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ENVIRONMENTAL SCIENCES DIVISION

Report on the Biological Monitoring Program at Paducah Gaseous Diffusion Plant January–December 1996

L. Adams Kszos

Environmental Sciences Division
Publication No. 4636

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Report on the Biological Monitoring Program at Paducah Gaseous Diffusion Plant January-December 1996

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ACRONYMS

ANOVA	analysis of variance
BMAP	Biological Monitoring and Abatement Program
BMP	Biological Monitoring Program
BBK	Big Bayou Creek kilometer
DOE	U.S. Department of Energy
ESD	Environmental Sciences Division
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, Trichoptera
FDA	U.S. Department of Agriculture Food and Drug Administration
GC/ECD	gas chromatography/electron capture detection
GLM	general linear model
HINDS CR	Hinds Creek
IC	inhibition concentration
KDOW	Kentucky Division of Water
KPDES	Kentucky Pollutant Discharge Elimination System
LMES	Lockheed Martin Energy Systems, Inc.
LMUS	Lockheed Martin Utility Systems, Inc.
LUK	Little Bayou Creek kilometer
MAK	Massac Creek kilometer
MS-222	tricaine methanesulfonate
NOEC	no-observed-effect concentration
NPDES	National Pollutant Discharge Elimination System
ORNL	Oak Ridge National Laboratory
PCB	polychlorinated biphenyl
PGDP	Paducah Gaseous Diffusion Plant
QA	quality assurance
RGA	regional gravel aquifer
SAS	statistical analysis system
SD	standard deviation
SE	standard error
SRP	soluble reactive phosphorus
TR	total residual
TRC	total residual chlorine
TSS	total suspended solids
TU	toxicity unit(s)
TUc	chronic toxicity unit(s)
USEC	United States Enrichment Corporation
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Service
WKWMA	West Kentucky Wildlife Management Area

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EXECUTIVE SUMMARY

On September 24, 1987, the Commonwealth of Kentucky Natural Resources and Environmental Protection Cabinet issued an Agreed Order that required the development of a Biological Monitoring Program (BMP) for the Paducah Gaseous Diffusion Plant (PGDP). The PGDP BMP was conducted by the University of Kentucky between 1987 and 1992 and by staff of the Environmental Sciences Division (ESD) at Oak Ridge National Laboratory (ORNL) from 1991 to present. The goals of BMP are to (1) demonstrate that the effluent limitations established for PGDP protect and maintain the use of Little Bayou and Big Bayou creeks for growth and propagation of fish and other aquatic life, (2) characterize potential environmental impacts, and (3) document the effects of pollution abatement facilities on stream. In September 1992, a renewed Kentucky Pollutant Discharge Elimination System (KPDES) permit was issued to PGDP. The renewed permit requires toxicity monitoring of continuous and intermittent outfalls on a quarterly basis. On April 6, 1996, an Agreed Order between U.S. Department of Energy (DOE), United States Enrichment Corporation (USEC), and the Kentucky Division of Water (KDOW) was signed that settled issues involving a challenge to the KPDES permit. The Agreed Order lists the requirements for limits on copper, cadmium, chromium, lead, nickel, zinc, temperature, phosphorous, pH levels, and chronic toxicity. A BMP is not required in either the 1996 Agreed Order or the renewed permit; however, biological monitoring of the DOE facilities at PGDP is required under DOE Order 5400.1, General Environmental Protection Program. Data collected under BMP will also be used to support two studies in the Agreed Order.

The BMP for PGDP consists of three major tasks: (1) effluent toxicity monitoring, (2) bioaccumulation studies, and (3) ecological surveys of stream communities (i.e., benthic macroinvertebrates and fish). This report focuses on ESD activities occurring from January 1996 to December 1996, although activities conducted outside this time period are included as appropriate.

Study Area

The PGDP is owned by DOE. Production facilities are leased to the USEC and are managed by Lockheed Martin Utility Systems, Inc. (LMUS). The environmental restoration and waste management activities are managed by Lockheed Martin Energy Systems, Inc. (LMES). Construction of the plant was completed in 1954, although production began in 1952. PGDP is an active uranium enrichment facility consisting of a diffusion cascade and extensive support facilities. Support facilities include a steam plant, four electrical switchyards, four sets of cooling towers, a chemical cleaning and decontamination facility, water and wastewater treatment plants, a chromium reduction facility, and maintenance and laboratory facilities.

PGDP is located in the western part of the Ohio River basin. Surface drainage from PGDP enters Big Bayou Creek and Little Bayou Creek. Big Bayou Creek is a perennial stream with a drainage basin extending from ~4 km south of PGDP to the Ohio River. Part of its 14.5-km course flows along the western boundary of the plant. Little Bayou Creek originates in the Western Kentucky State Wildlife Management Area and flows for 10.5 km north toward the Ohio River before joining with Big Bayou Creek; its course includes part of the eastern boundary of PGDP. Four continuously flowing outfalls (001, 006, 008, and 009) discharge to Big Bayou Creek. Outfalls 002, 010, 011, and 012 are combined at the C617 pond and discharged via Outfall 010 into Little Bayou Creek. Effluent from outfalls 013, 015, 016, 017, and 018 regularly discharge into Big Bayou and Little Bayou creeks when it rains.

Three sites on Big Bayou Creek were included in the sampling: Big Bayou Creek kilometers (BBK) 12.5, 10.0, and 9.1. One site on Little Bayou Creek, Little Bayou Creek kilometer (LUK) 7.2, and one off-site reference station on Massac Creek, Massac Creek kilometer (MAK) 13.8, were also routinely sampled to assess the ecological health of the stream and to evaluate ambient toxicity. Three additional sites (BBK 2.8, LUK 9.0, and LUK 4.3) were sampled as part of the bioaccumulation monitoring task, and one additional site was sampled in 1995 as part of the toxicity monitoring task (BBK 10.8). Qualitative fish community sampling was conducted at LUK 4.3 prior to September 1996. Toxicity monitoring was conducted quarterly. Fish and benthic community sampling and bioaccumulation sampling were conducted twice annually in the spring and fall. KPDES outfalls evaluated for effluent toxicity in 1996 included 001, 006, 008, 009, 010, 013, 015, 016, 017, and 018.

Toxicity Monitoring

*Ceriodaphnia dubia** and fathead minnow toxicity tests of effluents from the continuously flowing outfalls (001, 006, 008, 009, and 010) and the intermittently flowing outfalls (013, 015, 016, 017, and 018) were conducted quarterly as required by the KPDES permit. Tests with *Ceriodaphnia* and fathead minnows were typically conducted concurrently. The 25% inhibition concentrations (IC25: that concentration causing a 25% reduction in fathead minnow growth or *Ceriodaphnia* survival compared with the control) were determined for each test. The chronic toxicity unit rating (TU_c=100/IC25) is required as a compliance endpoint in the renewed permit (September 1992 to present). The higher the TU_c, the more toxic an effluent. Because Little Bayou and Big Bayou creeks have been determined to have a low flow of zero, a $TU_c > 1.0$ would be considered a noncompliance (for the continuously flowing outfalls) and an indicator of potential instream toxicity. This report summarizes the toxicity test results for all tests conducted from 1991 to 1996 and the chemistry analyses for 1996. Most of the outfalls have been evaluated at least 22 times.

During 1996, effluent samples from Outfall 006 exceeded the permit limit for fathead minnows of $TU_c > 1.0$ in March, and samples from Outfall 010 exceeded the permit limit for fathead minnows of $TU_c > 1.0$ in March and August. Confirmatory tests were conducted within 2 weeks of each exceedance and, for each test, the resulting TU_c was < 1.0, demonstrating that the effluent was no longer toxic. The toxic contaminants that were present are unknown but because the confirmatory tests documented that the effluent was no longer toxic, the presence of the contaminant may have been intermittent or the concentration of the contaminant may have decreased.

Full-strength effluent from the intermittent outfalls was never toxic to fathead minnows, which resulted in $TU_c < 1.0$ for every test. The results of the toxicity tests of the intermittent outfalls shows continued improvement in the number of times the TU_c has been < 1.0 for the fathead minnows. For example, Outfall 015 exceeded a TU_c of 1.0 in 6 of 12

[1]For purposes of economy, *C. dubia* will be referred to as simply *Ceriodaphnia* throughout this document.

fathead minnow tests conducted from 1992 to 1994. During 1995–1996 there were no exceedances for fathead minnows. Effluent from intermittent outfalls 013, 017, and 018 exceeded a TU_c of 1.0 in January for *Ceriodaphnia*. The total suspended solids were unusually high during the January test and may have contributed to or been associated with a contaminant that reduced *Ceriodaphnia* reproduction.

In December 1996, a bioavailability study was initiated to develop alternative metal limits for cadmium, chromium, copper, lead, nickel, and zinc. As stipulated in the Agreed Order, DOE/USEC must demonstrate to the satisfaction of the Cabinet that a more appropriate analytical technique or criteria is available that provides a better measurement of levels of metals present that would be toxic to aquatic life. Phase I of the study will develop alternative limits for the continuously flowing outfalls and will be completed in 1998. The overall objectives of the study are to

- evaluate the toxicity of continuous outfalls (001, 008, 009, and 010) and intermittent outfalls (003, 013, 015, 016, 017, and 018) at PGDP,
- determine the mean ratio of dissolved to total recoverable metal for Cd, Cr, Cu, Pb, Ni, and Zn in the continuous and intermittent outfalls,
- determine whether the concentration of total residual (TR) metal discharged causes toxicity to fathead minnows and/or *Ceriodaphnia*, and
- determine alternative metal limits for each metal of concern (Cd, Cr, Cu, Pb, Ni, and Zn).

Bioaccumulation

Bioaccumulation monitoring conducted previously as part of the BMP identified polychlorinated biphenyl (PCB) contamination in fish in Little Bayou Creek, and to a lesser extent, Big Bayou Creek, as primary concerns. Mercury concentrations in fish in Big Bayou Creek were found to be higher in fish downstream from PGDP discharges than in fish from an upstream site. The main objective of the 1995–1996 bioaccumulation monitoring was to evaluate spatial and temporal changes in PCB contamination in fish from Big Bayou and Little Bayou creeks with a secondary objective of annually monitoring mercury concentrations in fish from those creeks. Monitoring for mercury in fish was restricted to spotted bass from Big Bayou Creek. Longear sunfish and spotted bass were collected from Big Bayou Creek and Little Bayou Creek in October 1995, and longear sunfish in April 1996 for mercury and PCB analyses. Spotted bass were collected from Big Bayou Creek in October 1995 for PCB and mercury analysis. Upper Big Bayou Creek (2–3 km upstream from PGDP) served as a reference site for PCBs and mercury in sunfish, and Massac Creek in McCracken County, Kentucky, served as reference site for mercury in spotted bass. Hinds Creek, Anderson County, Tennessee, is used as a reference site for biological monitoring activities at other DOE sites, and provided data on background concentrations at another uncontaminated site and sunfish samples for use as analytical controls.

Mean PCB concentrations in sunfish from Little Bayou Creek were higher than in fish from reference sites in both October 1995 and April 1996. In Big Bayou Creek, average PCB concentrations in sunfish were very low and similar to those from reference sites in October 1995, but higher concentrations were detected in April 1996. As in past years, the highest concentrations again were found in fish from upper Little Bayou Creek on both sampling dates, and a sharp decrease in average concentration with distance downstream was once more obvious. The trend of decreasing PCB contamination over time in sunfish in Little Bayou Creek continued, with PCB concentrations in sunfish at the uppermost Little Bayou Creek site averaging about 0.5 $\mu g/g$ in 1995/1996 versus nearly 2 $\mu g/g$ in 1992.

Mean mercury concentrations in sunfish and bass from Big Bayou Creek and Little Bayou Creek in 1995 were typical of previous years, with the exception of the upstream reference site in Big Bayou Creek where mercury in fish exceeded 0.3 $\mu g/g$. Average mercury concentrations in spotted bass from Big Bayou Creek below PGDP were about 0.5 $\mu g/g$, with the largest specimen exceeding the FDA threshold limit of 1 $\mu g/g$. Mercury in bass from Massac Creek averaged over 0.3 $\mu g/g$, reinforcing the inference that the bioavailability of naturally occurring mercury is high in streams in the vicinity of PGDP.

The reappearance of PCB contamination in sunfish in Big Bayou Creek following its decline to background levels illustrates the high temporal variability of PCB contamination in stream fish, and the value of continued monitoring as an early warning of changes in trends. Similarly, the decrease in PCB contamination in fish in Little Bayou Creek provides evidence of effective controls and remediation of sources within PGDP, and will help assess whether additional controls are needed. Future bioaccumulation monitoring will continue to focus efforts on PCB contamination in Little Bayou Creek, with continued but less intensive examination of trends in mercury and PCB contamination in Big Bayou Creek.

Ecological Monitoring

Quantitative sampling of the fish community was conducted at three sites in Big Bayou Creek, one site in Little Bayou Creek, and at one offsite reference station (Massac Creek) during March–April and September 1996. Qualitative sampling was conducted at one site in Little Bayou Creek during April 1996 and at 31 sites from 1990 to 1996. Data on the fish communities of Big Bayou Creek and Little Bayou Creek downstream of PGDP were compared to data from reference sites located on Big Bayou Creek above PGDP and on Massac Creek. These comparisons indicated a slight but noticeable degradation in the communities downstream of PGDP. Effects on the fish community were greatest just downstream from PGDP at BBK 10.0. The fish community at this site had a low mean and total species richness, and no sensitive species, whereas there were four sensitive species at the Massac Creek reference site. The lower species richness, compared with reference sites, may be a result of thermal impacts associated with outfalls (see Roy et al. 1996). Although the temperatures may not be lethal, they could produce avoidance by some thermally sensitive species of the areas of Big Bayou Creek near the plant outfalls. Although density and biomass at BBK 10.0 were not as high as in past samples, they were still dominated by one species, the herbivorous stoneroller. This numerical dominance by a herbivorous species, combined with the low numbers of benthic insectivores, is an expected effect of nutrient enrichment at BBK 10.0, associated with discharges from Outfall 004. Nutrient samples taken in April 1996 indicate enriched conditions at BBK 10.0, as well as at BBK 9.1, when compared to levels at Massac Creek and upper Big Bayou Creek. Biomass at BBK 10.0 reached a low point in March 1995, and the 1996 values continue a modest increasing trend in biomass first seen in September 1995. A spring to spring production estimate indicated a leveling of productivity at BBK 10.0. Overall the fish community at BBK 10.0 has demonstrated shortcomings in several evaluation metrics.

The fish community at BBK 9.1 showed signs of less impact than at BBK 10.0. Mean and total species richness were lower than at MAK 13.8 but similar to BBK 12.5. Although there were fewer sensitive species and at lower densities at BBK 9.1 than at MAK 13.8, more sensitive species were found at BBK 9.1 than at BBK 10.0. Density was less than or equal to that at MAK 13.8, and species richness was slightly increased from 1993. As with BBK 10.0, production estimates declined four-fold from 1992–93 to 1994–95 but increased during 1995–96. These trends indicate a lessening of impacts on recruitment success for the fish community at BBK 9.1. The possible causes for this minor impact could include slightly elevated temperatures or high nutrient levels resulting from outfall discharges.

The fish community at LUK 7.2 was similar to that at the BBK 12.5 reference site. The mean species richness values were similar to those of the reference site and had rebounded substantially from a low point in fall 1994. Biomass also reached a record level for this site in September 1996. Unlike conditions in Big Bayou Creek sites, productivity did decline in 1995–96 sampling.

The downstream qualitative site, LUK 4.3, did not appear to be affected by plant operations. Species richness was similar to that found in earlier sampling. The community was well represented in all families and significant absences in feeding guilds were not demonstrated. The relative abundance and catch-per-effort data were average for this site.

Monitoring of the fish communities associated with PGDP streams indicated some depressed conditions but did not specifically identify causative agents. The impacts were limited to sites below the plant, which suggests that PGDP discharges (with resultant temperature increases and nutrient enrichment) may be the cause. It is also possible that the low species richness and lack of sensitive species may reflect degraded habitat conditions or be a common characteristic of the Big Bayou Creek watershed. To help determine whether the pattern seen in Big Bayou Creek is unique, qualitative surveys were made in Massac Creek and other area streams, such as Humphrey Creek. These surveys suggested the fauna in Big Bayou Creek watershed was limited compared with some regional streams (e.g., Massac and Humphrey Creeks), but were not as impacted as other streams.

Benthic macroinvertebrate samples were collected from three sites in Big Bayou Creek and one site each in Little Bayou Creek and Massac Creek in September 1995 and March 1996. These data, along with data collected since monitoring began in September 1991, showed no evidence of major impacts to the benthic macroinvertebrate communities of Big Bayou Creek and Little Bayou Creek. Thus, relative to characteristics exhibited by the macroinvertebrate communities of reference streams, it appears that PGDP operations are having no major, adverse effects on the macroinvertebrate communities of Big Bayou Creek or Little Bayou Creek. Major persistent changes in the macroinvertebrate communities of these streams were also not detected for this period, suggesting that the macroinvertebrate communities have remained in a "steady state" since 1991. However, subtle differences in benthic community structure, at LUK 7.2, BBK 9.1, and BBK 10.0, are consistent with nutrient enrichment associated with PGDP discharges. This hypothesis was supported with recently collected nutrient data that showed nutrient concentrations at BBK 9.1, BBK 10.0, and LUK 7.2 at least periodically exceed those of the reference sites.

1. INTRODUCTION

L. A. Kszos

On September 24, 1987, the Commonwealth of Kentucky Natural Resources and Environmental Protection Cabinet issued an Agreed Order that required the development of a Biological Monitoring Program (BMP) for the Paducah Gaseous Diffusion Plant (PGDP). A plan for the biological monitoring of the receiving streams (Little Bayou Creek and Big Bayou Creek) was prepared by the University of Kentucky, reviewed by staff at PGDP and Oak Ridge National Laboratory (ORNL), and submitted by the U.S. Department of Energy (DOE) to the Kentucky Division of Water (KDOW) for approval. The PGDP BMP was implemented in 1987 and consisted of ecological surveys, toxicity monitoring of effluents and receiving streams, evaluation of bioaccumulation of trace contaminants in biota, and supplemental chemical characterization of effluents. The PGDP BMP was patterned after plans that were implemented in 1985 for the Oak Ridge Y-12 Plant (Loar et al. 1989) and in 1986 for ORNL (Loar et al. 1991) and the Oak Ridge Gaseous Diffusion Plant (presently the Oak Ridge K-25 Site, Kszos et al. 1993). Because research staff from the Environmental Sciences Division (ESD) at ORNL were experienced in biological monitoring, they served as reviewers and advisers throughout the planning and implementation of the PGDP BMP. Data resulting from BMP conducted by the University of Kentucky were presented in a 3-year report issued in December 1990 (Birge et al. 1990) and an annual report issued in December 1991 (Birge et al. 1992).

Beginning in fall 1991, ESD added data collection and report preparation to its responsibilities for the PGDP BMP. The BMP has been continued because it has proven to be extremely valuable in (1) identifying those effluents with the potential for adversely affecting instream fauna, (2) assessing the ecological health of receiving streams, (3) guiding plans for remediation, and (4) protecting human health. For example, BMP has documented the improved health of the streams in the vicinity of PGDP; continued documentation of ecological recovery and improvement of water quality may be used to develop appropriate chemical limits and monitoring requirements. BMP has shown that (1) contaminants bioaccumulate to a significant degree in aquatic species and (2) the fish communities in Big Bayou Creek have been negatively impacted. Continued biological monitoring will assess the degree to which abatement actions ecologically benefit Big Bayou Creek and Little Bayou Creek. Data from continued monitoring can also be used to evaluate the need for additional remediation and to assess the impact of inadvertent spills or fish kills. Furthermore, BMP results can be used to educate the public about PGDP's commitment to environmental protection.

In September 1992, a renewed Kentucky Pollutant Discharge Elimination System (KPDES) permit was issued to PGDP. The renewed permit requires toxicity monitoring of continuous and intermittent outfalls on a quarterly basis. On April 6, 1996, an Agreed Order between DOE, United States Enrichment Corporation (USEC), and the KDOW was signed which settled issues involving a challenge to the KPDES permit. The Agreed Order lists the requirements for limits on copper, cadmium, chromium, lead, nickel, zinc, temperature, phosphorous, pH and chronic toxicity. A BMP is not required in either the Agreed Order or the renewed permit; however, biological monitoring of the DOE facilities at PGDP is required under DOE Order 5400.1, General Environmental Protection Program. Data collected under BMP will also be used to support three studies in the Agreed Order: (1) temperature variability and instream effects of elevated temperature from PGDP outfalls, (2) development of site-specific metal limits for outfalls, and (3) instream monitoring for pH in Big Bayou and Little Bayou creeks.

