10/4-3-92 JS(1)

ornl

ORNL/TM-11926

OAK RIDGE
NATIONAL
LABORATORY

MARTIN MARIETTA

Ecological Effects of Contaminants in McCoy Branch, 1989–1990

M. G. Ryon

Environmental Sciences Division

Publication No. 3837

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM--11926

DE92 010368

Environmental Sciences Division

ECOLOGICAL EFFECTS OF CONTAMINANTS IN MCCOY BRANCH, 1989–1990

Editor
M. G. Ryon

Contributors

R. L. Hinzman[1]
M. J. Peterson[2]
T. D. Richardson[3]
M. G. Ryon
J. G. Smith
G. R. Southworth
A. J. Stewart
V. R. Tolbert

Environmental Sciences Division
Publication No. 3837

[1]Oak Ridge Research Institute, Oak Ridge, Tennessee
[2]Automated Sciences Group, Inc., Oak Ridge, Tennessee
[3]Postdoctoral Associate, Oak Ridge Associated Universities

Date of Issue--January 1992

Prepared for
S. Walker
Environmental Restoration Program
Y-12 Plant
Oak Ridge, Tennessee 37831

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

CONTENTS

CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

ACRONYMS

AA	Atomic Absorption Spectroscopy
ACD	Analytical Chemistry Division
ANOVA	Analysis of Variation
BMAP	Biological Monitoring and Abatement Program
CPI	Cohort production interval
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DEM	Department of Environmental Management
DO	Dissolved oxygen
DOE	Department of Energy
EFK	East Fork Poplar Creek kilometer
EFPC	East Fork Poplar Creek
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera richness
ES	Emission Spectroscopy
ESD	Environmental Sciences Division, ORNL
FDA	U.S. Food and Drug Administration
G	Value derived from a median test for multiple samples
GCK	Grassy Creek kilometer
GC/ECD	Gas chromatography/electron capture detector
GC/MS	Gas chromatography/mass spectrophotometry
HESA	Department of Health, Safety, and Environmental Affairs
HSRD	Health and Safety Research Division
LCT	Life-Cycle Test
LOEC	Lowest observed-effect level
LR-o	Lake Reality outfall
MAF	Mean annual flow
MCK	McCoy Branch kilometer
NOEC	No observed-effect concentration
NPDES	National Pollutant Discharge Elimination System
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PAH	Polycyclic aromatic hydrocarbons
P/B	Production/biomass
PCB	Polychlorinated biphenyl
PGV	Preliminary guidance values
PPM	Parts per million
QA	Quality Assurance
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facilities Investigation
RQ	Rogers Quarry
SD	Standard deviation
SE	Standard error
TDC	Tennessee Department of Conservation
TL	Total length
TRC	Total residual chlorine

TRE	Toxicity reduction evaluation
TSCA	Toxic Substances Control Act
TSS	Total suspended solids
TVA	Tennessee Valley Authority
WCK	White Oak Creek kilometer
WOC	White Oak Creek

ACKNOWLEDGMENTS

We thank D. K. Cox, W. C. Kyker, L. M. Stubbs, W. M. Harris, B. A. Carrico, E. M. Schilling, R. D. Bailey, P. W. Braden, L. S. Ewald, L. A. Kszos, G. P. Morris, and L. F. Wicker for their assistance in the laboratory and/or field. We thank M. Maskarinec, N. M. Ferguson, and other staff of the Oak Ridge National Laboratory Analytical Chemistry Division for sample analysis. We thank B. F. Clark, W. D. Dickinson, A. W. McWhorter, and J. A. Wojtowicz for processing the benthic macroinvertebrate samples. We are grateful to W. R. Hill of The University of Tennessee, Steve Walker of the Y-12 Plant, and R. R. Turner of ESD who reviewed an earlier draft of this report and provided many helpful comments.

This work was funded by the Y-12 Plant Environmental Restoration Program. The Y-12 Plant and Oak Ridge National Laboratory are managed by Martin Marietta Energy Systems, Inc., under contract DE-AC05-84OR21400 with the U.S. Department of Energy.

EXECUTIVE SUMMARY

The 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act (RCRA) required assessment of all current and former solid waste management units. Such a RCRA Facility Investigation (RFI) was required of the Y-12 Plant for their Filled Coal Ash Pond on McCoy Branch. Because the disposal of coal ash in the ash pond, McCoy Branch, and Rogers Quarry was not consistent with the Tennessee Water Quality Act, several remediation steps were implemented or planned for McCoy Branch to address disposal problems.

The McCoy Branch RFI plan included provisions for biological monitoring of the McCoy Branch watershed. The objectives of the biological monitoring were to: (1) document changes in biological quality of McCoy Branch after completion of a pipeline and after termination of all discharges to Rogers Quarry, (2) provide guidance on the need for additional remediation, and (3) evaluate the effectiveness of implemented remedial actions. The data from the biological monitoring program will also determine if the classified uses, as identified by the State of Tennessee, of McCoy Branch are being protected and maintained.

BACKGROUND

In connection with the coal ash disposal, McCoy Branch has been segmented into four basic areas: (1) the headwater sections of McCoy Branch and a large coal ash pond created by a 19-m earthen dam; (2) a section of free-flowing stream that flows from under the dam into Rogers Quarry; (3) Rogers Quarry, a deep, steep-sided lake; and (4) a section of free-flowing stream that flows from Rogers Quarry into Melton Hill Reservoir, with an associated embayment area. Prior to May 1990, the major source of water for McCoy Branch was the coal-ash slurry pumped from the Y-12 Steam Plant. Initially (1955), the slurry was piped to the upper reaches and was contained behind the earthen dam. As the area behind the dam filled in (1965), the slurry was transferred by overflow to Rogers Quarry; at first through McCoy Branch and then in 1989 via a pipeline. Four measures were initiated in 1986 to reduce the volume of coal ash discharged to Rogers Quarry: (1) the Y-12 Steam Plant switched to a higher grade of washed coal; (2) the Steam Plant was converted to use natural gas as the primary fuel type in the winter of 1988; (3) a dry ash handling system was installed to collect fly ash in May 1990, after which, fly ash was no longer discharged to Rogers Quarry; and (4) the Steam Plant is scheduled to install a bottom ash dewatering system in 1993, at which time all discharges to Rogers Quarry will cease.

WATER QUALITY

In 1986, coal ash slurry discharged from the Y-12 Steam Plant was found to contain elevated amounts of aluminum, barium, boron, calcium, iron, magnesium, sodium, arsenic, strontium, potassium, total suspended solids, total phosphorous, sulfide, and sulfate when compared to background water concentrations. A comparison of water quality data from

Rogers Quarry to data for the effluents from 14 ash ponds associated with TVA coal-fired power plants revealed that Rogers Quarry effluent was similar to effluent from other coal ash disposal ponds in the Tennessee Valley. Water quality data collected from a National Pollutant Discharge Elimination System site below Rogers Quarry show a decrease in mean weekly levels of sulfate, arsenic, and selenium after the Y-12 Steam Plant converted from coal to natural gas as the primary fuel source.

TOXICITY TESTING

The results of the toxicity tests of water from McCoy Branch did not show much evidence for toxic conditions in this stream. In 7-d laboratory tests, survival and growth of fathead minnow larvae and survival and fecundity of *Ceriodaphnia* were generally high, although a few exceptions to this trend were evident. Similarly, in full life-cycle tests, *Ceriodaphnia* had significantly fewer broods and a slightly lower mean daily fecundity in McCoy Branch water than they did in the controls, but the number of neonates per brood tended to be greater than that in controls. Thus, the net effect of McCoy Branch water on *Ceriodaphnia* fecundity was small. In the in situ tests, snails apparently experienced more stress in McCoy Branch at McCoy Branch kilometer (MCK) 1.60 (below Rogers Quarry) than they did at either MCK 1.92 (above Rogers Quarry) or at White Oak Creek kilometer (WCK) 6.3 (reference stream). At MCK 1.60, the net movement of snails was downstream; whereas, the net movement of the snails at the other two sites was upstream. Typically, upstream movement of snails occurs in noncontaminated streams, and the net movement is downstream in contaminated streams. Snails may actively move downstream as an escape behavior or may be passively transported downstream by flow. In 7-d laboratory tests, snails consumed less food when tested in water from McCoy Branch at MCK 1.60 than they did in water from either MCK 1.92 or WCK 6.3, but this difference was not statistically significant. The results of associated chemical analyses also suggest the stream is not highly perturbed.

BIOACCUMULATION STUDIES

Concentrations of selenium, arsenic, and possibly thallium are elevated in largemouth bass from Rogers Quarry relative to bass from Melton Hill Reservoir and sunfish from Hinds Creek. Levels of selenium and possibly arsenic appeared to be elevated above background in bass from McCoy Branch embayment of Melton Hill Reservoir. Only arsenic exceeds conservatively based screening criteria; however, virtually all biological materials exceed this criterion for arsenic. Cessation of inputs of fly ash to the system, coupled with the rapid biological turnover of selenium and arsenic, should result in continuing decreases in concentrations of these elements in fish. The very low concentrations of mercury in fish from Rogers Quarry are consistent with findings of other research on interaction between selenium and the bioaccumulation of mercury, and suggest research areas for possible remediation of local mercury-contaminated systems. Some fish from Rogers Quarry had deformed bony structures. These effects were not described in literature on effects of selenium or arsenic; although the age of the fish indicated they were exposed in the period of higher concentrations. Bioaccumulation of organic contaminants was not indicated in the McCoy Branch discharge.

FISH COMMUNITY ASSESSMENT

The fish community of McCoy Branch was evaluated using qualitative samples above Rogers Quarry and quantitative samples below Rogers Quarry at MCK 1.56. Electrofishing samples were made in May 1989, October 1989, and May 1990 to provide population estimates. Results from the fish assessments indicate that McCoy Branch was under severe stress. No fish populations were found above the quarry. This suggests past ash disposal practices were lethal to fish; current conditions could not be evaluated because repopulation of this section of McCoy Branch is prevented by Rogers Quarry. The community below Rogers Quarry, although permanent, appears stressed and greatly influenced by the proximity to Melton Hill Reservoir. The species composition is not typical for a small stream, and those species that inhabit the stream are generally more tolerant of degraded conditions. Additionally, abnormalities such as deformed heads and eroded fins that are typically infrequent in a normal stream population occur in a substantial percentage of the sunfish population. These deformities are the same types that were reported by the bioaccumulation studies.

BENTHIC MACROINVERTEBRATE COMMUNITY ASSESSMENT

The structure and composition of the benthic macroinvertebrate community in McCoy Branch are indicative of moderate stress. Maximum impact within this stream occurs upstream of Rogers Quarry as is exemplified by MCK 2.03. At MCK 2.03, substantial increases were observed in density, biomass, taxonomic richness, and Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness during the October and January sampling periods compared with April and July sampling, which suggests water quality improvement, but may also reflect seasonal impacts. Rogers Quarry acts as a settling basin for coal ash and reduces the impact of ash deposition on the benthic community downstream of the quarry. Although Rogers Quarry appears to reduce these impacts, it may also alter the physical and chemical environment downstream, which in turn alters the invertebrate community. Some improvement in water quality was evident downstream of the quarry, as demonstrated by significantly higher density and biomass at MCK 1.40. However, taxonomic richness, EPT richness, and diversity were significantly lower at this site, compared to the reference site, indicating that the invertebrate community was impacted. The benthic community at MCK 1.40 did not exhibit the temporal increases in density, biomass, or taxonomic and EPT richness shown by MCK 2.03, indicating this community is not experiencing similar changes in water quality. The stress on the benthic macroinvertebrate community in McCoy Branch appears to be habitat alteration as a result of ash deposition within the stream channel and possibly leaching of potential toxicants (e.g., arsenic and selenium) from the ash. As stresses to McCoy Branch are further reduced or eliminated, a steady recovery of the benthic fauna at MCK 2.03 should occur; however, the recovery at MCK 2.03 may be slowed by the loss of supplemental flow to McCoy Branch.

FUTURE STUDIES

Quarterly ambient toxicity tests will continue at MCK 1.60 and MCK 1.92 to monitor changes in water quality. Snail release studies are planned to determine whether snails can survive and grow in upper McCoy Branch. Largemouth bass from Rogers Quarry and McCoy Branch embayment will be sampled and analyzed to determine whether metal concentrations decrease as expected. A more detailed investigation of bony structure deformities will also be conducted. Fish populations will be surveyed at MCK 1.56 twice a year, with qualitative surveys conducted annually in upper McCoy Branch. An additional reference site will be added for comparison with the fish community data and additional qualitative surveys will be made to assess immigration potential. Long-term plans will be made to reintroduce fish into upper McCoy Branch. Benthic communities will continue to be sampled quarterly at the current sites, and an additional reference site will be added to evaluate differences related to the absence or presence of snails.

1. INTRODUCTION

The 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act (RCRA) required assessment of all current and former solid waste management units. Such an assessment or RCRA Facility Investigation (RFI) was required of the Y-12 Plant for their Filled Coal Ash Pond (Murphy 1988). The Filled Coal Ash Pond (referred to as the "ash pond" in this report) was constructed in the 1950s on the upper portion of the McCoy Branch watershed. It received coal ash through a pipeline in a slurry from the coal-fired steam plant at Y-12. Because disposal of coal ash in the ash pond, and later in McCoy Branch and Rogers Quarry, was not consistent with the Tennessee Water Quality Act, several remediation steps (e.g., extending pipeline to Rogers Quarry) were implemented or planned for McCoy Branch to address disposal problems. The initial RFI plan examined the ash pond (Murphy 1988) and associated disposal concerns. An expanded RFI plan was also written to assess remediation in McCoy Branch and some downstream components of this waste management unit (e.g., Rogers Quarry) (Murphy and Loar 1988).

The McCoy Branch RFI plan included provisions for biological monitoring of the McCoy Branch watershed. The objectives of the biological monitoring were to: "(1) document the degree of improvement in biological quality of McCoy Branch after completion of the pipeline and after all ash discharges to Rogers Quarry are terminated; (2) provide guidance on the need for additional remediation; and (3) evaluate the effectiveness of the remedial actions that are implemented. The data from the biological monitoring program will also be sufficient to determine if the classified uses of McCoy Branch, as identified in the State of Tennessee Water Quality Management Plan for the Clinch River Basin (TDPH 1978), are being adequately protected and maintained" (Murphy and Loar 1988).

The overall strategy for the biological assessment was based on four considerations: (1) Because remediation efforts are phased temporally, the biological monitoring would also be implemented in stages with increased monitoring as the system recovered. (2) The size of the stream restricted the application of assessment techniques to certain areas. (3) The fauna of McCoy Branch appeared depauperate; therefore, some constraints were necessary on the parameters to be measured, and the need was recognized for a limited number of reference sites. and (4) Because the time frame for reaching hydrologic equilibrium following remediation is unknown, the biological monitoring must consider changes in hydrologic regime and improvement in water quality (Murphy and Loar 1988). Therefore, to address these considerations, the biological monitoring applied to McCoy Branch consisted of an integrated multitiered program. The program included four primary tasks: (1) toxicity monitoring, (2) bioaccumulation assessments, (3) fish community assessments, and (4) benthic community assessments.

The initial results of these four tasks are presented in this report. The results focus on the period from 1989 to 1990, but some previous data from 1974 to 1989 are also presented.

2. DESCRIPTION OF THE McCOY BRANCH WATERSHED

The McCoy Branch watershed is located south of the Y-12 Plant (Fig. 2-1) within the Department of Energy's (DOE) Oak Ridge Reservation (ORR). The ORR is located in the Valley and Ridge physiographic province, which is characterized by southwest-northeast oriented, parallel ridges of sandstone, shale, and cherty dolomite, separated by valleys of less resistant limestone and shale (Murphy 1988). The watershed drains Fanny's Knob on the southern slope of Chestnut Ridge and supplies water to Melton Hill Reservoir. Land use in the watershed includes grass covered slopes and fields, selected marshy pockets in the floodplain, agricultural buildings, roads, and heavily forested slopes.

The eastern branch of McCoy Branch has been extensively modified for coal ash disposal purposes. (This report will deal only with the eastern branch.) In connection with the coal ash disposal, McCoy Branch (Fig. 2-2) has been segmented into four basic areas (1) the headwater sections of McCoy Branch and a large coal filled ash pond created by a 19-m high earthen dam; (2) a section of free-flowing stream that flows from under the dam into Rogers Quarry and that, after rain, is supplemented by flow over the top of the dam; (3) Rogers Quarry, a deep, steep-sided lake; and (4) a section of free-flowing stream that flows from Rogers Quarry into Melton Hill Reservoir, with an associated embayment area. The western branch of McCoy Branch also enters this embayment.

The headwaters of McCoy Branch consist of two intermittent streams with minimal discharge (Turner et al. 1986). A large pipe that was used to transfer coal ash slurry from Y-12 to the ash pond is located between these two streams. In the past, the flow from these three sources combined in the ash pond, which contains the ash slurry from the early years of disposal. The channel in the pond was shallow and meandered over the surface of the ash to the earthen dam. During ash sluicing and high storm runoff, flows reached the dam and were transported downstream via the overflow spillway on the eastern side of the dam.

Water in McCoy Branch below the dam derives primarily from several large springs. The spring at the base of the dam is heavily vegetated and is fed by groundwater discharges. From the dam the stream flows approximately 0.9 km to Rogers Quarry and is typically narrow (about 0.5 to 2.0 m in width) and fast-flowing, consisting of a series of runs and riffles. Just above Rogers Quarry lies a marshy area with a large spring between McCoy Branch (to the east) and the municipal sludge farm to the west. This is where McCoy Branch flowed before being diverted to fill Rogers Quarry (Murphy and Loar 1988).

Rogers Quarry is a 4-hectare lake located about midway in McCoy Branch. It was used as a source of stone in the 1940s and was abandoned when it began to fill with water in the 1950s (Bogle and Turner 1989). After leaving Rogers Quarry the stream flows through Bethel Valley, to the McCoy Branch Embayment on the Melton Hill Reservoir. The stream below the quarry is heavily vegetated and also receives flow from several spring-fed tributaries.

ORNL DWG 91-16946

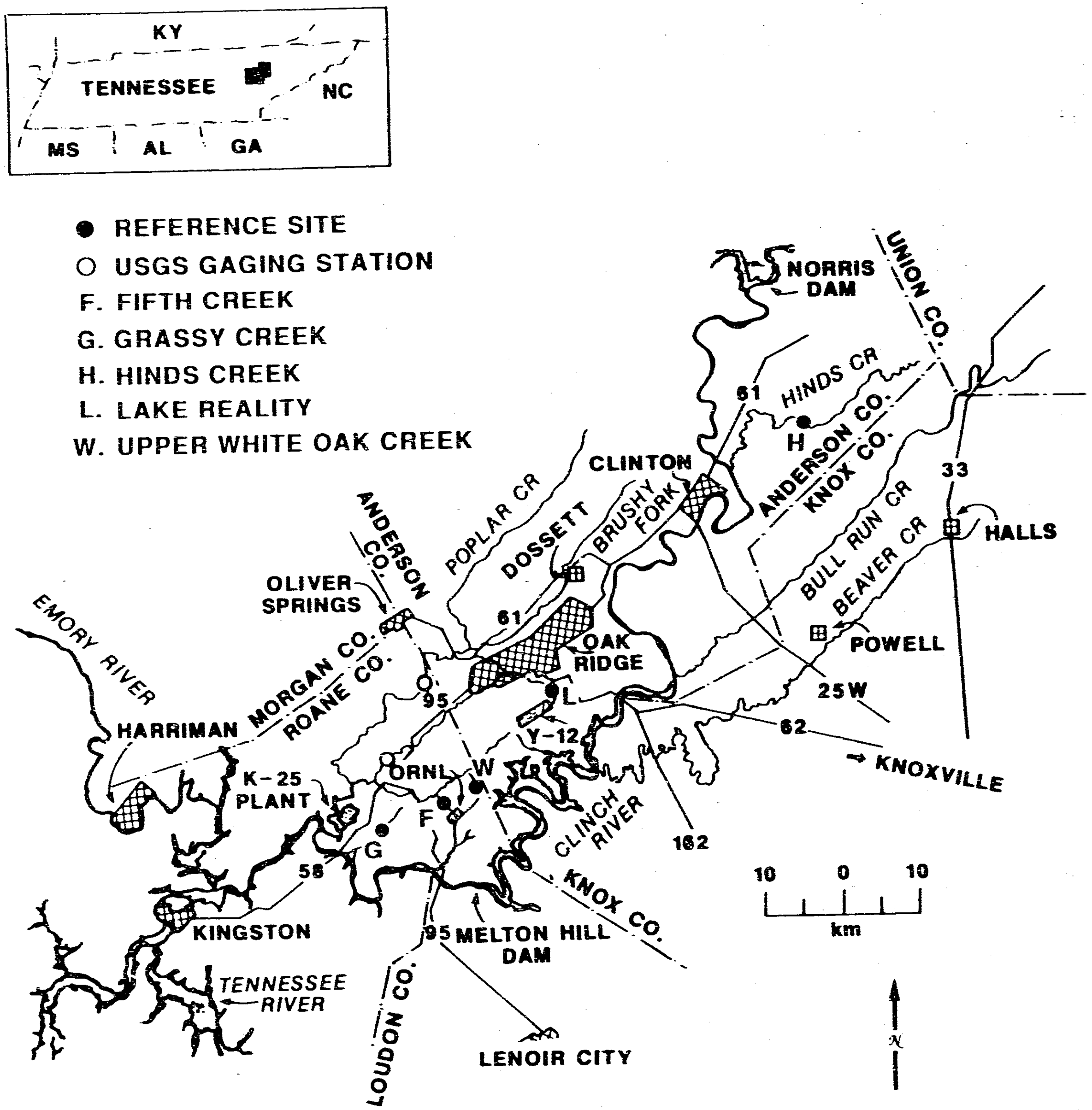

Fig. 2-1. Map of the Oak Ridge area showing locations of the reference sites.

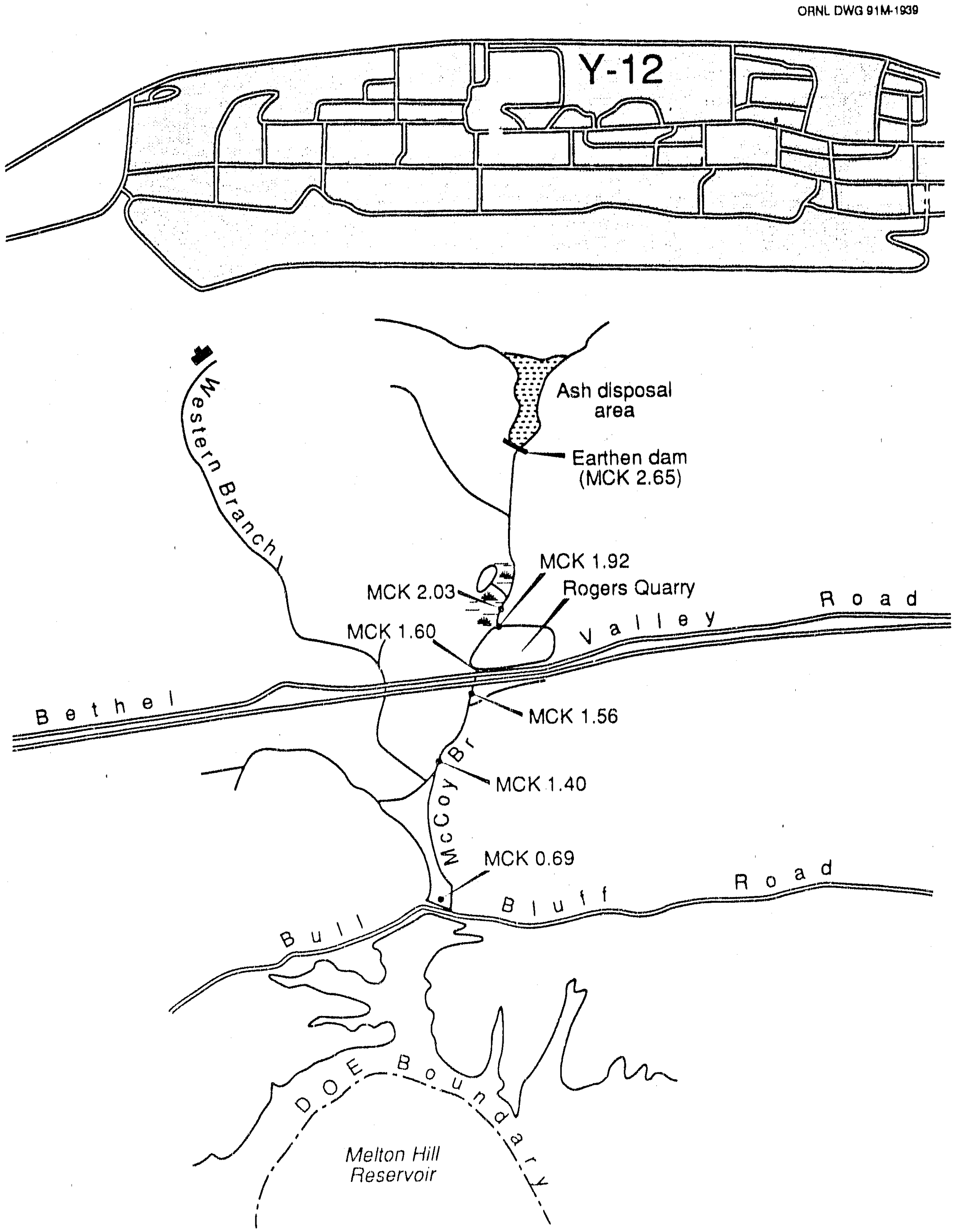

Fig. 2-2. Map of the McCoy Branch showing the primary features and monitoring sites.

McCoy Branch is geographically separated from the Y-12 Plant by Chestnut Ridge. The distance from the ash slurry pipe on top of the ridge to the discharge into Melton Hill Reservoir is approximately 1.5 km. The elevation at the ash slurry pipe at the top of the ridge is about 335 m; elevation at the point where McCoy Branch discharges into Melton Hill Reservoir is approximately 244 m. The watershed has a drainage area of about 148 hectares above Rogers Quarry, 63 ha of which lie above the earthen dam located in the headwaters.

2.1 GEOHYDROLOGY

McCoy Branch is underlain by the Knox group, a highly crystalline dolomite interbedded with shale and mudstone beds, a few very thin sandstone beds, aphanitic limestone lenses, numerous calcite and quartz filled fractures and cavities, and chert beds and nodules (Murphy 1988). Ketelle and Huff (1984) found that water movement in the bedrock of the Knox Group on Chestnut Ridge is controlled by the location and orientation of the cavities. Primary orientation of cavity systems are controlled by the local bedding orientation and orientation of penetrative joints and fractures, which are widened by dissolution. The actual groundwater flow paths in the bedrock are expected to resemble trellis drainage patterns, flowing parallel to strike and diverted by shorter cross-strike channels to other strike-controlled zones or emanated in surface streams. Within both the soil and bedrock aquifers, flow is from the higher topographic areas toward the lower areas, with gradients indicating flow toward the nearest perennial surface water features (Ketelle and Huff 1984; Murphy 1988).

The major source of water for the upstream reach of McCoy Branch is spring flow and precipitation. Craig and Tschantz (1986) estimated the combined base flow of these springs to be in the range of 0.42–0.53 million liters per day. For a more comprehensive characterization of the geology and hydrology of the ash pond see Murphy (1988), Jones and Mishu (1986), and Turner et al. (1986).

2.2 WATER QUALITY

Water quality of McCoy Branch has been primarily affected by coal ash discharge. The ash sluice water was enriched with total suspended solids, sulfates, phosphorous, and various metals (Turner et al. 1986). Sluicing of the ash was intermittent, with seasonal variation in the amount of ash discharged from about 0.76 million liters per day in summer to 3.8 million liters per day in winter (Murphy 1988; Bogle and Turner 1989).

2.2.1 Description and History of Discharges to McCoy Branch and Rogers Quarry

Prior to May 1990, the major source of water for McCoy Branch was the coal-ash slurry pumped from the Y-12 Steam Plant. The Steam Plant, built in 1954, has undergone several renovations and upgrades including conversion to a baghouse-type fly ash collection system in 1985 (Turner et al. 1986). The plant consists of four boiler units that used pulverized coal as the sole fuel source from 1954 to 1988. In the winter of 1988, the plant was converted to use natural gas as the primary fuel source and coal as a secondary source. When burning coal, the steam plant produces two types of ash. Historically, fly ash (dry ash) generated at the Y-12 Steam Plant was removed by a wet collection system, and bottom ash (ash collected from the bottom of the boiler in wet form) was removed by high pressure water jets. The ash was then sluiced (pumped) in series: first the fly ash and then the bottom ash, as a slurry over the crest of Chestnut Ridge. Gravity flow carried the effluent to the ash pond, a broad earthen retention basin of about 8 hectares, which provided sedimentation for the ash slurry before discharge into McCoy Branch (Turner et al. 1986; M. A. Kane, Y-12 Plant, personal communication). The pond was expected to hold 20 years of Y-12 Steam Plant ash, but was filled to within almost 1 m of the top of the dam by July 1967 (Murphy 1988). Subsequently, flow from McCoy Branch was used to channel the slurry to Rogers Quarry. Since 1962, Rogers Quarry has been used for the disposal of ash slurry from the Y-12 Plant. However, between 1965 and 1981 the quarry was also used for the disposal of weapons related and classified items (Table 5 in McCauley 1986; Bogle and Turner 1989). For a complete description of Rogers Quarry see Bogle and Turner (1989). In November 1989, ash slurry discharge to the upper reaches of McCoy Branch was terminated by extending the pipeline directly to Rogers Quarry, which has an estimated life expectancy for ash disposal of 65 to 115 years (Murphy 1988; M. A. Kane, Y-12 Plant, personal communication).

Discharges into McCoy Branch and Rogers Quarry are in violation of the Tennessee Water Quality Act. Several interim actions have taken place, or are anticipated, to assure compliance by July 1, 1993, when all discharges to Rogers Quarry must be terminated (Murphy and Loar 1988). Four measures were initiated in 1986 to reduce the volume of coal ash discharged to Rogers Quarry. (1) The Y-12 Steam Plant switched to a higher grade of washed coal, increasing efficiency and decreasing the total volume of coal utilized in 1986. (2) The Steam Plant was converted in the winter of 1988 to use natural gas as the primary fuel type. The targeted yearly ratio of energy derived from gas compared to that from coal is approximately 5 to 1, with a higher percentage of coal being used in winter months. (3) A dry vacuum system was installed in May 1990 to collect dry fly ash. Fly ash is now put in a landfill, and all fly ash sluice water discharge to Rogers Quarry has been terminated. (4) Present discharges to Rogers Quarry include only bottom ash sluice water and steam plant washdown water. The Y-12 Steam Plant is scheduled to install a bottom ash dewatering system in 1993, at which time bottom ash will be landfilled and washdown water will be processed through the Steam Plant's wastewater treatment facility.

2.2.2 Characterization of the Contaminant Source

In a study by Pulliam (1985a,b) water upstream from Rogers Quarry had higher levels of most metals than did water samples taken downstream of Rogers Quarry (Appendix A, Table A-1). These data were supported by results in ERDA 1975 (Appendix A, Table A-2). In a study by Turner et al. (1986), coal ash sluice water discharged from the Y-12 Steam Plant was found to contain elevated amounts of aluminum, barium, boron, calcium, iron, magnesium, sodium, arsenic, strontium, potassium, total suspended solids, total phosphorous, sulfide, and sulfate when compared to background water concentrations (Appendix A, Tables A-3, A-4, A-5, and A-6). Turner et al. (1986) also noted that the filled ash pond provided little or no treatment, did not remove suspended solids, and the flow of McCoy Branch was so small that it was incapable of providing appreciable dilution to the ash sluice water. Turner et al. (1986) also compared water quality data from Rogers Quarry to data for the effluents from 14 ash ponds associated with Tennessee Valley Authority (TVA) coal-fired power plants. The comparison revealed that Rogers Quarry effluent was similar to effluent from other ash disposal ponds in the Tennessee Valley. Notable differences included higher concentrations of total phosphorous and arsenic, and lower concentrations of aluminum and iron, than in effluent from the TVA ash ponds. Turner et al. (1986) also reported that nearly all organic compounds were below analytical detection limits in all samples.

As part of the recent RFI for McCoy Branch, more surface water quality data were taken from McCoy Branch during dry weather (July 30, 1990) and during wet weather (after a 4.5-cm rain event) on October 8, 1990 (Appendix A, Tables A-7 to A-13). Under both conditions, lower levels of sulfate, selenium, and arsenic were seen in comparison with historical water quality data measured when the slurry was being discharged to upper McCoy Branch. More substantial decreases were seen in levels of suspended solids and lead, but increased levels of magnesium and potassium were also noted. Values for most volatile and semivolatile organic compounds in surface water were below detection limits.

Water quality data collected from a National Pollutant Discharge Elimination System (NPDES) site below Rogers Quarry (Outfall 302) show a decrease in mean weekly levels of sulfate, arsenic, and selenium (Table 2-1 and Figures 2-3, 2-4, and 2-5) after the Y-12 Steam Plant converted from coal to natural gas as the primary fuel source (R. R. Turner, Environmental Sciences Division, ORNL, personal communication). At the time of publication, there are no water quality data available for current ash sluice discharges into Rogers Quarry. Recent data collected by the Off-site Environmental Restoration Program indicate a peak in arsenic levels below the discharge from Rogers Quarry and exhibit a dilution effect downstream in McCoy Branch embayment (Table 2-2).

2.2.3 Temperature

Temperature data for McCoy Branch before December 1989 are limited. Turner et al. (1986) reported that ash sluicing did not appear to affect temperatures in McCoy Branch, presumably because untreated (except for chlorination) Clinch River water was used for sluicing. Current temperature data show little difference between temperatures in McCoy Branch above Rogers Quarry, upper White Oak Creek (WOC), and upper Fifth Creek (Table A-14 and Figure 2-6). Mean weekly temperatures in McCoy Branch below Rogers Quarry are similar to reference streams in winter but up to 10°C higher in summer months. Elevated summer temperatures may be explained by thermal layering in, and epilimnetic discharges from, Rogers Quarry.

2.2.4 Sediments and Groundwater

Ash deposits, which occurred when the creek's flow overtopped its banks, vary greatly along the stream. In a preliminary study, Murphy (1988) found that immediately downstream of the ash pond dam, the deposits cover the entire valley through which McCoy Branch flows. Further downstream, the deposits are limited to no more than a couple of meters horizontally from the edge of the creek.

