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FIELD OFFICE

A RESOURCE and CONTAMINANT ASSESSMENT of the BEAR CREEK WATERSHED McCREARY COUNTY, KENTUCKY and SCOTT COUNTY, TENNESSEE

U.S. Fish and Wildlife Service
Ecological Services
446 Neal Street
Cookeville, Tennessee 38501

April 1997

U.S. FISH and WILDLIFE SERVICE / SOUTHEAST REGION / ATLANTA, GEORGIA

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Prepared by

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CONVERSIONS

mg/kg = ppm = μg/g
mg/l = ppm = μg/ml
μg/l = ppb

ACRONYMS and ABBREVIATIONS

Ag	Silver
Al	Aluminum
AMD	Acid Mine Drainage
AML	Abandoned Mine Land
As	Arsenic
Ba	Barium
Be	Beryllium
BHC	Hexachlorocyclohexane
BMP	Best Management Practice
Cd	Cadmium
CFS	Cubic Feet Per Second
Co	Cobalt
Cr	Chromium
Cu	Copper
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
dw	Dry Weight
E	Endangered
EPA	U.S. Environmental Protection Agency
ERL	Effects Range Low
ERM	Effects Range Median
Fe	Iron
g	Grams
KDEP	Kentucky Department for Environmental Protection
KDOW	Kentucky Division of Water
Hg	Mercury
IJC	International Joint Commission
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Guideline
mg/kg	Milligrams Per Kilogram
mg/l	Milligrams Per Liter
ml	Milliliter

ACRONYMS and ABBREVIATIONS

Mn	Manganese
MP	Mile Point
MSL	Mean Sea Level
NRCS	Natural Resources Conservation Service
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
OSM	Office of Surface Mining
Pb	Lead
PCB	Polychlorinated Biphenyl
ppb	Parts Per Billion
ppm	Parts Per Million
Se	Selenium
SMCL	Secondary Maximum Contaminant Level
SPMD	Semi-permeable Membrane Device
T	Threatened
TDEC	Tennessee Department of Environment and Conservation
USGS	United States Geological Survey
μg/g	Micrograms Per Gram
μg/l	Micrograms Per Liter
μg/ml	Micrograms Per Milliliter
ww	Wet Weight
Zn	Zinc

COMMON AND SCIENTIFIC NAMES

American beech	*Fagus grandifolia*
American holly	*Ilex opaca*
Barred owl	*Strix varia*
Belted kingfisher	*Megaceryle alcyon*
Bigleaf magnolia	*Magnolia macrophylla*
Black bear	*Ursus americanus*
Black gum	*Nyssa sylvatica*
Black oak	*Quercus velutina*
Broad-winged hawk	*Buteo platypterus*
Canadian hemlock	*Tsuga canadensis*
Chestnut oak	*Quercus montana*
Coyote	*Canis latrans*
Creek chub	*Semotilus atromaculatus*
Downy woodpecker	*Picoides pubescens*
Eastern screechowl	*Otus asio*
Flowering dogwood	*Cornus florida*
Gray squirrel	*Sciurus carolinensis*
Green heron	*Butorides striatus*
Great horned owl	*Bubo virginianus*
Hairy woodpecker	*Picoides villosus*
Hazel nut	*Corylus americana*
Killdeer	*Charadrius vociferus*
Mayapple	*Podophyllum peltatum*
Mink	*Mustela vison*
Mockernut hickory	*Carya tomentosa*
Mountain laurel	*Kalmia latifolia*
Mourning dove	*Zenaida macroura*
Northern flicker	*Colaptes auratus*
Northern red oak	*Quercus rubra*
Opossum	*Didelphis virginiana*
Pawpaw	*Asimina triloba*
Pignut hickory	*Carya glabra*
Pileated woodpecker	*Dryocopus pileatus*
Raccoon	*Procyon lotor*
Red-bellied woodpecker	*Centurus carolinus*
Red bud	*Cercis canadensis*
Red maple	*Acer rubrum*
Red-shouldered hawk	*Buteo lineatus*
Red-tailed hawk	*Buteo jamaicensis*
Rhododendron (great laurel)	*Rhododendron maximum*

COMMON AND SCIENTIFIC NAMES

River otter	*Lontra canadensis*
Rock dove	*Columba livia*
Ruffed grouse	*Bonasa umbellus*
Sharp-shinned hawk	*Accipiter striatus*
Shortleaf pine	*Pinus echinata*
Smooth alder	*Alnus serrulata*
Sourwood	*Oxydendrum arboreum*
Striped maple	*Acer pensylvanicum*
Striped skunk	*Mephitis mephitis*
Sugar maple	*Acer saccharum*
Sweetgum	*Liquidambar styraciflua*
Tulip tree	*Liriodendron tulipfera*
Turkey	*Meleagris gallopavo*
Turkey vulture	*Cathartes aura*
Umbrella magnolia	*Magnolia tripetela*
Virginia pine	*Pinus virginiana*
White oak	*Quercus alba*
White pine	*Pinus strobus*
White-tailed deer	*Odocoileus virginianus*
Wild boar	*Sus scrofa*
Wood duck	*Aix sponsa*
Yellow birch	*Betula alleghaniensis*

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EXECUTIVE SUMMARY

Water samples from three mainstem and twenty-six tributary sites in the Bear Creek watershed were analyzed for 12 metals and 7 water quality-related parameters. Semi-permeable membrane devices (SPMD's) were deployed at four locations and the dialysates analyzed for 26 organochlorine compounds, none of which were detected. Sediment samples from three mainstem sites, two tributary sites, and two constructed wetlands were analyzed for 15 metals, 11 (73%) of which were detected at all sites.

Aluminum, cobalt, manganese, and nickel concentrations in water were highest at the tributary site WB4. Arsenic and cadmium were also detected at low concentrations at this site. Chromium, copper, and iron levels were highest at tributary site WB5. Mercury was also detected at this site and at low concentrations at the mainstem site BC1.

Geometric means for aluminum and barium water concentrations were higher in the West Branch Bear Creek tributary sites. Average cobalt, copper, iron, manganese, and nickel concentrations in water were higher for the East Branch Bear Creek tributary sites. None of the differences observed metal concentrations in water between East Branch and West Branch or between tributary and mainstem sites were statistically significant.

Values for pH at most sites were below minimum applicable criteria in Tennessee and Kentucky for domestic water supply, recreation, and aquatic life. Sulfate values exceeded secondary maximum contaminant levels and the Kentucky maximum allowable in-stream concentration (domestic water supply) at 12 of the 29 sites (41%). Aluminum, iron, manganese, and nickel concentrations at a majority of the sites exceeded applicable Federal and State criteria for domestic water.

Copper, iron, nickel, and lead concentrations in some samples exceeded aquatic life criteria and were at levels associated with lethal and sub-lethal effects to a variety of aquatic organisms in non-acid mine drainage related studies. Cadmium and mercury were detected in five samples at levels which exceeded applicable aquatic life criteria. Previous investigations in the Bear Creek watershed identified zinc levels which exceeded applicable aquatic life criteria and have been associated with toxicity to fish and mussels in non-acid mine drainage related studies.

Sediment analyses identified maximum aluminum and chromium levels at one tributary site with constructed wetlands (SU2) and at site CH3G. Maximum arsenic, barium, copper, and lead concentrations were highest at one tributary site, CH3G, immediately downstream from a constructed BMP (best management practice) facility (Site CH3W). Mercury was detected in one sediment sample from a constructed wetland at Site SU2. This site also had the highest individual values for cobalt and zinc, and the highest average iron concentration. Average values for cobalt and zinc were greatest at Site EB4, which also had the highest selenium and manganese concentrations.

The maximum individual iron concentration occurred at the Line Fork (LF) site, which also had the only detected concentration of beryllium. Silver and cadmium were not detected in any sediment samples.

Statistical analyses of log-transformed wet-weight results indicated significant differences between the tributary and mainstem site sediment concentrations of aluminum, arsenic, barium, copper, and lead. Significant differences for aluminum, copper, and selenium were also noted between the tributary sites and control site (LF4). Significant correlations with aluminum and iron were observed for all sediment metals except barium, cobalt, and manganese.

Geometric means for copper and iron in the tributary sites were higher than those found in surficial soils of the eastern United States. Tributary and mainstem concentrations of arsenic and selenium were also substantially higher. Arsenic and iron were elevated in tributary samples when compared with Illinois stream sediment classification guidelines. Chromium and mercury were also elevated in constructed wetland sediments. Arsenic levels were elevated in the mainstem samples and exceeded the sediment limit of tolerance at all sites developed by the Ontario Ministry of Environment. Geometric mean concentrations of copper and iron in the tributary samples also exceeded the limit of tolerance. Results for the other 12 metals were below the Ontario lowest effect levels.

Copper, lead, and zinc sediment concentrations at several sites were in ranges associated with reduced amphipod and chironimid survival in 10-day sediment toxicity tests. Selenium levels were significantly higher than those associated with aquatic organism reproductive failure and mortality in non-acid mine drainage related studies.

Analyses of previous water quality investigations and flow measurements revealed statistically significant positive correlations of aluminum and zinc concentrations with flow at tributary site CH3G and at mainstem site EB4. A similar relationship was observed for iron and flow at site EB4, where a statistically significant negative correlation between aluminum and pH was also observed. Negative correlations were observed at the constructed wetland site CH3 for iron and dissolved oxygen, and at the constructed wetland site SU2 for iron, manganese, and cobalt with dissolved oxygen.

Contaminant loading estimates--based on previous investigations for aluminum, iron, manganese, and zinc at the tributary site CH3G and the mainstem site EB4--indicated substantial metals loading in the Bear Creek watershed. Without extensive additional remediation efforts, Bear Creek should not be considered for domestic water supply. If enhancement of existing best management practices and additional remediation are not performed, substantial investments in water treatment technologies would be required before the watershed could be considered as a potentially reliable drinking water source.

Instream cover exhibited slight variability and was considered to be optimal. Instream epifaunal substrate was prevalent and also considered optimal. Embeddedness was rated as sub-optimal at all stream sites due to extensive sedimentation from road construction, landfill construction, and poor forestry practices.

Aluminum, copper, iron, manganese, nickel, lead, selenium, and zinc in Bear Creek water and sediments have adversely impacted the aquatic communities that historically were present in the watershed and, without continued acid mine drainage remediation efforts, will prevent the re-colonization of aquatic life. Discharges from Bear Creek are contributing to degradation of the Big South Fork Cumberland River, adversely impacting federally listed mussel and fish species.

A variety of rare, threatened, or endangered species could benefit from improved water quality in Bear Creek. Most of these are mussel and fish species with records of occurrence in Scott County (Tennessee) or McCreary County (Kentucky). Increased recreational use, industrial or residential development, or construction of a water supply impoundment could also impact non-aquatic species such as the red-cockaded woodpecker or the Cumberland sandwort. Future watershed management decisions should fully consider these types of impacts.

The following items are recommended for consideration in additional best management practice construction and any future investigations of the Bear Creek watershed: 1) ensure that constructed wetlands are sized appropriately for adequate retention time and to contain storm events; 2) construct an aerobic wetland as the furthest downstream component of any passive treatment system; 3) develop a maintenance plan for existing and future best management practices which includes contingencies for ensuring aerobic conditions in the furthest downstream component, and the disposal of contaminated sediment and vegetation; 4) develop a periodic water quality monitoring plan which addresses the effectiveness of the components of constructed passive treatment systems, including monitoring for selenium and zinc; and 5) analyze sediment samples for total organic carbon, acid volatile sulfides, and simultaneously extracted metals.

The effects of AMD on the continued viability of mussel populations in the Big South Fork Cumberland River should be assessed. The following items are recommended for consideration: 1) use a suite of sediment toxicity tests, including larval and juvenile mussels; 2) measure contaminants in water and sediment in conjunction with toxicity tests; and 3) determine contaminant residues in non-listed mussel species which are co-located with listed species.

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INTRODUCTION

The Cookeville Field Office participated in a joint project (1) to identify contaminants associated with acid mine drainage or other potential sources in the Bear Creek watershed in Scott County, Tennessee, and McCreary County, Kentucky, and (2) evaluate impacts to fish and wildlife resources. The project also involved the Natural Resources Conservation Service, National Park Service, Office of Surface Mining, Tennessee Department of Environment and Conservation, and Kentucky Department for Environmental Protection. This report combines the results of the sampling and analyses conducted by the Cookeville Field Office with an analysis of prior investigations conducted in this watershed by the National Park Service, Tennessee Department of Health, Tennessee Department for Environment and Conservation, and the United States Geological Survey.

STUDY AREA DESCRIPTION

Bear Creek Watershed

The Bear Creek watershed encompasses approximately 14,900 acres in Tennessee and Kentucky. The basin includes portions of Scott County, Tennessee, and McCreary County, Kentucky. Both the East Fork and the West Fork of Bear Creek originate near Oneida, Scott County, Tennessee. The two forks confluence in the northern portion of Scott County approximately one mile south of the Kentucky State Line. Bear Creek continues northward through Scott County and enters McCreary County, Kentucky. From there it flows north to northwest until it confluences with the Big South Fork Cumberland River at MP 50.6. Major Bear Creek mainstem tributaries include Line Fork, Tappley Branch, Turkey Branch, Slavens Creek, and Jerry West Branch . Tributaries to the West Branch or East Branch of Bear Creek include Fox Trap Branch, Sexton Branch, and Previt Branch (Figure 1). The watershed is designated with the USGS Hydrologic Unit Code (HUC) No. 05130104.

Both Scott County and McCreary County lie within the Mountains and Eastern Coal Fields Physiographic Region, which is part of the Cumberland Plateau section of the Appalachian Plateau Physiographic Province (USDA 1970). The Bear Creek watershed is characterized by steep topography (20-60% slopes) with elevations ranging from approximately 800 to 1500 feet above MSL. This basin lies within an area described by Omernik (1987) as the Southwestern Appalachians and is considered by the Fish and Wildlife Service as part of the Lower Tennessee-Cumberland Ecosystem (FWS 1995).

Soil types within the watershed are primarily of the Ramsey-Muskingum association. Typically, these are loamy, somewhat excessively drained soils formed from weathered sandstone bedrock. They are considered strongly acidic with a weak to medium granular structure in the A and E horizons. Texture changes within the B horizon to a weak to medium sub-angular blocky structure, with fragments of imbedded sandstone. Depth to bedrock averages 8 to 20 inches (USDA 1970, 1991). Pyritic material within the various geologic formations is abundant.

Mineral extraction activities began in Scott County in the late 1800's. Most operations were underground with some surface mining occurring from the 1950's to the 1970's. Operations continued sporadically and were virtually non-existent at about the time of passage of the Surface Mining Reclamation and Control Act in 1977. Based on GIS analyses, approximately 766 acres of reclaimed and AML currently exist in the Bear Creek watershed.

A portion of the watershed is within the Big South Fork National River and Recreation Area (BSFNRRA) which is managed by the National Park Service. The Kentucky portion of the watershed is entirely within the BSFNRRA, except the upstream sections of Dardy Branch and Turkey Branch. Primary land uses within the watershed include forestry, agriculture, some industry near Oneida, and recreation. There are no permitted National Pollutant Discharge

Elimination System (NPDES) discharges in the watershed (Barbara Hamilton, TDEC, personal communication).

The Bear Creek watershed is approximately 80 percent forested and is comprised primarily of oak-hickory, oak-yellow pine, and yellow pine-oak associations (USDA 1997). The NPS performed a detailed vegetation survey within the nearby North White Oak Creek watershed (Allawos 1994). Based on the proximity of North White Oak Creek, plant community composition is expected to be similar in the Bear Creek watershed. A list of the frequently, commonly, and occasionally occurring vascular flora species expected in the Bear Creek watershed is included in Appendix I. Oak and pine species include white oak, chestnut oak, northern red oak, black oak, Virginia pine, white pine, and shortleaf pine. Other tree species found in the watershed include Canadian hemlock, American beech, red maple, sugar maple, striped maple, yellow birch, sweetgum, pignut hickory, mockernut hickory, tulip tree, bigleaf magnolia, umbrella magnolia, and black gum. Common understory representatives from the shrub and herbaceous layers are flowering dogwood, red bud, sourwood, rhododendron, great laurel, pawpaw, hazel nut, smooth alder, American holly, mayapple, and a wide variety of ferns, sedges, and grasses.

The Big South Fork Cumberland River supports diverse fish, mussel, and macroinvertebrate populations upstream of the confluence with Bear Creek. Within the BSFNRRA, approximately 44 fish species and 22 mussel species (Tables 1 and 2) have been collected or observed in recent years. Historically, the Big South Fork Cumberland River supported 44 mussel species (Bakaletz 1991). Downstream of the confluence with Bear Creek, no mussels and limited fish species have been collected for approximately 12 miles.

Various game and non-game wildlife species utilize the BSFNRRA and the Bear Creek watershed. Observations during field sampling included gray squirrel, wild turkey, ruffed grouse, and white-tailed deer. Raccoons, opossums, and the striped skunk are common while the coyote may occur as a transient species within the watershed. Confirmed or highly probable breeding populations of avian species within the BSFNRRA include green heron, wood duck, belted kingfisher, killdeer, turkey vulture, sharp-shinned hawk, red-shouldered hawk, broad-winged hawk, red-tailed hawk, rock dove, mourning dove, eastern screech-owl, great horned owl, barred owl, red-bellied woodpecker, downy woodpecker, hairy woodpecker, pileated woodpecker, and northern flicker. A variety of other avian species, including neotropical migrants, also utilize the watershed. These common and less-common breeding populations, based on surveys conducted by National Park Service personnel on the BSFNRRA, are included in Appendix II.

Due to the absence of preferred aquatic food species and habitat disturbances, it is highly unlikely that avian and mammalian species such as the bald eagle, river otter, mink, wild boar, and bats which prefer foraging over water, would be observed in the Bear Creek watershed. These species have, however, been observed in other portions of the BSFNRRA. Also, the NPS is currently re-introducing the black bear to remote areas within the park boundaries.

Threatened and Endangered Species

Scott County distribution records for endangered (E) and threatened (T) species include:

Cumberland bean pearlymussel	*Villosa trabalis* (E)
Cumberland combshell	*Epioblasma brevidens* (E)
Cumberland elktoe mussel	*Alasmidonta atropurpurea* (E)
Cumberland rosemary	*Conradina verticillata* (T)
Cumberland sandwort	*Arenaria cumberlandensis* (E)
Duskytail darter	*Etheostoma (Catonotus) sp.* (E)
Little-winged pearlymussel	*Pegias fabula* (E)
Blackside dace	*Phoxinus cumberlandensis* (T)
Oyster mussel	*Epioblasma capsaeformis* (E)
Red-cockaded woodpecker	*Picoides borealis* (E)
Virginia spiraea	*Spiraea virginiana* (T)

Seven other species with records from Scott County are considered as primary species of concern. Although these species currently have no federal status, they are declining and warrant special consideration in future watershed management decisions. These are:

Tennessee clubshell mussel	*Pleurobema oviforme*
Granite rock stonecrop	*Sedum nevii*
Kentucky ladyslipper	*Cypripedium kentuckiense*
Lucy Braun's white snakeroot	*Eupatorium luciae-brauniae*
Mountain heartleaf	*Hexastylis contracta*
Rockcastle aster	*Aster saxicastellii*
Allegheny (Eastern) woodrat	*Neotoma magister*

McCreary County distribution records for endangered and threatened species include:

Bald eagle	*Haliaeetus leucocephalus* (T)
Chaff-seed	*Schwalbea americana* (E)
Clubshell	*Pleurobema clava* (E)
Cracking pearly mussel	*Hemistena lata* (E)
Cumberland bean pearly mussel	*Villosa trabilis* (E)
Cumberland combshell	*Epioblasma brevidens* (E)
Cumberland elktoe	*Alasmidonta atropurpurea* (E)
Cumberland rosemary	*Conradina verticillata* (T)
Cumberland sandwort	*Arenaria cumberlandensis* (E)
Dromedary pearlymussel	*Dromus dromas* (E)
Indiana bat	*Myotis sodalis* (E)
Littlewing pearlymussel	*Pegias fabula* (E)
Blackside dace	*Phoxinus cumberlandensis* (T)

Oyster mussel	*Epioblasma capsaeformis* (E)
Paleozone shiner	*Notropis* sp. (E)
Red-cockaded woodpecker	*Picoides borealis* (E)

In addition to the federally-listed endangered or threatened species listed above, at least eight plant, four mussel, three mammal, two fish, and one reptile species are considered to be primary species of concern in McCreary County. These include the following 21 species:

Barbara's buttons	*Marshallia grandiflora*
Cliff-green	*Paxistima canbyi*
False foxglove	*Aureolaia patula*
Kentucky's ladyslipper	*Cypripedium kentuckiense*
Lucy Braun's white snakeroot	*Eupatorium luciae-brauniae*
Mountain heartleaf	*Hexastylis contracta*
Rockcastle aster	*Aster saxicastellii*
White fringeless orchid	*Platanthera integrilabia*
Purple lilliput mussel	*Toxolasma lividus*
Rabbitsfoot mussel	*Quadrula cylindrica cylindrica*
Snuffbox mussel	*Epioblasma triquetra*
Tennessee clubshell	*Pleurobema oviforme*
Armored rocksnail	*Lithasia armigera*
Ornate rocksnail	*Lithasia geniculata*
Allegheny (Eastern) woodrat	*Neotoma magister*
Eastern small-footed bat	*Myotis leibii*
Rafinesque's big-eared bat	*Plecotus rafinesque*
Cumberland Johnny darter	*Etheostoma nigrum susanae*
Olive darter	*Percina squamata*
Lake sturgeon	*Acipenser fluvescens*
Northern pine snake	*Pituophis melanoleucus melanoleucus*

While these species do not presently have federal status, they are listed for consideration in future resource management plans for the Bear Creek watershed and the Big South Fork National River and Recreation Area.

In addition to species which are of federal concern, 21 species with records in Scott County have been listed as endangered (4), threatened (10), or given some other special concern status (9) by the State of Tennessee. These include the following:

Endangered

Sweet-fern	*Comptonia peregrine*
American water-pennywort	*Hydrocotyle americana*
Wood lilly	*Lilium philadelphicum*
Large-flowered Barbara's button	*Marshallia grandiflora*

Threatened

Round-leaf watercress	*Cardamine rotundiflora*
Green and gold	*Chryusogonum virginianum*
Spotted coralroot	*Corallorhiza maculata*
Mountain witch-alder	*Fothergilla major*
Goldenseal	*Hydrastis canadensis*
Canada lily	*Lilium canadense*
American ginseng	*Panax quinquefolium*
Tennessee pondweed	*Potamogeton tennesseensis*
Roundleaf fameflower	*Talinum teretifolium*
Bristle-fern	*Trichomanes boschianum*

Species of Concern

Virginia heartleaf	*Hexastylis virginica*

Deemed in Need of Management

Cooper's hawk	*Accipiter cooperii*
Swainson's warbler	*Limnothlypis swainsonii*
Eastern woodrat	*Neotoma floridana*
Eastern slender glass lizard	*Ophisaurus attenduatus longicaudus*
Black mountain dusky salamander	*Desmognathus welteri*
Ashy darter	*Etheostoma cinerum*
Arrow darter	*Etheostoma sagitta*
Tippecanoe darter	*Etheostoma tippecanoe*

While Federally listed fish and mussel species are not presently known to occur in Bear Creek, there are a variety of rare, threatened or endangered species which could benefit from improved water quality in Bear Creek. Other species, such as the red-cockaded woodpecker or the Cumberland sandwort, while not typically considered to be riparian species, could be impacted by increased recreational use or development of the watershed. In future watershed management decisions, full consideration should be given to minimizing impacts to the species listed or presented or listed/discussed above.

Wetlands

Approximately 57 acres of wetlands exist in the Bear Creek watershed (Figure 2). Although a detailed survey of wetlands in the Bear Creek watershed has not been performed, the majority of the wetlands observed during our field reconnaissance activities had resulted from standard mine land drainage control and reclamation techniques; road construction with inadequately sized drainage culverts; or were specifically constructed to treat acid mine drainage (AMD). Palustrine wetland systems were the predominant type observed in the Bear Creek watershed. Palustrine systems include all non-tidal wetlands dominated by trees, shrubs, persistent emergents, and emergent mosses or lichens. They also include: 1) wetlands lacking this type of vegetation; 2) areas less than 20 acres with active wave-formed or bedrock shorelines with a water depth in the deepest part of the basin less than 2 meters, and 3) small, shallow, permanent or intermittent water bodies (ponds). Riverine wetland systems are also present in the Bear Creek watershed. They include all wetlands and deepwater habitats contained within a well-defined channel except those dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. Hydrologically, these riverine systems are further defined by water permanence, gradient, water velocity, substrate, and the extent of floodplain development. Additional classes (substrate type), sub-classes, and vegetative dominance descriptions are utilized to further characterize the palustrine and riverine systems. These wetland areas were mapped in the mid- to late-1980's through the National Wetlands Inventory system and are classified by the Cowardin system (Cowardin et al. 1979) as follows:

PFO1A	Palustrine, Forested, Broad-leaved Deciduous, Temporarily Flooded
PFO1C	Palustrine, Forested, Broad-leaved Deciduous, Seasonally Flooded
PFO4A	Palustrine, Forested, Needle-leaved Evergreen, Temporarily Flooded
POWHh	Palustrine, Open Water, Permanently Flooded, Diked/Impounded
POWHx	Palustrine, Open Water, Permanently Flooded, Excavated
PUSCh	Palustrine, Unconsolidated Shore, Seasonally Flooded, Diked/Impounded
PEM1Ah	Palustrine, Emergent, Persistent, Temporarily Flooded, Diked/Impounded
PEM1C	Palustrine, Emergent, Persistent, Seasonally Flooded
R4SBF	Riverine, Intermittent, Streambed, Semi-permanently Flooded
R3OWH	Riverine, Upper Perennial, Open Water, Permanently Flooded

Previous Investigations

The Tennessee Department of Health (TDH) conducted aquatic biological surveys in the region during 1990-1992 and 1994-1995 in conjunction with on-going abandoned mine land (AML) reclamation projects (Stucki 1995). Their survey stations coincided with our CH3W, SU2, and EB4 sites in the East Branch of Bear Creek, and BC2 in the mainstem of Bear Creek. In addition, TDH had a watershed reference station, LF4, in Line Fork, and an ecoregion reference station, LS2, in Laurel Fork of Station Camp Creek. Laurel Fork has habitat characteristics similar to the mainstem of Bear Creek. Line Fork is comparable in habitat characteristics to the East Branch of Bear Creek.

The TDH surveys identified significant impacts to the aquatic biological communities in the Bear Creek watershed as a result of AMD, sedimentation, and metal precipitates. Quantitative and qualitative metrics revealed elevated densities of pollution-tolerant species associated with low taxa richness (12-27) at sites CH3, SU2, EB4, and BC3 compared with the reference station, LF4 (62) (Stucki 1995). Organisms such as *Chironomus* sp., *Hydrobaenus* sp., *Polypedilum* sp., *Pseudorthocladius* sp., and acid-tolerant Megalopterans were predominant in the East Branch AML areas, indicating a stressed aquatic community. Only one fish species, the creek chub (*Semotilus atromaculatus*), was collected at site EB4 and declines in individuals collected were observed over the course of the study.

The watershed reference station in Line Fork contained most orders of aquatic insects. Of these taxa, 36.7% were comprised of Ephemeroptera, Plecoptera, and Trichoptera species (Stucki 1995), indicating a relatively unimpacted stream with a high taxa richness of pollution intolerant macroinvertebrate organisms. The creek chub was common in Line Fork. The ecoregion reference stream, Laurel Fork of Station Camp Creek, had a similar macroinvertebrate community structure (average taxa richness of 94) and also contained a diverse fish community comprised of centrarchids, cyprinids, and percids. On a comparative basis, Bear Creek should exhibit similar characteristics as Laurel Fork based on available habitat, however, no fish species and very few representatives of the Ephemeroptera, Plecoptera, and Trichoptera groups were collected at site BC3.

The Kentucky Division of Water (KDOW) routinely collects water quality data from a series of reference reach and ambient monitoring stations throughout the State. One station, Rock Creek, is within the Big South Fork Cumberland River watershed and possesses good water quality before being impacted from AMD originating in the White Oak Creek watershed. Water quality in Rock Creek, above the confluence of White Oak Creek, is characteristic of unimpacted streams in the Upper Cumberland basin and could serve as a reference comparison for the Bear Creek watershed. Water quality data collected in October 1994 had DO, pH, conductivity, and sulfate values of 9.8 mg/l, 6.9 S.U., 55 μmhos/cm, and 4.34 mg/l, respectively. Analyses for select metals (Al, As, Cd, Cr, Co, Cu, Pb, Hg, and Zn) were less than their analytical detection limits of 0.056, 0.002, 0.001, 0.001, 0.002, 0.002, 0.002, 0.0001, and 0.002 mg/l, respectively. Barium (0.018 mg/l), Fe (0.233 mg/l), Mn (0.008 mg/l), and Zn (0.004 mg/l) were detected in the water samples (Lajuanda Maybriar, KDOW, personal communication).

The Tennessee Department of Environment and Conservation and the Kentucky Department for Environmental Protection identified Bear Creek as not supporting the designated uses of fish and aquatic life (Denton et al. 1994), warm water aquatic habitat (aquatic life), and primary/ secondary contact recreation, such as swimming (KNREPC 1996). In Tennessee and Kentucky, 19.6 and 3.2 miles, respectively, did not support these uses. These determinations were based on water quality and biological monitoring data collected during 1982-1996 by State and Federal agencies. Metals, pH, and siltation were of primary concern. Water quality standards in both states were exceeded for pH and certain metals.

Table 1. Fish Species of the Big South Fork Cumberland River (Rickard et al. 1986).

Common Name	Scientific Name
Allegheny brook lamprey	*Ichthyomyzon greeleyi*
Arrow darter	*Etheostoma sagitta*
Ashy darter	*Etheostoma cinereum*
Barcheek darter	*Etheostoma obeyense*
Bigeye chub	*Hybopsis amblops*
Black redhorse	*Moxostoma duquesnii*
Blacknose dace	*Rhinichthys atratulus*
Blackside darter	*Percina maculata*
Bluebreast darter	*Etheostoma camurum*
Bluegill	*Lepomis macrochirus*
Brown trout	*Salmo trutta*
Channel catfish	*Ictalurus punctatus*
Common shiner	*Notropis c. chrysocephalus*
Creek chub	*Semotilus atromaculatus*
Flathead catfish	*Pylodictis olivaris*
Freshwater drum	*Aplodinotus grunniens*
Greenside darter	*Etheostoma blennioides*
Largemouth bass	*Micropterus salmoides*
Logperch	*Percina caprodes*
Longear sunfish	*Lepomis megalotis*
Mimic shiner	*Notropis volucellus*
Northern hog sucker	*Hypentelium nigricans*
Olive darter	*Percina squamata*
Rainbow darter	*Etheostoma caeruleum*

Table 1. Continued.

Common Name	Scientific Name
Rainbow trout	*Salmo gairdneri*
River chub	*Nocomis micropogan*
Rockbass	*Ambloplites rupestris*
Rosefin shiner	*Lythrurus ardens*
Rosyface shiner	*Notropis rubellus*
Sand shiner	*Notropis stramineus*
Sawfin shiner	*Notropis sp.*
Smallmouth bass	*Micropterus dolomieui*
Southern redbelly dace	*Phoxinus erythrogaster*
Speckled darter	*Etheostoma stigmaeum*
Spotfin shiner	*Cyprinella spiloptera*
Spotted bass	*Micropterus punctulatus*
Spotted darter	*Etheostoma maculatum*
Stonecat	*Noturus flavus*
Stoneroller	*Campostoma anomalum*
Telescope shiner	*Notropis telescopus*
Walleye	*Stizostedion vitreum*
Warmouth	*Lepomis gulosus*
White sucker	*Catostomus commersoni*
Whitetail shiner	*Cyprinella galactura*

Table 2. Mussels of the Big South Fork Cumberland River (Bakaletz 1991).

Common Name	Scientific Name
Black sandshell	*Ligumia recta*
Cumberland bean	***Villosa trabalis* (E)***
Cumberland elktoe	***Alasmidonta atropurpurea* (E)**
Cumberland moccasinshell	*Medionidus conradicus*
Cumberlandian combshell	***Epioblasma brevidens* (E)**
Flutedshell	*Lasmigona costata*
Fluted kidneyshell	*Ptychobranchus subtentum*
Kidneyshell	*Ptychobranchus fasciolaris*
Littlewing pearlymussel	***Pegias fabula* (E)**
Painted creekshell	*Villosa taeniata*
Pheasantshell	*Actinonaias pectorosa*
Pimpleback	*Quadrula pustulosa*
Pink heelsplitter	*Potamilus alatus*
Pistolgrip	*Tritogonia verrucosa*
Pocketbook	*Lampsilis ovata*
Rainbow	*Villosa iris*
Round pigtoe	*Pleurobema sintoxia*
Spike	*Elliptio dilatata*
Squawfoot	*Strophitus undulatus*
Tan riffleshell	***Epioblasma florentina walkeri* (E)**
Tennessee clubshell	*Pleurobema oviforme*
Wavyrayed lampmussel	*Lampsilis fasciola*

*denotes species Federally listed as endangered

Figure 1. Bear Creek Watershed and Project Sampling Locations

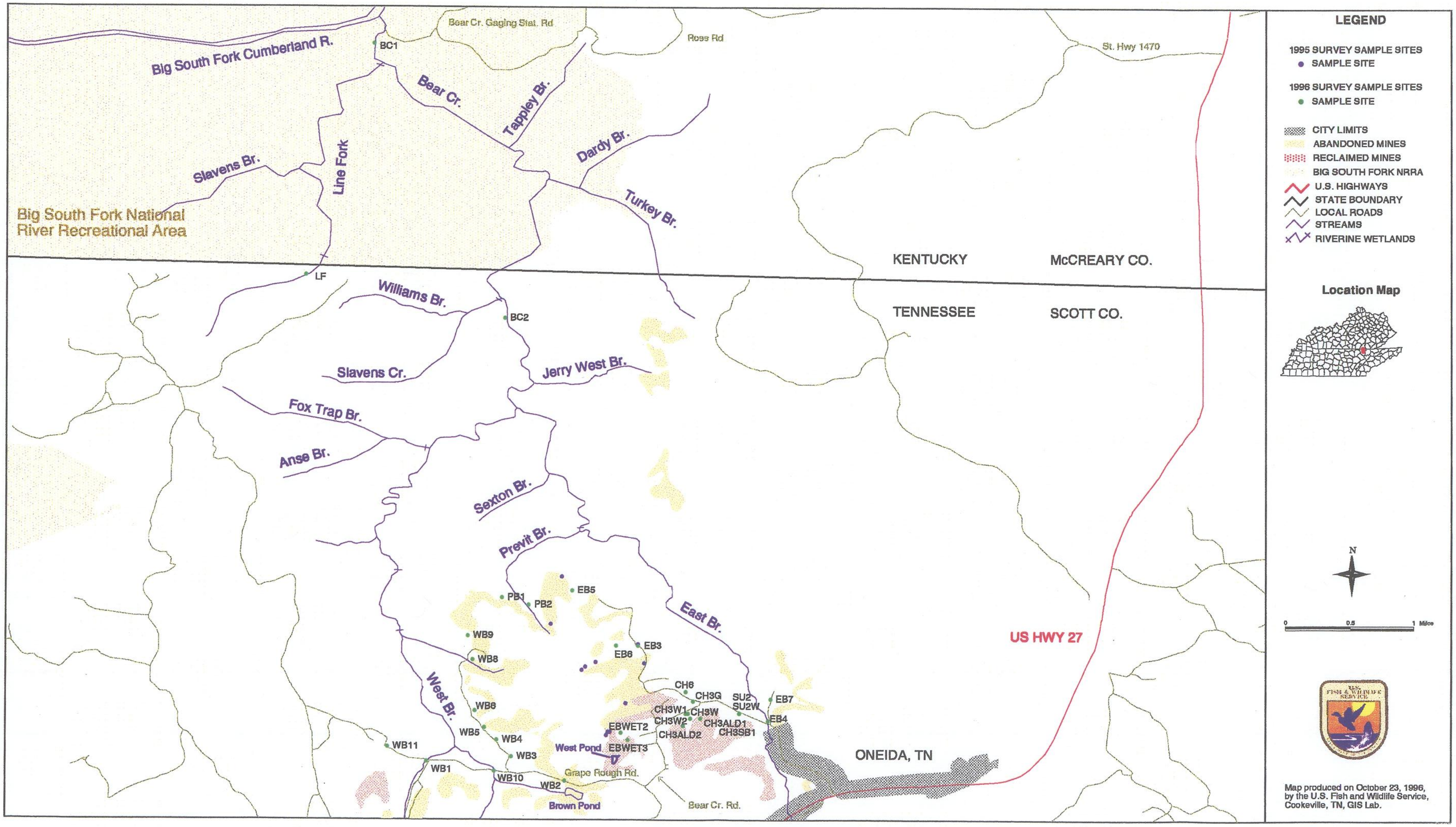
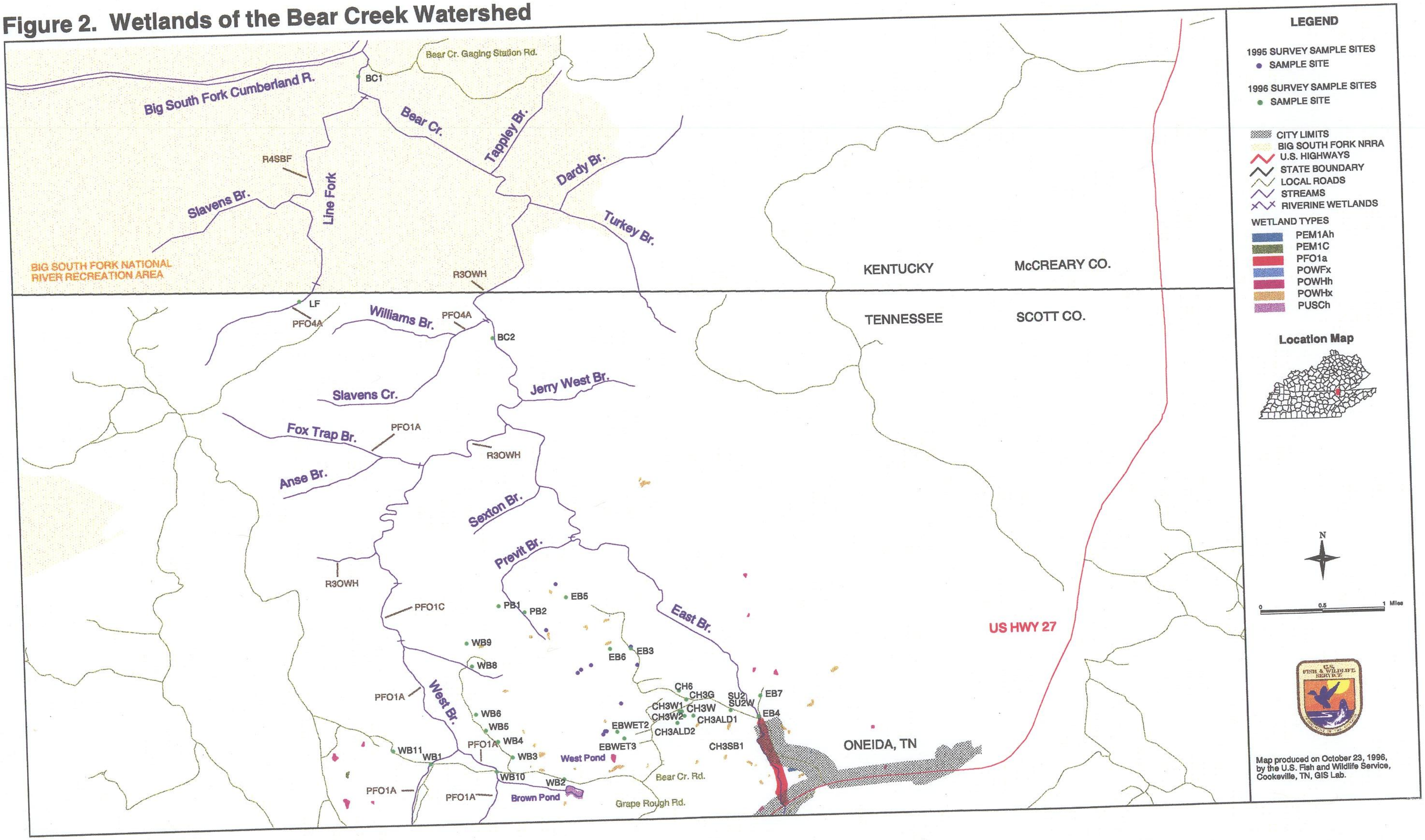


Figure 2. Wetlands of the Bear Creek Watershed



METHODS

Seven locations for semi-permeable membrane device (SPMD) deployment and sediment collection within the Bear Creek watershed were selected for this investigation (Figure 1, Table 3). Sampling locations included: two mainstem sites (BC1 and BC2); one site in the East Branch of Bear Creek (EB4); three tributary sites in the East Branch (CH3G, CH3W, and SU2); and one control site in Line Fork (LF). Sample sites were chosen, in part, to supplement previous investigations of the Bear Creek watershed by the National Park Service (NPS), the Tennessee Department of Environment and Conservation (TDEC), and the Office of Surface Mining (OSM).