The BMP for PGDP consists of three major tasks: (1) effluent toxicity monitoring, (2) bioaccumulation studies, and (3) ecological surveys of stream communities (i.e., benthic macroinvertebrates and fish). This report focuses on ESD activities occurring from January to December 1996. Activities conducted outside this time period, particularly historical data used to describe trends, are also included as appropriate.

2. DESCRIPTION OF STUDY AREA*

L. A. Kszos

2.1 SITE DESCRIPTION

The PGDP is owned by DOE. In July 1993, DOE leased the plant production operations facilities, which are managed by Lockheed Martin Utility Systems, Inc. (LMUS), to USEC. Under this lease, USEC has assumed responsibility for compliance activities directly associated with uranium enrichment operations. DOE maintains responsibility for the environmental restoration and waste management activities through its management contractor, Lockheed Martin Energy Systems, Inc. (LMES). Construction of the plant was completed in 1954, although production began in 1952. PGDP is an active uranium enrichment facility consisting of a diffusion cascade and extensive support facilities (Kornegay et al. 1994). The uranium enrichment gaseous diffusion process involves more than 1800 stages with operations housed in 5 buildings covering ~300 ha. Including support facilities, the plant has ~30 permanent buildings located on a 1386-ha site (Oakes et al. 1987). Support facilities include a steam plant, four electrical switchyards, four sets of cooling towers, a chemical cleaning and decontamination facility, water and wastewater treatment plants, a chromium reduction facility, and maintenance and laboratory facilities. Several inactive facilities are also located on the site. Currently, the Paducah cascade processes are being used for the enrichment of uranium up to 2.5% ^{235}U. This product is then transferred to the Portsmouth (Ohio) Gaseous Diffusion Plant for further enrichment (Oakes et al. 1987). Most of the uranium produced is used for national defense and commercial reactors in the United States and abroad.

2.1.1 Land Use

The area surrounding PGDP is mostly rural, with residences and farms surrounding the plant. Immediately adjacent to PGDP is the West Kentucky Wildlife Management Area (WKWMA), 2821 ha of natural habitat, state-maintained forage crops, and ponds, used by

*Sections 2.1 and 2.2 contain large excerpts from: V. M. Jones, Site and Operations Overview, Section 1 and D. W. Jones et al., Nonradiological Effluent Monitoring, Section 7. *IN* Kornegay et al. 1994. Paducah Gaseous Diffusion Plant Annual Site Environmental Report for 1993. ES/ESH-53. Oak Ridge National Laboratory. Oak Ridge, Tenn.

hunters and fishermen. About 20 of the 35 ponds support fishing, and ~200 deer are harvested annually.

The population within a 80-km radius of the plant is about 300,500 people. The unincorporated communities of Grahamville and Heath are within 2–3 km, east of the facility. The largest cities in the region are Paducah, Kentucky, and Cape Girardeau, Missouri, located about 16 and 64 air km away respectively (U.S. Department of Commerce 1991).

For information on the geohydrology of the region, see Kszos 1994a, 1994b; Kornegay et al. 1994; CH2M Hill 1991; D'Appolonia 1983; TERRAN 1990; GeoTrans 1990.

2.1.2 Surface Water

The PGDP is located in the western part of the Ohio River basin. The confluence of the Ohio River with the Tennessee River is ~24 km upstream of the site, and the confluence of the Ohio River with the Mississippi River is ~90 km downstream of the site. Surface drainage from PGDP enters the Ohio River through Big Bayou Creek and Little Bayou Creek (Fig. 2.1). These streams meet ~4.8 km north of the site and discharge to the Ohio River at kilometer 1524 (Fig. 2.2), which is ~56 km upstream of the confluence of the Ohio and Mississippi rivers. The PGDP is located on a local drainage divide; surface flow is east-northeast toward Little Bayou Creek and west-northwest toward Big Bayou Creek. Big Bayou Creek is a perennial stream with a drainage basin extending from ~4 km south of PGDP to the Ohio River; part of its 14.5-km course flows along the western boundary of the plant. Little Bayou Creek originates in the WKWMA and flows for 10.5 km north toward the Ohio River; its course includes part of the eastern boundary of the plant. The watershed areas for Big Bayou Creek and Little Bayou Creek are about 4819 and 2428 ha respectively. These streams exhibit widely fluctuating discharge characteristics that are closely tied to local precipitation and facility effluent discharge rates. Natural runoff makes up a small portion of the flow; and, during dry weather, effluents from PGDP operations can constitute about 85% of the normal base flow in Big Bayou Creek and 100% in Little Bayou Creek. During the dry season which extends from summer to early fall, no-flow conditions may occur in the upper section of Little Bayou Creek (Birge et al. 1992). Precipitation in the region averages about 120 cm per year. Precipitation was 133 cm in 1996, with the highest rainfall occurring in June (Table 2.1). There were seven major storms (≥5 cm in 24–48 hours): two in June, one in July, three in September, and one in November. The storm in November consisted of

ORNL-DWG 95M-7163

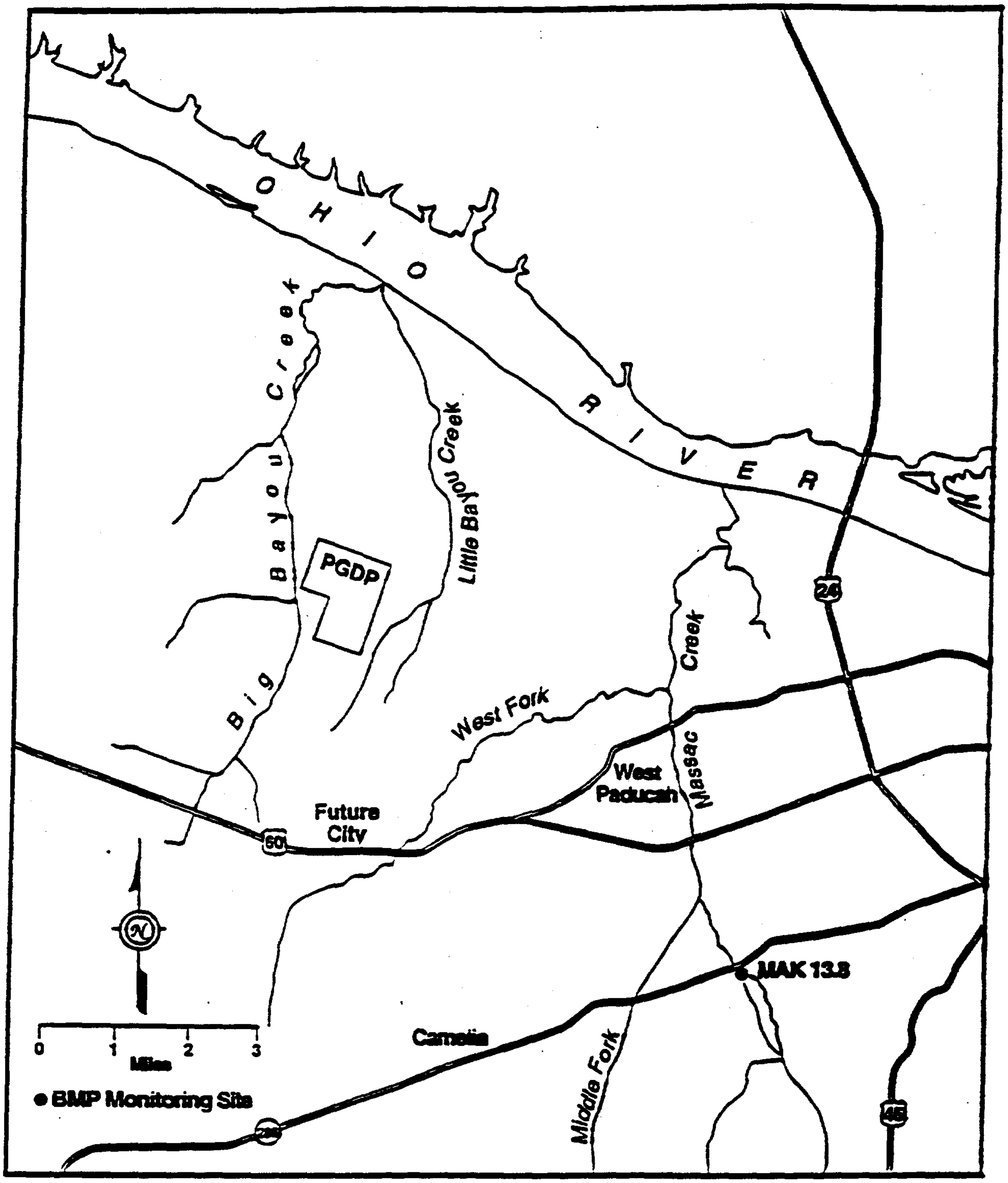
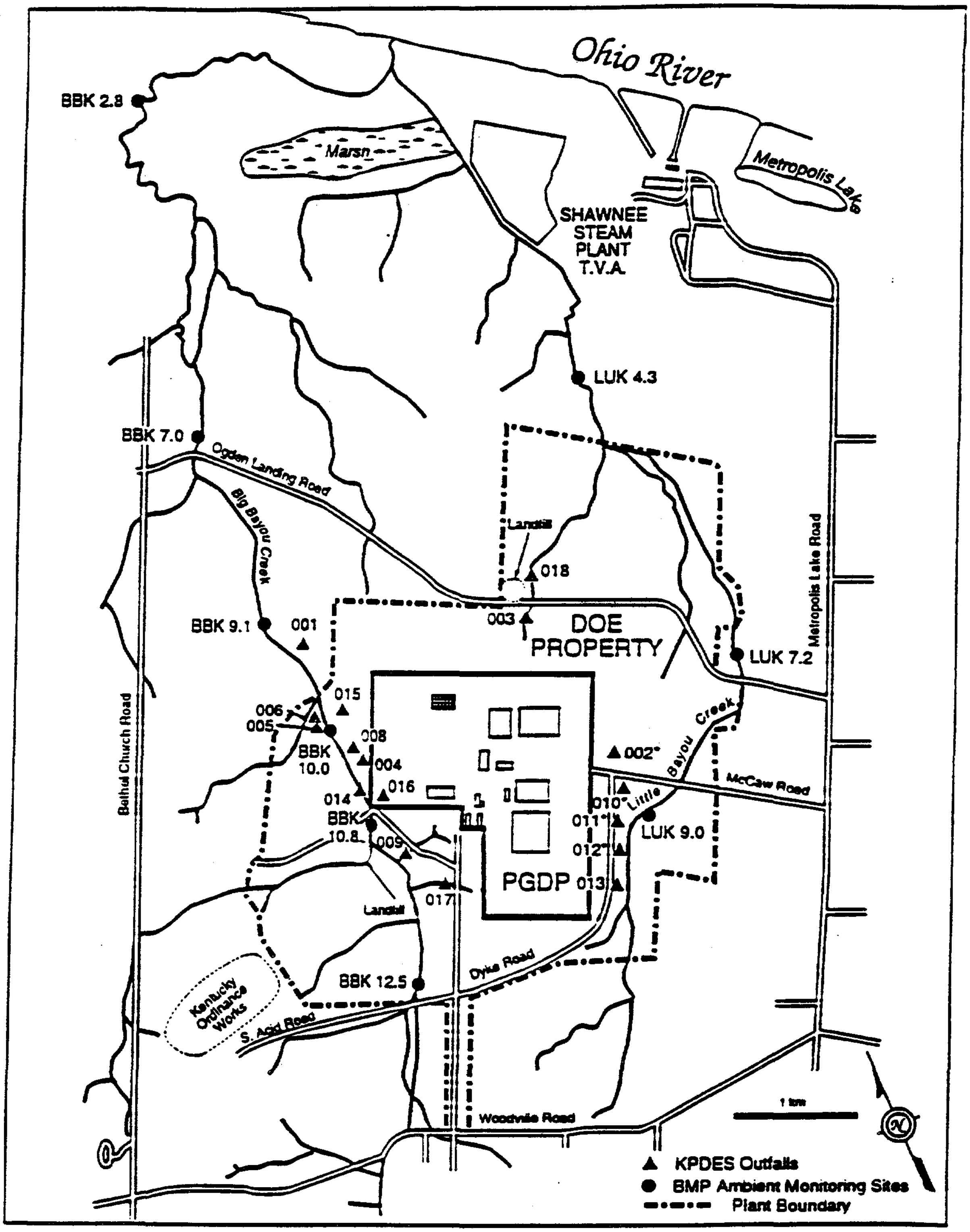


Fig. 2.1. Map of Paducah Gaseous Diffusion Plant (PGDP) in relation to the geographic region. The reference site for PGDP biological monitoring activities is located on Massac Creek at kilometer (MAK) 13.8.

ORNL-DWG 95M-7164R



*Combined at C617 pond and discharged through 011/010

Fig. 2.2. Location of Biological Monitoring Program (BMP) sites and Kentucky Pollutant Discharge Elimination System (KPDES) permitted outfalls for the Paducah Gaseous Diffusion Plant (PGDP). BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; T.V.A. = Tennessee Valley Authority; DOE = U.S. Department of Energy.

Table 2.1. Summary of rainfall in Paducah, Kentucky, during 1996

Month	Total (cm)
January	8.59
February	2.77
March	8.26
April	11.73
May	13.26
June	19.84
July	15.52
August	0.25
September	17.65
October	9.27
November	18.06
December	8.61
Total	133.81

Source: Midwestern Climate Center, Champaign, IL, Station ID156110, Barkley Regional Airport, Paducah National Weather Service.

12.45 cm in 24-h. Daily rainfall data for 1996 is provided in Appendix A. See Kszos et al. (1994b, 1995, 1996) for information on precipitation during 1992–95. The lower Bayou drainage has low to moderate gradient, and the lower reaches are within the flood plain of the Ohio River. The drainage basin is included in ecoregion 72 (Interior River Lowland) of the contiguous United States (Omernik 1987). Vegetation is a mosaic of forest, woodland, pasture, and cropland.

The majority of effluents at PGDP consist of once-through cooling water, although a variety of effluents (uranium-contaminated as well as noncontaminated) result from activities associated with uranium precipitation and facility-cleaning operations. Sodium hexametaphosphate is used for corrosion control in the plant's sanitary water and therefore is present in the once-through cooling water. As a result, phosphate is present in many of the continuously flowing outfalls (Table 2.2). Outfall 008 phosphate level is typically higher than the other outfalls because of the sewage treatment plant effluent (C. C. Travis, Environmental Waste Management Division, Environmental Compliance Department, personal communication). The influence of discharges from PGDP on water chemistry of Big Bayou and Little Bayou creeks has been reported previously (Kszos 1996). From 1991 to 1995, water chemistry collected quarterly over 7 days showed that effluent from outfalls 001 and 006 had the largest influence on conductivity, hardness, and pH. Conductivity and hardness were significantly higher at BBK 9.1 than BBK 10.0, and pH is often higher at BBK 9.1 than BBK 10.0. Chemical measurements were discontinued in 1996, but because there have been few changes in the process discharges, it is likely that the instream chemical changes were also present in 1996. Conventional liquid discharges such as domestic sewage, steam-plant wastewaters, and coal-pile runoff also occur. Routine monitoring activities provide data to quantify total discharges to surface water in order to demonstrate compliance with federal, state, and DOE requirements. Monitoring also assists with evaluating the effectiveness of effluent treatment and control programs.

2.2 WATER QUALITY AND PGDP EFFLUENTS

The Clean Water Act is currently administered for PGDP by the KDOW through the KPDES Wastewater Discharge Permitting Program. PGDP currently operates under KPDES Permit No. KY0004049 issued in September 1992. This permit became effective November 1, 1992, and is enforced by the KDOW. PGDP adjudicated the portions of the permit that contained unattainable effluent limits and implemented the portions of the permit not under adjudication (Kornegay et al. 1994). On April 6, 1996, an Agreed Order between DOE, USEC, and the KDOW was signed which settled issues involving a challenge to the KPDES permit. The Agreed Order lists the requirements for limits on copper, cadmium, chromium, lead, nickel, zinc, temperature, phosphorous, pH, and chronic toxicity.

Monitoring of 17 individual outfalls is conducted in accordance with the KPDES Permit. Table 2.2 lists all outfalls and their contributing processes; Fig. 2.2 shows the location of the outfalls. Eight of the 17 outfalls discharge continuously to the receiving streams. Outfalls 001, 006, 008, and 009 discharge continuously to Big Bayou Creek; Outfalls 002, 010, 011, and 012 are combined at the C-617 pond and discharge through Outfall 010 continuously to Little Bayou Creek. After PCBs were detected in sediments from Outfall 011 in June 1994,

Table 2.2. Kentucky Pollutant Discharge Elimination System (KPDES) permitted outfalls at Paducah Gaseous Diffusion Plant

Location[a]	Discharge source	Flow[b]	Contributing processes
001	C-616, C-600, C-400, C-410, C-635, C-335, C-337, C-535, C-537, C-746-A, C-747-A, C-635-6	8.8±1.7	Recirculating cooling water blowdown treatment effluent, coal-pile runoff, once-through cooling water, surface runoff, roof and floor drains, treated uranium solutions, sink drains, discharge from the Northwest Plume Pump and Treat Facility
002	C-360, C-637, C-337-A	1.6±3.9	Once through cooling water, roof and floor drains, sink drains, extended aeration sewage treatment system
003	North edge of plant	NM[c]	Storm overflow of north/south diversion ditch discharges
004	C-615 sewage treatment plant, C-710, C-728, C-750, C-100, C-620, C-400	1.2±0.2	Domestic sewage, laboratory sink drains, motor cleaning, garage drains, laundry, machine coolant treatment filtrate, condensate blowdown, once-through cooling water
005	C-611 primary sludge lagoon	NM[c]	Water treatment plant sludge, sand filter backwash, laboratory sink drains
006	C-611 secondary lagoon	3.3±0.8	Water treatment plant sludge, sand filter backwash, laboratory sink drains from Outfall 005
007	Although outfall is still listed on the permit, the only discharge is storm water runoff, which has no monitoring requirements or limitations	NM[c]	
008	C-743, C-742, C-741, C-723, C-721, C-728, C-729, C-400, C-420, C-410, C-727, C-411, C-331, C-310, C-724, C-744, C-600, C-405, C-409, C-631, C-720	2.8±2.1	Surface drainage, roof and floor drains, once-through cooling water, paint shop discharge, condensate, instrument shop cleaning area, metal-cleaning rinse water, sink drains
009	C-810, C-811, C-331, C-333, C-310, C-100, C-102, C-101, C-212, C-200, C-300, C-320, C-302, C-750, C-710, C-720	1.5±2.5	Surface drainage, roof and floor drains, condensate, once-through cooling water, sink drains
010	C-531, C-331	2.3±0.7	Switchyard runoff, roof and floor drains, condensate, sink drains
011	C-340, C-533, C-532, C-315, C-333, C-331	0.3±0.4	Once-through cooling water, roof and floor drains, switchyard runoff, condensate, sink drains
012	C-633, C-533, C-333-A	4.1±12.1	Roof, floor, and sink drains, condensate, surface runoff, extended aeration sewage treatment system
013	Southeast corner of the plant	3.4±7.0	Surface runoff
014	C-611 U-shaped sludge lagoon	NM[c]	Sand filter backwash, sanitary water
015	West central plant areas	1.0±1.3	Surface runoff
016	Southwest corner of the plant	0.2±0.3	Surface runoff
017	Extreme south area of the plant	1.4±3.2	Surface runoff
018	Landfill at north of plant	6.4± 10.8	Surface runoff

[a]Numeral indicates outfall designation. Locations also identified in Fig. 2.2 of this report.

[b]Mean discharge in millions of liters per day ± 1 standard deviation. NA = not available. Mean value based on KPDES measurements for 1995.

[c]NM = Not monitored

Note: This table was taken from Kornegay et al. 1994 (Paducah Gaseous Diffusion Plant Environmental Report for 1993. ES/ESH-53. Oak Ridge National Laboratory, Oak Ridge, Tennessee) the combined C-617 lagoon discharge was diverted on a full-time basis to Outfall 010. Outfall 011 has been a stormwater outfall since the change (C. C. Travis, Environmental Waste Management Division, Environmental Compliance Department, personal communication). Table 2.3 lists the KPDES issues for 1996 and includes exceedances and corrective actions.

