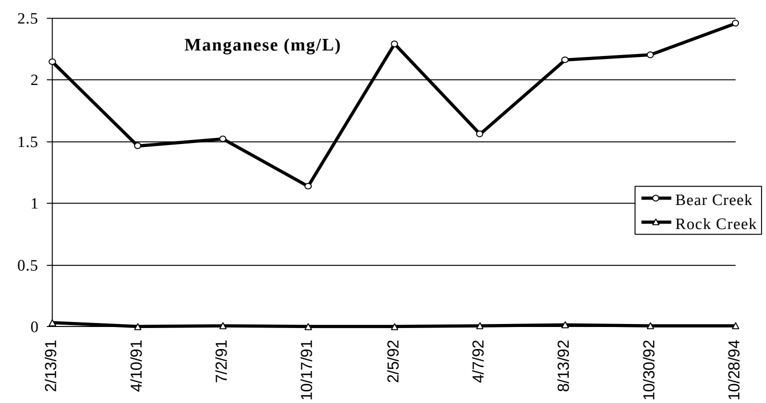


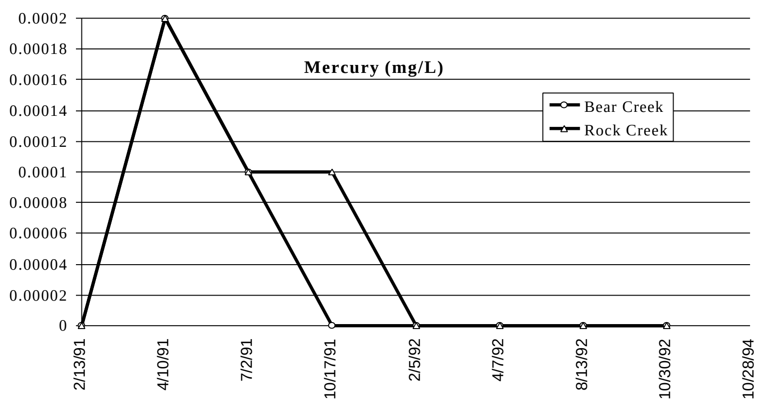
Hardness, total (mg/L)
Bear Creek
Rock Creek
100
90
80
70
60
50
40
30
20
10
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

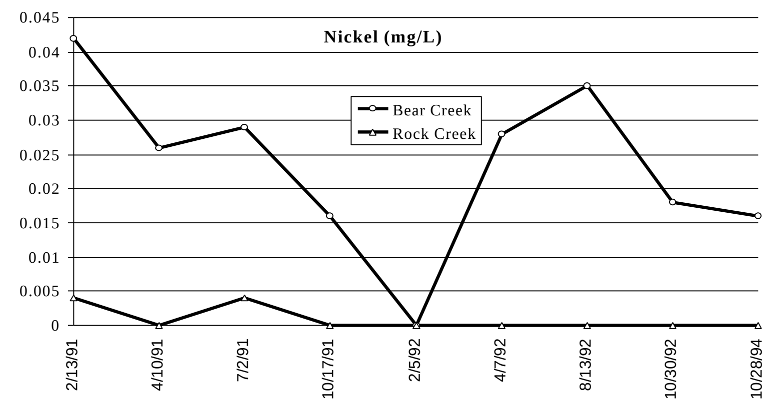


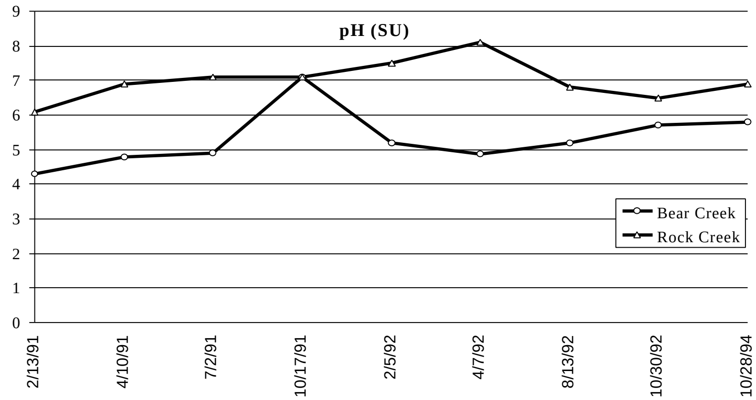
Iron (mg/L)
Bear Creek
Rock Creek
3
2.5
2
1.5
1
0.5
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