Table 2-1. Mean (standard error) for selected National Pollutant Discharge Elimination System water quality parameters for Outfall 302 for 1986 to 1990 (data for 1990 through week 26)[a]

	1986	1987	1988	1989	1990
Arsenic (mg/L)	0.21 (0.007)	0.26 (0.007)	0.19 (0.006)	0.07 (0.006)	0.04 (0.003)
Flow (L/s)	55.2 (8.5)	38.2 (3.7)	33.9 (3.0)	46.6 (5.3)	43.1 (6.1)
Iron (mg/L)	0.48 (0.33)	0.13 (0.01)	0.13 (0.02)	0.14 (0.04)	0.10 (0.02)
pH (pH units)	8.4 (0.09)	8.5 (0.07)	8.1 (0.07)	8.3 (0.07)	8.3 (0.06)
Selenium (mg/L)	0.019 (0.002)	0.025 (0.0008)	0.02 (0.001)	0.006 (0.0006)	0.004 (0.0002)
Sulfate (mg/L)	90.9 (12.5)	75.8 (1.2)	92.0 (6.3)	50.6 (2.5)	32.3 (0.9)
Total Suspended Solids (mg/L)	4.5 (0.36)	4.4 (0.59)	3.6 (0.43)	4.4 (0.78)	3.3 (0.28)

[a]Data are derived from mean weekly values. *Source*: R. R. Turner, Environmental Sciences Division, ORNL, personal communication.

ORNL-DWG91-17421

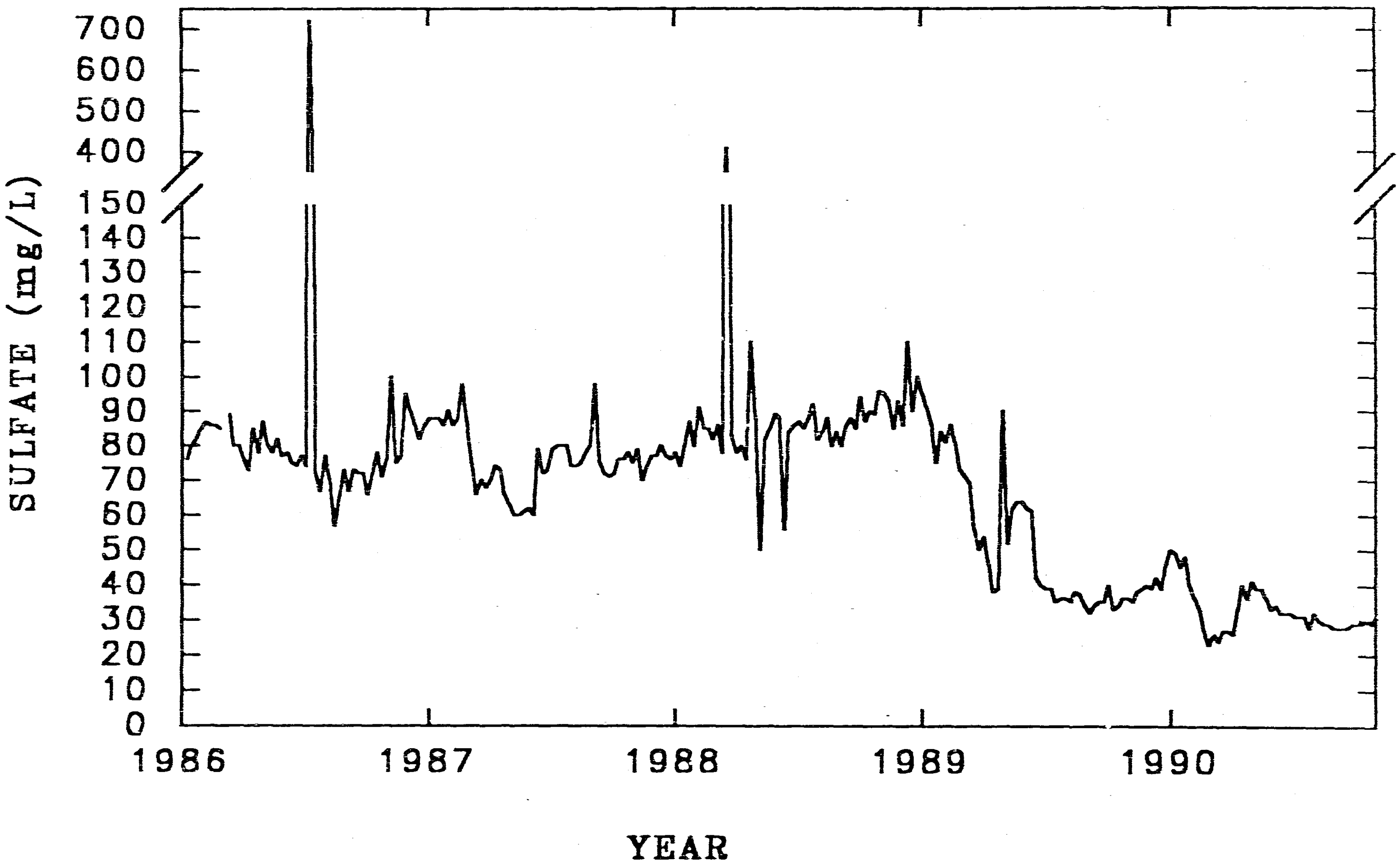

Fig. 2-3. **Mean weekly values for sulfate in the water from McCoy Branch at Outfall 302, below Rogers Quarry, from 1986 to 1990.** *Source:* R. R. Turner, Environmental Sciences Division, Oak Ridge National Laboratory, personal communication.

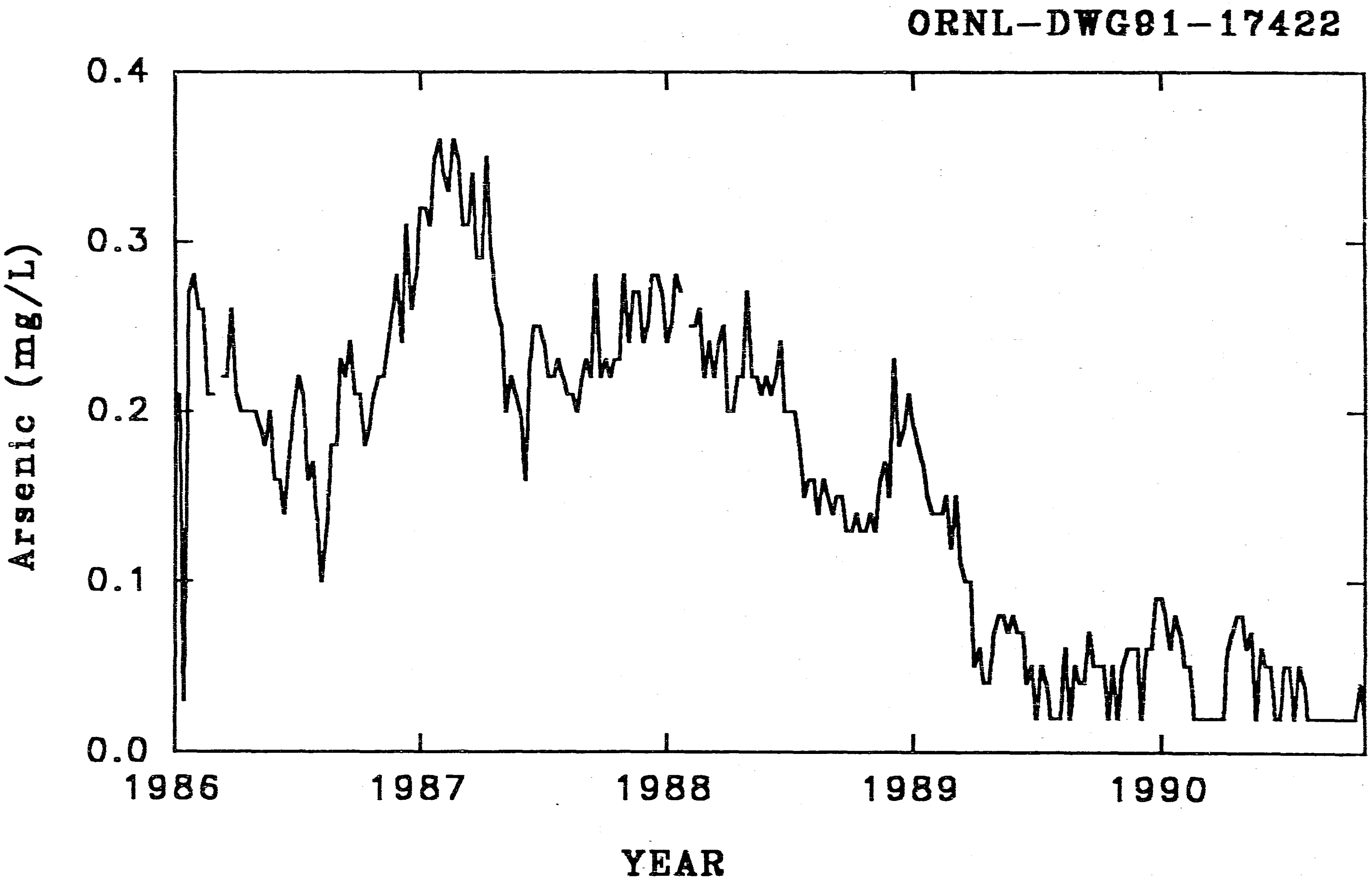

Fig. 2-4. **Mean weekly values for arsenic in the water from McCoy Branch at Outfall 302, below Rogers Quarry, from 1986 to 1990.** *Source:* R. R. Turner, Environmental Sciences Division, Oak Ridge National Laboratory, personal communication.

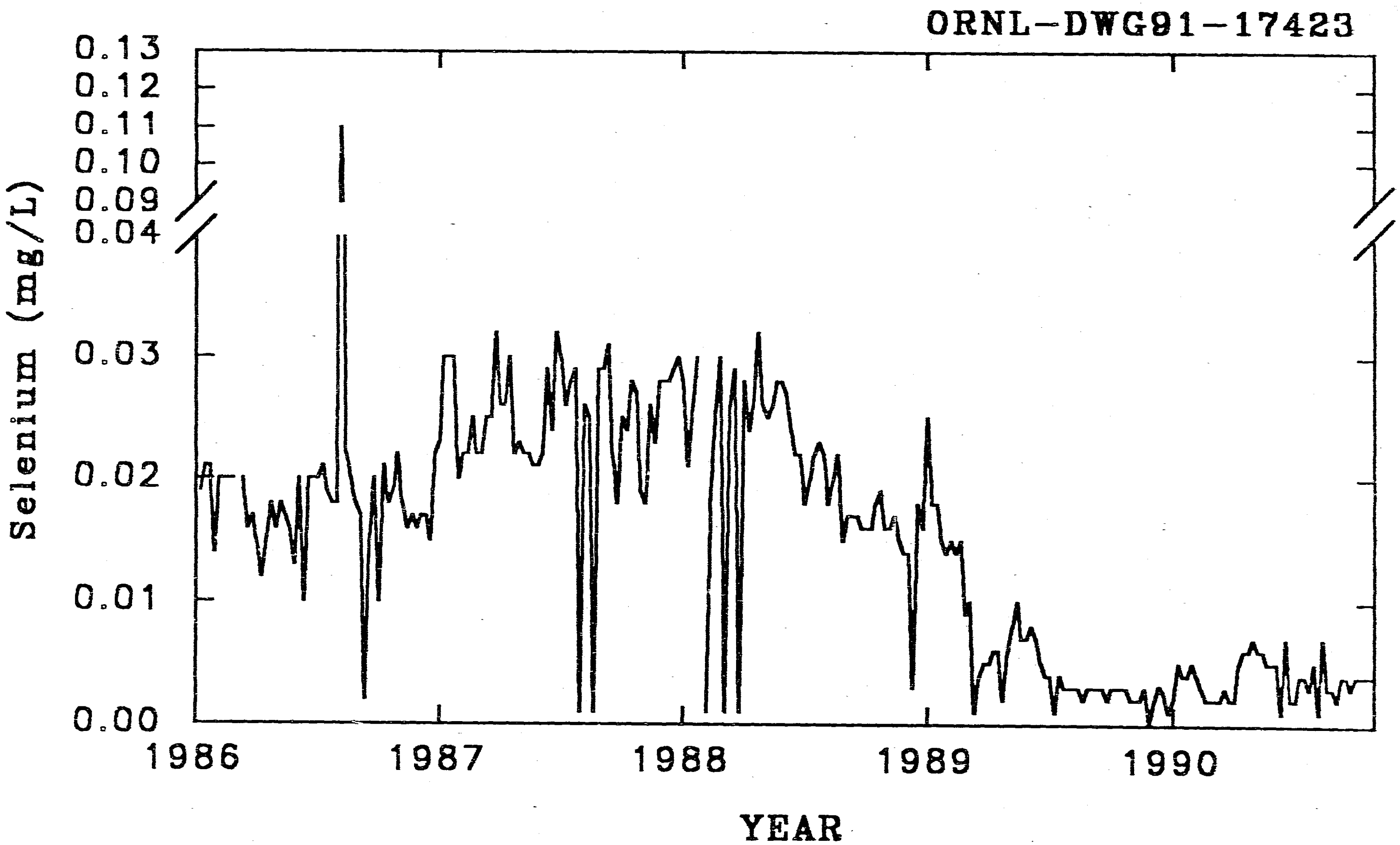

Fig. 2-5. **Mean weekly values for selenium in water from McCoy Branch at Outfall 302, Rogers Quarry, from 1986 to 1990.**
Source: R. R. Turner, Environmental Sciences Division, Oak Ridge National Laboratory, personal communication.

Table 2-2. **Arsenic levels in McCoy Branch on March 15, 1990**[a]

Station	Location	Total As (μg/L)
MCK 1.92	Weir above Rogers Quarry	2.9
MCK 1.71	Below Rogers Quarry	29.5
MCK 0.69	Upstream of culvert	5.3
MCK 0.65	Downstream of culvert	1.2
MCK 0.30	McCoy Branch Embayment	0.05

[a]Data collected by the Off-site Environmental Restoration Program, Clinch River Remedial Investigation. *Source*: James T. Byrd, Skidway Institute of Oceanography, Savannah Georgia, personal communication.

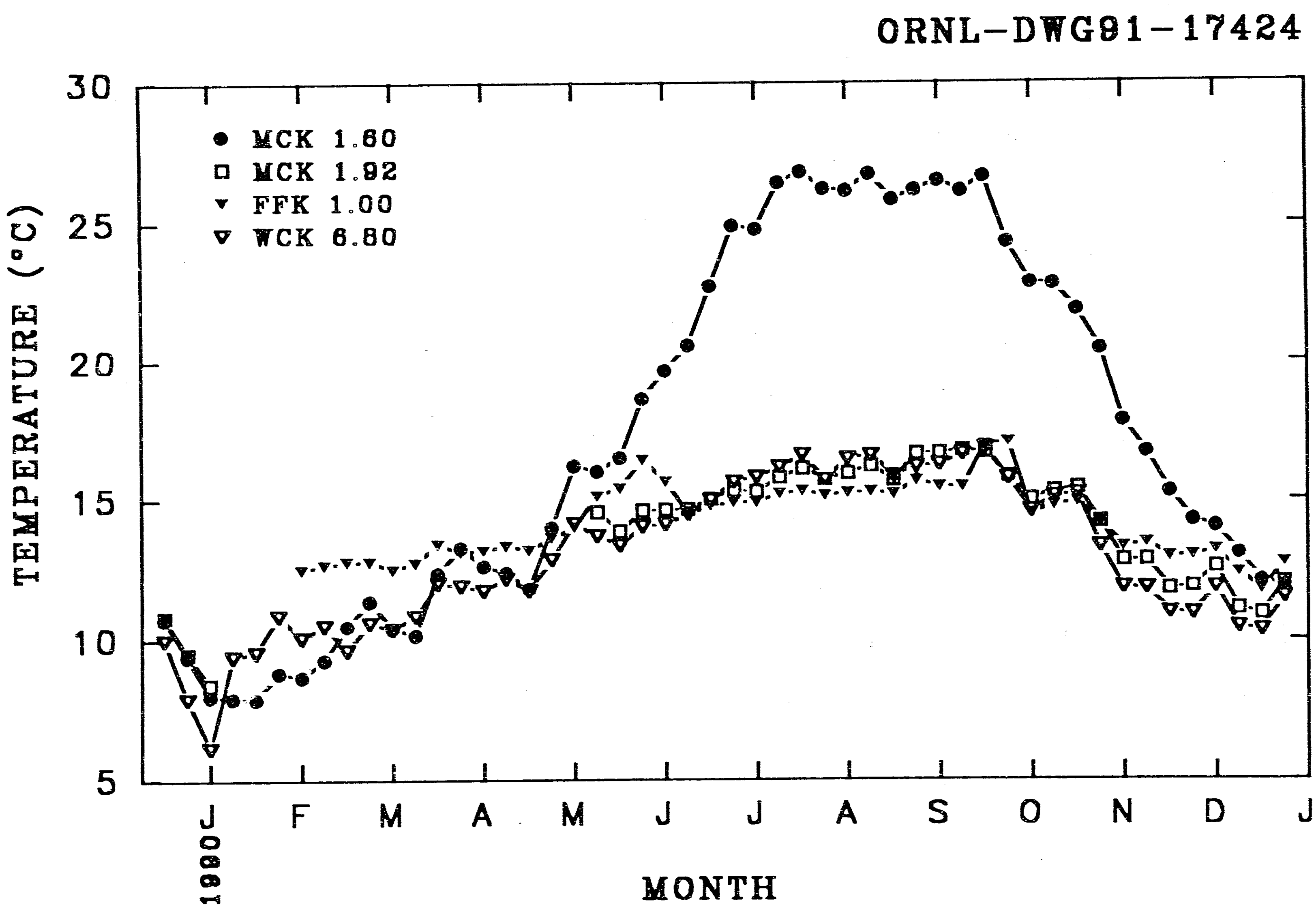

Fig. 2-6. Weekly mean temperature (°C) for McCoy Branch (MCK 1.60 and MCK 1.92), and for two reference sites, upper White Oak Creek (WCK 6.8) and upper Fifth Creek (FFK 1.0). Data were obtained hourly with a Ryan TempMentor digital temperature recorder.

Sediment analysis for McCoy Branch from 1974 to 1975 (ERDA 1975) showed elevated levels of some metals (Appendix A, Table A-15). In accordance with the RCRA Facilities Investigation (RFI), an assessment is being conducted of the impact that coal ash deposits may have had in the area immediately adjacent to McCoy Branch (Murphy 1988). Phase I of the assessment will be to determine the extent, both horizontal and vertical, of coal ash deposits in the McCoy Branch floodplain from the point of discharge at the dam to the point of discharge of McCoy Branch into Rogers Quarry. Phase II will include sampling the ash and underlying soil to determine the extent contaminants from the coal may have migrated into the soil. For a more detailed description of the methodology for the sediment analysis see Murphy (1988). Initial analyses of these ash and sediment samples collected during 1990 from McCoy Branch show elevated levels of Cd, Mn, Ba, Ca, Fe, K, Mg, Na, and Ni (Appendix A, Tables A-16 and A-17) compared to data collected in 1974–1985 (Table A-15). The only analyzed elements occasionally falling below detection limits were niobium and selenium. Levels of oil and grease were <0.1% for all sediment sites. Levels of radioactivity for each site are given in Appendix A, Table A-18.

Coal ashes typically exhibit leachability of ash constituents. Groundwater may be a receptor of contaminants from the coal ash disposal system and may act as a pathway for contamination migration near the Y-12 Plant (Murphy 1988). Groundwater sampled in October 1987, February 1988, May 1988 (Murphy 1988, Table 7-1), and October 1990 (Appendix A, Tables A-19 and A-20) showed no evidence of contamination above regulatory standards or above expected background.

3. TOXICITY MONITORING

Biological tests can be used reliably to detect water quality problems that may not be evident with routine chemical analyses. For this reason and because remedial actions are driven ultimately by the need to protect living organisms and ecological processes from hazardous chemicals, biological tests are gaining acceptance for making regulatory decisions about water quality and environmental remediation.

To obtain data for such decisions, bioassays were used periodically to assess water from three sites in McCoy Branch. Four types of biological tests were used: (1) a series of 7-d tests with fish larvae (the fathead minnow; *Pimephales promelas*) and a microcrustacean (*Ceriodaphnia dubia*); (2) a full life-cycle test (LCT) with *C. dubia*; (3) an in situ test with snails (*Elimia* sp.); and (4) a 7-d laboratory test with *Elimia* sp. The methods used for each of these tests and the sites evaluated with particular tests are described in Sect. 3.1.

3.1 MATERIALS AND METHODS

3.1.1 Seven-Day Toxicity Tests

Seven-day tests with fathead minnow larvae and *Ceriodaphnia* are U.S. Environmental Protection Agency (EPA) approved, static-renewal bioassays; tests with these two organisms are commonly used to estimate acute and chronic toxicity of wastewaters and freshwater receiving systems (Weber et al. 1989). The fathead minnow test estimates toxicity by comparing survival and growth of larval fish in water samples being tested with the survival and growth of larvae in control water known to be of high biological quality. Relative to this control, reductions in fish survival or growth can be attributed to the presence of toxicants. The *Ceriodaphnia* test is fundamentally similar to the fathead minnow test but uses survival and fecundity, rather than survival and growth, as endpoints. The procedures used to conduct the 7-d minnow and *Ceriodaphnia* tests of water from McCoy Branch are given in Stewart et al. (1990) and Kszos and Stewart (1991).

This report gives the results of 7-d minnow and *Ceriodaphnia* tests for seven test periods; the first period started on January 5, 1989, and the last ended on August 6, 1990. In the first test period, only *Ceriodaphnia* was tested. In the remaining six test periods, fathead minnow larvae and *Ceriodaphnia* tests were conducted concurrently. The 7-d minnow and *Ceriodaphnia* tests were used to evaluate water from the outfall of Rogers Quarry (MCK 1.60), at the quarry's inlet (MCK 1.92), and from a spring near the base of the ash pond dam.

3.1.2 Full Life-Cycle Tests

The second type of bioassay consisted of *Ceriodaphnia* full LCTs. LCTs are considered to be more sensitive than 7-d tests because they substantially extend the exposure period, thereby providing more time for the organisms to accumulate and respond to materials potentially present in solution. Relative to 7-d tests, *Ceriodaphnia* LCTs are not used frequently in water quality assessments. LCTs are substantially more intensive and, thus, expensive than the 7-d tests; they require 35–40 d for completion and need more replicates (e.g., 50 versus 10) for satisfactory statistical analyses.

The procedures used in the *Ceriodaphnia* LCTs were identical to those in the 7-d *Ceriodaphnia* tests, including feeding and daily renewal of test solution. However, the LCTs differed from the 7-d tests in three ways: (1) Although water samples were collected fresh daily for the 7-d tests, samples for the LCTs were collected on Tuesdays and Fridays. Between collection events, LCT water samples were stored in a refrigerator at 7°C; however, the daily subsamples were warmed to 25 ± 1°C before use. (2) LCTs evaluated only full-strength water. The 7-d tests, in contrast, employed various concentrations of McCoy Branch water; typically 100, 80, 60, and 40% of full strength (Table 3-1). (3) The LCTs used 50 replicate beakers (1 neonate per beaker) for each water type, but the 7-d tests used only 10 replicates per concentration.

An LCT to evaluate water from McCoy Branch at MCK 1.92 was started on July 28, 1990. Simultaneously, an LCT was initiated to evaluate water quality from East Fork Poplar Creek at the outfall of Lake Reality (LR-o). Water from LR-o provided a contaminated reference suitable for establishing a contrast with McCoy Branch. A set of 50 beakers containing diluted mineral water was included as a negative control for these two LCTs. The LCTs continued until September 5, 1990 (a 40-d period), when the last animal died.

Analysis of variance (ANOVA) was used to analyze survival and reproduction data from the LCTs (SAS 1985a,b). Three sites [McCoy Branch at Rogers Quarry inlet (MCK 1.92), East Fork Poplar Creek at LR-o, and controls] yyywere included in the analysis. Seven dependent variables were inspected to determine how well their variance patterns could be attributed to site. The variables were (1) *Ceriodaphnia* life span (in days); (2) the total number of offspring produced by each animal for all animals that produced any offspring; (3) the number of broods produced per female; (4) the mean number of offspring per brood (i.e., brood size); (5) the number of offspring in the largest brood of each female; (6) the brood-to-brood variability (expressed as the coefficient of variation, CV%) in numbers of offspring produced per female; and (7) mean daily fecundity (the total number of offspring produced by a female divided by that female's reproductive life span). *Ceriodaphnia dubia* neonates are not reproductively active for the first 3 d of their life. Thus, a female's reproductive life span was computed by subtracting 3 d from her total life span.

3.1.3 In situ Snail Tests

Previous studies have shown that pleurocerid snails (e.g., *Elimia clavaeformis*) tend naturally to move upstream and that this behavior can be significantly affected by the presence of contaminants (Burris et al. 1990). Based on these findings, 150 snails (*E. clavaeformis*) were collected from upper White Oak Creek (WCK 6.3) on July 23, 1990. Each animal was marked by placing a dot of fingernail polish on the shell. The animals were all of similar size and were acclimated, stepwise, over a 7-d period, from field temperature (about 17°C) to testing temperature (25°C) before use. The snails were fed

Table 3-1. Results of 7-d toxicity tests (fathead minnow larvae and *Ceriodaphnia dubia*) of water from McCoy Branch at MCK 1.92 (inlet to Rogers Quarry)[a]

Date	Concentration (%)	Minnow survival (%)	Minnow growth (mg dry wt/minnow)	*Ceriodaphnia* survival (%)	*Ceriodaphnia* fecundity (neonates/female)
5 Jan 1989	Control	---	---	100	20.2 ± 2.6
	100	---	---	100	13.2 ± 6.2
	80	---	---	90	20.0 ± 3.6
	60	---	---	70	18.3 ± 4.0
	40	---	---	100	17.0 ± 3.6
	20	---	---	100	20.5 ± 5.6
6 Apr 1989	Control	72.5 ± 18.9	0.30 ± 0.03	100	21.5 ± 1.8
	100	47.5 ± 5.0	0.48 ± 0.05	100	19.2 ± 3.2
	80	52.5 ± 9.6	0.39 ± 0.05	90	22.2 ± 2.7
	60	65.0 ± 12.9	0.32 ± 0.05	100	23.9 ± 2.4
	40	32.5 ± 17.1	0.53 ± 0.24	100	23.2 ± 2.6
7 Jul 1989	Control	100.0 ± 0.0	0.51 ± 0.05	90	24.2 ± 2.8
	100	87.5 ± 15.0	0.52 ± 0.11	90	26.2 ± 3.7
	80	87.5 ± 5.0	0.51 ± 0.04	80	26.0 ± 4.0
	60	85.0 ± 30.0	0.45 ± 0.07	100	28.0 ± 2.9
	40	97.5 ± 5.0	0.45 ± 0.03	100	27.4 ± 1.9
13 Oct 1989	Control	97.5 ± 5.0	0.48 ± 0.09	90	24.7 ± 2.2
	100	97.5 ± 5.0	0.47 ± 0.06	90	23.0 ± 1.8
	80	97.5 ± 5.0	0.59 ± 0.07	90	22.1 ± 2.7
	60	92.5 ± 15.0	0.50 ± 0.08	80	24.4 ± 3.0
	40	77.5 ± 26.3	0.53 ± 0.06	90	24.1 ± 3.4

Table 3-1 (Continued)

Date	Concentration (%)	Minnow survival (%)	Minnow growth (mg dry wt/minnow)	*Ceriodaphnia* survival (%)	*Ceriodaphnia* fecundity (neonates/female)
4 Jan 1990	Control	92.5 ± 9.6	0.49 ± 0.02	100	22.5 ± 3.7
	100	47.5 ± 25.0	0.56 ± 0.08	90	26.3 ± 2.7
	80	65.0 ± 25.2	0.56 ± 0.03	80	23.5 ± 5.0
	60	60.0 ± 28.3	0.50 ± 0.10	100	28.0 ± 5.2
	40	42.5 ± 28.7	0.59 ± 0.15	90	25.4 ± 3.3
5 Apr 1990	Control	90.0 ± 10.7	0.55 ± 0.09	100	19.7 ± 2.3
	100	40.0 ± 32.7	0.47 ± 0.10	100	22.4 ± 5.7
	80	30.0 ± 14.1	0.44 ± 0.11	100	22.4 ± 2.8
	60	27.5 ± 17.1	0.52 ± 0.13	90	19.9 ± 3.8
	40	—	—	—	—
30 Jul 1990	Control	100.0 ± 0.0	0.53 ± 0.09	90	24.0 ± 3.4
	100	100.0 ± 0.0	0.66 ± 0.09	90	11.1 ± 8.1
	80	—	—	100	11.5 ± 9.7
	60	—	—	100	21.0 ± 9.0
	40	—	—	70	15.6 ± 8.6

[a]Values are means ± SD for four replicates (minnow test) or ten replicates (*Ceriodaphnia*) in each test period.

commercial lettuce leaves during the acclimation period. On July 30, 1990, 50 of the marked snails were released at each of three sites: McCoy Branch 10 m above Rogers Quarry (MCK 1.92), McCoy Branch at MCK 1.60 (below Rogers Quarry), and White Oak Creek at WCK 6.3. Forty-eight hours after the snails had been released, each site was surveyed for the snails. The searches were initiated 10 m downstream of the release point and continued upstream beyond the release point for 20 m. The position of each marked snail, relative to the release point, was measured to the nearest centimeter. A median test for multiple samples was used to determine if the median distance the snails moved upstream differed among the three sites (Steel and Torrie 1980).

3.1.4 Seven-Day Snail Test

A 7-d static-renewal test with snails was used to determine if the snails' feeding rate was affected by water from two sites in McCoy Branch (MCK 1.92 and MCK 1.60). Snails were collected from WCK 6.3 on July 23, 1990, and acclimated as described in Sect. 3.1.3.

Test chambers consisted of 600-mL beakers. Each beaker contained 12 snails and 250 mL of water; 4 replicate beakers were used for each treatment. Treatments consisted of full-strength water from each of three sites: McCoy Branch at MCK 1.92, McCoy Branch at MCK 1.60, and for reference purposes, White Oak Creek at WCK 6.3. The contents of the beakers were maintained at 25 $\pm$ 1°C throughout the test by a water bath. Two pre-weighed lettuce leaf discs (each 3.0 cm^2) were added to each beaker at the start of the test. After 24 h and daily thereafter, the remains of the discs were removed, new discs were added, and the water was changed. The remnants of the discs taken from each beaker were blotted dry with paper towels and weighed to the nearest 0.1 mg. The difference between initial weight and final weight of the discs in each beaker was used to estimate the wet mass of lettuce leaf eaten daily by the snails in that replicate.

Differences among feeding rates among treatments were analyzed using SAS-GLM with a repeated-measures subroutine (SAS 1985a,b).

3.1.5 Chemical Analyses of Water Quality

A majority of water samples collected for use in any of the tests described above were analyzed chemically for pH, conductivity, alkalinity (EPA method 130.1), and hardness (EPA method 130.2). The methods used for each of these analyses are described by Kszos et al. (1989).

During one 7-d test period (April 5–11, 1990), water from two McCoy Branch sites (MCK 1.92 and the large spring at the base of the earthen dam) was analyzed for orthophosphate and sulfate (EPA methods 365.1 and 375.2, respectively). During another 7-d period (July 7–13, 1989), samples collected daily from McCoy Branch at MCK 1.92 were analyzed for nitrate, orthophosphate, and sulfate.

3.2 RESULTS

3.2.1 Seven-Day Toxicity Tests

The results of the *Ceriodaphnia* and fathead minnow toxicity tests of water from McCoy Branch at MCK 1.92 are summarized in Table 3-1; the results of tests with these two species applied to water from McCoy Branch at MCK 1.60 and at the spring near the base of the dam at the ash pond are summarized in Table 3-2.

Overall, the 7-d tests provided little consistent evidence for toxicity to either species. On three occasions, specific problems with test conditions were suggested. First, in the test started on January 5, 1989, fecundity of *Ceriodaphnia* reared in water from McCoy Branch was unusually low and variable (13.2 ± 6.2, mean ± SD) relative to controls (20.2 ± 2.6). The high variability in fecundity for the animals in McCoy Branch water in this test (C.V. = 47%) is difficult to interpret biologically. Second, the minnow test conducted during April 6–13, 1989, appeared flawed. Survival and growth rates of fish in the controls and in McCoy Branch water were both unusually low, suggesting inadequate food. Survival and reproduction of *Ceriodaphnia* in this test were high both for controls and for water from McCoy Branch. Third, survival (but not growth) of the fish was low in McCoy Branch water in the tests that started on January 4, 1990, and April 5, 1990 (Table 3-1). During these two test periods no evidence of toxicity was detected using *Ceriodaphnia*. Additionally, no conspicuous relationship between fish survival and concentration of McCoy Branch water in either of these tests (Table 3-1) was detected. These considerations suggest that the 'toxicity' in McCoy Branch during each of these three test periods was probably artifactual.

3.2.2 Full-Life Cycle Tests

Mean values for each of the 7 dependent variables for *Ceriodaphnia* in each of the three water types are given in Table 3-3. The mean number of broods by *Ceriodaphnia* tested in McCoy Branch water was lower than that of *Ceriodaphnia* in the control (10.1 versus 12.4 offspring per female, Table 3-3). The mean daily fecundity of *Ceriodaphnia* in McCoy Branch water was also substantially lower than that of controls (5.3 versus 6.1 offspring per female per day, Table 3-3). The overall difference in total fecundity of *Ceriodaphnia* in controls versus McCoy Branch water, though, was not very great (122 versus 109.3 offspring per female, Table 3-3) because *Ceriodaphnia* in McCoy Branch water tended to have slightly larger broods than *Ceriodaphnia* in the control (10.7 versus 9.8 offspring per brood, Table 3-3).