2.3 DESCRIPTION OF STUDY SITES

Three sites on Big Bayou Creek (Fig. 2.2), Big Bayou Creek kilometer (BBK) 12.5, BBK 10.0, and BBK 9.1; one site on Little Bayou Creek (Fig. 2.2), Little Bayou Creek kilometer (LUK) 7.2; and one off-site reference station on Massac Creek (Fig. 2.1), Massac Creek kilometer (MAK) 13.8, were routinely sampled to assess the ecological health of the stream. Prior to ORNL's initiation of the instream monitoring task for the PGDP BMP, a site selection study was conducted in 1990. Results of this study are presented in Kszos et al. 1994a. Sites BBK 12.5, BBK 10.8, BBK 9.1, LUK 7.2, and MAK 13.8 were routinely sampled to evaluate ambient toxicity in 1995. A summary of the site locations is given in Table 2.4. Two additional sites (LUK 9.0, and LUK 4.3; Fig 2.2) were sampled as part of the bioaccumulation monitoring task. Hinds Creek in East Tennessee also served as a reference site for the bioaccumulation monitoring task. A more detailed description of the sampling locations for the bioaccumulation monitoring is provided in Sect. 4. Biological monitoring activities conducted through December 1996 are outlined in Table 2.5; a summary of sampling locations is provided in Table 2.6. Toxicity monitoring was conducted quarterly, and fish community, benthic community, and bioaccumulation sampling were conducted twice annually (in the spring and fall). KPDES outfalls at which effluents were evaluated for toxicity during 1996 included 001, 006, 008, 009, 011, 013, 015, 016, 017, and 018.

Table 2.3. Summary of Kentucky Pollutant Discharge Elimination System issues in 1996

Outfall	Issue	Date
004	On February 5, 1996, the fecal coliform concentration was 600 colonies/100 ml which exceeded the KPDES limit of 400 colonies/100 ml. The chlorine concentration at the discharge from C-615 was increased to prevent recurrence of the high fecal coliform concentrations. This is a KPDES permit exceedance.	2/5/96
010, 012, 013	During a routine KPDES outfall inspection, it was discovered that flow from outfalls 010, 012, and 013 was muddy and exhibited floating solids. During a driving tour of the southeast portion of the plant, two gasoline pumps were discovered pumping muddy water from a DOE/LMES excavation south of C-333 which was causing the muddy flow in 010, 012, and 013. This is a violation of 401 KAR 5:031, Section 2, which prohibits degradation of surface waters of the Commonwealth by substances that "produce objectionable color, odor, taste or turbidity." USEC notified DOE that LMES was pumping water and requested the pumping be discontinued. Pumping was discontinued. LMES contacted Kentucky Division of Environmental Protection (KDEP) Regional Office to discuss the issue. After conferring with the KDEP Headquarters the KDEP Regional Office gave LMES permission to resume pumping the "milky" water. The outfall was inspected on May 23, 1996. No discoloration was detected. This is not a KPDES permit exceedance.	5/15/96
008	Rupture of hydraulic line on a cylinder hauler resulted in a spill of approximately 10 gal of hydraulic oil during heavy rains. The oil was washed by the heavy rain to a storm drain where it appeared as a sheen on Outfall 008. Absorbent booms were placed on the outfall to contain the sheen. The majority of the spill was cleaned at the spill site by application of absorbent pads. This is not KPDES permit exceedance.	6/12/96
004	Samples taken at Outfall 004 on 9/19/96 indicated a fecal coliform concentration of 450 colonies per 100 ml of sample. The KPDES limit is 400 colonies per 100 ml of sample. Utilities Operations investigated the exceedance, but could determine no cause. This is a KPDES permit exceedance.	9/19/96

Table 2.3 (continued)

Outfall	Issue	Date
006	On October 16, 1996, the September monthly suspended solids average concentration for Outfall 006 was determined to be 36 mg/L. The KPDES limit is 30 mg/L. The exceedance was due to dredging operations in the water treatment plant lagoons. KDEP was notified before the dredging operations began that an exceedance was possible. The dredging operation was planned to minimize, to the greatest extent possible, suspended solids in the effluent. However, due to the nature of the operation, an exceedance was likely to occur. The bypass of the treatment system due to necessary maintenance is covered in Kentucky regulations. The regulations require prior notice to the KDEP that this is type of bypass could cause an exceedance of the permit limit. The required written notification was made by PGDP due to the possibility that an exceedance would occur. This is a KPDES permit exceedance.	10/16/96
006	Hydraulic line rupture on dredging equipment caused a visible sheen of oil on Outfall 006. Discharge of water from full flow lagoon (source of sheen) was stopped. Booms and pads placed in outfall and on visible sheen. This is not a KPDES permit exceedance.	11/6/96
008	The chlorine limit of 0.019 mg/l daily maximum and 0.01 mg/L monthly average was exceeded at Outfall 008. Samples result was 0.47 mg/l. The sodium thiosulfate feed pump at C-615 was plugged. Sodium thiosulfate is used to dechlorinate the effluents. The blockage was removed and the sodium thiosulfate feed was restored to outfall 008. This is a KPDES permit exceedance.	12/10/96

Source: C. C. Travis, Environmental Waste Management Division, Environmental Compliance Department, personal communication).

Table 2.4. Locations and names of sampling sites included in Paducah Gaseous Diffusion Plant Biological Monitoring Program for the Instream Monitoring Task

Current site name[a]	Location[b]
Big Bayou Creek	
BBK 12.5[c]	~200 m downstream of bridge on South Acid Road
BBK 10.8	~5 m upstream of Waterworks Road
BBK 10.0	~50 m upstream of Outfall 006
BBK 9.1	~25 m upstream of flume at gaging station at Bobo Road
Little Bayou Creek	
LUK 9.0	~25 m downstream of Outfall 010
LUK 7.2	~110 m downstream of bridge on Route 358
LUK 4.3	~500 m downstream of Outfall 018
Massac Creek	
MAK 13.8[c]	~40 m upstream of bridge on Route 62, 10 km SE of PGDP

[a]Site names are based on stream name and distance of the site from the mouth of the stream. For example, Big Bayou Creek kilometer (BBK) 9.1 is located 9.1 km upstream of the mouth; LUK = Little Bayou Creek kilometer; and MAK = Massac Creek kilometer.

[b]Locations are based on approximate distances from a major landmark (e.g., bridge or outfall) to the bottom of the reach.

[c]Reference site.

Table 2.5. Sampling schedule for the four components of the Biological Monitoring Program at Paducah Gaseous Diffusion Plant, January–December 1996

Month	Toxicity monitoring	Bioaccumulation	Fishes	Benthic macroinvertebrates
Jan.				
Feb.				
Mar.	X		X	X
Apr.		X	X[a]	
May	X			
June				
July				
Aug.	X			
Sept.	X[b]		X	X
Oct.		X		
Nov.	X			
Dec.				

[a]Sampling required due to inclement weather in March.
[b]Outfall 010 only.

Table 2.6. Summary of sampling locations for tasks of the Biological Monitoring Program 1991–96

Location[a]	Toxicity Monitoring[b]	Bioaccumulation		Invertebrates	Fish	
		PCB[c]	Hg[d]		Quantitative	Qualitative[e]
Big Bayou Creek						
BBK 12.5	✓	✓		✓	✓	
BBK 10.8	✓					
BBK 10.0	✓	✓		✓	✓	
BBK 9.1	✓	✓	✓	✓	✓	
BBK 2.8		✓				
Little Bayou Creek						
LUK 9.0		✓				
LUK 7.2	✓	✓	✓	✓	✓	
LUK 4.3		✓				✓
Massac Creek						
MAK 13.8	✓			✓	✓	
Hinds Creek		✓				

[a]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer. Hinds Creek = reference site located in Anderson County, Tennessee.

[b]Ambient toxicity testing eliminated in 1996.

[c]PCB = polychlorinated biphenyl; BBK 2.8 eliminated in April 1995; BBK 10.0 eliminated in April 1996.

[d]Hg = mercury; spring sampling eliminated in April 1995.

[e]Qualitative sampling eliminated in September 1996.

3. TOXICITY MONITORING

L. A. Kszos and B. K. Konetsky

The toxicity monitoring task for BMP measures the toxicity of effluents as required by the KPDES permit. Until 1996, ambient water toxicity was monitored at four sites in Big Bayou Creek, one site in Little Bayou Creek, and one reference site in Massac Creek. The ambient monitoring was eliminated from BMP because there was consistently no evidence of chronic toxicity, no correlation between reductions in fathead minnow survival or growth at the continuously flowing outfalls with reductions in fathead minnow survival or growth at ambient locations, and no significant change in the water chemistry of the ambient sites or outfalls (Kszos 1996).

3.1 INTRODUCTION

The ESD Toxicology Laboratory at ORNL began evaluating the toxicity of continuous and intermittent outfalls at PGDP in October 1991. As required by a draft Agreed Order, *Ceriodaphnia* and fathead minnow tests of the continuous and intermittent outfalls were conducted quarterly. In September 1992, a renewed KPDES permit was issued to PGDP. Under the requirements of this permit, *Ceriodaphnia* and fathead minnow tests were continued on a quarterly basis. As required, the test methods used are the Cladoceran (*Ceriodaphnia dubia*) Survival and Reproduction Test (hereinafter referred to as the *Ceriodaphnia* test) and the Fathead Minnow (*Pimephales promelas*) Larval Survival and Growth Test (hereinafter referred to as the fathead minnow test; Lewis et al. 1994). After May 1995, tests of continuously flowing Outfalls 006, 008, 009, and 010 were reduced to the more sensitive species (fathead minnow larvae). Tests of continuously flowing Outfall 001 continued with *Ceriodaphnia* and fathead minnow larvae. After January 1996, tests of intermittently flowing Outfalls 013, 015, 016, 017, and 018 were reduced to the more sensitive species (fathead minnow larvae).

3.2 MATERIALS AND METHODS

Toxicity tests of effluents from the continuously flowing outfalls (001, 006, 008, 009, and 011) and the intermittently flowing outfalls (013, 015, 016, 017, and 018) were conducted according to the schedule shown in Tables 3.1 and 3.2 respectively. After PCBs were detected at Outfall 011 in June 1994, effluent from the C-617 lagoon was diverted from Outfall 011 to Outfall 010. As a result, after June 1994, effluent from Outfall 010 rather than Outfall 011 was tested for toxicity. This report summarizes the toxicity test results for all tests conducted from 1991 to 1996 and the chemistry analyses for 1996. Most of the outfalls have been evaluated at least 22 times.

Prior to September 1992, tests of the continuously flowing outfalls were conducted using seven consecutive, daily grab samples collected at the KPDES discharge points. From September 1992 to July 1995, tests used seven 24-h composite samples. Beginning in August 1995, three 24-h composite samples have been used. Samples from the continuously flowing outfalls were collected by personnel from ESD and transported to a nearby offsite laboratory at the Paducah Community College. The intermittently flowing outfalls are rainfall dependent; thus, tests were conducted using one grab sample. Samples from the intermittently flowing outfalls were collected by personnel from PGDP, refrigerated, and shipped to ESD using 24-h delivery. All samples were collected and delivered according to established chain-of-custody procedures (Kszos et al. 1989). Time of collection, water temperature, and arrival time in the laboratory were recorded.

The *Ceriodaphnia* and fathead minnow tests are static-renewal tests, meaning that test water is replaced daily for 6 or 7 consecutive days. The fathead minnow test consists of four replicates per test concentration with ten animals per replicate. Each day before the water was replaced, the number of surviving larvae was recorded. At the end of 7 d, the larvae were dried and weighed to obtain an estimate of growth. The *Ceriodaphnia* test consists of ten replicates per test concentration with one animal per replicate. Each day the animals were transferred from a beaker containing old test solution and placed in a beaker containing fresh test solution. At this time, survival and the number of offspring produced were recorded. A control consisting of dilute mineral water augmented with trace metals was included with each test. On each fresh sample, subsamples of each effluent were routinely analyzed for pH, conductivity, alkalinity, water hardness, and total residual and free chlorine (Kszos et al.

Table 3.1. Summary of toxicity test dates for continuous outfalls 001, 006, 008, 009, 010, 011

	Ceriodaphnia dubia					Fathead minnow				
Test date	001	006	008	009	011	001	006	008	009	011
October 24-31, 1991	X	X	X	X	X	X	X	X	X	X
February 13-20, 1992	X	X	X	X	X	X	X	X	X	X
May 21-28, 1992	X	X	X	X	X	X	X	X	X	X
August 13-20, 1992	X	X	X	X	X	X	X	X	X	X
October 22-29, 1992	X	X	X	X	X	X	X	X	X	X
February 11-18, 1993	X	X	X	X	X	X	X	X	X	X
May 20-27, 1993	X	X	X	X	X	X	X	X	X	X
August 9-16, 1993	X	X	X	X	X	X	X	X	X	X
October 14-21, 1993	X	X	X	X	X	X	X	X	X	X
December 2-9, 1993	—	—	—	—	—	—	—	X	—	—
March 10-17, 1994	X	X	X	X	X	X	X	X	X	X
March 25-April 1, 1994	—	—	—	—	—	—	X	—	—	X
April 28-May 5, 1994	—	X	—	—	X	—	X	—	—	X
May 25-June 2, 1994	X	—	X	X	—	X	—	X	X	—
June 16-23, 1994	—	—	—	—	—	—	—	X	X	—
Test date	001	006	008	009	010	001	006	008	009	010
August 11-18, 1994	X	X	X	X	X	X	X	X	X	X
September 8-16, 1994	—	X	—	—	—	—	—	X	X	—
October 27-November 4, 1994	X	X	X	X	X	X	X	X	X	X
November 16-23, 1994	X	—	—	—	—	—	—	—	X	—
March 9-16, 1995	X	X	X	X	X	X	X	X	X	X
May 10-17, 1995	X	X	X	X	X	X	X	X	X	X
August 9-16, 1995	X	—	—	—	—	X	X	X	X	X
October 25-Movember 1, 1995	X	—	—	—	—	X	X	X	X	X
November 15-21, 1995	X	—	—	—	—	—	—	—	—	—
March 9-16, 1996	X	—	—	—	—	X	X	X	X	X
March 28-April 4, 1996	—	—	—	—	—	—	X	—	—	X
May 9-16, 1996	X	—	—	—	—	X	X	X	X	X
August 13-20, 1996	X	—	—	—	—	X	X	X	X	X
September 5-12, 1996	—	—	—	—	—	—	—	—	—	X
November 5-12, 1996	X	—	—	—	—	X	X	X	X	X

Note: Beginning in August 1994, Outfall 010 was tested in place of Outfall 011.

Table 3.2. Summary of toxicity test dates for intermittent outfalls

	Ceriodaphnia dubia					Fathead minnow				
Test Date	013	015	016	017	018	013	015	016	017	018
December 27, 1991–January 3, 1992	X	X	X	X	X	X	X	X	X	X
March 20–27, 1992	X	X	X	X	X	X	X	X	X	X
June 26–July 3, 1992[a]	X	X	—	X	X	X	X	—	X	X
September 22–29, 1992	—	—	—	—	—	X	X	X	X	X
September 29–October 6, 1992	X	X	X	X	X	—	—	—	—	—
November 13–20, 1992	X	X	X	X	X	X	X	X	X	X
January 6–13, 1993	X	X	X	X	X	X	X	X	X	X
May 4–11, 1993	X	X	X	X	X	X	X	X	X	X
September 16–23, 1993	X	X	X	X	X	X	X	X	X	X
November 16–23, 1993	X	X	X	X	X	X	X	X	X	X
February 15–22, 1994	X	X	X	X	X	X	X	X	X	X
April 7–14, 1994	X	X	X	X	X	X	X	X	X	X
September 24–October 1, 1994	X	X	X	X	X	X	X	X	X	X
November 17–24, 1994	X	X	X	X	X	X	X	X	X	X
January 19–26, 1995	X	X	X	X	X	X	X	X	X	X
April 21–28, 1995	X	X	X	X	X	X	X	X	X	X
July 6–13, 1995	X	X	X	X	X	X	X	X	X	X
November 8–15, 1995	X	X	X	X	X	X	X	X	X	X
January 3–10, 1996	X	X	X	X	X	X	X	X	X	X
April 24–May 1, 1996	—	—	—	—	—	X	X	X	X	X
July 16–23, 1996	—	—	—	—	—	X	X	X	X	X
October 19–26, 1996	—	—	—	—	—	X	X	X	X	X

[a]Outfall 016 was not tested due to lack of flow.

1989). The concentration of total suspended solids (TSS) was measured on each sample from the intermittent outfalls (Kszos et al. 1989).

A linear interpolation method (Lewis et al. 1994) was used to determine the 25% inhibition concentration (IC25, that concentration causing a 25% reduction in fathead minnow growth or *Ceriodaphnia* reproduction compared to a control). A computer program (A Linear Interpolation Method for Sublethal Toxicity: Inhibition Concentration [ICp] Approach, version 2.0) distributed by the EPA (Environmental Research Laboratory, Duluth, Minnesota) was used for the calculation. The chronic toxicity unit (TU_c = 100/IC25) is required as a compliance endpoint in the renewed permit (September 1992 to present). The higher the TU_c, the more toxic an effluent. Because Little Bayou and Big Bayou creeks have been determined to have a low flow of zero, a $TU_c > 1.0$ for the continuously flowing effluents would be considered a noncompliance and an indicator of potential instream toxicity. Summary statistics (e.g., mean, standard deviation) were calculated using SAS (SAS 1985a, 1985b).

3.3 RESULTS

3.3.1 Continuously Flowing Outfalls 001, 006, 008, 009, and 010

Mean survival and growth of fathead minnows and survival and mean reproduction of *Ceriodaphnia* for each outfall and test during 1996 are provided in Tables B.1 and B.2. A summary of the TU_cs for all toxicity tests conducted during 1991–95 are provided in Table 3.3. During 1996, effluent from Outfall 010 exceeded the permit limit ($TU_c > 1.0$) in March and August. The resulting TU_cs for fathead minnows were 8.62 and 3.29 respectively. Confirmatory tests were conducted within 2 weeks of each exceedance and for each test, the resulting TU_c was <1.0, showing no evidence of toxicity. Effluent from Outfall 006 exceeded the permit limit during March. The resulting TU_c for fathead minnows was 2.33. A confirmatory test conducted within 2 weeks of the exceedance demonstrated that the TU_c was <1.0 and the effluent samples were no longer toxic.