Semi-permeable membrane devices were deployed at four locations (BC1, BC2, LF, and SU2) in November 1995. The SPMD's were not retrieved until January 1996 because of a temporary federal government shutdown. An SPMD blank was utilized and exposed to the ambient atmosphere during deployment and retrieval. The membranes were refrigerated and held until shipment to the analytical laboratory (CIA/EST Laboratories, St. Joseph, Missouri). The membrane devices were extracted and the dialysate returned to the Cookeville Field Office. The dialysates were shipped on dry ice to the analytical laboratory (Commonwealth Technology, Inc., Lexington, Kentucky) for analysis.

Duplicate sediment samples were collected from all seven locations during November 1995 and January 1996, using a stainless steel scoop or ladel. Each sample was then transferred to a chemically pre-cleaned glass container and stored on ice for transport to the Cookeville Field Office. All samples were refrigerated and held until shipment to the analytical laboratory (Commonwealth Technology, Inc., Lexington, Kentucky) in January 1996.

Water samples were collected from 29 sites in the East Branch and West Branch of Bear Creek, various underground seeps and surface treatment facilities, and the mainstem of Bear Creek during April and May, 1996 (Figure 1). These samples were preserved with concentrated nitric acid in the field and refrigerated for shipment to the analytical laboratory (Division of Environmental Services, Kentucky Department for Environmental Protection, Frankfort, Kentucky).

The SPMD dialysates were analyzed for 26 organochlorine compounds (Table 4) by gas chromatography. Sediment samples were analyzed for 12 metals by inductively coupled plasma spectroscopy, arsenic (As) and selenium (Se) by graphite furnace, and mercury (Hg) by cold vapor atomic absorption (Table 4). The water samples were analyzed for total and dissolved metal constituents (aluminum (Al), As, barium (Ba), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), Hg, nickel (Ni), and lead (Pb)) and 7 other parameters (acidity, alkalinity, conductivity, nitrates, pH, sulfate, and total suspended solids). Sample extraction and analytical methods adhered to EPA protocols (USEPA-600, Rev. 1983; USEPA SW846, 3rd ed; APHA 1992). Locational data for each individual sample site was obtained through the use of a Rockwell Precision Lightweight Global Positioning System Receiver.

Descriptive summary statistics, data transformations and statistical analyses were done following techniques described in Snedecor and Cochran (1980) and Steel and Torrie (1960). Univariate parametric and nonparametric inferential statistical test methods included: T-tests, F-tests, analysis of variance, analysis of covariance, regression analysis, least significant differences (LSD) intervals, Tukey honestly significant differences (HSD) intervals, Duncan, Kruskal-Wallis, Scheffe intervals, and Bonferroni intervals. Statgraphics for Windows was used to calculate summary statistics, perform logarithmic transformations and run various statistical analyses. Analytical results reported as below detection levels were set equal to the detection level for calculation purposes only.

Habitat evaluations based on the Rapid Bioassessment Protocols developed by USEPA (1989) were performed at each sample site. The following parameters were included: instream cover, epifaunal substrate, embeddedness, channel alteration, sediment deposition, frequency of riffles, channel flow, bank vegetative protection, bank stability and riparian vegetative zone width.

Quality Assurance/Quality Control

Analytical quality control procedures utilized by the contract laboratories were certified by the U.S. Environmental Protection Agency. Duplicate and spike analyses, as well as standard reference material checks, were performed. Quality assurance/quality control analyses results are included in Appendices III-IX. Analytical accuracy, as measured by spiked sample recoveries and reference material analysis, was generally acceptable. Results of calibration check samples and method blank samples indicated acceptable performance of the analytical instruments.

Table 3. Sediment and SPMD Sampling Sites for the Bear Creek Project.

Site	Latitude Longitude	County, State	Location
LF	36°35'49" 84°32'30"	Scott, TN McCreary, KY	Line Fork Creek at Stateline
CH3W	36°32'46" 84°29'52"	Scott, TN	Constructed Wetland off Bear Creek Road
SU2	36°32'46" 84°29'31"	Scott, TN	Constructed Wetland off Bear Creek Road
CH3G	36°32'51" 84°29'50"	Scott, TN	Unnamed Tributary to East Branch Bear Creek at USGS Gauging Station
EB4	36°32'43" 84°29'19"	Scott, TN	50 m Downstream of USGS Gauging Station on East Branch Bear Creek
BC2	36°35'31" 84°31'08"	Scott, TN	Mainstem Bear Creek Downstream of the Confluence of the East Branch and West Branch
BC1	36°37'26" 84°32'02"	McCreary, KY	Mainstem Bear Creek Approximately 100 m Upstream of the Confluence with the Big South Fork of the Cumberland River

Table 4. Contaminants and Water Quality Parameters Analyzed for the Bear Creek Project.

SPMD	Sediment	Water
4-4'-DDD	Silver (Ag)	Aluminum (Al)
4-4'-DDE	Aluminum (Al)	Arsenic (As)
4-4'-DDT	Arsenic (As)	Barium (Ba)
Aldrin	Barium (Ba)	Cadmium (Cd)
Alpha-BHC	Beryllium (Be)	Cobalt (Co)
Aroclor-1016	Cadmium (Cd)	Chromium (Cr)
Aroclor-1221	Cobalt (Co)	Copper (Cu)
Aroclor-1232	Chromium (Cr)	Iron (Fe)
Aroclor-1242	Copper (Cu)	Mercury (Hg)
Aroclor-1248	Iron (Fe)	Manganese (Mn)
Aroclor-1254	Mercury (Hg)	Nickel (Ni)
Aroclor-1260	Manganese (Mn)	Lead (Pb)
Beta-BHC	Lead (Pb)	Acidity
Chlordane	Selenium (Se)	Alkalinity
Delta-BHC	Zinc (Zn)	Conductivity
Dieldrin		Nitrates
Endosulfan I		pH
Endosulfan II		Sulfate
Endrin		Total Suspended Solids
Endrin Aldehyde		
Gamma-BHC		
Heptachlor		
Heptachlor Epoxide		
Methoxychlor		
Toxaphene		

RESULTS

Chemical Analyses

Fifteen metals in sediment and 26 organochlorine compounds in SPMD dialysates were analyzed (Table 4). Sediment was analyzed at five locations along Bear Creek, Bear Creek tributaries, and Line Fork. Sediment from two constructed wetlands (SU2 and CH3W) was also analyzed. SPMD dialysates were analyzed from two locations in Bear Creek, Line Fork, and one constructed wetland (SU2). Prior to discharging into the constructed wetland areas, the AMD receives primary treatment from anoxic limestone drains.

Individual and average values for Al and Cr in sediment were greatest at the constructed wetland location SU2 followed by sites CH3G and CH3W. The only detected value for Hg was found at Site SU2.

Site CH3G had the greatest individual and average sediment concentrations of As, Ba, Cu, and Pb. This site also had the maximum values for Co and Zn, and the highest average Fe concentration (Table 5). Average values for Co and Zn were greatest at Site EB4 located on the East Branch of Bear Creek. The maximum Fe concentration was observed at the Line Fork (LF) site, which also had the only detected value for Be. Maximum individual and average concentrations for Mn and Se were observed at Site EB4.

Silver and Cd were not detected in sediment at any of the sites sampled. Likewise, no target organochlorine analytes were detected in any of the SPMD dialysates. Detection limits for the organochlorine analytes are included in Table 6. Average sediment concentrations for seven (64%) of the 11 metals detected at all sites were noticeably higher in the tributary sites when compared to the mainstem of Bear Creek and Line Fork (Table 7). Site EB4 was included in the mainstem data set. Variability in the metals values was generally greater in the tributary samples (Figures 3, 4, and 5). Statistical analysis (least significant differences) of log-transformed wet-weight results indicated significant differences ($p < 0.05$, 13 df) between the mainstem and the tributary sites for Al, As, Ba, Cu, and Pb (Figures 6, 7, 8, 9, and 10). This analysis also indicated significant differences ($p < 0.05$, 13df) between the control and tributary sites for Al, Cu, and Se (Figure 11). Regression analysis indicated all metals except Co and Mn correlated significantly ($p < 0.05$, 13 df) with Al. Likewise, all metals except Ba, Co, and Mn correlated significantly ($p < 0.05$, 13df) with Fe. Wet weight results were also converted to dry weight concentrations (Table 5) for comparison to existing sediment quality criteria.

Water analyses for total and dissolved constituents (Table 8) indicated severe water quality degradation at most sample sites. Values for pH ranged from 3.2 to 7.0. Two recently constructed wetlands in the East Branch, EB Wet2 and EB Wet3, had pH values of 6.5 and 7.0, respectively. Values for pH in the mainstem sites were 5.8 at EB4, and duplicate samples at BC1 had values of 5.0 and 5.3. Maximum sulfate (1,140 mg/l), conductivity (1,770 μmhos/cm) and acidity (210 mg/l) measurements were recorded at Site SU2W, a constructed wetland in the East Branch. Although the lowest laboratory conductivity (24.2 μmhos/cm) was noted for an anoxic limestone drain in the East Branch (CH3-ALD1), the field conductivity measured at this site was 696 μmhos/cm. Sulfate and acidity values were lowest at Site EB7 (25.2 mg/l) and WB10 (2.6 mg/l), respectively. Natural alkalinity from carbonate or bicarbonate sources was not present in most samples and detectable concentrations were generally associated with effluents from anoxic limestone drains or limestone-lined wetland cells. Concentrations for nitrates and total suspended solids are also included in Table 8.

Of the 12 metals (total constituents) analyzed in water samples, 50% were detected at every site. Dissolved metal concentrations approximated total recoverable concentrations and were generally higher at constructed wetland sites, naturally developing wetland areas, and underground seeps. Typically, lower concentrations were observed at tributary and mainstem sites downstream of the constructed BMP's in the watershed.

Maximum concentrations (mg/l) for Al (62.3), Co (0.651), Mn (45.4), and Ni (0.947) were detected at Site WB4, which was located on a small tributary to the West Branch with a developing wetland complex. Site WB4 also had low concentrations of dissolved As (0.002 mg/l) and Cd (0.001 mg/l). Site WB5, a surface drainage receiving effluent from a possible deep mine site, had the greatest concentrations of Cr (0.014 mg/l), Cu (0.037 mg/l), and Fe (46.4 mg/l). Mercury (0.003 mg/l) was also detected at this site and at low concentrations (0.002 mg/l dissolved, 0.0004 mg/l total) at the mouth of Bear Creek (BC1).

Concentrations of Pb ranged from <0.002 to 0.004 mg/l at site EB3. Lead was also detected at sites SU2W, EB5, EB Wet2, WB5, and Prewit Branch 1 and 2. Dissolved Pb was detected at site CH3 W2 (0.002 mg/l).

The sites were divided into four groups (tributaries, mainstem, East Branch, and West Branch) and summary statistics calculated using dissolved constituent results. Results from Previt Branch were included in the East Branch grouping. Geometric mean concentrations for Al, Ba, and Cr (3.76, 0.032, and 0.002 mg/l, respectively) were higher in the West Branch sites. Geometric mean concentrations for Co, Cu, Fe, Mn, and Ni (0.092, 0.005, 2.09, 8.69, and 0.166 mg/l, respectively) were higher in the East Branch sites. One-way analysis of variance ($p>0.05$, 26df) did not indicate significant differences between the East Branch and West Branch or the tributaries and mainstem.

Habitat Assessments

Instream cover (i.e., snags, submerged logs, undercut streambanks) exhibited slight variability and was considered to be optimal, with greater than a 50% mix of stable habitat present, at all sites except CH3W, SU2, and CH3G. These three sites had a 30-50% mix of stable habitat and were considered to be sub-optimal. Epifaunal substrate (defined as well-developed riffles with a length extending two times the width of the stream and as wide as the stream with an abundance of cobble) was prevalent and considered to be optimal at all sites except CH3W, SU2, and CH3G. Embeddedness was fairly constant and averaged 25-50% coarse material (gravel, cobble and boulders) surrounded by fine sediment. Embeddedness was considered sub-optimal at all sample sites due to extensive sedimentation.

Dredging, channelization, or other channel alterations were essentially absent in the East and West Branches and in the mainstem. Significant alterations were observed in tributary sites and were primarily the result of road construction and best management practice (BMP) installation. There was evidence indicating recent deposition of course and fine materials near islands and point bars in the mainstem of Bear Creek. The patterns which were observed are subject to periodic change based on the dynamics of the fine and coarse particles in the stream bed, the frequency of high flow events, the occurrence of natural stream obstructions, and the construction of new BMP's in the watershed. Significant sedimentation from erosion due to poor forestry practices was also observed. Additional erosion was observed in areas of recent residential development, road construction, and landfill construction in tributaries and the Bear Creek headwaters.

Significant distances between riffle/run complexes at the tributary sites were observed. At sites where the stream gradient declined, pool areas were more prevalent. Riffle/run complexes were considered optimal at the two mainstem sites, BC1 and BC2. Channel flow was also considered to be optimal at BC1, BC2, EB4, CH3G, and LF where water reached both banks and a minimal amount of channel substrate was exposed. Minimal areas of bank scour and failure were observed at all sites. The average width of the riparian zones was estimated to be greater than 18 meters with a predominance of native vegetation covering more than 90% of the streambank surfaces.

Table 5. Metals detected in Bear Creek and tributary sediment samples (mg/kg, wet weight).

	Sites													
Metal	LF1	LF2	CH3W1	CH3W2	SU2-1	SU2-2	CH3G1	CH3G2	EB4-1	EB4-2	BC2-1	BC2-2	BC1-1	BC1-2
Ag	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Al	2400	1800	4900	7700	9500	6000	6400	6200	4100	4400	2300	1100	1500	2500
As	10.0	4.4	5.3	6.8	8.6	9.7	14.0	15.0	5.0	5.0	7.7	2.5	4.6	6.4
Ba	16.0	40.0	27.0	30.0	42.0	34.0	28.0	52.0	19.0	25.0	11.0	4.3	5.0	12.0
Be	0.8	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.7	<0.5	<0.5	<0.5	<0.5
Cd	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cr	12.0	1.6	8.0	11.0	14.0	9.0	9.0	13.0	5.0	8.0	10.0	1.8	5.0	4.0
Co	7.0	2.9	5.1	9.1	4.9	4.2	2.4	12.0	10.0	11.0	3.2	2.0	3.4	5.4
Cu	4.0	1.7	11.0	9.0	13.0	11.0	11.0	14.0	7.0	8.0	5.0	1.6	3.0	5.0
Fe	24000	5300	10000	17000	17000	13000	21000	23000	9700	12000	14000	4800	8500	10000
Hg	ND	ND	ND	ND	0.110	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mn	100	230	130	110	88	150	59	140	370	390	67	27	49	180
Pb	4.50	5.60	9.00	8.00	8.00	12.00	10.00	18.00	5.60	7.10	2.50	0.87	1.10	2.10
Se	2.7	1.2	3.5	4.0	3.0	4.6	4.4	4.3	5.0	5.0	2.4	1.2	2.7	2.6
Zn	26.0	9.7	18.0	26.0	21.0	15.0	13.0	46.0	33.0	43.0	13.0	9.2	12.0	14.0

Table 5. Continued (mg/kg, dry weight).

	Sites													
Metal	LF1	LF2	CH3W1	CH3W2	SU2-1	SU2-2	CH3G1	CH3G2	EB4-1	EB4-2	BC2-1	BC2-2	BC1-1	BC1-2
Ag	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Al	3429	2571	7000	11000	13571	8571	9143	8857	5857	6286	3286	1571	2143	3571
As	14.3	6.3	7.6	9.7	12.3	13.9	20.0	21.4	7.1	7.1	11.0	3.6	6.6	9.1
Ba	22.9	57.1	38.6	42.9	60.0	48.6	40.0	74.3	27.1	35.7	15.7	6.1	7.1	17.1
Be	1.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.7	<0.5	<0.5	<0.5	<0.5
Cd	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cr	17.1	2.3	11.4	15.7	20.0	12.9	12.9	18.6	7.1	11.4	14.3	2.6	7.1	5.7
Co	10.0	4.1	7.3	13.0	7.0	6.0	3.4	17.1	14.3	15.7	4.6	2.9	4.9	7.7
Cu	5.7	2.4	15.7	12.9	18.6	15.7	15.7	20.0	10.0	11.4	7.1	2.3	4.3	7.1
Fe	34286	7571	14286	24286	24286	18571	30000	32857	13857	17143	20000	6857	12143	14286
Hg	ND	ND	ND	ND	0.157	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mn	143	329	186	157	126	214	84	200	529	557	96	39	70	257
Pb	6.43	8.00	12.86	11.43	11.43	17.14	14.29	25.71	8.00	10.14	3.57	1.24	1.57	3.00
Se	3.9	1.7	5.0	5.7	4.3	6.6	6.3	6.1	7.1	7.1	3.4	1.7	3.9	3.7
Zn	37.1	13.9	25.7	37.1	30.0	21.4	18.6	65.7	47.1	61.4	18.6	13.1	17.1	20.0

*Bear Creek and Line Fork metals based on a 30% moisture value dw=ww/[(100-(% moisture/100)]

Table 6. SPMD Dialysate Analyte Detection Limits (μg/ml).

Compound	Detection Limit
4-4'-DDD	0.050
4-4'-DDE	0.050
4-4'-DDT	0.050
Aldrin	0.050
Alpha-BHC	0.050
Aroclor-1016	0.100
Aroclor-1221	0.100
Aroclor-1232	0.100
Aroclor-1242	0.100
Aroclor-1248	0.100
Aroclor-1254	0.100
Aroclor-1260	0.100
Beta-BHC	0.050
Chlordane	0.100
Delta-BHC	0.050
Dieldrin	0.050
Endosulfan I	0.050
Endosulfan II	0.050
Endosulfan Sulfate	0.050
Endrin	0.050
Endrin Aldehyde	0.050
Gamma-BHC	0.050
Heptachlor	0.050
Heptachlor Epoxide	0.050
Methoxychlor	0.050
Toxaphene	0.100

Table 7. Comparison of metals results (mg/kg, wet weight) for sediment samples from tributary and mainstem Bear Creek sites.

	Tributary Sites			Mainstem Sites		
Metals	Average	Standard Deviation	**Geometric Mean**	Average	Standard Deviation	**Geometric Mean**
Al	6783.33	1604.27	6635.22	2650.00	1344.25	2356.30
As	9.90	3.88	9.26	5.20	1.76	4.92
Ba	35.50	9.75	34.49	12.72	8.05	10.51
Co	6.28	3.56	5.49	5.83	3.79	4.84
Cr	10.67	2.42	10.44	5.63	2.93	4.93
Cu	11.50	1.76	11.39	4.93	2.39	4.34
Fe	16833.30	4833.91	16210.60	9833.33	3137.30	9342.37
Mn	112.83	34.46	107.68	180.50	163.42	114.91
Pb	10.83	3.82	10.37	3.21	2.55	2.42
Se	3.97	0.61	3.92	3.15	1.53	2.82
Zn	23.17	12.09	21.10	20.70	13.86	17.48

Table 8. Bear Creek Water Analyses: Total Constituents (mg/l).

Site	Latitude Longitude	Elev. (MSL)	pH	SO_4	Acid.	Alk.	Cond. (μmho/cm)	NO_3	TSS
SU2 W	36°32'46" 84°29'31"	1367	**3.3**[*]	**1140**[**]	210	ND	1770	ND[P]	ND
CH3 ALD1	36°32'44" 84°29'47"	1384	**6.3**[1]	**431**[**]	62.7	85.8	24.2	ND[P]	24
CH3 ALD2	36°32'41" 84°29'54"	1451	**6.2**[1]	**577**[**]	30.4	45.5	840	.032[T]	14
CH3 SB1	36°32'44" 84°29'47"	1428	**3.7**[*]	**695**[**]	88	ND	1700	ND[T]	19
CH3 W1	36°32'46" 84°29'53"	1375	**3.7**[*]	**579**[**]	47.7	ND	1430	ND[T]	2
CH3 W2	36°32'44" 84°29'51"	1387	**4.6**[*]	**584**[**]	78.9	ND	1000	.032[T]	17
CH6	36°32'55" 84°29'53"	1392	**3.6**[*]	**392**[**]	79.6	ND	715	.204[P]	2
CH3G	36°32'51" 84°29'50"	1340	**4.6**[*]	**393**[**]	26.8	ND	593	.230[P]	1
EB3	36°33'14" 84°30'13"	1399	**3.2**[*]	**384**[**]	135	ND	809	.023[T]	60
EB4	36°32'43" 84°29'19"	1358	**5.8**[*]	**292**[**]	6.9	2.7	199	.076[T]	8
EB5	36°33'37" 84°30'40"	1472	**3.2**[*]	**308**[**]	130	ND	1390	ND[T]	ND
EB6	36°33'14" 84°30'22"	1415	**4.6**[*]	52.5	6.3	ND	111	.080[T]	ND
EB7	36°32'52" 84°29'18"	1377	**5.1**[*]	25.2	4.4	ND	75.8	.038[T]	8
EB Wet2	36°32'38" 84°30'20"	1439	6.5	**251**[**]	42.1	48.7	551	.042[T]	22
EB Wet3	36°32'35" 84°30'17"	1448	7.0	**299**[**]	24.9	69.7	541	.084[T]	16

Table 8. Continued.

Site	Latitude Longitude	Elev. (MSL)	pH	SO_4	Acid.	Alk.	Cond. (μmho/cm)	NO_3	TSS
WB1	36°32'26" 84°31'40"	1398	**3.8***	179	37.2	ND	428	.020^T	ND
WB2	36°32'18" 84°30'43"	1457	**3.9***	145	28.3	ND	313	ND^T	2
WB3	36°32'28" 84°31'05"	1437	**4.3***	101	24.2	ND	239	.020^T	ND
WB4	36°32"35" 84°31'11"	1416	**3.6***	---	313	ND	1660	ND^T	2
WB5	36°32'40" 84°31'16"	1488	**3.1***	**743****	302	ND	1490	.022^T	2
WB6	36°32'47" 84°31'20"	1488	**4.1***	75.8	25.8	ND	177	.016^T	ND
WB8	36°33'08" 84°31'21"	1450	**3.5***	**350****	69.2	ND	714	ND^T	ND
WB9	36°33'18" 84°31'23"	1498	**3.8***	94.1	24.2	ND	306	.055^T	6
WB10	36°32'22" 84°31'12"	1399	**6.1**[1]	53.5	2.6	ND	100	.036^T	3
WB11	36°32'32" 84°31'56"	1473	**3.6***	127	45.4	ND	375	.516^T	10
Previt Br. 1	36°33'34" 84°31'09"	1392	**3.9***	185	52.9	ND	455	.052^T	2
Previt Br. 2	36°33'31" 84°30'58"	1400	**4.3***	176	19.5	ND	337	.025^T	ND
BC1 1	36°37'26" 84°32'02"	812	**5.0***	---	5.5	0.1	143	.055^T	2
BC1 2	36°37'26" 84°32'02"	812	**5.3***	53.1	3.1	ND	95.6	.030^T	ND

P = Improper Preservative.
T = Holding Time Exceeded.
* = Tn. and Ky. Water Quality Criteria (Fish and Aquatic Life/Warm Water Aquatic Habitat) for pH Exceeded. Tn. Domestic Water Supply and Ky. Recreational Waters Criteria for pH Exceeded.
** = SMCL and Ky. Water Quality Criteria (Drinking Water) for Sulfate Exceeded.
1 = Tennessee Fish and Aquatic Life Criteria for pH Exceeded.

Table 8. Continued.

Site	Al	As	Ba	Co	Cr	Cu	Fe	Mn	Ni	Pb
SU2 W	**22.0**[3]	ND	.014	.538	.002	**.023**[6]	**24.4**[3,6]	**45.2**[3,4]	**.691**[1,4,6]	**.003**[2,6]
CH3 ALD1	**1.45**[3]	ND	.025	.337	ND	ND	**23.5**[3,6]	**28.9**[3,4]	**.460**[1,6]	ND
CH3 ALD2	**4.16**[3]	ND	.013	.078	.001	**.015**[6]	.253	**5.42**[3,4]	**.285**[1,6]	ND
CH3 SB1	**10.5**[3]	ND	.024	.272	.002	**.007**[6]	**17.1**[3,6]	**23.7**[3,4]	**.563**[1,6]	ND
CH3 W1	**6.12**[3]	ND	.024	.310	ND	.002	**1.33**[3,6]	**26.9**[3,4]	**.352**[1,6]	ND
CH3 W2	**15.9**[3]	ND	.018	.270	ND	**.015**[6]	**2.28**[3,6]	**14.7**[3,4]	**.481**[1,6]	ND
CH6	**10.7**[3]	ND	.028	.166	.001	**.010**[6]	**1.60**[3,6]	**15.7**[3,4]	**.169**[1,6]	ND
CH3G	**3.16**[3]	ND	.026	.123	ND	.003	**1.09**[3,6]	**8.02**[3,4]	**.146**[1,6]	ND
EB3	**12.8**[3]	ND	.031	.098	.005	**.009**[6]	**14.9**[3,6]	**7.74**[3,4]	**.145**[1,6]	**.004**[2,6]
EB4	**1.9**[3]	ND	.021	.041	ND	ND	**.633**[3]	**2.8**[3,4]	.036	ND
EB5	**9.3**[3]	ND	.031	.438	.002	**.007**[6]	**15.2**[3,6]	**32.7**[3,4]	**.802**[1,4,6]	**.003**[2,6]
EB6	**.277**[3]	ND	.046	.004	.002	.005	.147	**.811**[3,4]	.036	ND
EB7	**.295**[3]	ND	.030	.008	.002	.002	**.592**[3]	**1.16**[3,4]	.032	ND
EB Wet2	**2.75**[3]	ND	.038	.061	.002	.002	**6.94**[3,6]	**5.95**[3,4]	**.099**[6]	**.002**[2]
EB Wet3	**2.62**[3]	ND	.042	.052	.001	.002	**2.64**[3,6]	**4.03**[3,4]	**.103**[1,6]	ND

Table 8. Continued.

Site	Al	As	Ba	Co	Cr	Cu	Fe	Mn	Ni	Pb
WB1	**3.98**[3]	ND	.039	.050	.001	.003	**1.53**[3,6]	**8.24**[3,4]	**.175**[1,6]	ND
WB2	**2.5**[3]	ND	.028	.039	ND	**.010**[6]	**.430**[3]	**4.93**[3,4]	**.087**[6]	ND
WB3	**3.04**[3]	ND	.029	.050	ND	.002	**.365**[3]	**3.99**[3,4]	.076	ND
WB4**	**55.9**[3]	ND	.013	.651	.005	**.016**[6]	**1.99**[3,6]	**45.4**[3,4]	**.947**[1,4,6]	ND
WB5*	**24.2**[3]	ND	.018	.288	.014	**.037**[6]	**46.4**[3,6]	**17.3**[3,4]	**.538**[1,6]	**.003**[2,6]
WB6	**2.96**[3]	ND	.049	.060	.001	.002	**1.04**[3,6]	**4.46**[3,4]	.052	ND
WB8	**7.62**[3]	ND	.033	.147	.003	**.007**[6]	**3.7**[3,6]	**13.8**[3,4]	**.216**[1,6]	ND
WB9	**1.92**[3]	ND	.027	.030	.001	.004	**2.83**[3,6]	**3.0**[3,4]	.067	ND
WB10	**.315**[3]	ND	.029	.007	ND	.002	.294	**1.33**[3,4]	.032	ND
WB11	**3.07**[3]	ND	.050	.052	.003	.001	**8.8**[3,6]	**4.89**[3,4]	.078	ND
Previt Br. 1	**6.75**[3]	ND	.029	.091	.002	**.009**[6]	**3.08**[3,6]	**12.1**[3,4]	**.188**[1,6]	**.003**[2,6]
Previt Br. 2	**2.52**[3]	ND	.033	.059	.002	.003	**.409**[3]	**6.1**[3,4]	**.172**[1,6]	**.003**[2,6]
BC1 1*	**.88**[3]	ND	.037	.020	ND	ND	.133	**1.52**[3,4]	.080	ND
BC1 2	**.452**[3]	ND	.034	.022	.001	.002	.140	**1.13**[3,4]	.049	ND

* = Mercury Detected Above .000012 mg/l (Tn. Fish and Aquatic Life and Ky. Warm Water Aquatic Habitat Criteria Exceeded).
** = Cadmium Detected at .001 mg/l.
[1] = Federal MCL Exceeded.
[2] = Federal MCLG Exceeded.
[3] = Federal SMCL Exceeded.
[4] = Kentucky Maximum Allowable In-stream Concentration (Drinking Water) Exceeded.
[5] = Tennessee Fish and Aquatic Life Criteria Exceeded.
[6] = Kentucky Warm Water Aquatic Habitat Criteria Exceeded.
ND = Not Detected.
All Samples Analyzed For Cadmium Except WB4 Were Below Detection Limit.

Table 8. Continued (Dissolved Constituents).

Site	Al	As	Ba	Co	Cr	Cu	Fe	Mn	Ni	Pb
SU2 W	**22.4**[3]	ND	.020	.504	.002	**.022**[5,6]	**24.5**[3,6]	**45.9**[3,4]	**.655**[1,4,5,6]	**.003**[2,5,6]
CH3 ALD1	**.944**[3]	ND	.024	.157	ND	ND	**23.2**[3,6]	**28.9**[3,4]	**.453**[1,5,6]	ND
CH3 ALD2	**.822**[3]	ND	.008	.080	.001	**.007**[5,6]	.171	**4.03**[3,4]	**.249**[1,5,6]	ND
CH3 SB1	**10.2**[3]	ND	.019	.217	ND	**.007**[5,6]	**14.8**[3,6]	**24.5**[3,4]	**.519**[1,5,6]	ND
CH3 W1	**5.58**[3]	ND	.017	.301	ND	.002	**1.15**[3,6]	**24.6**[3,4]	**.340**[1,5,6]	ND
CH3 W2**	**11.1**[3]	ND	.025	.212	.001	**.014**[5,6]	**.842**[3]	**12.5**[3,4]	**.334**[1,5,6]	**.002**[2,5,6]
CH6	**10.6**[3]	ND	.020	.153	.001	**.009**[5,6]	**1.56**[3,6]	**15.6**[3,4]	**.156**[1,5,6]	ND
CH3G	**3.51**[3]	ND	.031	.135	.006	.006	**1.15**[3,6]	**9.82**[3,4]	**.174**[1,5,6]	ND
EB3	**12.9**[3]	ND	.028	.128	.003	**.009**[5,6]	**13.7**[3,6]	**8.06**[3,4]	**.153**[1,5,6]	**.003**[2,5,6]
EB4	**2.17**[3]	ND	.024	.037	.004	.005	**.736**[3]	**3.12**[3,4]	.045	ND
EB5	**9.56**[3]	ND	.034	.469	.004	**.012**[5,6]	**15.3**[3,6]	**33.5**[3,4]	**.855**[1,4,5,6]	**.003**[2,5,6]
EB6	**.234**[3]	ND	.049	.004	.002	.001	.113	**.798**[3,4]	.032	ND
EB7	**.190**[3]	ND	.030	.008	.001	ND	**.447**[3]	**1.17**[3,4]	.030	ND
EB Wet2	**.118**[3]	ND	.039	.061	.001	.003	**6.41**[3,6]	**5.73**[3,4]	.087	ND
EB Wet3	ND	ND	.048	.047	.002	.001	**2.71**[3,6]	**4.40**[3,4]	.083	ND

Table 8. Continued.

Site	Al	As	Ba	Co	Cr	Cu	Fe	Mn	Ni	Pb
WB1	**3.91**[3]	ND	.037	.050	.001	.004	**1.49**[3,6]	**8.13**[3,4]	**.205**[1,5,6]	ND
WB2	**2.53**[3]	ND	.028	.038	ND	.005	**.396**[3]	**4.96**[3,4]	**.089**[5,6]	ND
WB3	**2.92**[3]	ND	.034	.053	ND	.002	**.408**[3]	**3.85**[3,4]	.079	ND
WB4**	**62.3**[3]	.002	.023	.788	.005	**.017**[5,6]	**2.07**[3,6]	**49.2**[3,4]	**.901**[1,4,5,6]	ND
WB5*	**21.0**[3]	ND	.016	.279	.013	**.035**[5,6]	**40.1**[3,6]	**15.2**[3,4]	**.481**[1,5,6]	ND
WB6	**2.88**[3]	ND	.055	.059	.002	.002	**1.02**[3,6]	**4.41**[3,4]	.060	ND
WB8	**7.39**[3]	ND	.035	.110	.002	.006	**3.35**[3,6]	**13.5**[3,4]	**.208**[1,5,6]	ND
WB9	**1.85**[3]	ND	.024	.032	.001	.005	**2.44**[3,6]	**2.94**[3,4]	.076	ND
WB10	**.127**[3]	ND	.031	.010	.002	.002	.100	**1.45**[3,4]	.031	ND
WB11	**2.95**[3]	ND	.052	.060	.002	.004	**6.93**[3,6]	**4.98**[3,4]	.078	ND
Previt Br. 1	**6.77**[3]	ND	.032	.096	.002	**.009**[5,6]	**2.69**[3,6]	**12.6**[3,4]	**.227**[1,5,6]	**.002**[2,5,6]
Previt Br. 2	**2.42**[3]	ND	.033	.064	.002	.004	**.299**[3]	**5.97**[3,4]	.050	**.002**[2,5,6]
BC1 1*	**.990**[3]	ND	.039	.018	.003	.001	.154	**1.72**[3,4]	.032	ND
BC1 2	**.307**[3]	ND	.034	.024	.002	.002	.071	**1.14**[3,4]	.026	ND

* = Mercury Detected Above .000012 mg/l (Tn. Fish and Aquatic Life and Ky. Warm Water Aquatic Habitat Criteria Exceeded).
** = Cadmium Detected at .001 mg/l.
[1] = Federal MCL Exceeded.
[2] = Federal MCLG Exceeded.
[3] = Federal SMCL Exceeded.
[4] = Kentucky Maximum Allowable In-stream Concentration (Drinking Water) Exceeded.
[5] = Tennessee Fish and Aquatic Life Criteria Exceeded.
[6] = Kentucky Warm Water Aquatic Habitat Criteria Exceeded.
ND = Not Detected.