Separate sets of one-way ANOVAs were conducted to contrast reproductive patterns of *Ceriodaphnia* tested in MCK 1.92 to control water (Table 3-4) and water from LR-0 (Table 3-5). These analyses showed that the contrast in reproductive patterns of *Ceriodaphnia* tested in water from MCK 1.92 versus LR-o (Table 3-4) was similar in two important respects to the contrast between water from MCK 1.92 versus control water (Table 3-5). First, the number of broods and the mean number of offspring per brood tended to be among the more dynamic parameters in both comparisons, based on the magnitude of change in p (about 123-fold for the number of broods and 8.6-fold for the number of offspring per brood, Tables 3-4 and 3-5). The number of broods and the mean

Table 3-2. Results of 7-d toxicity tests (fathead minnow larvae and *Ceriodaphnia*) of water from McCoy Branch at the spring near the base of the ash pond dam (spring) and from McCoy Branch below Rogers Quarry (MCK 1.60)[a]

Site	Date[b]	Concentration (%)	Minnow survival (%)	Minnow growth[c] mg dry wt/minnow	*Ceriodaphnia* survival (%)	*Ceriodaphnia* fecundity[d]
Spring	5 Apr 1990	Control	90.0	0.55 ± 0.09	100	19.7 ± 2.3
		100	77.5	0.57 ± 0.09	80	25.6 ± 2.7
		80	82.5	0.59 ± 0.03	90	25.9 ± 2.5
MCK 1.60	30 July 1990	Control	100.0	0.53 ± 0.09	90	24.0 ± 3.4
		100	100.0	0.64 ± 0.04	90	18.3 ± 10.8
		80	97.5	0.60 ± 0.11	—	—

[a]Values are mean ± SD.
[b]When each 7-d test was started.
[c]Computed as increase in weight.
[d]*Ceriodaphnia* fecundity is computed using females that survived all 7 d, and their young.

Table 3-3. Means of *Ceriodaphnia* survival and reproduction parameters for life-cycle tests with control water, water from McCoy Branch at the inlet to Rogers Quarry (MCK 1.92), and water from East Fork Poplar Creek at the outfall of Lake Reality (LR-o)

	Site		
Parameter	Control	LR-o	MCK 1.92
Life span (days)	23.1	25.6	24.3
Number of broods	12.4	9.7	10.1
No. of offspring/brood	9.8	12.0	10.7
Total No. of offspring	122.0	114.7	109.3
Largest brood	17.8	19.7	18.5
Variability in fecundity	51.7	51.8	56.2
Daily fecundity	6.1	5.5	5.3

Table 3-4. Analysis of variance results for *Ceriodaphnia* life-cycle tests of control water and water from McCoy Branch at MCK 1.92[a]

Dependent variable	Model DF	Error DF	R^2	F	P
Life span	1	98	0.0055	0.54	0.4634
Number of broods	1	96	0.0809	8.45	0.0045
No. of offspring/brood	1	96	0.0257	2.54	0.1146
Total No. offspring	1	96	0.0173	1.69	0.1967
Largest brood	1	96	0.0101	0.98	0.3240
Variability in fecundity	1	95	0.0199	1.93	0.1685
Daily fecundity	1	97	0.0394	3.98	0.0489

[a]The probability (p) that the difference between means of parameters for controls versus McCoy Branch was due to chance alone is given for each parameter; the p values were obtained by one-way analysis of variance tests. R^2 is the proportion of the total variation that can be explained by the difference in water type.

Table 3-5. Analysis of variance results for *Ceriodaphnia* life-cycle tests of water from Lake Reality outfall and McCoy Branch at MCK 1.92[a]

Dependent Variable	Model DF	Error DF	R^2	F	P
Life span	1	98	0.0070	0.69	0.4068
Number of broods	1	97	0.0036	0.35	0.5553
No. of offspring/brood	1	97	0.0615	6.35	0.0133
Total No. offspring	1	97	0.0054	0.52	0.4715
Largest brood	1	97	0.0351	3.53	0.0634
Variability in fecundity	1	96	0.0203	1.99	0.1620
Daily fecundity	1	97	0.0023	0.22	0.6366

[a]The probability (p) that the difference between means of parameters for Lake Reality outfall water versus McCoy Branch water was due to chance alone is given for each parameter; the p values were obtained by one-way analysis of variance tests. R^2 is the proportion of the total variation that can be explained by the difference in water type.

number of offspring per brood were inversely related as well, whereas, lifespan was more constant (cf Table 3-3). These points suggest that these daphnids are flexible reproductively, in that they "trade off" brood size and number per brood. This in turn suggests that reproduction is a major energetic expense to these animals, which supports the idea that *Ceriodaphnia* reproduction (over a fixed number of broods) should be a sensitive endpoint for toxicity assessments. It also suggests the hypothesis that reproduction may control longevity of these animals in predator-free situations. The second, and perhaps more important finding from the two sets of ANOVAs, was that the different water types did not affect any of the reproductive parameters very strongly: the proportion of variance in any parameter that could be explained by differences in water type never exceeded 8.1% (Tables 3-4 and 3-5). This consideration, in conjunction with the tendency for the animals to trade off brood size and number per brood, indicate that water from MCK 1.92 was not toxic. It also strongly suggests that food-related aspects of testing ambient waters with *Ceriodaphnia* may need to be addressed more carefully, both in effluent and ambient testing situations.

3.2.3 In Situ Snail Test

Snail movement patterns differed significantly among the three sites ($G = 22.95$, $p < 0.001$). Fewer than 25% of the snails released at MCK 1.60 moved upstream, whereas, >75% moved upstream at MCK 1.92 and WCK 6.3 (Fig. 3-1). In 48 h, the maximum downstream movement of the snails at MCK 1.60, MCK 1.92, and WCK 6.3 was 2.80, 0.60, and 1.88 m, respectively. Median distances that snails moved upstream did not appear to differ between MCK 1.92 and WCK 6.3 ($G = 4.045$, $0.05 > p > 0.020$), but did differ between MCK 1.60 and MCK 1.92 ($G = 22.132, p < 0.001$), and between WCK 6.3 and MCK 1.60 ($G = 13.718, p < 0.001$). Because of multiple testing, a conservative Type I error rate (0.020) was used. More than 50% of the marked snails were recovered at each of the McCoy Branch sites; 27% of the snails that had been marked and released were recovered from WCK 6.3.

3.2.4 Seven-Day Snail Test

The feeding rates of the snails in water from WCK 6.3 and McCoy Branch at MCK 1.92 were quite similar (56.3 ± 5.3 and 54.3 ± 6.4 mg wet mass consumed per day, respectively; means $\pm$ standard error); snails in water from MCK 1.60, in contrast, had feeding rates that were about 25% lower than those tested in water from the other two sites (i.e., 40.9 ± 5.3 mg wet mass per day). The feeding rates did not, however, differ statistically based on ANOVA ($p = 0.215$). Feeding rates differed among dates (ANOVA, $p = 0.0001$), and the rates increased uniformly towards the end of the experiment. The feeding rates showed no significant site X date interaction (ANOVA, $p = 0.3222$).

3.2.5 Chemical Analyses of Water Quality

Daily analyses of pH, conductivity, alkalinity and hardness were conducted for six of the 7-d toxicity testing periods (Table 3-6). Concentrations of nitrate, phosphate, and sulfate were measured in water from McCoy Branch at MCK 1.92 during two of the 7-d test periods (Table 3-7). During April 5–11, 1990, the phosphate levels at the upstream

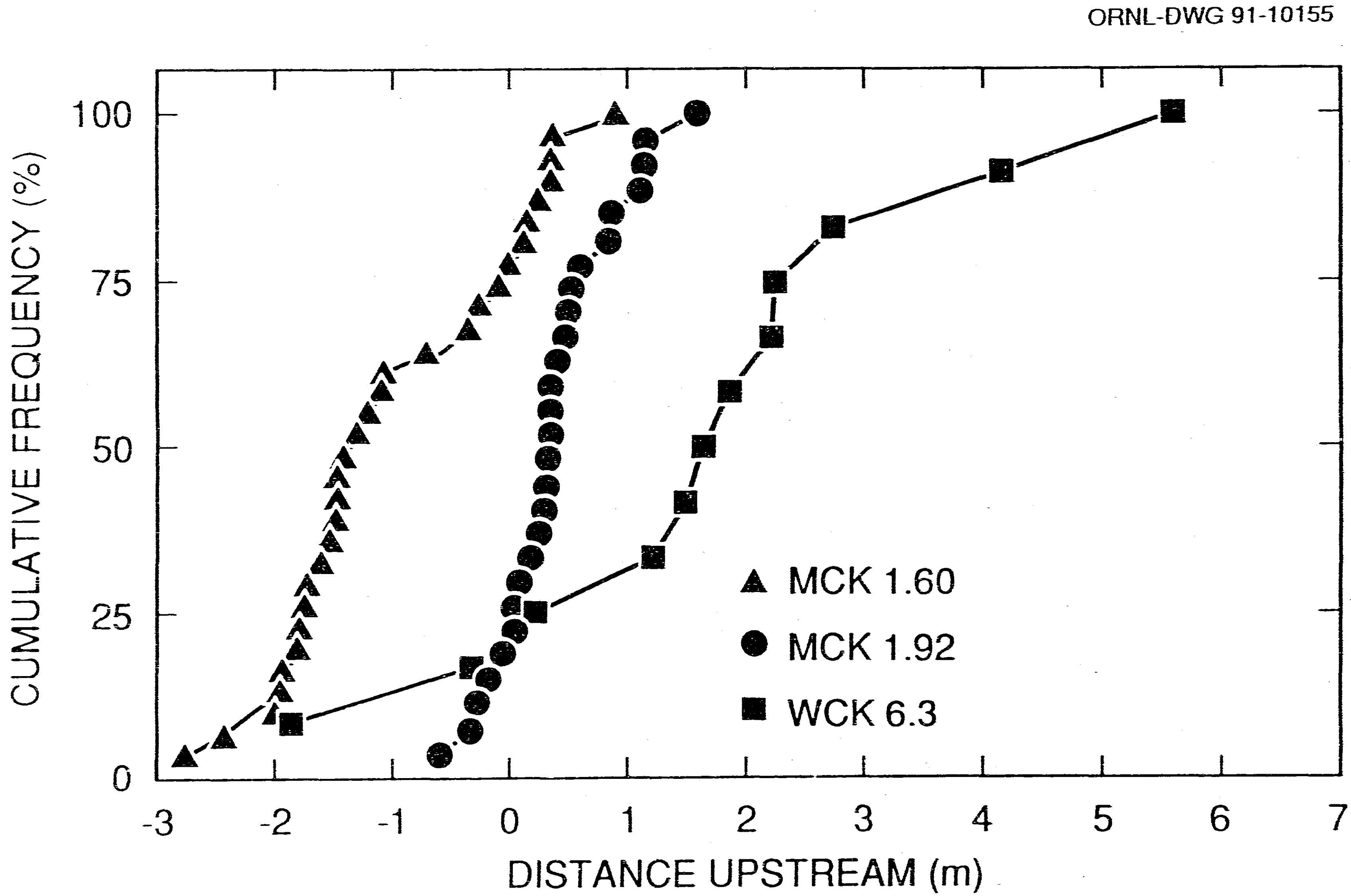

Fig. 3-1. Plot showing the number of snails recovered (cumulative percent) versus distance from the point of release for two sites in McCoy Branch and a noncontaminated site in White Oak Creek. (MCK = McCoy Branch kilometer and WCK = White Oak Creek kilometer.)

Table 3-6. Means (± SD) of pH (standard units), conductivity, alkalinity and hardness for daily grab samples (7-d periods) of water from McCoy Branch at MCK 1.92

Factor	Analysis period[a]					
	Apr 1989	Jul 1989	Oct 1989	Jan 1990	Apr 1990	Jul 1990
pH	7.8 ± 0.1	7.9 ± 0.1	8.0 ± 0.1	8.0 ± 0.2	8.0 ± 0.1	8.1 ± 0.1
Conductivity ($\mu S/cm$)	232 ± 18	272 ± 51	342 ± 24	238 ± 11	283 ± 10	336 ± 18
Alkalinity (mg/L as $CaCO_3$)	99 ± 9	118 ± 14	147 ± 11	102 ± 4	133 ± 4	165 ± 4
Hardness (mg/L as $CaCO_3$)	138 ± 14	147 ± 22	184 ± 7	127 ± 15	151 ± 5	190 ± 4

[a]The starting days of the analysis period are given in Table 3-1.

Table 3-7. Means (± SD) of nitrate, phosphate, and sulfate concentrations in daily grab samples (7-d period) of water from McCoy Branch at MCK 1.92 and the spring near the base of the ash pond dam

	Test Dates	Nitrate (mg/L)	Phosphate (μg/L)	Sulfate (mg/L)
MCK 1.92	July 7–13, 1989	0.364 ± 0.055	6.1 ± 1.6	27.9 ± 10.2
MCK 1.92	April 5–11, 1990	NA[a]	8.3 ± 1.6	40.9 ± 9.2
Spring	April 5–11, 1990	NA[a]	13.6 ± 3.0	19.7 ± 2.9

[a]NA = not analyzed.

spring site were higher than those at MCK 1.92, whereas, the sulfate values were lower (Table 3-7).

Water samples during July 30–August 5, 1990, from McCoy Branch at MCK 1.60 were analyzed for pH, conductivity, alkalinity and hardness. During April 5–11, 1990, samples from the spring at the base of the ash pond were also analyzed for these parameters. The results of these two sets of analyses are summarized in Table 3-8.

3.3 DISCUSSION

The results of the biological tests of water from McCoy Branch reported here did not show much evidence for toxic conditions in this stream. In 7-d laboratory tests, survival and growth of fathead minnow larvae, and survival and fecundity of *Ceriodaphnia* was generally high, although a few exceptions to this trend were evident. Similarly, full LCTs with *Ceriodaphnia*, which should be considerably more sensitive than 7-d tests, also failed to show much effect of McCoy Branch water. LCTs also showed *Ceriodaphnia* had significantly fewer broods and a slightly lower mean daily fecundity in McCoy Branch water than they did in the controls, but the number of neonates per brood tended to be greater than that in controls. Thus, the net effect of McCoy Branch water on *Ceriodaphnia* fecundity was small. Longevity of *Ceriodaphnia* in McCoy Branch water was also very similar to that for the controls (24.3 d for animals in McCoy Branch water versus 23.1 d for controls, Table 3-3).

In the in situ tests, snails apparently experienced more stress in McCoy Branch at MCK 1.60 than they did at either MCK 1.92 or at WCK 6.3. At MCK 1.60, the net movement of snails was downstream; whereas, the net movement of the snails at the other two sites was upstream. Studies of snails in noncontaminated streams have indicated that an upstream movement of snails is typical (Crutchfield 1966; Houp 1970; Burris et al. 1990). Conversely, when healthy snails were placed in contaminated streams, the net movement was downstream (Burris et al. 1990). Snails may actively move downstream as an escape behavior or may be passively transported downstream by flow.

In 7-d laboratory tests, snails consumed less food when tested in water from McCoy Branch at MCK 1.60 than they did in water from either MCK 1.92 or WCK 6.3, but this difference was not statistically significant.

During the summer, the water in McCoy Branch at MCK 1.60 is warmer than that at MCK 1.92 or WCK 6.3 (see Table A-8), primarily because MCK 1.60 receives epilimnetic flow from the quarry. Because *Elimia* are not very heat tolerant (Ross and Ultsch 1980), warmer temperature could account for the differences in snail behavior between MCK 1.60, and MCK 1.92 and WCK 6.3. However, heat stress is unlikely to account for differences seen in the laboratory where temperature was controlled.

The mean ratio of alkalinity to hardness (A:H) for MCK 1.92 was 0.811, and the mean conductivity was 284 μS/cm (Table 3-6). The A:H and conductivity values for MCK 1.92 are within the 95% confidence bounds for those reported for reference sites in upper WOC, First Creek, and Fifth Creek (Stewart 1990). Similarly, the A:H for samples

Table 3-8. Means (± SD) of pH, conductivity, alkalinity, and hardness for daily grab samples (7-d periods) of water from McCoy Branch at MCK 1.60 (July 30–August 5, 1990) and the spring at the base of the ash pond dam (April 5–11, 1990)

Factor	MCK 1.60	Spring
pH (standard units)	8.5 ± 0.1	7.5 ± 0.2
Conductivity (μS/cm)	233 ± 4	351 ± 54
Alkalinity (mg/L)	83 ± 2	151 ± 20
Hardness (mg/L)	125 ± 6	174 ± 11

from MCK 1.60 was 0.664; whereas, A:H for the spring at the base of the ash pond dam was 0.868 (Table 3-8). Thus, as for other streams, the overall trend was for a decline in A:H with distance downstream, but the rate and total extent of decline was not very great. Phosphate, which tends to be biologically quite reactive, was also present at relatively low concentrations in water from the spring at the base of the ash pond dam and from MCK 1.92 (Table 3-7). This element is often elevated by a factor of 10 to 100 in streams that receive industrial effluents. Thus, the results of the chemical analyses suggest that the stream is not highly perturbed. This conclusion is in good general agreement with the results of toxicity tests.

3.4 FUTURE STUDIES

Quarterly tests with *Ceriodaphnia* and fathead minnow larvae will be conducted at MCK 1.60 and MCK 1.92 to monitor possible changes in water quality that occur in McCoy Branch. Snail release studies will also be continued to determine if these grazers can persist and grow if transferred into McCoy Branch sites upstream from Rogers Quarry.

4. BIOACCUMULATION STUDIES

4.1 INTRODUCTION

McCoy Branch received discharges of coal ash effluents from Y-12 (Sect. 2.2.1). Metals and hydrophobic organic chemicals in these discharges (Sect. 2.2) may accumulate in the biota of McCoy Branch, Rogers Quarry, or downstream in Melton Hill Reservoir to levels that may diminish the value of these resources. The primary objectives of contaminant monitoring in McCoy Branch biota were to (1) identify any substances that accumulate to levels exceeding those observed in biota from nearby, uncontaminated reference streams and (2) evaluate the extent and significance of contamination by those substances in McCoy Branch and downstream aquatic systems. Secondary objectives were to assist in locating sources of contaminants that accumulate to unacceptable levels, and to evaluate the relative importance of present vs. past discharges in determining contaminant levels of biota.

Initial surveys of McCoy Branch indicated that only a limited area of the stream contained enough fish to sample for bioaccumulation potential in aquatic biota, and this area was open to immigration from Melton Hill Reservoir. Because Rogers Quarry contained suitable fish populations that are virtually isolated from immigration from Melton Hill Reservoir, the collections were made from this site to evaluate bioaccumulation concerns associated with the coal ash discharge. McCoy Branch embayment of Melton Hill Reservoir was sampled to provide a basis for evaluating if fish from the quarry contained elevated concentrations of certain contaminants, and also to ensure that no public health concerns were associated with the ultimate discharge of McCoy Branch water to that portion of the reservoir.

4.2 METHODS

Largemouth bass (*Micropterus salmoides*) were collected from Rogers Quarry and the adjacent McCoy Branch embayment of Melton Hill Reservoir in July 1990 by angling and electrofishing. The fish were placed on ice and returned to the laboratory where they were weighed and measured. The bass were filleted and skinned, and samples of the anterior dorsal portion of the fillet was removed for analysis for mercury, arsenic, selenium, other trace metals, chlorinated organic pesticides, and PCBs at the ORNL Analytical Chemistry Division (ACD). Mercury was analyzed by cold vapor atomic absorption spectrophotometry after digestion in a mixture of perchloric and nitric acids (EPA Methods 3050 and 245.5 for preparation and analysis, respectively, EPA 1986). Following digestion in nitric acid, arsenic, beryllium, and uranium were analyzed by inductively coupled plasma mass spectrometry; and antimony, cadmium, chromium, copper, lead, nickel, selenium, silver, thallium, and zinc were analyzed by inductively coupled plasma optical emission spectrometry (EPA Methods 3050 and 6010, EPA 1986). A 10-g sample of the fish fillet was extracted by ultrasonic disruption in methylene chloride, cleaned up by column chromatography, and analyzed for PCBs and chlorinated pesticides by gas chromatography with electron capture detection (EPA method 8080, EPA 1986).

Quality assurance (QA) was maintained using a combination of (1) blind duplicate analyses; (2) split sample analyses between the EPA Environmental Services Laboratory, Athens, Georgia, and the ACD Laboratory; and (3) the analyses of biological reference standards and uncontaminated fish. Recoveries of PCBs, selected metals, and organics were verified by spiking uncontaminated fish with known amounts and analyzing them.

Statistical evaluation of the data was conducted using linear regression, analysis of variance (ANOVA), Levenes test for homogeneity of variances, and analysis of covariance (SAS 1985a,b). All comparisons used alpha = 0.05.

4.3 RESULTS AND DISCUSSION

Concentrations of elements in individual largemouth bass from Rogers Quarry and McCoy Branch embayment are listed in Table 4-1. Mean concentrations of most metals (antimony, beryllium, cadmium, chromium, copper, lead, mercury, nickel, silver, uranium, and zinc) in bass from Rogers Quarry and McCoy Branch embayment were similar to concentrations in reference stream sunfish (Table 4-2). The concentrations in McCoy Branch bass were also similar to those found in various species from other sites both locally and nationwide (TVA 1985; Dycus and Hickman 1986; Dycus 1989; Lowe et al. 1985). The mean concentrations of elements were all below concentrations used by EPA (EPA, personal communication) and others (Hoffman et al. 1984; C. C. Travis, Health and Safety Division, ORNL, personal communication) to screen for levels of contamination that pose no threat for human consumption (Table 4-2). Only arsenic was present at concentrations above screening criteria; however, the screening concentration for arsenic is below the detection limit for arsenic in fish, and also well below concentrations typical of most biological materials (Bowen 1979).

Thallium was detected in seven of eight bass from Rogers Quarry, but not in fish from McCoy Branch embayment. However, the concentrations were at or near the analytical detection limit and, therefore, must be regarded cautiously. Although data suggest that thallium may be elevated above background levels in Rogers Quarry, evaluation with more sensitive analytical methods is needed for verification.

Concentrations of two elements, selenium and arsenic, in bass from Rogers Quarry were significantly (ANOVA) elevated above concentrations in bass from McCoy Branch embayment (Table 4-2). The mean concentration of arsenic in bass from the quarry was 0.29 ± 0.02 μg/g, about twice the amount (0.14 ± 0.02 μg/g) found in fish from the reservoir. Selenium was also substantially higher in the bass from Rogers Quarry, averaging 3.00 ± 0.11 μg/g versus 1.00 ± 0.29 μg/g. Thallium also appeared to be elevated in bass from the quarry; however, concentrations were too near the detection limit to regard this result as conclusive. Mercury concentrations in fish from the quarry were among the lowest observed in largemouth bass in the United States and substantially lower than concentrations in fish from Melton Hill Reservoir.

The mean concentrations of arsenic in the bass from McCoy Branch embayment may be elevated above typical background levels. Arsenic has never been found to exceed the detection limit (0.05 μg/g) in sunfish analyzed for biological monitoring programs at

Table 4-1. Concentrations of metals[a] (μg/g, wet wt) in individual fish collected in Rogers Quarry, McCoy Branch embayment, and a reference stream, Hinds Creek, July 1990

Site[b]	SPP[c]	Tag	Sex	Age (yr)	Wgt (g)	Lgth (cm)	As	Be	Se	Tl	U	Zn	Hg
ROGQUA	LMBASS	5878	M	2	467	34.4	0.30	<0.003	3.2	0.03	0.005	4.8	0.024
ROGQUA	LMBASS	5879	F	1	299	29.1	0.26	<0.003	2.9	0.02	<0.003	5.2	0.011
ROGQUA	LMBASS	5494	M	1	217	26.2	0.24	<0.003	3.3	0.03	<0.003	5.4	0.010
ROGQUA	LMBASS	5495	F	4	515	32.2	0.24	<0.003	2.4	<0.02	<0.003	5.0	0.027
ROGQUA	LMBASS	5496	F	1	180	24.2	0.27	<0.003	3.3	0.03	<0.003	6.1	0.010
ROGQUA	LMBASS	5497	M	1	193	25.0	0.24	0.004	3.1	0.03	<0.003	6.0	0.009
ROGQUA	LMBASS	5498	M	1	315	29.2	0.37	<0.003	3.0	0.03	<0.003	5.7	0.010
ROGQUA	LMBASS	5499	F	1	194	25.3	0.36	<0.003	2.7	0.03	<0.003	6.7	0.008
ROGQUA	LMBASS	8785[d]	.	.	.	.	0.34	<0.003	3.6	0.03	<0.003	4.8	0.028
MCYBRU	LMBASS	5477	M	3	808	41.0	0.09	<0.003	3.0	<0.02	<0.003	5.0	0.069
MCYBRD	LMBASS	5478	F	2	292	31.4	0.11	<0.003	1.0	<0.02	<0.003	7.7	0.079
MCYBRD	LMBASS	5479	M	1	135	22.4	0.23	<0.003	0.54	<0.02	<0.003	6.1	0.027
MCYBRD	LMBASS	5480	F	3	582	36.4	0.09	<0.003	0.65	<0.02	<0.003	6.5	0.118
MCYBRD	LMBASS	5481	F	3	452	32.6	0.13	<0.003	0.54	<0.02	<0.003	6.8	0.058
MCYBRD	LMBASS	5482	M	2	328	30.5	0.14	<0.003	0.64	<0.02	<0.003	4.8	0.083
MCYBRD	LMBASS	5484	M	3	547	36.4	0.19	<0.003	0.77	<0.02	<0.003	5.8	0.109
MCYBRD	LMBASS	5485	F	2	303	30.3	0.15	0.007	0.83	<0.02	<0.003	6.9	0.038
MCYBRD	LMBASS	0845[e]	.	.	.	.	0.09	0.003	0.72	<0.02	<0.003	6.1	0.134
HINDSCR	BLUGIL	5464	F		81.2	16.8	<0.05	0.004	<0.43	<0.02	<0.003	6.3	0.054
HINDSCR	REDBRE	5469	M		82.5	16.6	<0.05	0.005	<0.46	<0.02	<0.003	4.8	0.075

[a]The following metals were below the respective limits of detection: Ag, <0.18; Cd, <0.18; Cr, <0.44; Cu, <0.44; Ni, <0.44; Pb, <0.44; Sb, <0.44.

[b]ROGQUA = Rogers Quarry, MCYBRU = McCoy Branch embayment upstream from culvert at Bull Bluff Road, MCYBRD = McCoy Branch embayment downstream from culvert at Bull Bluff Road, HINDSCR = Hinds Creek, Anderson Co., TN.

[c]LMBASS = largemouth bass (*Micropterus salmoides*) BLUGIL = bluegill sunfish (*Lepomis macrochirus*) REDBRE = redbreast sunfish (*Lepomis auritus*).

[d]Duplicate for 5878.

[e]Duplicate for 5480.

Table 4-2. Metal concentrations (μg/g, wet wt) in largemouth bass (*Micropterus salmoides*) from Rogers Quarry and McCoy Branch embayment and sunfish (*Lepomis auritus* and *L. macrochirus*) from Hinds Creek, a reference stream[a]

Metal	Rogers Quarry[b]	McCoy Branch Embayment[b]	Hinds Creek[c]	TVA[d]	USFWS[e]	PGV[f]	EPA[g]
Antimony	<0.44	<0.44	<0.44	<2	---	5.2	43.1
Arsenic	0.29 (0.02)	0.14 (0.02)	<0.05	0.16	0.16	0.0007	0.0062
Beryllium	<0.003	<0.003	0.005 (0.005)	<0.02	---	0.004	0.0025
Cadmium	<0.18	<0.18	<0.18	0.02	0.04	1.0	10.8
Chromium	<0.44	<0.44	<0.44	0.82	---	1.8	10800
Copper	<0.44	<0.44	<0.44	1.2	0.86	36	---
Lead	<0.44	<0.44	<0.44	0.06	0.19	1.8	---
Mercury	0.014 (0.002)	0.073 (0.011)	0.065 (0.011)	0.30	0.11	0.42	1.0
Nickel	<0.44	<0.44	<0.44	<1.0	---	5.2	215
Selenium	3.00 (0.11)	1.00 (0.29)	<0.45	0.28	0.46	12	5.4
Silver	<0.18	<0.18	<0.18	<0.2	---	0.29	2.48
Thallium	0.03 (0.00)	<0.02	<0.02	<1	---	0.66	5.71
Uranium	<0.003	<0.003	<0.003	---	---	1.6	---
Zinc	5.6 (0.22)	6.2 (0.35)	5.6 (0.80)	9.2	25.6	180	---

[a]Tabular values for these sites are mean and SE (in parentheses). Additional data are reference concentrations from other studies (Tennessee Valley Authority, United States Fish and Wildlife Service) and risk based criteria (Preliminary Guidance Value, Environmental Protection Agency).

[b]N = 8.

[c]N = 2.

[d]Composite largemouth bass, N = 10 (Dycus 1989; Dycus and Hickman 1986).

[e]Lowe et al. 1985.

[f]Preliminary Guidance Values (Hoffman et al. 1984; C. C. Travis, Health and Safety Division, ORNL, personal communication).

[g]Environmental Protection Agency, personal communication.

ORNL, Y-12, and K-25 (Southworth 1991; G. R. Southworth, Environmental Sciences Division, ORNL, personal communication); however, all the largemouth bass collected from McCoy Branch embayment contained measurable arsenic concentrations (Table 4-1). The mean concentration of arsenic found in McCoy Branch embayment bass was similar to the nationwide mean concentration found in the National Contaminant Biomonitoring Program (Lowe et al. 1985) sampling various species (Table 4-2). The McCoy Branch mean was also similar to the mean concentration found in composite largemouth bass samples from seven sites in the TVA region (Table 4-2) in screening studies conducted by TVA (Dycus and Hickman 1986; Dycus 1989). The criterion used to indicate a need for follow-up sampling in the TVA screening studies is 0.5 μg/g for arsenic.

The mean selenium concentration in bass from McCoy Branch embayment exceeded the mean concentrations observed in both the National Contaminant Biomonitoring Program (Lowe et al. 1985) and the TVA investigations (Dycus and Hickman 1986; Dycus 1989) (Table 4-2). Typical concentrations observed in sunfish in the ORR Biological Monitoring Programs were 0.4 to 0.6 μg/g (Southworth 1991; G. R. Southworth, Environmental Sciences Division, ORNL, personal communication). Thus, selenium concentrations in bass from McCoy Branch embayment are clearly elevated. Although they are well below concentrations used to screen for human health concerns in fish consumers (Table 4-2), the mean concentration is equal to the criteria used by TVA to initiate follow up studies (Dycus 1989).

The presence of elevated concentrations of selenium and arsenic in fish from Rogers Quarry was not surprising, because surface water in McCoy Branch contained high concentrations of these substances for several years prior to the reduction of coal burned at the Y-12 Steam Plant in 1988 and subsequent elimination of fly ash discharges to Rogers Quarry in 1990 (Fig. 2-5). Average concentrations of these elements measured by NPDES monitoring in McCoy Branch were much lower, averaging <46 μg/L arsenic and 4.3 μg/L selenium in the year preceding the fish sampling (Sect. 2.2.2, Figs. 2-4 and 2-5).

Several recent studies have suggested that adding selenium to waters in which mercury bioaccumulation in fish is excessive could ameliorate the problem (Rudd et al. 1980, Turner and Rudd 1983, Turner and Swick 1983, Bjornberg et al. 1988). However, a recent study by Curvin and Furness (1988) found that simultaneous exposure of minnows to dissolved mercury and selenium resulted in more rapid accumulation of mercury than was observed in the absence of selenium. They also note the positive correlation between tissue concentrations of mercury and selenium in large oceanic fish.

The mean mercury concentration in largemouth bass from Rogers Quarry, 0.014 ± 0.002 μg/g, was much lower than that in fish from the adjacent reservoir, 0.073 ± 0.011 μg/g (Table 4-2). A positive correlation between fish size and mercury concentration is commonly found in fish from the same site, which complicates comparisons of mercury concentrations among fish from different sites, because the mean weight of the fish sampled from Rogers Quarry was smaller than that of fish from McCoy Branch embayment. In this case, fish from Rogers Quarry exhibited a statistically significant relationship between fish weight and mercury concentration:

$$[Hg] = 5.40 \times 10^{-5} (wgt) - 0.002 \quad (4\text{-}1)$$

A similar relationship was found in the McCoy Branch embayment fish, but the slope of the relationship did not differ significantly from zero:

$$[Hg] = 8.11 \times 10^{-5} (wgt) + 0.038 \quad (4\text{-}2)$$

Because slopes of the two relationships did not differ significantly from each other, mercury concentrations could be compared in a straightforward fashion using analysis of covariance. The results of such a comparison indicated that the difference in mercury concentrations in fish between the two sites was indeed statistically significant. If Eq. 1 is used to estimate the mercury concentration in Rogers Quarry fish of mean weight (430 g) equal to the mean weight in the Melton Hill Reservoir collection, the difference remains very large, 0.025 versus 0.073 μg/g.

Mercury concentrations in largemouth bass from Rogers Quarry are among the lowest reported for this species. Concentrations measured by TVA in bass from 11 other sites in the upper Tennessee Valley all equaled or exceeded 0.2 μg/g (Dycus and Hickman 1986; Dycus 1989). The lowest mean concentrations observed in an extensive survey (96 sites) of lakes and streams in Florida were 0.04 and 0.07 μg/g in two highly eutrophic lakes (Hand and Friedman 1990). Concentrations at other locations typically exceeded 0.2 μg/g in that study, with most exceeding 0.5 μg/g. Only one of 39 composite largemouth bass samples analyzed in the National Contaminant Biomonitoring Program, 1978–1981, contained 0.02 μg/g or less of mercury (Lowe et al. 1985).

Although mercury concentrations in fish from Rogers Quarry were far lower than those typically found in largemouth bass, similar concentrations have been observed previously in bass from Melton Hill Reservoir. Largemouth bass collected in 1976 averaged 0.02 μg/L (Elwood 1984). Monitoring conducted from 1979 to 1983 by ORNL found mercury concentrations in single composite samples of largemouth bass to range from 0.01 to 0.10 μg/g, averaging 0.05 μg/g (Martin Marietta Energy Systems 1985). Analyses of individual fish were conducted in 1984 and 1985, and reported mean concentrations of 0.02 and 0.05 μg/g, respectively (Martin Marietta Energy Systems 1986). Sampling by TVA in 1984 reported a mean concentration of 0.12 μg/g for 10 fish (TVA 1985). Bass collected in fall 1989 from two sites on Melton Hill Reservoir averaged 0.10 μg/g ($n = 8$) (S. M. Adams, Environmental Sciences Division, ORNL, personal communication). Thus, it appears that mercury concentrations measured in bass from Melton Hill Reservoir in the past have been quite low and not unlike those observed in fish from Rogers Quarry. However, it also appears that measurements of mercury in Melton Hill Reservoir bass made since 1984 indicate that concentrations much higher than those observed in fish from Rogers Quarry are now typical of this lake.