Water quality measurements (pH, conductivity, alkalinity, and hardness) for each outfall and test during 1996 are provided in Table B.3. A summary of water quality parameters for the continuously flowing outfalls during 1996 is provided in Table 3.4. The water chemistry was similar to that in previous years with the exception of high conductivity in Outfall 009 during March. There were no known unusual events during the sampling period, so it is unknown what caused the variation in chemistry. In samples collected during 1996, the pH ranged from a minimum of 7.2 (Outfall 008) to a maximum of 9.41 (Outfall 001). Effluent from Outfall 006 had the highest mean pH (8.88). Mean alkalinity ranged from 35 (Outfall 008) to 57 mg/L as $CaCO_3$ (Outfall 009). Mean hardness and conductivity were highest in effluent from Outfall 001 (283 mg/L as $CaCO_3$ and 1049 μS/cm respectively). Mean

Table 3.3. Results of effluent toxicity tests for outfalls 001, 006, 008, 009, 010, and 011

		Chronic Toxicity Units (TU_c)[a]	
Outfall	Test Date	Fathead Minnow	*Ceriodaphnia*
001	October 1991	ND[b]	<1
	February 1992	<1	<1
	May 1992	ND[b]	4.5
	August 1992	<1	<1
	October 1992	<1	<1
	February 1993	<1	<1
	May 1993	<1	<1
	August 1993	<1	<1
	October 1993	<1	1.09
	March 1994	<1	<1
	May 1994	<1	<1
	August 1994	<1	<1
	October 1994	<1	I[d]
	November 1994	NT[c]	<1
	March 1995	< 1	< 1
	May 1995	< 1	< 1
	August 1995	< 1	< 1
	October 1995	< 1	9.18
	November 1995	NT	1.59
	March 1996	< 1	< 1
	May 1996	< 1	< 1
	August 1996	< 1	< 1
	November 1996	< 1	< 1

Table 3.3 (continued)

		Chronic Toxicity Units (TU_c)[a]	
Outfall	Test Date	Fathead Minnow	*Ceriodaphnia*
006	October 1991	ND	< 1
	February 1992	1.39	1.56
	May 1992	ND	<1
	August 1992	<1	<1
	October 1992	<1	<1
	February 1993	<1	<1
	May 1993	<1	I[d]
	June 1993	NT[c]	<1
	August 1993	<1	<1
	October 1993	<1	<1
	March 1994	5.97	<1
	March 1994	18.32	NT[c]
	April 1994	<1	<1
	August 1994	<1	1.36
	September 1994	NT[c]	<1
	October 1994	< 1	< 1
	March 1995	< 1	< 1
	May 1995	< 1	< 1
	August 1995	< 1	NT[c]
	October 1995	< 1	NT[c]
	March 1996	2.33	NT[c]
	March 1996	< 1	NT[c]
	May 1996	< 1	NT[c]
	August 1996	< 1	NT[c]
	November 1996	< 1	NT[c]

Table 3.3 (continued)

		Chronic Toxicity Units (TU_c)[a]	
Outfall	Test Date	Fathead Minnow	*Ceriodaphnia*
008	October 1991	ND[b]	<1
	February 1992	9.77	<1
	May 1992	ND	<1
	August 1992	<1	<1
	October 1992	<1	<1
	February 1993	<1	<1
	May 1993	<1	I[d]
	June 1993	NT[c]	<1
	August 1993	<1	<1
	October 1993	4.08	<1
	December 1993	<1	NT[c]
	March 1994	<1	<1
	May 1994	1.30	<1
	June 1994	<1	NT[c]
	August 1994	1.56	<1
	September 1994	<1	NT[c]
	October 1994	<1	<1
	March 1995	< 1	< 1
	May 1995	< 1	< 1
	August 1995	< 1	NT[c]
	October 1995	< 1	NT[c]
	March 1996	< 1	NT[c]
	May 1996	< 1	NT[c]
	August 1996	< 1	NT[c]
	November 1996	< 1	NT[c]

Table 3.3 (continued)

Outfall	Test Date	Chronic Toxicity Units (TU_c)[a]	
		Fathead Minnow	*Ceriodaphnia*
009	October 1991	ND	< 1
	February 1992	7.87	<1
	May 1992	<1	<1
	August 1992	<1	<1
	October 1992	2.16	1.05
	February 1993	<1	<1
	May 1993	<1	I[d]
	June 1993	NT[c]	<1
	August 1993	<1	<1
	October 1993	<1	<1
	March 1994	<1	<1
	May 1994	1.09	<1
	June 1994	<1	NT[c]
	August 1994	2.09	<1
	September 1994	<1	NT[c]
	October 1994	10.73	<1
	November 1994	3.38	NT[c]
	March 1995	< 1	< 1
	May 1995	< 1	< 1
	August 1995	< 1	NT[c]
	October 1995	< 1	NT[c]
	March 1996	< 1	NT[c]
	May 1996	< 1	NT[c]
	August 1996	< 1	NT[c]
	November 1996	< 1	NT[c]

Table 3.3 (continued)

		Chronic Toxicity Units (TU_c)[a]	
Outfall	Test Date	Fathead Minnow	*Ceriodaphnia*
010[e]	August 1994	< 1	< 1
	October 1994	< 1	< 1
	March 1995	< 1	< 1
	May 1995	< 1	< 1
	August 1995	< 1	NT[c]
	October 1995	< 1	NT[c]
	March 1996	8.62	NT[c]
	March 1996	< 1	NT[c]
	May 1996	< 1	NT[c]
	August 1996	3.29	NT[c]
	September 1996	< 1	NT[c]
	November 1996	< 1	NT[c]
011	October 1991	ND	<1
	February 1992	7.69	<1
	May 1992	ND	<1
	August 1992	<1	<1
	October 1992	<1	<1
	February 1993	<1	<1
	May 1993	<1	<1
	August 1993	<1	<1
	October 1993	<1	<1
	March 1994	23.53	<1
	March 1994	32.57	NT[c]
	April 1994	<1	<1
	August 1994	NT[e]	NT[e]

[a]Chronic toxicity unit = 100/IC25; IC25 = the concentration causing a 25% reduction in fathead minnow growth or *Ceriodaphnia* reproduction. IC = inhibition concentration.
[b]ND = not determined.
[c]NT = not tested.
[d]I = Invalid test due to low reproduction in the control water.
[e]Outfall 011 is no longer being tested for toxicity. Outfall 010 is tested in place of outfall 011.

Table 3.4. Summary of water chemistry of full-strength samples from continuously flowing outfalls in 1996

Sample	pH (Standard units)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity ($\mu S/cm$)
Outfall 001				
Mean (± SD)	8.82 (0.42)	39.8 (6.7)	282.7 (41.6)	1048.8 (132.9)
Range	8.20–9.41	33–57	182–338	726–1171
n	12	12	12	12
Outfall 006				
Mean (± SD)	8.88 (0.33)	51.7 (4.4)	73.7 (5.7)	206.7 (15.3)
Range	8.28–9.36	45–61	62–80	186–235
n	15	15	15	15
Outfall 008				
Mean (± SD)	7.42 (0.14)	35.3 (10.9)	73.2 (11.5)	280.0 (64.3)
Range	7.20–7.64	23–55	54–92	210–432
n	12	12	12	12
Outfall 009				
Mean (± SD)	7.93 (0.13)	57.3 (20.9)	93.8 (25.5)	463.5 (345.7)
Range	7.69–8.12	27–99	58–130	192–1263
n	12	12	12	12
Outfall 010				
Mean (± SD)	7.65 (0.25)	36.3 (10.4)	79.9 (9.7)	278.6 (27.1)
Range	7.21–7.98	22–60	66–100	240–327
n	18	18	18	18

hardness at the remaining outfalls ranged from 73 to 94 mg/L as $CaCO_3$ and mean conductivity ranged from 206 to 463 $\mu S/cm$.

3.3.2 Intermittently Flowing Outfalls 013, 015, 016, 017, and 018

Mean survival and growth of fathead minnows for each outfall and test during 1996 are provided in Tables B.4 and B.5. A summary of the TU_cs for all toxicity tests conducted during 1991–96 is provided in Table 3.5. Although PGDP does not have a compliance limit

Table 3.5. Results of effluent toxicity tests for outfalls 013, 015, 016, 017, and 018

		Chronic toxicity unit (TU_c)[a]	
Outfall	Test Date	Fathead minnow	*Ceriodaphnia*
013	December 1991	<1	<1
	March 1992	5.82	<1
	June 1992	1.02	<1
	September 1992	<1	<1
	November 1992	1.96	<1
	January 1993	<1	6.99
	May 1993	1.3	<1
	September 1993	1.39	<1
	November 1993	<1	<1
	February 1994	11.31	1.04
	April 1994	<1	<1
	September 1994	<1	<1
	November 1994	<1	<1
	January 1995	< 1	< 1
	April 1995	< 1	< 1
	July 1995	< 1	< 1
	October 1995	< 1	< 1
	January 1996	< 1	34.60
	April 1996	< 1	NT[b]
	July 1996	< 1	NT
	October 1996	< 1	NT
015	December 1991	<1	<1
	March 1992	7.91	<1
	June 1992	<1	<1
	September 1992	<1	ND[c]
	November 1992	<1	<1
	January 1993	1.52	<1
	May 1993	3.62	<1
	September 1993	<1	<1
	November 1993	<1	<1
	February 1994	2.04	<1
	April 1994	11.15	<1
	September 1994	<1	<1
	November 1994	17.54	< 1

Table 3.5 (continued)

Outfall	Test Date	Chronic toxicity unit (TU_c)[a]	
		Fathead minnow	*Ceriodaphnia*
	January 1995	< 1	< 1
	April 1995	< 1	< 1
	July 1995	< 1	< 1
	October 1995	< 1	< 1
	January 1996	< 1	< 1
	April 1996	< 1	NT
	July 1996	< 1	NT
	October 1996	< 1	NT
016	December 1991	<1	<1
	March 1992	1.74	<1
	September 1992	<1	<1
	November 1992	1.32	<1
	January 1993	2.04	<1
	May 1993	<1	<1
	September 1993	<1	<1
	November 1993	<1	<1
	February 1994	<1	<1
	April 1994	<1	<1
	September 1994	<1	<1
	November 1994	23.47	<1
	January 1995	< 1	< 1
	April 1995	< 1	< 1
	July 1995	< 1	< 1
	November 1995	< 1	< 1
	January 1996	< 1	< 1
	April 1996	< 1	NT
	July 1996	< 1	NT
	October 1996	< 1	NT
017	December 1991	ND	<1
	March 1992	4.54	<1
	June 1992	<1	<1
	September 1992	5.01	<1
	November 1992	<1	<1

Table 3.5 (continued)

Outfall	Test Date	Chronic toxicity unit (TU_c)[a]	
		Fathead minnow	*Ceriodaphnia*
	January 1993	<1	<1
	May 1993	23.8	<1
	September 1993	<1	<1
	November 1993	<1	<1
	February 1994	2.83	<1
	April 1994	1.79	<1
	September 1994	<1	<1
	November 1994	66.23	<1
	January 1995	< 1	< 1
	April 1995	< 1	< 1
	July 1995	< 1	< 1
	November 1995	< 1	< 1
	January 1996	< 1	25.91
	April 1996	< 1	NT
	July 1996	< 1	NT
	October 1996	< 1	NT
018	December 1991	<1	<1
	March 1992	5.27	<1
	June 1992	<1	<1
	September 1992	<1	<1
	November 1992	1.43	<1
	January 1993	8.47	<1
	May 1993	21.7	<1
	September 1993	<1	<1
	November 1993	<1	<1
	February 1994	<1	<1
	April 1994	1.39	<1
	September 1994	<1	3.47
	November 1994	<1	<1
	January 1995	< 1	1.01
	April 1995	1.87	< 1

Table 3.5 (continued)

Outfall	Test Date	Chronic toxicity unit (TU_c)[a] Fathead minnow	*Ceriodaphnia*
	July 1995	< 1	< 1
	November 1995	< 1	< 1
018	January 1996	< 1	6.73
	April 1996	< 1	NT
	July 1996	< 1	NT
	October 1996	< 1	NT

[a]Chronic toxicity unit = 100/IC25; IC25 = the concentration causing a 25% reduction in fathead minnow growth or *Ceriodaphnia* reproduction. IC = inhibition concentration.
[b]NT = not tested. Toxicity tests with *Ceriodaphnia* have been discontinued.
[c]ND = not determined.

for the intermittent outfalls, $TU_c > 1.0$ was used as a benchmark. During 1996, the only exceedances of $TU_c > 1.0$ were for the *Ceriodaphnia* tests of outfalls 013, 017, and 018 in January. There were no exceedances for the fathead minnow tests.

Water quality measurements (pH, conductivity, alkalinity, hardness and TSS) for each outfall and test during 1996 are provided in Table B.6. A summary of the water quality parameters (pH, conductivity, alkalinity, and hardness) for each outfall during 1996 is provided in Table 3.6. In general, water from the intermittent outfalls had higher alkalinity and hardness than the continuous outfalls and was similar to previous years. In samples collected during 1996, mean alkalinity ranged from 60 to 99 mg/L $CaCO_3$ and mean hardness ranged from 114 to 195 mg/L $CaCO_3$. Minimum pH ranged from 7.48 to 7.85 S.U. and maximum pH ranged from 7.70 to 8.10 S.U. Mean conductivity ranged from 227 to 405 μS/cm. Total suspended solids in the effluent from the intermittent outfalls were within the range measured during 1995 with the exception of January 1996. During January, total suspended solids in outfalls 013, 015, 016, 017, and 018 were 181, 424, 8, 159, and 253 mg/L respectively.

3.4 DISCUSSION

During 1996, effluent samples from Outfall 006 exceeded the permit limit for fathead minnows of $TU_c > 1.0$ in March and samples from Outfall 010 exceeded the permit limit for fathead minnows of $TU_c > 1.0$ in March and August. The toxic contaminants are unknown, but because the confirmatory tests documented that the effluent was no longer toxic, the

Table 3.6. Summary of water chemistry analyses of full-strength samples from intermittently flowing effluents in 1996

Sample	pH (Standard units)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Outfall 013				
Mean (± SD)	7.71 (0.16)	75.0 (24.2)	195.0 (88.3)	405.3 (150.5)
Range	7.48–7.86	47–106	86–288	204–556
n	4	4	4	4
Outfall 015				
Mean (± SD)	7.81 (0.15)	74.3 (5.7)	124.0 (49.8)	356.5 (115.3)
Range	7.61–7.97	67–81	84–196	258–504
n	4	4	4	4
Outfall 016				
Mean (± SD)	7.81 (0.11)	97.8 (37.9)	155.0 (68.6)	380.5 (155.9)
Range	7.69–7.95	72–154	92–246	251–589
n	4	4	4	4
Outfall 017				
Mean (± SD)	8.00 (0.11)	98.8 (22.3)	137.0 (35.5)	297.3 (53.6)
Range	7.85–8.10	80–130	104–180	239–359
n	4	4	4	4
Outfall 018				
Mean (± SD)	7.67 (0.02)	60.5 (12.4)	114.0 (28.3)	227.3 (81.7)
Range	7.65–7.70	46–76	84–152	126–326
n	4	4	4	4

presence of the contaminant may have been intermittent or the concentration of the contaminant may have decreased. Total residual chlorine (TRC) was not measured in the discharges, but it is likely to be the contaminant because no KPDES violations of TRC have occurred, nor was measurable TRC present in tests conducted in 1994–95.

Full-strength effluent from the intermittent outfalls was never toxic to fathead minnows, which resulted in $TU_c < 1.0$ for every test. The results of the intermittent toxicity tests show continued improvement in the number of times the TU_c has been < 1.0 for the fathead minnows. For example, Outfall 015 exceeded a TU_c of 1.0 in 6 of 12 fathead minnow tests conducted from 1992–1994, but from 1995 to 1996 there were no exceedances.

Ceriodaphnia toxicity tests of the intermittent outfalls were conducted in January and exceeded a TU_c of 1.0 in outfalls 015, 017, and 018. This was an unusual event because the TU_c s had almost always been <1.0 previously. The TSS in January was also atypically high; for all of the outfalls except 016, the TSS concentrations were 2–7 times higher than during any other test period. A comparison of the sampling dates with rainfall data (Table A.1) shows that the samples were collected during a low rainfall event (January 2) compared to other sampling dates (April 23, July 15, October 18). The high TSS or a contaminant associated with the TSS was the most likely cause of the reduced *Ceriodaphnia* reproduction during January.

3.5 BIOAVAILABILITY STUDY

On April 5, 1996, the Commonwealth of Kentucky Natural Resources and Environmental Protection Cabinet issued an Agreed Order that required the development of a plan to conduct studies that would identify alternative metal limits for the continuous and intermittent outfalls (001, 002, 003, 008, 009, 010, 011, 012, 013, 015, 016, 017, and 018). Alternative metal limits may be developed for cadmium, chromium, copper, lead, nickel, and zinc. As stipulated in the Agreed Order, DOE/USEC must demonstrate to the satisfaction of the Cabinet that a more appropriate analytical technique or criteria is available that provides a better measurement of levels of metals present that would be toxic to aquatic life.

In May 1996, the KDOW issued revised *Procedures to Facilitate Alternative Metals Limits*. The revised KDOW procedures provide an alternative method for deriving site-specific metals limits; combining biomonitoring with chemical-specific analyses. The procedure provides an alternative method of measuring compliance to total recoverable metal limits. KDOW developed these procedures to address derivation of alternative metal limits for discharges into zero flow streams. Alternative permit limits are determined by multiplying the total recoverable metal concentration by the dissolved metal:total recoverable (TR) metal ratio. The result is then multiplied by the reciprocal of the U.S. Environmental Protection Agency's (EPA's) freshwater criteria conversion factor for each metal of concern. Using the method developed by the KDOW, biomonitoring results and chemical data will be used to recommend alternative metal limits for the outfalls of concern. The data will be used to meet the objectives of the study:

- evaluate the toxicity of continuous outfalls (001, 008, 009, and 010) and intermittent outfalls (003, 013, 015, 016, 017, and 018) at PGDP;
- determine the mean ratio of dissolved to TR metal for Cd, Cr, Cu, Pb, Ni, and Zn in the continuous and intermittent outfalls;
- determine whether the concentration of TR metal discharged causes toxicity to fathead minnows and/or *Ceriodaphnia*; and
- determine alternative metal limits for each metal of concern (Cd, Cr, Cu, Pb, Ni, and Zn).

Sampling and analysis for this study began in December 1996 and are fully described in Phipps and Kszos (1996). Two phases of the study are planned. Phase I will develop alternative metal limits for continuously discharging outfalls and will be completed in 1998. Phase II will develop alternative metal limits for intermittently discharging outfalls. If prior to implementation of the schedules identified in the study plan (Phipps and Kszos 1996), KDOW issues to PGDP a new KPDES permit that includes metals limits, and such limits are not challenged by PGDP, then all activities scheduled to be completed in Phase II will be canceled and PGDP will meet the limits established in the new KPDES permit.

4. BIOACCUMULATION

M. J. Peterson, G. R. Southworth, and R. B. Petrie

4.1 INTRODUCTION

Bioaccumulation monitoring conducted to date as part of the BMP at PGDP has identified PCB contamination in fish in Big Bayou Creek and Little Bayou Creek as major concerns (Birge et al. 1990, 1992; Kszos 1993, 1994, 1995, 1996). Mercury concentrations in fish from Big Bayou Creek were also found to be higher in fish collected downstream from PGDP discharges than in fish from an upstream site (Birge et al. 1990, 1992; Kszos 1993, 1994, 1995, 1996). Concentrations of various other metals and organics in fish from Big Bayou Creek and Little Bayou Creek were well below levels of concern for human consumption.

The primary objective of the 1995–1996 bioaccumulation monitoring was to evaluate spatial and temporal changes in PCB contamination in sunfish from Little Bayou Creek. PCB contamination in fish in Big Bayou Creek had declined to near background levels over the 1992–1995 period, and monitoring in this stream was consequently reduced to a single site immediately downstream from the lowermost PGDP discharge to Big Bayou Creek. Similarly, mercury monitoring was conducted only at that site in Big Bayou Creek. Because Big Bayou Creek is capable of supporting a limited sport fishery for larger game fish, spotted bass were analyzed for mercury and PCBs to evaluate the maximum concentrations likely in fish near the PGDP.

4.2 STUDY SITES

Longear sunfish (*Lepomis megalotis*) were collected for PCB analysis at BBK 12.5 (the upstream reference site on Big Bayou Creek), BBK 10.0, and BBK 9.1 on Big Bayou Creek below PGDP, and LUK 9.0, LUK 7.2 and LUK 4.3 on Little Bayou Creek (Fig. 2.2). Longear sunfish from BBK 12.5, BBK 9.1, and LUK 7.2 were also analyzed for total mercury. Spotted bass, *Micropterus punctulatus*, were collected from BBK 9.1 in October 1995 for mercury PCB analysis. Adult spotted bass, uncommon in Little Bayou Creek, were taken for PCB analysis if found at any of the other sites in Little Bayou Creek. Hinds Creek in Anderson County, Tennessee, served as another source of uncontaminated reference fish. This stream has been used as a reference site for monitoring conducted at DOE facilities in Oak Ridge since 1985, and concentrations of various metals and organic contaminants in fish from this site are well characterized (Ashwood 1994).

Mercury concentrations in fish from Big Bayou Creek (including the upstream reference section) have typically been higher than background levels in fish from the ridge and valley province of east Tennessee. In October 1995, spotted bass were collected from Massac Creek in McCracken County, Kentucky to serve as a background reference for bass collected from Big Bayou Creek.

The length of stream sampled at each site varied with the degree of difficulty in obtaining fish but was held to less than or equal to 1000 m. The BBK 9.1 site encompassed the reach from BBK 9.1 up to Outfall 001 (Fig. 2.2). Bass require large pools and deeper water. Because such habitat is scarce at sites in Big Bayou Creek close to PGDP, a 1000-m reach below BBK 9.1 that contains such habitat was used for collection.

In Little Bayou Creek, the very sharp decrease in PCB contamination in fish between LUK 9.0 and LUK 7.2 (LB2 and LB3 in Birge et al. 1990, 1992) required that collections be confined to relatively short reaches near LUK 9.0 and 7.2. The LUK 9.0 sampling reach in October 1995 and April 1996 extended from Outfall 011 downstream to the bridge at McCaw road. Removal of beaver dams has created more habitat suitable for longear sunfish at this site, and eliminated the need to sample downstream from the bridge. LUK 7.2 encompassed an approximately 250-m reach upstream of Ogden Landing road. The most downstream site was 1000 m centered at LUK 4.3.

4.3 MATERIALS AND METHODS

Because sunfish are short-lived and have small home ranges, they represent recent contaminant exposure at the site of collection, and are thus ideal monitoring tools for evaluating spatial and temporal trends in contamination. Collections of sunfish were restricted whenever possible to fish of a size large enough to be taken by sport fisherman in order to minimize effects of covariance between size and contaminant concentrations and to provide data directly applicable to assessing risks to people who might eat fish from these creeks. In general, high fish densities enabled the collection of eight specimens of sunfish >30 g at all sites except the upper Little Bayou sites.