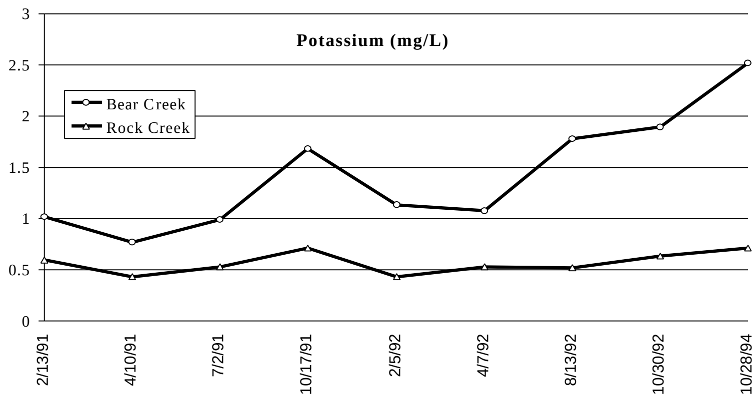

Magnesium (mg/L)
Bear Creek
Rock Creek
14
12
10
8
6
4
2
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

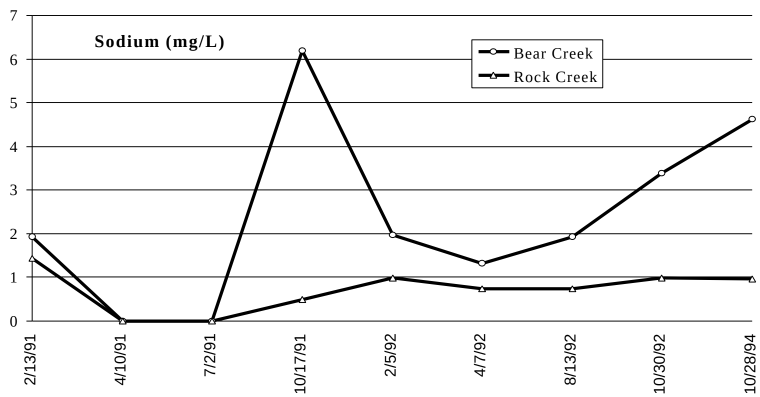

Manganese (mg/L)
Bear Creek
Rock Creek
2.5
2
1.5
1
0.5
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

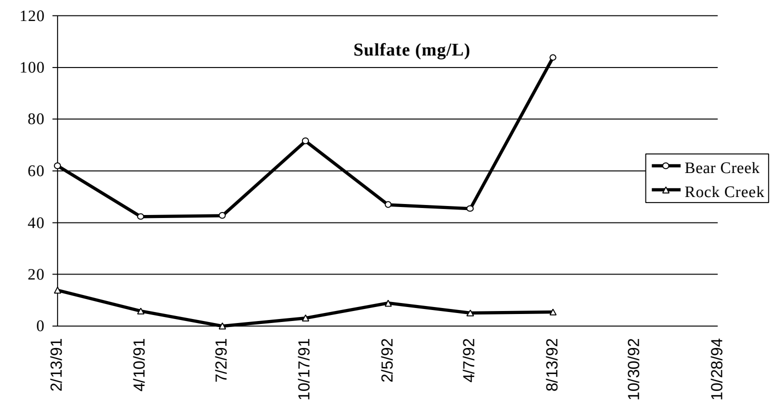

Mercury (mg/L)
Bear Creek
Rock Creek
0.0002
0.00018
0.00016
0.00014
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

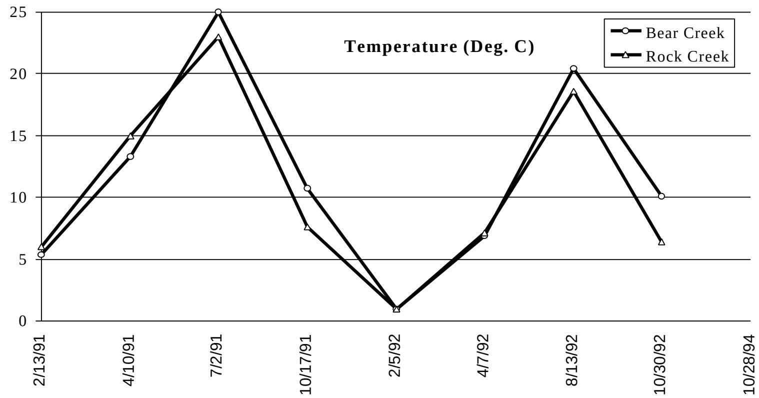

Nickel (mg/L)
Bear Creek
Rock Creek
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