Figure 3. Geometric Mean Metal Concentrations in Bear Creek Sediments

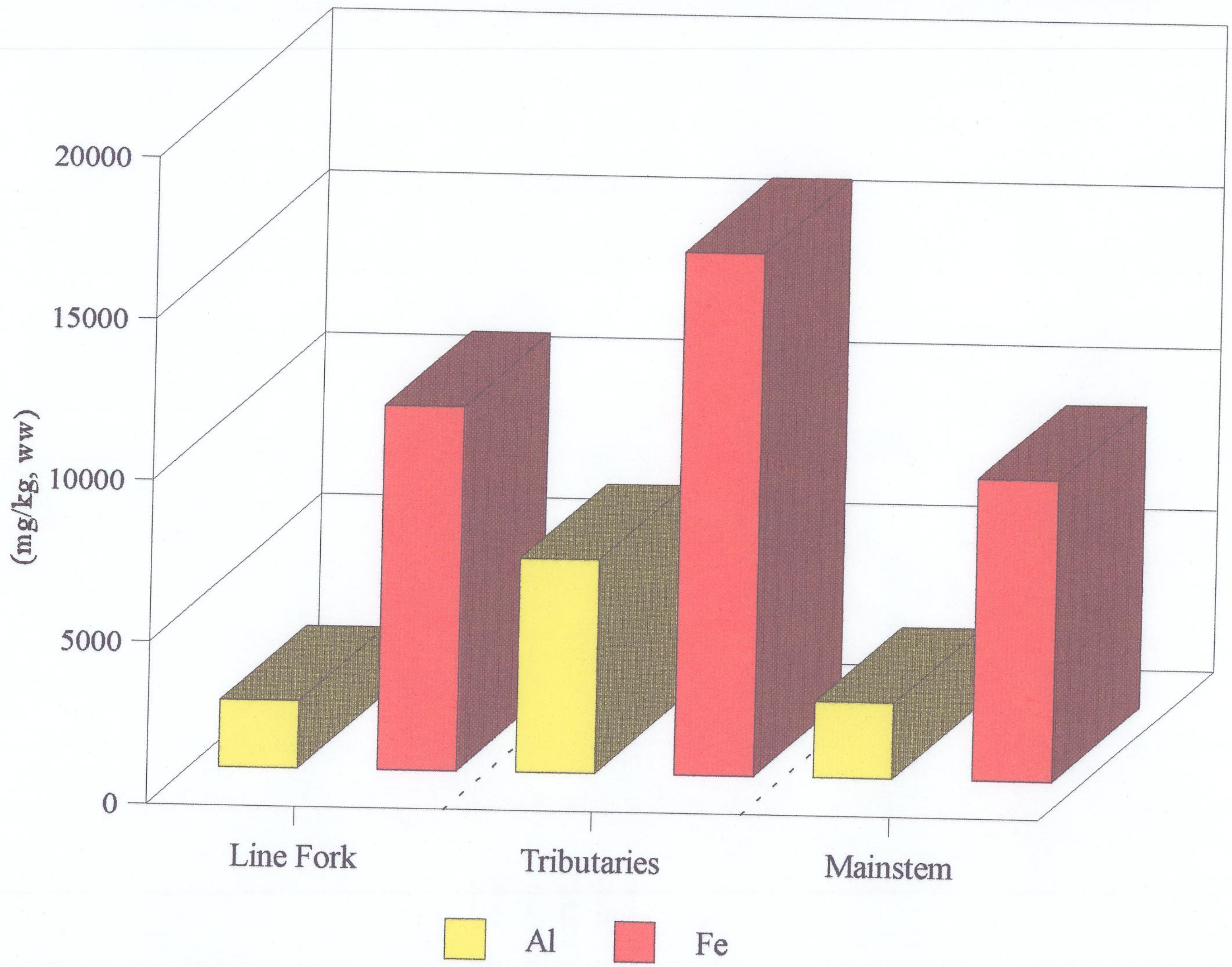


Figure 4. Geometric Mean Metal Concentrations in Bear Creek Sediments

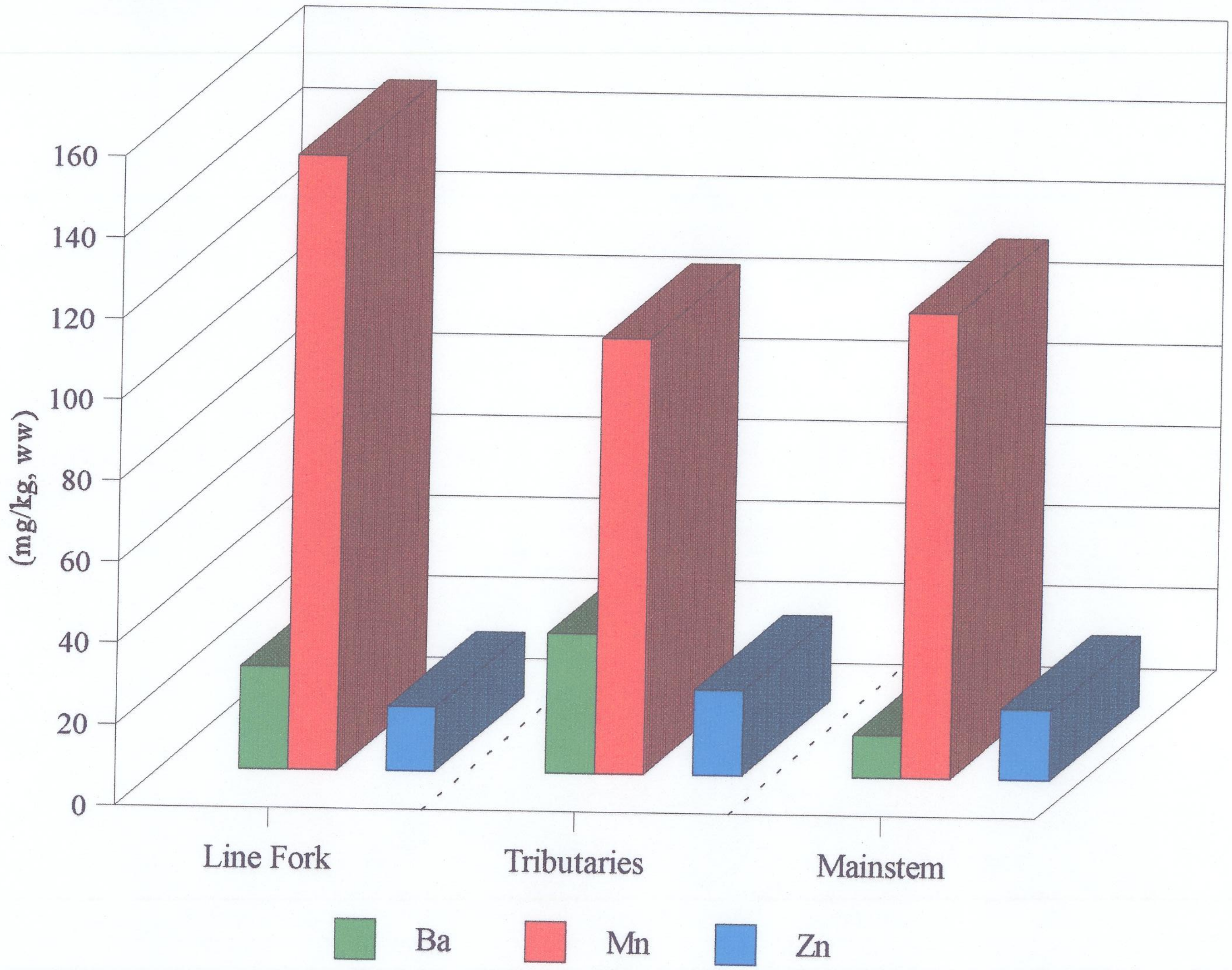


Figure 5. Geometric Mean Metal Concentrations in Bear Creek Sediments

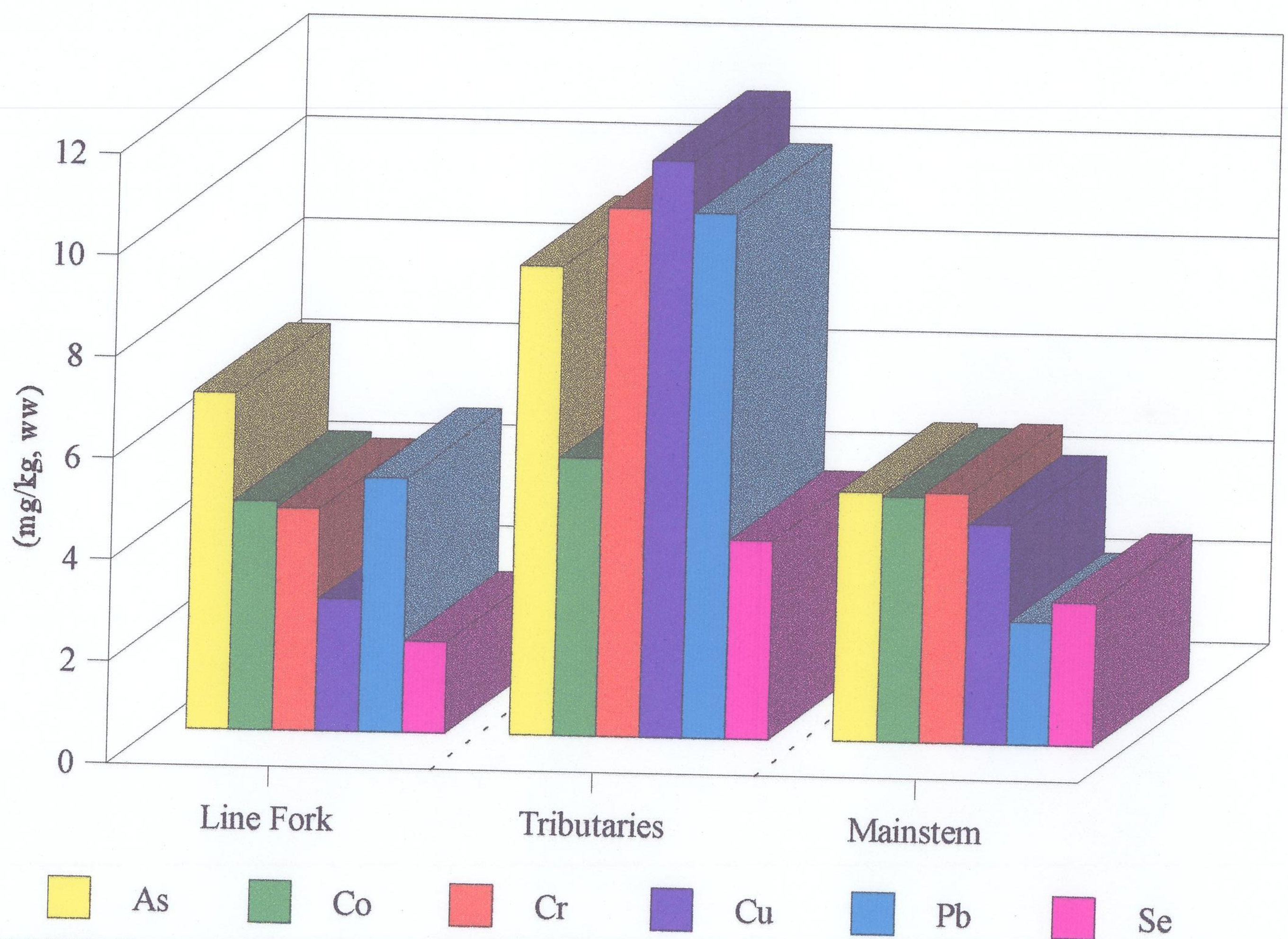


Figure 6. Log of Al Mean Concentrations in Sediment and 95% LSD Intervals.

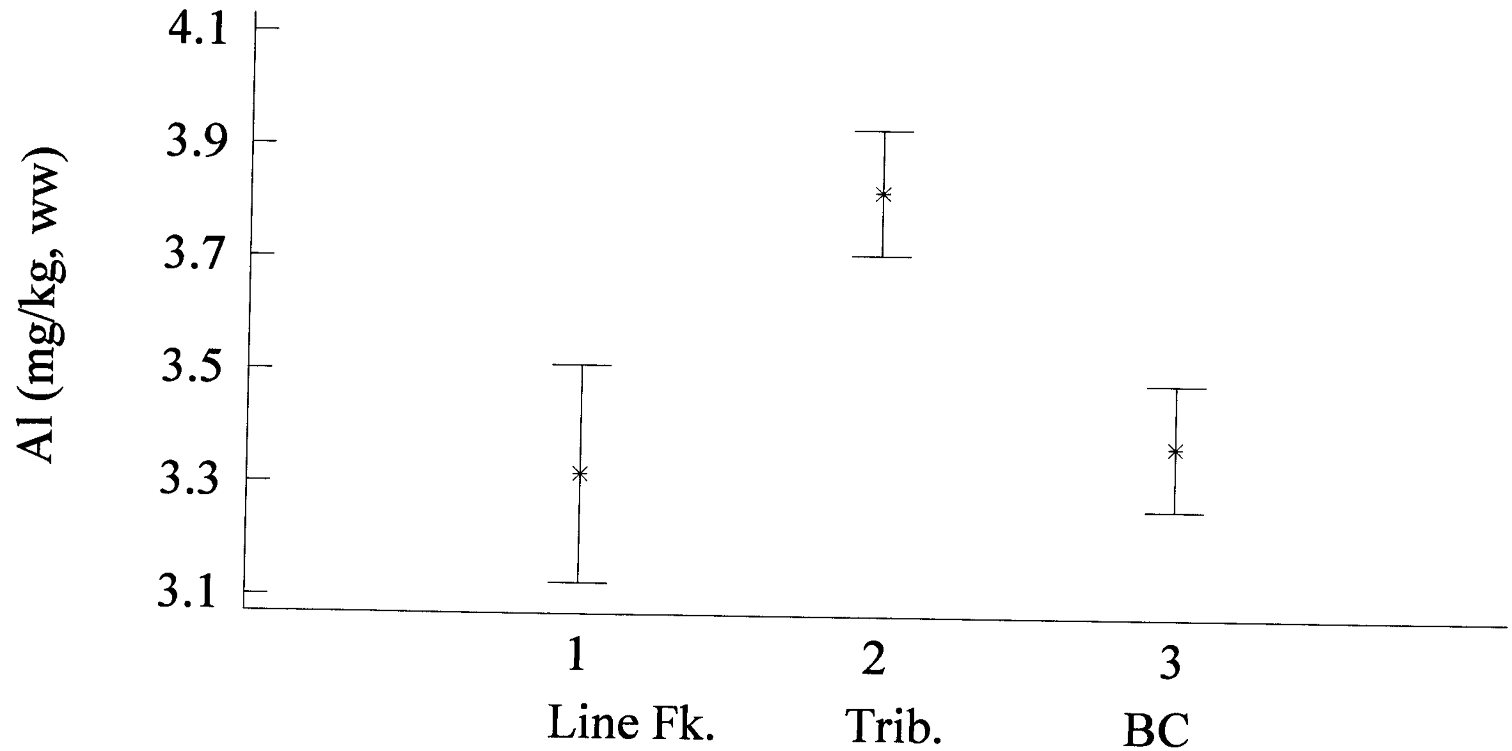


Figure 7. Log of As Mean Concentrations in Sediment and 95% LSD Intervals.

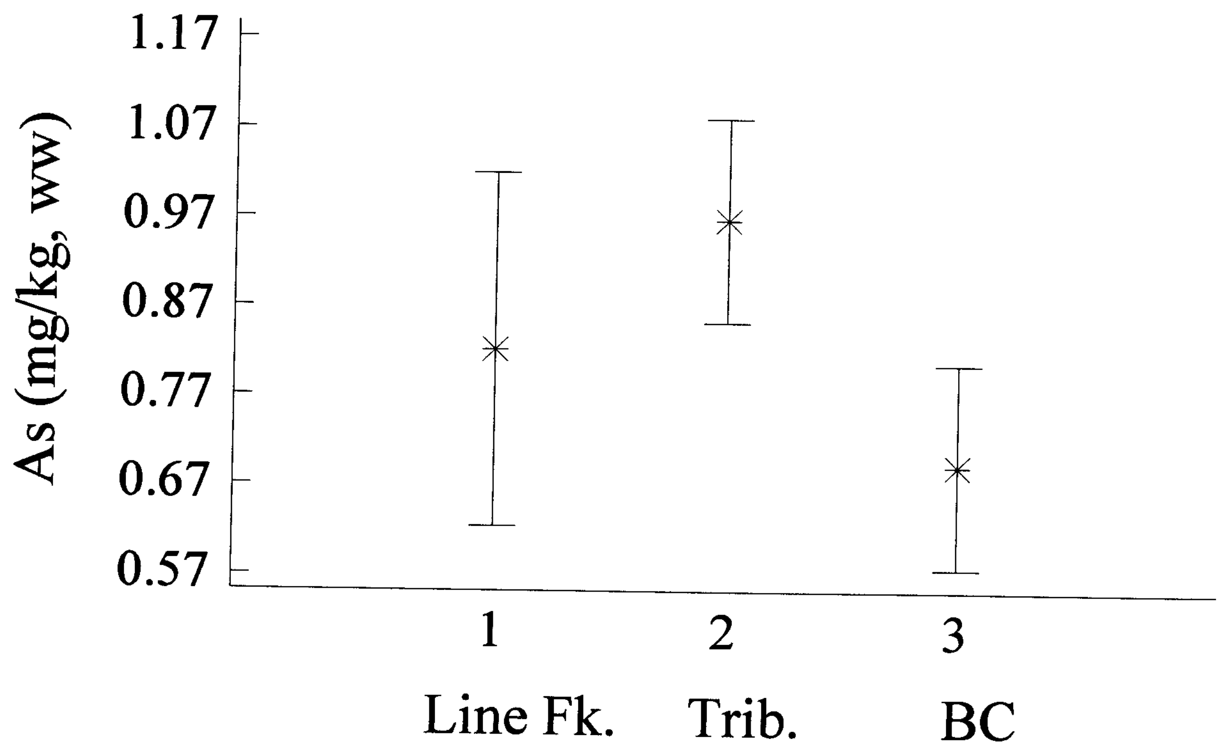


Figure 8. Log of Ba Mean Concentrations in Sediment and 95% LSD Intervals.

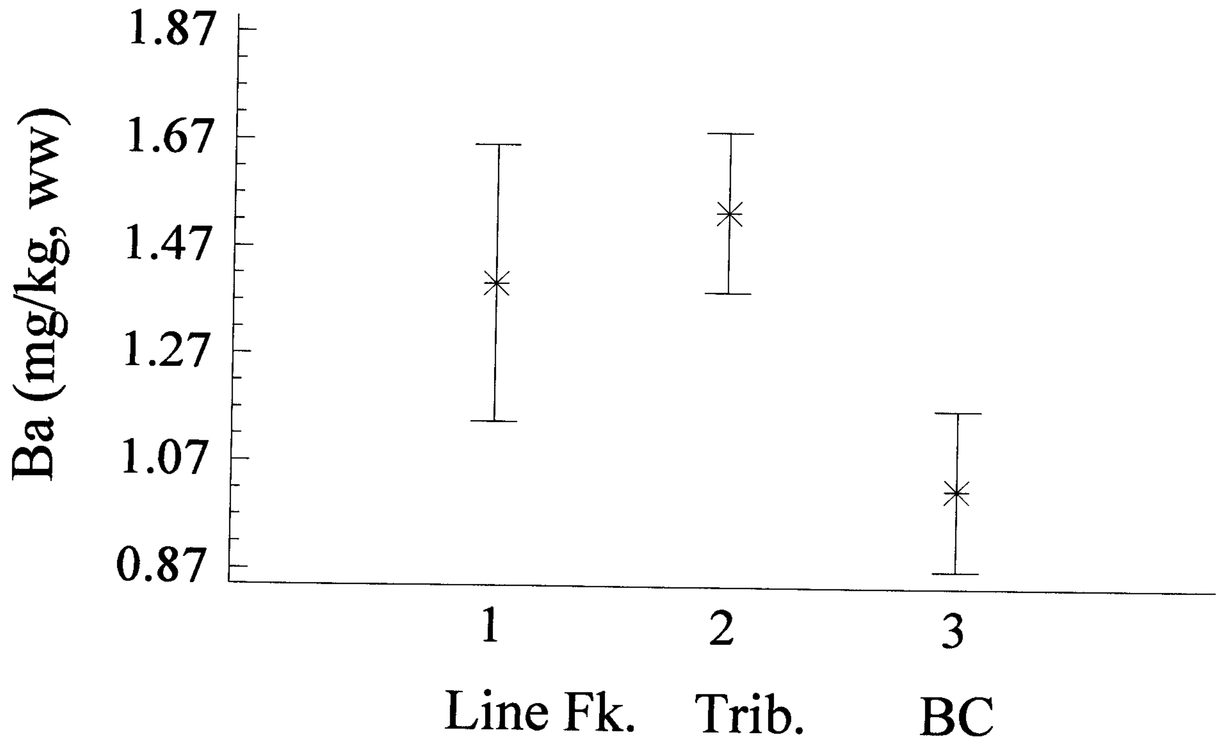


Figure 9. Log of Cu Mean Concentrations in Sediment and 95% LSD Intervals.

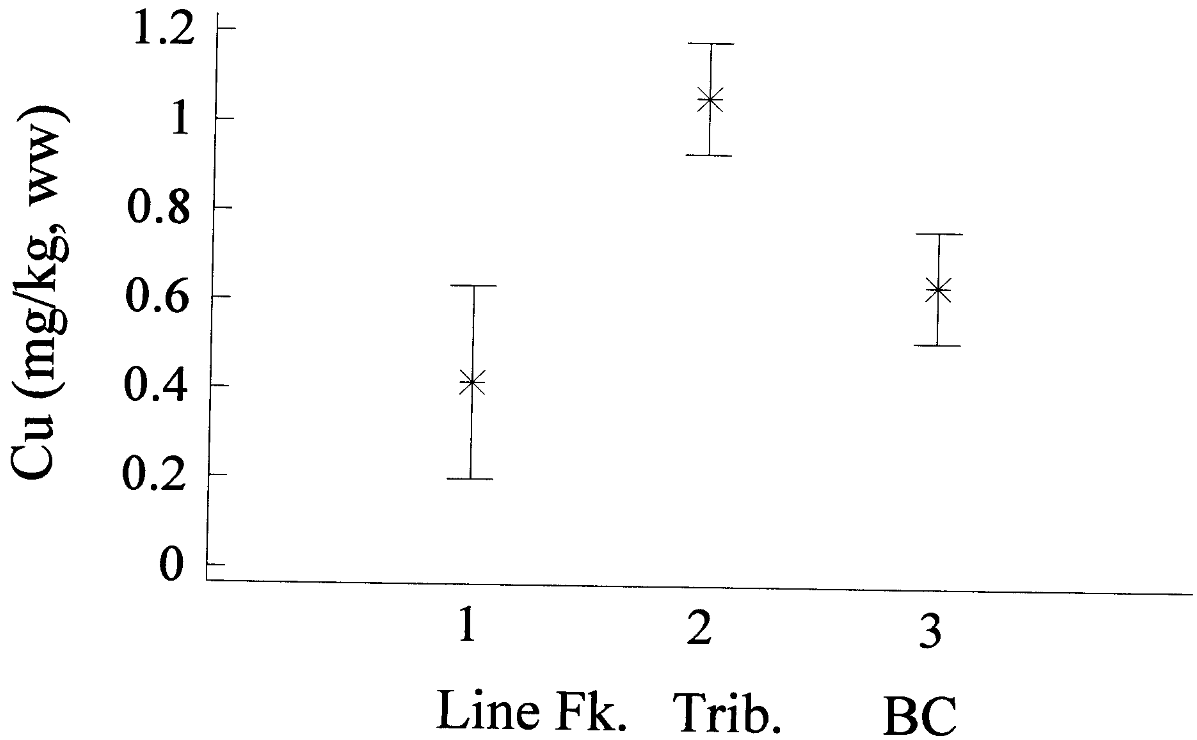


Figure 10. Log of Pb Mean Concentrations in Sediment and 95% LSD Intervals.

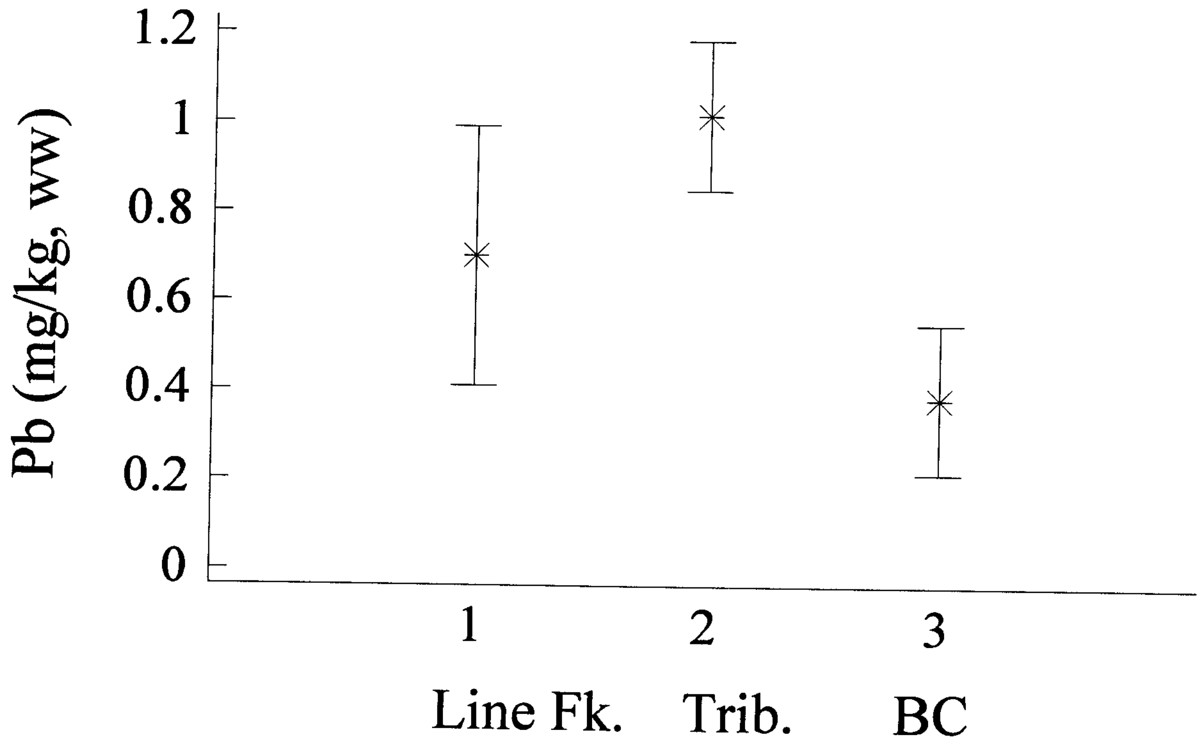
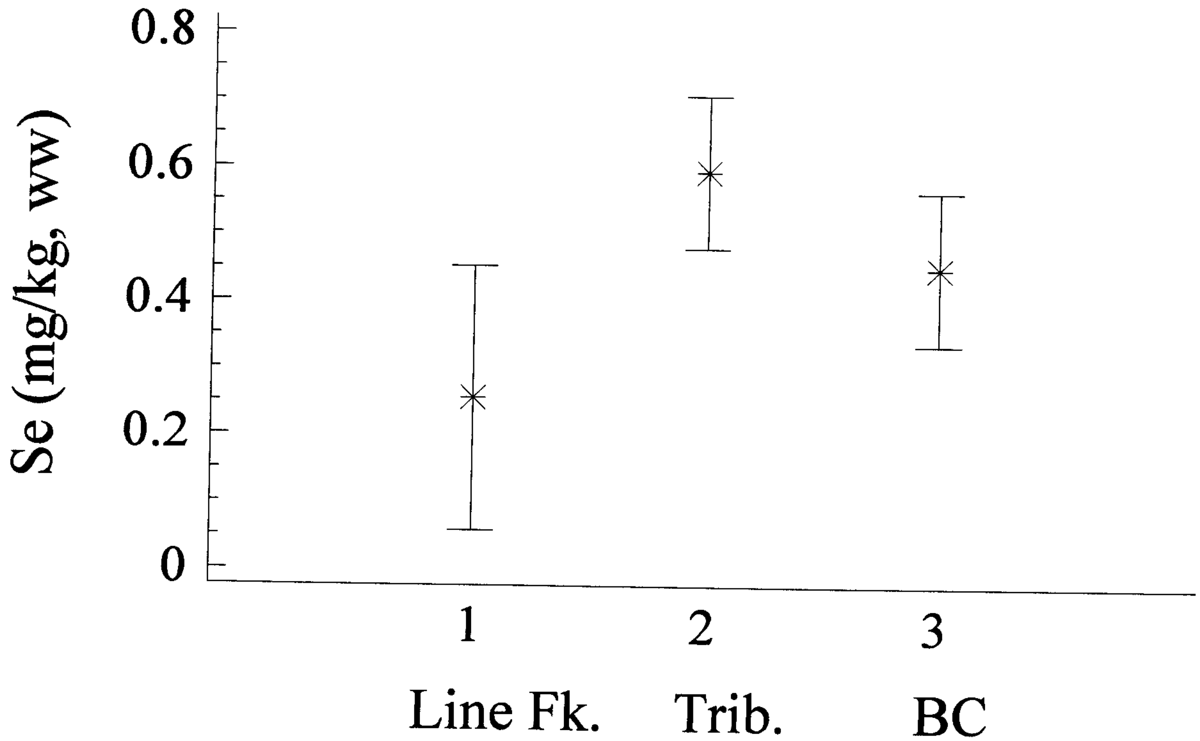


Figure 11. Log of Se Mean Concentrations in Sediment and 95% LSD Intervals.



DISCUSSION

Previous Investigations

NPS, TDEC (1990-1992), KDOW

The Bear Creek watershed has been intensively surveyed for AMD by various resource and water management agencies since the early 1980's. Some of the earliest work was conducted by the National Park Service (NPS) for development of the Big South Fork National River and Recreation Area (BSFNRRA) Water Quality Report (Rickard et al. 1986). The BSFNRRA was established in 1974 as a result of the enabling legislation, Section 108 of the Water Resources Development Act (Public Law 93-251). Two early monitoring stations established on Bear Creek, BR3 (our BC2) and BR1 (our BC1) are still monitored by NPS personnel. Typical water quality parameters included temperature, pH, conductivity, dissolved oxygen, acidity, hardness, alkalinity, sulfate, Fe, Mn, chloride, turbidity, and bacterial colonies. Results of routine NPS water quality monitoring from October 1982 to October 1984 (Tables 9 and 10) generally agreed with the results obtained in our sampling.

Sediment and intensive water sampling efforts in the Bear Creek watershed were initiated by other agencies as a result of the initial NPS efforts. The Kentucky Division of Water (KDOW) collected sediment samples from Bear Creek and the Big South Fork Cumberland River above and below Bear Creek in 1988 (Table 11). KDOW's sediment metals results were generally comparable to ours with the exception of Hg and Mn, which were higher than ours. In June and July of 1990, TDEC conducted storm event sampling within the watershed to establish baseline conditions. Monitoring stations were initially established at sites EB-4, BR-1 (our BC1), LF-4 (our LF), EB-5, and CB-3. Parameters monitored were pH, conductivity, turbidity, and total recoverable and dissolved concentrations of Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, and Zn (Tables 12 and 13). Results of the 1990 storm event sampling performed by TDEC did not consistently result in metal concentrations greater than our sampling. TDEC results for Mn were typically greater than ours, while their Fe values were generally much less. Results for several metals analyzed in both studies were comparable (Al, As, Cr, Cu, Pb, Ni).

Tennessee's Nonpoint Source Program, in conjunction with the Tennessee Division of Land Reclamation, developed a reclamation plan for the watershed. During 1991, funding from Section 319 of the Clean Water Act was utilized to construct BMP's (ALD's, limestone channels, and constructed wetlands) and to monitor water quality downstream of the remediation efforts (Barbara Hamilton, TDEC, personal communication). Monitoring stations were established at sites EB4, CH3G, and SU2 where sampling was performed in June and November 1992 to evaluate the success of the reclamation efforts (Tables 14 and 15). A review of the 1990 and 1992 storm-event analyses did not indicate substantial differences in water quality between pre-and post-BMP construction.

TDEC Water Quality Analyses, 1993-1995

TDEC personnel collected samples for water quality and metals analyses on 32 separate dates during December 1993 through February 1995 at stations SU2, CH3, and EB4 (Tables 16-18). Parameters analyzed included: DO, pH, conductivity, acidity, hardness, sulfate, and the following 12 metals: Al, As, Ba, Cd, Co, Cr, Cu, Fe, Mn, Hg, Pb, and Zn. In addition, flow was estimated from staff gauge heights. Results obtained from this sampling effort were provided by Ms. Barbara Hamilton (TDEC) for inclusion and discussion in this report. These data are included here at TDEC's request because: 1) they have not previously been incorporated into a report by TDEC; 2) TDEC is participating in NRCS's Bear Creek project; and 3) the data supplement the work done during our investigation. Aquatic life and drinking water standards are also briefly discussed. The TDEC results are included in subsequent tables and discussed by sample site. Data tables 16-18 indicate when specific State or Federal water quality standards for aquatic life, water supply and recreational uses, or Maximum Contaminant Levels (MCLs) for drinking water, were exceeded. Relevant water quality criteria for the Bear Creek watershed are included in Table 19.

The frequency of analyses for some metals were not consistent; detection limits varied according to date; and four metals (As, Cr, Hg, Pb) were essentially dropped about midway through the monitoring period based on infrequent detections. Summary statistics and a comparison to existing Tennessee and Kentucky water quality standards were performed using total hardness concentrations of 50 mg/l to calculate site-specific metals criteria based on in-stream measurements performed by various agencies. Hardness values measured by TDEC ranged from 186 to 968 mg/l at site SU2 and from 65 to 540 mg/l at site CH3. The hardness values at these constructed wetland sites may be indicative of bicarbonate alkalinity from the chemical reactions associated with AMD and from the influences of Ca and Mg associated with limestone. Calcium and Mg values at site SU2 ranged from 3 to 223 mg/l and 7 to 129 mg/l, respectively. Calcium and Mg values at site CH3 ranged from 9 to 64 mg/l and 9 to 48 mg/l, respectively.

Both Kentucky and Tennessee water quality standards were compared to concentrations at all sites to obtain the most protective criteria for the resource (aquatic life and drinking water), and because the Bear Creek watershed lies within both states. In contrast to Tennessee, Kentucky has specifically promulgated total As, Be, and Fe standards for warm water aquatic habitat, and Ag, chloride, Cr (III),Cu, fluoride, NO_3-N, Mn, and SO_4 standards for domestic water supply. An evaluation of Cr for warmwater aquatic habitat was not performed because different criteria exist for Cr (III) and Cr (VI) in Kentucky and the analytical methods used did not differentiate between Cr species. Tennessee has established a numeric criteria for total Cr of 100 μg/l, however, concentrations of the samples did not exceed that limit. Total recoverable metal and dissolved metal concentrations for both states were used for comparison to existing aquatic life criteria. Metals criteria in Kentucky are based on total recoverable constituents. Cadmium, Cu, Pb, Ni, and Zn criteria in Tennessee are based on total dissolved constituents.

The current federal drinking water standards were established by EPA, in part, as a result of the statutory requirements of the Safe Drinking Water Act. Maximum contaminant levels (MCLs) are enforceable and are derived from the following considerations: 1) the availability and performance of technologies for treating the contaminant; 2) technology costs; and 3) the availability of analytical methods which consistently and accurately measure the contaminant level. The MCL Goals (MCLGs) are established based on contaminant levels where no known or anticipated adverse health effects would be expected. The Secondary MCLs (SMCLs) are intended to control contaminants that would primarily affect the aesthetic qualities of drinking water. Although MCLGs and SMCLs are non-enforceable guidelines intended for the states, contaminant concentrations exceeding these values, particularly when other standards do not exist, could have negative implications for human health. Total recoverable metal concentrations for comparison to drinking water criteria were utilized in our evaluation.

Site SU2

Water quality and metals results (Table 16) indicated that various Kentucky and Tennessee water quality standards or Federal MCLs were consistently exceeded for pH, SO_4, Al, Cd, Cu, Fe, Mn, and Zn. While most of these exceeded various upper limits that have been established, pH was typically below minimum standards (6.0 for KY; 6.5 for TN). Likewise, during May to mid-November of 1994, DO concentrations were below minimum aquatic life standards used by both states (5.0 mg/l). Although Pb was detected only four times at this site, each time it exceeded aquatic life standards used by both states.

Site CH3

Water quality and metals results (Table 17) were similar to those for Site SU2. All values for pH were below minimum aquatic life standards for both Tennessee and Kentucky. Likewise, DO concentrations during May to early November of 1994 were below minimum aquatic life standards used by both states. Water quality standards for Kentucky and Tennessee, along with Federal MCLs, were exceeded for SO_4, Al, Cd, Cu, Fe, Mn, and Zn. Each of the four times Pb was detected at this site, it exceeded aquatic life standards use by both states.