Longear sunfish were collected in Big Bayou Creek and Little Bayou Creek on October 24–25, 1995, and on April 24, 1996, as part of routine twice yearly monitoring of PCB concentrations in this species. Some of the longear sunfish collected from Big Bayou Creek and Little Bayou Creek in October 1995 were analyzed for total mercury.

Concentrations of contaminants in sunfish provide an effective monitor of temporal and spatial changes in contamination within stream fishes but do not provide a direct estimate of the maximum concentrations that may be present in stream biota. Larger, older, fattier fish, such as carp (*Cyprinus carpio*), black bass (*Micropterus* spp.), and catfish (*Ictalurus* spp.) accumulate several times higher contaminant concentrations under the same exposure conditions (Southworth 1990). Although concentrations in these larger species can be inferred from concentrations in sunfish, direct measurement provides a more reliable estimate.

Spotted bass are abundant in Big Bayou Creek downstream from PGDP, and the fish attain large enough size to make the creek an attractive sport fishing resource. Although large fish such as carp are occasionally present in Big Bayou and can contain very high PCB levels (Kszos 1993), spotted bass are probably the most likely species in the creek to be eaten in significant numbers by anglers. Collections of spotted bass for PCB and mercury monitoring were made on October 24 and 25, 1995, in Big Bayou Creek (BBK 9.1), Little Bayou Creek (LUK 7.2), and Massac Creek (MAK 13.8), a local reference site. Eight spotted bass were taken at BBK 9.1; one at LUK 7.2, and four from Massac Creek.

Each fish was individually tagged with a unique four-digit tag wired to the lower jaw and placed on ice in a labeled ice chest. Fish were held on ice overnight and processed within 48 hours. Each fish was weighed and measured, then fileted, scaled, and rinsed in process tap water. Samples of sunfish for specific analyses were excised, wrapped in heavy duty aluminum foil, labeled, and frozen in a standard freezer at −15°C. For larger fish (bass), filets were wrapped and labeled as were sunfish samples, but at a later date the frozen filets were partially thawed, cut into 2- to 4-cm pieces, and homogenized in a stainless steel blender. A 25-g sample of the ground tissue was wrapped in heavy duty aluminum foil, labeled, frozen, and submitted to LMES Analytical Chemistry Organization for PCB and mercury analyses. Any remaining tissue from filets of sunfish or larger fish was wrapped in foil, labeled, and placed in the freezer for short-term archival storage.

PCB analyses were conducted using Soxhlet extraction techniques according to SW-846 Method 3540 and analysis by capillary column gas chromatography using SW-846 Method

8080 (EPA 1986). Fish were analyzed for total mercury by cold vapor atomic absorption spectrophotometry following digestion in HNO_3/H_2SO_4 (EPA 1991, procedure 245.6).

Quality assurance was evaluated by a combination of blind duplicate analyses, analysis of biological reference standards and uncontaminated fish, and determination of recoveries of analyte spikes to uncontaminated fish. Statistical evaluations of mercury concentrations in bass were made using SAS procedures and software (SAS 1985a,b) for ANOVA and linear regression analysis. The level of significance used for all statistical tests was 5% ($p < 0.05$). SAS procedures were used to calculate the mean, standard error, and standard deviation of mercury and PCB concentrations in fish at each site.

4.4 RESULTS AND DISCUSSION

4.4.1 PCBs

4.4.1.1 Spatial trends

Fall 1995. Results of PCB analyses of sunfish collected from Big Bayou Creek and Little Bayou Creek in October 1995 are presented in Table 4.1 and Appendix C. PCB concentrations measured in Big Bayou sunfish were virtually indistinguishable from background levels. Detectable concentrations were found in only three of sixteen fish from BBK 10.0 and BBK 9.1. PCB concentrations in sunfish from upper Little Bayou Creek (LUK 9.0) near PGDP were much higher, averaging 0.76 μg/g. Fish from LUK 9.0 have contained the highest PCB concentrations in all previous sampling of the two creeks (Birge et al. 1990, 1992; Kszos 1993, 1994, 1995). The mean PCB concentration in Little Bayou fish decreased steadily with distance downstream, averaging 0.50 μg/g at LUK 7.2 and 0.15 μg/g at LUK 4.3. This pattern of decreasing PCB concentrations in sunfish with increasing distance from PGDP discharges (Fig 4.1) has been consistent from year to year throughout the monitoring program. Composition of the PCB mixtures found in sunfish resembled Aroclor 1254 and 1260 at all sites.

Spotted bass from Big Bayou Creek (BBK 9.1) averaged (± SE) 0.16 ± 0.05 μg/g PCBs, a level not much different from that typical of longear sunfish at the same site in previous years. Concentrations in the eight fish ranged from 0.06 to 0.46 μg/g, and only the highly chlorinated materials similar to Aroclor 1254/1260 were present (Appendix C). PCB concentration in the single bass collected from Little Bayou Creek was 0.91 μg/g.

Table 4.1. Mean concentrations of PCBs ($\mu g/g$, wet weight) in fish from streams near Paducah Gaseous Diffusion Plant in October 1995 and April 1996

Site	Species[a]	Mean[b]	SE	Range	n
<u>October 1995:</u>					
BBK 12.5	LNGEAR	≤0.02		<0.01–0.04	8
BBK 10.0	LNGEAR	≤0.03		<0.00–0.11	8
BBK 9.1	LNGEAR	≤0.03		<0.01–0.17	8
	SPOBASS	0.16	0.047	0.06–0.46	8
LUK 9.0	LNGEAR	0.76	0.1	0.32–1.35	8
LUK 7.2	LNGEAR	0.50	0.07	0.18–0.82	8
	SPOBASS	0.91	...	...	1
LUK 4.3	LNGEAR	0.15	0.016	0.12–0.21	8
<u>April 1996:</u>					
BBK 12.5	LNGEAR	<0.04[b]	...	<0.02–<0.07	4
BBK 9.1	LNGEAR	0.26[c]	0.043	<0.05–0.43	8
LUK 9.0	LNGEAR	0.53	0.040	0.41–0.68	8
LUK 7.2	LNGEAR	0.41	0.053	0.21–0.74	8
LUK 4.3	LNGEAR	0.17[c]	0.026	<0.03–0.26	8

[a]LNGEAR - longear sunfish, *Lepomis megalotis*; SPOBASS - spotted bass, *Micropterus punctulatus*.
[b]When more than 50% of analyses were below detection limit, value is mean of measured values and individual detection limits.
[c]When a single value is below detection limit, a value of 1/2 the detection limit was used to calculate mean.

ORNL-DWG 97-5597

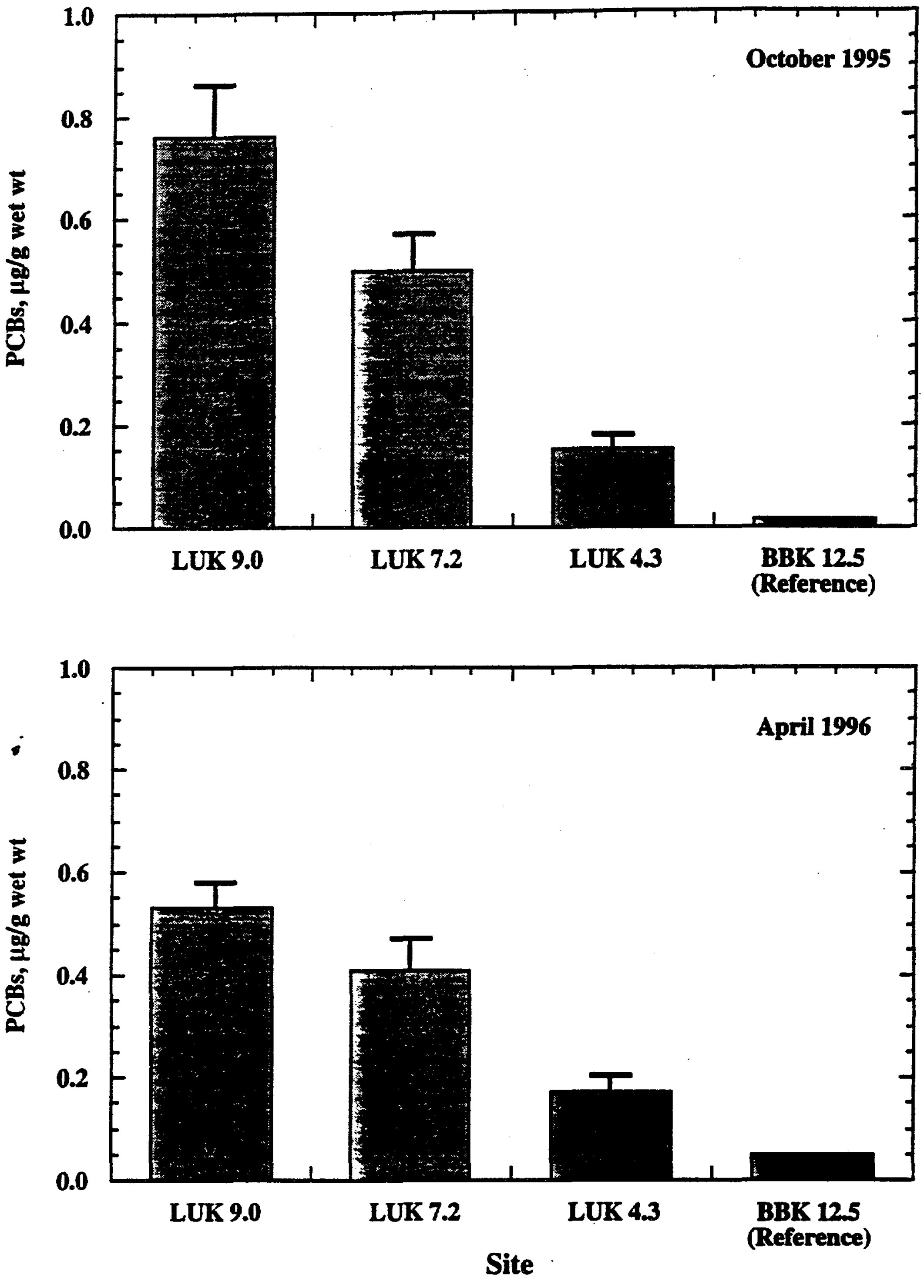


Fig. 4.1. Downstream profile of mean PCB concentrations in longear sunfsh collected from Little Bayou Creek in October 1995 and April 1996.

Spring 1996. In spring 1995, PCB contamination was evident in longear sunfish collected from both Big Bayou and Little Bayou creeks (Table 4.1 and Appendix C). Seven of eight sunfish from Big Bayou (BBK 9.1) contained detectable concentrations of PCBs, while none of the fish from the upstream reference site (BBK 12.5) contained detectable concentrations. The constituents of the PCB mixtures extracted from fish resembled Aroclor 1254 and 1260. As has been the case since October 1994, lower chlorinated PCBs (such as Arochlor 1248) were not found in any Little Bayou or Big Bayou fish.

As has been the case in all previous sampling, the highest mean concentration (0.53 ± 0.04 μg/g) again occurred in fish from the site in Little Bayou Creek immediately downstream from the 010 and 011 outfalls (LUK 9.0). The typical pattern of decreasing concentrations with distance downstream was again evident in April 1996 (Fig. 4.1). The strong downstream gradient in PCB contamination in sunfish, along with the close association between degree of contamination and proximity to outfalls demonstrated to be PCB sources in the past, suggests that the pattern of contamination is sustained by continuing low-level contamination of waters discharged to the creeks, rather than a result of residual PCB contamination in sediments of the creeks themselves. PCB residues in upstream ditch or pond sediments could act as primary continuing sources, or various in-plant sources of fugitive PCBs may continue to contribute concentrations below levels detectable in aqueous phase monitoring.

4.4.1.2 Temporal trends

Results of the October 1995 and April 1996 sampling (Fig. 4.2) reaffirm the variable nature of PCB contamination in stream sunfish and suggest continuing inputs to both Big Bayou and Little Bayou creeks from PGDP discharges or contaminated sediments in the immediate vicinity of those discharges. Considerable improvement is evident in PCB contamination in Little Bayou Creek, where average concentrations in sunfish at LUK 9.0 have decreased from nearly 2 μg/g in spring 1992 to about 0.5 μg/g in spring 1996. It was feared that decreases at this site in 1994/1995 were caused in part by habitat changes that required changes in the species collected, size of individuals, and length of the sampling reach. The 1995/1996 results indicate that the decrease in PCB contamination since 1992 does indeed reflect decreased inputs from upstream sources.

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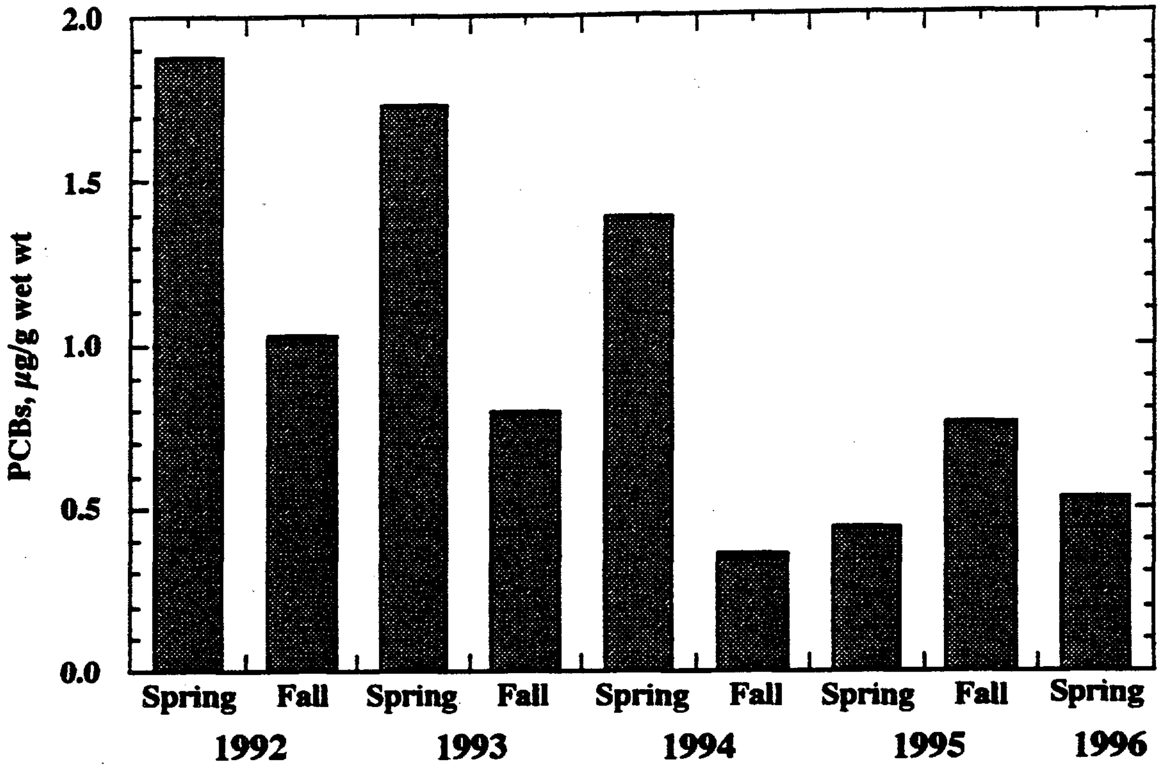

Fig. 4.2. Changes over time in average PCB concentrations in longear sunfish (*Lepomis megalotis*) from Little Bayou Creek near the PGDP Plant (LUK 9.0).

The high temporal variability observed in fish at some sites (Fig. 4.2) suggests that PCB levels in fish may not remain consistently low, and indeed the increase in PCB concentrations in sunfish at BBK 9.1 between fall 1995 and spring 1996 is a case in point. However, the overall decreasing trend and the seasonal pattern of PCB contamination in fish in Little Bayou Creek is encouraging in that it suggests that sunfish are highly responsive to changes in plant practices and/or other in-plant remedial actions that reduce PCB inputs (Milne 1996). The observed pattern is not consistent with residual contamination in stream sediments being a major source of PCBs.

4.4.2 Mercury

Mercury monitoring of sunfish was historically conducted on an annual basis in the spring of each year at a number of Big Bayou and Little Bayou Creek sites. In 1995, the number of sites monitored for mercury accumulation in sunfish was reduced to one site below

PGDP discharges on each stream (LUK 7.2 and BBK 9.1), and the sunfish sampling was moved from spring to fall to correspond with the mercury monitoring at the same sites as spotted bass.

Previous monitoring (prior to October 1995) showed that mean mercury concentrations in sunfish from Little Bayou and Big Bayou creeks downstream of PGDP were somewhat higher than upstream. Fish from most sites contained mercury concentrations that were elevated relative to other reference sites (including Massac Creek in Kentucky and Hinds Creek in Tennessee). In October 1995, mercury concentrations collected from two locations downstream of the PGDP were within the range observed in previous years, averaging 0.18 ± 0.02 (± SE) and 0.32 ± 0.04 μg/g at LUK 7.2 and BBK 9.1 respectively (Fig. 4.3). However, unlike the previous year's results, the October 1995 mean mercury concentration in sunfish from the upstream reference site on Big Bayou Creek (BBK 12.5) was similar to that in sunfish from below PGDP outfalls, averaging 0.36 ± 0.07 μg/g. Sunfish from Hinds Creek, the reference stream for several monitoring programs at DOE sites in east Tennessee, contained mercury concentrations typical of the background levels for that region, averaging 0.13 ± 0.02 μg/g.

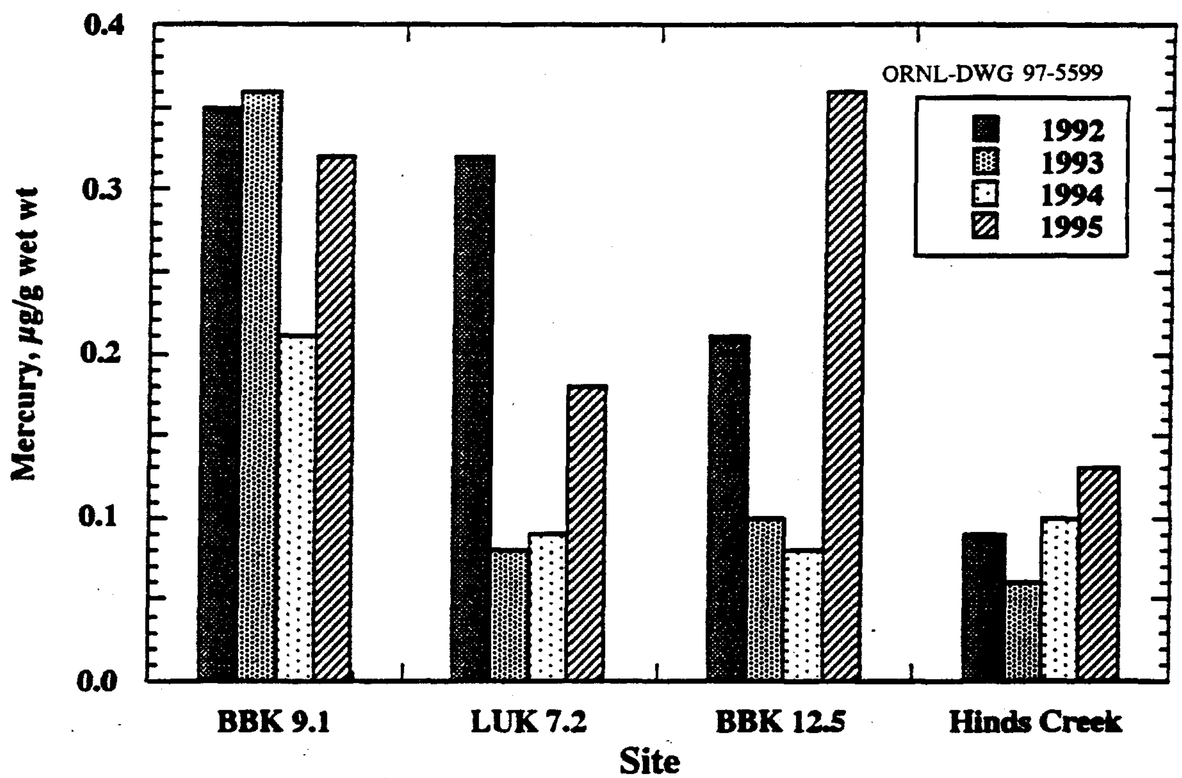

Fig. 4.3. Average total mercury concentrations in longear sunfish (*Lepomis megalotis*) from sites in Little Bayou and Big Bayou creeks and reference sites (BBK 12.5, Hinds CR), 1992–1995.