The fact that very low concentrations of mercury have been observed in Melton Hill Reservoir fish in the past suggest that the low concentrations found in Rogers Quarry fish may result not from the presence of elevated concentrations of selenium in water and biota, but rather from unusually low concentrations of mercury in the water or some other factor limiting the production of methylmercury in this system. While it is impossible to disprove this hypothesis with the limited monitoring data presented here, NPDES monitoring of aqueous mercury concentrations in McCoy Branch suggest that this stream has occasionally contained elevated mercury concentrations in the past (Rogers et al. 1988, 1989). Thus, it is unlikely that the low concentrations of mercury in Rogers Quarry fish are a result of unusually low concentrations of mercury in the quarry water, and it is likely that the quarry actually contains higher concentrations of mercury than uncontaminated natural waters. It appears that the presence of 2–4 μg/L selenium in water in Rogers Quarry reduced the natural accumulation of mercury by a substantial amount, in agreement with speculation of Turner and Rudd (1983).

The measurements of selenium and arsenic concentrations in fish and water from Roger Quarry can also be used to calculate bioconcentration factors for these two elements. Although a simple ratio cannot adequately describe or predict bioaccumulation of inorganic substances such as these because they: (1) may be to some extent homeostatically regulated in fish, (2) may not exhibit a linear relationship between aqueous phase and biotic concentrations, and (3) may be accumulated significantly via food as well as direct aqueous uptake; nevertheless, such ratios can be useful in extrapolating to similar circumstances and perhaps in providing additional indices for evaluating the potential of contaminants to bioaccumulate. Bioconcentration factors were calculated for these two compounds by dividing the mean concentrations in fish in the quarry by the mean aqueous phase concentration in the quarry measured over the preceding year. Results of this calculation yielded bioconcentration factors for selenium and arsenic of 940 and 6.3, respectively. For comparison, bioconcentration factors used in formulating EPA water quality criteria for these two elements were 6 and 44 for selenium and arsenic, respectively. The large discrepancy for selenium may be due to the fact that ingestion of selenium-contaminated food is an important pathway in the accumulation of this element in fish (Hodson 1990), and bioconcentration factors as used in EPA water quality criteria are based strictly on direct uptake from aqueous exposure.

Concentrations of pesticides and PCBs in individual bass from Rogers Quarry are listed in Table 4-3. In all cases, the concentrations were far below the estimated detection limits (Table 4-3), but extremely low concentrations of four pesticides and pesticide metabolites (heptachlor, DDT, DDE, and chlordane) were, nevertheless, estimated in some individual fish. These estimated concentrations were well below EPA water quality criteria screening levels (EPA 1990) listed in Table 4-3, which were calculated using the EPA Integrated Risk Information System (IRIS 1989). Such extremely low estimated concentrations of organic contaminants cannot be used to reliably infer that these compounds are in fact present in the fish.

Two of eight fish collected in Rogers Quarry for contaminant analysis were deformed. Observed abnormalities involved bony structures of the fish including skull, gill opercula, fins, and scales. Each fish had severe erosion or incomplete development of the skull, giving it a misshapen, concave head. The bony portions of most fins were missing or eroded, and pelvic fins were missing. The bony portion of the outer gill covers was malformed or incomplete in both fish. Lateral line scales were missing in one fish; in the other, some lateral line scales were absent, and the remaining scales had a pronounced ridge. Both deformed fish were older than the remaining six fish collected in Rogers Quarry, with age estimated from scale annuli at 2 and 4 years, versus 1 year for the normal appearing fish (Table 4-2). Additional fish were captured and released in Rogers Quarry

Table 4-3. Concentrations of chlorinated pesticides and PCBs[a] in fish from Rogers Quarry (ROGQUA), and Hinds Creek (HINDSCR) July 1990

Site	Spp[b]	Tag	Sex	Wt (g)	Lgth (cm)	Heptachlor	DDT	DDE	Chlordane[c]
						(μg/g wet wt)			
ROGQUA	LMBASS	5878	M	467	34.4	0.0002	0.0004	<0.018	0.0001
ROGQUA	LMBASS	5879	F	299	29.1	0.0004	0.0010	0.0007	0.0003
ROGQUA	LMBASS	5494	M	217	26.2	0.0003	<0.022	0.0005	0.0002
ROGQUA	LMBASS	5495	F	515	32.2	<0.012	<0.024	0.0002	<0.012
ROGQUA	LMBASS	5496	F	180	24.2	<0.012	<0.024	0.0002	<0.012
ROGQUA	LMBASS	5497	M	193	25.0	<0.012	<0.024	0.0004	<0.012
ROGQUA	LMBASS	5498	M	315	29.2	<0.012	<0.024	0.0009	0.0004
ROGQUA	LMBASS	5499	F	194	25.3	<0.012	<0.024	<0.024	<0.012
ROGQUA	LMBASS	8785[d]	.	.	.	<0.012	0.0016	<0.024	<0.012
HINDSCR	BLUGIL	5465	F	82.7	17.0	<0.025	<0.049	<0.049	<0.025
EPA IRIS SCREENING CRITERIA[e]						0.0024	0.032	0.032	0.008

[a]All other pesticides and PCBs below limit of detection.

Compound	Detection limit (μg/g wet wt.)
ALPHA-BHC	<0.012
BETA-BHC	<0.012
DELTA-BHC	<0.012
GAMMA-BHC	<0.012
HEPTACHLOR	<0.012
ALDRIN	<0.012
HEPTACHLOR EPOXIDE	<0.012
ENDOSULFAN I	<0.012
DIELDRIN	<0.024
4,4'-DDE	<0.024
ENDRIN	<0.024
ENDOSULFAN II	<0.024
4,4'-DDD	<0.024
ENDOSULFAN SULFATE	<0.024
4,4'-DDT	<0.024
ENDRIN KETONE	<0.024
METHOXYCHLOR	<0.024
TOXAPHENE	<0.024
ARCHLOR 1016	<0.024
ARCHLOR 1221	<0.024
ARCHLOR 1232	<0.024
ARCHLOR 1242	<0.024
ARCHLOR 1248	<0.024
ARCHLOR 1254	<0.024
ARCHLOR 1260	<0.024

When analytes are not detected, the Oak Ridge National Laboratory, Analytical Chemistry Division Organics Analysis lab reports values as less than the quantitation limit. Concentrations lower than the quantitation limit can be detected, but with lower accuracy and precision than is required to define the quantification limit. The detection limit used in this table was estimated by dividing the reported quantification limit by a factor of ten. In some cases, the laboratory reported even lower concentrations to be detected. These values are reported, but are unlikely to actually indicate the presence of the specified analyte.

[b]LMBASS = largemouth bass; BLUGIL = bluegill sunfish.

[c]Sum of alpha and gamma chlordane.

[d]Duplicate for 5878.

[e]EPA, personal communication.

because the collection effort was attempting to collect individuals representing a broad range of sizes and ages. All fish released (approximately six) were similar in size and appearance to the six undeformed fish in the collection. No abnormal bass were collected or observed in McCoy Branch embayment of Melton Hill Reservoir.

The concentrations of selenium in water from Rogers Quarry for the 12 months preceding the fish sampling were somewhat lower than concentrations (5–10 μg/L) observed in a selenium-contaminated lake (Belews Lake) where fish exhibited severe adverse impacts (Hodson 1990). Selenium concentrations in fish from Belews Lake (10–50 μg/g) were also higher than in Rogers Quarry (Hodson 1990). However, aqueous selenium concentrations in Rogers Quarry in the years preceding 1989 were substantially higher than those reported for Belews Lake (Fig. 2-5). The deformed bass collected in Rogers Quarry would have been exposed to these higher selenium (and arsenic) concentrations if they were lifetime residents of the quarry. The undeformed fish collected in 1990 were all from the age class spawned in spring 1989 and, thus, would never have been exposed to the very high contaminant concentrations that occurred previously.

Physiological changes characteristic of selenium poisoning were reported in fish from Belews Lake (Hodson 1990; Sorensen et al. 1984) and another fly-ash-contaminated system, Martin Lake (Sorensen and Bauer 1983). At Belews Lake, selenium exposure caused reproductive failure and a severe decline in fish populations within the affected area (Hodson 1990); however, bony tissue abnormalities were not cited in either system. It appears likely that the abnormalities observed in Rogers Quarry bass are related to some dissolved constituent(s) in the coal ash discharge that has declined in concentration substantially since fly ash discharge to the quarry ceased. It does not appear likely that selenium was the cause of the abnormalities. To date, we have not found evidence in the literature that arsenic or thallium may be contributors to these effects.

4.4 CONCLUSIONS

Concentrations of selenium, arsenic, and possibly thallium are elevated in largemouth bass from Rogers Quarry relative to bass from McCoy Branch embayment and sunfish from Hinds Creek. Levels of selenium and possibly arsenic appeared to be elevated above background in bass from McCoy Branch embayment of Melton Hill Reservoir. Only arsenic exceeds conservatively based screening criteria; however virtually all biological materials exceed this criterion for arsenic. Cessation of inputs of fly ash to the system, coupled with the rapid biological turnover of selenium and arsenic, should result in continuing decreases in concentrations of these elements in fish. The very low concentrations of mercury in fish from Rogers Quarry are consistent with findings of other research on interaction between selenium and the bioaccumulation of mercury, and suggest research areas for possible remediation of local mercury-contaminated systems.

Bioaccumulation of organic contaminants was not indicated in the McCoy Branch discharge.

4.5 FUTURE STUDIES

Largemouth bass in Rogers Quarry and McCoy Branch embayment will be sampled and analyzed for metals again in 1991 to ascertain whether or not concentrations of arsenic, selenium, and thallium decrease as expected. Largemouth bass will also be collected from a reference site more similar to Rogers Quarry, such as Lambert Quarry. At the same time, a more extensive survey of the incidence of bony structure deformities will be carried out. Further review of the scientific literature for possible agents that cause abnormalities similar to those found in Rogers Quarry bass will be conducted.

5. FISH COMMUNITY ASSESSMENT

5.1 INTRODUCTION

Fish population and community studies can be used to assess the ecological effects of water quality and habitat. These studies offer several advantages over other indicators of environmental quality (Karr et al. 1986; Karr 1987) and are relevant to any evaluation of the biotic integrity of streams such as McCoy Branch. Fish communities, for example, comprise several trophic levels with species that are at, or near, the end of food chains. Consequently, they integrate the direct effects of water quality and habitat changes on primary producers (periphyton) and consumers (benthic invertebrates), which are used for food. Because of these trophic interrelationships, the well-being of fish populations has often been used as an index of water quality (Weber 1973; Greeson et al. 1977; Karr et al. 1986). Moreover, statements about the condition of the fish community are better understood by the general public (Karr 1981).

The initial objectives of the fish community monitoring task were to (1) characterize spatial and temporal patterns in distribution and abundance of fishes in McCoy Branch, and (2) document any effects on fish community structure and function resulting from implementation of the remedial actions as discussed in the McCoy Branch RFI (Murphy and Loar 1988).

5.2 METHODS

The fish community in McCoy Branch was evaluated at one area upstream and one area downstream from Rogers Quarry (Fig. 2-2); both areas are potentially impacted by coal ash effluent (Sect. 2.2.3). The upstream area was sampled qualitatively over a long stream reach to determine absence or presence of fish. The downstream area was sampled quantitatively at McCoy Branch kilometer (MCK) 1.56 to measure population parameters. Similar quantitative samples were made at two nearby reference sites [Grassy Creek kilometer (GCK) 2.4 and White Oak Creek kilometer (WCK) 6.8] for comparison of population parameters (Fig. 2-1). No attempt was made to survey the quarry itself.

Both qualitative and quantitative sampling was conducted using a Smith-Root Model 15A backpack electrofisher. The unit has a self-contained, gasoline-powered generator capable of delivering up to 1200 V of pulsed, direct current. The pulse frequency and the output voltage can be varied, but generally a pulse frequency of 90–120 Hz and a voltage of less than 400 V was used.

For qualitative sampling, one electrofisher and one netter made a single electrofishing survey upstream through the stream. A majority of the stream and all major tributaries were sampled. Two surveys (11 May 1989 and 15 June 1990) covered the stream from the Rogers Quarry inlet (MCK 1.92) to a large earthen dam (MCK 2.65) upstream. Another survey (14 December 1987) was made of the stream sections above the earthen dam. Stunned fish were to be kept and identified to species.

For quantitative sampling, a 0.64-cm mesh seine was placed across the upper and lower boundaries of the fish sampling site to restrict fish movement. The sampling site (MCK 1.56) varied between 46–50 m in length (Table 5-1) for the three sampling surveys. A quantitative sample involved one electrofisher and one or two netters. This sampling team electrofished upstream through the site, collecting stunned fish for three separate passes. The fish were separated by pass in buckets prior to processing. Depending upon the turbidity of the water, the consecutive passes could not always be made immediately. Rather, fish were processed after each pass to allow sufficient time for the water to clear before another pass was started.

Following the electrofishing, fish were anesthetized with MS-222 (tricaine methanesulfonate) and processed. To process the fish, they were identified, measured to the nearest 0.1 cm (total length), and weighed to the nearest 0.1 g (for fish < 100 g) or gram (for fish > 100 g) using Pesola spring scales. At sites with high fish densities, individuals were recorded by 1-cm size classes and species. After 25 individuals of a species-size class were measured and weighed, additional members of that size class were only measured. Length-weight regressions were later used to estimate weight for unweighed fish (Railsback et al. 1989). Other data recorded (if possible to determine), included sex, reproductive state, disposition (i.e., dead or kept for laboratory identification and inclusion in a reference collection), and the presence of any abnormalities (e.g., external parasites or skeletal deformities). After processing fish from all passes, the fish were allowed to fully recover from the anesthetic and were returned to the stream within the sampling site. Any additional mortality occurring as a result of processing was noted at that time.

In addition to data on individual fish, data on selected physical and chemical parameters and the sampling effort were recorded. An Horiba Model U-7 Water Quality Checker was used to measure pH, temperature, dissolved oxygen, and conductivity. An HF Instruments Model DRT-15 turbidimeter was used to measure turbidity. The duration of the electrofishing effort was recorded for each pass, and a visual estimate was made of percent cloud cover. Following completion of fish sampling, the length, widths (at 5-m intervals), and depths (at 3 points on the width transect) of the sampling reach were measured at each site.

Species population estimates were calculated using the three-pass removal method of Carle and Strub (1978). Biomass was estimated by multiplying the population estimate by the mean weight per individual. Total numbers and biomass were divided by the surface area (m^2) of the sampling site to calculate values per unit area. For each sampling date, surface area was estimated by multiplying the length of sampling reach by the mean width based on measurements taken at 5-m intervals (Table 5-1).

The population structure of the three most abundant species was examined by length frequencies. The lengths of the estimated fish population were separated into 1- or 2-cm size classes, depending on the maximum size of the species. These frequencies indicated whether the population included young and adult individuals and if any unusual mortality had affected a size class.

Table 5-1. Length, mean width, mean depth, area, and pool-riffle ratio (P/R) of fish sampling sites on McCoy Branch and two reference streams, Grassy Creek and White Oak Creek, for each sampling date

Site[a] (km)	Date	Length (m)	Width (m)	Depth (cm)	Area (m^2)	Pool/ riffle
MCK 1.56	05/11/89	46	1.6	18.6	74	0.4
	10/27/89	50	0.9	10.5	45	0.4
	05/16/90	50	0.9	13.6	45	0.5
GCK 2.4	04/06/89	60	1.9	13	114	0.8
	10/23/89	61	1.4	9	85	1.8
	04/19/90	61	1.6	8	98	0.8
WCK 6.8	04/20/89	60	2.3	6.3	138	0.4
	10/31/89	60	2.0	8.1	120	0.7
	04/03/90	55	2.5	7.7	138	NM[b]

[a]MCK = McCoy Branch kilometer; GCK = Grassy Creek kilometer; WCK = White Oak Creek kilometer.

[b]NM = not measured.

The procedures used for calculating density, biomass, and length frequency are given in more detail in Railsback et al. (1989).

Condition factors measure the degree of plumpness of a fish as a measure of relative health (Bennett 1970). A condition factor (K) was calculated for individual fish by site using the following formula:

$$K = 100\ (\text{weight/length}^3) \tag{5-1}$$

where the weight is in grams and total length in centimeters (Hile 1936). Fish without measured weights were not used in the calculation of condition factors. A comparison of condition factors between sampling periods was made with an analysis of variance (ANOVA) on untransformed data (SAS 1985b) because the condition factors exhibited homogeneity of variance (SAS 1985a). If the ANOVA indicated significant differences in condition factors between groups, the Tukey test was performed to identify those groups that were significantly different (alpha = 0.05).

5.3 RESULTS AND DISCUSSION

5.3.1 Community Structure

Surveys of upper McCoy Branch above Rogers Quarry failed to locate any fish. The three surveys at MCK 1.56 indicated the stream below the quarry had a permanent fish community. At MCK 1.56, species richness (total number of species) ranged from 9 to 11 species for the three surveys made from May 1989 to May 1990 (Table 5-2). The total number of species taken during this period was 14, but only 6 species were taken in all surveys. Species richness in McCoy Branch was considerably higher than the 3–5 species found in the reference sites.

The variability in species number and composition in McCoy Branch is related to proximity of the site to Melton Hill Reservoir. The closeness of the reservoir allows species to be found in McCoy Branch that are atypical for a stream the size of McCoy Branch. Only blacknose dace (*Rhinichthys atratulus*), central stoneroller (*Campostoma anomalum*), redbreast sunfish (*Lepomis auritus*), and snubnose darter (*Etheostoma simoterum*) are typical inhabitants of similar-sized streams in this area (Ryon and Loar 1988). Comparisons with the reference streams indicate that several species expected to occur in streams of this size were missing. These species include creek chub (*Semotilus atromaculatus*), striped shiner (*Luxilus chrysocephalus*), white sucker (*Catostomus commersoni*), and banded sculpin (*Cottus carolinae*). The absence of these species may reflect past extermination by coal ash discharges and prevention of recolonization from Melton Hill Reservoir. The variable association of fish species and the presence of fish atypical for a stream of this size suggest that the community contains many individuals that move in and out from the reservoir.

The fish community at MCK 1.56 contained four species [green sunfish (*L. cyanellus*), carp (*Cyprinus carpio*), yellow bullhead (*Ameiurus natalis*), and spotfin shiner (*Cyprinella spiloptera*)] that are considered to be insensitive to many habitat and water

Table 5-2. Fish densities (number fish/m²) in McCoy Branch and in two reference streams, White Oak Creek and Grassy Creek, for April–May 1989 to April–May 1990

Species	April–May 1989	October 1989	April–May 1990
	McCoy Branch kilometer 1.56		
Blacknose dace		<0.1[a]	
Bluntnose minnnow	0.5	0.7	0.1
Carp	0.1		
Spotfin shiner	0.1		
Stoneroller	<0.1		
Bluegill sunfish	5.2	0.4	1.4
Green sunfish	0.3	0.9	0.8
Largemouth bass		0.1	<0.1
Redbreast sunfish	0.1	0.2	<0.1
Redear sunfish	<0.1	<0.1	
Warmouth		0.1	<0.1
Greenside darter	<0.1		<0.1
Snubnose darter	<0.1	0.1	<0.1
Yellow bullhead	<0.1	0.2	0.1
Total number species	11	10	9
Total density	6.4	2.7	2.6
	White Oak Creek kilometer 6.8		
Blacknose dace	1.0	1.9	1.1
Creek chub	0.1	0.2	<0.1
Stoneroller		<0.1	
Banded sculpin	0.2	0.3	0.3
Total number of species	3	4	3
Total density	1.3	2.4	1.4
	Grassy Creek kilometer 2.4		
Blacknose dace	0.1	2.2	0.9
Creek chub	0.1	0.5	0.3
Striped shiner	<0.1		<0.1
Green sunfish		<0.1	
White sucker	<0.1	<0.1	<0.1
Banded sculpin		<0.1	<0.1
Total number of species	4	5	5
Total density	0.2	2.8	1.3

[a]Value of <0.1 indicates species was present at very low densities.

quality stressors. They would be considered tolerant species in an impact assessment methodology such as the Index of Biotic Integrity (Karr et al. 1986). Only two species were found that would be considered slightly intolerant or sensitive to stress, the Tennessee snubnose darter and greenside darter (*E. blennioides*), and these species were represented by only a few individuals. This pattern suggests that McCoy Branch is a stressed system.

Trophic composition of the community can indicate further stress on the system. A nonimpacted stream will have many benthic insectivores, few generalist feeders, and a stable piscivore population. The fish community of McCoy Branch included many omnivores or generalist feeders, few benthic insectivores, and fewer piscivores. Generalist feeders are readily able to switch prey items and are more successful in stressed stream systems (Leonard and Orth 1986). In McCoy Branch the generalist feeders included the blacknose dace, carp, bluegill sunfish (*L. macrochirus*), warmouth (*L. gulosus*), and yellow bullhead. Benthic insectivores are specialized feeders that are limited in the prey items they can eat, are more successful in undisturbed streams (Leonard and Orth 1986), and in McCoy Branch, included only the two darter species. The largemouth bass (*Micropterus salmoides*) was the only piscivore; it was present in low numbers (Table 5-2) and only at small sizes.

5.3.2 Population Densities

Densities at MCK 1.56 for the three sampling periods ranged from 2.6 to 6.4 fish/m^2 (Table 5-2). The density in May 1989 of 6.4 fish/m^2, included 5.2 bluegill/m^2. Later samples did not have such a strong component of bluegills, and the densities were much lower. Compared with reference streams, MCK 1.56 densities were generally higher than either densities at GCK 2.4 or WCK 6.8. The high densities may be affected by immigration from Melton Hill Reservoir and/or Rogers Quarry.

The densities of individual species were proportionally similar for each sampling period. The community density was dominated by bluntnose minnow, bluegill, and green sunfish; however, none of these species occurred in the reference streams. Conversely, the dominant species in the reference streams, blacknose dace and creek chub, were present in low numbers or absent altogether from McCoy Branch.

5.3.3 Population Biomass

Fish biomass values (g wet wt/m^2) paralleled the trends observed in population density (Table 5-3). The initial sample in May 1989 had an extremely high biomass of 107.5 g wet wt/m^2 and was due to the presence of several large carp and a substantial number of sunfish. The sample in October 1989 had a much lower biomass (17.4 g wet wt/m^2) than in May due to the absence of many large sunfish. However, the community biomass rebounded in May 1990 (50.3 g wet wt/m^2), when more large sunfish returned to the site. The biomass in McCoy Branch was 2–100 times higher than the values found in the reference streams (Table 5-3) at comparable sampling dates.

The dominant species (excluding carp), in terms of biomass, were bluegill, green, and redbreast sunfish. Most of the biomass for bluegill and green sunfish came from large numbers of several intermediate size classes, while the biomass of the redbreast sunfish

Table 5-3. Fish biomass (g fish/m²) in McCoy Branch and in two reference streams, White Oak Creek and Grassy Creek, for April–May 1989 to April–May 1990

Species	April–May 1989	October 1989	April–May 1990
	McCoy Branch kilometer 1.56		
Blacknose dace		0.1	
Bluntnose minnnow	1.7	0.9	0.2
Carp	74.6		
Spotfin shiner	0.5		
Stoneroller	0.1		
Bluegill sunfish	20.1	3.1	35.8
Green sunfish	3.9	1.8	6.2
Largemouth bass		0.8	0.3
Redbreast sunfish	6.1	6.7	2.3
Redear sunfish	0.2	0.5	
Warmouth		0.9	0.6
Greenside darter	0.1		0.3
Snubnose darter	<0.1	0.2	0.1
Yellow bullhead	0.2	2.4	4.5
Total biomass	107.5	17.4	50.3
	White Oak Creek kilometer 6.8		
Blacknose dace	1.3	8.4	1.2
Creek chub	0.4	0.3	0.1
Stoneroller		<0.1	
Banded sculpin	1.0	1.2	0.9
Total biomass	2.7	9.9	2.2
	Grassy Creek kilometer 2.4		
Blacknose dace	0.2	1.5	1.1
Creek chub	0.4	2.1	1.6
Striped shiner	0.1		0.5
Green sunfish		0.7	
White sucker	0.2	0.2	0.3
Banded sculpin		0.6	<0.1
Total biomass	0.9	5.1	3.5

was based on a few large individuals. The dominance by sunfish of the community biomass reflected the influence of Melton Hill Reservoir.

5.3.4 Length Frequency

The length-frequency histograms for the three most abundant species reflected their reproductive patterns and any potential stress from coal ash on these patterns. The most abundant species, the bluegill sunfish, showed a strong dominance by the 4- to 7.9-cm size classes in the spring 1989 sample (Fig. 5-1). However, the fall 1989 sample does not show any small size classes, suggesting a lack of bluegill reproduction in McCoy Branch. Also the general bluegill population declined. In 1990, the population remained small with a shift towards more large individuals in the site.

The green sunfish showed a more balanced pattern, with large numbers of small- to medium-sized individuals and a few large individuals at all sample dates (Fig. 5-1). In the fall 1989 sample, the two smallest size classes had substantial numbers of fish. This suggests a relatively stable reproductive effort.

The bluntnose minnow had a much narrower size range, which was dominated by larger size classes in the spring samples (Fig. 5-1). The smaller individuals in the fall 1989 sample are an indication of some reproduction (or immigration from nearby embayment areas).

5.3.5 Condition Factors

Comparisons of condition factors (K) should provide information on the relative well-being of the fish, because those with more weight per length have a higher condition factor (Everhart et al. 1975). Data were not available for a statistical comparison of condition factors between MCK 1.56 and the reference sites because there was so little species overlap. When compared with condition factors of redbreast and bluegill sunfish in other areas of WOC (M. G. Ryon, Environmental Sciences Division, ORNL, personal communication), condition factors of these species at MCK 1.56 were within the range of values. Seasonal comparisons of condition factors in McCoy Branch were made for nine species. Three species, bluegill sunfish, green sunfish, and bluntnose minnow demonstrated statistically greater condition factors in spring samples than in fall samples. Six other species did not show any significant differences.

5.3.6 Observed Abnormalities

As part of the normal processing procedure for population estimates, observations of abnormalities or attached parasites are made of the fish specimens. Usually, these abnormalities are limited to less than 1–5% of the population in a minimally stressed system; a highly stressed system would have 5% or more abnormalities (Karr et al. 1986). Such abnormalities may include spinal deformities, open skin lesions, fin rot or erosion, or distended eyes ('popeye'). The number of such observations made in McCoy Branch seemed unusually high.

ORNL-DWG91-17425

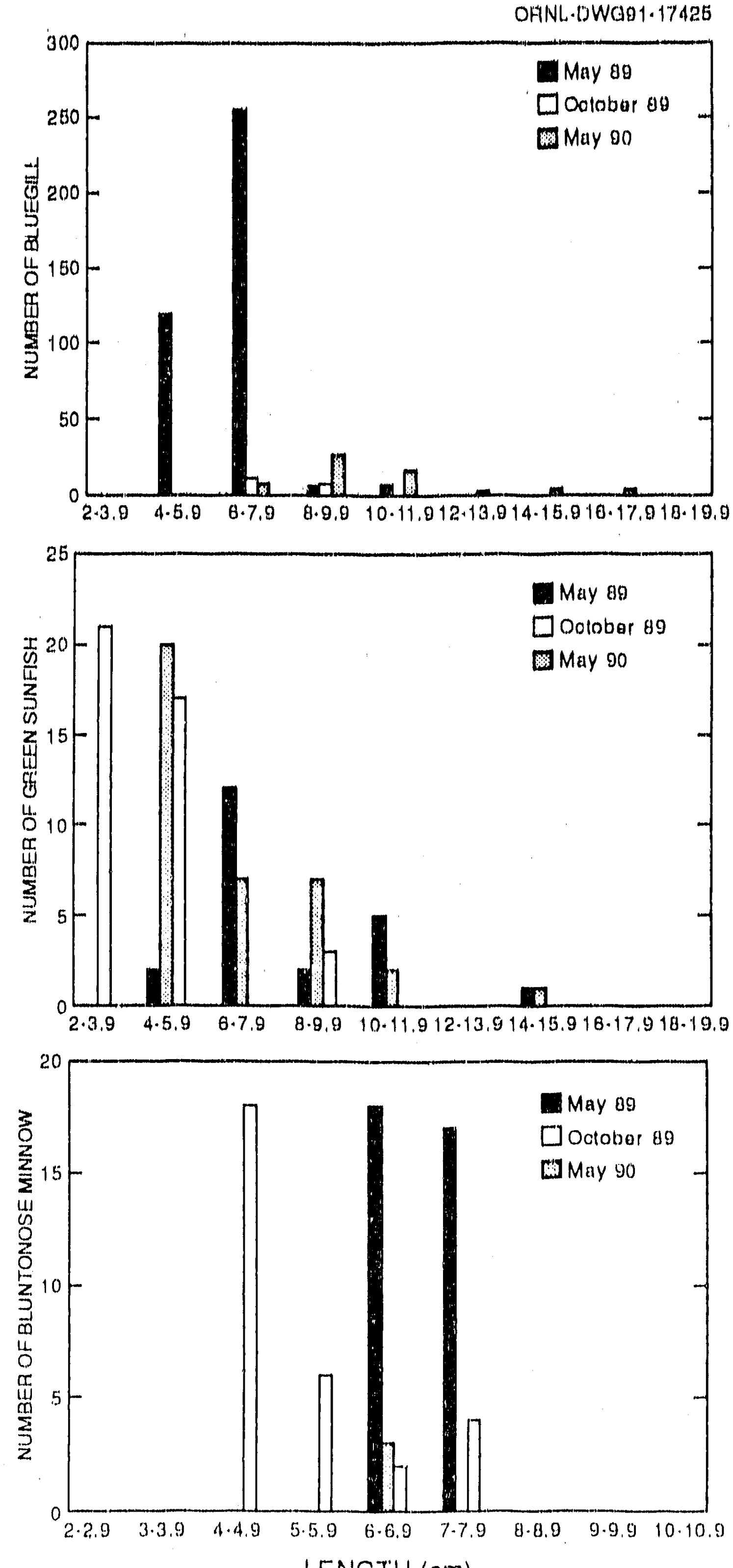

Fig. 5-1. Length-frequency histograms for bluegill sunfish, green sunfish, and bluntnose minnow for May 1989, October 1989, and May 1990 from McCoy Branch site MCK 1.56.

In the May 1989 sample, 27% of the green sunfish (6.3–15.7 mm TL) and 73% of the redbreast sunfish (10.9–17.5 mm TL) had one abnormality, extremely eroded fins. The pelvic, pectoral, and anal fins were often missing or reduced to mere fin rays without any membranes and tipped by an enlarged knob. The occurrence of abnormalities decreased substantially in the October 1989 fish population sample (2%). However, the May 1990 sample again demonstrated severe abnormalities. Eroded fins were found in 8% of the green sunfish (9.1–14.5 mm TL) and 13% of the bluegill sunfish. Also, 11% of the bluegill (9.2–18.1 mm TL) showed another abnormality, a misshapened head that appeared to be a skull deformity. Similar deformities were noted in largemouth bass taken in bioaccumulation sampling of Rogers Quarry (Sect. 4.3). The reference streams did not have any specimens with either eroded fins or deformed heads during these sampling periods. The presence of the deformities suggests an extreme stress in McCoy Branch, perhaps related to the high levels of arsenic or selenium in McCoy Branch water (Sect. 2.2.2 and 4.3).

5.4 CONCLUSIONS

Data on the fish populations of McCoy Branch demonstrated the stream has received considerable stress from the coal ash operations. The total lack of species above the quarry indicate that conditions were lethal to fish in that section. The cessation of the coal ash sluicing through that section after November 1989 should have reduced that stress. However, Rogers Quarry effectively acts as a migration barrier to species that might repopulate upper McCoy Branch.

The fish community below Rogers Quarry, although permanent, demonstrates a lesser degree of impact than that of upper McCoy Branch. The stress is related to both coal ash discharges and the impacts of Melton Hill Reservoir. The species composition, and the most abundant species, reflect conditions inappropriate for a stream the size of McCoy Branch. Species that should occur in such a stream are missing and have been replaced by those from the adjacent reservoir. Even those species demonstrate several degrees of stress. The species occurring in the stream include those most tolerant of degraded conditions. This applies to both tolerance of physical and chemical stress and a flexibility in feeding requirements. Finally, substantial numbers of individuals within the community demonstrate severe physical abnormalities only rarely found in other systems.

5.5 FUTURE STUDIES

The future plans for assessing the fish community in McCoy Branch will continue the twice a year (spring and fall) sampling schedule. Until fish populations are found in upper McCoy Branch, sampling in that area will be restricted to qualitative surveys. An additional reference site will be sampled quantitatively. This selected site will more closely approximate the species and the conditions of MCK 1.56. For example, the site will be situated close to an embayment or main section of Melton Hill Reservoir. During the quantitative processing, additional attention will be given to assessing abnormalities.

Because immigration of individuals and species into McCoy Branch from Melton Hill Reservoir is occurring, further qualitative sampling will be conducted to assess immigration. If possible, additional qualitative sampling will include the quarry; this may be a cooperative effort with sampling for the bioaccumulation task.

Long-term plans for McCoy Branch studies may include the reintroduction of fish species into upper McCoy Branch above Rogers Quarry. The fish would be species expected to occur in such a stream (e.g., blacknose dace) and population dynamics would be monitored after the reintroduction.

6. BENTHIC MACROINVERTEBRATE COMMUNITY ASSESSMENT

6.1 INTRODUCTION

Benthic macroinvertebrates are those organisms which live on or in the substrate of flowing and nonflowing bodies of water and are large enough to be seen without the aid of magnification. Their limited mobility and relatively long life spans (a few months to more than a year) of most taxa make them ideal for evaluating the ecological effects of effluent discharges to streams (Platts et al. 1983). Thus, the composition and structure of the benthic community reflect the relatively recent past, and they can be considerably more informative than alternative methods that rely solely on water quality analyses but miss the potential synergistic effects often associated with complex effluents. The objective of the initial phase of this study is to provide a detailed spatial and temporal characterization of the benthic invertebrate community of McCoy Branch. These data will be used as a baseline from which the effectiveness of major remedial actions within the McCoy Branch watershed can be assessed. The data will also be used to provide direction for future studies.