Site EB4

Water quality analyses (Table 18) indicated that 15 of 32 pH values (47%) were below minimum aquatic life standards used by Tennessee or Kentucky. Nine of the pH values (32%) were below the Tennessee standards for domestic water supply and the Kentucky standard for recreational waters. Of the 30 DO values reported, five (17%) were below minimum aquatic life standards used by either state. Only two sulfate values (6%) exceeded State or Federal drinking water MCLs. Several standards for Al, Cu, Fe, and Mn were consistently exceeded at this site. All detected values for Cd (6) and Pb (5) exceeded aquatic life standards used by either state.

Regression and Correlation Analyses

Linear regression analysis of log-transformed TDEC monitoring results at sites CH3 and EB4 and log-transformed flow values obtained from USGS stream gauge data (Tables 20 and 21) at sites CH3G and EB4 was performed using data collected on the same days during the sampling period. Comparisons of log-transformed metals results with pH and log-transformed DO concentrations were also performed. A significant correlation between concentration and flow was observed at site CH3G for Al ($r = 0.73$, $p<.01$, 16 df, Figure 12) and Zn ($r = 0.58$, $p<.02$, 16 df, Figure 13). Although not considered statistically significant ($p>0.05$), a positive trend was also observed for copper. Assuming that the effluent from the BMP's at CH3 is the principal source of flow at CH3G, these results suggest that Al and Zn are strongly related to flow and that the constructed wetland may not have sufficient retention time, DO concentration, or pH to precipitate these metals. Conductivity values observed in the effluent, indicative of total dissolved solids, also support these assumptions. There may also be other sources of AMD that are not captured by the constructed BMPs at CH3. Significant negative correlations were observed for Co ($r = -0.56$, $p<.03$, 15 df, Figure 14), Mn ($r = -0.84$, $p = .00$, 16 df, Figure 15), and SO_4 ($r = -0.59$, $p<.02$, 16 df, Figure 16). These data suggest that Co, Mn, and SO_4 are more efficiently retained in the constructed wetland sediments, more closely associated with adsorption to sediments in the tributary and wetland area (CH3G), or are being diluted during high flow periods.

Significant correlations were observed between concentration and flow at site EB4 for Al ($r = 0.88$, $p = .00$, 16df, Figure 17), Fe ($r = 0.49$, $p<.0499$, 16df, Figure 18), and Zn ($r = 0.53$, $p<.03$, 16df, Figure 19). Although not considered statistically significant ($p>.05$), a positive trend was also observed for copper. There were no significant negative correlations observed at site EB4.

At site CH3, there was a significant negative correlation ($r = -0.67$, $p = 0.0001$, 28df, Figure 20) of Fe with DO. Observed reductions in DO content can influence the solution of Fe hydroxides and other adsorbed heavy metals (Hounslow 1995). Ferric iron will remain in solution at low pH, and may accumulate in solution as ferrous iron under anoxic conditions. Photoreduction of Fe^{+3} will also increase the concentration of Fe^{+2}. Oxidation of ferrous iron (Fe^{+2}) to ferric iron (Fe^{+3}) will occur as the pH increases downstream of the constructed wetlands or through microbial transformation. This has resulted in numerous observations of Fe precipitate, the hydrated iron (III) oxide, in Bear Creek tributaries. The combination of low pH and DO observed at CH3 may have influenced additional export of ferrous and ferric iron accumulated in the constructed wetland.

A similar relationship was also observed at Site SU2. There were significant negative correlations of Fe ($r = -0.66$, $p = 0.0001$, 27df; Figure 21), Mn ($r = -0.47$, $p = 0.011$, 28df, Figure 22), and Co ($r = -0.54$, $p =0.004$, 25df; Figure 23) with DO. Field analyses indicated that the concentration of DO in the effluent from the ALD was 11.89 mg/l, which was substantially higher than the observed concentrations (3.48 and 4.9 mg/l) in the ALD effluents at Site CH3.

The geometric mean concentration of DO (5.43 mg/l) observed in the effluent of the constructed wetland at Site SU2 was lower than that observed (6.76 mg/l) in the constructed wetland at Site CH3.

A significant (r = -0.36, p = 0.04, 30df, Figure 24) negative correlation between Al and pH and a positive trend between SO_4 and pH (Figure 25) was observed at EB4. This may be indicative of an aluminum sulfate mineral precipitating out of solution. The basic sulfate mineral $AlOHSO_4$ has been shown to influence Al solubility at a pH below 6.5, while amorphous $Al(OH)_3$ controls Al solubility at a pH above 6.5 (Sullivan et al. 1985). In acidic waters, the solubility of $Al(OH)_3$ increases with decreases in temperature.

Contaminant Loading Estimates

Recent investigations have estimated mass contaminant loading ranging from 511 to 5730 lbs/day at the mouth of Bear Creek (Steve Bakaletz, NPS, personal communication). Contaminant loading rates were determined at one tributary and one headwater mainstem site from the data collected by TDEC and stream gauge data obtained from USGS. The formula (Q (flow in cfs) X Concentration (mg/l) X 5.4 (constant) = lbs./day) was utilized for estimating loading rates at CH3G and EB4 (Thomann and Mueller 1987). Results are included for metals with a geometric mean concentration of $\geq$ 40 μg/l (Table 22). A seasonal analysis was also performed by grouping monthly minimum and maximum mean flow data and using the geometric mean concentration of water samples collected by TDEC during their entire sampling period. The analyses were conducted to establish a reliable prediction of mean loading rates at the sites where the USGS recorded flow. A comparison to minimum and maximum flow values was also performed to establish a range associated with periods of low flow and high precipitation events during the operational period of the USGS gauging stations.

Flow data collected at Site CH3G during the spring season (April-June 1994 and April 1995) indicated a minimum mean of 0.34 cfs and a maximum mean of 2.59 cfs (Table 20). The geometric mean concentrations of Al, Fe, Mn, and Zn were 10.23, 5.59, 9.61, and 0.29 mg/l, respectively (Table 17). Contaminant loading rates at the minimum mean flow observed for Al, Fe, Mn, and Zn were 18.78, 10.26, 17.64, and 0.53 lbs/day, respectively. Contaminant loading rates at the maximum mean flow observed for Al, Fe, Mn, and Zn were 143, 78, 134, and 4 lbs/day, respectively. With 91 days in the spring sampling period, mass contaminant loading for Al could have ranged from 1709 to 13,020 lbs. Mass contaminant loading for Fe, Mn, and Zn could have ranged from 934 to 7114 lbs, 1605 to 12,231 lbs, and 48 to 369 lbs, respectively. The minimum and maximum flow rates observed at Site CH3G during the spring sampling period were 0.17 and 9.4 cfs. Under these flow conditions, contaminant loading rates for Al could have approximated 9.39 and 519 lbs/day, 5.13 and 284 lbs/day for Fe, 8.82 and 488 lbs/day for Mn, and 0.27 and 14.67 lbs/day for Zn.

Summer flow data were recorded during July - September 1994 with minimum and maximum mean values of 0.19 and 0.25 cfs. Contaminant loading rates at the minimum mean flow for Al, Fe, Mn, and Zn would have been equivalent to 10.50, 5.74, 9.86, and 0.30 lbs/day, respectively. Contaminant loading rates at the maximum mean flow for Al, Fe, Mn, and Zn would have approached 13.81, 7.55, 12.97, and 0.39 lbs/day, respectively. With 92 days in the summer sampling period, mass contaminant loading for Al, Fe, Mn, and Zn could have ranged from 966 to 1271 lbs, 528 to 695 lbs, 907 to 1193 lbs, and 27.60 to 35.88 lbs, respectively. For the minimum and maximum flow conditions observed (0.08 and 1.5 cfs), contaminant loading rates for Al, Fe, Mn, and Zn could have been 4.42 and 82.9 lbs/day, 2.41 and 45.28 lbs/day, 4.15 and 77.84 lbs/day, and 0.12 and 2.34 lbs/day, respectively.

Fall flow data were recorded during October - December 1994 with minimum and maximum mean values of 0.08 and 0.21 cfs. Contaminant loading rates at the minimum mean flow for Al, Fe, Mn, and Zn approached 4.42, 2.41, 4.15, and 0.12 lbs/day, respectively. Contaminant loading rates at the maximum mean flow for Al, Fe, Mn, and Zn approached 11.60, 6.34, 10.90, and 0.33 lbs/day, respectively. With 92 days in the fall sampling period, mass contaminant loading for Al, Fe, Mn, and Zn could have ranged from 407 to 1067 lbs, 222 to 583 lbs, 382 to 1003 lbs, and 11.04 to 30.36 lbs, respectively. Contaminant loading rates for the minimum and maximum (0.04 and 3.20 cfs) flow for Al, Fe, Mn, and Zn would have been equivalent to 2.21 and 177 lbs/day, 1.21 and 97 lbs/day, 2.08 and 166 lbs/day, and 0.06 and 4.99 lbs/day, respectively.

Winter flow data were recorded during January - March 1995 with a minimum and maximum mean values of 0.70 and 0.98 cfs. Contaminant loading rates at the minimum mean flow for Al, Fe, Mn, and Zn approached 38.67, 21.13, 36.33, and 1.09 lbs/day, respectively. Contaminant loading rates at the maximum mean flow for Al, Fe, Mn, and Zn were equivalent to 54.14, 29.58, 50.86, and 1.53 lbs/day, respectively. With 90 days in the winter sampling period, mass contaminant loading for Al, Fe, Mn, and Zn could have ranged from 3480 to 4873 lbs, 1902 to 2662 lbs, 3270 to 4577 lbs, and 98 to 138 lbs, respectively. Contaminant loading rates for the minimum and maximum flow (0.10 and 8.00 cfs) for Al, Fe, Mn, and Zn were equivalent to 5.52 and 442 lbs/day, 3.02 and 241 lbs/day, 5.19 and 415 lbs/day, and 0.16 and 12.48 lbs/day, respectively.

Flow data collected at Site EB4 during the spring season (April 1994, May 1994, June 1994, April 1995) indicated a minimum mean of 1.28 cfs and a maximum mean of 17.5 cfs (Table 21). The geometric mean concentrations of Al, Fe, Mn, and Zn were 1.12, 1.03, 2.78, and 0.05 mg/l, respectively (Table 18). Contaminant loading rates at the minimum mean flow observed for Al, Fe, Mn, and Zn were 7.74, 7.12, 19.22, and 0.35 lbs/day, respectively. Contaminant loading rates at the maximum mean flow observed for Al, Fe, Mn, and Zn were 106, 97, 263, and 4.73 lbs/day, respectively. With 91 days in the spring sampling period, mass contaminant loading for Al could have ranged from 704 to 9631 lbs. Mass contaminant loading for Fe, Mn, and Zn could have ranged from 648 to 8858 lbs, 1749 to 23,907 lbs, and 32 to 430 lbs, respectively. The minimum and maximum flow rates observed at Site EB4 during the spring sampling period were

0.31 and 68.0 cfs. Under these flow conditions, contaminant loading rates for Al could have approximated 1.87 and 411 lbs/day, 1.72 and 378 lbs/day for Fe, 4.65 and 1021 lbs/day for Mn, and 0.08 and 18.36 lbs/day for Zn.

Summer flow data were recorded during July - September 1994 with minimum and maximum mean values of 0.30 and 1.05 cfs. Contaminant loading rates at the minimum mean flow for Al, Fe, Mn, and Zn would have been equivalent to 1.81, 1.67, 4.50, and 0.08 lbs/day, respectively. Contaminant loading rates at the maximum mean flow for Al, Fe, Mn, and Zn would have approached 6.35, 5.84, 15.76, and 0.28 lbs/day, respectively. With 92 days in the summer sampling period, mass contaminant loading for Al, Fe, Mn, and Zn could have ranged from 167 to 584 lbs, 154 to 537 lbs, 414 to 1450 lbs, and 7.36 to 25.76 lbs, respectively. For the minimum and maximum flow conditions observed (0.03 and 16.0 cfs), contaminant loading rates for Al, Fe, Mn, and Zn could have been 0.18 and 96.77 lbs/day, 0.17 and 88.99 lbs/day, 0.45 and 240.19 lbs/day, and 0.01 and 4.32 lbs/day, respectively.

Fall flow data were recorded during October - December 1994 with minimum and maximum mean values of 0.17 and 1.28 cfs. Contaminant loading rates at the minimum mean flow for Al, Fe, Mn, and Zn approached 1.03, 0.95, 2.55, and 0.05 lbs/day, respectively. Contaminant loading rates at the maximum mean flow for Al, Fe, Mn, and Zn approached 7.74, 7.12, 19.22, and 0.35 lbs/day, respectively. With 92 days in the fall sampling period, mass contaminant loading for Al, Fe, Mn, and Zn could have ranged from 94.76 to 712 lbs, 87.40 to 655 lbs, 235 to 1768 lbs, and 4.60 to 32.20 lbs, respectively. Contaminant loading rates for the minimum and maximum (0.05 and 12.0 cfs) flow for Al, Fe, Mn, and Zn were equivalent to 0.30 and 72.58 lbs/day, 0.28 and 66.74 lbs/day, 0.75 and 180 lbs/day, and 0.01 and 3.24 lbs/day, respectively.

Winter flow data were recorded during January - March 1995 with a minimum and maximum mean values of 5.04 and 7.62 cfs. Contaminant loading rates at the minimum mean flow for Al, Fe, Mn, and Zn approached 30.48, 28.03, 75.66, and 1.36 lbs/day, respectively. Contaminant loading rates at the maximum mean flow for Al, Fe, Mn, and Zn were equivalent to 46.09, 42.38, 114, and 2.06 lbs/day, respectively. With 90 days in the winter sampling period, mass contaminant loading for Al, Fe, Mn, and Zn could have ranged from 2743 to 4148 lbs, 2523 to 3814 lbs, 6809 to 10,295 lbs, and 122 to 185 lbs, respectively. Contaminant loading rates for the minimum and maximum flow (0.29 and 68.0 cfs) for Al, Fe, Mn, and Zn were equivalent to 1.75 and 411 lbs/day, 1.61 and 378 lbs/day, 4.35 and 1021 lbs/day, and 0.08 and 18.36 lbs/day, respectively.

NPS Water Quality Analyses, 1993-1997

The NPS has conducted routine water quality analysis at sites BC2 and BC1 prior to and since incorporation into the National Park system. The results of analyses obtained since January 1993 are included in Tables 23 and 24. Summary statistics were calculated and a comparison to existing water quality standards for Tennessee and Kentucky were performed.

Water quality analyses at Site BC2 indicated continued degradation of some parameters. Values for pH ranged from 4.3 to 6.6 with a geometric mean of 5.6. A majority of the pH observations were below the Tennessee domestic water supply and Kentucky recreational waters criteria. Most were also below Tennessee's and Kentucky's criteria for fish and aquatic life and warm water aquatic habitat. Concentrations of Fe ranged from <0.2 to 0.44 mg/l which exceeded the SMCL for drinking water. Manganese values ranged from 0.64 to 5.05 mg/l with a geometric mean of 2.15 mg/l. All Mn values exceeded the SMCL and Kentucky maximum allowable in-stream concentration for drinking water.

Water quality analyses at Site BC1 also exhibited the same trend as the upstream BC2 site. Values for pH ranged from 4.6 to 7.2 with a geometric mean of 5.87. A majority of the pH observations were below the Tennessee domestic water supply and Kentucky recreational waters criteria. Most were also below Tennessee's and Kentucky's criteria for fish and aquatic life and warm water aquatic habitat. Concentrations of Fe ranged from <0.2 to 0.74 mg/l. Three of the four values which were above the detection limit (0.2 mg/l) exceeded the SMCL for drinking water. Manganese values ranged from 0.50 to 3.0 mg/l with a geometric mean of 1.3 mg/l. All but four observations exceeded the Kentucky maximum allowable in-stream concentration for drinking water and the federal SMCL.

Surveys within the East Branch Bear Creek were conducted in 1995 by personnel from NPS, NRCS, and OSM. These surveys primarily concentrated on locating collapsed mine portals and seeps which were contributing AMD to the East Branch. Field measurements for pH were taken and locational information obtained with the use of a Global Positioning System (GPS) receiver (Table 25).

FWS Investigation

Water

The water quality analyses conducted during 1996 (Table 8) confirm and enhance the previous investigations conducted for storm events, BMP monitoring, and routine sampling. Most values for pH were below the Tennessee domestic water supply and Kentucky recreational waters criteria. They were also below the Tennessee and Kentucky criteria for fish and aquatic life and warm water aquatic habitat. Sulfate values were extremely elevated (584 to 1140 mg/l) at the constructed BMP sites, SU2 and CH3, and exceeded the SMCL and the Kentucky maximum allowable in-stream concentration for drinking water. Sulfate concentrations at sites CH6, CH3G, EB3, EB4, EB5, EB Wet2, EB Wet3, WB5, and WB8 also exceeded these criteria. Based on a relatively high DO value (11.89 mg/l) recorded on field instruments at the effluent of the ALD at SU2, it would appear that the ALD is not functioning properly. Lower DO values (3.48 and 4.90 mg/l) were observed in the effluents of ALDs at CH3.

Aluminum concentrations exceeded the SMCL for drinking water. Although an official numeric criteria for Al has not been established for aquatic species, it is recommended that the four-day average and one-hour average not exceed 87 μg/l and 750 μg/l, respectively (USEPA 1988). These recommended criteria were established for waters with a pH of 6.5 to 9.0. All but one of the observed dissolved values (< 0.056 mg/l) at site EB Wet3 exceeded these recommendations, however, pH values were well below those used in standard EPA test methods. Toxicity associated with aluminum is not fully understood and is considered to be related to the specific form of Al, the mechanism of aluminum uptake, individual species tolerance mechanisms, and pH. Aquatic invertebrates may accumulate Al and concentrate the metal to levels that are toxic to predators (Sparling and Lowe 1996). The monomeric form is considered to be the most toxic to fish and appears to be greatest in the pH range 4.8 to 5.4. This is primarily due to a failure of ionoregulation, caused by a combination of Al and H^+ effects, and respiratory failure. Recent studies have indicated, however, that toxicity to brown trout is more pronounced in freshly mixed acidic and neutral water, at low concentrations of Al, and at a pH of 6.4 (Witters et al. 1996).

Arsenic, Cd, and Hg concentrations in the samples were generally below the analytical detection limits. At site WB4, the As concentration (.002 mg/l) was below the Kentucky chronic criteria for warm water aquatic habitat. Arsenate and arsenite compounds, at levels from 0.040 to 0.1 mg/l, have resulted in lethal and sub-lethal effects to a variety of aquatic organisms (Eisler 1988a). The EPA is currently developing criteria for As in drinking water. Cadmium is considered a teratogen and a carcinogen. A majority of the Bear Creek water analyses did not indicate the presence of Cd, however, dissolved Cd was detected at sites CH3, W2, and WB4 at 0.001 mg/l, which exceeds the Tennessee criterion continuous concentration for fish and aquatic life and the Kentucky chronic criteria for warm water aquatic habitat. Eisler (1985) reported a variety of lethal and sub-lethal effects for aquatic organisms at concentrations of 0.7 to 5.0 μg/l, especially in low alkalinity waters.

Mercury was detected in two samples, one from site BC1 (0.0004 mg/l total and 0.0002 mg/l dissolved) at the mouth of Bear Creek, and one from site WB5 (0.0003 mg/l) in the West Branch Bear Creek. Both detections exceeded the Tennessee criterion continuous concentration for fish and aquatic life and the Kentucky chronic criteria for warm water aquatic habitat. Although these were the only samples where Hg was detected, previous investigations by the KDOW also detected Hg at the mouth of Bear Creek (KDOW, unpublished data). Mercury is classified as a mutagen, teratogen, and carcinogen. Synergistic effects with other metals have also been reported. Concentrations in normal stream, river, and lake waters range from 0.01 to 0.1 μg/l, and in coal mine waters range from 1.0 to 10.0 μg/l (D'Itri 1972). Complete mortality to rainbow trout have been reported at a concentration of 0.1 μg/l of inorganic Hg and reproductive impairment to the fathead minnow at exposures of 0.12 μg/l for three months (Birge et al. 1979). Birge et al. (1979) also reported complete mortality of eggs of catfish, goldfish, largemouth bass, and rainbow trout within 8 days, in three replicate experiments, at concentrations of 0.10-0.14 μg/l. Eisler (1987) reported mortality to birds at dietary concentrations of 4.0 to 40.0 mg/kg and to mammals at 1.0 to 5.0 mg/kg. Research efforts have also focused on the effects of methylmercury to a variety of aquatic organisms. The current acute freshwater life criterion (2.4 μg/l) may not be sufficiently protective against reproductive and growth impairments (Eisler 1987).

Copper concentrations at sites SU2W, CH3 W2, CH6, EB3, EB5, WB4, WB5, and Prewit Br.1 exceeded the Tennessee criterion maximum concentration for fish and aquatic life and Kentucky acute criteria for warm water aquatic habitat. Concentrations at sites CH3 ALD2 and CH3 SB1 also exceeded the Tennessee criterion continuous concentration for fish and aquatic life and the Kentucky chronic criteria for warm water aquatic habitat. Chronic toxicity studies performed on mussels have indicated lethal effects at concentrations of 25 μg/l (Imlay 1971). Other studies have investigated wastewater treatment plant (WWTP) effluents in the Clinch River using the rainbow mussel (*Villosa iris*) and the Asian clam (*Corbicula fluminea*) (Goudreau et al. 1993), and the impacts of Cu and Zn (in water) on benthic insect communities (Clements et al. 1992). In studies with outdoor experimental streams, Clements et al. (1992) noted that several species of Ephemeroptera were completed eliminated when exposed to 25 ppb Cu for ten days, but that chironomids (Chironomidae: Orthocladiini) abundance increased. In field studies on the Clinch River, these investigators reported that numbers of taxa and individuals were severely reduced downstream of the Clinch River Steam Plant (Russell County, Virginia), and did not recover to upstream numbers for about two miles downstream. Effluent Cu concentrations (ppb) measured by Clements et al. (1992) during 1986-1989 varied from 480 (1987) to 260 (1989). Corresponding instream concentrations measured about 50 m downstream from the effluent were 127 (1987) and 52 (1989).

Although Zn was not analyzed for during the 1996 sampling effort, the data obtained from TDEC at sites SU2, CH3, and EB4 would indicate potential problems associated with toxicity. All but one analysis at sites SU2 and CH3 (60 μg/l) exceeded the Tennessee criterion maximum and continuous concentration for fish and aquatic life and the Kentucky acute and chronic warm water aquatic habitat criteria. Four analyses at site EB4 exceeded these criteria also. Teratogenic effects and median lethal concentrations of 130 to 620 μg/l Zn have been reported for embryo-larval stages of the fathead minnow (*Pimephales promelas*)(Ramey 1988). Her results indicated that sub-lethal effects were more pronounced during the posthatch stage. The current acute and chronic criteria may not be protective of sensitive aquatic species, especially mussels and developing fish embryos and larvae (Ramey 1988, USEPA 1986).

Iron concentrations at all sites except CH3, ALD2, EB6, WB10, and BC1 exceeded the SMCL for drinking water. The Kentucky warm water aquatic habitat criterion was exceeded at all sites except CH3 ALD2, EB4, EB6, EB7, WB2, WB3, WB10, Pewit Br. 2, and BC1. Lethal and sub-lethal effects to macroinvertebrate species have been documented at concentrations of 0.32 to 30 mg/l (Biesinger and Christensen 1972; Havas and Hutchinson 1982). An LC 50 of 1.75 mg/l Fe at pH 7.0 and 0.41 mg/l Fe at pH 5.5 was also reported for brook trout (Decker and Menendez 1974). Predicting all potential toxicity associated with Fe in AMD impacted waters is difficult. There have been no substantive toxicity studies performed with the ferrous (Fe^{+2}) iron species. Water quality analyses at the mouth of Bear Creek indicated that the Fe^{+2} species comprised approximately 50% of the Fe detected (Steve Bakaletz, personal communication). It is known, however, that iron (Fe^{+3}) hydroxide precipitates, in AMD impacted watersheds, will cover the stream bottom and fill the interstitial spaces in available substrate. This eliminates essential benthic habitat, reduces available food items, and smothers demersal eggs.

Manganese concentrations at all sites exceeded the federal SMCL and the Kentucky maximum allowable in-stream concentration for drinking water. Nickel concentrations at sites SU2W, CH3 ALD1, CH3 ALD2, CH3 SB1, CH3 W1, CH3 W2, CH6, CH3G, EB3, EB5, WB1, WB4, WB5, WB8, and Prewit Br. 1 exceeded the MCL for drinking water, the Tennessee criterion continuous concentration for fish and aquatic life, and the Kentucky chronic criterion for warm water aquatic habitat. Concentrations at sites EB5 and WB4 exceeded the Tennessee criterion maximum concentration for fish and aquatic life and the Kentucky acute warm water aquatic habitat criteria. The Kentucky maximum allowable in-stream concentration for drinking water (610 μg/l) was exceeded at sites SU2W, EB5, and WB4.

Detectable Pb concentrations at sites SU2W, EB3, EB5, EB Wet2, WB5, Prewit Br. 1, and Prewit Br. 2 exceeded the federal MCLG for drinking water, the Tennessee criterion continuous concentration for fish and aquatic life, and the Kentucky chronic criterion for warm water aquatic habitat. Eisler (1988b) reported that Pb is highly soluble in acidic waters which increases its toxicity potential, especially to juvenile aquatic organisms. Adverse sub-lethal effects (growth and reproduction) were reported at concentrations of 1.3 μg/l to 7.7 μg/l.

Sediment

The geometric means for As and Se in sediment measured at the Bear Creek tributary and mainstem sites, as well as the reference site in Line Fork, were substantially greater than the geometric mean for surficial soils in the eastern United States reported by Shacklette and Boerngen (1984). Iron and Cu were also higher in the tributary samples. Geometric means for the other 7 metals were below those reported by Shacklette and Boerngen (1984) for the eastern United States (Table 26). Individual samples taken from Site EB4 (529 and 557 mg/kg, dry weight) did exceed the geometric mean (260 mg/kg, dw) for Mn in the eastern United States. Results obtained from the KDOW (Table 11) for Mn, in the Big South Fork of the Cumberland River below the confluence of Bear Creek (1,100 mg/kg), substantially exceeded the geometric mean for the eastern United States. Their results for the mainstem Bear Creek and the Big South Fork of the Cumberland River above the confluence with Bear Creek (503 and 475 mg/kg, respectively) also exceeded those reported by Shacklette and Boerngen.

Application of the Illinois stream sediment classification developed by Kelly and Hite (1984) to the results for the geometric means of nine metals (dw) in Bear Creek (Table 27) indicated that Cr, Cu, Mn, Pb, and Zn were in their respective non-elevated categories. The geometric mean for As (9.48 mg/kg) was in the slightly elevated category in Line Fork and elevated in Bear Creek tributaries (13.23 mg/kg). The geometric mean concentration of Fe (23,158 mg/kg) in

Bear Creek tributaries was also elevated. Individual sample results for As (>17 mg/kg) and Fe (>32,000 mg/kg) were in the highly elevated category at Site CH3G, four metals (As (>11 mg/kg), Cr (>16 mg/kg), Fe, and Hg (>0.10 mg/kg)) were elevated or slightly elevated at Site SU2, and two metals (As and Fe) were slightly elevated or elevated at Site CH3W (Table 27). Arsenic was elevated in the mainstem, at Sites BC2 and BC1. One Fe sample from the reference site at LF was in the highly elevated category. The results obtained for metals in sediment by the KDOW indicated the respective metals were in the non-elevated categories.

Sediment guidelines for nine metals (As, Cd, Cr, Cu, Pb, Hg, Ni and Zn) were developed by Sullivan et al. (1985) for the State of Wisconsin. These guidelines range from 0.1 ppm (Hg) to 100 ppm (Cr, Cu, and Zn). Results exceeded the respective Wisconsin guidelines for Hg for one sample collected at Site SU2.

Stewart et al. (1992) reported concentrations (ppm, dw) of Cd (13), Cr (298), Cu (339), Hg (56), Ni (164), and Zn (954) in the sediment samples from East Fork Poplar Creek near Oak Ridge, Tennessee. Their results were much higher than the 1996 samples collected from Bear Creek tributaries and the mainstem and the 1988 samples collected by the KDOW (Table 11).

The Ontario Ministry of the Environment (Persaud et al 1989; Jaagumagi 1992) has developed sediment criteria for ten metals. The geometric mean for As at all sites exceeded the 1992 lowest effect level of 6.0 mg/kg (Table 28). The geometric means for Cu and Fe in the Bear Creek tributaries exceeded the 1992 lowest effect levels, 16.0 mg/kg and 2% respectively. The majority of the other metal concentrations were below their respective no effect levels. Results obtained from the 1988 analyses of sediments in Bear Creek and the Big South Fork of the Cumberland River by the KDOW (Table 11) were below their respective no effect levels.

Our Cd, Fe, Hg, and Zn results were typically near or below those reported by Birge et al. (1987) and Francis et al. (1984) for control sediment used to evaluate sediment toxicity. These investigators noted that rainbow trout early life stage survival was reduced to 70%, 45%, and 23% when exposed to sediment containing 0.180 ppm, 1.050 ppm, and 12.10 ppm Hg, respectively. They also reported significant reductions in rainbow trout early life stage survival using sediment with 2.15 ppm Cd, and also with sediment containing Zn at 121.4 ppm.

In tests with Cd-enriched sediment using embryo-larval stages of the leopard frog (*Rana pipiens*), goldfish (*Carassius auratus*) and largemouth bass (*Micropterus salmoides*), Francis et al. (1984) reported significant mortality at hatching or posthatching when sediment Cd concentrations were about 1000 ppm. It is important to note, however, that these three organisms did not have direct contact with the sediment, and that they have a shorter developmental time than rainbow trout. While our individual results for Hg, Cd, and Zn were below the sediment concentrations used by Birge et al. (1987) and Francis et al. (1984), their studies were not concerned with impacts associated with acid drainage.

Becker et al. (1995) observed that amphipod survival was reduced at three sites and chironomid survival at four sites using 10-d sediment toxicity tests. They used sediments containing Cd (0.9-3 ppm), Cr (19-33 ppm), Cu (12-83 ppm), Pb (12-150 ppm), Hg (0.9-69 ppm), Ni (7-29 ppm), and Zn (50-220 ppm). In our samples, Cu, Pb, and Zn fell in these ranges at several sites, while Cd and Hg were below these ranges at all sites. Analyses conducted by the KDOW revealed concentrations of Ni which fell within this range in Bear Creek and the Big South Fork of the Cumberland River below the Bear Creek confluence (Table 11).

Of the metals detected at all sites, seven metals (Cd, Cr, Cu, Pb, Hg, Ni, and Zn) were below concentrations in control sediments used by Wiederholm and Dave (1989) in toxicity tests with *Daphnia magna* and *Tubifex tubifex*. Acute tests (24-hr and 48-hr) were performed with *D. magna*. Survival, weight, and number of young were measured in the tests with *T. tubifex* which ran 270 days.

Analysis of total organic carbon (TOC), acid-volatile sulfides (AVSs), and simultaneously extracted metals (SEM) should be considered in future investigations of metals in Bear Creek sediments. While AVSs may help explain the toxicity of some metals (Allen et al. 1993; Ankley et al. 1994; Di Toro et al. 1992), it must be used cautiously (Chapman 1996).

In an analysis of mussels and sediment in the Little South Fork of the Cumberland River (LSFCR), Hg was detected in three of ten sediment samples at a maximum concentration of 0.068 mg/kg (dw). Concentrations in mussels were about 14 to 16 times greater than those in sediment and averaged 0.833 mg/kg (Robison 1996). While sediment concentrations of several metals (Al, As, Ba, Cu, Fe) in LSFCR were comparable to those observed in Bear Creek tributaries, Se concentrations were 11-15 times greater in the Bear Creek system. Conversely, Mn concentrations were about seven times lower in the Bear Creek samples. Arsenic and Mn concentrations were determined to be of concern in the Little South Fork.

The concentration of Se in Bear Creek sediments may be of significant concern. Concentrations rarely exceed 2 μg/g in non-weathered sedimentary rock, in contrast to areas such as the western United States (USFWS 1987). The sources observed in the western United States originate from agricultural irrigation return flows from Se rich soils and drainage water from fly- and bottom-ash storage areas adjacent to coal-fired power plants. Biological, chemical, and physical processes continuously move Se into and out of sediments. Dissolved Se is then absorbed or ingested by aquatic organisms, bound to particulate matter, or can remain free in solution.

One significant characteristic of Se is its ability to bioaccumulate in aquatic organisms. The bioconcentration may be one or more orders of magnitude greater than the concentrations in water or food. In LSFCR, Se concentrations in mussels were about 14 times higher than sediment concentrations (Robison 1996). Biomagnification of Se usually ranges from 2 to 6 times greater between producers (algae and plants) and the lower consumers (invertebrates and forage fish), and generally occurs at concentrations of 2 to 5 μg/l in water (USFWS 1987). Reproductive failure and mortality due to food-chain bioconcentration have been reported at concentrations of ≥ 4 μg/g, dw Se in sediment (Finley 1985; Garret and Inman 1984) Although we did not analyze for Se in our water samples, teratogenic effects and mortality of a wide variety of fish and wildlife species have been observed in water and dietary concentrations ranging from 2 to 1,100 μg/l or μg/g (USFWS 1987).

Significant correlations of several metals with aluminum and iron existed, but our dataset is fairly small. Also, we are not aware of a suitable database for use in evaluating aluminum and iron as reference elements in this area, as some investigators have done in other parts of the country (Pardue et al. 1992; Schropp et al. 1990; White and Tittlebaum 1984, 1985).

Table 9. National Park Service: Mainstem Bear Creek (BC1) Water Quality Analyses 1982-1984 (mg/l).

Date	pH	Cond. (μmho/cm.)	DO	Acid.	Hard.	Alk.	SO_4	Fe	Mn	Cl	Turb. (NTU)
10/27/82	5.8	280	11.3	21.0	118.0	2.5	---	0.42	---	---	0.9
12/07/82	5.3	123	11.8	9.9	44.8	2.3	52	<0.2	---	---	3.9
01/08/83	5.1	---	13.0	16.9	71.2	2.5	>80	0.25	---	---	1.5
01/30/83	4.7	140	12.0	12.8	52.5	2.0	68	0.20	---	---	4.3
03/02/83	4.8	140	12.7	13.9	51.2	2.3	67	<0.2	2.7	---	1.5
04/19/83	4.7	138	12.2	10.4	47.8	2.9	66	<0.2	1.9	2.4	3.5
05/17/83	5.4	76	10.8	9.8	29.0	2.6	33	0.20	0.6	2.5	9.7
06/14/83	4.7	---	9.8	19.3	73.9	1.5	80	<0.2	1.4	2.5	1.7
07/06/83	4.5	180	8.7	18.0	67.7	2.2	75	<0.2	3.4	2.5	8.8
08/16/83	5.2	190	---	11.4	79.4	2.6	80	<0.2	3.3	3.5	1.5
09/09/83	5.8	220	7.0	9.7	72.0	4.0	51	<0.2	2.5	12.0	1.7
10/03/83	6.4	210	8.3	18.4	62.0	5.9	15	<0.2	<0.5	5.0	1.6
11/01/83	4.5	430	10.0	29.3	205.0	2.6	>80	<0.2	8.0	4.0	0.4
12/05/83	5.1	121	11.1	9.4	38.1	3.7	41	<0.2	1.5	1.0	6.3
01/09/84	5.3	165	13.7	14.2	65.4	2.2	61	<0.2	3.1	1.5	1.0
02/14/84	6.5	91	12.0	13.0	34.1	1.5	32	<0.2	2.6	3.0	12.0
03/06/84	4.8	132	12.1	13.1	46.6	1.5	51	<0.2	2.1	1.5	3.1

Table 9. Continued.

Date	pH	Cond. (μmho/cm.)	DO	Acid.	Hard.	Alk.	SO_4	Fe	Mn	Cl	Turb. (NTU)
04/02/84	4.8	126	12.2	11.9	42.8	2.8	47	0.20	1.7	1.5	1.8
05/15/84	4.5	179	9.8	17.8	65.2	1.5	66	<0.2	3.0	1.5	---
06/04/84	4.3	260	9.5	22.9	93.0	0.0	>80	<0.2	4.0	2.0	0.9
07/12/84	5.5	210	7.9	18.1	101.0	0.0	>80	<0.2	<0.5	2.5	2.1
09/05/84	4.5	325	8.7	18.1	120.0	1.7	>80	<0.2	3.3	5.0	1.0
10/09/84	---	255	9.3	14.8	100.0	2.0	>80	0.25	2.5	1.5	6.3
Minimum	4.3	76	7.0	9.4	29.0	0.0	15	<0.20	<0.5	1.0	0.4
Maximum	6.5	430	13.7	29.3	205.0	5.9	>80	0.42	8.0	12.0	12.0
Average	---	190	10.6	15.4	73.1	2.3	62	0.21	2.6	3.1	3.4
Geometric Mean	4.8	174	10.5	14.7	65.7	---	58	0.21	2.1	2.5	2.3
Standard Deviation	---	85	1.8	5.0	38.4	1.2	19	0.05	1.7	2.5	3.2

Table 10. National Park Service: Mainstem Bear Creek (BC2) Water Quality Analyses 1982-1984 (mg/l).