The bioaccumulation of mercury by fish is predominantly a food chain mediated process, thus predatory species that occupy trophic positions at or near the top of the aquatic food web would be expected to contain higher concentrations of mercury than species lower in the food chain. Spotted bass in Big Bayou Creek occupy that role of terminal predator and are monitored by this task to evaluate the maximum mercury level likely in fish from that creek. The mean mercury concentration in spotted bass collected in October 1995 was 0.52 $\pm$ 0.12 μg/g (Fig. 4.4). The largest fish in the collection, a bass that weighed 680 g, exceeded the FDA threshold limit of 1 μg/g (Appendix C). The 1995 results are consistent with the pattern observed in previous monitoring, that is, mercury concentrations in Big Bayou Creek bass average around 0.5 μg/g and the largest fish approach or exceed commonly-cited human health threshold limits.

In October 1995, mercury was measured in spotted bass from a local reference stream, Massac Creek, in order to assess what level of mercury might be typical to bass in the West Kentucky region. The mean mercury concentration in four spotted bass from Massac Creek was 0.34 $\pm$ 0.02 μg/g. Although this level is lower than the average observed in Big Bayou Creek bass, it is still substantially higher than levels measured previously (Kszos 1994, 1995, 1996) in Massac Creek sunfish. Given that sunfish from upstream of PGDP discharges have at least occasionally contained elevated mercury concentrations, and bass from a reference stream also contain significant quantities of mercury, it seems likely that at least part of the mercury burden in Big Bayou Creek fish is attributable to geologic sources.

4.5 FUTURE STUDIES

The high temporal variability in PCB concentrations in fish indicates that routine monitoring of Little Bayou and Big Bayou fish is warranted. Monitoring of similar PCB problems in Oak Ridge has shown that dramatic year-to-year changes can occur while cleanup activities and other in-plant processes are ongoing. Sunfish have been shown to be effective indicators of PCB exposure and can be effectively used to evaluate the effects of plant discharges. Future monitoring will continue to focus on PCB contamination in Little Bayou Creek with less effort in Big Bayou Creek. Monitoring of mercury contamination in fish will focus on the most contaminated site on Big Bayou Creek immediately downstream from PGDP discharges.

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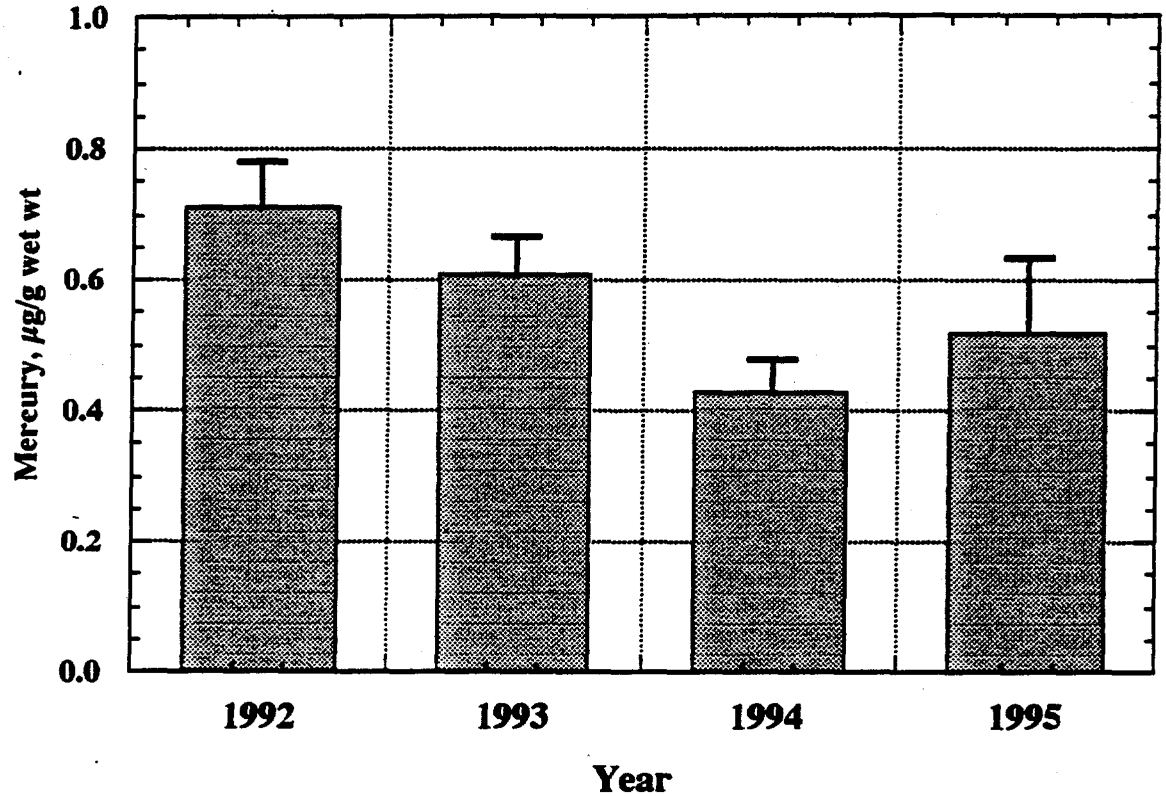

Fig. 4.4. Average concentrations (± 1 SE) of total mercury in spotted bass (*Micropterus punctulas*) from Big Bayou Creek downstream from PGDP (BBK 9.1), 1992–1995.

5. ECOLOGICAL MONITORING STUDIES

5.1 FISHES *(M. G. Ryon)*

5.1.1 Introduction

Fish population and community studies can be used to assess the ecological effects of changes in water quality and habitat. These studies offer several advantages over other indicators of environmental quality (see Karr et al. 1986, Karr 1987) and are especially relevant to assessment of the biotic integrity of Little Bayou and Big Bayou creeks. Monitoring of fish communities has been used by the Biological Monitoring and Abatement Program (BMAP) in ESD for receiving streams at ORNL (Loar et al. 1991); K-25 Site (Loar et al. 1992, Ryon 1993a); the Portsmouth Gaseous Diffusion Plant (Ryon 1994f); and the Y-12 Plant (Loar et al. 1989, Ryon 1992a, Southworth et al. 1992), with some programs operational since 1984. Changes in the fish communities in these systems have indicated recovery (Ryon 1994b,d) as well as documented impacts (Ryon 1993b, 1994c).

The objectives of the instream fish monitoring task were (1) to characterize spatial and temporal patterns in the distribution and abundance of fishes in Little Bayou and Big Bayou creeks, (2) to document the effects of PGDP operations on fish community structure and function, and (3) to document any recovery of the community associated with remedial actions conducted by PGDP.

5.1.2 Study Sites

Quantitative sampling of the fish community was conducted at five sites: three sites on Big Bayou Creek (BBK 12.5, BBK 10.0, and BBK 9.1; Fig. 2.2); one site on Little Bayou Creek (LUK 7.2, Fig. 2.2); and one offsite reference station on Massac Creek (MAK 13.8, Fig. 2.1). MAK 13.8 was chosen as a reference site for BBK 9.1 and BBK 10.0. The upper site on Big Bayou Creek (BBK 12.5) was selected as a smaller reference site to be comparable to LUK 7.2. A qualitative sampling site (LUK 4.3) was established to evaluate the fish community in this area in response to earlier concerns of possible PGDP impacts (see Ryon 1994a). Additional qualitative samples were made at sites throughout the Coastal Plain Province near the PGDP. The additional sample sites were located on Perkins Creek, Massac

Creek, Big Bayou Creek, Little Bayou Creek, Newton Creek, Humphrey Creek, and Shawnee Creek watersheds (Fig. 5.1).

5.1.3 Materials and Methods

Quantitative sampling of the fish populations was conducted by electrofishing on March 3–5, April 8–9, and September 9–11, 1996. Data from these samples were used to estimate species richness, population size (numbers and biomass per unit area), and calculate annual production. Fish sampling sites either overlapped or were within 100 m of the sites included in the benthic macroinvertebrate monitoring task (Sect. 5.2). Qualitative fish sampling at LUK 4.3 was conducted by electrofishing on April 9, 1996. Data from this sample were used to determine species richness and number of specimens (relative abundance) based on sampling a known length of stream.

Qualitative samples were also taken in streams near the PGDP that were within the Coastal Plain Province and thus of similar geological, habitat, and environmental conditions. These samples were taken during 1990 to 1996 to provide regional information on the relative quality of fish communities of Little Bayou Creek, Big Bayou Creek, and Massac Creek. These efforts were an extension of the initial selection of reference sites (see Kszos et al. 1994). All field sampling was conducted according to standard operating procedures (Schilling et al. 1995).

5.1.3.1 Quantitative field sampling procedures

All stream sampling was conducted using two or three Smith-Root backpack electrofishers, depending on stream size. Each unit can deliver up to 1200 V of pulsed direct current in order to stun fish.

After 0.64-cm-mesh seines were placed across the upper and lower boundaries of the fish sampling site to restrict fish movement, a five- to nine-person sampling team electrofished the site in an upstream direction on three consecutive passes. Stunned fish were collected and stored, by pass, in seine-net holding pens (0.64-cm-diam mesh) or in buckets during further sampling.

Following the electrofishing, fish were anesthetized with MS-222 (tricaine methanesulfonate), identified, measured (total length), and weighed using Pesola spring scales. Individuals were recorded by 1-cm size classes and species. After ten individuals of a

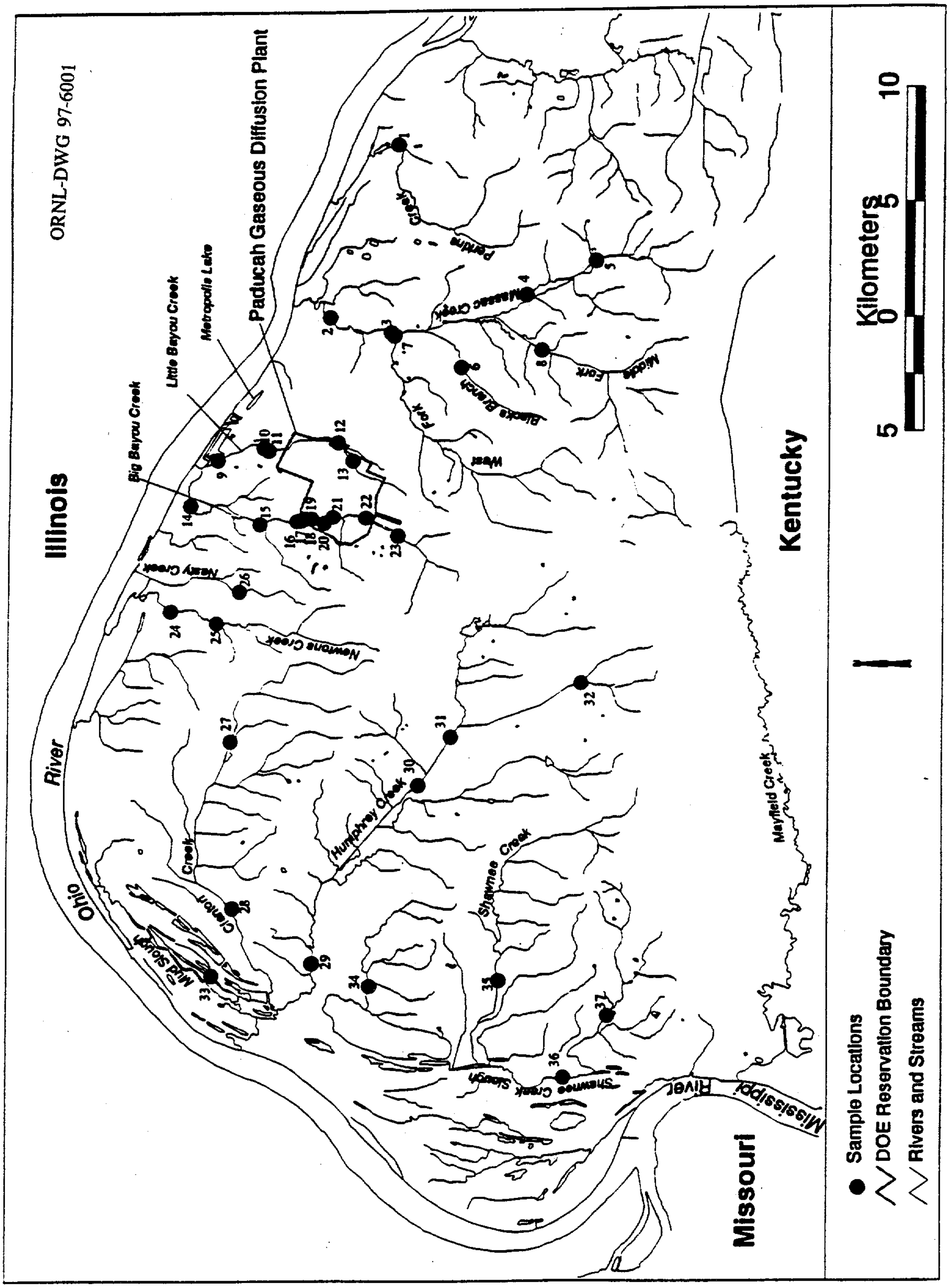

Fig. 5.1. Sample locations for qualitative surveys conducted in streams near the Paducah Gaseous Diffusion Plant in the Coastal Plains Province.

species-size class were measured and weighed, additional members of that size class were only measured. At sites with extremely high densities, specimens of some species were merely counted after a sufficient number of lengths and weights had been obtained. Length-weight regressions based on the measured individuals were used to estimate missing length and weight data.

After processing fish from all passes, the fish were allowed to fully recover from the anesthesia and were returned to the stream. Any additional mortality that occurred as a result of processing was noted at that time. Following completion of fish sampling, the length, mean width, mean depth, and pool:riffle ratio of the sampling reach were measured at each site.

To evaluate the role nutrients might play in structuring the fish community, water samples were taken at all sites in April 1996. These samples were analyzed for total nitrate/nitrite, ammonia, and soluble reactive phosphorus (SRP). Concentrations of ammonia were measured by phenate colorimetry (APHA 1992) and nitrates/nitrites were measured by Cu-Cd reduction followed by azo dye colorimetry (APHA 1992), both using a Bran Lubbe TRAACS 800 auto-analyzer. Concentrations of SRP were determined by the ascorbic acid - molybdenum blue method (APHA 1992).

5.1.3.2 Qualitative field sampling procedures

Qualitative sampling at LUK 4.3 involved electrofishing a limited length of stream for one pass and collecting all stunned fish. A four-person sampling team electrofished for approximately 1 h using two Smith-Root backpack electrofishers. The sample reach began at an established location in the stream and sampling proceeded upstream no further than a designated stopping point. Stunned fish were netted, placed in buckets, and given to a two-person shore crew for processing. The shore crew counted and identified all specimens; easily identifiable species were immediately released downstream from the sampling crew. Species that were more difficult to identify were preserved in 10% formaldehyde and taken to the ESD laboratory for positive identification. Representative specimens of each species were also kept in a voucher collection to verify species identifications. The duration of the electrofishing effort (in minutes) and the length of stream sampled (in meters) were recorded.

Qualitative sampling of streams within the Coastal Plain Province involved electrofishing a length of stream, based upon its relative size, for one pass and collecting all stunned fish. Sampling teams of two to eight people electrofished upstream for 1 to 2 h using up to 3

Smith-Root backpack electrofishers. The majority of stunned fish were identified and released, with voucher collections taken for laboratory identification and documentation.

5.1.3.3 Data analysis

Population Size. Quantitative species population estimates were calculated using the method of Carle and Strub (1978). Biomass was estimated by multiplying the population estimate by the mean weight per size class. To calculate density and biomass per unit area, total numbers and biomass were divided by the surface area (m^2) of the study reach. These data were compiled and analyzed by a comprehensive Fortran 77 program developed by ESD staff (Railsback et al. 1989). Qualitative samples were compared using total number of species and specimens and the relative abundance of the specimens. Relative abundance of species was rated as follows: 1 specimen = rare, 2 to 20 specimens = uncommon, 21 to 100 specimens = common, and >100 specimens = abundant.

Annual Production. Annual production was estimated at each site for each species using a size-frequency method (Garman and Waters 1983) as modified by Railsback et al. (1989). Production was calculated for the period between the spring 1995 and spring 1996 sampling dates.

5.1.4 Results

The physical parameters of the sample sites showed only minor differences between the March-April (spring) and September (fall) samples (Table 5.1). The sites were generally deeper, wider and had more pool area in fall sampling compared to spring samples. The pattern is a return to the pattern seen in earlier sampling (Ryon 1994a,e). A noticeable difference was the greater proportion of pools in fall samples (higher pool:riffle ratios) than in spring samples. Because a key, defining parameter for riffle and run habitat is a faster water velocity, a high pool:riffle ratio indicates slower flow in the fall sample period.

Nutrient samples taken in April 1996 indicate a substantial difference between the enrichment regime in lower Big Bayou Creek and the reference sites. Levels of ammonia and SRP were much higher at BBK 9.1 and BBK 10.0 than upstream in Big Bayou Creek or in Massac Creek (Table 5.1). These nutrients are usually short-lived in natural systems, becoming bound to particles or processed by biota within a short distance. Thus, the high

Table 5.1. Lengths, mean width, mean depth, surface area, pool:riffle ratio, and nutrient levels of fish sampling sites in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, for March–April and September 1996

Site[a]	Length (m)	Mean width (m)	Mean depth (cm)	Surface area (m^2)	Pool:riffle ratio
PHYSICAL MEASUREMENTS					
March-April 1996					
BBK 9.1	90	6.2	23.9	569	1.1
BBK 10.0	101	5.1	12.0	514	1.2
BBK 12.5	115	6.4	11.6	734	1.7
LUK 7.2	108	3.1	7.3	338	0.4
MAK 13.8	99	5.8	18.7	572	1.1
September 1996					
BBK 9.1	120	7.6	27.0	907	1.4
BBK 10.0	82	6.1	12.2	500	3.1
BBK 12.5	120	7.4	15.4	890	3.8
LUK 7.2	122	3.5	8.6	426	1.3
MAK 13.8	114	4.3	17.0	495	3.4

NUTRIENT MEASUREMENTS ($\mu g/L$)

April 1996	Nitrates/Nitrites	Ammonia	Phosphorus
BBK 9.1	2066	210	73
BBK 10.0	777	372	155
BBK 12.5	256	31	4
LUK 7.2	661	26	95
MAK 13.8	559	28	3

[a]Site designations are Big Bayou Creek kilometer (BBK), Little Bayou Creek kilometer (LUK), and Massac Creek kilometer (MAK).

levels are almost certainly related to PGDP discharges, probably from the wastewater treatment plant and anticorrosion additives used in cooling systems. The high nitrate/nitrite concentrations at all locations probably reflect some agricultural influences in both watersheds, as these nutrients are more long-lived. The higher nitrate/nitrite levels at LUK 7.2, BBK 9.1, and BBK 10.0 show additional influence of PGDP discharges.

5.1.4.1 Quantitative sampling

Species richness and composition. A total of 31 fish species were found at the 5 sites on Big Bayou Creek, Little Bayou Creek, and Massac Creek (Table 5.2) for the March–April and September 1996 samples. BBK 9.1 and BBK 10.0 had 20 and 14 species, respectively, for the two sampling seasons, compared to 26 species at the reference stream, MAK 13.8. The number of species at BBK 9.1 was similar to that seen in 1994 sampling (Ryon 1996a) and lower than in 1995 (Ryon 1996b). The LUK 7.2 site had 21 species during the year, while the comparable reference site, BBK 12.5, had 18 species. Mean species richness for 1996 for MAK 13.8, BBK 9.1, and BBK 10.0 was 21.5, 16.0, and 11.0 respectively (Table 5.3). At LUK 7.2 and BBK 12.5, the mean richness was 15.0 and 14.0 respectively. The core species assemblage at all sites included the central stoneroller (*Campostoma anomalum*), creek chub (*Semotilus atromaculatus*), yellow bullhead (*Ameiurus natalis*), blackspotted topminnow (*Fundulus olivaceus*), mosquitofish (*Gambusia affinis*), green sunfish (*Lepomis cyanellus*), bluegill (*L. macrochirus*), and longear sunfish (*L. megalotis*). Of the species collected, five were considered to be sensitive to water quality and/or habitat degradation (see Karr et al. 1986; Ohio EPA 1987, 1988) and eight were rated as tolerant to such conditions (Appendix D, Table D.1).