6.2 MATERIALS AND METHODS

Benthic macroinvertebrates were sampled at approximately quarterly intervals beginning in April 1989 through January 1990 at two sites in McCoy Branch (Fig. 2-2). Because an unimpacted reference site was not available on McCoy Branch, a relatively unimpacted reach of upper WOC served as a reference site. Upper WOC is similar in size to McCoy Branch, and is located just north of ORNL, approximately 3 Km west of McCoy Branch (Fig. 2-1). Three random quantitative samples were collected from a permanently marked riffle at each site with a Surber bottom sampler (0.09 m^2) fitted with a 363-μm-mesh collection net. To obtain additional information on taxonomic richness, a qualitative sample consisting of collections from riffle and nonriffle habitats (e.g., pools, leaf packs, detritus, and snags) was taken from each site in spring 1989. Qualitative samples were collected with a D-frame aquatic dip net (mesh of 800 μm × 900 μm). All samples were placed in prelabeled, polyurethane-coated glass jars and preserved in 80% ethanol; the ethanol was replaced with fresh ethanol (80%) within 10 d of collection.

Supplemental information on water quality and stream characteristics was recorded at the time of sampling. Temperature, conductivity, dissolved oxygen, and pH were measured with an Horiba Model U-7 Water Quality Checker. Water depth, location within the riffle area (distance from permanent headstakes on the stream bank), visual determination of relative stream velocity (very slow, slow, moderate, or fast), and substrate type [visual determination based on a modified Wentworth particle size scale (Loar 1985)] were recorded for each sample.

All samples were washed in the laboratory using a U.S. Standard Series No. 60 sieve (250-μm mesh) and placed in an 8- x 10-inch white, plastic tray for sorting. Organisms were removed from the debris with forceps and placed in labeled vials containing 80% ethanol. Organisms were identified to the lowest practical taxonomic level using a stereoscopic dissecting microscope. After chironomid larvae were sorted into groups based on morphological similarities, one or more representatives of each group were mounted on a slide in CMC-10 mounting medium and identified using a compound microscope. The remaining chironomid larvae were then identified at a magnification of 50X to 100X with a dissecting microscope. A blotted wet weight of all individuals combined in each taxon was determined to the nearest 0.01 mg on a Mettler analytical balance.

Slides of mounted chironomid larvae were retained in slide boxes, and individuals of the remaining taxa from a given site and sampling date were preserved in separate vials containing 80% ethanol. A reference collection of these specimens will be maintained at ORNL.

The Shannon-Weiner index (H′) was used to calculate the taxonomic diversity of benthic macroinvertebrates at each site (Pielou 1977):

$$H' = -\sum P_j \log_2 P_j \qquad (6\text{-}1)$$

where P_j is the proportion of the benthic invertebrate community made up of species j. H′ values of 3 or greater are typical of clean water, while values of 1–3 are usually associated with moderate pollution, and values of less than 1 characterize heavily polluted water (Platts et al. 1983).

All data analyses were done with the Statistical Analysis System (SAS 1985a,b). Mean values for density[1]; biomass[1]; number of taxa per sample (taxonomic richness); number of Ephemeroptera, Plecoptera, and Trichoptera taxa per sample (EPT richness); and taxonomic diversity were compared separately with a one-way analysis of variance (ANOVA) on quarterly sampling period-specific data with site as the main effect; all analyses were based on three replicates per site and date. Prior to performing the ANOVAs, data were transformed

$$\log 10(X+1) \qquad (6\text{-}2)$$

where X = individual values for density, biomass, etc. (Elliott 1977). Where significant differences were found between sites, treatment means were compared using a Tukey standardized range test (α = 0.05) to discriminate these differences.

[1]Comparisons between sites in density and biomass were made both with and without Mollusca (snails and mussels) and Decapoda (crayfish) since these taxa are typically very heavy but numerically unimportant and can thus suppress the importance of the weight changes of the other organisms. Therefore, unless otherwise noted, trends presented in both spatial and temporal patterns in density include both Decapoda and Mollusca, while trends in biomass exclude these two groups.

6.3 RESULTS

6.3.1 Taxonomic Composition

A checklist of the benthic invertebrates collected from McCoy Branch and a reference site at WCK 6.8 from April 1989 through January 1990, is presented in Appendix B, Table B-1. A total of 163 distinct taxa, 145 of which were insects, were collected in quantitative samples from the designated sampling sites in the two streams. Nine orders of insects, including Collembola (springtails), Ephemeroptera (mayflies), Coleoptera (beetles), Diptera (true flies), Hemiptera (true bugs), Megaloptera (alderflies, fishflies, and dobsonflies), Odonata (dragonflies and damselflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), were collected from these streams. The order Diptera was the most taxonomically rich group with 76 representative taxa, 50 of which were from the family Chironomidae (true midges). Of the remaining insect orders, Trichoptera, Ephemeroptera, and Plecoptera had the greatest number of taxa with 23, 20, and 16 taxa, respectively. The numbers of taxa from these three orders were greater from the reference site than from either of the two McCoy Branch sites. Of the nine insect orders represented in the quantitative samples, Megaloptera were absent from MCK 1.40, and Hemiptera were absent from MCK 2.03.

In addition to insects, taxa representing ten other major taxonomic groups were collected including Amphipoda (sideswimmers), Copepoda (copepods), Decapoda (crayfish), Gastropoda (snails), Hydracarina (water mites), Nematoda (roundworms), Oligochaeta (aquatic earthworms), Ostracoda (seed shrimp), Bivalvia (mussels and clams), and Tricladida (planaria or flatworms) (Appendix B, Table B-1). Copepoda and Ostracoda were collected only from McCoy Branch.

Twenty-seven additional taxa were collected from McCoy Branch and 25 from WOC in qualitative samples (Appendix B, Table B-1). Decapods, amphipods, and water mites were found in McCoy Branch only in the qualitative samples (Appendix B, Table B-1). Of the additional taxa collected from McCoy Branch, only one belonged to the order Ephemeroptera. In the WCK 6.8 sample, there were 11 additional taxa of Ephemeroptera, Plecoptera, and Trichoptera. The group containing the greatest number of additional taxa was the dipterans (7 from WCK 6.8 and 23 from the MCK sites).

6.3.2 Density and Biomass

The annual means for density and biomass of the benthic macroinvertebrates at each sampling site are presented in Table 6-1. The density of invertebrates (including and excluding mollusks and decapods) at MCK 1.40 and WCK 6.8 was almost twice that at MCK 2.03 (Table 6-1); these differences were statistically significant (Table 6-2). The biomass of macroinvertebrates (all taxa) at WCK 6.8 was more than 13 times higher than at MCK 2.03, and almost 6 times higher than at MCK 1.40 (Table 6-1). When mollusks and decapods were excluded, the biomass at WCK 6.8 was similar to the biomass at MCK 1.40 but still was almost 2.5 times higher than at MCK 2.03. Statistical comparisons showed that the biomass at MCK 2.03 was significantly lower than at MCK 1.40 and WCK 6.8 (with or without the mollusks and decapods), while the biomass at MCK 1.40 differed from WCK 6.8 only when all taxa were considered (Table 6.2).

Table 6-1. Mean annual density, biomass, taxonomic richness, Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness, and diversity of benthic macroinvertebrates in McCoy Branch and White Oak Creek, April 1989 to January 1990[a]

Sites[b]	Density[c,d]	Density[c,e]	Biomass[d,f]	Biomass[e,f]	Taxonomic richness[g]	EPT richness[h]	Diversity[i]
MCK 1.40	669.5 (186.7)	662.7 (185.0)	473.1 (104.2)	442.6 (109.3)	25.6 (3.0)	4.9 (0.8)	2.90 (0.08)
MCK 2.03	388.9 (248.9)	385.0 (247.0)	206.8 (112.5)	187.4 (97.2)	23.8 (7.0)	5.5 (3.1)	3.02 (0.24)
WCK 6.8	714.1 (194.1)	675.1 (194.2)	2751.2 (568.3)	452.0 (117.8)	45.8 (2.3)	15.7 (1.4)	3.98 (0.20)

[a]Values in parentheses are ± 1 SE.
[b]MCK = McCoy Branch kilometer; WCK = White Oak Creek kilometer.
[c]No. of individuals/0.1 m^2.
[d]Includes all taxa.
[e]Excludes Mollusca and Decapoda.
[f]Expressed as mg wet wt/0.1 m^2.
[g]Expressed as No. of taxa/sample.
[h]Expressed as No. of EPT taxa/sample.
[i]Expressed as H′; the Shannon-Weiner index (H′) was used to calculate the taxonomic diversity using the equation $\mathbf{H'} = -\sum \mathbf{P}_j \log_2 \mathbf{P}_j$, where P_j is the proportion of the benthic invertebrate community made up of species *j*. H′ ≥3 indicates values typical of clean water, 1 ≤ H′ <3 are moderate pollution, and H′ <1 indicates heavily polluted water.

Table 6-2. Statistical comparisons[a] of mean annual benthic macroinvertebrate density, biomass, taxonomic richness, Ephemeroptera, Plectoptera and Trichoptera (EPT) richness, and species diversity in McCoy Branch[b] and the reference stream, White Oak Creek[c]

Parameter type

Density **(all taxa)**

WCK 6.8 __________ MCK 1.40   MCK 2.03

Density (excluding Mollusca and Decapoda)

WCK 6.8   MCK 1.40   MCK 2.03

Biomass **(all taxa)**

WCK 6.8   MCK 1.40   MCK 2.03

Biomass **(excluding Mollusks & Decopoda)**

WCK 6.8 __________ MCK 1.40   MCK 2.03

Richness

WCK 6.8   MCK 1.40 __________ MCK 2.03

EPT Richness

WCK 6.8   MCK 1.40 __________ MCK 2.03

Diversity

WCK 6.8   MCK 1.40 __________ MCK 2.03

[a]Sites not joined by lines are significantly different (α = 0.05), based on Tukey's studentized range test (HSD). n = 12 for each site.
[b]McCoy Branch kilometer = MCK.
[c]White Oak Creek kilometer = WCK.

Temporal patterns in density of macroinvertebrates at MCK 1.40 and WCK 6.8 were similar with the highest density at both sites occurring in July 1989 (Fig. 6-1). In contrast, the greatest density at MCK 2.03 occurred in January 1990 when the density was four times greater than during the previous three sampling periods. During each sampling period, chironomids and coleopterans were generally the most abundant taxa at MCK 1.40, although a July peak in density was primarily the result of a substantial increase in the numbers of trichopterans and nonchironomid dipterans. Chironomids, ephemeropterans, and plecopterans were consistently the most abundant taxa at WCK 6.8. The July peak in density at this site resulted primarily from an increase in the numbers of ephemeropterans and nonchironomid dipterans and to a lesser extent plecopterans and chironomids (Fig. 6-2). Chironomid densities were generally higher than the densities of other taxa at MCK 2.03; however, ephemeropterans (primarily *Baetis*) were responsible for a dramatic increase in density at this site in January.

Seasonal trends in biomass were similar to those of density, with the highest values for biomass at MCK 1.40 and WCK 6.8 occurring in July, and the highest value at MCK 2.03 occurring in January (Fig. 6-1). Seasonal changes in biomass at MCK 1.40 largely reflected the seasonal changes of Trichoptera, while at MCK 2.03 and WCK 6.8 several taxa, particularly Trichoptera and Diptera, contributed to the seasonal changes (Fig. 6-3).

6.3.3 Community Structure

6.3.3.1 Taxonomic Richness

The number of taxa collected per sample at WCK 6.8 was almost two times greater than at either McCoy Branch site; this difference was statistically significant (Tables 6-1 and 6-2). Taxonomic richness at the two McCoy Branch sites was similar, although the much higher standard error at MCK 2.03 demonstrated that fluctuations in richness between sampling periods were considerable. In contrast, richness at MCK 1.40 and WCK 6.8 remained relatively stable.

Temporal changes in taxonomic richness were similar at MCK 1.40 and WCK 6.8 with each site exhibiting both increases and decreases through time (Fig. 6-4). In contrast, taxonomic richness at MCK 2.03 increased considerably through time with the January 1990 value being four times as high as the value than in April 1989. Notwithstanding these between-site differences, all three sites exhibited peaks in richness in January.

6.3.3.2 EPT Richness

Mean Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness for all sampling periods was significantly greater in WOC than in either McCoy Branch site (Tables 6-1 and 6-2). The mean number of EPT taxa at the WCK 6.8 site was three times that of either McCoy Branch site. Mean EPT richness at the two McCoy Branch sites was similar, although variability between sampling periods was considerably greater at MCK 2.03.

ORNL-DWG91-17426

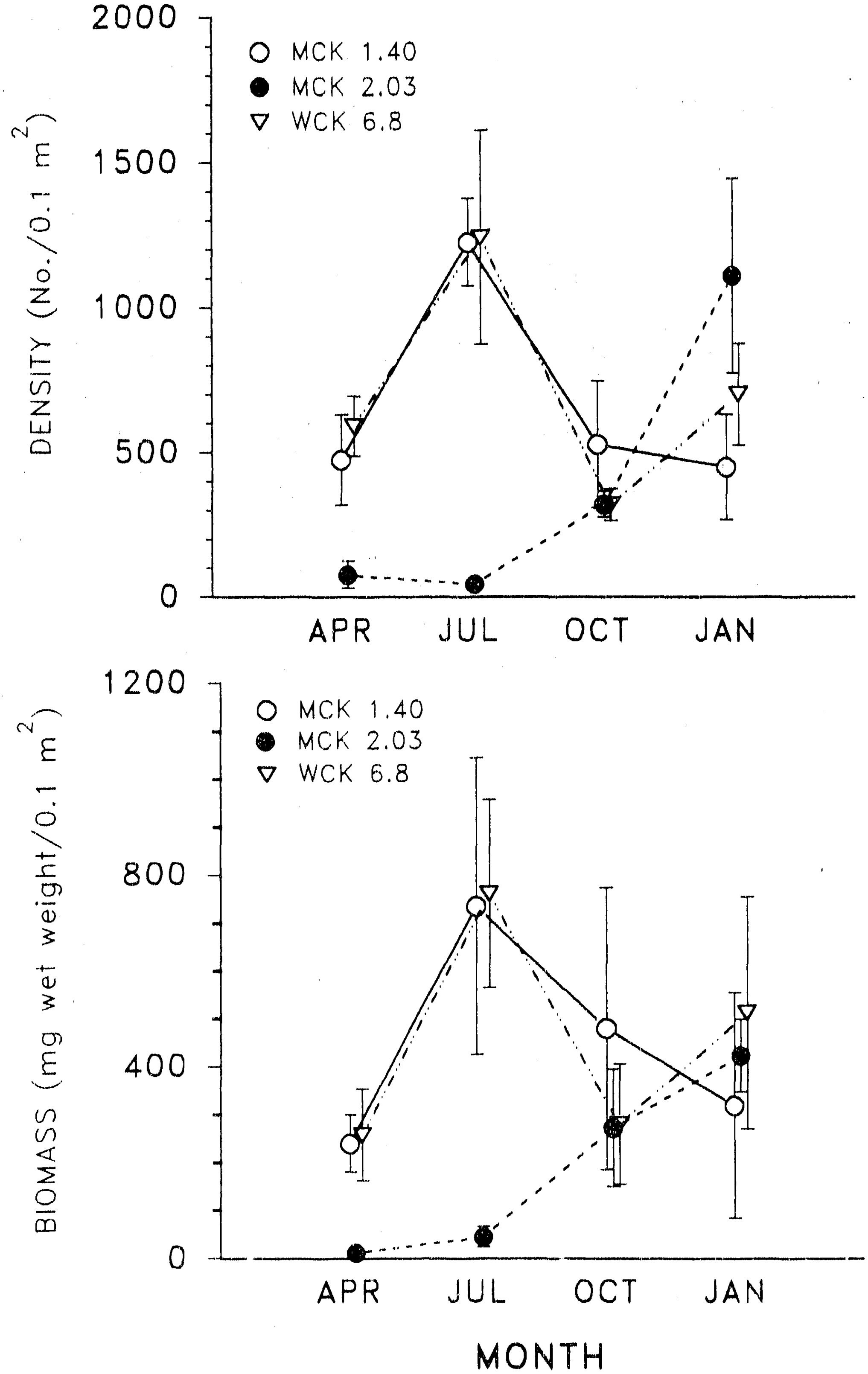

Fig. 6-1. Mean seasonal density (all taxa) and biomass (excluding Mollusca and Decapoda) of benthic macroinvertebrates in McCoy Branch and White Oak Creek, April 1989 to January 1990. Vertical bars are ± 1 SE. MCK = McCoy Branch kilometer and WCK = White Oak Creek kilometer.

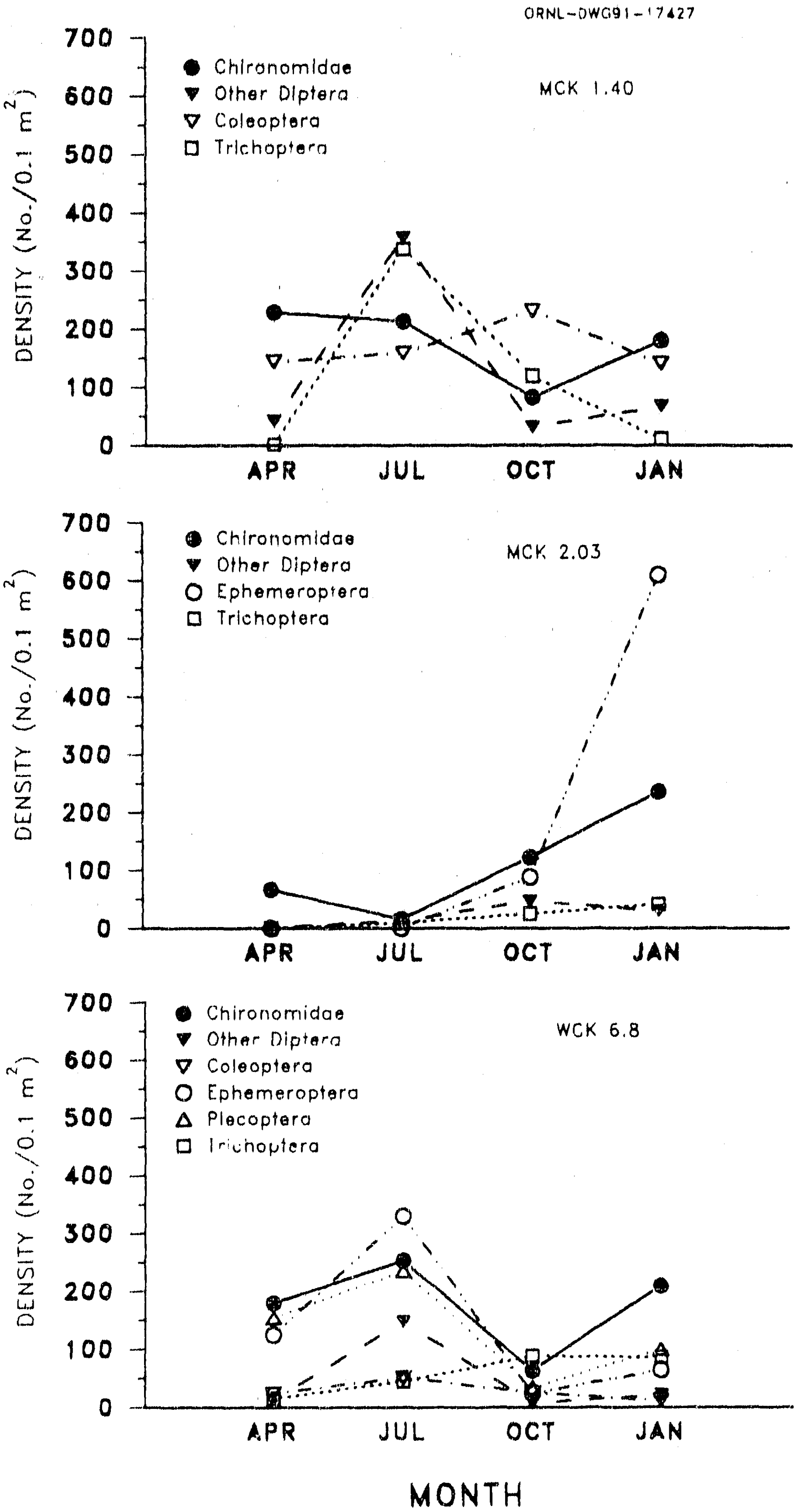

Fig 6-2. Mean seasonal density (No. of individuals/0.1 m^2) for selected taxa in McCoy Branch and White Oak Creek, April 1989 to January 1990. MCK = McCoy Branch kilometer and WCK = White Oak Creek kilometer.

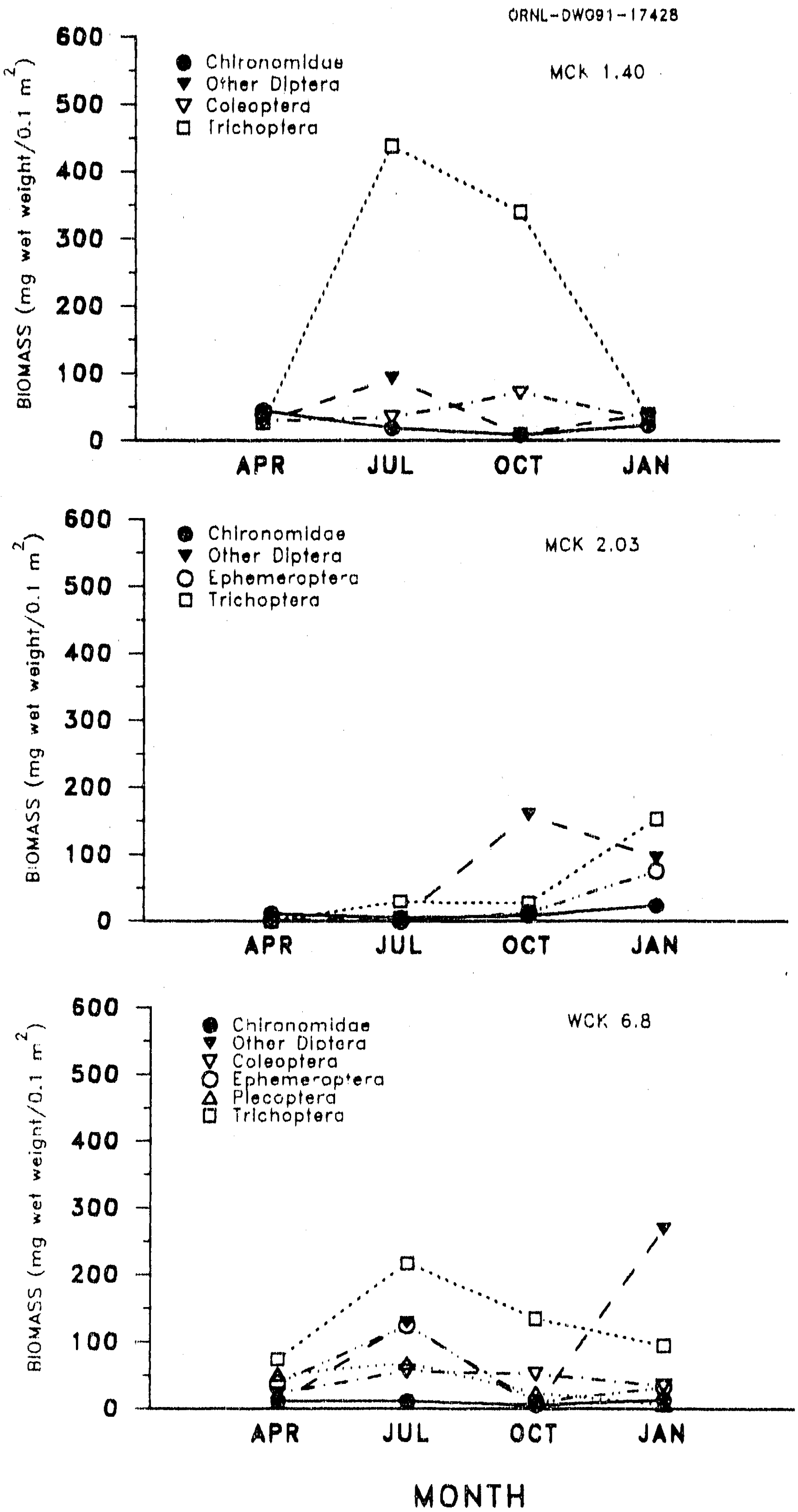

Fig 6-3. Mean seasonal biomass (mg wet wt./0.1 m^2) for selected taxa in McCoy Branch and White Oak Creek, April 1989 to January 1990. MCK = McCoy Branch kilometer and WCK = White Oak Creek kilometer.

ORNL-DWG91-17429

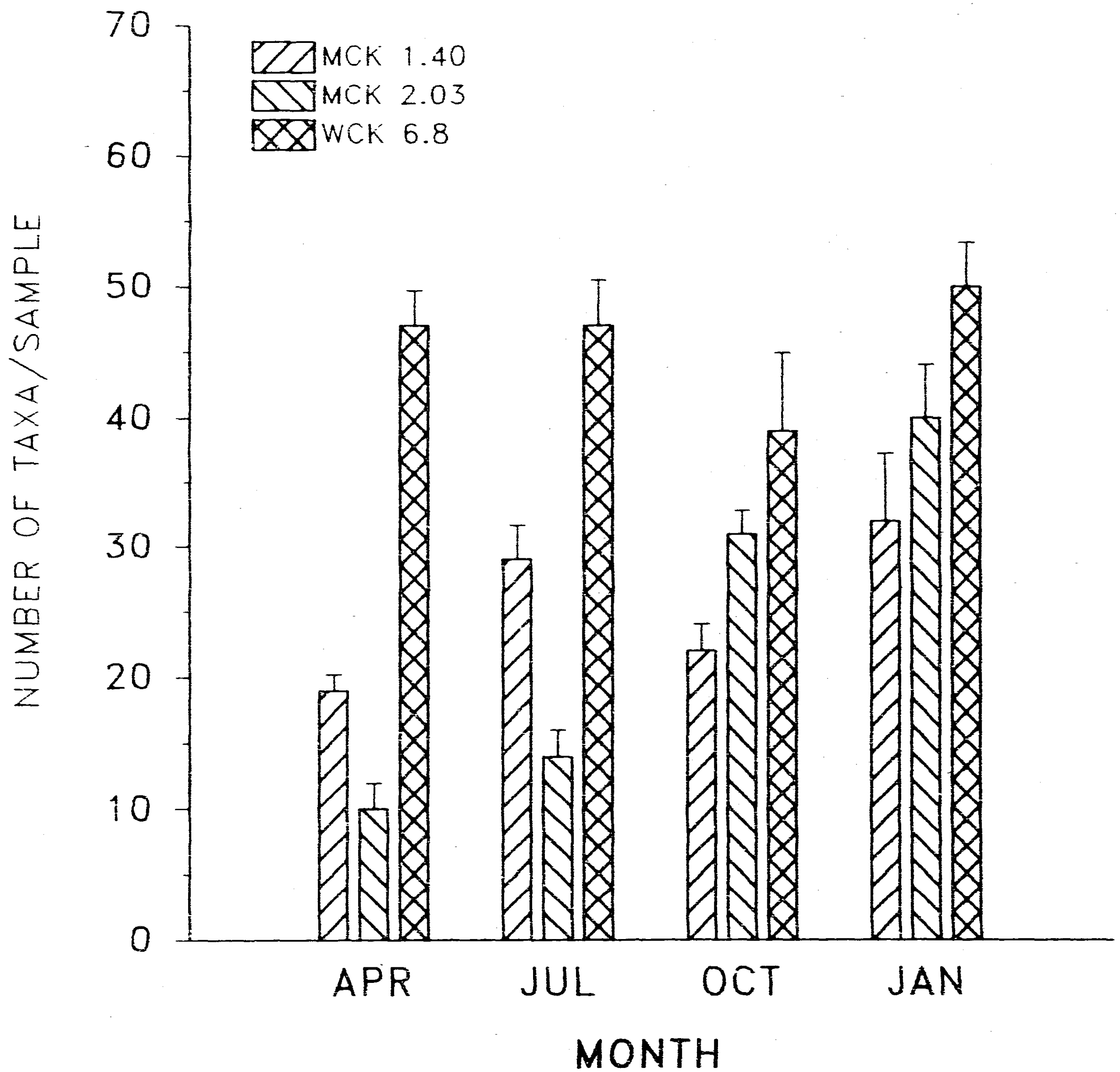

Fig 6-4. Mean seasonal taxonomic richness (number of taxa/sample) of benthic macroinvertebrates in McCoy Branch and White Oak Creek, April 1989 to January 1990. Vertical bars are ± 1 standard error. MCK = McCoy Branch kilometer and WCK = White Oak Creek kilometer.

EPT taxa were collected from all sites during all sampling periods (Fig. 6-5). The richness of these taxa was particularly low at MCK 2.03 in April and July when an average of fewer than two EPT taxa were collected in each sample. As with taxonomic richness,the mean number of EPT taxa from WCK 6.8 was always higher than at either McCoy Branch site. The number of EPT taxa remained relatively stable through time at WCK 6.8 and MCK 1.40, while the greatest variability between sampling periods was exhibited at MCK 2.03.

6.3.3.3 Species Diversity

Spatial patterns in taxonomic diversity (H′) were similar to those observed for taxonomic and EPT richness (Table 6-1); diversity was significantly higher at WCK 6.8 than at either McCoy Branch site while at the two McCoy Branch sites diversity was similar (Table 6-2). Also, as for taxonomic and EPT richness, diversity was highest at WCK 6.8 during all sampling periods (Fig. 6-6). Temporally, MCK 1.40 exhibited less dramatic fluctuations in diversity than the other two sites, staying close to 3.0 in all sampling periods (Fig. 6-6). The other two sites exhibited similar magnitudes of fluctuation between each sampling period although not the same patterns.

6.4 DISCUSSION

The benthic invertebrate community of McCoy Branch, which historically has received fly ash and bottom ash sluiced from the steam plant at the Oak Ridge Y-12 Plant, exhibited evidence of moderate degradation of water quality and/or physical habitat. Relative to the reference site on White Oak Creek (WCK 6.8), both McCoy Branch sites exhibited significantly lower values for taxonomic and EPT richness, and diversity. Additionally, both density and biomass were significantly lower at MCK 2.03 than at WCK 6.8 and MCK 1.40, suggesting that a greater degree of degradation exists upstream of Rogers Quarry. The most notable differences between the reference site and both McCoy Branch sites were in taxonomic and EPT richness; taxonomic richness was two times higher and EPT richness at least three times higher at WCK 6.8. The greater number of EPT taxa at WCK 6.8 is indicative of the overall health of this site, because EPT taxa generally tend to be very sensitive to alterations in water quality and physical habitat (Wiederholm 1984; Lenat 1984; Lenat 1988).

Smith (1991a) found that the most highly-stressed invertebrate communities in streams on or near the ORR are almost exclusively comprised of chironomids and/or oligochaetes, while less pollution-tolerant EPT taxa are virtually absent. While EPT richness was reduced in McCoy Branch relative to WCK 6.8, EPT taxa were collected during each sampling period from both sites. Although the EPT values from the McCoy Branch sites are consistently lower than for sites in other relatively undisturbed streams that drain the south slope of Chestnut Ridge near ORNL (J. G. Smith, Environmental Sciences Division, ORNL, personal communication), the EPT values are comparable to those of a relatively undisturbed reach of Mitchell Branch (MIK 1.43) located just east of the Oak Ridge K-25 Site (J. G. Smith, Environmental Sciences Division, ORNL, personal communication). This suggests that the degree of stress to the benthic macroinvertebrate community in McCoy Branch is relatively moderate. Greater stress at MCK 2.03 relative

ORNL-DWG91-17430

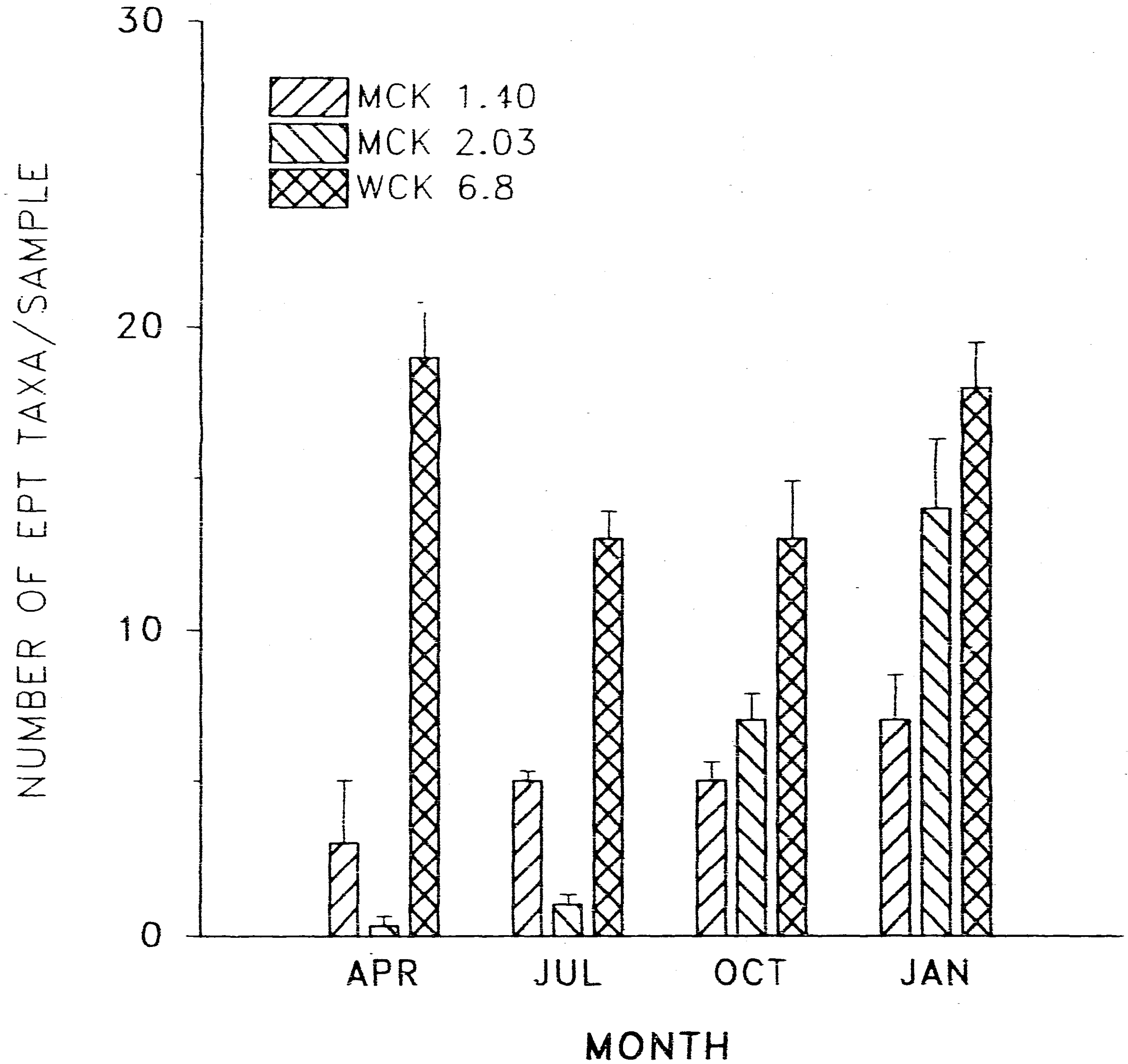

Fig. 6-5. Mean seasonal Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness (number of taxa/sample) in McCoy Branch and White Oak Creek, April 1989 to January 1990. Vertical bars are ± 1 standard error. MCK = McCoy Branch kilometer and WCK = White Oak Creek kilometer.