Date	pH	Cond. (μmho/cm.)	DO	Acid.	Hard.	Alk.	SO_4	Fe	Mn	Cl	Turb. (NTU)
11/01/82	4.5	355	9.1	----	----	---	---	----	---	---	---
01/13/83	4.4	210	13.7	19.4	80.1	0.0	>80	0.25	---	---	4.0
02/22/83	4.1	260	11.8	27.3	102.3	0.0	>80	0.40	---	---	1.1
03/23/83	4.5	180	13.1	19.3	75.2	1.5	>80	0.45	3.7	---	3.6
04/22/83	4.2	175	11.7	15.4	62.0	1.0	77	<0.2	1.8	2.5	2.1
05/12/83	4.5	165	10.5	15.8	80.1	0.0	72	<0.2	1.9	2.5	2.2
06/13/83	4.1	285	9.3	28.1	102.7	0.0	>80	0.25	2.6	2.5	1.4
07/22/83	3.9	320	7.3	30.0	136.0	0.0	>80	<0.2	7.0	2.5	1.0
08/08/83	4.4	310	7.4	19.9	123.4	1.0	>80	<0.2	6.4	2.5	0.9
10/24/83	3.9	490	9.3	56.6	201.0	0.0	>80	0.85	9.9	2.5	1.3
01/26/84	5.5	171	12.6	16.2	55.8	0.0	54	0.20	2.6	2.5	5.8
03/13/84	4.2	271	11.8	30.9	98.2	0.0	>80	1.60	10.0	2.0	87.0
05/16/84	4.3	300	10.4	28.2	104.4	0.0	>80	0.25	4.7	1.0	---
06/27/84	4.2	450	8.4	38.6	150.0	0.0	>80	0.35	7.5	2.0	0.7

Table 10. Continued.

Date	pH	Cond. (μmho/cm.)	DO	Acid.	Hard.	Alk.	SO_4	Fe	Mn	Cl	Turb. (NTU)
07/23/84	4.3	415	8.1	33.0	157.4	0.0	>80	0.20	6.0	2.5	0.8
08/21/84	4.2	---	8.5	33.4	145.0	0.0	>80	0.20	5.1	2.0	0.7
10/11/84	4.1	420	8.5	45.3	168.0	0.0	>80	0.50	5.0	1.5	1.0
Minimum	3.9	165	7.3	15.4	55.8	0.0	54	<0.20	1.8	1.0	0.7
Maximum	5.5	490	13.7	56.6	201.0	1.5	>80	1.60	10.0	2.5	87.0
Average	---	299	10.1	28.6	115.1	0.2	77.7	0.39	5.3	2.2	7.6
Geometric Mean	4.3	281	9.9	26.6	108.1	---	77.4	0.31	4.6	2.1	2.0
Standard Deviation	---	105	2.0	11.4	41.4	0.5	6.7	0.37	2.7	0.5	22.0

Table 11. Metals in Sediment of Bear Creek and the Big South Fork Cumberland River October 1988 (mg/kg).*

Metal	Bear Creek	Big South Fork above Bear Creek	Big South Fork below Bear Creek
Aluminum	4,900	854	1,680
Arsenic	3.46	<0.194	1.56
Cadmium	<0.010	<0.010	<0.010
Chromium	5.50	2.03	4.40
Copper	6.45	2.24	3.63
Iron	11,000	2,370	4,620
Lead	7.40	2.33	5.00
Manganese	503	475	1,100
Mercury	0.019	0.016	0.019
Nickel	12.7	6.32	12.4
Zinc	39.5	11.5	26.0

*Kentucky Division of Water.

Table 12. TDEC: June 1990 Storm Event Water Quality Analyses (mg/l).

Parameter	Site EB-4	Site BR-1 (BC1)	Site LF-4
pH	3.9	4.7	6.7
Conductivity (μmho/cm)	369	181	26.9
Turbidity (NTU)	41	0.5	3.8
Aluminum	3.03	0.73	0.28
Arsenic	<0.005	<0.005	<0.005
Cadmium	<0.005	<0.005	<0.005
Chromium	<0.005	<0.005	<0.005
Copper	<0.01	<0.01	<0.01
Iron	0.080	0.024	0.014
Lead	<0.005	<0.005	<0.005
Manganese	7.050	2.620	0.388
Mercury	<0.001	<0.001	<0.001
Nickel	0.11	0.05	<0.01
Zinc	0.103	0.061	<0.005

Table 13. TDEC: July 1990 Storm Event Water Quality Analyses (mg/l).

Parameter	Site BR-1 (BC1)	Site EB-5	Site CB-3	Site LF-4
pH	5.1	6.4	3.2	6.8
Conductivity (μmho/cm)	110	263	789	31
Hardness	51	156	352	13
Turbidity (NTU)	13.8	12.0	20.0	14.5
Chloride	1.13	5.21	4.13	1.57
Alkalinity	0.5	10.1	<0.1	8.5
SO_4	56.5	157.0	512.0	5.54
Aluminum (total)	0.50	0.04	12.7	0.44
Aluminum (dissolved)	0.42	0.04	12.7	0.14
Arsenic (total)	<0.02	<0.02	<0.02	<0.02
Arsenic (dissolved)	<0.02	<0.02	<0.02	<0.02
Cadmium (total)	<0.005	<0.005	<0.005	<0.005
Cadmium (dissolved)	<0.005	<0.005	<0.005	<0.005
Chromium (total)	<0.005	<0.005	<0.005	<0.005
Chromium (dissolved)	<0.005	<0.005	<0.005	<0.005
Copper (total)	<0.005	<0.005	<0.005	<0.005
Copper (dissolved)	<0.005	<0.005	<0.005	<0.005
Iron (total)	0.199	0.074	5.710	0.592
Iron (dissolved)	0.023	0.020	5.71	0.372
Lead (total)	<0.002	<0.002	0.016	<0.002
Lead (dissolved)	<0.002	<0.002	-----	<0.002
Manganese (total)	1.90	5.97	17.30	<0.005
Mercury (total)	<0.005	<0.005	<0.005	<0.005
Nickel (total)	0.02	0.05	0.35	<0.01
Nickel (dissolved)	<0.01	0.05	0.23	<0.01
Zinc (total)	0.046	0.044	0.512	<0.005
Zinc (dissolved)	0.046	0.044	0.464	<0.005

Table 14. TDEC: June 1992 Storm Event Water Quality Sampling, Site EB4 (mg/l).

Date Time	pH	Cond. (μmho/cm)	D.O.	Acid.	Hard.	SO_4	Staff Gauge (ft.)
Baseline 06/03/92 2:50 P.M.	5.8	210	6.7	---	---	---	0.58
06/03/92 9:40 P.M.	6.2	210	8.3	15	144	165	0.68
06/03/92 10:20	6.3	360	6.8				0.80
06/03/92 10:40	4.6	290	6.6				0.84
06/03/92 11:10	5.2	210	6.5	6	105	86	0.95
06/03/92 11:40	6.4	290	6.4				1.00
06/04/92 12:10 A.M.	6.3	160	6.1				1.00
06/04/92 12:40	6.5	190	8.2	10	107	91	0.98
06/04/92 1:10	6.3	200	8.3				0.94
06/04/92 1:40	6.6	160	8.3				0.92
06/04/92 2:10 A.M.	6.3	190	8.5				0.92

Acidity, hardness, and sulfate values are based on composite samples taken from 9:40-10:40, 11:10-12:10, and 12:40-2:40.

Table 14. Continued (Site CH3G).

Date Time	pH	Cond. (μmho/cm)	D.O.	Acid.	Hard.	SO_4	Staff Gauge (ft.)
Baseline 06/03/92 2:35 P.M.	3.2	750	5.3				0.00
06/03/92 9:55 P.M.	3.0	650	5.7	89	261	327	0.10
06/03/92 10:25	2.9	475	5.8				0.20
06/03/92 10:55	3.0	550	4.7				0.30
06/03/92 11:25	3.1	520	4.7	71	254	279	0.40
06/03/92 11:55	3.0	510	5.0				0.35
06/04/92 12:25 A.M.	3.4	510	5.5				0.35
06/04/92 12:55	3.3	510	5.4	75	243	279	0.32
06/04/92 1:25	3.3	530	5.2				0.32
06/04/92 2:25 A.M.	3.4	550	5.7				0.28

Acidity, hardness, and sulfate values are based on composite samples taken from 9:55-10:55, 11:25-12:25, and 12:55-2:25.

Table 14. Continued (Site SU2).

Date Time	pH	Cond. (μmho/cm)	D.O.	Acid.	Hard.	SO_4	Staff Gauge (ft.)
Baseline 06/03/92 12:30 A.M.	3.1	1200	5.2				0.08
06/03/92 10:10 P.M.	3.1	890	5.0	135	396	606	0.16
06/03/92 10:40	3.0	900	5.7				0.20
06/03/92 11:10	3.0	950	5.1				0.20
06/03/92 11:40	2.9	750	4.9	133	394	606	0.20
06/04/92 12:10 A.M.	3.0	1000	5.3				0.18
06/04/92 12:40	3.0	950	5.5				0.18
06/04/92 1:40	3.2	900	5.2	128	366	606	0.15
06/04/92 2:40 A.M.	3.4	920	5.5				0.13

Acidity, hardness, and sulfate values are based on composite samples taken from 10:10-11:10, 11:40-12:40, and 1:10-2:40.

Table 14. Continued (μg/l).

EB4	Metal	9:40-10:40 P.M.	11:10-12:10 P.M.	12:40-2:40 A.M.
	Aluminum	3830	7750	11,240
	Arsenic	6	<2	<2
	Barium	53	53	64
	Cadmium	2	2	<1
	Chromium	5	14	14
	Cobalt	834	492	497
	Copper	13	8	50
	Iron	8980	8840	14,800
	Lead	<4	7	8
	Manganese	5160	2540	3190
	Mercury	<0.2	<0.2	<0.2
	Nickel	98	59	60
	Zinc	140	107	110
CH3G	**Metal**	**9:55-10:55 P.M.**	**11:25-12:25 A.M.**	**12:55-2:25 A.M.**
	Aluminum	7480	5240	5800
	Arsenic	<2	<2	<2
	Barium	71	60	64
	Cadmium	6	1	1
	Chromium	2	2	1
	Cobalt	167	153	160
	Copper	35	29	16
	Iron	5950	3210	2960
	Lead	<4	<4	<4
	Manganese	10,200	9540	9740
	Mercury	0.2	0.3	<0.2
	Nickel	204	178	192
	Zinc	301	305	276

Table 14. Continued.

SU2	Metal	10:10-11:10 P.M.	11:40-12:40 A.M.	1:10-2:40 A.M.
	Aluminum	13,800	15,200	14,000
	Arsenic	<2	<2	<2
	Barium	41	72	57
	Cadmium	19	2	2
	Chromium	<1	2	2
	Cobalt	421	459	416
	Copper	34	32	32
	Iron	6550	5880	4940
	Lead	<4	<4	<4
	Manganese	28,000	27,600	26,400
	Mercury	<0.2	0.3	0.3
	Nickel	452	497	457
	Zinc	611	672	614

Table 15. TDEC: November 1992 Storm Event Water Quality Sampling, Site EB4 (mg/l).

Date Time	pH	Cond. (μmho/cm)	D.O.	Acid.	Hard.	SO_4	Staff Gauge (ft.)
Baseline 11/12/92 11:00 A.M.	7.49	281	9.6				0.52
11/12/92 2:10 P.M.	7.30	277	8.1	4	124	83	0.58
11/12/92 4:45	----	---	---				0.57
11/12/92 5:00	7.46	282	7.9				0.66
11/12/92 5:10	7.40	229	7.6				0.69
11/12/92 5:25	7.25	218	7.2	8	98	64	0.70
11/12/92 5:35	7.48	221	7.4				0.70
11/12/92 5:45	7.48	221	6.6				0.70
11/12/92 5:55	7.29	261	6.1				0.70
11/12/92 6:10	7.36	252	6.1				0.69
11/12/92 6:25	7.46	254	6.3	<1	124	76	0.69
11/12/92 6:35	7.53	259	5.2				0.68
11/12/92 6:45	7.38	262	4.8				0.68
11/12/92 6:55 P.M.	7.37	264	5.3				0.68

Acidity, hardness, and sulfate values are based on composite samples taken from 2:10-5:10, 5:25-5:55, and 6:20-6:55.

Table 15. Continued (Site SU2).

Date Time	pH	Cond. (μmho/cm)	D.O.	Acid.	Hard.	SO_4	Staff Gauge (ft.)
Baseline 11/12/92 10:30 A.M.	3.2	900	9.0				0.08
11/12/92 1:30 P.M.	2.9	820	9.4	112	534	556	0.15
11/12/92 1:45	2.9	800	9.4				0.16
11/12/92 2:00	2.9	800	9.0				0.17
11/12/92 2:15	2.9	700	9.2				0.19
11/12/92 2:30	2.9	700	9.6				0.195
11/12/92 5:00	2.8	750	9.4				0.20
11/12/92 5:10	2.8	750	9.4				0.20
11/12/92 5:20	2.8	690	9.2				0.21
11/12/92 5:30	2.9	610	9.4				0.22
11/12/92 6:00	2.9	650	9.0				0.24
11/12/92 6:10	2.8	690	9.6				0.24
11/12/92 6:20	2.9	700	9.6				0.24
11/12/92 6:30	2.9	710	9.6	114	398	551	0.24
11/12/92 6:40	2.9	750	9.4				0.24
11/12/92 6:50	2.9	750	8.9	111	658	604	0.24
11/12/92 7:00	2.8	750	9.0				0.24
11/12/92 7:10	2.8	750	9.0				0.23
11/12/92 7:20 P.M.	2.9	700	9.2				0.23

Acidity, hardness, and sulfate values are based on composite samples taken from 1:30-2:15, 6:25-645, and 6:50-7:20.

Table 15. Continued (Site CH3G).

Date Time	pH	Cond. (μmho/cm)	D.O.	Acid.	Hard.	SO_4	Staff Gauge (ft.)
Baseline 11/12/92 11:30 A.M.	3.12	700	7.8				0.00
11/12/92 1:25 P.M.	3.16	600	7.8	105	267	320	0.10
11/12/92 1:45	3.33	610	7.3				0.16
11/12/92 2:15	3.28	690	7.3				0.17
11/12/92 4:45	----	---	---				0.16
11/12/92 5:00	3.32	650	7.8				0.23
11/12/92 6:00	3.48	600	7.8				0.25
11/12/92 6:15	----	---	---	84	274	320	0.25
11/12/92 6:20	----	---	---				0.25
11/12/92 6:30	3.49	595	8.0				0.25
11/12/92 6:35	----	---	---				0.29
11/12/92 6:40	----	---	---				0.29
11/12/92 6:45	3.47	595	8.0				0.29
11/12/92 6:55	----	---	---				0.30
11/12/92 7:00	----	---	---				0.28
11/12/92 7:05	3.40	575	8.0				0.28
11/12/92 7:15	----	---	---	86	265	370	0.28
11/12/92 7:20	----	---	---				0.28
11/12/92 7:25	3.40	510	8.0				0.28
11/12/92 7:35	----	---	---				0.27
11/12/92 7:40	----	---	---				0.26
11/12/92 7:45	3.38	550	8.0				0.25

Acidity, hardness, and sulfate values are based on composite samples taken from 1:20-5:00, 6:10-6:45, and 7:15-7:45.

Table 15. Continued (μg/l).

EB4	Metal	2:10-5:10 P.M.	5:25-5:55 P.M.	6:20-6:55 P.M.
	Aluminum	2840	4160	4130
	Arsenic	<2	<2	<2
	Barium	26	21	30
	Cadmium	<1	<1	<1
	Chromium	1	3	2
	Cobalt	32	30	35
	Copper	12	3	7
	Iron	3460	2980	4960
	Lead	<4	<4	<4
	Manganese	2950	2630	3060
	Mercury	<0.2	<0.2	<0.2
	Nickel	34	35	37
	Zinc	55	50	69
CH3G	**Metal**	**1:20-5:00 P.M.**	**6:10-6:45 P.M.**	**7:15-7:45 P.M.**
	Aluminum	9280	7940	7900
	Arsenic	<2	<2	<2
	Barium	15	29	20
	Cadmium	<1	<1	<1
	Chromium	4	1	1
	Cobalt	180	174	172
	Copper	16	14	16
	Iron	6550	3750	3310
	Lead	<4	<4	<4
	Manganese	9020	8400	10,900
	Mercury	<0.2	<0.2	<0.2
	Nickel	192	186	190
	Zinc	313	358	362

Table 15. Continued.

SU2	Metal	1:30-2:15 P.M.	6:25-6:45 P.M.	6:50-7:20 P.M.
	Aluminum	10,400	11,200	13,800
	Arsenic	<2	<2	<2
	Barium	10	15	<1
	Cadmium	<1	<1	<1
	Chromium	2	2	<1
	Cobalt	434	421	490
	Copper	9	6	7
	Iron	7030	4760	4370
	Lead	<4	<4	<4
	Manganese	2430	20,400	22,900
	Mercury	<0.2	<0.2	<0.2
	Nickel	385	404	456
	Zinc	477	490	595

Table 16. East Branch Bear Creek Site No. SU2 Water Quality Analyses (mg/l). TDEC 1993-1995.

Date	Staff Gauge (ft.)	D.O.	pH	Cond. (μmho/cm)	Acid.	Hard.	SO_4
12-06-93	0.78	9.2	**5.66***	707	81	297	**376**[1]
12-13-93	0.06	10.6	**4.09***	1122	126	422	**593**[1]
12-20-93	0.06	7.1	**4.35***	1567	139	640	**874**[1]
12-28-93	0.12	8.6	**3.98***	1465	147	621	**899**[1]
1-03-94	0.10	---	**3.70***	981	152	571	**786**[1]
1-10-94	0.08	8.4	**3.86***	1411	177	504	**808**[1]
1-24-94	0.10	---	**3.80***	1556	182	750	**860**[1]
2-01-94	0.95	9.8	**3.38***	1686	227	555	**901**[1]
2-08-94	0.08	9.1	**3.23***	1922	194	627	**1045**[1]
2-15-94	0.16	8.7	**3.35***	1258	5	---	46
2-22-94	0.11	9.9	**3.13***	1512	189	450	**770**[1]
3-01-94	0.10	10.4	**3.44***	1612	212	555	**924**[1]
3-08-94	0.12	8.8	**3.83***	1147	183	479	**745**[1]
3-15-94	0.10	8.4	**3.34***	1696	200	855	**560**[1]
3-31-94	----	10.8	**3.44***	800	132	588	**1320**[1]
4-28-94	0.13	**4.3****	**3.27***	1150	136	593	**1890**[1]
5-12-94	0.08	6.8	**3.46***	1400	132	968	**1800**[1]
5-26-94	0.08	**4.6****	**3.37***	1500	91	282	**411**[1]
6-08-94	0.02	**3.4****	**3.42***	1500	146	631	**1000**[1]

Table 16. Continued.

Date	Staff Gauge (ft.)	D.O.	pH	Cond. (μmho/cm)	Acid.	Hard.	SO_4
6-23-94	0.0	3.0**	3.34*	1400	140	674	2130[1]
7-06-94	<0.0	1.5**	3.27*	1300	162	735	985[1]
8-04-94	<0.0	1.4**	3.57*	1350	183	747	3980[1]
9-01-94	0.0	2.8**	3.44*	900	103	798	555[1]
10-07-94	<0.0	0.4**	4.40*	1200	220	855	1100[1]
11-03-94	0.03	1.6**	3.80*	1100	177	639	1230[1]
11-17-94	0.04	1.4**	4.20*	1225	212	934	1220[1]
11-29-94	0.03	7.1	3.80*	883	34	392	530[1]
12-15-94	0.04	---	----	----	89	570	775[1]
1-11-95	0.02	9.7	6.90	852	42	186	574[1]
1-27-95	0.04	10.3	4.49*	1274	107	755	945[1]
2-08-95	----	10.2	4.43*	132	99	812	1450[1]
2-22-95	0.04	11.9	3.77*	1355	<2	715	2238[1]
Average	0.13	6.90	----	1256.87	142.55	619.36	1072.50[1]
Minimum	0.00	0.40**	3.13*	132.00	5.00	186.00	46.00
Maximum	0.95	11.90	6.90	1922.00	227.00	968.00	3980.00[1]
Geometric Mean	----	5.43**	----	1171.35	122.14	585.79	872.15[1]
Standard Deviation	0.22	3.56	----	355.77	55.97	187.22	724.99

* = Tn. and Ky. Water Quality Criteria (Fish and Aquatic Life/Warm Water Aquatic Habitat) for pH Exceeded. Tn. Domestic Water Supply and Ky. Recreational Waters Criteria for pH Exceeded.

** = Tn. and Ky. Water Quality Criteria (Fish and Aquatic Life/Warm Water Aquatic Habitat) for D.O. Exceeded.

[1] = Federal SMCL and Kentucky Maximum In-stream Concentration (Drinking Water) for Sulfate Exceeded.

Table 16. Continued (μg/l).

Date	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
12-06-93	**8840**[3]	<2	11	**5**[1,5,6]	232	<1	**12**[5,6]	**3500**[3,6]	**7800**[3,4]	**307**[1,5,6]	<4	**254**[5,6]
12-13-93	**14,500**[3]	<2	<1	**8**[1,5,6]	458	<1	**13**[5,6]	**4600**[3,6]	**25,500**[3,4]	**493**[1,5,6]	<4	**712**[5,6]
12-20-93	**16,600**[3]	<2	7	**5**[1,5,6]	598	<1	**18**[5,6]	**4970**[3,6]	**29,500**[3,4]	**753**[1,4,5,6]	<4	**903**[5,6]
12-28-93	**18,800**[3]	<2	<1	**9**[1,5,6]	272	<1	**29**[5,6]	**4420**[3,6]	**34,100**[3,4]	**724**[1,4,5,6]	<4	**977**[5,6]
1-03-94	**8080**[3]	<2	28	**8**[1,5,6]	290	<1	**27**[5,6]	**5110**[3,6]	**13,700**[3,4]	**689**[1,4,5,6]	<4	**902**[5,6]
1-10-94	**20,600**[3]	<2	<1	**3**[5,6]	161	<1	**31**[5,6]	**6640**[3,6]	**25,100**[3,4]	**690**[1,4,5,6]	**5**[2,5,6,7]	**842**[5,6]
1-24-94	**20,400**[3]	<2	<1	**2**[5,6]	466	<1	**55**[5,6]	**7550**[3,6]	**26,500**[3,4]	**458**[1,5,6]	<4	**918**[5,6]
2-01-94	**2260**[3]	<2	66	<1	293	<1	**48**[5,6]	**10,600**[3,6]	**25,300**[3,4]	**439**[1,5,6]	<4	**398**[5,6]
2-08-94	**21,100**[3]	<2	57	<1	358	<1	**35**[5,6]	**12,000**[3,6]	**39,500**[3,4]	**499**[1,5,6]	<4	**551**[5,6]
2-15-94	**23,000**[3]	<2	10	**5**[1,5,6]	471	2	**61**[5,6]	**17,100**[3,6]	**31,200**[3,4]	**400**[1,5,6]	<4	**496**[5,6]
2-22-94	**18,400**[3]	<2	14	**6**[1,5,6]	456	1	**23**[5,6]	**11,300**[3,6]	**27,900**[3,4]	**750**[1,4,5,6]	<4	**775**[5,6]
3-01-94	**17,900**[3]	<2	<1	**1**[5,6]	545	2	**32**[5,6]	**20,900**[3,6]	**35,200**[3,4]	**336**[1,5,6]	**7**[2,5,6,7]	**406**[5,6]
3-08-94	**17,600**[3]	<2	<1	**2**[5,6]	457	1	**27**[5,6]	**14,000**[3,6]	**26,400**[3,4]	**645**[1,4,5,6]	**7**[2,5,6,7]	**588**[5,6]
3-15-94	**22,000**[3]	<5	20	<5	550	<1	**40**[5,6]	**20,600**[3,6]	**38,900**[3,4]	**740**[1,4,5,6]	**3**[2,5,6]	**890**[5,6]
3-31-94	**2600**[3]	---	<100	<5	<15	---	<5	**3880**[3,6]	**2240**[3,4]	30	---	**60**[5,6]
4-28-94	**16,200**[3]	---	<100	<1	470	---	<5	**12,200**[3,6]	**27,700**[3,4]	**550**[1,5,6]	---	**670**[5,6]
5-12-94	**16,900**[3]	---	<100	<5	540	---	**40**[5,6]	----	**37,700**[3,4]	**650**[1,4,5,6]	---	**790**[5,6]
5-26-94	**10,800**[3]	---	<100	<5	160	---	**20**[5,6]	**7460**[3,6]	**10,190**[3,4]	**260**[1,5,6]	---	**410**[5,6]
6-08-94	**14,200**[3]	---	<100	<2	497	---	**20**[5,6]	**7960**[3,6]	**38,200**[3,4]	**552**[1,5,6]	---	**681**[5,6]
6-23-94	**13,900**[3]	---	<100	<2	474	---	**10**[5,6]	**9370**[3,6]	**34,900**[3,4]	**502**[1,5,6]	---	**597**[5,6]

Table 16. Continued.

Date	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
7-06-94	**12,700**[3]	---	<100	<2	604	---	**10**[5,6]	**12,300**[3,6]	**46,200**[3,4]	**548**[1,5,6]	---	**630**[5,6]
8-04-94	**12,600**[3]	---	<10	<1	722	---	<5	**25,000**[3,6]	**43,100**[3,4]	**510**[1,5,6]	---	**480**[5,6]
9-01-94	**13,500**[3]	---	<10	**1**[5,6]	452	---	<5	**7548**[3,6]	**23,000**[3,4]	**417**[1,5,6]	<3	**555**[5,6]
10-07-94	**9210**[3]	---	<10	<1	948	---	**7**[5,6]	**44,000**[3,6]	**61,500**[3,4]	**439**[1,5,6]	---	**407**[5,6]
11-03-94	**9880**[3]	---	20	<2	802	---	<8	**29,600**[3,6]	**63,600**[3,4]	**490**[1,5,6]	---	**447**[5,6]
11-17-94	**8810**[3]	---	44	<1	876	---	<5	**49,000**[3,6]	**69,500**[3,4]	**452**[1,5,6]	---	**368**[5,6]
11-29-94	**7980**[3]	---	88	**1**[5,6]	294	---	<5	**10,400**[3,6]	**23,500**[3,4]	**274**[1,5,6]	---	**327**[5,6]
12-15-94	**6290**[3]	---	20	<2	415	---	**9**[5,6]	**9570**[3,6]	**28,300**[3,4]	**326**[1,5,6]	---	**378**[5,6]
1-11-95	**5000**[3]	---	<10	<5	---	---	<10	**5900**[3,6]	**21,400**[3,4]	**320**[1,5,6]	---	**320**[5,6]
1-27-95	**13,100**[3]	---	<10	<5	---	---	<10	**3820**[3,6]	**3100**[3,4]	**480**[1,5,6]	---	**680**[5,6]
2-08-95	**15,800**[3]	---	40	<5	590	---	**18**[5,6]	**6110**[3,6]	**37,300**[3,4]	**621**[1,4,5,6]	---	**741**[5,6]
2-22-95	**17,200**[3]	---	<100	<5	509	---	**18**[5,6]	**4750**[3,6]	**32,400**[3,4]	**582**[1,5,6]	---	**287**[5,6]
Average	**13,648.4**[3]	---	40.0	**3.5**[5,6]	481.4	---	**20.7**[5,6]	**12,650.3**[3,6]	**30,950.9**[3,4]	**497.7**[1,5,6]	**4.4**[2,5,6]	**576.3**[5,6]
Minimum	**2260.0**[3]	---	1.0	**1.0**[5,6]	160.0	---	5.0	**3500.0**[3,6]	**2240.0**[3,4]	30.0	**3.0**[2,5,6]	**60.0**[5,6]
Maximum	**23,000.0**[3]	---	100.0	**9.0**[1,5,6]	948.0	---	**61.0**[5,6]	**49,000.0**[3,6]	**69,500.0**[3,4]	**753.0**[1,4,5,6]	**7.0**[2,5,6,7]	**977.0**[5,6]
Geometric Mean	**12,100.2**[3]	---	16.7	**2.7**[5,6]	442.4	---	**15.5**[5,6]	**9658.8**[3,6]	**25,634.9**[3,4]	**450.4**[1,5,6]	**4.3**[2,5,6]	**517.0**[5,6]
Standard Deviation	5588.8	---	40.4	2.4	191.8	---	15.5	11,111.2	15,477.1	166.9	1.2	229.9

[1] = Federal MCL and Tn. Domestic Water Supply Criteria Exceeded.
[2] = Federal MCLG Exceeded.
[3] = Federal SMCL Exceeded.
[4] = Kentucky Maximum Allowable In-stream Concentration (Drinking Water) Exceeded.
[5] = Tennessee Fish and Aquatic Life Criteria Exceeded.
[6] = Kentucky Warm Water Aquatic Habitat Criteria Exceeded.
[7]=Tennessee Domestic Water Supply Criteria Exceeded.

--- = Not Analyzed

Table 17. East Branch Bear Creek Site No. CH3 Water Quality Analyses (mg/l). TDEC 1993-1995.

Date	Staff Gauge (ft.)	D.O.	pH	Cond. (μmho/cm)	Acid.	Hard.	SO_4
12-06-93	0.05	8.1	**4.13***	701	107	242	**470**[1]
12-13-93	0.00	10.2	**3.73***	824	120	256	**394**[1]
12-20-93	0.00	7.1	**3.82***	933	137	297	**447**[1]
12-28-93	0.06	6.7	**3.33***	830	104	295	**349**[1]
1-03-94	0.00	---	**3.21***	445	118	272	**368**[1]
1-10-94	0.08	8.0	**3.32***	726	123	243	**328**[1]
1-24-94	0.02	---	----	897	119	298	**443**[1]
2-01-94	0.50	10.8	**3.25***	793	138	210	**364**[1]
2-08-94	0.29	10.0	**3.28***	859	153	219	**376**[1]
2-15-94	0.61	11.1	**3.28***	746	113	---	**304**[1]
2-22-94	0.32	9.8	**4.06***	708	111	214	**296**[1]
3-01-94	0.36	10.4	**4.04***	344	123	188	**350**[1]
3-08-94	0.77	8.4	**4.17***	493	102	226	**289**[1]
3-15-94	0.63	7.5	**3.59***	731	119	289	**355**[1]
3-31-94	0.86	10.1	**3.84***	350	75	192	**324**[1]
4-28-94	1.49	5.8	**3.42***	600	83	236	**368**[1]
5-12-94	1.38	**4.8****	**3.76***	700	79	265	90
5-26-94	1.00	**4.0****	**3.58***	700	25	65	91
6-08-94	1.36	**3.2****	**3.47***	800	100	281	101

Table 17. Continued.

Date	Staff Gauge (ft.)	D.O.	pH	Cond. (μmho/cm)	Acid.	Hard.	SO_4
6-23-94	1.32	**3.4****	**3.37***	900	126	339	**555**[1]
7-06-94	1.22	**2.5****	**3.20***	1050	143	352	**538**[1]
8-04-94	1.02	**2.6****	**3.46***	950	138	376	**795**[1]
9-01-94	1.34	**3.8****	**3.24***	800	93	285	**510**[1]
10-07-94	1.32	**2.2****	**3.85***	750	96	379	**538**[1]
11-03-94	1.38	**5.6****	**3.60***	650	110	540	**308**[1]
11-17-94	1.40	10.6	**3.50***	800	126	410	**418**[1]
11-29-94	1.34	8.4	**3.40***	826	97	322	**433**[1]
12-15-94	1.30	---	---	---	113	363	**520**[1]
1-11-95	1.34	10.2	**3.27***	763	74	190	**426**[1]
1-27-95	1.34	11.3	**3.99***	755	97	311	**475**[1]
2-08-95	----	9.8	**4.14***	738	93	312	**650**[1]
2-22-95	1.37	13.1	**3.71***	722	<2	352	**384**[1]
Average	0.82	7.57	----	738.19	108.23	284.48	**395.53**[1]
Minimum	0.00	**2.20****	**3.20***	344.00	25.00	65.00	90.00
Maximum	1.49	13.10	**4.17***	1050.00	153.00	540.00	**795.00**[1]
Geometric Mean	----	6.76	----	717.42	104.08	269.81	**360.16**[1]
Standard Deviation	0.56	3.17	----	160.19	25.23	85.71	146.71

* = Tn. and Ky. Water Quality Criteria (Fish and Aquatic Life/Warm Water Aquatic Habitat) for pH Exceeded. Tn. Domestic Water Supply and Ky. Recreational Waters Criteria for pH Exceeded.

** = Tn. and Ky. Water Quality Criteria (Fish and Aquatic Life/Warm Water Aquatic Habitat) for D.O. Exceeded.

[1] = Federal SMCL and Kentucky Maximum In-stream Concentration (Drinking Water) for Sulfate Exceeded.

Table 17. Continued (μg/l).

Date	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
12-06-93	-----	<2	13	---	165	<1	**25**[5,6]	**3990**[3,6]	**8680**[3,4]	**262**[1,5,6]	<4	**437**[5,6]
12-13-93	**14,100**[3]	<2	8	**5**[1,5,6]	199	1	**20**[5,6]	**5280**[3,6]	**11,600**[3,4]	**296**[1,5,6]	<4	**416**[5,6]
12-20-93	**14,600**[3]	<2	14	**6**[1,5,6]	229	<1	**12**[5,6]	**5820**[3,6]	**13,700**[3,4]	**325**[1,5,6]	<4	**403**[5,6]
12-28-93	**10,600**[3]	<2	<1	**4**[5,6]	175	<1	**15**[5,6]	**3560**[3,6]	**8930**[3,4]	**247**[1,5,6]	<4	**504**[5,6]
1-03-94	**10,700**[3]	<2	13	**4**[5,6]	197	<1	**26**[5,6]	**4660**[3,6]	**11,200**[3,4]	**249**[1,5,6]	<4	**371**[5,6]
1-10-94	**13,000**[3]	<2	8	**4**[5,6]	162	<1	**18**[5,6]	**4060**[3,6]	**8440**[3,4]	**271**[1,5,6]	**5**[2,5,6,7]	**408**[5,6]
1-24-94	**8760**[3]	<2	5	<1	187	<1	**20**[5,6]	**4170**[3,6]	**9050**[3,4]	**289**[1,5,6]	<4	**427**[5,6]
2-01-94	**1520**[3]	<2	31	<1	161	<1	**17**[5,6]	**4340**[3,6]	**8940**[3,4]	**108**[1,5,6]	<4	**233**[5,6]
2-08-94	**16,400**[3]	<2	37	<1	191	3	**15**[5,6]	**4280**[3,6]	**10,100**[3,4]	**171**[1,5,6]	**5**[2,5,6,7]	**98**[5,6]
2-15-94	**14,800**[3]	<2	6	**3**[5,6]	140	<1	**61**[5,6]	**3720**[3,6]	**7380**[3,4]	**161**[1,5,6]	<4	**226**[5,6]
2-22-94	**9390**[3]	<2	46	**3**[5,6]	140	<1	**12**[5,6]	**3190**[3,6]	**7800**[3,4]	**140**[1,5,6]	**9**[2,5,6,7]	**344**[5,6]
3-01-94	**10,700**[3]	3	28	<1	158	<1	**8**[5,6]	**3910**[3,6]	**8250**[3,4]	**292**[1,5,6]	**6**[2,5,6,7]	**377**[5,6]
3-08-94	**8400**[3]	<2	11	<1	152	1	**11**[5,6]	**2820**[3,6]	**7850**[3,4]	**111**[1,5,6]	<4	**339**[5,6]
3-15-94	**14,500**[3]	<5	20	<5	150	10	**10**[5,6]	**4110**[3,6]	**9290**[3,4]	**260**[1,5,6]	<3	**370**[5,6]
3-31-94	**10,200**[3]	---	<100	<5	120	---	**10**[5,6]	**2950**[3,6]	**6860**[3,4]	**220**[1,5,6]	---	**300**[5,6]
4-28-94	**9900**[3]	---	<100	<5	190	---	<5	**2680**[3,6]	**8190**[3,4]	**235**[1,5,6]	---	**315**[5,6]
5-12-94	**11,600**[3]	---	<100	<5	180	---	<5	**4040**[3,6]	**9420**[3,4]	**250**[1,5,6]	---	**350**[5,6]
5-26-94	**27,500**[3]	---	180	<5	20	---	**30**[5,6]	**51,100**[3,6]	**2370**[3,4]	60	---	**360**[5,6]
6-08-94	**8320**[3]	---	<100	<2	160	---	**20**[5,6]	**5950**[3,6]	**10,900**[3,4]	**239**[1,5,6]	---	**300**[5,6]
6-23-94	**9100**[3]	---	<100	<2	172	---	**10**[5,6]	**9720**[3,6]	**12,000**[3,4]	**247**[1,5,6]	---	**303**[5,6]
7-06-94	**8210**[3]	---	<100	<2	156	---	<5	**12,600**[3,6]	**12,000**[3,4]	**235**[1,5,6]	---	**258**[5,6]

Table 17. Continued (μg/l).