Noticeable this sampling year was the population explosion of the Mississippi silvery minnow (*Hybognathus nuchalis*) in the fall survey period. Previously, the silvery minnow had only been collected regularly in quantitative samples of Massac Creek. During September 1995, the silvery minnow began to appear in Big Bayou Creek and Little Bayou Creek samples. In September 1996, the silvery minnow was found at all sites and at high abundances at BBK 12.5, LUK 7.2 and MAK 13.8.

The most downstream site on Big Bayou Creek, BBK 9.1, had several species which are more common in larger streams, such as gizzard shad (*Dorosoma cepedianum*), white crappie (*Pomoxis annularus*), and common carp (*Cyprinus carpio*). These species were not taken in

Table 5.2. Species composition based on quantitative samples of Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March-April and September 1996

Species[b]	Sites[a]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Clupeidae					
Gizzard shad (*Dorosoma cepedianum*)	1[c]	0	0	0	1
Cyprinidae					
Central stoneroller (*Campostoma anomalum*)	2	2	2	2	2
Red shiner (*Cyprinella lutrensis*)[d]	0	0	1	2	2
Steelcolor shiner (*Cyprinella whipplei*)[d]	1	0	0	1	2
Common carp (*Cyprinus carpio*)	1	0	0	0	0
Mississippi silvery minnow (*Hybognathus nuchalis*)	1	1	1	1	1
Ribbon shiner (*Lythrurus fumeus*)[d]	0	0	0	0	2
Redfin shiner (*Lythrurus umbratilis*)[d]	0	1	2	1	2
Golden shiner (*Notemigonus crysoleucas*)	0	0	1	2	0
Bluntnose minnow (*Pimephales notatus*)	1	1	2	2	2
Fathead minnow (*Pimephales promelas*)	0	0	0	0	1
Creek chub (*Semotilus atromaculatus*)	2	2	2	2	2
Catostomidae					
White sucker (*Catostomus commersoni*)	0	0	0	0	1
Creek chubsucker (*Erimyzon oblongus*)	1	0	1	0	2
Spotted sucker (*Minytrema melanops*)	2	0	0	0	0
Ictaluridae					
Yellow bullhead (*Ameiurus natalis*)	2	2	2	2	2
Esocidae					
Grass pickerel (*Esox americanus*)	0	1	0	0	0
Aphredoderidae					
Pirate perch (*Aphredoderus sayanus*)	0	0	0	1	2
Cyprinodontidae					
Blackspotted topminnow (*Fundulus olivaceus*)	2	2	2	2	2
Poeciliidae					
Western mosquitofish (*Gambusia affinis*)	2	2	1	2	2
Centrarchidae					
Flier (*Centrarchus macropterus*)	1	0	0	1	0
Green sunfish (*Lepomis cyanellus*)	2	2	2	2	2
Warmouth (*Lepomis gulosus*)	0	0	0	1	1
Bluegill (*Lepomis macrochirus*)	2	2	2	1	2
Longear sunfish (*Lepomis megalotis*)	2	2	2	2	2
Hybrid sunfish	0	0	2	1	0
Spotted bass (*Micropterus punctulatus*)	2	1	2	1	1
Largemouth bass (*Micropterus salmoides*)	2	1	2	1	1
White crappie (*Pomoxis annularus*)	1	0	0	0	1
Percidae					
Slough darter (*Etheostoma gracile*)[d]	1	0	1	2	1
Logperch (*Percina caprodes*)	0	0	0	0	2
Blackside darter (*Percina maculata*)[d]	0	0	0	0	2
TOTAL SPECIES	20	14	18	21	26

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991) and Etnier and Starnes (1993).

[c]Numbers represent the number of sampling periods (N = 2) that a given species was collected at the site and a "0" indicates that the species was not collected.

[d]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

Table 5.3. Total fish density (individuals/m^2), biomass (g/m^2), and species richness for March-April and September 1996 and means for 1994–1996 at sampling sites[a] in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek

Sampling periods	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
March-April 1996					
Density	1.27	1.79	3.6	1.78	1.88
Biomass	26.59	9.33	15.08	2.18	5.94
Species richness	15	10	13	11	19
September 1996					
Density	0.82	2.69	3.68	2.49	2.42
Biomass	9.61	17.46	13.63	11.5	10.39
Species richness	17	12	15	19	24
Means 1994					
Density	1.08	3.47	3.68	3.79	3.62
Biomass	15.69	11.46	13.4	6.42	12.29
Species richness	14.5	11	13.5	14	21
Means 1995					
Density	1.86	4.64	3.5	3.66	2.89
Biomass	14.37	17.53	13.18	5.82	12.25
Species Richness	16.5	11	12.5	16	21
Means 1996					
Density	1.04	2.24	3.64	2.14	2.15
Biomass	18.1	13.4	14.36	6.84	8.17
Species Richness	16	11	14	15	21.5

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

quantitative samples at upstream Big Bayou Creek sites. BBK 9.1 had a community similar to the reference site, MAK 13.8, for most community parameters (Table 5.4). However, the number of percids, benthic insectivores, and intolerant species were lower and the percentage

Table 5.4. Fish community composition based on quantitative samples of Big Bayou Creek, Little Bayou Creek, and Massac Creek, March–April and September 1996[a]

Species categories	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Cyprinidae	6 (30)[b]	5 (35)	7 (39)	8 (38)	9 (35)
Catostomidae	2 (10)	0	1 (6)	0	2 (8)
Centrarchidae	7 (35)	5 (35)	6 (33)	8 (38)	7 (27)
Percidae	1 (5)	0	1 (6)	1 (5)	3 (12)
Tolerant species	5 (25)	3 (22)	4 (22)	4 (19)	7 (27)
Intolerant species	2 (10)	0	0	1 (5)	4 (15)
Piscivore	2 (10)	3 (22)	2 (11)	2 (10)	2 (8)
Benthic Insectivore	2 (10)	0	2 (11)	2 (10)	5 (19)
Generalist feeder	8 (40)	4 (28)	5 (28)	6 (29)	7 (27)

[a]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.
[b]Number of species at that site and in parentheses, percent of total species at that site.
Note: Because some species are classified in more than one category (e.g., log perch is a percidae, intolerant, benthic insectivore), numbers and percentages in each column do not add up to total number of species at a site or to 100 percent.

of generalist feeders was higher than the reference site. The intolerant species are those species susceptible to habitat degradation and/or pollution. Benthic insectivores are a feeding guild that can reflect impacts to the benthic macroinvertebrate availability (Miller et al. 1988), and generalist feeders are species that are capable of switching easily between food items and therefore can be more successful in streams exposed to a variety of stresses (Leonard and Orth 1986).

At BBK 10.0, most community parameters were comparable to MAK 13.8 (Table 5.4). However, there were no catostomid or percid species, no sensitive species, and no benthic insectivores. These deficiencies indicate some stress on the community. During 1996 one piscivore, the grass pickerel (*Esox americanus*) was taken at BBK 10.0, which represents the first time this species has been found in a quantitative sample of Big Bayou Creek.

The LUK 7.2 site had a comparable community to that found at the reference site, BBK 12.5 (Table 5.4), which indicates no substantial impacts at this site.

Density. Estimates of density (fish per square meter) were higher at most sites for the September samples than for the March-April samples (Table 5.3). This was the pattern in previous PGDP samples (Ryon 1994a,e, 1996a,b) and has been the dominant pattern for the BMAP sampling conducted at the approximately 50 sites in the Oak Ridge, Tennessee, area since 1985 (Loar 1992, Ryon 1992b; Southworth et al. 1992). The higher fall density reflects recruitment of fish into the community from the spring spawning periods and normally occurs at all sites.

The highest total density values were at BBK 12.5. The densities at BBK 9.1 were about one-half of the levels at BBK 10.0 and MAK 13.8 (Table 5.3). Overall, the densities at BBK 9.1 and BBK 10.0 were similar to most levels observed since 1990 (Fig 5.2).

Densities of individual species varied slightly among sites, with less variation among the two species with the highest values (Appendix D, Tables D.2 and D.4). During most sampling periods at BBK 9.1, BBK 10.0, and MAK 13.8, the species present in highest or next highest numbers were the central stoneroller or longear sunfish. However, unlike most sampling years, the presence of other species such as Mississippi silvery minnow, western mosquitofish, and blackspotted topminnow was also noted among the top two species at these sites.

At LUK 7.2, the density was lower in 1996 than in 1994 and 1995 (Table 5.3), but remained within the range of previous sampling (Fig. 5.3). The species with the highest densities were bluntnose minnow (*Pimephales notatus*), red shiner (*Cyprinella lutrensis*), blackspotted topminnow, and western mosquitofish (Tables D.2 and D.4). The BBK 12.5 reference site was similar to downstream Big Bayou Creek sites with highest densities for central stoneroller and Mississippi silvery minnow.

Biomass. The highest biomass (in grams per square meter) levels were seen at BBK 9.1 and BBK 10.0 (Table 5.3; Fig. 5.3). Mean fish biomass at MAK 13.8 was about half that at the lower Big Bayou Creek sites. Mean fish biomass at LUK 7.2 was half the mean fish biomass at the BBK 12.5 reference site.

Each site was evaluated for the species that constituted the two highest biomass values during each sample period. The longear sunfish species contributed the highest or next highest biomass at every site except LUK 7.2 and BBK 12.5 (Tables D.3 and D.5). Other fish species that were among the two highest biomass contributors included bluegill and spotted sucker (*Minytrema melanops*) at BBK 9.1 and central stoneroller at BBK 10.0 and MAK 13.8. At LUK 7.2 and BBK 12.5, the two highest biomass contributors varied among the creek chub, Mississippi silvery minnow, and central stoneroller.

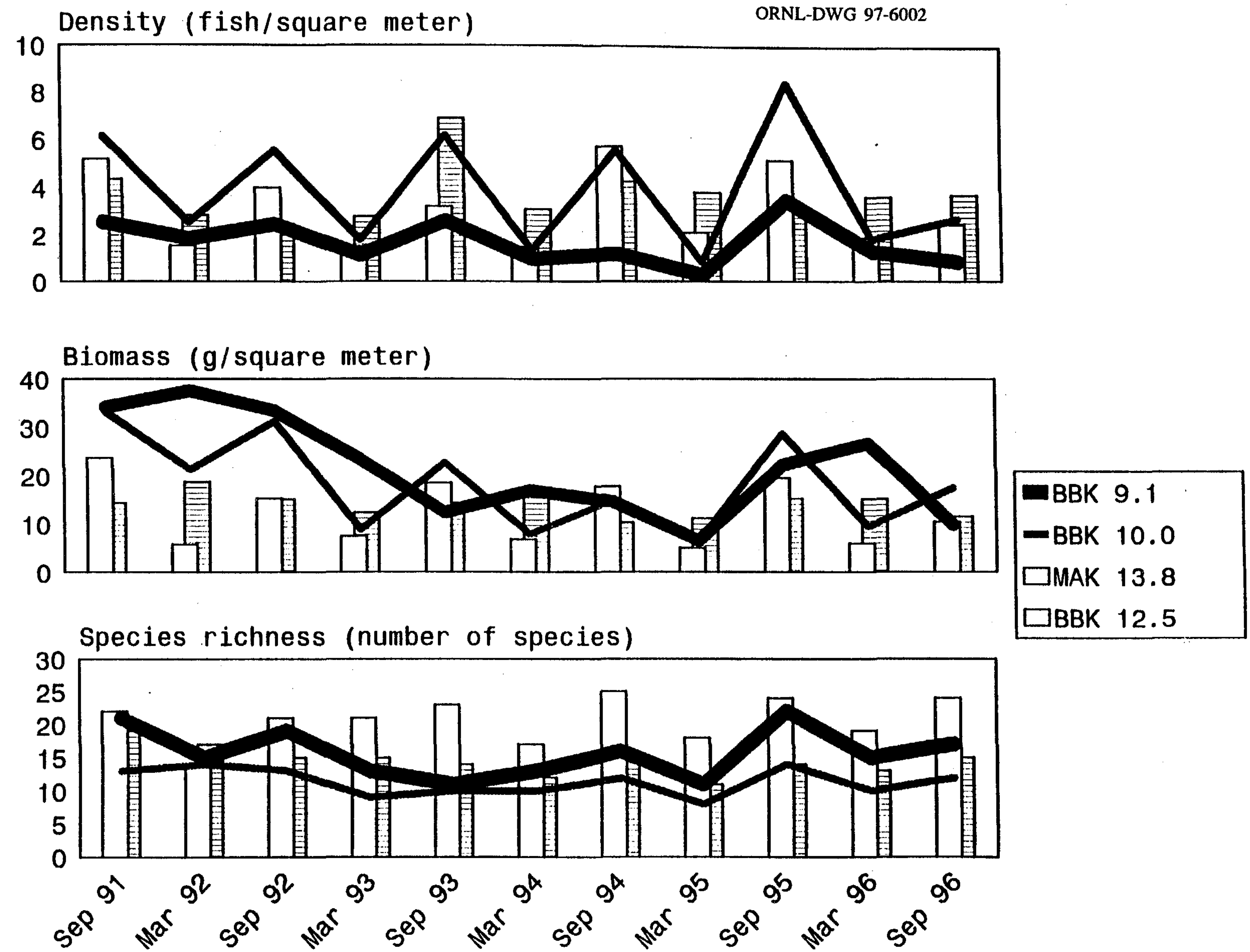

Fig. 5.2. Species richness, biomass, and density of fish at Big Bayou Creek sites and a reference stream, Massac Creek. BBK = Big Bayou Creek kilometer; MAK = Massac Creek kilometer.

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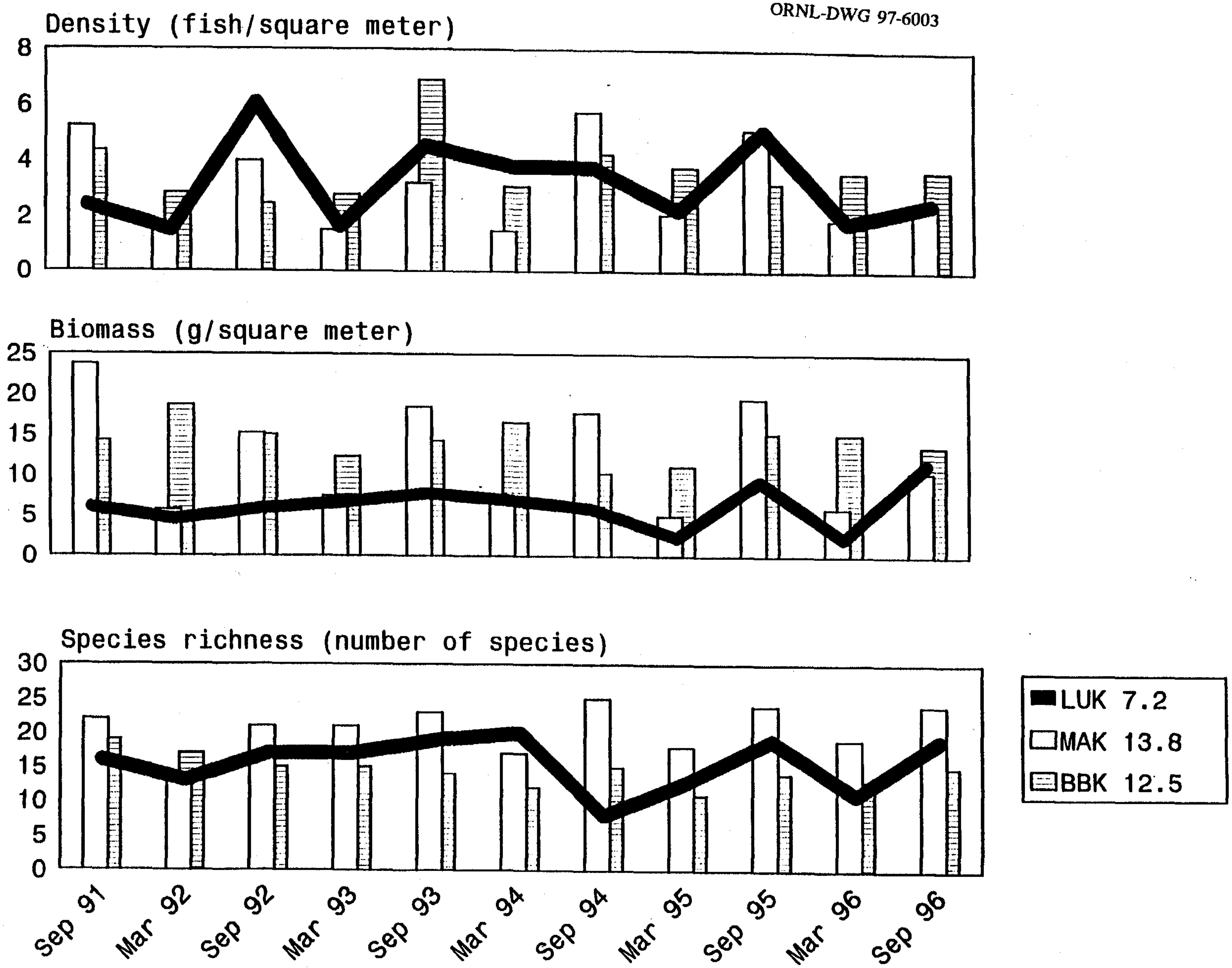

Fig. 5.3. Species richness, biomass, and density of fish at Little Bayou Creek site at kilometer (LUK) 7.2 and the reference sites, Big Bayou Creek at kilometer (BBK) 12.5 and Massac Creek at kilometer (MAK) 13.8.

Production. Production values were calculated for the spring 1995 to spring 1996 period at all sites. Total fish community production (in grams per square meter per year) was highest in Big Bayou Creek, increasing from downstream to upstream (Table 5.5). Production at BBK 9.1 was similar to that of Massac Creek. Production at BBK 10.0 was more than twice that at the reference site, MAK 13.8. This high production at BBK 10.0 resulted from the contribution of the central stoneroller. Further, the productivity remained low at both Big Bayou Creek sites compared to earlier levels at these sites, continuing a trend started in 1994–95 (Fig. 5.4). Productivity at the reference sites did not show such a declining trend. Production at LUK 7.2 was only 1/7 of that found at BBK 12.5 (Table 5.5). A ten-fold difference in production of central stoneroller and longear sunfish accounted for the majority of the disparity. The high level of production at BBK 10.0 might be expected given the evidence of enrichment (Table 5.1); however, the high productivity at BBK 12.5 was unexpected when compared to the lower productivity at the other reference stream.

The production found in these streams was within the range of production values found in warmwater streams of the southeastern United States, including production estimates generated by similar methods at monitoring sites at the Oak Ridge, Tennessee, DOE facilities (Table 5.5 in Ryon 1994e). Estimates of production in southeastern reference streams varied from 2.02 to 27.12 $g \cdot m^{-2} \cdot yr^{-1}$ compared to 4.20–15.65 $g \cdot m^{-2} \cdot yr^{-1}$ at PGDP area reference streams. Similarly, production at sites downstream of plant discharges ranged from 3.06 to 27.38 $g \cdot m^{-2} \cdot yr^{-1}$ in the southeast, v 2.12–8.17 $g \cdot m^{-2} \cdot yr^{-1}$ in Big Bayou Creek watershed.

5.1.4.2 Qualitative sampling

During qualitative sampling conducted on lower Little Bayou Creek (LUK 4.3) in April, totals of 22 species and 288 specimens were taken (Table 5.6). The numbers of species and specimens were similar to most previous samples (Fig. 5.5). The Little Bayou Creek community represented by this sample included seven cyprinid, seven centrarchid, and three percid species. There were two species sensitive to pollution and/or environmental degradation (Karr et al. 1986), and four tolerant species. This survey at LUK 4.3 found no impacts attributable to PGDP operations and documented the continued presence of a diverse fish community, with a variety of trophic levels and feeding guilds (Ryon 1994a,e, 1996a,b).