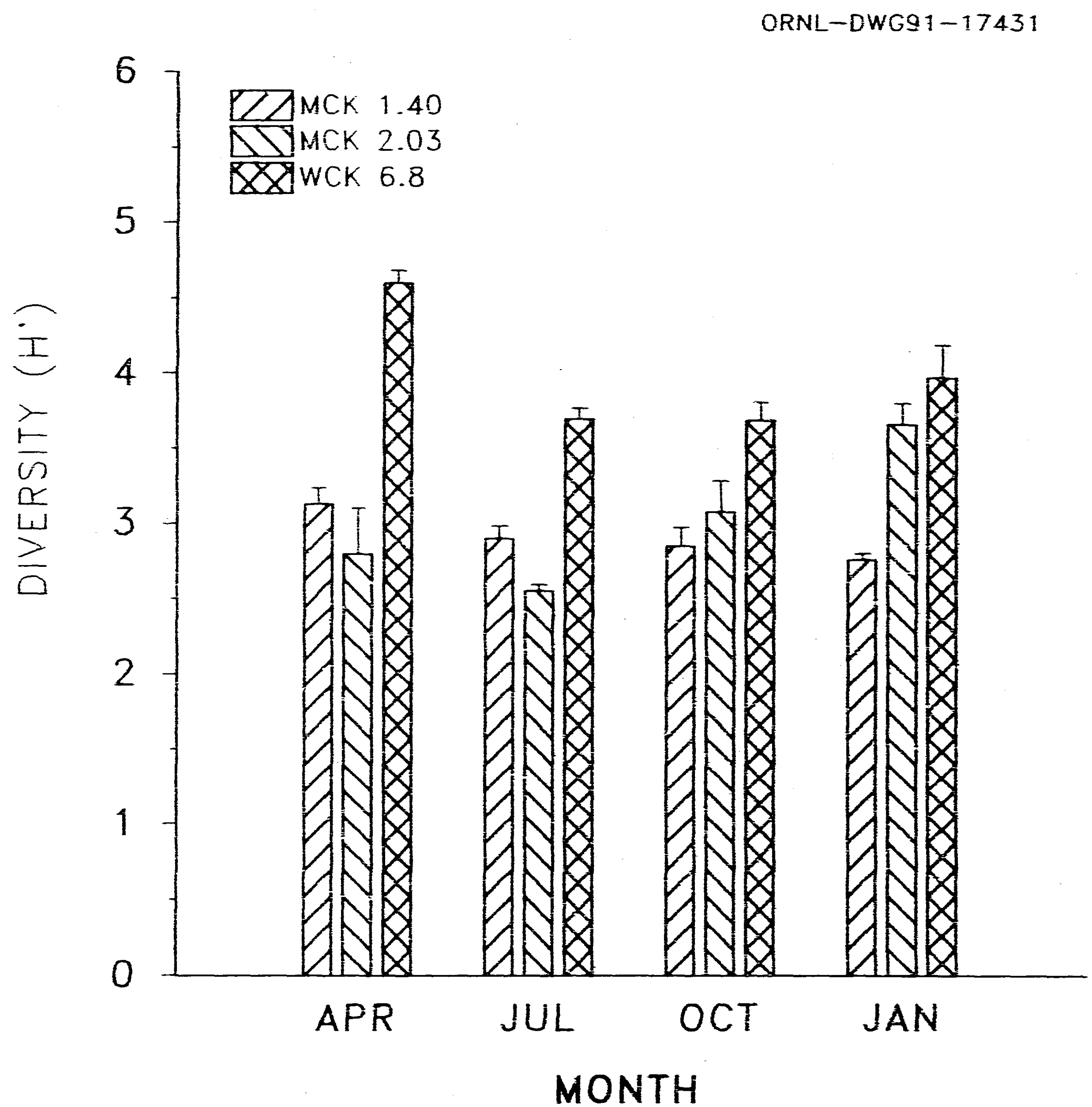

Fig. 6-6. Mean seasonal diversity (H') of benthic macroinvertebrates in McCoy Branch and White Oak Creek, April 1989 to January 1990. Vertical bars are ± 1 standard error. MCK = McCoy Branch kilometer and WCK = White Oak Creek kilometer.

to MCK 1.40 is implied by the significantly lower values for density and biomass. However, all parameters exhibited substantial increases at MCK 2.03 during the last two sampling periods which suggests that recovery related to improvements in water quality and/or physical habitat may have begun. These community changes may have been the result of several measures taken at the Y-12 steam plant since 1988 which have improved the water quality and reduced the quantity of coal ash discharged to McCoy Branch (Sect. 2.2.1 and 2.2.2). Continued monitoring should determine if this trend at MCK 2.03 is the result of remedial actions or is a response to other unidentified environmental factors.

Relatively high conductivity measurements, > 500 μS/cm, in McCoy Branch (J. G. Smith, Environmental Sciences Division, ORNL, personal communication) in April 1989 suggest that the concentration of dissolved solids may have been elevated. Lower conductivity values in McCoy Branch after April may reflect a reduction in the use of coal and subsequently, the quantity of ash produced at the Y-12 steam plant starting during winter 1988 with a further seasonal reduction by April 1989 (Sect. 2.2.2). Depending upon the flow, some flushing of deposited ash may have occurred downstream of the ash pond such that the concentration in the stream has decreased with time. Further sampling will verify if a trend toward lower conductivity exists.

The composition and structure of the benthic community in McCoy Branch downstream of the ash pond appear to be responding to both physical and chemical stress. Suspended solids resulting from ash transport downstream of the ash pond may be a major perturbation at MCK 2.03. Within Rogers Quarry, settling occurs so that the downstream load of suspended solids is reduced. Considerable deposits of coal ash were evident along and within the streambed at MCK 2.03 at the beginning of this project, while the presence of coal ash in lower McCoy Branch was much less evident (Sect. 2.2.4; J. G. Smith, Environmental Sciences Division, ORNL, personal observation). Deposited solids can adversely affect organisms either directly by obstructing food collection and/or respiration, or indirectly by reducing food availability (Hynes 1970). Suspended solid deposition and sediment accumulation have been shown to both decrease the density and biomass of benthic invertebrates by as much as 60% (Gammon 1970) and reduce diversity by eliminating stress-sensitive taxa (Mackenthun 1973; Wiederholm 1984). The deposition of fine-grained material also can provide a substrate favorable for colonization by taxa tolerant of these conditions such as chironomids (Wiederholm 1984). This may partially explain the prevalence of chironomids at MCK 2.03 compared to the other two sites.

In addition to deposited solids, some metals have historically occurred in elevated concentrations in McCoy Branch with higher levels above Rogers Quarry (Sect. 2.2.2, Tables A-3, A-4, A-5, and A-6, Fig. 2-4 and 2-5). Of the metals measured, arsenic and selenium have the greater potential for impacts on aquatic life.

Studies by Elwood in the 1970s (R. R. Turner, Environmental Sciences Division, ORNL, personal communication) showed elevated levels of arsenic in aquatic insects in McCoy Branch. Water quality samples taken between July 1986 and July 1990 show that levels of arsenic in McCoy Branch exceeded the recommended maximum concentration (50 μg/L) for protection of aquatic life (EPA 1976) from July 1986 until approximately

July 1989. Levels of arsenic in McCoy Branch above 50 μg/L also occurred periodically from January 1990 through approximately May 1990 (Fig. 2-4).

Levels of selenium in McCoy Branch consistently exceeded 10 μg/L from July 1986 through approximately January 1989. Maximum levels for protection of aquatic life are 260 μg/L for acute exposure and 35 μg/L for chronic exposure; however, concentrations of 5 μg/L have been shown to adversely effect fish production (RFI 1987). From April 1989 to January 1990 levels of selenium in McCoy Branch ranged from near zero to 10 μg/L with an average of approximately 5 μg/L (Fig. 2-5). It is possible that one or both of these metals could have an adverse effect on the benthic community in McCoy Branch. The low density and richness of sensitive taxa, particularly mayflies, which are generally very sensitive to metal pollution (Wiederholm 1984), and the relatively high percent composition of chironomids indicate the benthic macroinvertebrate community in McCoy Branch may be responding to long-term exposure to elevated levels of these or other potential toxicants.

Finally, the magnitude of seasonal change of all parameters was most similar between MCK 1.40 and the reference site (WCK 6.8). This implies that environmental conditions were more stable at MCK 1.40 than at MCK 2.03, which may be a reflection of Rogers Quarry functioning as a settling basin for both sediments and associated chemical contaminants. However, impoundments have been shown to alter chemical and physical conditions of streams, which in turn, alter the benthic invertebrate community (Ward and Stanford 1979). Thus, while reducing the impacts associated with coal ash, the quarry itself alters natural conditions which lead to alterations in the benthic invertebrate community. Future changes in the benthic community at MCK 1.40 in response to remedial actions may be mediated by the presence of the quarry.

6.5 CONCLUSIONS

The structure and composition of the benthic macroinvertebrate community in McCoy Branch are indicative of moderate stress. Maximum impact within this stream occurs upstream of Rogers Quarry as was exemplified by the significantly higher density and biomass at MCK 1.40 compared to MCK 2.03. Some improvement in water quality was evident downstream of the quarry, as demonstrated by significant increases in density and biomass of the benthic community at MCK 1.40. However, significantly lower values for taxonomic and EPT richness, and diversity at this site compared to the reference site, indicate some impact. At MCK 2.03, substantial increases were observed in density, biomass, and taxonomic and EPT richness, particularly during the October and January sampling periods, suggesting that improvements in water quality may be occurring. The cause of the stress on the benthic macroinvertebrate community in McCoy Branch, at least upstream of Rogers Quarry, is most likely the result of several factors related to the long-term discharge of coal ash from the Y-12 steam plant. The benthos, particularly upstream of the quarry (MCK 2.03), appears to be responding to habitat alteration as the result of ash deposition within the stream channel and possibly to leaching of potential toxicants (e.g., arsenic and selenium) from the ash. The benthic community at MCK 2.03 should recover as coal fines are removed from the streambed; however, recovery may be slowed by the loss of supplemental flow in the upper reaches of McCoy Branch which may increase the time required for natural cleansing of the stream.

Rogers Quarry acts as a settling basin for coal ash transported downstream from the ash pond, thereby diminishing the impact of ash deposition on the benthic community downstream of the quarry. The benthic community at MCK 1.40 did not exhibit the temporal trends in increased density, biomass, or taxonomic and EPT richness shown by MCK 2.03, suggesting this community may not be experiencing similar changes in water quality. Although Rogers Quarry appears to reduce the impacts associated with ash deposition, this impoundment likely alters the physical and chemical environment downstream, which in turn alters the invertebrate community. Finally, the direct discharge of ash to the quarry (initiated in May 1990) may cause the quarry to act as an immediate source of toxicants through leaching of metals from the ash. This may impact the benthic community at MCK 1.40.

6.6 FUTURE STUDIES

The current sampling program for benthic macroinvertebrates will continue. As for WCK 6.8, the snail *Elimia* is a prominent member of the benthic macroinvertebrate communities of several streams that drain the south slope of Chestnut Ridge and the ORR (Smith 1991b). However, some relatively undisturbed streams in these same areas do not contain snails (Smith 1991b), and no historical data on the benthic macroinvertebrates of McCoy Branch exists. Thus it is not known if *Elimia* have ever occurred in this stream. Therefore, an additional reference stream without snails (Fifth Creek, FFK 1.0) will be included in future analyses that will allow comparisons of McCoy Branch to reference streams with and without snails. This sampling program will provide a comprehensive characterization of the benthic community in McCoy Branch and an extensive data base that will allow documentation of the response of the benthic community as water quality changes occur as a result of remedial actions. The continued sampling program will provide further comparison of the benthic community at MCK 1.40 before and after direct discharge of bottom ash to Rogers Quarry and will document the response of the benthic community at MCK 2.03 to the absence of ash discharge from the Y-12 Plant.

7. REFERENCES

Bennett, G. W. 1970. Management of Lakes and Ponds. Van Nostrand Reinhold, New York.

Bjornberg, A., L. Hakanson, and K. Lundberg. 1988. A theory on the mechanisms regulating the bioavailability of mercury in natural waters. Environ. Pollut. 49:53–61.

Bogle, M. A., and R. R. Turner. 1989. Rogers Quarry water balance January 1, 1987 through June 30, 1988. Y/TS-506. Oak Ridge National Laboratory for Y-12 Plant, Oak Ridge, Tenn.

Bowen, H. J. M. 1979. Environmental Chemistry of the Elements. Academic Press, London.

Burris, J. A., M. S. Bamford, and A. J. Stewart. 1990. Behavioral responses of marked snails as indicators of water quality. Environ. Tox. Chem. 9:69–76.

Carle, F. L., and M. R. Strub. 1978. A new method for estimating population size from removal data. Biometrics 34:621–630.

Craig, P. M., and B. A. Tschantz. 1986. Preliminary seepage residual study by water balance method for Rogers Quarry. Y/SUB/86-1819/2. Y-12 Plant, Oak Ridge, Tenn.

Crutchfield, P. J. 1966. Positive rheotaxis in *Goniobasis proxima*. Nautilus 79:80–86.

Cuvin, M. L. A., and R. W. Furness. 1988. Uptake and elimination of inorganic mercury and selenium by minnows, *Phoxinus phoxinus*. Aquat. Toxicol., 13:205–216.

Dycus, D. L. 1989. Results of fish tissue screening studies from sites in the Tennessee and Cumberland Rivers in 1987. TVA/WR/AB - 89/5. Tennessee Valley Authority, Chattanooga, Tenn.

Dycus, D. L., and G. D. Hickman. 1986. Concentrations of PCBs, DDTr, and metals in fish from Tellico Reservoir. TVA/ONRED/AWR-87/25. Tennessee Valley Authority, Knoxville, Tenn.

Elliott, J. M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates. Freshwater Biological Association, Ambleside, England. Sci. Pub. No. 25.

Elwood, J. W. 1984. Mercury contamination in Poplar Creek and the Clinch River. ORNL/TM-8893. Oak Ridge National Laboratory, Oak Ridge, Tenn.

ERDA (Energy Research and Development Administration). 1975. Preliminary draft environmental analysis report. Oak Ridge Operations, Volume VI. Oak Ridge, Tenn.

Everhart, W. H., A. W. Eipper, and D. W. Youngs. 1975. Principles of Fishery Science. Cornell University Press, Ithaca, New York.

Gammon, J. R. 1970. The effect of inorganic sediment on stream biota. Water Pollution Control Research Series, 18050DWC12/70, Water Quality Office, U.S. Environmental Protection Agency, Washington, D.C.

Greeson, P. E., T. A. Ehlke, G. A. Irwin, B. W. Lium, and K. V. Slack. 1977. Methods for collection and analysis of aquatic biological and microbiological samples. Book 5, Chapter 4A, pp. 1–332. In U.S. Geological Survey, Techniques of Water-Resources Investigations of the United States Geological Survey. U.S. Government Printing Office, Washington, D.C.

Hand, J., and M. Friedman. 1990. Mercury, largemouth bass, and water quality: A preliminary report. Florida Department of Environmental Regulation, Tallahassee, Fla.

Hile, R. 1936. Age and growth of the cisco, *Leucichthys artedi* (LeSeur), in the lakes of the northeastern highlands, Wisconsin. U.S. Bur. Fish. Bull. 48:211–317.

Hodson, P. V. 1990. Indicators of ecosystem health at the species level and the example of selenium effects on fish. Environ. Monitor. Assess. 15:241–254.

Hoffman, F. O., B. G. Blaylock, C. C. Travis, K. L. Daniels, E. L. Etnier, K. E. Cowser, and C. W. Weber. 1984. Preliminary screening of contaminants in sediments. ORNL/TM-9370. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Houp, K. H. 1970. Population dynamics of *Pleurocera acuta* in a central Kentucky limestone stream. Am. Midl. Nat. 83:81–88.

Hynes, H. B. N. 1970. The Ecology of Running Water. University of Toronto Press, Toronto.

IRIS. 1989. Integrated Risk Information System (data base). U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Jones, R. A., and R. Mishu. 1986. Geotechnical and hydrologic evaluation of Y-12 Plant coal ash dam. Y-SUB/86-479701-1, prepared by Geotek Engineering Co. for the Oak Ridge Y-12 Plant. Oak Ridge, Tenn.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries. 6:21–27.

Karr, J. R. 1987. Biological monitoring and assessment: A conceptual framework. Environ. Manage. 11:249–256.

Karr, J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser. 1986. Assessing biological integrity in running waters: A method and its rationale. Illinois Natural History Survey Special Publication 5. Urbana, Ill.

Ketelle, R. H., and D. D. Huff. 1984. Site characterization of the West Chestnut Ridge Site. ORNL/TM-9229. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Kszos, L. A., and A. J. Stewart. 1991. Effort-allocation analysis of the 7-d fathead minnow (*Pimephales promelas*) and *Ceriodaphnia dubia* toxicity tests. Environmental Toxicology Chemistry (in press).

Kszos, L. A., A. J. Stewart, L. F. Wicker, and G. M. Logsdon. 1989. Environmental Sciences Division Toxicology Laboratory standard operating procedures. ORNL/TM-11194, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Lenat, D. R. 1984. Agriculture and stream water quality: A biological evaluation of erosion control practices. Environ. Manage. 8:333–344.

Lenat, D. R. 1988. Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. J. North Am. Benthol. Soc. 7:222–233.

Leonard, P. M. and D. J. Orth. 1986. Application and testing of an Index of Biotic Integrity in small, coolwater streams. Trans. Amer. Fish. Soc. 115:401–414.

Loar, J. M. (ed.). 1985. Application of habitat evaluation models in southern Appalachian trout streams. ORNL/TM-9323. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Lowe, T. P., T. W. May, W. G. Brumbaugh, and D. A. Kane. 1985. National contaminant biomonitoring program: Concentrations of seven elements in freshwater fish, 1978–1981. Arch. Environ. Contam. Toxicol. 14:363–388.

Mackenthun, K. M. 1973. Toward a Cleaner Aquatic Environment. U.S. Government Printing Office, Washington, D.C.

Martin Marietta Energy Systems, Inc. 1985. Environmental monitoring report, United States Department of Energy, Oak Ridge facilities, calendar year 1984. ORNL-6209. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Martin Marietta Energy Systems, Inc. 1986. Environmental surveillance of the Oak Ridge Reservation and surrounding environs during 1985. ORNL-6721. Oak Ridge National Laboratory, Oak Ridge, Tenn.

McCauley, L. L. 1986. Proposed ground-water monitoring plans for the Kerr Hollow and the Rogers Quarries. Y/SUB/85-00206C/4R1. Prepared by Geraughty and Miller, Inc. for the Oak Ridge Y-12 Plant, April 1986. Oak Ridge, Tenn.

Murphy, J. L. 1988. RCRA facility investigation plan filled coal ash pond (D-112) Oak Ridge Y-12 Plant Oak Ridge, Tennessee. Y/TS-411. Oak Ridge Y-12 Plant, Oak Ridge, Tenn.

Murphy, J. L., and J. M. Loar. 1988. Expanded RCRA facility investigation plan McCoy Branch Oak Ridge Y-12 Plant Oak Ridge, Tennessee. Y/TS-488. Oak Ridge Y-12 Plant, Oak Ridge, Tenn.

Pielou, E. C. 1977. Mathematical Ecology. John Wiley, New York.

Platts, W. S., Megahan, W. F., and Minshall, G. W. 1983. Methods for evaluating stream, riparian, and biotic conditions. U.S. Forest Service General Technical Report INT-138. Intermountain Forest and Range Experimental Station, Ogdon, Utah.

Pulliam, P. J. 1985a. Water quality data for 34 sites, April and June 1984, near the Y-12 Plant, the Oak Ridge Reservation, Tennessee. USGS 85-165. Nashville, Tenn.

Pulliam, P. J. 1985b. Water quality data for 35 sites, September 1984, near the Y-12 Plant, the Oak Ridge Reservation, Tennessee. USGS 85-553. Nashville, Tenn.

Railsback, S. F., B. D. Holcomb, and M. G. Ryon. 1989. A computer program for estimating fish population sizes and annual production rates. ORNL/TM-11061. Oak Ridge National Laboratory, Oak Ridge Tenn.

RFI. 1987. RCRA Facility Investigation (RFI) guidance. Vol. III. Air and surface water releases. EPA 530/SW-87-001. Waste Management Division, Office of Solid Waste, U.S. Environmental Protection Agency, Washington, D.C.

Rogers, J. G., K. L. Daniels, S. T. Goodpasture, C. W. Kimbrough, and E. W. Whitfield. 1988. Environmental surveillance of the U.S. Department of Energy Oak Ridge Reservation and surrounding environs during 1987, Vol. 1: Narrative, summary and conclusions. ES/ESH-4/V1. Environmental and Safety Activities, Martin Marietta Energy Systems, Inc., Oak Ridge, Tenn.

Rogers, J. G., K. L. Daniels, S. T. Goodpasture, C. W. Kimbrough, and N. L. Prince. 1989. Oak Ridge Reservation Environmental Report for 1988, Vol. 1: Narrative, Summary and conclusions. ES/ESH-8/V1. Environmental and Safety Activities, Martin Marietta Energy Systems, Inc., Oak Ridge, Tenn.

Ross, M. J. and G. R. Ultsch. 1980. Temperature and substate influence on habitat selection in two pleurocerid snails (*Goniobasis*). Am. Midl. Nat. 103:209–217.

Rudd, J. W. M., M. A. Turner, B. E. Townsend, A. Swick, and A. Furutani. 1980. Dynamics of selenium in mercury-contaminated experimental freshwater ecosystems. Can. J. Fish. Aquat. Sci. 37:848–857.

Ryon, M. G., and J. M. Loar. 1988. A checklist of fishes on the Department of Energy Oak Ridge Reservation. J. Tenn. Acad. Sci. 58(4):97–102.

SAS Institute, Inc. 1985a. SAS User's Guide: Basics, Version 5 edition. Sas Institute, Inc., Cary, N.C.

SAS Institute, Inc. 1985b. SAS User's Guide: Statistics, Version 5 edition. SAS Institute, Inc., Cary, N.C.

Smith, J. G. 1991a. Benthic macroinvertebrates. In J. M. Loar, (ed.), First annual report on the Y-12 Plant Biological Monitoring and Abatement Program. ORNL/TM-10861. Oak Ridge National Laboratory, Oak Ridge, Tenn. (in press).

Smith, J. G. 1991b. Benthic macroinvertebrates. In G. R. Southworth, (ed.), Ecological effects of contaminants and remedial actions in Bear Creek. ORNL/TM-10370. Oak Ridge National Laboratory, Oak Ridge, Tenn. (in press).

Sorensen, E. M. B., and T. L. Bauer. 1983. Hematological dyscrasia in teleosts chronically exposed to selenium-laden effluent. Arch. Environ. Contam. Toxicol. 12:135–141.

Sorensen, E. M. B., P. M. Cumbie, T. L. Bauer, J. S. Bell, and C. W. Harlan. 1984. Histopathological, hematological, condition factor, and organ weight changes associated with selenium accumulation in fish from Belews Lake, North Carolina. Arch. Environ. Contam. Toxicol. 13:153–162.

Southworth, G. R. 1991. Accumulation of contaminants by biota in East Fork Poplar Creek. In J. M. Loar, (ed.), First annual report on the Y-12 Plant Biological Monitoring and Abatement Program. ORNL/TM-10861. Oak Ridge National Laboratory, Oak Ridge, Tenn. (in press).

Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics, 2nd Ed. McGraw-Hill, New York.

Stewart, A. J. 1990. Monitoring of conservative water quality factors in ORNL streams may be operationally advantageous. In Environmental Sciences Division Annual Progress Report for Period Ending September 30, 1989. ORNL-6602. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Stewart, A. J., L. A. Kszos, B. C. Harvey, L. F. Wicker, G. J. Haynes, and R. D. Bailey. 1990. Ambient toxicity dynamics: Assessments using *Ceriodaphnia dubia* and fathead minnow (*Pimephales promelas*) larvae in short-term tests. Environ. Tox. Chem. 9:367–379.

TDPH (Tennessee Department of Public Health). 1978. Water quality management plan for the Clinch River Basin. Division of Water Quality Control, Tennessee Department of Public Health, Nashville, Tenn.

TVA (Tennessee Valley Authority). 1985. Instream contaminant study, Task 4: Fish sampling and analysis. Report to U.S. Department of Energy, Oak Ridge Operations Office. Tennessee Valley Authority, Office of Natural Resources and Economic Development, Knoxville, Tenn.

Turner, M. A., and J. W. M. Rudd. 1983. The English-Wabigoon River system: III. Selenium in lake enclosures: Its geochemistry, bioaccumulation, and ability to reduce mercury bioaccumulation. Can. J. Fish. Aquat. Sci. 40:2228–2240.

Turner, M. A., and A. L. Swick. 1983. The English-Wabigoon River system: IV. Interaction between mercury and selenium accumulated from waterborne and dietary sources by northern pike (*Esox lucius*). Can. J. Fish. Aquat. Sci. 40:2241–2250.

Turner, R. R., M. A. Bogle, M. A. Kane, and T. M. Mercer. 1986. Characterization of Y-12 Plant coal ash discharge to McCoy Branch. Y/TS-177. Oak Ridge Y-12 Plant, Oak Ridge, Tenn.

EPA (U. S. Environmental Protection Agency). 1976. Quality Criteria for Water. EPA 440/9-76-023, U. S. Environmental Protection Agency, Washington, D.C.

EPA (U. S. Environmental Protection Agency). 1986. Test methods for evaluating solid waste. SW 846, 3d ed. Office of Solid Waste and Emergency Response, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1990. Region IV toxic substances spreadsheet. U. S. EPA, Region IV, Atlanta, Georgia. July 1990. Unpublished mimeo, 8 pp.

Ward, J. V. and J. A. Stanford (eds.). 1979. The Ecology of Regulated Streams. Plenum Press, New York.

Weber, C. I. (ed.). 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. EPA 670/4-73-001. National Environmental Research Center, U.S. Environmental Protection Agency, Cincinnati.

Weber, C. I., W. H. Peltier, T. J. Norberg-King, W. B. Horning, F. A. Kessler, J. R. Mendedick, T. W. Neiheisel, P. A. Lewis, D. J. Klemm, Q. H. Pickering, E. L. Robinson, J. M. Lazorchak, L. J. Wymer, and R. W. Freyberg. 1989. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms. EPA/600/4-89/001, Environmental Monitoring Systems Laboratory, Cincinnati.

Wiederholm, T. 1984. Responses of aquatic insects to environmental pollution. pp. 508–557. In V. H. Resh and D. M. Rosenberg, (eds.), The ecology of aquatic insects. Praeger Publishers, New York.

APPENDIX A

WATER QUALITY DATA FOR MCCOY BRANCH WATERSHED FOR 1974–1990

Table A-1. Water quality data collected in 1984 for two sites in the McCoy Branch watershed[a]

Parameter	April & June 1984 Upstream site	April & June 1984 Downstream site	Sept. 1984 Downstream site
Alkalinity, lab (mg/L as $CaCO_3$)	143	111	NA
Alkalinity, field (mg/L as $CaCO_3$)	NA	NA	78
Arsenic, total (μg/L as As)	NA	NA	110
Barium, total recoverable (μg/L as Ba)	100	100	100
Beryllium, total recoverable (μg/L as Be)	<10	<10	<10
Cadmium, total recoverable (μg/L as Cd)	<1	<1	<1
Calcium, dissolved (mg/L as Ca)	41	40	32
Carbon, organic total (mg/L as C)	0.40	0.70	NA
Carbon, organic dissolved (mg/L as C)	NA	NA	2.7
Chloride, dissolved (mg/L as Cl)	2.7	3.8	3.6
Chromium, Total recoverable (μg/L as Cr)	3	7	<1
Cobalt, total recoverable (μg/L as Co)	NA	NA	<1
Cobalt, total recoverable (μg/L)	10	1	NA
Copper, total recoverable (μg/L as Cu)	1	4	1
Cyanide, total (mg/L as CN)	<0.01	<0.01	<0.01
Gross Beta, dissolved (pCi/L as Cs-137)	NA	<2.6	2.6
Gross Alpha, susp. total (μg/L as U-NAT)	NA	2.4	0.8
Gross Beta, susp. total (pCi/L as Cs-137)	NA	1.9	0.7
Gross Beta, dissolved (pCi/L as Sr/Y-90)	NA	<2.2	2.2
Gross Alpha, dissolved (μg/L as U-NAT)	NA	<4.6	<4.3
Gross Beta, susp. total (pCi/L as Sr/Y-90)	NA	1.7	0.6
Instantaneous discharge (L/s)	7.7	87.8	50.9
Iron, total recoverable (μg/L as Fe)	1600	290	390
Lead, total recoverable (μg/L as Pb)	5	5	3
Lithium, total recoverable (μg/L as Li)	90	90	70
Magnesium, dissolved (mg/L as Mg)	13	9.7	7
Manganese, total recoverable (μg/L as Mn)	1000	50	20
Mercury, total recoverable (μg/L as Hg)	<0.1	<0.1	<0.1
Molybdenum, total recoverable (μg/L as Mo)	11	32	35
Nickel, total recoverable (μg/L as Ni)	NA	NA	1
Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	0.100	<0.1	3.2
Nitrogen, ammonia + organic total (mg/L as N)	NA	NA	0.50
Nitrogen, ammonia dissolved (mg/L as N)	NA	NA	<0.01
Oxygen, dissolved (mg/L)	NA	12.6	9.5
Phosphorus, dissolved (mg/L as P)	0.030	0.080	<0.01
Phosphorus, ortho-dissolved (mg/L as P)	NA	NA	0.02
Phosphorus, total (mg/L as P)	NA	NA	0.04
Potassium, dissolved (mg/L as Na)	4.5	3.1	3.2
Selenium, total (μg/L as Se)	NA	NA	8
Sodium, dissolved (mg/L as Na)	2.5	3.3	3.3
Solids residue at 180 °C, dissolved (mg/L)	231	204	166

Table A-1 (Continued)

Parameter	April & June 1984 Upstream site	April & June 1984 Downstream site	Sept. 1984 Downstream ste
Specific conductance (μS/cm)	360	324	250
Strontium, total recoverable (μg/L as Sr)	770	230	250
Sulfate, dissolved (mg/L as SO_4)	34	48	50
Temperature(°C)	12.5	12.0	19.0
Uranium, natural dissolved (μg/L as U)	1.0	2.5	2.2
Vanadium, dissolved (μg/L as V)	<1	30	23
Zinc, total recoverable (μg/L as Zn)	20	20	10

[a]The upstream site is located between the ash pond and Rogers Quarry. The downstream site is located below Rogers Quarry. Data for some sites were not available (NA). *Sources*: P. J. Pullium (1985a and 1985b).

Table A-2. Water analyses for McCoy Branch, November 1974–March 1975[a]

Parameter	Sample month/station						
	Nov 1	Nov 2	Nov 2	Dec C	Dec 2	Jan 2	Mar 2
Temp (°C)	11	10	12	12	10	9	9
Turbidity[b]			5.0	15.0	6.0	12.0	9.5
Sus solids	17500	13	27	100	37	40	22
Dis solids	253	182	159	101	130	188	118
Dis oxygen	6.4	9.1	7.2	10.5	10.6	9.2	11.2
pH	7.53	7.74	7.39	6.73	7.43	7.65	8.02
Alkalinity	48	80	82	81	55	6	
Hardness[c]	151	126	121	81	90	113	101
Al - Dis	0.15	<0.05	<0.05			<0.05	<0.05
Al - Sus	171.0	0.24	0.52			0.49	0.20
Cd - Dis	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cd - Sus	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cr - Dis	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr - Sus	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu - Dis	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Cu - Sus	0.500	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Mn - Dis	0.020	0.010	0.020	<0.010	0.019	0.015	
Mn - Sus	0.580	<0.010	<0.010	0.055	0.010	0.018	
Pb - Dis	<0.010	<0.010	0.020	0.017	0.021	0.010	<0.010
Pb - Sus	0.16	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn - Dis			0.07			0.07	
Zn - Sus			<0.02			<0.02	
Hg	0.008	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
U			<0.01	<0.01	<0.01	<0.01	<0.01
NO_3			<1.0	1.4	0.7	<0.9	2.4

Table A-2 (Continued)

Parameter	Nov 1	Nov 2	Nov 2	Dec C	Dec 2	Jan 2	Mar 2
	Sample month/station						
PO_4			1.1	2.0	2.2	1.0	1.3
SO_4				30	94	60	32
B	0.10	0.06	0.06	0.10	0.15	0.06	0.06
Ba	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Ca	6	6	6	10	2	3	6
K	1.0	0.4	0.4	<0.2	<0.2	0.6	0.4
Mg	1.0	1.0	1.0	2.0	0.4	1.8	1.5
Na	0.50	0.20	<0.01	0.15	0.08	<1.00	0.30
Ni	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Si	0.20	3.00	0.40	1.00	0.15	0.40	0.40

[a]Stations 1 (200 m above Rogers Quarry), 2 (200 m below the quarry) and C (Control site on western branch of McCoy Branch). Dis = dissolved; Sus = suspended; all parameters in mg/L. *Source*: ERDA 1975.