Date	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
8-04-94	**8300**[3]	---	44	<1	151	---	**130**[5,6]	**22,000**[3,6]	**14,100**[3,4]	**169**[1,5,6]	---	**85**[5,6]
9-01-94	**9390**[3]	---	<10	<1	170	---	<5	**7221**[3,6]	**11,100**[3,4]	**220**[1,5,6]	---	**458**[5,6]
10-07-94	**6760**[3]	---	<10	<1	170	---	<5	**13,442**[3,6]	**12,900**[3,4]	**128**[1,5,6]	---	**181**[5,6]
11-03-94	**8620**[3]	---	30	<2	148	---	**10**[5,6]	**12,600**[3,6]	**15,100**[3,4]	**174**[1,5,6]	---	**190**[5,6]
11-17-94	**8990**[3]	---	88	<1	114	---	<5	**10,800**[3,6]	**14,700**[3,4]	**167**[1,5,6]	---	**168**[5,6]
11-29-94	**10,100**[3]	---	<10	**1**[5,6]	144	---	<5	**5800**[3,6]	**8330**[3,4]	**167**[1,5,6]	---	**240**[5,6]
12-15-94	**11,800**[3]	---	28	<2	184	---	**9**[5,6]	**6620**[3,6]	**11,300**[3,4]	**210**[1,5,6]	---	**294**[5,6]
1-11-95	**10,400**[3]	---	<100	<5	---	---	<10	**3700**[3,6]	**10,200**[3,4]	**230**[1,5,6]	---	**270**[5,6]
1-27-95	**11,200**[3]	---	<100	<5	230	---	<10	**3380**[3,6]	**10,000**[3,4]	**200**[1,5,6]	---	**290**[5,6]
2-08-95	**13,100**[3]	---	30	<5	183	---	5	**5100**[3,6]	**11,100**[3,4]	**217**[1,5,6]	---	**307**[5,6]
2-22-95	**11,200**[3]	---	<100	<5	157	---	**14**[5,6]	**2870**[3,6]	**9100**[3,4]	**196**[1,5,6]	---	**285**[5,6]
Average	**11,037.4**[3]	---	49.1	**3.0**[5,6]	163.1	---	**17.6**[5,6]	**7515.1**[3,6]	**10,027.5**[3,4]	**210.8**[1,5,6]	**4.6**[2,5,6]	**309.6**[5,6]
Minimum	**1520.0**[3]	---	1.0	**1.0**[5,6]	20.0	---	5.0	**2680.0**[3,6]	**2370.0**[3,4]	60.0	**3.0**[2,5,6]	**85.0**[5,6]
Maximum	**27,500.0**[3]	---	180.0	**6.0**[1,5,6]	230.0	---	**130.0**[5,6]	**51,100.0**[3,6]	**15,100.0**[3,4]	**325.0**[1,5,6]	**9.0**[2,5,6,7]	**504.0**[5,6]
Geometric Mean	**10,225.9**[3]	---	28.2	**2.4**[5,6]	154.9	---	**12.2**[5,6]	**5591.9**[3,6]	**9612.1**[3,4]	**200.1**[1,5,6]	**4.4**[2,5,6]	**289.7**[5,6]
Standard Deviation	4178.8	---	45.6	1.8	37.3	---	23.2	8982.2	2580.9	61.3	1.5	99.6

[1] = Federal MCL and Tn. Domestic Water Supply Criteria Exceeded.
[2] = Federal MCLG Exceeded.
[4] = Kentucky Maximum Allowable In-stream Concentration (Drinking Water) Exceeded.
[5] = Tennessee Fish and Aquatic Life Criteria Exceeded.
[7] = Tennessee Domestic Water Supply Criteria Exceeded.
--- = Not Analyzed
[3] = Federal SMCL Exceeded.
[6] = Kentucky Warm Water Aquatic Habitat Criteria Exceeded.

Table 18. East Branch Bear Creek Site No. EB4 Water Quality Analyses (mg/l). TDEC 1993-1995.

Date	Staff Gauge (ft.)	D.O.	pH	Cond. (μmho/cm)	Acid.	Hard.	SO_4
12-06-93	0.72	11.1	8.51	137	7	64	58
12-13-93	0.68	11.9	7.79	174	5	71	55
12-20-93	0.58	9.1	6.84	211	5	95	70
12-28-93	0.80	8.6	**5.30***	240	10	111	87
1-03-94	0.66	----	**5.65***	147	8	89	62
1-10-94	0.84	7.5	6.67	138	5	78	59
1-24-94	0.70	----	6.93	313	11	112	108
2-01-94	0.74	11.0	**6.32****	174	8	76	67
2-08-94	0.59	10.2	**5.62***	226	---	---	81
2-15-94	0.92	11.5	**5.93***	147	209	---	**907**[1]
2-22-94	----	9.6	**5.62***	129	6	58	48
3-01-94	0.76	11.2	**5.39***	187	5	83	71
3-08-94	0.91	9.8	**5.68***	174	6	79	55
3-15-94	0.74	10.4	**5.94***	175	8	141	13
3-31-94	1.10	11.1	6.47	480	5	72	70
4-28-94	0.84	5.0	**6.35****	110	5	59	9
5-12-94	0.67	6.2	6.56	150	3	76	128
5-26-94	0.60	**4.4*****	7.06	250	157	585	**1290**[1]
6-08-94	0.65	5.4	6.81	145	4	87	114

Table 18. Continued.

Date	Staff Gauge (ft.)	D.O.	pH	Cond. (μmho/cm)	Acid.	Hard.	SO_4
6-23-94	0.54	**4.4***	7.02	230	6	123	116
7-06-94	0.48	**4.4***	7.05	310	8	210	136
8-04-94	0.40	**3.6***	7.50	1350	5	226	247
9-01-94	0.58	5.2	6.76	900	63	125	72
10-07-94	0.48	**4.4***	7.68	1200	7	247	220
11-03-94	0.66	6.8	**6.20**	1100	14	545	197
11-17-94	0.65	11.8	7.40	350	11	236	151
11-29-94	0.60	10.3	**6.09**	245	10	117	129
12-15-94	0.56	----	----	----	8	109	170
1-11-95	0.68	11.1	**6.46**	852	64	192	81
1-27-95	0.66	11.4	**6.27**	1274	7	102	75
2-08-95	0.70	10.5	6.67	132	4	73	56
2-22-95	0.72	13.5	**5.95***	1355	9	77	105
Average	0.68	8.67	----	419.50	22.03	143.93	159.59
Minimum	0.40	**3.60***	**5.30***	110.00	3.00	58.00	9.00
Maximum	1.10	13.50	8.51	1355.00	209.00	585.00	**1290.00**[1]
Geometric Mean	0.67	8.09	----	288.20	9.47	115.78	94.38
Standard Deviation	0.14	2.98	----	416.91	45.77	126.72	256.88

* = Tn. and Ky. Water Quality Criteria (Fish and Aquatic Life/Warm Water Aquatic Habitat) for pH Exceeded. Tn. Domestic Water Supply Criteria and Ky. Recreational Waters Criteria for pH Exceeded.

** = Tn. Water Quality Criteria (Fish and Aquatic Life) for pH Exceeded.

*** = Tn. and Ky. Water Quality Criteria (Fish and Aquatic Life/Warm Water Aquatic Habitat) for D.O. Exceeded.

[1] = Federal SMCL and Kentucky Maximum In-stream Concentration (Drinking Water) for Sulfate Exceeded.

Table 18. Continued ($\mu g/l$).

Date	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
12-06-93	**1420**[3]	<2	32	**2**[5,6]	17	<1	**7**[5,6]	**1180**[3,6]	**1200**[3,4]	22	<4	56
12-13-93	**1210**[3]	<2	15	**2**[5,6]	21	<1	<1	**859**[3]	**1960**[3,4]	36	<4	28
12-20-93	**1180**[3]	<2	19	<1	32	<1	4	**932**[3]	**2770**[3,4]	31	<4	34
12-28-93	**3920**[3]	<2	20	**1**[5,6]	34	<1	**7**[5,6]	----	**2970**[3,4]	28	<4	58
1-03-94	**2520**[3]	<2	32	**4**[5,6]	31	1	**19**[5,6]	**3280**[3,6]	**2380**[3,4]	28	<4	**59**[5,6]
1-10-94	**1486**[3]	<2	23	<1	16	<1	5	**671**[3]	**1490**[3,4]	26	**5**[2,5,6,7]	35
1-24-94	**3370**[3]	<2	15	<1	30	<1	**44**[5,6]	**1380**[3,6]	**2640**[3,4]	41	**8**[2,5,6,7]	**60**[5,6]
2-01-94	**1320**[3]	<2	20	**2**[5,6]	31	<1	**8**[5,6]	**678**[3]	**1880**[3,4]	32	**7**[2,5,6,7]	41
2-08-94	**1740**[3]	<2	29	**3**[5,6]	39	<1	**25**[5,6]	**1100**[3,6]	**3120**[3,4]	46	**4**[2,5,6]	**68**[5]
2-15-94	**1250**[3]	<2	14	<1	22	<1	2	**794**[3]	**1490**[3,4]	29	<4	55
2-22-94	**1410**[3]	<2	11	<1	17	<1	5	**703**[3]	**1170**[3,4]	17	<4	34
3-01-94	**2070**[3]	<2	7	<1	30	<1	3	**837**[3]	**2270**[3,4]	41	**8**[2,5,6,7]	55
3-08-94	**1810**[3]	<2	10	<1	24	<1	5	**1020**[3,6]	**1720**[3,4]	39	**7**[2,5,6,7]	**78**[5,6]
3-15-94	**2100**[3]	<5	10	<5	20	<10	**10**[5,6]	**760**[3]	**2240**[3,4]	40	<3	50
3-31-94	**2500**[3]	---	<100	<5	<15	---	<5	**1260**[3,6]	**1370**[3,4]	40	---	40
4-28-94	**2000**[3]	---	<100	<5	30	---	<5	**1350**[3,6]	**1550**[3,4]	50	---	40
5-12-94	**900**[3]	---	<100	**7**[1,5,6]	20	<10	**20**[5,6]	**740**[3]	**2600**[3,4]	30	---	70
5-26-94	**19,600**[3]	---	<100	<5	580	---	**10**[5,6]	**9590**[3,6]	**37,500**[3,4]	**660**[1,4,5,6]	---	**800**[5,6]
6-08-94	**655**[3]	---	<100	<2	27	---	**10**[5,6]	**1440**[3,6]	**2480**[3,4]	42	---	40
6-23-94	**600**[3]	---	<100	<2	33	---	<5	**970**[3]	**3600**[3,4]	38	---	40
7-06-94	**465**[3]	---	<100	<2	29	---	<5	**1140**[3,6]	**3730**[3,4]	30	---	39

Table 18. Continued.

Date	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
8-04-94	100	---	<10	<1	<15	<10	<5	**1030**[3,6]	**5380**[3,4]	<30	---	<30
9-01-94	**1575**[3]	---	<10	<1	18	---	<5	**3074**[3,6]	**2800**[3,4]	43	---	30
10-07-94	157	---	<10	<1	61	---	<5	**1356**[3,6]	**5130**[3,4]	<30	---	<20
11-03-94	196	---	30	<2	75	---	<8	**319**[3]	**9380**[3,4]	56	---	**61**[5,6]
11-17-94	<100	---	<10	<1	25	---	<5	280	**6360**[3,4]	<30	---	20
11-29-94	**614**[3]	---	88	<1	25	---	<5	**1000**[3,6]	**3260**[3,4]	<30	---	<20
12-15-94	**950**[3]	---	26	<2	37	---	**8**[5,6]	**1200**[3,6]	**3440**[3,4]	36	---	51
1-11-95	**1000**[3]	---	<100	<5	<30	---	<10	**790**[3]	**2030**[3,4]	<20	---	40
1-27-95	**1300**[3]	---	<100	<5	---	---	<10	**660**[3]	**3000**[3,4]	<20	---	50
2-08-95	**1200**[3]	---	<10	<5	21	---	<5	**857**[3]	**2210**[3,4]	<30	---	31
2-22-95	**1500**[3]	---	<100	<5	<15	---	<5	**756**[3]	**2110**[3,4]	<30	---	40
Average	**1944.3**[3]	---	45.3	**2.6**[5,6]	45.8	---	**8.6**[5,6]	**1355.0**[3,6]	**3975.9**[3,4]	53.2	**5.0**[5,6,7]	**67.9**[5,6]
Minimum	100.0	---	7.0	**1.0**[5,6]	15.0	---	1.0	280.0	**1170.0**[3,4]	17.0	**3.0**[5,6]	20.0
Maximum	**19,600.0**[3]	---	100.0	**7.0**[1,5,6]	580.0	---	**44.0**[5,6]	**9590.0**[3,6]	**37,500.0**[3,4]	**660.0**[1,4,5,6]	**8.0**[5,6,7]	**800.0**[5,6]
Geometric Mean	**1116.6**[3]	---	29.3	2.0	28.6	---	**6.6**[5,6]	**1027.5**[3,6]	**2781.1**[3,4]	35.6	**4.8**[5,6]	45.7
Standard Deviation	3340.5	---	40.0	1.8	100.0	---	8.3	1652.1	6343.7	166.9	1.7	134.4

[1] =Federal MCL Exceeded and Tn. Domestic Water Supply Criteria Exceeded. --- = Not Analyzed
[2] =Federal MCLG Exceeded.
[3] =Federal SMCL Exceeded.
[4] =Kentucky Maximum Allowable In-stream Concentration (Drinking Water) Exceeded.
[5] =Tennessee Fish and Aquatic Life Criteria Exceeded.
[6] =Kentucky Warm Water Aquatic Habitat Criteria Exceeded.
[7] =Tennessee Domestic Water Supply Criteria Exceeded.

Table 19. **Water Quality Standards (Acute/Chronic)[1] Relevant to Bear Creek.**

Parameter	KENTUCKY		TENNESSEE		EPA		
	WAH*	MAIC (DWS)*	FAL*	DWS	MCL*	SMCL*	MCLG*
D.O.	5.0/4.0		5.0/3.0				
pH	6 - 9		6.5 - 9.0			6.5 - 8.5	
SO_4		250				250	
Al						50 - 200	
As (Total)				50	50		
Ba		1000		2000	2000		
Cd	1.8/0.7	10	1.8/0.7	5	5		
Co							
Cr (Total)		50	100	100	100		
Cu	9.2/6.5	1000	9.2/6.5				1300
Fe	4000/1000					300	
Hg	2.4/0.012	0.144	2.4/0.012	2	2		
Mn		50				50	
Ni	789/87.7	610	789/87.7	100	100		
Pb	33.8/1.3	50	33.8/1.3	5			0
Se	20/5	10	20/5	50	50		
Zn	65/58.9		65/58.9			5000	

*WAH - Warmwater Aquatic Habitat
DWS - Domestic Water Supply
MCL - Maximum Contaminant Level
MCLG - Maximum Contaminant Level Goal
MAIC - Maximum Allowable In-stream Concentration (Domestic Water Supply)
FAL - Fish and Aquatic Life
SMCL - Secondary Maximum Contaminant Level

[1]Concentrations for DO and SO_4 are mg/l while values shown for metals are μg/l and for hardness dependent criteria were calculated for aquatic life using a hardness of 50 mg/l.

Table 20. USGS Stream Gauge Data: East Branch Bear Creek Tributary (CH3G) Discharge (CFS).

Day	4/94	5/94	6/94	7/94	8/94	9/94	10/94	11/94	12/94	1/95	2/95	3/95	4/95
1	1.9	2.3	.24	.18	.12	.26	.10	.08	.20	.12	.32	.35	.27
2	1.5	1.3	.24	.16	.11	.23	.10	.07	.18	.13	.39	.31	.27
3	1.5	1.3	.23	.14	.10	.19	.11	.07	.18	.11	.37	.32	.26
4	1.2	1.1	.20	.14	.11	.17	.09	.07	.57	.10	.44	.31	.26
5	1.2	.87	.19	.13	.22	.19	.09	.07	.77	.10	.37	.60	.24
6	2.5	.73	.22	.12	.15	.23	.08	.09	.23	3.7	.37	1.7	.23
7	1.6	1.2	.38	.11	.14	.19	.07	.08	.17	1.3	.36	.85	.22
8	1.2	1.1	.68	.13	.14	.17	.07	.08	.14	.53	.34	8.0	.22
9	1.1	.67	.31	.14	.12	.16	.18	.09	.14	.39	.34	2.2	.22
10	2.4	.56	.29	.13	.11	.15	.13	.11	.90	.32	.40	1.6	.22
11	8.5	.47	.25	.23	.10	.14	.09	.09	.39	.89	.39	1.4	.23
12	8.9	.42	.21	.20	.09	.14	.07	.08	.20	.72	.33	1.1	.69
13	5.4	.38	.19	1.5	.08	.13	.14	.08	.16	.45	.33	.82	.31
14	2.3	.36	.33	.44	.08	.13	.08	.08	.14	6.5	.34	.68	.26
15	9.4	.62	1.0	.29	.09	.14	.06	.08	.13	5.0	5.2	.58	.25
16	5.7	.43	.39	.92	.09	.14	.05	.09	.15	2.1	2.6	.50	.25
17	2.4	.33	.25	.46	.10	.51	.05	.09	.16	1.1	1.3	.45	.34

Table 20. Continued.

Day	4/94	5/94	6/94	7/94	8/94	9/94	10/94	11/94	12/94	1/95	2/95	3/95	4/95
18	1.7	.30	.21	.25	.10	.32	.04	.08	.13	.76	.90	.40	.31
19	1.4	.28	.19	.19	.09	.24	.07	.09	.12	.87	.72	.36	.27
20	1.2	.27	.17	.17	.20	.20	.07	.08	.11	.72	.60	.66	.39
21	.99	.25	.62	.16	1.2	.19	.06	.09	.11	.51	.51	.64	2.4
22	.89	.23	.45	.18	.20	.17	.07	.08	.11	.43	.43	.42	.58
23	.77	.22	.29	.17	.14	.18	.07	.08	.11	.38	.40	.39	1.5
24	.70	.20	.30	.15	.13	.24	.06	.08	.10	.36	.37	.33	1.3
25	.64	.28	.23	.14	.12	.19	.06	.09	.10	.34	.34	.31	.57
26	.62	4.0	.79	.16	1.5	.16	.06	.09	.10	.31	.32	.30	.40
27	2.4	.98	.59	.17	.42	.15	.06	.28	.10	.32	.39	.37	.33
28	.92	.49	.31	.17	.20	.14	.06	3.2	.10	.55	.44	.31	.30
29	7.8	.37	.28	.15	.85	.13	.06	.32	.10	.56	---	.29	.26
30	4.1	.30	.22	.15	.81	.10	.07	.23	.10	.39	---	.29	.37
31	---	.26	---	.13	.85	---	.07	---	.10	.35	---	.27	---
Total	77.83	22.57	10.25	7.76	7.76	5.68	2.44	6.19	6.30	30.41	19.61	27.11	13.72
Min.	.62	.20	.17	.11	.08	.10	.04	.07	.10	.10	.32	.27	.22
Max.	9.4	4.0	1.0	1.5	1.5	.51	.18	3.2	.90	6.5	5.2	8.0	2.4
Mean	2.59	.73	.34	.25	.25	.19	.08	.21	.20	.98	.70	.87	.46

Table 21. USGS Stream Gauge Data: East Branch Bear Creek (EB4) Discharge (CFS).

Day	4/94	5/94	6/94	7/94	8/94	9/94	10/94	11/94	12/94	1/95	2/95	3/95	4/95
1	e12.0	17.0	.76	.67	.09	e1.0	.10	.15	.62	.37	2.9	1.8	1.1
2	9.9	10.0	.70	.46	.08	.55	.09	.12	.51	.50	2.9	1.7	1.1
3	8.8	8.4	.66	.35	.07	.38	.15	.11	.44	.35	2.6	1.7	1.0
4	7.2	7.1	.47	.29	.06	.28	.14	.10	2.2	.34	3.1	1.7	.97
5	7.0	5.9	.39	.26	.32	.27	.13	.10	5.4	.29	2.6	3.5	.87
6	17.0	4.8	.45	.20	.12	.37	.11	.13	2.1	25.0	2.5	13.0	.85
7	15.0	6.6	1.2	e.16	.08	.26	.08	.12	1.3	16.0	2.4	10.0	.82
8	11.0	8.5	4.5	e.20	.07	.20	.05	.10	.93	5.4	2.1	68.0	.77
9	8.2	6.0	1.3	e.30	.06	.17	.48	.10	.77	3.4	2.0	17.0	.76
10	15.0	4.4	1.1	e.25	.05	.15	.27	.16	5.5	2.3	1.4	12.0	.70
11	62.0	3.3	.96	e.45	.05	.13	.15	.13	5.1	5.4	1.3	11.0	.65
12	32.0	2.6	.67	e.35	.04	.09	.11	.11	2.5	8.2	1.2	8.8	2.3
13	51.0	2.0	.53	e5.0	.04	.08	.59	.10	1.6	5.2	1.2	6.4	1.6
14	16.0	1.7	2.2	e2.0	.04	.07	.30	.10	1.2	47.0	1.1	4.8	1.4
15	58.0	3.8	1.7	e.60	.03	.07	.24	.10	.92	41.0	36.0	3.9	1.3
16	37.0	2.6	1.0	e1.5	.03	.07	.19	.12	.91	20.0	23.0	3.1	1.2
17	13.0	1.7	.72	e.40	.03	1.2	.14	.12	1.0	8.8	14.0	2.5	1.4

Table 21. Continued.

Day	4/94	5/94	6/94	7/94	8/94	9/94	10/94	11/94	12/94	1/95	2/95	3/95	4/95
18	7.8	1.3	.62	e.30	.03	.61	.11	.09	.79	5.5	8.6	2.2	1.3
19	5.5	1.1	.40	e.25	.03	.33	.17	.08	.68	5.2	6.1	1.9	1.1
20	3.9	1.0	.31	e.20	.54	.25	.20	.07	.62	4.7	4.8	2.7	1.6
21	2.9	.89	1.6	e.28	3.9	.20	.16	.07	.55	3.8	3.8	4.2	13.0
22	2.4	.79	1.4	.39	.23	.18	.17	.07	.52	3.1	2.9	3.6	7.1
23	1.9	.68	.76	.25	.11	.27	.19	.06	.50	2.6	2.6	3.2	8.4
24	1.5	.61	.87	.16	.07	.48	.15	.05	.45	2.1	2.2	2.4	11.0
25	1.2	.53	.57	.13	.07	.38	.13	.05	.42	1.8	1.8	2.0	6.6
26	.99	19.0	3.8	.29	16.0	.32	.12	.06	.38	1.6	1.8	1.8	4.4
27	6.7	11.0	4.2	.18	2.8	.25	.10	.95	.37	1.6	2.0	2.1	3.2
28	4.9	4.1	2.0	.17	.54	.20	.10	12.0	.34	3.1	2.3	1.6	2.4
29	68.0	2.2	1.5	.19	3.7	.17	.10	1.7	.34	4.1	---	1.4	1.9
30	37.0	1.4	1.0	.15	1.2	.13	.11	.91	.32	4.0	---	1.3	2.4
31	---	.96	---	.10	e2.0	---	.13	---	.33	3.4	---	1.2	---
Total	524.79	141.96	38.34	16.48	32.48	9.11	5.26	18.13	39.61	236.15	141.2	202.5	83.19
Min.	.99	.53	.31	.10	.03	.07	.05	.05	.32	.29	1.1	1.2	.65
Max.	68.0	19.0	4.5	5.0	16.0	1.2	.59	12.0	5.5	47.0	36.0	68.0	13.0
Mean	17.5	4.58	1.28	.53	1.05	.30	.17	.60	1.28	7.62	5.04	6.53	2.77

e = estimate

Table 22. Contaminant Loading Rates in the Bear Creek Watershed (lbs/day).

	CH3G					EB4				
Date	Flow	Al	Fe	Mn	Zn	Flow	Al	Fe	Mn	Zn
4-28-94	0.92	49.2	13.3	40.7	1.6	4.9	52.9	35.7	41.0	1.1
5-12-94	0.42	26.3	9.2	21.4	0.8	2.6	12.6	10.4	36.5	1.0
5-26-94	4.00	594.0	1103.8	51.2	7.8	19.0	2011.0	983.9	3847.5	82.1
6-08-94	0.68	30.6	21.9	40.0	1.1	4.5	15.9	35.0	60.3	1.0
6-23-94	0.29	14.3	15.2	18.8	0.5	0.76	2.5	4.0	14.8	0.2
7-06-94	0.12	5.3	8.2	7.8	0.2	0.20	0.5	1.2	4.0	0.04
8-04-94	0.11	4.9	13.1	8.4	0.05	0.06	0.03	0.3	1.7	0.01
9-01-94	0.26	13.2	10.1	15.6	0.6	1.00	8.5	16.6	15.1	0.2
10-07-94	0.07	2.6	5.1	4.9	0.1	0.08	0.1	0.6	2.2	0.01
11-03-94	0.07	3.3	4.8	5.7	0.01	0.11	0.1	0.2	5.6	0.04
11-17-94	0.09	4.4	5.3	7.1	0.1	0.12	0.1	0.2	4.1	0.01
11-29-94	0.32	17.5	10.0	14.4	0.4	1.70	5.6	9.2	29.9	0.2
12-15-94	0.13	8.3	4.7	7.9	0.2	0.92	4.7	6.0	17.1	0.3
1-11-95	0.89	50.0	17.8	49.0	1.3	5.40	29.2	23.0	59.2	1.2
1-27-95	0.32	19.4	5.8	17.3	0.5	1.60	11.2	5.7	25.9	0.4
2-08-95	0.34	24.1	9.4	20.4	0.6	2.10	13.6	9.7	25.1	0.4
2-22-95	0.43	26.0	6.7	21.1	0.7	2.90	23.5	11.8	33.0	0.6

Table 23. National Park Service: Mainstem Bear Creek (BC2) Water Quality Analyses (mg/l).

Date	pH	Cond. (μmho/cm)	DO	Acid.	Hard.	Alk.	SO_4	Fe	Mn	NH_3	Cl	Turb. (NTU)	F. coli (col./100 ml.)	F. strep (col./100 ml.)
3/31/93	**6.1****	90	11.8	11.8	78	3.6	69	<0.2	**1.80**[3,4]	---	2.2	1.9	0	0
6/15/93	**5.3***	100	8.2	10.2	98	2.1	62	<0.2	**1.70**[3,4]	---	2.0	0.8	4	70
8/25/93	**6.2****	265	6.7	12.0	138	6.0	>80	<0.2	**3.80**[3,4]	---	3.9	1.6	0	50
9/08/93	**5.9***	240	7.0	16.1	142	5.6	76	<0.2	**3.20**[3,4]	---	2.8	1.3	0	30
10/22/93	**5.4***	250	8.1	21.2	195	2.2	80	**0.44**[3]	**3.70**[3,4]	---	4.2	3.1	9	66
11/23/93	**5.4***	200	11.6	21.5	182	3.2	>80	<0.2	**5.05**[3,4]	---	4.9	0.6	0	16
12/28/93	**5.6***	180	11.8	19.6	152	3.0	>80	<0.2	**4.13**[3,4]	---	3.8	2.3	0	8
1/11/94	**5.4***	110	12.4	18.6	126	2.2	>80	<0.2	**2.54**[3,4]	---	2.6	2.3	0	11
3/30/94	**5.9***	100	11.6	25.1	95	2.8	>80	<0.2	**3.91**[3,4]	---	3.4	1.2	0	18
5/16/94	**5.9***	175	10.2	13.4	107	3.5	77	<0.2	**2.81**[3,4]	---	2.8	2.5	5	61
6/23/94	**6.0****	185	8.0	10.9	89	4.1	>80	0.21	**1.92**[3,4]	---	3.8	1.9	10	54
9/26/94	**6.2****	135	8.3	9.6	88	5.8	78	<0.2	**1.67**[3,4]	---	4.8	2.0	3	35
11/30/94	**5.8***	195	11.1	15.4	129	2.2	>80	<0.2	**0.68**[3,4]	---	3.6	3.0	0	27
12/20/94	**5.6***	210	12.8	9.8	125	5.4	69	0.21	**1.21**[3,4]	---	2.4	2.5	0	12
1/30/95	**5.1***	130	11.8	13.4	108	2.8	71	<0.2	**1.73**[3,4]	---	2.2	2.6	0	5
3/06/95	**5.6***	150	12.3	15.0	106	4.9	>80	<0.2	**2.34**[3,4]	---	2.0	1.9	5	6

Table 23. Continued.

Date	pH	Cond. µmho/cm	DO	Acid.	Hard.	Alk.	SO_4	Fe	Mn	NH_3	Cl	Turb. NTU	F. coli (col./100 ml.)	F. strep (col./100 ml.)
6/05/95	**5.8***	120	8.2	11.5	89	3.8	77	<0.2	**1.83**[3,4]	---	3.5	1.6	5	32
7/26/95	6.5	210	7.1	11.6	112	5.7	>80	<0.2	**2.77**[3,4]	---	3.6	2.1	0	95
9/25/95	6.6	140	8.0	8.5	79	6.4	77	<0.2	**1.80**[3,4]	---	2.3	6.4	0	28
10/30/95	**5.2***	267	11.3	16.0	123	2.8	>80	0.21	**0.64**[3,4]	0.56	4.8	1.3	---	---
2/14/96	**4.5***	156	11.6	12.2	103	2.5	73	<0.2	**1.83**[3,4]	0.34	2.5	2.4	0	10
3/14/96	**4.3***	170	12.0	14.2	79	5.6	80	<0.2	**2.26**[3,4]	0.39	2.0	2.1	7	2
5/01/96	**4.5***	131	10.0	10.3	73	2.7	55	0.2	**1.70**[3,4]	0.58	2.6	5.4	0	33
8/29/96	**5.5***	285	12.4	10.6	131	5.5	>80	<0.2	**2.72**[3,4]	0.51	5.3	2.2	1	24
10/16/96	**6.1****	313	8.6	11.7	120	7.2	80	0.2	**1.65**[3,4]	0.43	4.8	3.0	1	260
11/6/96	**5.4***	318	11.1	8.9	139	4.6	80	0.2	**3.75**[3,4]	0.39	5.6	1.4	0	18
1/8/97	**5.5***	144	13.4	7.8	77	4.5	58	0.2	**1.67**[3,4]	0.11	2.8	5.0	0	3

Table 23. Continued.

	pH	Cond. (μmho/cm)	DO	Acid.	Hard.	Alk.	SO_4	Fe	Mn	NH_3	Cl	Turb. NTU	F. coli (col./100 ml.)	F. strep col./100 ml.
Min.	**4.3***[*]	90	6.7	7.8	73	2.1	55	<0.2	**0.64**[3,4]	0.11	2.00	0.6	1	2
Max.	6.6	318	13.4	25.1	195	7.2	>80	**0.44**[3]	**5.05**[3,4]	0.58	5.60	6.4	10	260
Average	---	184	10.3	13.6	114	4.1	76	---	**2.40**[3,4]	0.41	3.38	2.4	5	39
Geo. Mean	**5.6**[*]	173	10.1	13.0	110	3.8	75	---	**2.15**[3,4]	0.38	3.21	2.1	4	22
Std. Deviation	---	66	2.1	4.4	31	1.5	7.2	---	1.10	0.15	1.11	1.3	3	52

[*] = Tn. and Ky. Water Quality Criteria (Fish and Aquatic Life/Warm Water Aquatic Habitat) for pH Exceeded. Tn. Domestic Water Supply and Ky. Recreational Waters Criteria for pH Exceeded.

[**] = Tennessee Fish and Aquatic Life Criteria for pH Exceeded.

[3] = Federal SMCL Exceeded.

[4] = Kentucky Maximum Allowable In-stream Concentration (Drinking Water) Exceeded.

Table 24. National Park Service: Mainstem Bear Creek (BC1) Water Quality Analyses (mg/l).

Date	pH	Cond. (μmho/cm)	DO	Acid.	Hard.	Alk.	SO_4	Fe	Mn	NH_3	Cl	Turb. (NTU)	F. coli (col./100 ml.)	F. strep (col./100 ml.)
1/26/93	6.5	55	12.9	8.5	62.0	5.9	39	<0.2	**1.20**[3,4]	---	2.4	5.9	---	1
3/22/93	6.2**	55	12.8	8.3	34.8	2.7	37	<0.2	**0.90**[3,4]	---	2.9	4.5	---	140
4/22/93	5.4*	95	11.8	9.9	58.0	2.1	51	<0.2	**1.80**[3,4]	---	2.6	2.7	---	---
5/13/93	5.7*	100	10.4	8.9	58.0	3.3	50	<0.2	**1.40**[3,4]	---	2.9	7.0	2	50
6/24/93	5.3*	100	8.4	11.2	98.0	2.9	66	<0.2	**1.50**[3,4]	---	2.6	0.7	---	75
8/24/93	6.5	205	7.9	10.3	111.0	5.8	>80	<0.2	**2.20**[3,4]	---	2.6	2.3	---	---
10/07/93	6.7	190	9.2	9.2	121.0	6.9	>80	<0.2	**1.50**[3,4]	---	5.5	1.0	---	---
10/25/93	6.9	180	---	11.3	135.0	6.1	>80	<0.2	**1.80**[3,4]	---	3.4	2.2	4	55
11/09/93	6.2**	190	11.7	10.7	150.0	2.8	>80	<0.2	**0.50**[3,4]	---	4.7	0.5	---	140
11/18/93	6.9	70	12.0	7.4	57.0	5.9	47	<0.2	**1.10**[3,4]	---	2.8	1.1	---	---
12/21/93	5.7*	175	12.0	12.0	172.0	2.6	>80	<0.2	**2.51**[3,4]	---	5.1	1.0	---	180
2/03/94	---	70	12.9	13.1	65.0	2.8	63	<0.2	**1.50**[3,4]	---	3.3	1.4	---	1
3/21/94	5.9*	90	11.2	11.8	69.0	2.3	55	<0.2	**1.65**[3,4]	---	2.2	2.5	---	---
5/11/94	5.4*	110	10.2	14.3	84.0	1.9	71	**0.31**[3]	**2.04**[3,4]	---	2.4	2.1	3	24
6/01/94	6.3**	95	10.2	9.5	61.0	4.8	58	<0.2	**1.72**[3,4]	---	2.7	1.3	8	82
9/20/94	5.3*	210	8.6	12.6	111.0	4.8	>80	<0.2	**3.00**[3,4]	---	4.1	2.0	1	290

Table 24. Continued.

Date	pH	Cond. μmho/cm	DO	Acid.	Hard.	Alk.	SO_4	Fe	Mn	NH_3	Cl	Turb. NTU	F. coli (col./100 ml.)	F. strep (col./100 ml.)
11/09/94	**4.9***	95	11.5	8.7	74.0	2.1	73	<0.2	**1.24**[3,4]	---	2.8	2.8	---	8
1/18/95	**6.2****	55	10.9	7.9	31.7	3.2	41	<0.2	**0.80**[3,4]	---	2.1	4.8	---	39
3/30/95	**6.0****	120	10.2	12.4	97.0	2.9	>80	**0.30**[3]	**2.22**[3,4]	---	2.1	1.1	---	3
5/23/95	**5.9***	60	9.4	15.6	87.0	1.7	>80	**0.31**[3]	**2.13**[3,4]	---	1.8	2.1	1	10
6/13/95	**6.4****	94	10.2	7.2	58.0	5.5	55	<0.2	**1.80**[3,4]	---	2.8	7.9	15	70
8/03/95	6.7	125	6.7	7.0	50.0	6.3	57	**0.74**[3]	**0.70**[3,4]	---	2.1	37.7	---	---
9/05/95	6.6	135	7.2	9.7	76.0	5.8	63	0.22	**0.50**[3,4]	---	4.2	3.1	11	69
10/02/95	7.2	120	8.7	6.4	50.0	7.7	55	<0.2	**0.50**[3,4]	---	4.5	2.6	2	80
11/06/95	**5.9***	140	12.0	7.1	85.0	5.1	63	<0.2	**1.07**[3,4]	0.31	3.3	1.4	---	---
1/29/96	**5.1***	93	11.4	7.1	71.0	2.8	43	<0.2	**0.85**[3,4]	0.26	2.3	3.5	1	1
3/11/96	**4.7***	89	12.8	9.6	49.0	2.7	41	<0.2	**0.60**[3,4]	0.23	2.2	5.5	---	---
4/16/96	**4.7***	150	12.0	10.4	75.0	2.8	52	0.2	**1.40**[3,4]	---	3.3	55.0	---	---
5/22/96	**4.6***	147	9.2	9.0	81.0	4.6	58	0.2	**2.30**[3,4]	0.13	4.5	2.3	---	12
8/29/96	**5.7***	190	12.0	8.2	89.0	5.8	77	<0.2	**0.50**[3,4]	0.23	6.2	2.6	42	252
9/10/96	**5.8***	155	8.5	10.6	74.0	5.4	63	0.23	**0.50**[3,4]	0.15	4.9	12.2	75	382
11/4/96	**5.7***	257	11.8	10.5	112.0	5.3	73	0.21	**0.56**[3,4]	0.23	4.7	2.3	2	26
1/08/97	**5.8***	100	13.5	7.0	62.0	2.9	43	0.20	**1.14**[3,4]	---	3.0	3.6	---	1

Table 24. Continued.

	pH	Cond. (μmho/cm)	DO	Acid.	Hard.	Alk.	SO_4	Fe	Mn	NH_3	Cl	Turb. NTU	F. coli (col./100 ml.)	F. strep col./100 ml.
Min.	**4.6***	55.0	6.7	6.4	31.7	1.7	37.0	<0.2	**0.50**[3,4]	0.13	1.8	0.5	1	1
Max.	7.2	257.0	13.5	15.6	172.0	7.7	>80	**0.74**[3]	**3.0**[3,4]	0.31	6.2	55.0	75	382
Average	---	124.7	10.6	9.8	80.9	4.1	61.6	---	**1.4**[3,4]	0.22	3.3	5.7	13	83
Geo. Mean	**5.86***	114.6	10.5	9.6	75.3	3.8	59.9	---	**1.2**[3,4]	0.21	3.1	2.9	5	28
Std. Deviation	---	51.8	1.8	2.3	31.8	1.7	14.5	---	0.7	0.06	1.1	11.0	22	102

* = Tn. and Ky. Water Quality Criteria (Fish and Aquatic Life/Warm Water Aquatic Habitat) for pH Exceeded. Tn. Domestic Water Supply and Ky. Recreational Waters Criteria for pH Exceeded.
** = Tennessee Fish and Aquatic Life Criteria for pH Exceeded.
[3] = Federal SMCL Exceeded.
[4] = Kentucky Maximum Allowable In-stream Concentration (Drinking Water) Exceeded.