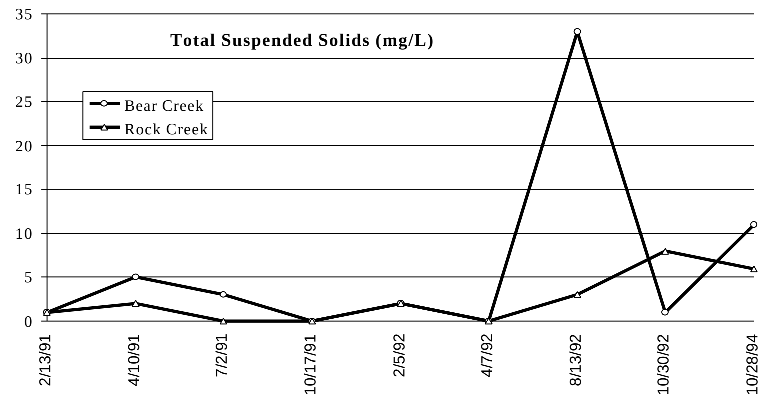

pH (SU)
Bear Creek
Rock Creek
0
1
2
3
4
5
6
7
8
9
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

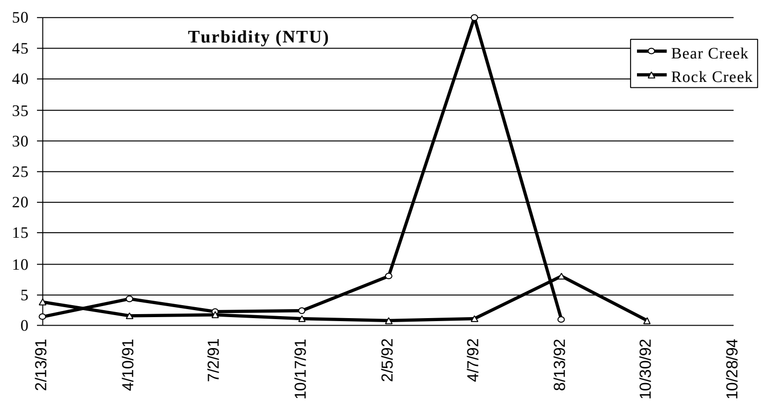

Potassium (mg/L)
Bear Creek
Rock Creek
0
0.5
1
1.5
2
2.5
3
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

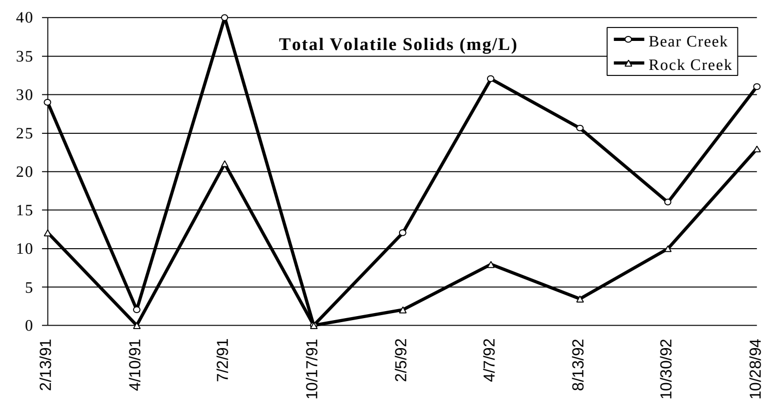

Sodium (mg/L)
Bear Creek
Rock Creek
0
1
2
3
4
5
6
7
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94

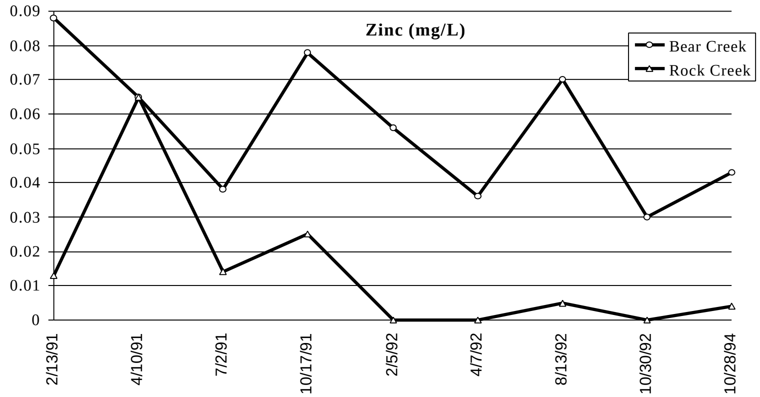

Sulfate (mg/L)
Bear Creek
Rock Creek
0
20
40
60
80
100
120
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94


Temperature (Deg. C)
Bear Creek
Rock Creek
25
20
15
10
5
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94


Total Suspended Solids (mg/L)
Bear Creek
Rock Creek
35
30
25
20
15
10
5
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94


Turbidity (NTU)
Bear Creek
Rock Creek
50
45
40
35
30
25
20
15
10
5
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94


Total Volatile Solids (mg/L)
Bear Creek
Rock Creek
40
35
30
25
20
15
10
5
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94



Zinc (mg/L)
Bear Creek
Rock Creek
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2/13/91
4/10/91
7/2/91
10/17/91
2/5/92
4/7/92
8/13/92
10/30/92
10/28/94