[b]Turbidity as SiO_2.

[c]Hardness as $CaCO_3$.

Table A-3. Concentrations (mean values) and mass loadings of nonmetal pollutants. 'Less than' prefixes have been ignored in calculating mean concentration values. *Source*Turner et al. 1986

Nonmetals	Intake water		MBK 1.17 (Ash sluice)[a]		Spring	
	Concentration (mg/L)	Mass (lb/d)	Concentration (mg/L)	Mass (lb/d)	Concentration (mg/L)	Mass (lb/d)
Ammonia nitrogen	0.100	0.690	0.15	1.0	0.100	0.080
Biological oxygen demand (BOD)	5.000	34.500	6.00	41.4	5.000	3.984
Bromide	1.000	6.900	1.00	6.9	1.000	0.797
Chemical oxygen demand (COD)	6.333	43.700	4.90	33.8	3.000	2.390
Chloride	6.730	46.437	6.33	43.7	4.026	3.208
Chlorine, total residual	1.150	7.935	0.07	0.5	0.000	0.000
Cyanide, total	0.002	0.011	0.00	0.0	0.001	0.001
Fluoride	0.500	3.450	1.05	7.3	0.500	0.398
Nitrate-nitrite nitrogen	0.330	2.277	0.15	1.1	0.010	0.008
Oil and grease	2.000	13.800	2.44	16.9	2.250	1.793
Phenols, total	0.001	0.007	0.00	0.0	0.001	0.001
Phosphorus, total (as P)	0.240	1.656	16.75	115.6	0.380	0.303
Sulfate (as SO_4)	26.333	181.700	253.90	1751.9	57.600	45.896
Sulfide (as S)	0.133	0.920	22.24	153.5	0.100	0.080
Sulfide (HACH HS-7)	0.000	0.000	0.00	0.0	0.000	0.000
Sulfite (as SO_3)	0.500	3.450	0.43	3.0	0.400	0.319
Total alkalinity	108.333	747.500	40.00	276.0	135.000	107.568
Total kjeldahl nitrogen	0.220	1.518	0.98	6.8	0.200	0.159
Total suspended solids	18.667	128.800	9919.20	68442.5	39.400	31.394
Total organic carbon (TOC)	1.600	11.040	0.50	2.7	0.500	0.398

[a]Site is equivalent to MCK 2.65.

Table A-4. Concentrations (mean values) and mass loadings of total metals. 'Less than' prefixes have been ignored in calculating mean concentration values.
Source: Turner et al. 1986

Total metals	Intake water		MBK 1.17 (Ash sluice)[a]		Spring	
	Concentration (mg/L)	Mass (lb/d)	Concentration (mg/L)	Mass (lb/d)	Concentration (mg/L)	Mass (lb/d)
Aluminum	0.1000	0.690	310.000	2139.00	0.0200	0.0159
Antimony	0.0200	0.138	0.280	1.93	0.0200	0.0159
Arsenic (AAS)	0.0050	0.034	4.933	34.04	0.0300	0.0239
Barium	0.0440	0.304	0.533	3.68	0.0740	0.0590
Beryllium	0.0002	0.001	0.057	0.40	0.0002	0.0002
Boron	0.0080	0.055	1.500	10.35	0.3300	0.2629
Cadmium	0.0005	0.003	0.010	0.07	0.0005	0.0004
Calcium	35.0000	241.500	142.667	984.40	48.0000	38.2464
Chromium	0.0040	0.028	0.253	1.75	0.0040	0.0032
Cobalt	0.0010	0.007	0.141	0.98	0.0032	0.0025
Copper	0.0350	0.241	0.983	6.78	0.0020	0.0016
Gallium	0.0300	0.207	0.420	2.90	0.0300	0.0239
Iron	0.3300	2.277	133.333	920.00	0.4300	0.3426
Lead	0.0200	0.138	0.367	2.53	0.0200	0.0159
Lithium	0.0250	0.172	2.533	17.48	0.3000	0.2390
Magnesium	9.1000	62.790	32.667	225.40	14.0000	11.1552
Manganese	0.0360	0.248	0.903	6.23	0.5300	0.4223
Mercury (AAS)	NM[b]	NM	0.009	0.06	0.0001	0.0001
Molybdenum	0.0040	0.028	0.167	1.15	0.0100	0.0080
Nickel	0.0060	0.041	0.353	2.44	0.0060	0.0048
Potassium	1.7000	11.730	43.500	300.15	6.2000	4.9402
Selenium (AAS)	0.0050	0.034	0.243	1.68	0.0050	0.0040
Silicon	1.9000	13.110	2.417	16.67	4.4000	3.5059
Silver	0.0050	0.034	0.087	0.60	0.0050	0.0040
Sodium	8.6000	59.340	20.000	138.00	6.8000	5.4182
Strontium	0.0670	0.462	7.900	54.51	0.9100	0.7251
Thallium (AAS)	0.0010	0.007	0.120	0.83	0.0010	0.0008
Tin	0.0050	0.034	0.105	0.72	0.0050	0.0040
Titanium	0.0020	0.014	8.033	55.43	0.0044	0.0035
Uranium	0.0100	0.069	0.010	0.07	0.0100	0.0080
Vanadium	0.0024	0.017	1.647	11.36	0.0024	0.0019
Zinc	0.0020	0.014	0.453	3.13	0.0020	0.0016
Zirconium	0.0020	0.014	0.091	0.63	0.0020	0.0016

[a]Site is equivalent to MCK 2.65.
[b]NM = not measured.

Table A-5. Concentrations (mean values) and mass loadings of total recoverable metals. 'Less than' prefixes have been ignored in calculating mean concentration values. *Source:* Turner et al. 1986

Total recoverable metals	Intake water		MBK 1.17 (Ash sluice)[a]		Spring	
	Concentration (mg/L)	Mass (lb/d)	Concentration (mg/L)	Mass (lb/d)	Concentration (mg/L)	Mass (lb/d)
Aluminum	0.1905	1.314	228.857	1579.11	0.1607	0.1281
Antimony	0.1100	0.759	0.187	1.29	0.1100	0.0876
Arsenic (AAS)	0.0050	0.034	2.971	20.50	0.0265	0.0211
Barium	0.0300	0.207	3.086	21.29	0.0722	0.0576
Beryllium	0.0011	0.008	0.038	0.26	0.0015	0.0012
Boron	0.0440	0.304	1.814	12.52	0.2750	0.2191
Cadmium	0.0027	0.019	0.005	0.03	0.0040	0.0032
Calcium	37.0000	255.300	151.429	1044.86	45.5000	36.2544
Chromium	0.0220	0.152	0.224	1.55	0.0317	0.0252
Cobalt	0.0055	0.038	0.098	0.68	0.0080	0.0064
Copper	0.0133	0.092	0.720	4.97	0.0155	0.0124
Gallium	0.1650	1.138	0.280	1.93	0.1650	0.1315
Iron	0.2250	1.552	141.571	976.84	0.5275	0.4203
Lead	0.1100	0.759	0.263	1.81	0.1550	0.1235
Lithium	0.1100	0.759	2.650	18.28	0.2050	0.1633
Magnesium	9.7000	66.930	29.714	205.03	13.5000	10.7568
Manganese	0.0755	0.521	0.616	4.25	0.4825	0.3845
Mercury (AAS)	0.0001	0.001	0.010	0.07	0.0001	0.0001
Molybdenum	0.0220	0.152	0.233	1.61	0.0323	0.0257
Nickel	0.0330	0.228	0.260	1.79	0.0465	0.0371
Potassium	1.8000	12.420	60.400	416.76	4.9750	3.9641
Selenium (AAS)	0.0050	0.034	0.189	1.30	0.0050	0.0040
Silicon	0.8600	5.934	19.214	132.58	5.2350	4.1712
Silver	0.0275	0.190	0.047	0.33	0.0387	0.0309
Sodium	6.2000	42.780	33.143	228.69	4.1500	3.3067
Strontium	0.1025	0.707	5.033	34.73	0.9700	0.7729
Thallium (AAS)	0.0010	0.007	0.057	0.39	0.0010	0.0008
Tin	0.0275	0.190	0.047	0.32	0.0275	0.0219
Titanium	0.0110	0.076	5.767	39.79	0.0110	0.0088
Uranium	0.0100	0.069	0.023	0.16	0.0550	0.0438
Vanadium	0.0061	0.042	1.321	9.12	0.0080	0.0064
Zinc	0.0170	0.117	0.396	2.73	0.0169	0.0135
Zirconium	0.0110	0.076	0.061	0.42	0.0110	0.0088

[a]Site is equivalent to MCK 2.65.

Table A-6. Concentrations (mean values) and mass loadings of total dissolved metals. 'Less than' prefixes have been ignored in calculating mean concentration values. *Source:* Turner et al. 1986

Total dissolved metals	Intake water		MBK 1.17 (Ash sluice)[a]		Spring	
	Concentration (mg/L)	Mass (lb/d)	Concentration (mg/L)	Mass (lb/d)	Concentration (mg/L)	Mass (lb/d)
Aluminum	0.200	1.380	0.8667	5.980	0.200	0.1594
Antimony	0.200	1.380	0.2000	1.380	0.200	0.1594
Arsenic (AAS)	0.005	0.034	0.3567	2.461	0.020	0.0159
Barium	0.034	0.235	0.1767	1.219	0.082	0.0653
Beryllium	0.002	0.014	0.0020	0.014	0.002	0.0016
Boron	0.080	0.552	0.9733	6.716	0.400	0.3187
Cadmium	0.005	0.034	0.0050	0.034	0.005	0.0040
Calcium	37.000	255.300	89.6667	618.700	55.000	43.8240
Chromium	0.040	0.276	0.0400	0.276	0.040	0.0319
Cobalt	0.010	0.069	0.0100	0.069	0.010	0.0080
Copper	0.020	0.138	0.0200	0.138	0.020	0.0159
Gallium	0.300	2.070	0.3000	2.070	0.300	0.2390
Iron	0.200	1.380	0.2000	1.380	0.200	0.1594
Lithium	0.200	1.380	1.4200	9.798	0.200	0.1594
Magnesium	11.000	75.900	12.3333	85.100	16.000	12.7488
Manganese	0.005	0.034	0.0203	0.140	0.480	0.3825
Mercury (AAS)	NM[b]	NM	NM	NM	NM	NM
Molybdenum	0.040	0.276	0.2033	2.093	0.040	0.0319
Nickel	0.060	0.414	0.0600	0.414	0.060	0.0478
Potassium	1.700	11.730	17.0000	117.300	5.400	4.3027
Selenium (AAS)	0.005	0.034	0.0227	0.156	0.005	0.0040
Silicon	1.200	8.280	1.5667	10.810	7.700	6.1354
Silver	0.050	0.345	0.0500	0.345	0.050	0.0398
Sodium	7.300	50.370	15.6667	108.100	3.900	3.1075
Strontium	0.120	0.828	0.8167	5.635	1.000	0.7968
Thallium (AAS)	0.001	0.007	0.0010	0.007	0.001	0.0008
Tin	0.050	0.345	0.0500	0.345	0.050	0.0398
Titanium	0.020	0.138	0.0200	0.138	0.020	0.0159
Uranium	0.010	0.069	0.0100	0.069	0.010	0.0080
Vanadium	0.010	0.069	0.0873	0.603	0.011	0.0088
Zinc	0.020	0.138	0.0200	0.138	0.020	0.0159
Zirconium	0.020	0.138	0.0200	0.138	0.020	0.0159

[a] Site is equivalent to MCK 2.65.
[b] NM = not measured.

Table A-7. Sample types and locations for surface water, groundwater, coal ash, and floodplain sediment samples of McCoy Branch, July 30–October 17, 1990.
Source: CH2M Hill, personal communication

Dry Weather Surface Water Sampling, July 30, 1990		
Sample No.	Approximate stream location	Sample type
S3	MCK 2.62	Environmental - Aqueous
S4	MCK 2.52	Environmental - Aqueous
S5	MCK 1.92	Environmental - Aqueous
S6	MCK 1.92	Duplicate of S5

Wet Weather Water Sampling, October 8, 1990[a]		
Sample No.	Approximate stream location	Sample type
WW-S1	MCK 1.92	Environmental - Aqueous
WW-S3	MCK 2.62	Environmental - Aqueous
WW-S4	MCK 2.52	Environmental - Aqueous
WW-S6	---	Field Blank - Aqueous
WW-S7	---	Equipment Blank - Aqueous

Groundwater sampling			
Sample No.	Location	Approximate stream location[b]	Sample date
5000	GW-321	MCK 2.62	16 OCT 90
5001	GW-672	MCK 2.61	15 OCT 90
5002	GW-673	MCK 2.40	16 OCT 90
5003	GW-674	MCK 2.38	16 OCT 90
5004	GW-676	MCK 2.14	17 OCT 90
5005	GW-676	MCK 2.14	17 OCT 90
5006	GW-676	MCK 2.14	17 OCT 90
5007	GW-672	MCK 2.61	15 OCT 90

Table A-7 (Continued)

Ash/Soil Sampling				
Sample No.	Location	Approximate stream location[b]	Sample type[c]	
A1-S1	A1	MCK 2.38	Environmental Soil	(0-6" BL)
A1-S2	A1	MCK 2.38	Environmental Soil	(6-12" BL)
A2-A	A2	MCK 2.62	Environmental Soil	(ASH)
A2-S1	A2	MCK 2.62	Environmental Soil	(0-6" BA)
A3-A	A3	MCK 2.52	Environmental Soil	(ASH)
A3-S1	A3	MCK 2.52	Environmental Soil	(0-6" BA)
A3-S2	A3	MCK 2.52	Environmental Soil	(6-12" BA)
A4-A	A4	MCK 2.40	Environmental Soil	(ASH)
A4-S1	A4	MCK 2.40	Environmental Soil	(0-6" BA)
A4-S2	A4	MCK 2.40	Environmental Soil	(6-12" BA)
A5-A	A5	MCK 2.10	Environmental Soil	(ASH)
A5-S1	A5	MCK 2.10	Environmental Soil	(0-6" BA)
A5-S2	A5	MCK 2.10	Environmental Soil	(6-12" BA)
A6-A	A6	MCK 1.97	Environmental Soil	(ASH)
A6-S1	A6	MCK 1.97	Environmental Soil	(0-6" BA)
A6-S2	A6	MCK 1.97	Environmental Soil	(6-12" BA)
A7-A	A3	MCK 2.52	Environmental Soil	(ASH)
A7-S1	A3	MCK 2.52	Environmental Soil	(0-6" BA)
A7-S2	A3	MCK 2.52	Environmental Soil	(6-12" BA)

[a]Wet weather sample taken after a 4.5-cm rain event, measured at the gage at Rogers Quarry.

[b]Location in terms of stream kilometers; actual sample sites are located in floodplain and may be several meters east or west from stream kilometer.

[c]BA = Below ash; BL = Below land.

Table A-8. Concentrations of volatile organic compounds measured in surface water samples of McCoy Branch, July 30, 1990.
Source: CH2M Hill, personal communication

Compound (μg/L)	Site			
	MCK 2.62	MCK 2.52	MCK 1.92	MCK 1.92[a]
1,1-Dichloroethane	5	5	5	5
1,1-Dichloroethene	5	5	5	5
1,1,1-Trichloroethane	5	5	5	5
1,1,2-Trichloroethane	5 UJ[b]	5 UJ	5 UJ	5 UJ
1,1,2,2-Tetrachloroethane	5	5	5	5
1,2-Dichloroethane	5	5	5	5
1,2-Dichloroethane-d4[c]	49.5	48.5	49.1	49.2
1,2-Dichloroethene (Total)	5	5	5	5
1,2-Dichloropropane	5	5	5	5
2-Butanone	10	10	10	10
2-Hexanone	10	10	10	10
4-Methyl-2-Pentanone	10	10	10	10
Acetone	7 UJ	6 UJ	19 UJ	5 UJ
Benzene	5	5	5	5
Bromodichloromethane	5	5	5	5
Bromofluorobenzene[c]	53.9	57.4	53.6	52.5
Bromoform	5 UJ	5 UJ	5 UJ	5 UJ
Bromomethane	10	10	10	10
Carbon disulfide	5	5	5	5
Carbon tetrachloride	5	5	5	5
Chlorobenzene	5	5	5	5
Chloroethane	10	10	10	10
Chloroform	5	5	5	5
Chloromethane	10	10	10	10
cis-1,3-Dichloropropene	5 UJ	5 UJ	5 UJ	5 UJ
Dibromochloromethane	5 UJ	5 UJ	5 UJ	5 UJ
Ethylbenzene	5	5	5	5
Methylene chloride	5	5	5	5
Styrene	5	5	5	5
Tetrachloroethene	5	5	5	5
Toluene	5	5	5	5
Toluene-d8[c]	54.4	54.9	53.8	53.5
Total xylenes	5	5	5	5
trans-1,3-Dichloropropene	5 UJ	5 UJ	5 UJ	5 UJ

Table A-8 (Continued)

Compound (μg/L)	Site			
	MCK 2.62	MCK 2.52	MCK 1.92	MCK 1.92[a]
Trichloroethene	5	5	5	5
Vinyl chloride	10	10	10	10
Vinyl acetate	2 UJ	2 UJ	2 UJ	2 UJ

[a]Duplicate samples.
[b]J = estimated value; U = undetected—below method detection level.
[c]Tentatively identified compounds.

Table A-9. Concentrations of semivolatile organic compounds measured in surface water samples from McCoy Branch, July 30, 1990.
Source: CH2M Hill, personal communication

Compound (μg/L)	MCK 2.62	MCK 2.52	MCK 1.92	MCK 1.92[a]
1,2-Dichlorobenzene	10	10 UJ[b]	10 UJ	10 UJ
1,2,4-Trichlorobenzene	10 U	10 UJ	10 UJ	10 UJ
1,3-Dichlorobenzene	10 U	10 UJ	10 UJ	10 UJ
1,4-Dichlrobenzene	10	10 UJ	10 UJ	10 UJ
2-Chloronaphthalene	10 U	10 UJ	10 UJ	10 UJ
2-Chlorophenol	R[b]	R	10 UJ	10 UJ
2-Methylnaphthalene	10 U	10 UJ	10 UJ	10 UJ
2-Methylphenol	R	R	10 UJ	10 UJ
2-Nitroaniline	50	50 UJ	50 UJ	50 UJ
2-Nitrophenol	R	R	10 UJ	10 UJ
2,4-Dichlorophenol	R	R	10 UJ	10 UJ
2,4-Dimethylphenol	R	R	10 UJ	10 UJ
2,4-Dinitrophenol	R	R	50 UJ	50 UJ
2,4-Dinitrotoluene	10	10 UJ	10 UJ	10 UJ
2,4,5-Trichlorophenol	R	R	50 UJ	50 UJ
2,4,6-Trichlorophenol	R	R	10 UJ	10 UJ
2,6-Dinitrotoluene	10 U	10 UJ	10 UJ	10 UJ
3-Nitroaniline	50 U	50 UJ	50 UJ	50 UJ
3,3'-Dichlorobenzidine	20	20 UJ	20 UJ	20 UJ
4-Bromophenyl-phenylether	10	10 UJ	10 UJ	10 UJ
4-Chloro-3-methylphenol	R	R	10 UJ	10 UJ
4-Chloroaniline	10	10 UJ	10 UJ	10 UJ
4-Chlorophenyl-phenylether	10	10 UJ	10 UJ	10 UJ
4-Methylphenol	R	R	10 UJ	10 UJ
4-Nitroaniline	50	50 UJ	50 UJ	50 UJ
4-Nitrophenol	R	R	50 UJ	50 UJ
4,6-Dinitro-2-methylphenol	R	R	50 UJ	50 UJ
Acenaphthene	10 U	10 UJ	10 UJ	10 UJ
Acenaphthylene	10	10 UJ	10 UJ	10 UJ
Anthracene	10	10 UJ	10 UJ	10 UJ
Benzo(a)pyrene	10	10 UJ	10 UJ	10 UJ
Benzo(a,h)anthracene	10	10 UJ	10 UJ	10 UJ
Benzo(b)fluoranthene	10	10 UJ	10 UJ	10 UJ
Benzo(g,h,i)perylene	10	10 UJ	10 UJ	10 UJ
Benzo(k)fluoranthene	10	10 UJ	10 UJ	10 UJ

Table A-9 (Continued)

Compound (μg/L)	MCK 2.62	MCK 2.52	MCK 1.92	MCK 1.92[a]
Benzoic Acid	R	R	50 UJ	50 UJ
Benzyl Alcohol	10	10 UJ	10 UJ	10 UJ
bis(2-Chloroethoxy)methane	10 U	10 UJ	10 UJ	10 UJ
bis(2-Chloroethyl) Ether	10 U	10 UJ	10 UJ	10 UJ
bis(2-chloroisopropyl)ether	10 UJ	10 UJ	10 UJ	10 UJ
bis(2-Ethylhexyl)phthalate	10 UJ	10 UJ	10 UJ	10 UJ
Butylbenzylphthalate	10 UJ	10 UJ	10 UJ	10 UJ
Chrysene	10 UJ	10 UJ	10 UJ	10 UJ
Di-n-butylphthalate	10 UJ	10 UJ	10 UJ	10 UJ
Di-n-octylphthalate	10 UJ	27 J	10 UJ	10 UJ
Dibenz(a,h)anthracene	10 UJ	10 UJ	10 UJ	10 UJ
Dibenzofuran	10 UJ	10 UJ	10 UJ	10 UJ
Diethylphthalate	10 UJ	10 UJ	10 UJ	10 UJ
Dimethylphthalate	10 UJ	10 UJ	10 UJ	10 UJ
Fluoranthene	10 UJ	10 UJ	10 UJ	10 UJ
Fluorene	10 UJ	10 UJ	10 UJ	10 UJ
Hexachlorethane	10 UJ	10 UJ	10 UJ	10 UJ
Hexachlorobenzene	10 UJ	10 UJ	10 UJ	10 UJ
Hexachlorocyclobutadiene	10 UJ	10 UJ	10 UJ	10 UJ
Hexachlorocyclopentadiene	10 UJ	10 UJ	10 UJ	10 UJ
Hexane, 3-methoxy		4.87 UJ		
Indeno(1,2,3-cd)pyrene	10 UJ	10 UJ	10 UJ	10 UJ
Isophorone	10 UJ	10 UJ	10 UJ	10 UJ
N-Nitrose-Di-n-propylamine	10 UJ	10 UJ	10 UJ	10 UJ
N-Nitrosodiphenylamine (1)	10 UJ	10 UJ	10 UJ	10 UJ
Napthalene	10 UJ	10 UJ	10 UJ	10 UJ
Nitrobenzene	10 UJ	10 UJ	10 UJ	10 UJ
Pentachlorophenol	R	R	50 UJ	50 UJ
Phenanthrene	10 UJ	10 UJ	10 UJ	10 UJ
Phenol	R	R	10 UJ	10 UJ
Pyrene	10 UJ	10 UJ	10 UJ	10 UJ
Unknown	4.92 UJ	4.79 UJ	4.91 UJ	4.87 UJ
Unknown	7.06 UJ			9.33 UJ

[a]Duplicate sample taken at MCK 1.92.

[b]J = estimated value; R = rejected value; U = undetected—below method detection level.

Table A-10. Water quality data for surface water samples of McCoy Branch, July 30, 1990.
Source: CH2M Hill, personal communication

Parameter mg/L unless otherwise noted	MCK 2.62	MCK 2.52	MCK 1.92	MCK 1.92[a]
Alpha activity (pCi/L)	378.67 ± 67.2	352.13 ± 64.9	−143 ± 160 UJ	−1.27 ± 160 UJ
Beta activity (pCi/L)	936.17 ± 114.7	580.17 ± 99.6	−22.35 ± 350 U	−33.53 ± 330 U
Alkalinity	148	159	164	161
Chloride IC	3	2	2	2
Conductivity (μmho/cm)	340	339	335	334
Dissolved solids	180	180	168	174
Fluoride IC	0.2	0.2	0.2	0.2
Nitrate	<1 UJ[b]	<1 UJ	1 J	1 J
pH	7.4	7.8	7.9	8
Phenols	0.03 J	<0.03 UJ	<0.03 UJ	<0.03 UJ
Sulfate	24	26	14	14
Suspended solids	5	8	1	2
Total organic carbon (TOC)	<1	<1	<1	<1
Total organic halides (TOX) (μg/L)	10 J	<10 UJ	<10 UJ	16 J
Uranium-fluorometric	0.001	0.001	<0.001	<0.001

[a]Duplicate sample taken at MCK 1.92.
[b]J = estimated value; R = rejected value; U = undetected—below method detection level.

Table A-11. Concentrations of elements measured in surface water samples of McCoy Branch, July 30, 1990. Sites labeled -F are filtered samples.
Source: CH2M Hill, personal communication

Element (μg/L)	MCK 2.62	MCK 2.62-F	MCK 2.52	MCK 2.52-F	MCK 1.92	MCK 1.92-F	MCK 1.92[a]	MCK 1.92-F[a]
Aluminum	129 J[b]	32.0	39.4 J	38.2	39.4 J	38.2	48.7 J	50.5
Antimony	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Arsenic	84.8	32.0	21.0	19.9	2.1	2.1	2.1	2.1
Barium	60.6	65.6	49.6	48.9	78.5	78.2	70.2	77.9
Beryllium	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Cadmium	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Calcium	43900	43200	45500	44200	44700	45300	32300	44800
Chromium	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Cobalt	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Copper	4.0	7.1	4.0	4.5	4.1	4.9	4.0	4.0
Iron	1360	316	5.8	14.7 J	4.0	18.3 J	4.0	15.1 J
Lead	0.80 UJ	0.80 UJ	0.80 UJ	0.80	0.80 UJ	0.80	0.80 UJ	0.80 J
Magnesium	13600	13200	13500	12900	14700	14400	13600	14200
Manganese	513	1000	16.8	29.6	1.0	28.1	1.0	28.8
Mercury	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Nickel	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Niobium	7.0 UJ	7.0 UJ	7.0 UJ	8.5	7.9	7.0 UJ	7.0 UJ	7.0 UJ
Phosphorous	200 UJ	200 UJ	200 UJ	200 UJ	200 UJ	200 UJ	200 UJ	200 UJ
Potassium	4940	4430	4530	4450	2070	2130	2040	2000
Selenium	2.0 UJ	2.0 UJ	2.0 UJ	2.0	2.0 UJ	2.0	2.0 UJ	2.0
Silver	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Sodium	2780	2740	2920	3160	1850	1730	1690	1720
Vanadium	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Zinc	3.3 J	6.0 J	2.9 J	3.1 J	3.6 J	5.0 J	2.1 J	5.6 J

[a]Duplicate sample taken at MCK 1.92.
[b]J = estimated value; R = rejected value; U = undetected—below method detection level.

Table A-12. Water quality data for surface water samples of McCoy Branch, October 8, 1990, after a 4.5-cm rain event.
Source: CH2M Hill, personal communication

Parameter mg/L unless otherwise noted	MCK 2.62	MCK 2.52	MCK 1.92	Field Blank
Alpha activity (pCi/L)	−1.28 ± 3.5 UJ[a]	2.37 ± 4.0	−0.60 ± 3.6 UJ	0.69 ± 3.8 J
Beta activity (pCi/L)	−5.35 ± 7.3 UJ	−3.49 ± 7.4	3.03 ± 7.7 J	-8.61 ± 7.1 U
Alkalinity	155	152	171	2
Chloride IC	3	3	2	<1
Conductivity (μmho/cm)	342	340	350	1.2
Dissolved solids	226	214	194	<1
Flouride IC	0.1	0.1	0.2	<0.1
Nitrate	<1 UJ	<1 UJ	<1 UJ	<1 UJ
pH	7.63	8.15	7.99	6.55
Phenols	<0.03 UJ	<0.03 UJ	<0.03 UJ	<0.03 UJ
Sulfate	24	26	18	<1
Suspended solids	<1	<1	<1	<1
Total organic carbon (TOC)	<1	1	1	2
Total organic halides (TOX) (μg/L)	<10 UJ	<10 UJ	<10 UJ	<10 UJ
Uranium-fluorometric	0.001	0.001	<0.001	<0.001

[a]J = estimated value; R = rejected value; U = undetected—below method detection level.

Table A-13. Concentrations of elements measured in surface water samples of McCoy Branch, October 8, 1990, after a 4.5-cm rain event.
Source: CH2M Hill, personal communication

Element (μg/L)	MCK 2.62	MCK 2.62-F	MCK 2.52	MCK 2.52-F	MCK 1.92	MCK 1.92-F	Field blank	Equip blank
Aluminum	79.8 J[a]	48.7 J	76.7 J	26.9 J	76.7 J	61.1 J	33.2 J	20.0
Antimony	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Arsenic	35.4	20.9	20.8	23.9	2.4	2.4	2.1	2.1
Barium	71.7	67.2	53.4	48.9	84.1	82.8	1.3	1.3
Beryllium	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Cadmium	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Calcium	46700	45900	46100	45600	51200	50400	93.6 J	133
Chromium	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Cobalt	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Copper	4.0	4.0	4.0	4.0	8.9	4.0	4.0	4.0
Iron	550	97.3	170	4.0	122	60.8	4.0	4.0
Lead	0.80 UJ	0.80 UJ	0.80 UJ	0.80 UJ	0.80 UJ	0.80 UJ	0.80 UJ	0.80 UJ
Magnesium	14400	14100	13900	13700	14500	14200	12.2 J	11.6 J
Manganese	1090	940	204	1.0	53.3	47.4	1.0	2.2
Mercury	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Nickel	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Niobium	9.5 J	8.7 J	7.0 UJ	7.0 UJ	7.0 UJ	8.1 J	7.0 UJ	7.0 UJ
Phosphorous	200 UJ	200 UJ	200 UJ	200 UJ	200 UJ	200 UJ	200 UJ	200 UJ
Potassium	4700	4510	4720	4920	2410	2490	600	600
Selenium	2.0 UJ	2.0 UJ	2.0 UJ	2.0 UJ	2.0 UJ	2.0 UJ	2.0 UJ	2.0 UJ
Silver	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Sodium	2960	2800	2780	2890	2020	1890	248	274
Vanadium	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Zinc	7.0 J	5.4 J	15.3	4.7 J	9.1 J	5.1 J	2.4 J	6.3 J

[a]J = estimated value; R = rejected value; U = undetected—below method detection level.

Table A-14. Monthly means (standard deviation) and range (number of measurements) of water temperature (°C) in McCoy Branch (MCK), in upper White Oak Creek (WCK 6.8) and in upper Fifth Creek (FFK 1.0), two reference sites. Data were obtained with a Ryan TempMentor digital temperature recorder with values recorded every hour. NA=temperature data not available

Sampling Period		MCK 1.60		MCK 1.92		WCK 6.8		FFK 1.0	
Year	Month	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1989	December	9.53 (1.15)	7.5-11.5 (504)	9.71 (1.25)	6.7-12.3 (500)	8.76 (1.95)	3.9-12.7 (672)	NA	NA
1990	January	8.36 (0.58)	6.3-10.0 (744)	NA	NA	9.96 (0.94)	7.2-12.6 (744)	12.53 (0.39)	11.1-13.4 (192)
	February	10.38 (0.92)	8.1-12.6 (672)	NA	NA	10.25 (2.10)	2.2-15.2 (672)	12.71 (0.53)	11.5-14.0 (672)
	March	12.17 (1.62)	9.2-16.5 (744)	NA	NA	11.65 (1.22)	9.2-15.3 (744)	13.15 (0.63)	11.6-15.0 (744)
	April	13.64 (2.06)	10.3-19.6 (720)	NA	NA	12.76 (1.95)	8.6-18.1 (720)	13.57 (0.75)	11.8-15.4 (718)
	May	17.90 (1.57)	15.2-21.6 (696)	14.41 (1.01)	12.0-18.4 (696)	13.83 (0.89	11.6-16.3 (720)	15.66 (2.96)	8.1-24.1 (720)
	June	23.26 (1.97)	19.6-27.4 (720)	15.08 (0.73)	13.4-17.0 (720)	15.23 (1.07)	12.6-18.3 (720)	14.76 (0.63)	13.5-19.0 (720)
	July	26.40 (0.78)	24.0-28.9 (744)	15.89 (0.72)	14.7-19.8 (744)	16.24 (0.99)	14.4-19.3 (744)	15.22 (0.68)	14.4-20.0 (744)
	August	26.32 (0.82)	17.6-29.0 (744)	16.29 (0.90)	11.1-19.9 (744)	16.19 (0.78)	14.7-19.4 (744)	15.39 (0.66)	11.8-19.7 (744)
	September	24.67 (1.85)	20.2-28.1 (576)	15.87 (1.23)	12.6-18.7 (576)	15.76 (1.51)	11.6-18.8 (576)	15.02 (0.85)	12.6-18.4 (576)
	October	20.55 (2.15)	15.2-23.8 (744)	14.35 (1.69)	10.5-18.4 (744)	13.84 (2.07)	8.6-18.2 (744)	14.24 (1.11)	11.3-16.8 (744)
	November	15.04 (1.2)	12.8-17.8 (720)	12.27 (1.33)	9.4-15.9 (720)	11.37 (1.52)	8.0-15.9 (720)	13.14 (0.96)	10.2-16.1 (720)
	December	12.42 (0.63)	10.0-13.8 (453)	11.19 (1.09)	8.9-13.8 (453)	10.59 (1.20)	6.8-13.3 (454)	12.19 (0.99)	9.8-14.2 (455)

Table A-15. Sediment analyses for McCoy Branch, October 1974–January 1975. Stations 1 (200 m above Rogers Quarry), 2 (200 m below the quarry) and C (Control site on western branch of McCoy Branch. AA = Atomic absorption spectroscopy; units are μg/g. ES = emission spectroscopy; units are percent. *Source*: ERDA 1975

Parameter		Sample month/station					
		Oct 2	Nov 1 1	Nov 2	Dec C	Dec 2	Jan 1
Al	(AA)	11000	7300	4550			
Cd	(AA)	1.4	<2.0	<2.0	<2.0	<2.0	<2.0
Cr	(AA)	12	6	10	20	16	14
Cu	(AA)	12	23	8	13	16	34
Mn	(AA)	520	62	579			
Pb	(AA)	21	8	18	34	22	46
Zn	(AA)	68		34			
Hg	(AA)	4.00	0.14	<0.20	<0.20	<0.20	0.40
U	(AA)	0.4	2.2	<1.0	<1.0	<1.0	<1.0
PCB	(AA)	<0.1	0.3	<0.1	<0.1	<0.1	<0.1
Al	(ES)				4.0	5.0	2.5
B	(ES)	0.025	<0.01	<0.01	<0.01	<0.01	<0.01
Ba	(ES)	0.04	0.08	0.04	0.04	0.04	0.04
Ca	(ES)	20.0	0.5	2.5	0.6	10.0	1.2
Cs	(ES)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Fe	(ES)	11.0	5.0	1.2	2.5	1.2	2.5
K	(ES)	1.2	0.3	0.6	0.3	0.3	0.6
Li	(ES)	0.10		0.03	<0.02	0.06	<0.02
Mg	(ES)	2.50	0.30	0.15	0.30	0.80	0.30
Mn	(ES)				0.15	0.15	0.15
Mo	(ES)						<0.02
Na	(ES)	0.30	0.02	0.08	0.04	0.04	0.04
Ni	(ES)	<0.01	0.01	0.01	<0.01	<0.01	<0.01
Si	(ES)	20	15	20	20	15	20
Ti	(ES)	0.8	0.3	0.3	0.3	0.3	0.3
Y	(ES)	0.015	0.005	0.005	0.010	0.010	0.010
Zr	(ES)						0.02

Table A-16. Concentrations of elements measured in coal ash samples of the McCoy Branch floodplain, October 17, 1990.
Source: CH2M Hill, personal communication

Element	Site[a]						
(μg/L)	A1S1	A1S2	A2A	A2S1	A3A	A3S1	A3S2
Aluminum	9030	9550	18600	15300	20800	5830	7480
Antimony	R[b]	R	R	R	R	10.6 J	R
Arsenic	2.2 J	2.2 J	54.5 J	24.3 J	46.2 J	28.3 J	22.0 J
Barium	89.0	118	684	109	548	71.4	77.1
Beryllium	0.60	0.71	3.2	1.2	2.9	0.49	0.56
Cadmium	2.1	0.88	1.0	1.5	4.2	1.2	1.7
Calcium	2230	686	3460	1880	5130	858	906
Chromium	25.0	17.4	15.5	12.0	18.2	5.6	10.1
Cobalt	18.0	25.0	12.0	27.5	21.9	13.0	11.1
Copper	6.1	5.5	74.9	24.1	53.5	11.8	11.5
Iron	19200	16900	18300	19800	64300	20100	19600
Lead	33.4	36.2	13.0	26.0	15.4	12.5	6.5
Magnesium	597	525	1140	970	1690	473	614
Manganese	2240	2600	81.3	1830	672	965	702
Mercury	0.10	0.12	0.73	0.11	0.66	0.05	0.06
Nickel	6.7	8.3	29.1	34.2	40.7	22.3	15.5
Niobium	1.7 UJ	1.7 UJ	2.4 UJ	2.0 UJ	2.7 UJ	1.5 UJ	1.6 UJ
Phosphorus	326 J	211 J	2180 J	272 J	1060 J	129 J	145 J
Potassium	544	651	3570	1960	3670	911	1310
Selenium	0.24 UJ	0.24 UJ	9.1 J	2.2 J	5.3 J	0.47 J	0.23 UJ
Silver	1.4	1.5	2.1	1.7	2.3	1.3	1.4
Sodium	49.6 J	88.8 J	326	141 J	384	141 J	135 J
Vanadium	39.4	34.3	83.7	50.0	74.2	22.1	33.4
Zinc	34.4	33.9	39.3	102	75.7	56.1	43.5

[a]Approximate stream kilometers for sites are given in Table A-7.
[b]J = estimated value; R = rejected value; U = undetected—below method detection level.