Table 25. Bear Creek Water Quality Surveys Conducted in 1995.

Site	Latitude Longitude	pH
UNEBC-D1	36°33'05" 84°30'35"	**3.20***
UNEBC-D2	36°32'37" 84°30'26"	**5.70***
UNEBC-D3	36°32'38" 84°30'25"	**4.50***
UNEBC-S1	36°33'07" 84°30'11"	**5.46***
UNEBC-S2	36°32'50" 84°30'18"	**4.70***
UNEBC-S3	36°33'43" 84°30'44"	6.60
EBC-W1	36°33'23" 84°30'49"	**6.00****
UNEBC-1	36°33'04" 84°30'36"	**6.10****
UNEBC-2	36°33'07" 84°30'30"	**3.00***
UNEBC-3	36°33'15" 84°30'13"	**4.00***
CB-D2.D3	36°32'38" 84°30'25"	**4.30***

* = Tn. and Ky. Water Quality Criteria (Fish and Aquatic Life/Warm Water Aquatic Habitat) for pH Exceeded. Tn. Domestic Water Supply and Ky. Recreational Waters Criteria for pH Exceeded.

** = Tennessee Fish and Aquatic Life Criteria for pH Exceeded.

Table 26. Comparison of geometric means for metals (mg/kg, dry weight) in Bear Creek sediments with those reported by Shacklette and Boerngen (1984).

Metals	Eastern United States	Line Fork	Bear Creek Tributaries	Bear Creek Mainstem
Al (%)	3.30	0.30	0.95	0.34
As	4.80	**9.48**	**13.23**	**7.03**
Ba	290.00	36.14	49.28	15.01
Co	5.90	6.44	7.85	6.92
Cr	33.00	6.26	14.92	7.05
Cu	13.00	3.73	**16.27**	6.21
Fe (%)	1.40	1.61	**2.32**	1.33
Mn	260.00	216.65	153.83	164.16
Pb	14.00	7.17	14.82	3.45
Se	0.30	**2.57**	**5.61**	**4.03**
Zn	40.00	22.69	30.14	24.97

* Values for Al and Fe are expressed as percent. Bear Creek and Line Fork metals are expressed in mg/kg dry weight based on a 30% moisture value for sediment samples.

Table 27. Comparison of metals detected in Bear Creek and tributary sediment samples (mg/kg, dry weight) with the Illinois stream sediment classification* developed by Kelly and Hite (1984).

	Sites						
Metals	CH3W	SU2	CH3G	EB4	BC2	BC1	LF
As	SE	**E**	**HE**	NE	**E**	SE	SE
Cd	NE	NE	NE	NE	NE	NE	NE
Cr	NE	SE	SE	NE	NE	NE	NE
Cu	NE	NE	NE	NE	NE	NE	NE
Fe	**E**	**E**	**HE**	NE	SE	NE	**HE**
Hg	NE	**E**	NE	NE	NE	NE	NE
Mn	NE	NE	NE	NE	NE	NE	NE
Pb	NE	NE	NE	NE	NE	NE	NE
Zn	NE	NE	NE	NE	NE	NE	NE

* NE-non-elevated; SE-slightly elevated; E-elevated; HE-highly elevated; Ex-extremely elevated

Table 28. Sediment quality criteria (mg/kg, dry weight) developed by the Ontario Ministry of the Environment.

Metals	No Effect Level	Lowest Effect Level 1989*	Lowest Effect Level 1992**	Limit of Tolerance*	Severe Effect Level**
As	4.0	5.5	6.0	33.0	33.0
Cd	0.6	1.0	0.6	10.0	10.0
Cr	22.0	31.0	26.0	111.0	110.0
Cu	15.0	25.0	16.0	114.0	110.0
Fe (%)	2.0	3.0	2.0	4.0	4.0
Pb	23.0	31.0	31.0	250.0	250.0
Mn	400.0	457.0	460.0	1110.0	1100.0
Hg	0.1	0.12	0.20	2.0	2.0
Ni	15.0	31.0	16.0	90.0	75.0
Zn	65.0	110.0	120.0	800.0	820.0

* Persaud, et al. (1989).
** Jaagumaji (1992).

Figure 12. Log of Al Concentration in Water vs. Log of Flow (CH3).

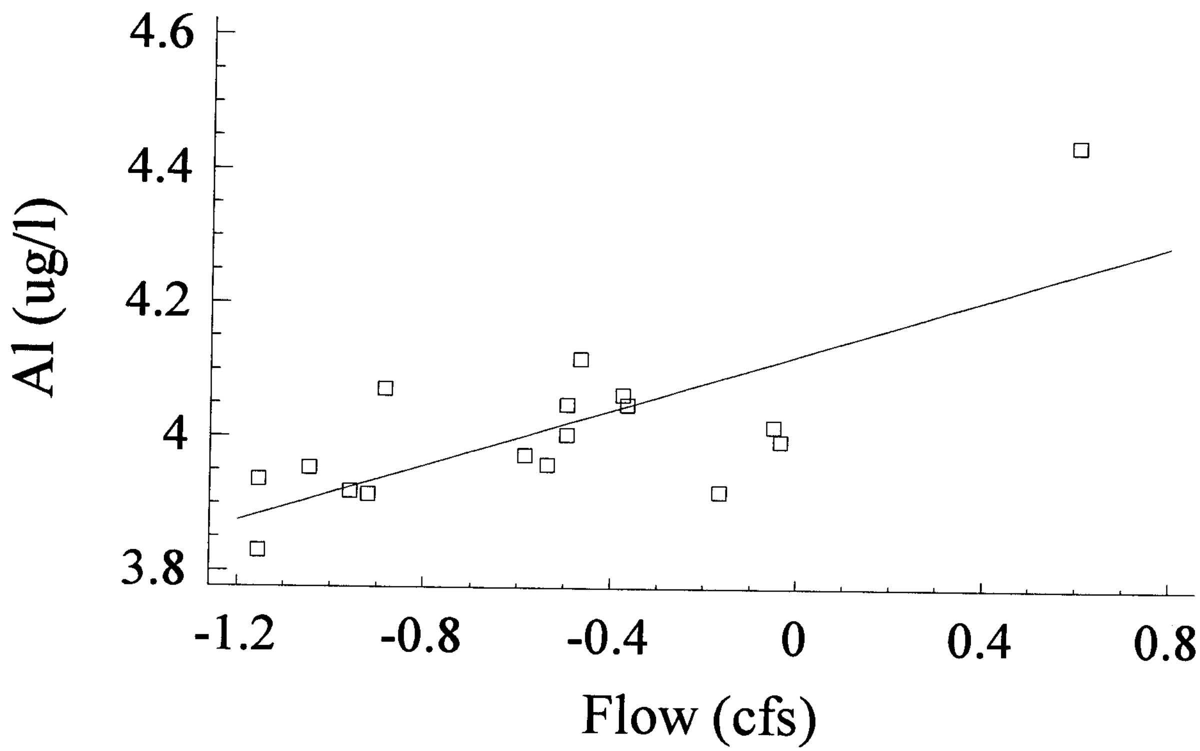


Figure 13. Log of Zn Concentration in Water vs. Log of Flow (CH3).

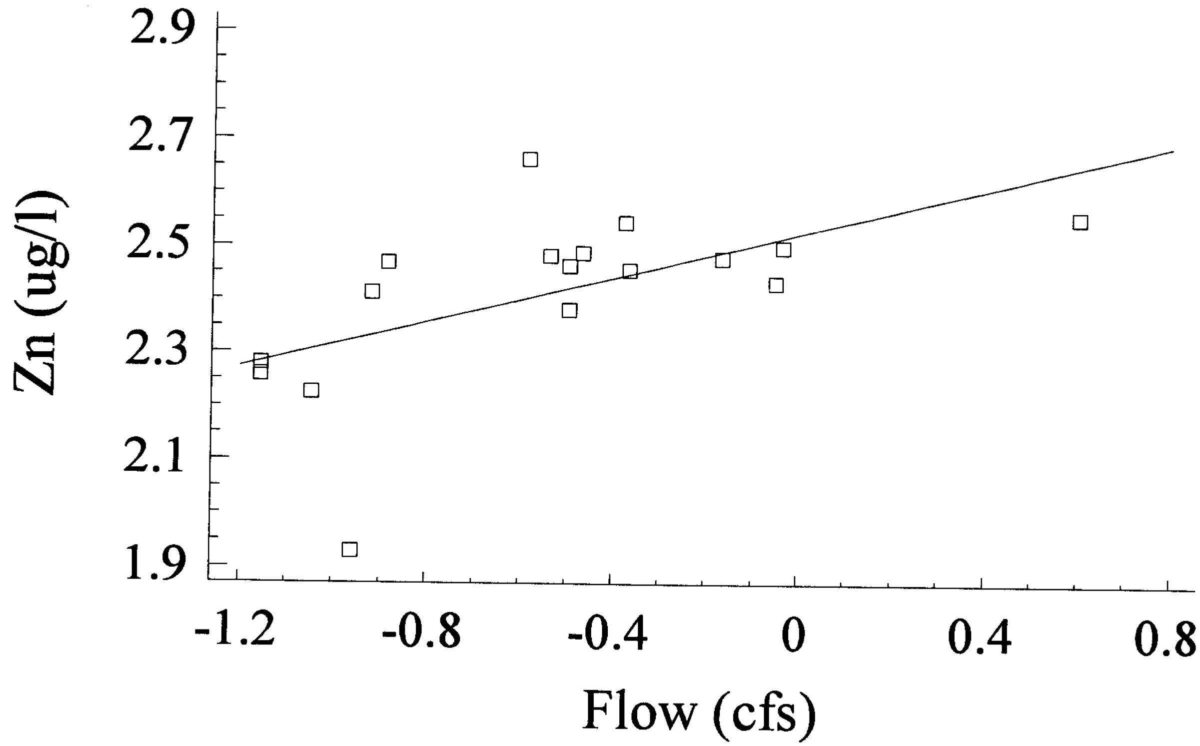


Figure 14. Log of Co Concentration in Water vs. Log of Flow (CH3).

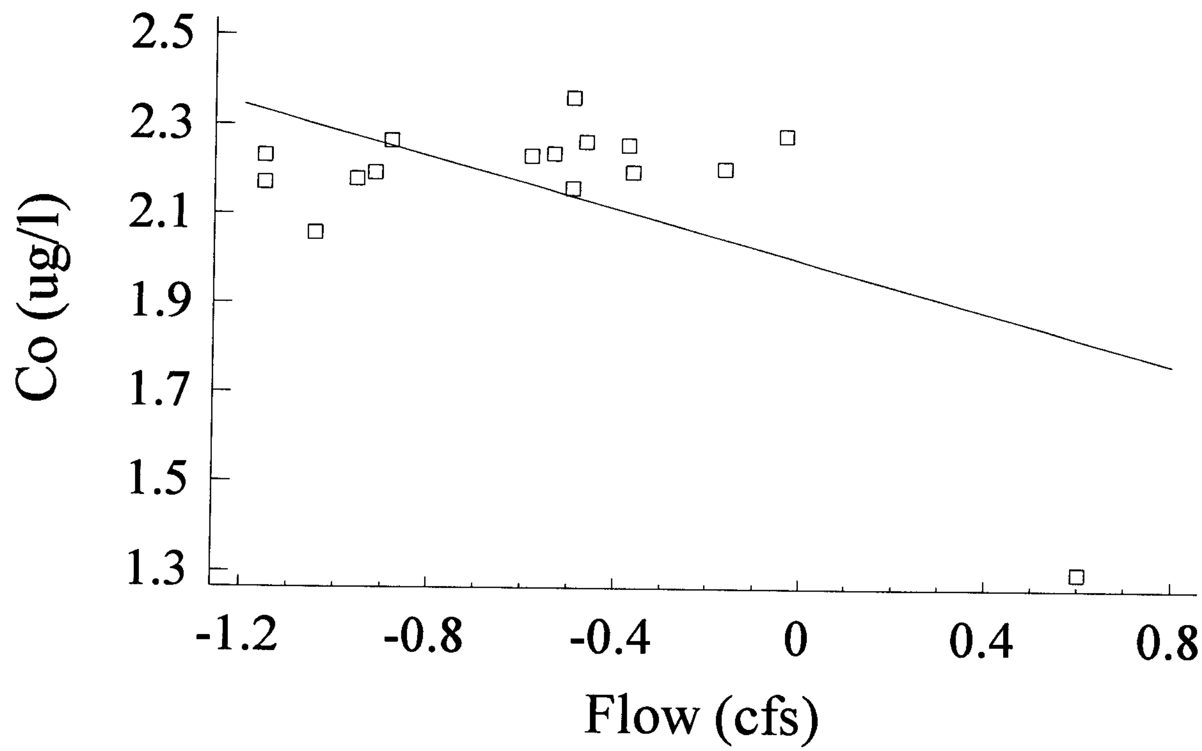


Figure 15. Log of Mn Concentration in Water vs. Log of Flow (CH3).

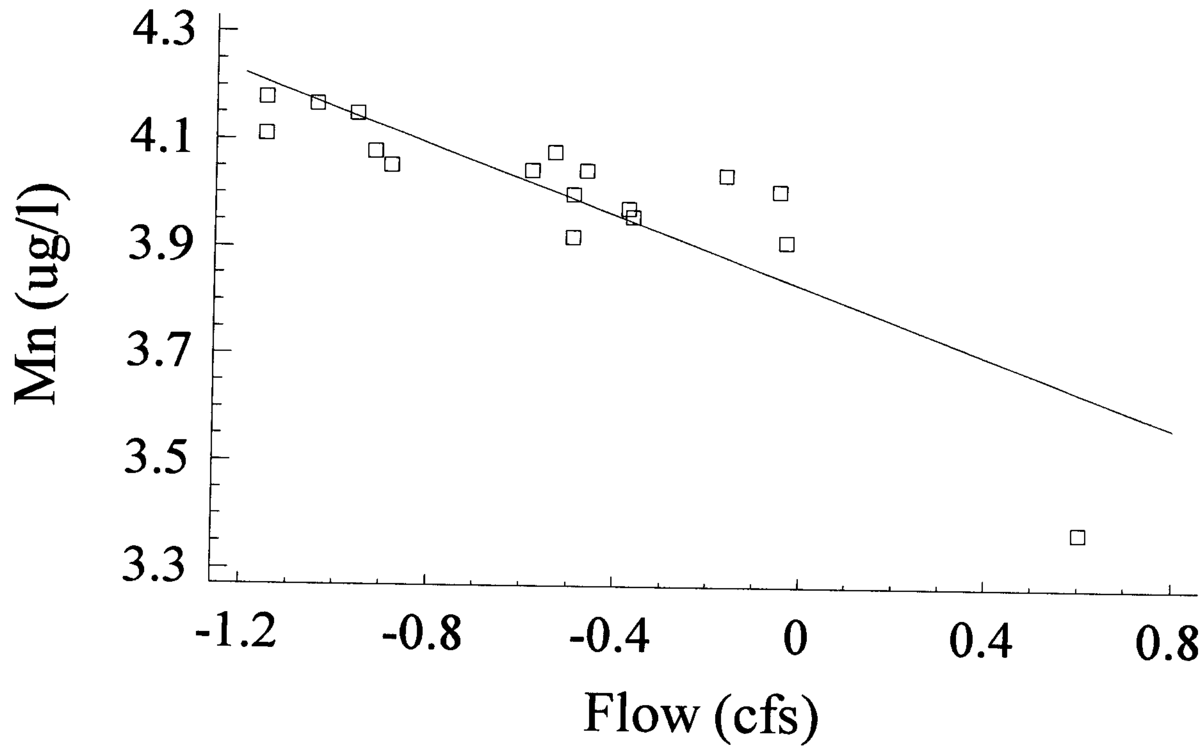


Figure 16. Log of SO4 Concentration in Water vs. Log of Flow (CH3).

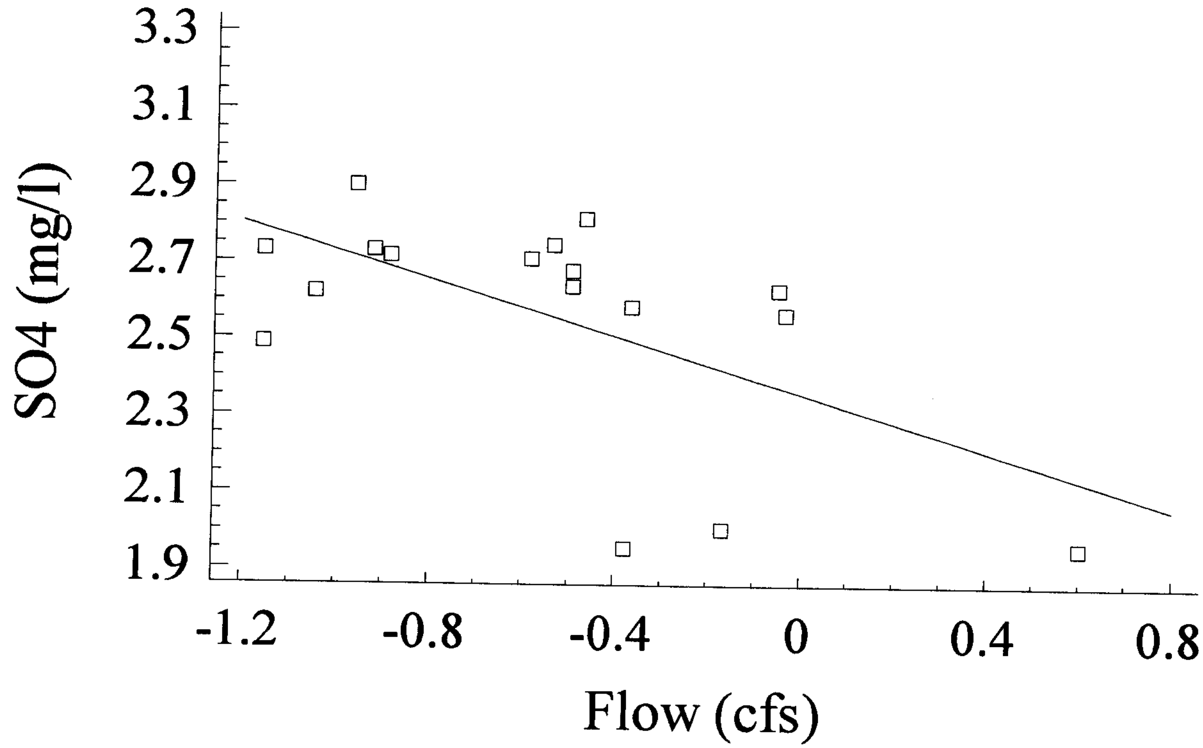


Figure 17. Log of Al Concentration in Water vs. Log of Flow (EB4).

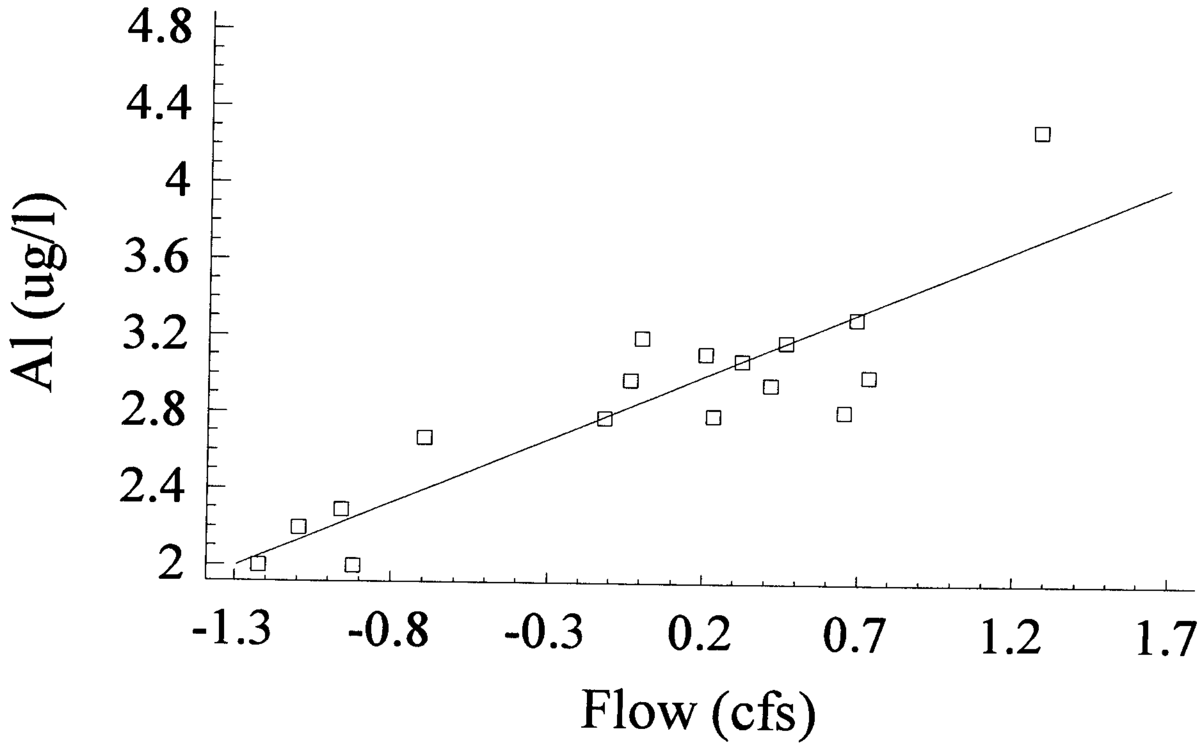


Figure 18. Log of Fe Concentration in Water vs. Log of Flow (EB4).

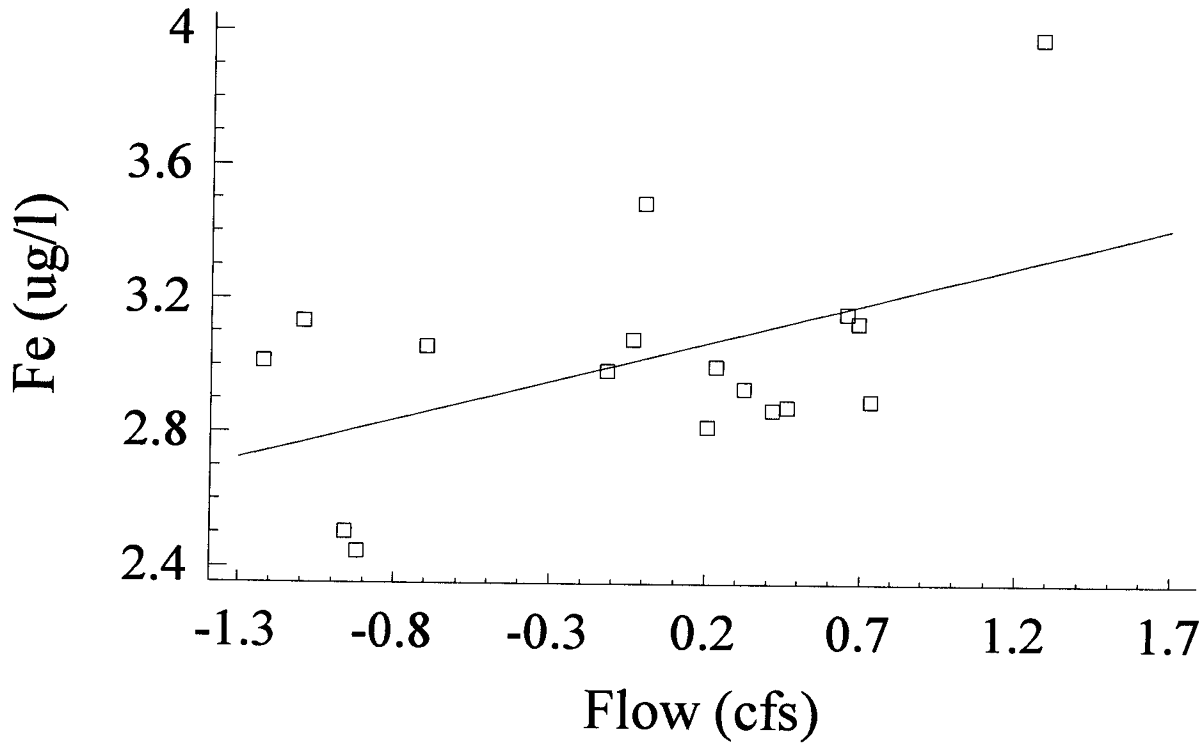


Figure 19. Log of Zn Concentration in Water vs. Log of Flow (EB4).

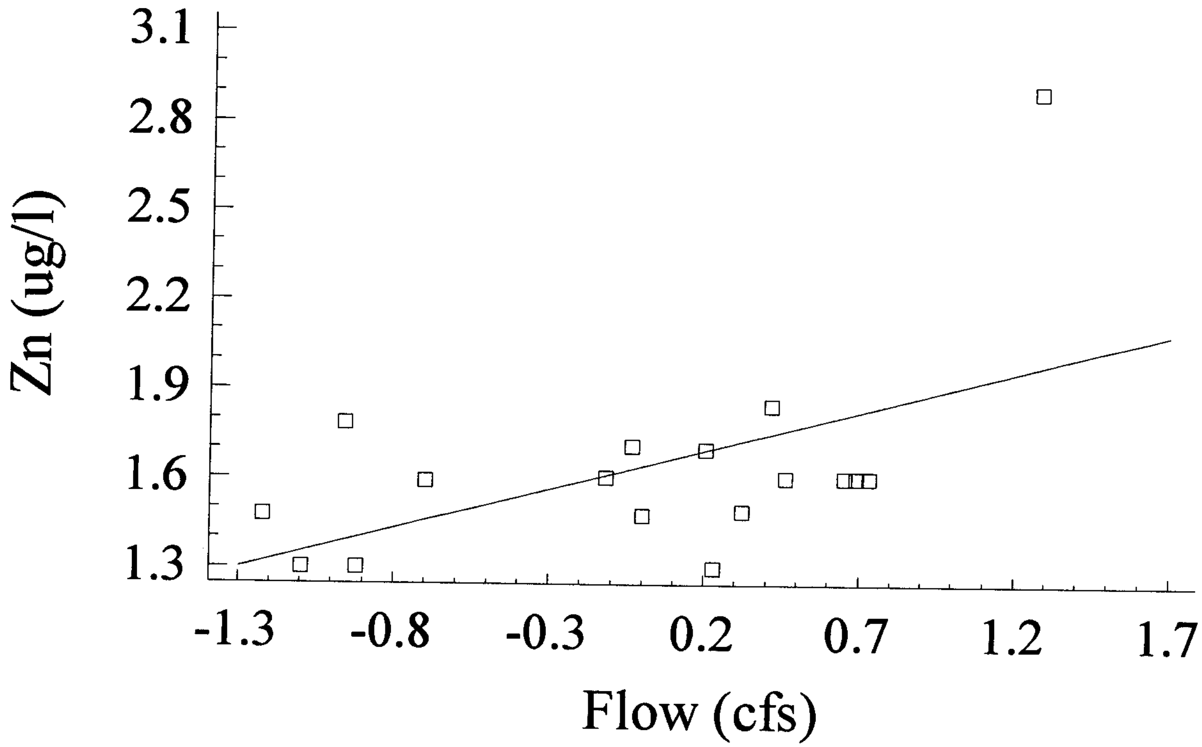


Figure 20. Log of Fe Concentration in Water vs. Log of DO (CH3).

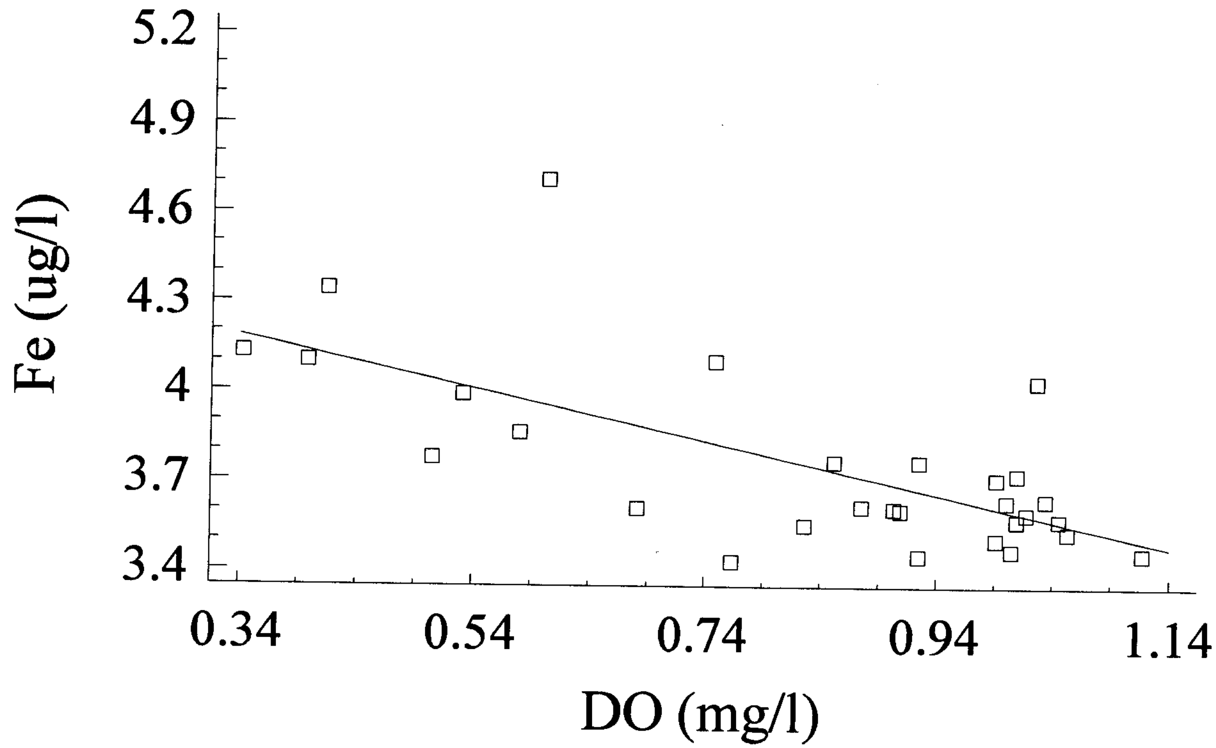


Figure 21. Log of Fe Concentration in Water vs. Log of DO (SU2).

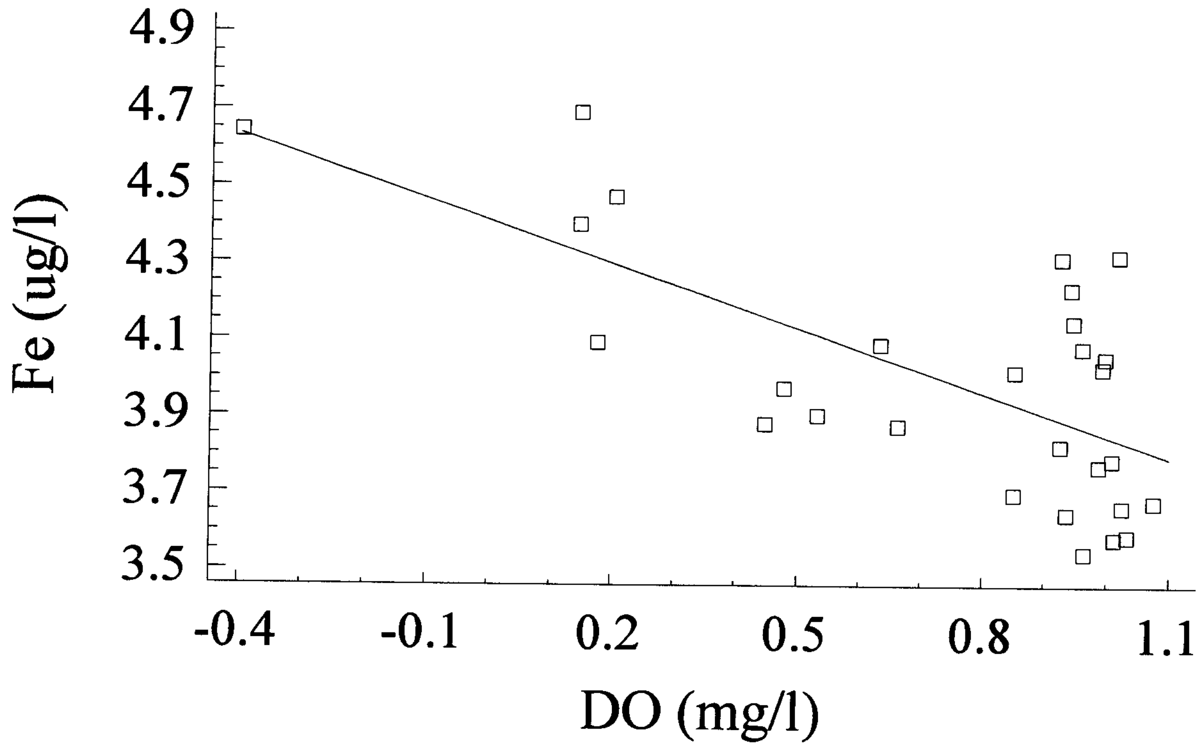


Figure 22. Log of Mn Concentration in Water vs. Log of DO (SU2).

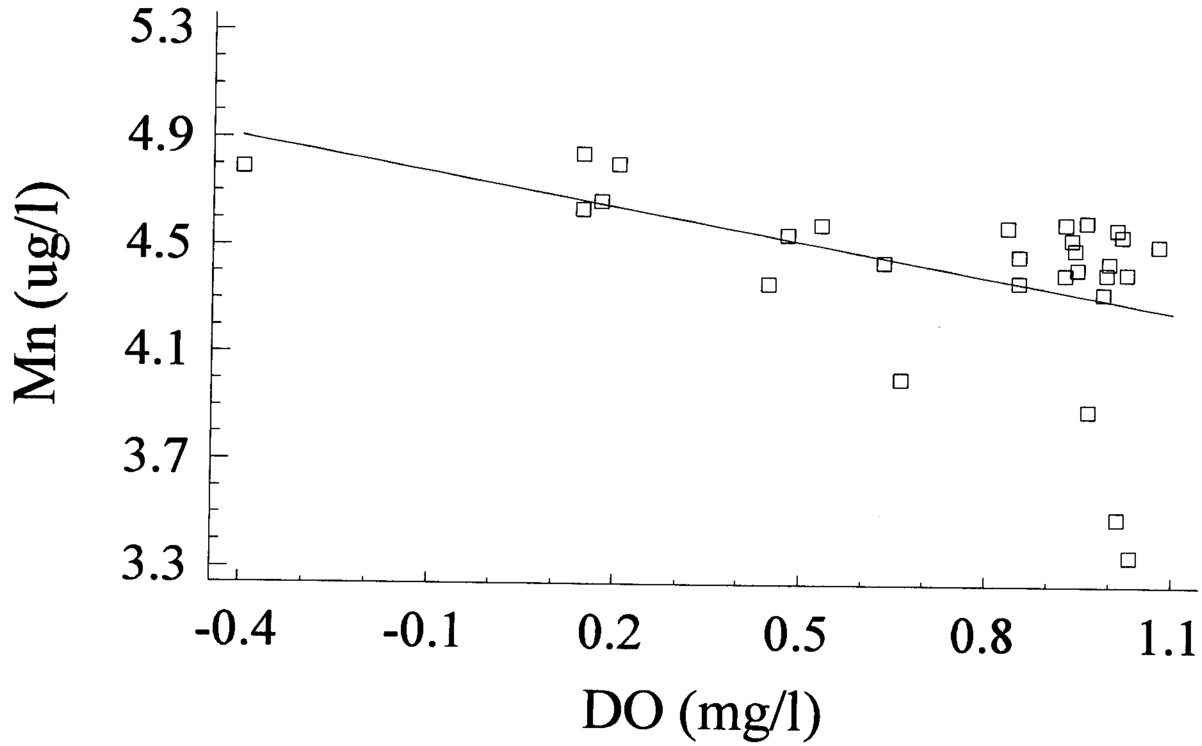


Figure 23. Log of Co Concentration in Water vs. Log of DO (SU2).

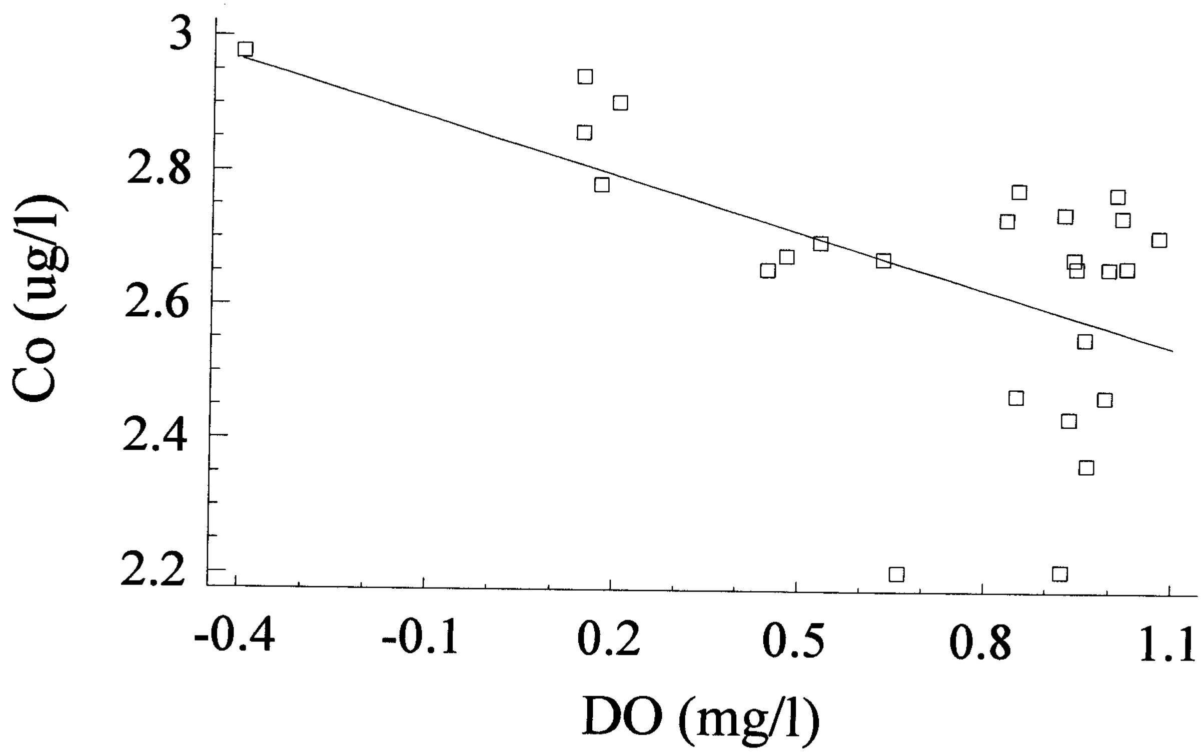


Figure 24. Log of Al Concentration in Water vs. pH (EB4).