Table A-17. Concentrations of elements measured in coal ash samples of the McCoy Branch floodplain, October 17, 1990.
Source: CH2M Hill, personal communication

Element (µg/L)	A4A	A4S1	A4S2	A5A	A5S1	A5S2	Site[a] A6A	A6S1	A6S2	A7A	A7S1	A7S2
Aluminum	20200	11200	9500	12300	6080	18600	15000	9210	9460	14900	6670	8540
Antimony	R[b]	R	R	R	R	R	R	R	R	R	R	R
Arsenic	54.2 J	15.3 J	10.6 J	53.2 J	10.3 J	11.5 J	15.6 J	3.2 J	3.0 J	59.2 J	43.6 J	41.7 J
Barium	355	48.1	39.3	250	71.0	196	252	79.5	71.6	425	96.0	76.6
Beryllium	2.3	0.72	0.59	1.1	0.86	1.4	1.2	0.69	0.69	2.4	0.56	0.62
Cadmium	1.6	1.2	1.2	4.2	22.8	2.3	1.4	7.0	1.5	2.6	1.8	1.2
Calcium	3210	620	518	3300	12400	17800	6950	250000	220000	3830	1030	963
Chromium	16.4	8.6	8.6	9.1	50.6	21.5	14.3	22.9	8.9	11.5	6.8	7.4
Cobalt	15.7	18.8	21.4	12.5	29.5	10.2	20.0	11.4	8.6	11.9	17.0	18.9
Copper	37.7	11.2	10.7	27.6	70.2	4.9	26.0	9.1	23.1	40.8	15.1	11.9
Iron	29900	14500	13600	51500	372000	21300	25200	13700	13000	36800	24900	16700
Lead	14.3	8.6	15.1	10.4	14.5	13.8	15.1	21.7	27.1	16.6	11.4	11.9
Magnesium	1620	977	732	1090	3740	3320	1610	11200	7880	1210	653	694
Manganese	575	1030	1050	577	2380	248	1200	425	320	194	820	1020
Mercury	0.19	0.07	0.07	0.13	0.09	0.09	0.19	0.05	0.05	0.30	0.07	0.07
Nickel	32.3	22.1	18.0	26.4	40.4	15.3	21.0	22.9	9.9	27.8	21.9	18.4
Niobium	2.2 UJ	1.6 UJ	1.6 UJ	2.1 UJ	20.1 UJ	2.0 UJ	2.4 UJ	16.0 UJ	1.6 UJ	2.2 UJ	1.6 UJ	1.6 UJ
Phosphorus	767 J	97.3 J	47.0 UJ	262 J	575 UJ	269 J	375 J	457 UJ	227 J	1000 J	143	126
Potassium	3900	1780	1320	2100	1720	2190	2800	2140	1990	2930	1070	1370
Selenium	1.7 J	0.23 UJ	0.24 UJ	2.7 J	0.30 J	0.30 UJ	1.5 J	1.2 UJ	0.24 UJ	1.4 J	0.89 J	0.50 J
Silver	1.9	1.3	1.4	1.8	17.2	1.7	2.1	13.7	1.4	1.9	1.3	1.3
Sodium	355	95.9 J	45.4 J	257	626	125 J	290	177	189	332	86.0 J	106 J
Vanadium	52.7	27.7	25.2	37.7	94.0	29.4	40.2	12.7	16.2	55.8	26.0	26.0
Zinc	66.5	90.2	79.6	46.2	81.7	46.6	72.3	84.5	79.3	34.2	59.1	55.3

[a] Approximate stream kilometers for sites are given in Table A-7.
[b] J = estimated value; R = rejected value; U = undetected—below method detection level.

Table A-18. Radioactivity and percent oil and grease in coal ash samples from the McCoy Branch floodplain, October 17, 1990.
Source: CH2M Hill, personal communication

Site[a]	Alpha activity (pCi/g)	Beta activity (pCi/g)	Cesium-137 (pCi/g)	Uranium fluorometric (μg/g)	Oil and grease (%)	Uranium-235 (Weight %)	Misc.[b] (pCi/g)
A1S1	0.04 ± 2.3 J[c]	-1.79 ± 4.2 UJ	$7.30^{E-1} \pm 2.2^{E-1}$	4	<0.1	LOW U ± XXX	
A1S2	0.46 ± 2.4 U	-3.13 ± 4.2 UJ	$3.30^{E-1} \pm 1.7^{E-1}$	3	<0.1	LOW U ± XXX	
A2A	-0.38 ± 2.3 UJ	-0.67 ± 4.3 UJ	$1.52^{E-1} \pm 2.0^{E-1}$J	7	<0.1	INSUFF U ± 0.0	
A2S1	0.62 ± 2.4 J	-3.13 ± 4.2 UJ	$2.07^{E-1} \pm 1.9^{E-1}$	5	<0.1	LOW U ± XXX	
A3A	1.35 ± 2.5 J	-1.12 ± 4.3 UJ	$1.39^{E-1} \pm 2.0^{E-1}$ J	8	<0.1	0.76 ± 0.01	
A3S1	2.82 ± 1.7	2.46 ± 3.3 J	$6.45^{E-2} \pm 1.5^{E-1}$ J	4	<0.1	LOW U ± XXX	
A3S2	3.44 ± 1.7	2.91 ± 3.4 J	$8.55^{E-2} \pm 2.3^{E-1}$ J	3	<0.1	LOW U ± XXX	
A4A	-0.20 ± 2.3 UJ	-2.35 ± 4.2 UJ	$2.65^{E-2} \pm 1.5^{E-1}$	7	<0.1	INSUFF U ± 0.0	$3.32^{E-1} \pm 2.4^{E-b}$
A4S1	2.78 ± 1.7	0.78 ± 3.2 J	$1.06^{E-1} \pm 1.5^{E-1}$ J	3	<0.1	LOW U ± XXX	
A4S2	5.99 ± 2.0	3.24 ± 3.4 J	$8.15^{E-2} \pm 1.5^{E-1}$ J	3	<0.1	LOW U ± XXX	5.15 ± 1.3
A5A	2.39 ± 1.6	2.01 ± 3.3 J	$9.35^{E-2} \pm 1.9^{E-1}$ J	6	<0.1	INSUFF U ± 0.0	
A5S1	1.21 ± 1.4 J	-0.78 ± 3.2 UJ	$2.68^{E-1} \pm 1.9^{E-1}$	3	<0.1	LOW U ± XXX	
A5S2	3.38 ± 1.7	3.13 ± 3.4 J	$5.90^{E-2} \pm 1.6^{E-1}$ J	7	<0.1	INSUFF U ± 0.0	
A6A	5.75 ± 2.0	7.27 ± 3.6	$6.95^{E-2} \pm 1.5^{E-1}$ J	8	<0.1		6.30 ± 1.4 9.2 ± 5.5[d]
A6S1	0.60 ± 1.3 J	0.11 ± 3.2 J	$-5.65^{E-2} \pm 1.5^{E-1}$ UJ	2	<0.1	LOW U ± XXX	5.10 ± 1.3
A6S2	1.6 ± 1.5	4.14 ± 3.4	$-6.80^{E-2} \pm 2.0^{E-1}$ UJ	2	0.1	LOW U ± XXX	
A7A	1.21 ± 2.4 J	-4.14 ± 4.1 UJ	$5.05^{E-2} \pm 1.5^{E-1}$ J	13	<0.1		
A7S1	-1.44 ± 2.2	5.59 ± 3.4 R	$4.47^{E-2} \pm 1.5^{E-1}$ J	3	<0.1	LOW U ± XXX	
A7S2	6.30 ± 2.1	1.68 ± 3.3 J	$1.03^{E-1} \pm 1.5^{E-1}$ J	3	<0.1	LOW U ± XXX	

[a]Approximate stream kilometers for sites are given in Table A-7.
[b]Uranium-235 at site A4A; Th-234 at sites A452, A6A, and A651.
[c]J = estimated value; R = rejected value; U = undetected—below method detection level.
[d]Th-223.

Table A-19. Groundwater data for McCoy Branch, October 15–17, 1990.
Source: CH2M Hill, personal communication

Parameter	Site[a]					
mg/L unless otherwise noted	50002 GW-321	5000-F GW-321	5001 GW-672	5001-F GW-672	5002 GW-673	5002-F GW-673
Alpha activity (pCi/L)	-14.51 ± 29.8 UJ[b]	27.10 ± 35.4	21.08 ± 34.9 J	11.45 ± 33.3 J	91.34 ± 43.0	1.61 ± 32.2 J
Beta activity (pCi/L)	-60.53 ± 75.4 UJ	-72.17 ± 74.8	-11.64 ± 77.9 UJ	-83.80 ± 74.2 U	25.61 ± 79.8 U	-39.57 ± 76.5 UJ
Alkalinity	119	119	282	279	121	143
Chloride IC	1	1	3	3	2	2
Conductivity (μmho/cm)	228	225	622	632	375	376
Dissolved solids	148	138	382	374	222	226
Flouride IC	<0.1	<0.1	0.1	0.1	1	1
Nitrate	1 J	1 J	3 J	4 J	1 J	<1 UJ
pH	8.2	8.2	7.7	7.6	9.9	10.0
Phenols	<0.03 UJ	<0.03 UJ	<0.03 UJ	<0.03 UJ	<0.03 UJ	<0.03 UJ
Sulfate	2	2	37	37	27	27
Suspended solids	38	<1	1170	2	<1	<1
Total organic carbon (TOC)	4	2	2 J	2 J	10	9
Total organic halides (TOX) (μg/L)	<10 UJ	<10 UJ	54 J	120 J	351 J	<10 UJ
Uranium-fluorometric	<0.001	<0.001	0.002	0.002	0.001	0.001

Table A-19 (Continued)

Parameter mg/L unless otherwise noted	Site[a] 5003 FCAP GW-674	5003 FCAP-F GW-674	5004 FCAP GW-676	5004 FCAP-F GW-676	5005 FCAP GW-676	5005 FCAP-F GW-676	5006 FCAP GW-676	5007 FCAP GW-676
Alpha activity (pCi/L)	46.07 ± 37.8	-27.23 ± 27.6 UJ	-0.19 ± 36.0 UJ	R	70.56 ± 40.9	11.04 ± 33.6 J	58.83 ± 39.7 J	24.14 ± 27.6 UJ
Beta activity (pCi/L)	-90.79 ± 73.9 U	-93.12 ± 73.8 U	15.65 ± 74.3 J	-37.25 ± 76.6	128.04 ± 84.6	-65.18 ± 75.2 UJ	76.82 ± 82.2 J	-97.77 ± 73.5 U
Alkalinity	224	226	185	216	208	230	3	3
Chloride IC	2	2	5	4	5	4	<1	<1
Conductivity (μmho/cm)	450	462	504	535	525	540	2.6	2.1
Dissolved solids	260	268	336	314	298	318	28	14
Flouride IC	0.2	0.2	0.2	0.2	0.2	0.2	<0.1	<0.1
Nitrate	<1 UJ	<1 UJ	7 J	5 J	7 J	5 J	<1 UJ	<1 UJ
pH	7.8	7.6	7	7.9	7.7	7.8	7.2	7.3
Phenols	<0.03 UJ	<0.03 UJ	<0.03 UJ	<0.03 UJ	<0.03 UJ	<0.03 UJ	<0.03 UJ	<0.03 UJ
Sulfate	27	27	10	8	10	8	<1	<1
Suspended solids	<1	2	526	<1	408	3	<1	<1
Total organic carbon (TOC)	7	8	1	2	1	2	18	<1 UJ
Total organic halides (TOX) (μg/L)	<10 UJ	<10 UJ	<10 UJ	13 J	<10 UJ	<10 UJ	<10 UJ	<10 UJ
Uranium-fluorometric	0.002	0.002	0.001	0.002	0.2	0.002	<0.001	<0.001

[a]Approximate stream kilometers for sites are given in Table A-7.
[b]J = estimated value; R = rejected value; U = undetected—below method detection level.

Table A-20. Concentrations of elements measured in groundwater from McCoy Branch, October 15–17, 1990.
Source: CH2M Hill, personal communication

Element	Site[a]							
µg/L	5000 GW-321	5000-F GW-321	5001 GW-672	5001-F GW-672	5002 GW-673	5002- GW-673F	5003 GW-674	5003-F GW-674
Aluminum	42.9		12000	910	1060	48.7 J[b]	21800	70.4 J
Antimony	50.0		50.0	50.0	50.0	50.0	50.0	50.0
Arsenic		2.0	2.7	2.0	2.0	2.0	3.2	2.0
Barium	43.3		255	133	46.9	29.6	674	236
Beryllium	0.30		1.3	0.30	0.30	0.30	4.0	0.30
Cadmium	3.0		3.0	3.0	3.0	3.0	8.0	3.0
Calcium	24300		114000	95200	8310	5290	93200	62200
Chromium	10.0		24.9	10.0	74.7	10.0	31.4	10.0
Cobalt	5.0		21.1	5.6	5.0	5.0	27.6	5.0
Copper	4.0		30.1	11.1	52.5	6.3	73.5	6.6
Iron	22.8		16100	1110	2110	37.1	33500	20.6
Lead		3.9 J	6.5 J	2.4 J	10.4 J	R	52.9 J	R
Magnesium	13900		33900	25500	12100	11200	37400	21100
Manganese	5.2		2750	1380	44.6	3.8	2460	224
Mercury		0.20	0.26	0.20	0.20	0.20	0.33	0.20
Nickel	10.0		25.4	10.0	32.9	10.0	41.1	10.0
Niobium	8.4		7.0 UJ	7.0 UJ	7.0 UJ	7.0 UJ	7.0 UJ	8.8
Phosphorus	200 UJ		200 UJ	200 UJ	200 UJ	200 UJ	200 UJ	200 UJ
Potassium	775		4960	3960	67900	65500	7710	4230
Selenium		2.0	8.0	2.2	2.0	2.0	4.0	2.0
Silver	6.0		6.0	6.0	6.0	6.0	6.0	6.0
Sodium	660		3870	4200	16800	17000	3510	3540
Vanadium	5.0		34.3	5.0	5.0	5.0	62.7	5.0
Zinc	50.0		244	56.2	134	16.3	2070	73.5

Table A-20 (Continued)

Element μg/L	5004 GW-676	5004-F GW-676	5005 GW-676	Site[a] 5005-F GW-676	5006 GW-676	5006-F GW-676	5007 GW-672
Aluminum	11700	52.1	1620	73.5	30.6		20.7
Antimony	50.0	50.0	50.0	50.0	50.0		50.0
Arsenic	2.0	2.0	2.0	2.0		2.0	2.0
Barium	179	62.8	66.3	61.8	5.0		3.1
Beryllium	0.50	0.30	0.30	0.30	0.30		0.30
Cadmium	3.0	3.0	3.0	3.0	3.0		3.0
Calcium	159000	76600	77800	77100	250		152
Chromium	22.0	10.0	10.0	10.0	10.0		10.0
Cobalt	13.1	5.0	5.0	5.0	5.0		5.0
Copper	15.0	4.0	4.0	4.0	4.0		4.0
Iron	17700	26.3	1030	23.9	13.1		14.6
Lead	8.1	3.1	3.7	2.2		2.0	2.0
Magnesium	21200	16400	19000	16500	15.0		23.4
Manganese	1610	680	361	682	1.5		2.2
Mercury	0.20	0.20	0.20	0.20		0.20	0.2
Nickel	13.4	10.0	10.0	10.0	10.0		10.0
Niobium	7.0 U	7.0 U	7.0 U	7.0 U	10.2		7.0 U
Phosphorus	530	200 U	200 U	200 U	200 U		200 U
Potassium	4100	1470	1950	1410	600		600
Selenium	4.0	2.0	2.0	2.0		2.0	2.0
Silver	6.0	6.0	6.0	6.0	6.0		6.0
Sodium	8250	7720	10500	7460	448		378
Vanadium	18.5	5.0	5.0	5.0	5.0		5.0
Zinc	87.1	32.3	17.2	18.2	4.8		14.6

[a]Approximate stream kilometers for sites are given in Table A-7.
[b]J = estimated value; R = rejected value; U = undetected—below method detection level.

APPENDIX B

CHECKLIST OF BENTHIC MACROINVERTEBRATE TAXA FROM MCCOY BRANCH AND WHITE OAK CREEK, APRIL 1989–JANUARY 1990

Table B-1. Checklist of benthic macroinvertebrate taxa collected from McCoy Branch (MCK) and White Oak Creek (WCK), a reference stream, April 1989—January 1990. The 'X' indicates that the taxon was collected at least once in quantitative samples during the sampling period. The 'Q' indicates that the taxon was collected in qualitative samples only

Taxon	Site MCK 1.40	 MCK 2.03	 WCK 6.8
Coelenterata (hydras)			X
Hydridae			
Hydra			
Turbellaria			
Tricladida			
Planariidae (flat worms)	X	X	X
Copepoda (copepods)	X		
Nematoda (roundworms)	X		X
Annelida			
Oligochaeta (aquatic earthworms)	X	X	X
Ostracoda (seed shrimp)	X	X	
Crustacea			
Amphipoda (sideswimmers)			
Gammaridae			
Crangonyx		Q	X
Decapoda (crayfish)			X
Cambaridae	Q	Q	X
Cambarus			Q
Hydracarina (water mites)		X	X
Insecta			
Collembola (springtails)			
Anthropleona			
Entomobryomorpha	X	X	X
Sminthuridae	X		

Table B-1 (Continued)

Taxon	Site MCK 1.40	Site MCK 2.03	Site WCK 6.8
Ephemeroptera (mayflies)			
Baetidae?			X
Baetidae		X	
Baetis	X	X	X
Baetis pluto			Q
Baetis tricaudatus	Q		Q
Pseudocloeon	X		X
Ephemerellidae			X
Ephemerella		X	X
Ephemerella?			Q
Ephemerella invaria			Q
Eurylophella	X	X	X
Eurylophella doris/temporalis			Q
Ephemeridae			
Ephemera			X
Heptageniidae			X
Stenacron			X
Stenacron interpunctatum			Q
Stenonema			X
Stenonema?			X
Leptophlebiidae		X	X
Habrophlebiodes	X	X	X
Paraleptophlebia			X
Oligoneuriidae			
Isonychia			X
Odonata			
Anisoptera (dragonflies)			
Aeshnidae			
Boyeria		Q	
Cordulegastridae			
Cordulegaster		X	
Gomphidae			X
Stylogomphus		X	X
Stylogomphus albistylus			Q
Stylogomphus?			X
Libellulidae	X		
Zygoptera (damselflies)			

Table B-1 (Continued)

Taxon	Site		
	MCK 1.40	MCK 2.03	WCK 6.8
Calopterygidae		X	
Calopteryx		X	
Calopteryx?		X	
Coenagrionidae	X		
Ischnura			
Plecoptera (stoneflies)	X		
Chloroperlidae			X
Haploperla			X
Sweltsa			X
Sweltsa?			X
Leuctridae			
Leuctra		X	X
Leuctra?		X	X
Nemouridae			
Amphinemura	X	X	X
Amphinemura delosa			Q
Peltoperlidae			
Tallaperla		X	
Viehoperla?			X
Perlidae		X	X
Eccoptura xanthenes			X
Perlesta			X
Perlodidae	X	X	X
Isoperla	X		
Isoperla holochlora?			Q
Isoperla?			X
Hemiptera (true bugs)			
Veliidae			
Microvelia	X		
Microvelia americana?			Q
Hydrometridae			
Hydrometra	X		
Mesoveliidae?	X		
Corixidae			
Sigara			Q

Table B-1 (Continued)

Taxon	Site MCK 1.40	Site MCK 2.03	Site WCK 6.8
Megaloptera			
Corydalidae (dobsonflies, fishflies)			
Nigronia		X	X
Nigronia fasciatus			X
Nigronia serricornis			X
Sialidae (alderflies)			
Sialis			X
Trichoptera (caddisflies)	X		X
Glossosomatidae			
Agapetus			X
Glossosoma		X	
Hydropsychidae	X	X	X
Cheumatopsyche	X	X	X
Diplectrona modesta		X	X
Hydropsyche	X	X	X
Hydropsyche?			X
Hydroptilidae			
Hydroptila	X	X	X
Limnephilidae			
Neophylax	X	X	X
Pycnopsyche	X	X	
Pycnopsyche gentilis			Q
Pycnopsyche luculenta			Q
Pycnopsyche scabripennis			Q
Odontoceridae			
Psilotreta			X
Philopotamidae			
Chimarra	X	X	X
Dolophilodes distinctus			X
Wormaldia		X	X
Molannidae			
Molanna		X	

Table B-1 (Continued)

Taxon	Site MCK 1.40	MCK 2.03	WCK 6.8
Polycentropodidae			
Polycentropus	X		X
Polycentropus?			X
Psychomyiidae			
Lype diversa		X	
Rhyacophilidae			
Rhyacophila			X
Goeridae			
Goera			X
Lepidostomatidae			
Lepidostoma		X	X
Coleoptera (beetles)			
Dryopidae			
Helichus fastigiatus			Q
Elmidae	X	X	
Dubiraphia			Q
Optioservus	X	X	X
Stenelmis	X	X	X
Stenelmis?	X		
Microcylloepus pusillus	X	X	
Eubriidae			
Ectopria			X
Hydrophilidae			
Hydrobius		Q	
Psephenidae			
Psephenus herricki	X		X
Ptilodactylidae			
Anchytarsus bicolor	X		X
Diptera (true flies)	X		X
Muscomorpha	X		
Ceratopogonidae	X	X	X
Atrichopogon		X	

Table B-1 (Continued)

Taxon	Site MCK 1.40	MCK 2.03	WCK 6.8
Chironomidae	Q	Q	Q
Tanypodinae	X	X	X
Labrundinia	X		
Natarsia		X	
Nilotanypus		X	X
Nilotanypus?			X
Paramerina	Q		
Paramerina?	Q		
Thienemannimyia gp	X	X	X
Thienemannimyia?	X		X
Trissopelopia ogemawi			X
Trissopelopia?		X	
Zavrelimyia		X	
Zavrelimyia?		X	
Diamesinae			
Diamesa		X	
Orthocladiinae	X	X	X
Brillia		Q	
Chaetocladius	X	X	
Chaetocladius?		X	
Corynoneura	X	X	X
Corynoneura?	Q		X
Cricotopus bicinctus	Q	Q	
Cricotopus tremulus	Q		
Cricotopus/ Orthocladius	X	X	X
Cricotopus/ Orthocladius?		X	X
Diplocladius			X
Eukiefferiella	X	X	X
Eukiefferiella claripennis	Q	Q	
Eukiefferiella devonica			Q
Eukiefferiella?	X		
Heleniella			X
Heleniella?	X		X
Heterotrissocladius	X	Q	X
Heterotrissocladius marcidus			Q
Heterotrissocladius?	X		
Limnophyes	X		

Table B-1 (Continued)

Taxon	Site MCK 1.40	Site MCK 2.03	Site WCK 6.8
Lopescladius			X
Nanocladius	X		
Parakiefferiella	X		
Parametriocnemus	X	X	X
Psectrocladius		X	
Rheocricotopus			X
Smittia	X	X	
Symposiocladius	X	Q	
Thienemanniella	X	X	X
Tvetenia	X	X	X
Tvetenia bavarica	Q		Q
Chironominae	X	X	X
Chironomini			
Chironomus/Einfeldia		Q	
Cryptochironomus	X	X	X
Dicrotendipes	Q	X	
Microtendipes	Q		X
Microtendipes?			X
Paralauterborniella			Q
Paratendipes	X	X	
Paratendipes?		X	
Polypedilum	X	X	X
Stictochironomus	Q		
Tanytarsini	Q	X	
Micropsectra	X	X	X
Micropsectra?	X	X	X
Paratanytarsus	Q		
Paratanytarsus?		X	
Rheotanytarsus	X	X	X
Rheotonytarsus?		X	X
Stempellina			X
Stempellinella	X	X	X
Stempellinella?		X	X
Culicidae			
Anopheles	X		
Dixidae			
Dixa		X	X
Dolichopodidae	Q	Q	Q
Sciomyzidae		X	

Table B-1 (Continued)

Taxon	Site MCK 1.40	Site MCK 2.03	Site WCK 6.8
Simuliidae			
Simulium	X	X	X
Simulium?			Q
Muscidae	X		
Empididae			
Chelifera	X	Q	X
Clinocera		Q	X
Hemerodromia	X	X	X
Hemerodromia?			X
Psychodidae			
Pericoma			X
Stratiomyidae		X	
Caloparyphus		X	
Myxosargus	X		
Nemotelus		Q	
Odontomyia	X		
Tabanidae			
Chrysops	X		
Tabanus		Q	
Tipulidae		X	
Antocha			X
Hexatoma			X
Limnophila			Q
Limnophila?			X
Polymera			
Pseudolimnophila	X	X	X
Pseudolimnophila?			X
Tipula	X	X	X
Tipula abdominalis			X
Mollusca			X
Gastropoda (snails)	X	X	X
Lymnaeidae	X		
Pseudosuccinea columella	Q	Q	
Lymnaeidae?	X	X	
Physidae			
Physella	X	X	
Planorbidae	X		
Gyraulus	X		

Table B-1 (Continued)

Taxon	Site MCK 1.40	Site MCK 2.03	Site WCK 6.8
Pleuroceridae			
Elimia			X
Bivalvia (clams)			
Sphaeriidae			X
Pisidium			X
Pisidium?			X
Sphaerium	X		X
Corbicula fluminea	X	X	

INTERNAL DISTRIBUTION

1. L. J. Allison
2. T. L. Ashwood
3. B. G. Blaylock
4. W. R. Brown
5. G. F. Cada
6. S. W. Christensen
7. R. B. Clapp
8. R. B. Cook
9. M. F. P. DeLozier
10. M. L. Frank
11. C. W. Gehrs
12. S. G. Hildebrand
13. C. C. Hill
14. R. L. Hinzman
15. M. A. Huston
16. P. Kanciruk
17. B. L. Kimmel
18. J. M. Loar
19. R. B. McLean
20. L. W. McMahon
21. M. J. Peterson
22-29. M. G. Ryon
30. J. A. Shaakir-Ali
31. F. E. Sharples
32. E. M. Schilling
33. L. R. Shugart
34. J. G. Smith
35. G. R. Southworth
36. C. L. Stair
37. A. J. Stewart
38. J. E. Stone
39. G. W. Suter
40. D. W. Swindle
41. V. R. Tolbert
42. J. R. Trabalka
43. R. R. Turner
44. W. Van Winkle
45. L. D. Voorhees
46. S. Walker
47. R. K. White
48. Central Research Library
49-63. ESD Library
64-67. ER Document Management Ctr
68-69. Laboratory Records Department
70. Laboratory Records—RC
71. ORNL Patent Office
72. ORNL Y-12 Technical Library

EXTERNAL DISTRIBUTION

73. S. Ahlstedt, Division of Water Resources, Tennessee Valley Authority, Norris, TN 37828
74. D. S. Day, Environmental Division, U.S. Department of Energy, Savannah River Operations Office, Box A, Aiken, SC 29802
75. P. H. Edmonds, Radian Corporation, 120 South Jefferson Circle, Oak Ridge, TN 37830
76. W. Fisher, Department of Zoology, Oklahoma State University, Stillwater, OK 74078
77. J. F. Franklin, Bloedel Professor of Ecosystem Analysis, College of Forest Resources, University of Washington, Anderson Hall (AR-10), Seattle, WA 98195
78. C. S. Gist, Environmental Protection Division, SE-31, DOE Oak Ridge Field Office, Oak Ridge, P.O. Box 2001, Oak Ridge, TN 37831
79. H. W. Hibbitts, Deputy Assistant Manager, Department of Environment, Safety and Quality, SE-30, DOE Oak Ridge Field Office, P.O. Box 2001, Oak Ridge, TN 37830
80. D. R. Hopkins, U.S. Environmental Protection Agency, 345 Courtland Street, N.E., Atlanta, GA 30365
81. G. M. Hornberger, Professor, Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22903

82. G. Y. Jordy, Director, Office of Program Analysis, Office of Energy Research, ER-30, G-226, U.S. Department of Energy, Washington, DC 20545
83. T. Joseph, Environmental Remediation Branch, Environmental Protection Division, SE-312, DOE Oak Ridge Field Office, P.O. 2001, Oak Ridge, TN 37830
84. R. A. Jump, Environmental Restoration Division, EW-91, DOD Oak Ridge Field Office, P.O. Box 2001, Oak Ridge, TN 37830
85. W. A. Kocher, 1219 Riverbend Drive, Kingston, TN 37763
86. E. C. Leming, Director, DOE Oversight Division, 761 Emory Valley Road, Oak idge, TN 37830-7072
87. G. J. Marciante, Environmental Protection Division, SE-31, DOE Oak Ridge Field Office, P.O. Box 2001, Oak Ridge, Oak Ridge, TN 37830
88. A. D. McKinney, Chief, Environmental Services, TWRA, P.O. Box 40747, Ellington Agricultural Center, Nashville, TN 37204
89. W. G. McMillan, Environment and Protection, DOE Oak Ridge Field Office, P.O. Box 2001, Oak Ridge, TN 37830
90. C. R. Olsen, Environmental Sciences Division, Office of Health and Environmental Research, ER-74, U.S. Department of Energy, Washington, DC 20585
91. R. H. Olsen, Vice President for Research, University of Michigan, Medical Science Building II, #5605, 1301 East Catherine Street, Ann Arbor, MI 48109-0620
92. A. Patrinos, Acting Director, Environmental Sciences Division, Office of Health and Environmental Research, ER-74, U.S. Department of Energy, Washington, DC 20585
93. S. S. Perkins, c/o Labat-Anderson, Inc., Information Resource Center, Administrative Record File, 105 Broadway, Oak Ridge, TN 37830
94. T. D. Richardson, Department of Biology, Box 504-A, University of North Alabama, Florence, AL 35632-0001
95. S. P. Riddle, Environmental Restoration Division, EW-91, DOE Oak Ridge Field Office, P.O. Box 2001, Oak Ridge, TN 37830
96. W. Schacher, Aquatic Habitat Protection Biologist, Tennessee Wildlife Resources Agency, 6032 W. Andrew Johnson Highway, Talbot, TN 37877
97. R. C. Sleeman, Environmental Restoration Division, EW-91, DOE Oak Ridge Field Office, P.O. Box 2001, Oak Ridge, TN 37830
98. D. Turner, 1201 Tuskegee Drive, Oak Ridge, TN 37830
99. F. J. Wobber, Environmental Sciences Division, Office of Health and Environmental Research, ER-74, U.S. Department of Energy, Washington, DC 20585
100. Office of Assistant Manager for Energy Research and Development, DOE Oak Ridge Field Office, P.O. Box 2001, Oak Ridge, TN 37831-8600

101-110. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831

END

DATE FILMED

5/8/92