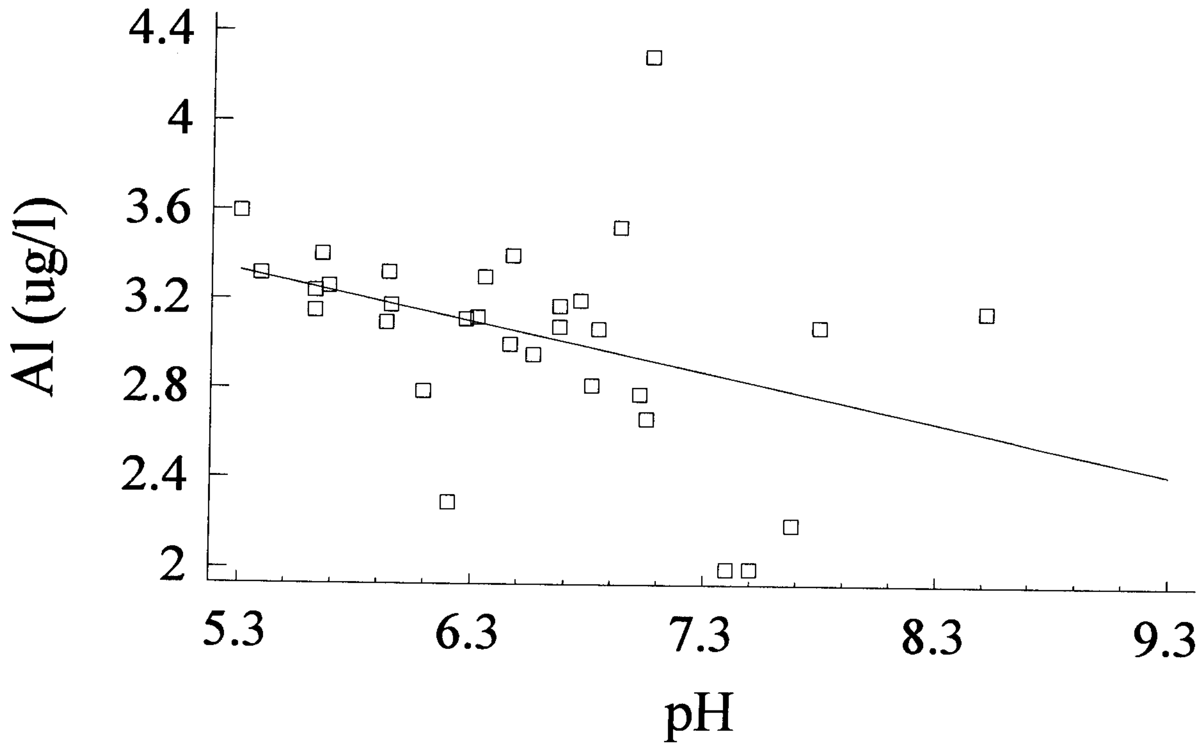
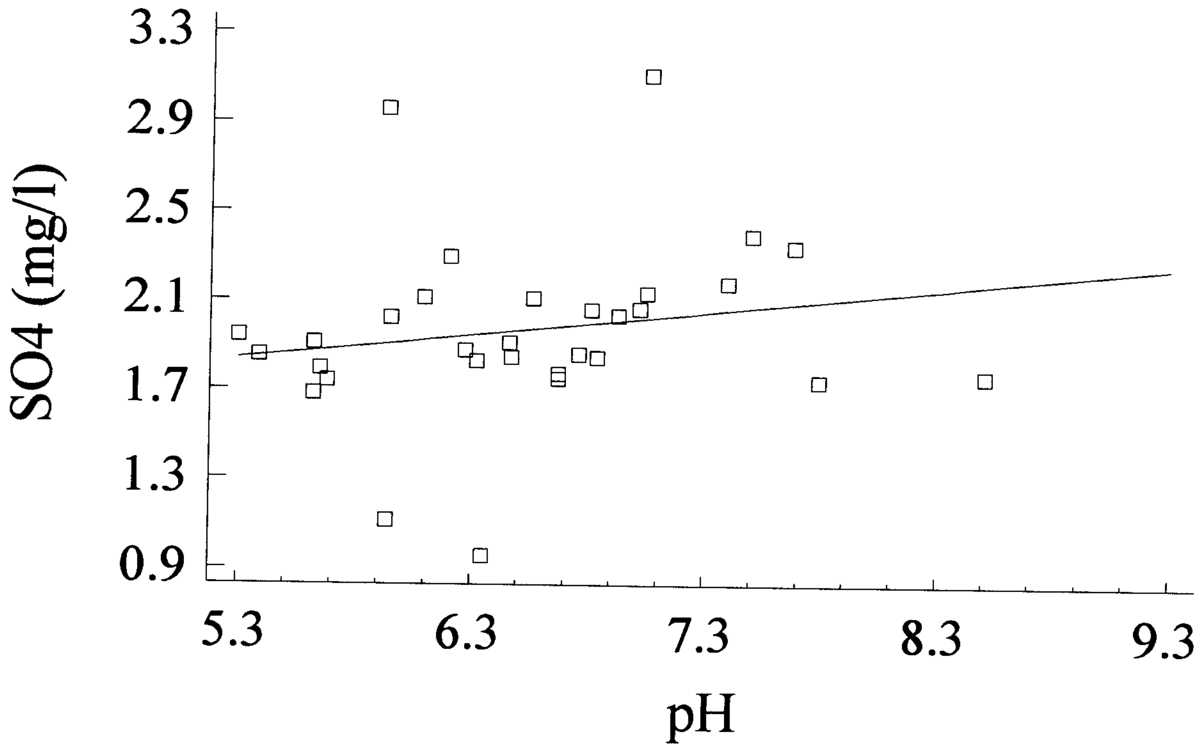


Figure 25. Log of SO4 Concentration in Water vs. pH (EB4).



CONCLUSIONS AND RECOMMENDATIONS

Contaminant loading estimates, based on previous investigations for aluminum, iron, manganese, and zinc at the tributary site CH3G and the mainstem site EB4, indicated substantial metals loading in the Bear Creek watershed. Without extensive additional remediation efforts, Bear Creek should not be considered for domestic water supply. If enhancement of existing best management practices and additional remediation are not performed, substantial investments in water treatment technologies would be required before the watershed could be considered as a potentially reliable drinking water source.

Instream cover exhibited slight variability and was considered to be optimal. Instream epifaunal substrate was prevalent and also considered optimal. Embeddedness was rated as sub-optimal at all stream sites due to extensive sedimentation from road and landfill construction, and from poor forestry practices.

Aluminum, copper, iron, manganese, nickel, lead, selenium, and zinc in Bear Creek water and sediments have adversely impacted the aquatic communities that were historically present in the watershed and, without continued acid mine drainage remediation efforts, will prevent the re-colonization of aquatic life. Discharges from Bear Creek are contributing to degradation of the Big South Fork Cumberland River, adversely impacting federally listed mussel and fish species.

Prior to our investigation, concerns were expressed regarding mercury contamination in Bear Creek. Although the results of our stream sediment sampling did not indicate that mercury was prevalent, soils were not sampled. As evidenced by the results for samples from the SU2 constructed wetland, mercury may become a greater concern because of the retention of fine-grained soil particles.

A variety of rare, threatened or endangered species could benefit from improved water quality in Bear Creek. Impacts to these, and other, species from increased recreational use or development in the watershed should be fully considered in future watershed management decisions.

The following items are recommended for consideration in additional best management practice construction and any future investigations of the Bear Creek watershed: 1) ensure that constructed wetlands are sized appropriately for adequate retention time and to contain storm events; 2) construct an aerobic wetland as the furthest downstream component of any passive treatment system; 3) develop a maintenance plan for existing and future best management practices which includes contingencies for ensuring aerobic conditions in the furthest downstream component, and the disposal of contaminated sediment and vegetation; 4) develop a periodic water quality monitoring plan which addresses the effectiveness of the components of constructed passive treatment systems, including monitoring for selenium and zinc; and 5) analyze sediment samples for total organic carbon, acid volatile sulfides, and simultaneously extracted metals.

The effects of AMD on the continued viability of mussel populations in the Big South Fork Cumberland River should be assessed. The following items are recommended for consideration: 1) use a suite of sediment toxicity tests, including larval and juvenile mussels; 2) measure contaminants in water and sediment in conjunction with toxicity tests; and 3) determine contaminant residues in non-listed mussel species which are co-located with listed species.

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APPENDIX I

Frequent, Common, and Occasional Occurrences of Vascular Flora in the North White Oak Creek Watershed

Appendix I. Frequent, Common, and Occasional Occurrences of Vascular Flora in the North White Oak Creek Watershed.

ASPLENIACEAE	
Ebony spleenwort	*Asplenium platyneuron*
Walking fern	*Asplenium rhizophyllum*
DENNSTAEDTIACEAE	
Hay scented fern	*Dennstaedtia punctilobula*
DRYOPTERIDACEAE	
Christmas fern	*Polystichum acrostichoides*
Intermediate wood fern	*Dryopteris intermedia*
Marginal wood fern	*Dryopteris marginalis*
LYCOPODIACEAE	
Ground pine	*Lycopodium obscurum*
OPHIOGLOSSACEAE	
Rattlesnake fern	*Botrychium biternatum*
OSMUNDACEAE	
Cinnamon fern	*Osmunda cinnamomea*
POLYPODIACEAE	
Common polypody	*Polypodium virginianum*
SCHIZAEACEAE	
Hartford climbing fern	*Lygodium palmatum*
THELYPTERIDACEAE	
Broad beech fern	*Thelypteris hexagonoptera*
New York fern	*Thelypteris noveboracensis*
WOODSIACEAE	
Lady fern	*Athyrium filix-femina*
ARACEAE	
Jack-in-the-pulpit	*Arisaema triphyllum*
COMMELINACEAE	
Spiderwort	*Tradescantia subaspera*

Appendix 1 (Continued).

CYPERACEAE	
Sedge	*Carex blanda*
Sedge	*Carex virescens*
Broad-leaved sedge	*Carex laxiflora*
Common sedge	*Carex communis*
Necklace sedge	*Carex debilis*
Roseate sedge	*Carex rosea*
Seersucker sedge	*Carex plantageninea*
Smaller hop sedge	*Carex lurida*
Swan's sedge	*Carex swanii*
DIOSCOREACEAE	
Wild yam	*Dioscorea villosa*
IRIDACEAE	
Dwarf crested iris	*Iris critata*
JUNCACEAE	
Path rush	*Juncus tenuis*
LILIACEAE	
Barksdale's trillium	*Trillium sulcatum*
Indian cucumber root	*Medeola virginiana*
False Soloman's seal	*Smilacina racemosa*
Solomon's seal	*Polygonatum biflorum*
Sweet Betsy	*Trillium cuneatum*
Yellow trillium	*Trillium luteum*
ORCHIDACEAE	
Cranefly orchid	*Tipularia discolor*
Rattlesnake plantain	*Goodyera pubescens*
POACEAE	
Common panic grass	*Panicum commutatum*
Melic grass	*Melica mutica*
Needle grass	*Stipa avenacea*
No common name	*Brachyelytrum erectum*
No common name	*Microstegium vimineum*
No common name	*Muhlenbergia tenuifolia*
Panic grass	*Panicum anceps*
Panic grass	*Panicum boscii*

Appendix 1 (Continued).

POACEAE (continued)	
Panic grass	*Panicum clandestinum*
Panic grass	*Panicum dichotomum*
Panic grass	*Panicum laxiflorum*
Panic grass	*Panicum microcarpon*
Purple top	*Tridens flavus*
Tall fescue	*Festuca arundinacea*
Virginia cutgrass	*Leersia virginica*
Wood manna grass	*Glyceria melicaria*
Woodland bluegrass	*Poa cuspidata*
Woodland fescue	*Festuca subverticillata*
SMILACACEAE	
Glaucus cat-brier	*Smilax glauca*
Green-brier	*Smilax rotundifolia*
ANACARDIACEAE	
Poison ivy	*Toxicodendron radicans*
APIACEAE	
Black snakeroot	*Sanicula canadensis*
Sweet cicily	*Osmorhiza claytonii*
Three leaved meadow parsnip	*Thaspium trifoliatum*
Wild chervil	*Cryptotaenia canadensis*
AQUIFOLIACEAE	
Winterberry	*Ilex verticillata*
ARISTOLOCHIACEAE	
Contracted hexastylis	*Hexastylis contracta*
Little brown jugs	*Hexastylis arifolia*
Wild ginger	*Asarum canadense*
ASTERACEAE	
Bushy aster	*Aster dumosus*
Calico aster	*Aster lateriflorus*
Coneflower	*Rudbeckia laciniata*
Daisy fleabane	*Erigeron strigosus*
Erect goldenrod	*Solidago erecta*
Golden ragwort	*Senecio aureus*
Goldenrod	*Solidago curtisii*
Hairy tobaccoweed	*Elephantopus tomentosus*

Appendix 1 (Continued).

ASTERACEAE

Heart-leaved aster	*Aster lowrieanus*
Joe-pye-weed	*Eupatorium fistulosum*
Joe-pye-weed	*Eupatorium purpureum*
Orange coneflower	*Rudbeckia fulgida*
Pale indian plantain	*Cacalia atriplicifolia*
Pussy-toes	*Antennaria solitaria*
Rattlesnake root	*Prenanthes altissima*
Rattlesnake weed	*Hieracium venosum*
Robin's plantain	*Erigeron pulchellus*
Rough goldenrod	*Solidago rugosa*
Small wood aster	*Helianthus microcephalus*
Two-flowered Cynthia	*Krigia biflora*
White wood aster	*Aster divaricatus*
Wild lettuce	*Lactuca canadensis*
Wingstem	*Verbesina occidentalis*
Wood tickseed	*Coreopsis major*
Zig-zag goldenrod	*Solidago flexicaulis*

BALSAMINACEAE

Spotted touch-me-not	*Impatiens capensis*

BIGNONIACEAE

Cross vine	*Bignonia capreolata*
Trumpet creeper	*Campsis radicans*

BRASSICACEAE

Cut-leaved toothwort	*Dentaria laciniata*
Toothwort	*Dentaria heterophylla*

CAMPANULACEAE

Cardinal flower	*Lobelia cardinalis*
Indian tobacco	*Lobelia inflata*
No common name	*Lobelia spicata*

CAPRIFOLIACEAE

Arrowwood	*Viburnum dentatum*
Maple-leaf arrowwood	*Vibernum acerifolium*

CARYOPHYLLACEAE

Giant chickweed	*Stellaria pubera*
Starry champion	*Silene stellata*

Appendix 1 (Continued).

CELASTRACEAE	
Strawberry bush	*Euonymus americanus*
CLUSIACEAE	
St. John's wort	*Hypericum mutilum*
St. John's wort	*Hypericum prolificum*
ERICACEAE	
Black huckleberry	*Gaylussacia baccata*
Highbush blueberry	*Vaccinium corymbosum*
Lowbush blueberry	*Vaccinium pallidum*
Pipsissewa	*Chimaphila maculata*
EUPHORBIACEAE	
Flowering spurge	*Euphorbia corollata*
FABACEAE	
Beggar tick	*Desmodium nudiflorum*
Tick trefoil	*Desmodium canescens*
GERANIACEAE	
Wild geranium	*Geranium maculatum*
HAMAMELIDACEAE	
Witch hazel	*Hamamelis virginiana*
LAMIACEAE	
Downy skullcap	*Scutellaria incana*
Lycopus	*Lycopus virginicus*
Lyre-leaved sage	*Salvia lyrata*
Self heal	*Prunella vulgaris*
LAURACEAE	
Sassafras	*Sassafras albidum*
Spicebush	*Lindera benzoin*
LINACEAE	
No common name	*Linum striatum*
OLEACEAE	
No common name	*Fraxinus americana*

Appendix 1 (Continued).

OROBANCHACEAE	
Beech drops	*Epifagus virginiana*
Cancer root	*Conopholis americana*
OXALIDACEAE	
Yellow wood-sorrel	*Oxalis stricta*
PAPAVERACEAE	
Bloodroot	*Sanguinaria canadensis*
PASSIFLORACEAE	
Yellow passion flower	*Passiflora lutea*
PLANTAGINACEAE	
Ribgrass	*Plantago lanceolata*
White man's footprint	*Plantago rugelii*
POLEMONIACEAE	
Meadow phlox	*Phlox maculata*
Smooth phlox	*Phlox glaberrima*
POLYGONACEAE	
Smartweed	*Polygonum caespitosum*
Virginia knotweed	*Polygonum virginianum*
PRIMULACEAE	
Whorled loosestrife	*Lysimachia quadrifolia*
RANUNCULACEAE	
Brook meadow rue	*Thalictrum clavatum*
Doll's eyes	*Actaea pachypoda*
Round-lobed hepatica	*Hepatica americana*
Rue anemone	*Thalictrum thalictroides*
Sharp-lobed hepatica	*Hepatica acutiloba*
Shrub yellowroot	*Xanthorhiza simplicissima*
Wood anemone	*Anemone quinquefolia*
ROSACEAE	
Barren strawberry	*Waldsteinia fragarioides*
Black raspberry	*Rubus occidentalis*
Common cinquefoil	*Potentilla simplex*

Appendix 1 (Continued).

ROSACEAE	
Dwarf cinquefoil	*Potentilla canadensis*
Highbush blackberry	*Rubus argutus*
RUBIACEAE	
Bluets	*Hedyotis caerulea*
Fragrant bedstraw	*Galium triflorum*
No common name	*Mitchella repens*
Wild licorice	*Galium circaezans*
SAXIFRAGACEAE	
Alum root	*Heuchera americana*
Bishop's cap	*Mitella diphylla*
Foamflower	*Tiarella cordifolia*
Hairy alum root	*Heuchera villosa*
Wild hydrangea	*Hydrangea arborescens*
VIOLACEAE	
Early yellow violet	*Viola rotundifolia*
Halberd-leaved violet	*Viola hastata*
Long spurred violet	*Viola rostrata*
March blue violet	*Viola cucullata*
Pale violet	*Viola striata*
Sweet white violet	*Viola blanda*
VITACEAE	
Muscadine	*Vitis rotundifolia*
Virginia creeper	*Parthenocissus quinquefolia*

APPENDIX II

Common, Less-common, and Probable Breeding Populations of Avian Species on the BSFNRRA

Appendix II. Common, Less-common, and Probable Breeding Populations of Avian Species on the BSFNRRA.

Common Name	**Scientific Name**
Acadian flycatcher	*Empidonax virescens*
American crow	*Corvus brachyrhynchos*
American goldfinch	*Carduelis tristis*
American redstart	*Setophaga ruticilla*
American robin	*Turdus migratorius*
American woodcock	*Philohela minor*
Barn swallow	*Hirundo rustica*
Black-throated green warbler	*Dendroica virens*
Black-and-white warbler	*Mniotilta varia*
Blue jay	*Cyanocitta cristata*
Blue-gray gnatcatcher	*Polioptila caerulea*
Brown thrasher	*Toxostoma rufum*
Brown-headed cowbird	*Molothrus ater*
Carolina chickadee	*Parus carolinensis*
Carolina wren	*Thryothorus ludovicianus*
Cerulean warbler	*Dendroica cerulea*
Chimney swift	*Chaetura pelagica*
Chipping sparrow	*Spizella passerina*
Common grackle	*Quiscalus quiscula*
Common yellowthroat	*Geothlypis trichas*
Dark-eyed junco	*Junco hyemalis*
Eastern bluebird	*Sialia sialis*
Eastern kingbird	*Tyrannus tyrannus*
Eastern phoebe	*Sayornis phoebe*
Eastern meadowlark	*Sturnella magna*
Eastern wood pewee	*Contopus virens*
European starling	*Sturnus vulgaris*
Field sparrow	*Spizella pusilla*
Gray catbird	*Dumetella carolinensis*
Great crested flycatcher	*Myiarchus crinitus*
Golden-crowned kinglet	*Regulus satrapa*
Hooded warbler	*Wilsonia citrina*
House sparrow	*Passer domesticus*
Indigo bunting	*Passerina cyanea*
Kentucky warbler	*Oporornis formosus*
Louisiana waterthrush	*Seiurus motacilla*

Appendix II (Continued).

Common Name	Scientific Name
Northern cardinal	*Cardinalis cardinalis*
Northern mockingbird	*Mimus polyglottos*
Northern parula	*Parula americana*
Northern rough-winged swallow	*Stelgidopteryx ruficollis*
Orchard oriole	*Icterus spurius*
Ovenbird	*Seiurus aurocapillus*
Pine warbler	*Dendroica pinus*
Prairie warbler	*Dendroica discolor*
Red-eyed vireo	*Vireo olivaceus*
Red-winged blackbird	*Agelaius phoeniceus*
Rufous-sided towhee	*Pipilo erythrophthalmus*
Scarlet tanager	*Piranga olivacea*
Solitary vireo	*Vireo solitarius*
Song sparrow	*Melospiza melodia*
Swainson's warbler	*Limnothlypis swainsonii*
Summer tanager	*Piranga rubra*
Tufted titmouse	*Parus bicolor*
Whip-poor-will	*Caprimulgus vociferus*
White-breasted nuthatch	*Sitta carolinensis*
White-eyed vireo	*Vireo griseus*
Wood thrush	*Hylocichla mustelina*
Worm-eating warbler	*Helmitheros vermivorus*
Yellow warbler	*Dendroica petechia*
Yellow-billed cuckoo	*Coccyzus americanus*
Yellow-breasted chat	*Icteria virens*
Yellow-rumped warbler	*Dendroica coronata*
Yellow-throated vireo	*Vireo flavifrons*
Yellow-throated warbler	*Dendroica dominica*

APPENDIX III

Organochlorine Percent Recovery (25, 50 and 100 ng/ml) Data

Appendix III. Organochlorine Percent Recovery Data (25 ng/ml).

Compound	Percent Recovery	Control Limits
Tetrachloro-m-xylene	101.0	75-125%
Propachlor	117.3	75-125%
Alpha-BHC	98.6	75-125%
Gamma-BHC	92.5	75-125%
Beta-BHC	97.9	75-125%
Heptachlor	93.5	75-125%
Delta-BHC	92.8	75-125%
Aldrin	94.4	75-125%
Dursban	94.6	75-125%
Heptachlor Epoxide	94.6	75-125%
Endosulfan I	94.6	75-125%
4'4-DDE	96.0	75-125%
Dieldrin	94.4	75-125%
Endrin	97.9	75-125%
4'4-DDD	86.9	75-125%
Endosulfan II	92.6	75-125%
4'4-DDT	114.1	75-125%
Endrin Aldehyde	92.1	75-125%
Endosulfan Sulfate	89.3	75-125%
Methoxychlor	110.5	75-125%
Decachlorobiphenyl*	73.1	75-125%

* = Surrogate Compound

Appendix III (Continued) (50ng/ml).

Compound	Percent Recovery	Control Limits
Tetrachloro-m-xylene	85.8	75-125%
Propachlor	91.5	75-125%
Alpha-BHC	98.4	75-125%
Gamma-BHC	87.2	75-125%
Beta-BHC	85.0	75-125%
Heptachlor	81.0	75-125%
Delta-BHC	87.2	75-125%
Aldrin	81.6	75-125%
Dursban	85.0	75-125%
Heptachlor Epoxide	86.0	75-125%
Endosulfan I	82.6	75-125%
4'4-DDE	84.6	75-125%
Dieldrin	84.0	75-125%
Endrin	89.6	75-125%
4'4-DDD	86.6	75-125%
Endosulfan II	87.2	75-125%
4'4-DDT	111.4	75-125%
Endrin Aldehyde	91.0	75-125%
Endosulfan Sulfate	95.0	75-125%
Methoxychlor	93.0	75-125%
Decachlorobiphenyl*	110.4	75-125%

* = Surrogate Compound

Appendix III (Continued) (100 ng/ml).

Compound	Percent Recovery	Control Limits
Tetrachloro-m-xylene	107.0	75-125%
Propachlor	89.8	75-125%
Alpha-BHC	100.9	75-125%
Gamma-BHC	96.9	75-125%
Beta-BHC	90.9	75-125%
Heptachlor	94.5	75-125%
Delta-BHC	93.4	75-125%
Aldrin	93.8	75-125%
Dursban	91.1	75-125%
Heptachlor Epoxide	88.2	75-125%
Endosulfan I	88.4	75-125%
4'4-DDE	90.4	75-125%
Dieldrin	91.2	75-125%
Endrin	92.4	75-125%
4'4-DDD	84.4	75-125%
Endosulfan II	85.5	75-125%
4'4-DDT	114.7	75-125%
Endrin Aldehyde	80.2	75-125%
Endosulfan Sulfate	77.4	75-125%
Methoxychlor	92.4	75-125%
Decachlorobiphenyl*	122.0	75-125%

* = Surrogate Compound

APPENDIX IV

Organochlorine Standard Curve (5-150 ng/ml) Percent Recovery Data

Appendix IV. Organochlorine Standard Curve (5-150 ng/ml) Percent Recovery Data.

Quality Control Measure	TCMX Percent Recovery	Decachlorobiphenyl Percent Recovery
Standard Curve 5 ng/ml	91	98
Standard Curve 10 ng/ml	91	99
Standard Curve 20 ng/ml	96	97
Standard Curve 50 ng/ml	92	90
Standard Curve 125 ng/ml	107	96
Standard Curve 150 ng/ml	98	102
Method Blank	34	75

APPENDIX V

Metals Quality Assurance/Quality Control Data (Selenium/Graphite Furnace Analyses) for Sediment Samples

Appendix V. Metals Quality Assurance/Quality Control Data (Selenium/Graphite Furnace Analyses).

QC Parameter	Sample Result	True	Percent Recovery/RPD*
QCS 1/20 ppb	0.014	0.020	70
QCS 2/40 ppb	0.039	0.040	97.5
Duplicate (#96101880)	0.038	0.028	30.3*
Duplicate (#96101887)	0.012	0.012	0.0*
Spike (#96101867)	0.054	0.025	88.0

*Relative Percent Difference

APPENDIX VI

Metals Percent Recovery Data (Inductively Coupled Plasma Analyses) for Sediment Samples

Appendix VI. Metals Percent Recovery Data (Inductively Coupled Plasma Analyses).

Metal (0.5ppm QCS)	Percent Recovery
Silver	106
Aluminum	104
Arsenic	107
Barium	105
Beryllium	102
Cadmium	106
Cobalt	106
Chromium	109
Copper	106
Iron	106
Lead	101
Manganese	103
Zinc	106

Metal (50ppm QCS)	Percent Recovery
Silver	98
Aluminum	99
Arsenic	100
Barium	100
Beryllium	Over Limit
Cadmium	98
Cobalt	98
Chromium	100
Copper	98
Iron	98
Lead	99
Manganese	Over Limit
Zinc	99

Appendix VI (Continued).

Metal (5.0ppm QCS 1)	**Percent Recovery**
Silver	107
Aluminum	101
Arsenic	99
Barium	102
Beryllium	99
Cadmium	101
Cobalt	101
Chromium	102
Copper	101
Iron	98
Lead	103
Manganese	98
Zinc	101

Metal (5.0ppm QCS 2)	**Percent Recovery**
Silver	103
Aluminum	100
Arsenic	98
Barium	101
Beryllium	97
Cadmium	99
Cobalt	99
Chromium	101
Copper	101
Iron	98
Lead	102
Manganese	96
Zinc	98

APPENDIX VII

Duplicate Inductively Coupled Plasma Analyses for Sediment Samples

Appendix VII. Duplicate Inductively Coupled Plasma Analyses.

Sample	Metal	RPD*
96101879	Silver	0.0
	Aluminum	31.9
	Arsenic	34.1
	Barium	30.4
	Beryllium	14.5
	Cadmium	0.0
	Cobalt	9.1
	Chromium	22.7
	Copper	1.7
	Iron	4.1
	Lead	4.9
	Manganese	17.0
	Zinc	29.4
96101883	Silver	0.0
	Aluminum	28.6
	Arsenic	13.5
	Barium	14.4
	Beryllium	21.1
	Cadmium	0.0
	Cobalt	31.8
	Chromium	26.0
	Copper	10.4
	Iron	21.1
	Lead	17.1
	Manganese	25.9
	Zinc	18.2

*Relative Percent Difference

Appendix VII (Continued).

Sample	Metal	RPD*
96101867	Silver	0.0
	Aluminum	2.6
	Arsenic	0.0
	Barium	4.5
	Beryllium	0.0
	Cadmium	0.0
	Cobalt	0.0
	Chromium	0.0
	Copper	3.7
	Iron	8.7
	Lead	0.0
	Manganese	3.3
	Zinc	6.0

*Relative Percent Difference

APPENDIX VIII

Spike Sample Recovery Data for Inductively Coupled Plasma Analyses for Sediment Samples

Appendix VIII. Spike Sample Recovery Data for Inductively Coupled Plasma Analyses.

Sample	Metal	Percent Spike Recovery
96101881	Silver	86.5
	Aluminum	105.0
	Arsenic	82.1
	Barium	97.0
	Beryllium	88.0
	Cadmium	85.0
	Cobalt	84.2
	Chromium	86.7
	Copper	85.1
	Iron	Over Limit
	Lead	82.0
	Manganese	78.5
	Zinc	82.5

APPENDIX IX

Quality Assurance/Quality Control Data for Water Samples

Appendix IX. Quality Assurance/Quality Control Data for Water Samples.

QC Parameter	True Value	%RSD	%Recovery
Acidity			
9601199d[1]		0.50	
9601394d		0.33	
9601397d		0.14	
9601198s[2]			76.24
9601393s			99.70
Alkalinity			
9601189d		0.02	
9601189s			98.30
9601200s			95.30
9601397s			98.50
Nitrate-Nitrite as N			
9601385d		22.00	
9601386d		28.00	
9601385s			95.50
QC1	0.860 mg/l		98.30
QC1	0.860 mg/l		105.50
QC1	0.860 mg/l		97.20
QC1	0.860 mg/l		96.70
pH			
9601199d		0.00	
9601206d		0.00	
9601394d		0.20	

Appendix IX. Continued.

QC Parameter	True Value	%RSD	%Recovery
pH (continued)			
9601397d		1.30	
Specific Conductance			
9601194d		0.67	
9601206d		0.15	
9601395d		0.80	
9601397d		0.00	
Sulfate			
9601195d		1.30	
9601393d		5.90	
9601397d		0.40	
9601393s			108.40
9601397s			90.70
Total Suspended Solids			
9601390d		18.90	
Turbidity			
9601199d		0.26	
9601205d		5.84	
9601390d		5.50	
9601385s			102.00

Appendix IX. Continued.

QC Parameter	True Value	%RSD	%Recovery
Arsenic (GFAA)[3]			
9601206F[4]s			106.00
9601388s			114.50
QC-XCWK	50 μg/l		100.80
QC-XCWK	50 μg/l		98.40
Cadmium (GFAA)			
9601206d		2.00	
9601206Fs			83.20
9601388s			105.40
9601396Fs			124.50
QC-XCWK	25 μg/l		102.80
QC-XCWK	25 μg/l		99.60
Chromium (GFAA)			
9601197d		1.46	
9601206Fd		1.28	
9601387d		3.44	
9601391d		7.89	
9601395Fd		13.80	
9601206Fs			116.80
9601388s			114.00
9601396s			131.20
QC-XCWK	50 μg/l		92.00
QC-XCWK	50 μg/l		99.60

Appendix IX. Continued.

QC Parameter	True Value	%RSD	%Recovery
Cobalt (GFAA)			
9601191d		25.80	
9601197d		4.70	
9601201d		11.20	
9601387d		13.60	
9601391d		9.70	
9601395Fd		22.90	
9601388s			97.40
9601396Fs			113.40
QC-XCWK	50 μg/l		91.60
QC-XCWK	50 μg/l		98.00
Copper (GFAA)			
9601197d		15.70	
9601206Fd		1.00	
9601387d		2.50	
9601391d		18.70	
9601395Fd		3.70	
9601206Fs			99.20
9601388s			126.80
9601396Fs			126.10
QC-XCWK	50 μg/l		102.80
QC-XCWK	50 μg/l		102.0

Appendix IX. Continued.

QC Parameter	True Value	%RSD	%Recovery
Lead (GFAA)			
9601197d		2.40	
9601206Fd		0.00	
9601387d		4.70	
9601206Fs			98.40
9601388s			107.00
9601396Fs			129.70
QC-XCWK	50 μg/l		98.00
QC-XCWK	50 μg/l		98.00
Mercury (Cold Vapor)			
9601197Fd		0.00	
QC-0.200	0.2 μg/l		100.00
QC-0.200	0.2 μg/l		100.00
Nickel (GFAA)			
9601191d		2.20	
9601197d		0.30	
9601200Fd		1.50	
9601201d		14.20	
9601387d		18.50	
9601391d		9.80	
9601395Fd		5.20	
9601388s			80.40
9601396Fs			119.70

Appendix IX. Continued.

QC Parameter	True Value	%RSD	%Recovery
Nickel (continued)			
QC-XCWK	50 µg/l		102.80
QC-XCWK	50 µg/l		89.20
Aluminum (ICP)[5]			
9601191d		14.00	
9601200d		6.10	
9601201d		12.20	
9601206d		16.40	
9601385d		4.60	
9601390d		2.70	
9601395d		14.90	
9601192s			65.00
9601202s			75.00
9601396s			134.00
(4/30/96)QC-ICV1	1.00 mg/l		99.20
(5/10/96)QC-ICV1	1.00 mg/l		95.20
Barium (ICP)			
9601191d		15.80	
9601200d		3.70	
9601201d		14.90	
9601206d		7.50	
9601385d		5.50	
9601390d		8.60	

Appendix IX. Continued.

QC Parameter	True Value	%RSD	%Recovery
Barium (continued)			
9601395d		9.20	
9601192s			95.80
9601202s			71.80
9601396s			130.00
(4/30/96)QC-ICV1	1.00 mg/l		102.00
(5/10/96)QC-ICV1	1.00 mg/l		101.00
Calcium (ICP)			
9601191d		12.70	
9601200d		5.50	
9601201d		13.50	
9601206d		17.60	
9601385d		3.80	
9601390d		2.10	
9601395d		6.10	
9601192s			90.00
9601202s			75.00
9601396s			132.00
(4/30/96)QC-ICV1	10.00 mg/l		98.00
(5/10/96)QC-ICV1	10.00 mg/l		97.20
Iron (ICP)			
9601191d		13.20	
9601200d		7.10	

Appendix IX. Continued.

QC Parameter	True Value	%RSD	%Recovery
Iron (continued)			
9601201d		12.60	
9601206d		17.10	
9601385d		4.10	
9601390d		5.50	
9601395d		17.20	
9601192s			100.00
9601202s			80.00
9601396s			130.00
(4/30/96)QC-ICV1	1.00 mg/l		101.00
(5/10/96)QC-ICV1	1.00 mg/l		98.00
Magnesium (ICP)			
9601191d		12.80	
9601200d		5.98	
9601201d		14.20	
9601206d		16.30	
9601385d		4.20	
9601390d		1.80	
9601395d		5.60	
9601192s			100.00
9601202s			75.00
9601396s			130.00
(4/30/96)QC-ICV1	10.00 mg/l		103.00
(5/10/96)QC-ICV1	10.00 mg/l		101.00

Appendix IX. Continued.

QC Parameter	True Value	%RSD	%Recovery
Manganese (ICP)			
9601191d		12.90	
9601200d		5.40	
9601201d		13.30	
9601206d		18.00	
9601385d		4.10	
9601390d		2.30	
9601395d		6.10	
9601192s			Over Limit
9601202s			85.00
9601396s			129.00
(4/30/96)QC-ICV1	1.00 mg/l		100.00
(5/10/96)QC-ICV1	1.00 mg/l		98.70
Potassium (ICP)			
9601191d		14.10	
9601200d		4.10	
9601201d		14.60	
9601206d		13.30	
9601385d		5.20	
9601390d		2.10	
9601395d		5.30	
9601192s			87.00
9601202s			71.70
9601396s			123.50

Appendix IX. Continued.

QC Parameter	True Value	%RSD	%Recovery
Potassium (continued)			
(4/30/96)QC-ICV1			96.20
(5/10/96)QC-ICV1			98.40

[1] = duplicate
[2] = spike
[3] = graphite furnace atomic absorption
[4] = filtered
[5] = inductively coupled plasma
Analyses performed by Kentucky Division of Environmental Services