Qualitative sampling of area streams in the Coastal Plain Province (Fig. 5.1) indicated that Massac Creek (sites 2-8) has the most diverse fish community and contains more

Table 5.5. Fish annual production (g/m²/yr) in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March 1995 to March–April 1996

	Sites[a]				
Species[b]	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Stoneroller	0.82	7.52	10.21	0.81	1.77
Red shiner	-	-	0.04	0.35	0
Steelcolor shiner	-	-	-	-	0.02
Common carp	-0.06	-	-	-	-
Ribbon shiner	-	-	-	-	<-0.01
Redfin shiner	<-0.01	-0.02	0.03	0.01	0.09
Golden shiner	-	-	<-0.01	<-0.01	-
Bluntnose minnow	-	-0.01	0.32	0.35	0.31
Creek chub	-0.05	0.22	1.83	0.29	0.17
White sucker	-0.07	-	-	-	-0.1
Creek chubsucker	-0.19	-	-0.01	-	0.02
Golden redhorse	-0.19	-	-	-	-
Yellow bullhead	-0.07	-0.01	0.28	<-0.01	0.03
Pirate perch	-	-	-	-	-0.02
Blackspotted topminnow	-0.01	0.09	0.37	0.09	0.26
Western mosquitofish	0	0.04	-	0.17	<-0.01
Green sunfish	0.26	-0.01	0.29	<-0.01	0.2
Warmouth	-	-	-	0	<-0.01
Bluegill	0.73	-0.03	-0.01	0	-0.01
Longear sunfish	4.92	0.38	2.29	<-0.01	1.49
Redear sunfish	-0.03	-	-	-	-
Spotted bass	-1.25	-	<-0.01	-	-0.03
Largemouth bass	-0.03	-	0.01	-	-
Slough darter	0	-	-	0.05	<-0.01
Logperch	-	-	-	-	0.01
Blackside darter	-	-	-	-	-0.01
Total production	4.81	8.17	15.65	2.12	4.2

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

[b]Common names according to the American Fisheries Society (Robins et al. 1991).

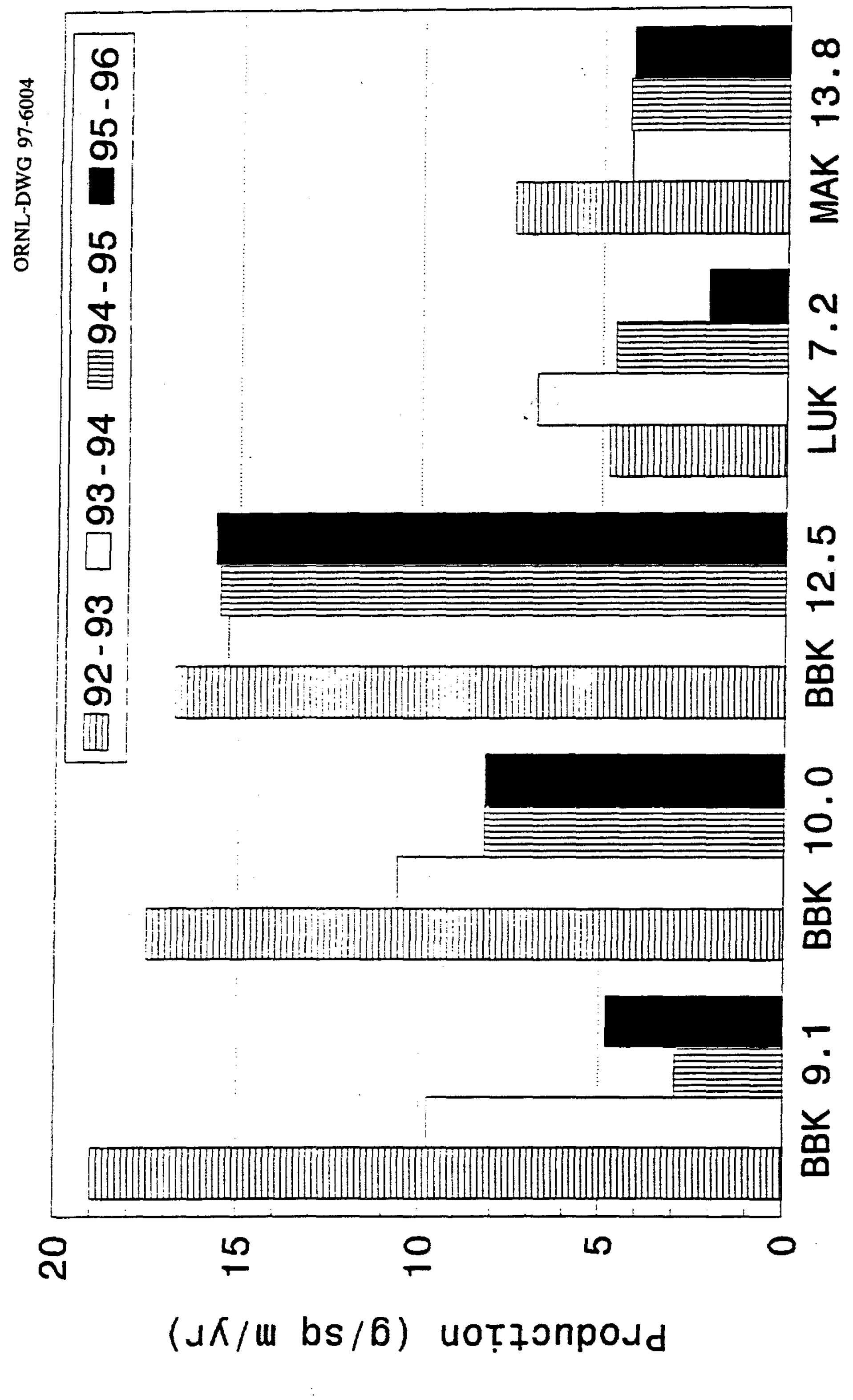

Fig. 5.4. Total annual production (in grams per square meter per year) for Big Bayou Creek kilometer (BBK) sites, Little Bayou Creek kilometer (LUK) site, and Massac Creek kilometer (MAK) site for 1992 to 1996.

Table 5.6. Species composition of the qualitative fish sampling[a] conducted on Little Bayou Creek, April 9, 1996

Species[b]	Number of specimens	Relative abundance[c]
Cyprinidae		
Red shiner (*Cyprinella lutrensis*)	7	UC
Mississippi silvery minnow (*Hybognathus nuchalis*)	5	UC
Ribbon shiner (*Lythrurus fumeus*)[d]	29	C
Redfin shiner (*Lythrurus umbratilis*)[d]	68	C
Emerald shiner (*Notropis atherinoides*)[d]	1	R
Bluntnose minnow (*Pimephales notatus*)[d]	25	C
Creek chub (*Semotilus atromaculatus*)	8	UC
Ictaluridae		
Yellow bullhead (*Ameiurus natalis*)	3	UC
Esocidae		
Grass pickerel (*Esox americanus vermiculatus*)	1	R
Aphredoderidae		
Pirate perch (*Aphredoderus sayanus*)	9	UC
Cyprinodontidae		
Blackspotted topminnow (*Fundulus olivaceus*)	53	C
Poeciliidae		
Western mosquitofish (*Gambusia affinis*)	2	UC
Centrarchidae		
Flier (*Centrarchus macropterus*)	2	UC
Green sunfish (*Lepomis cyanellus*)	4	UC
Warmouth (*Lepomis gulosus*)	7	UC
Bluegill (*Lepomis macrochirus*)	7	UC
Longear sunfish (*Lepomis megalotis*)	46	C
Redear sunfish (*Lepomis microlophus*)	1	R
Spotted bass (*Micropterus punctulatus*)	1	R
Percidae		
Mud darter (*Etheostoma asprigene*)[d]	5	UC
Bluntnose darter (*Etheostoma chlorosomum*)	3	UC
Slough darter (*Etheostoma gracile*)	1	R
TOTAL SPECIES	22	
TOTAL SPECIMENS	288	
CATCH PER EFFORT (FISH/MIN)	3.7	

[a]Two electroshockers used for 202 m and 77 min.

[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991) and Etnier and Starnes (1993).

[c]Relative abundance is defined as: rare (R) 1 specimen; uncommon (UC) 2-20 specimens; common (C) 21-99 specimens; and abundant (A) >99 specimens.

[d]Species identification were confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

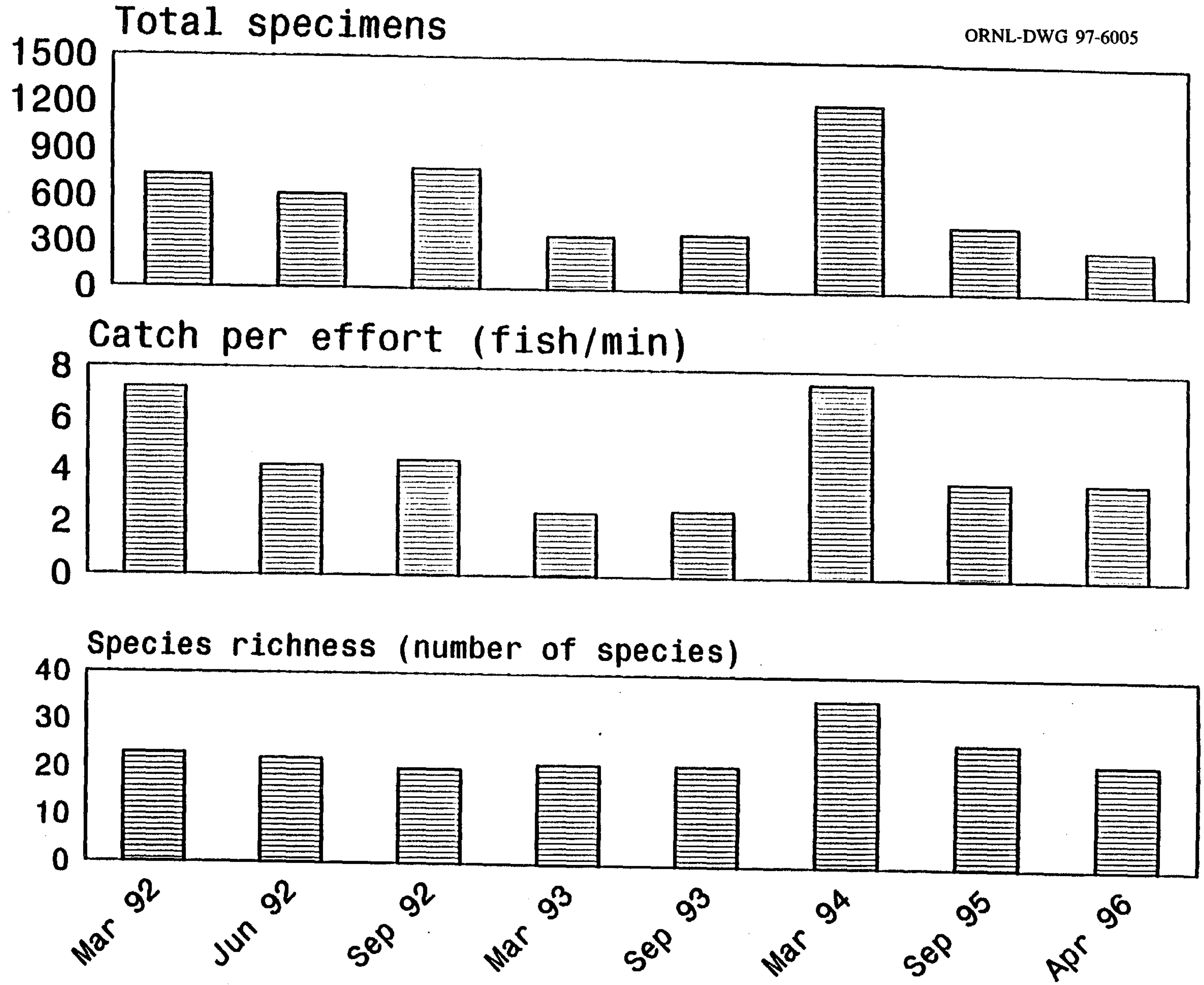

Fig. 5.5. Species richness, catch per effort, and total specimens at Little Bayou Creek qualitative site at kilometer (LUK) 4.3.

environmentally sensitive species than any other stream in the region (Table 5.7). It had more species, more intolerant species, more catostomids, and more percids than the other sampled streams. Humphrey Creek watershed (sites 26-33) showed the next highest diversity and given a similar level of sampling effort would probably match Massac Creek in terms of species richness. Community differences would probably still exist between the two streams, because Massac Creek is more upland in character than Humphrey Creek. Little Bayou Creek (sites 9-13) and Big Bayou Creek (sites 14-23) fell within the range of most streams in the region, certainly not as impacted as Perkins Creek (site 1) which flows through the city of Paducah but not as diverse as Massac Creek or Humphrey Creek.

5.1.5 Discussion

Data on the fish communities of Big Bayou Creek and Little Bayou Creek downstream of PGDP were compared to data from reference sites located on Big Bayou Creek above PGDP and on Massac Creek. These comparisons indicated a slight but noticeable degradation in the communities downstream of PGDP.

Data indicated that the effects on the fish community were greatest just downstream from PGDP at BBK 10.0. The fish community at this site had the lowest mean and total species richness in comparison with MAK 13.8. No sensitive species were found in the communities downstream from PGDP, compared to four sensitive species at the reference site. The number of benthic insectivores was low, although other feeding guilds were similar to levels seen at MAK 13.8. Density and biomass at BBK 10.0 were similar to or higher than those at the reference sites (Fig. 5.2). The high level of stoneroller production also suggested impacts. Overall, the fish community at BBK 10.0 has demonstrated shortcomings.

The fish community at BBK 9.1 showed signs of less severe impact than at BBK 10.0. Mean and total species richness were lower than at MAK 13.8. Although there were fewer sensitive species and at lower densities at BBK 9.1 than at MAK 13.8, more sensitive species were found at BBK 9.1 than at BBK 10.0. The tolerant species were common and abundant. Density was less than or equal to that at MAK 13.8, and species richness has continued to increase (Fig. 5.2) since 1993. Productivity estimates showed a substantial decline from 1992-1993 to 1994-1995, but leveled out or increased during 1995-1996 (Fig. 5.4). The reversal of the four-fold decrease in production may indicate some moderation of impacts on recruitment success for the fish community at BBK 9.1.

Table 5.7. Species composition of quantitative and qualitative samples of streams located near the Paducah Gaseous Diffusion Plant, 1990 through 1996

Species[a]	Watershed						
	Little Bayou Creek	Big Bayou Creek	Massac Creek	Humphrey Creek	Shawnee Creek	Newton Creek	Perkins Creek
Sample sites	5	10	7	7	4	3	1
Number of samples	33	65	21	7	4	3	1
Lepisostediae							
Spotted gar (*Lepisosteus oculatus*)[c]			1[b]	1			
Longnose gar (*Lepisosteus osseus*)			1				
Shortnose gar (*Lepisosteus platostomus*)[c]			1	2			
Amiidae							
Bowfin (*Amia calva*)		2	1				
Clupeidae							
Gizzard shad (*Dorosoma cepedianum*)				3			
Threadfin shad (*Dorosoma petenense*)[c]	1	7	3	1			
Cyprinidae							
Central stoneroller (*Campostoma anomalum*)	3	9	7	4	2	2	
Goldfish (*Carassius auratus*)			1				
Grass carp (*Ctenopharyngodon idella*)		1					
Red shiner (*Cyprinella lutrensis*)[c]	4	9	5	3			
Spotfin shiner (*Cyprinella spiloptera*)[c]	2	2	3	1			
Steelcolor shiner (*Cyprinella whipplei*)[c]	2	6	4				

Table 5.7 (continued)

Species[a]	Watershed						
	Little Bayou Creek	Big Bayou Creek	Massac Creek	Humphrey Creek	Shawnee Creek	Newton Creek	Perkins Creek
Common carp (*Cyprinus carpio*)	1	3	4	5			1
Mississippi silvery minnow (*Hybognathus nuchalis*)[c]	3	5	4	2		1	1
Ribbon shiner (*Lythrurus fumeus*)[c]	4	4	3	3			
Redfin shiner (*Lythrurus umbratilis*)[c]	5	5	2	3	1	1	
Silver chub (*Macrhybopsis storeiana*)[c]				1			
Golden shiner (*Notemigonus crysoleucas*)	3	6	4	4	3	2	1
Emerald shiner (*Notropis atherinoides*)[c]	2	1	1	1			
River shiner (*Notropis blennius*)[c]	1						
Sand shiner (*Notropis stammineus*)[c]	1						
Mimic shiner (*Notropis volucellus*)[c]			1				
Suckermouth minnow (*Phenacobius mirabilis*)	3	6	3	1			
Bluntnose minnow (*Pimephales notatus*)	4	7	7	5		1	
Fathead minnow (*Pimephales promelas*)[c]		2	1				
Bullhead minnow (*Pimephales vigilax*)[c]			2	1			
Creek chub (*Semotilus atromaculatus*)	4	7	4	5	2	2	
Catostomidae							
River carpsucker (*Carpiodes carpio*)[c]			1				
Quillback (*Carpiodes cyprinus*)[c]			2				
White sucker (*Catostomus commersoni*)	1	5	5	3			

Table 5.7 (continued)

Species[a]	Watershed						
	Little Bayou Creek	Big Bayou Creek	Massac Creek	Humphrey Creek	Shawnee Creek	Newton Creek	Perkins Creek
Creek chubsucker (*Erimyzon oblongus*)	5	6	7	5	3	1	
Smallmouth buffalo (*Ictiobus bubalus*)[c]			2	2			1
Bigmouth buffalo (*Ictiobus cyprinellus*)[c]		2	2	1			1
Black buffalo (*Ictiobus niger*)[c]	1	1	1				
Spotted sucker (*Minytrema melanops*)	2	3	3	2			
Black redhorse (*Moxostoma duquesnei*)			2				
Golden redhorse (*Moxostoma erythrurum*)[c]	1	3	5				
Ictaluridae							
Black bullhead (*Ameiurus melas*)[c]	1	4	1	2	1		
Yellow bullhead (*Ameiurus natalis*)	4	8	6	6	1	2	
Brown bullhead (*Ameiurus nebulosus*)[c]				1			
Channel catfish (*Ictalurus punctatus*)		1	2	1			
Tadpole madtom (*Noturus gyrinus*)[c]	2		1	1			
Freckled madtom (*Noturus nocturnus*)[c]		1	1				
Esocidae							
Grass pickerel (*Esox americanus*)[c]	1	3	4	1	2		

Table 5.7 (continued)

Species[a]	Watershed						
	Little Bayou Creek	Big Bayou Creek	Massac Creek	Humphrey Creek	Shawnee Creek	Newton Creek	Perkins Creek
Aphredoderidae							
Pirate perch (*Aphredoderus sayanus*)	4	5	4	5	2	1	1
Cyprinodontidae							
Blackspotted topminnow (*Fundulus olivaceus*)[c]	4	9	6	6	3	2	
Poeciliidae							
Western mosquitofish (*Gambusia affinis*)	4	7	5	6	3	2	1
Atherinidae							
Brook silverside (*Labidesthes sicculus*)			3	1	1		
Percichthyidae							
White bass (*Morone chrysops*)[c]			2	2			
Yellow bass (*Morone mississippiensis*)[c]			1	2			
Centrarchidae							
Flier (*Centrarhus macropterus*)	2	4	1		2	2	
Green sunfish (*Lepomis cyanellus*)	4	10	6	6	1	2	
Warmouth (*Lepomis gulosus*)	4	6	4	5	1	2	
Orangespotted sunfish (*Lepomis humilus*)[c]	1	1		2			

Table 5.7 (continued)

Species[a]	Watershed						
	Little Bayou Creek	Big Bayou Creek	Massac Creek	Humphrey Creek	Shawnee Creek	Newton Creek	Perkins Creek
Bluegill (*Lepomis macrochirus*)	5	10	6	6	1	1	
Longear sunfish (*Lepomis megalotis*)	5	10	6	6	1		
Redear sunfish (*Lepomis microlophus*)	2	3		3			
Redspotted sunfish (*Lepomis miniatus*)[c]	2	1		1	1		
Spotted bass (*Micropterus punctulatus*)[c]	5	7	5	1			
Largemouth bass (*Micropterus salmoides*)[c]	4	7	4	5	1	1	1
White crappie (*Pomoxis annularus*)[c]	1	4	2	1			
Black crappie (*Pomoxis nigromaculatus*)[c]			1	2	1		
Percidae							
Mud darter (*Etheostoma asprigene*)[c]	1	1	1	1	1		
Bluntnose darter (*Etheostoma chlorosomum*)[c]	2	1	2	2	1		
Slough darter (*Etheostoma gracile*)[c]	4	5	4	3	2	1	
Yellow Perch (*Perca flavescens*)[c]		1					
Logperch (*Percina caprodes*)	1	1	3	1			
Blackside darter (*Percina maculata*)[c]			3				
River darter (*Percina shumardi*)[c]			1				
Sauger (*Stizostedion canadense*)[c]			1				

Table 5.7 (continued)

Species[a]	Watershed						
	Little Bayou Creek	Big Bayou Creek	Massac Creek	Humphrey Creek	Shawnee Creek	Newton Creek	Perkins Creek
Sciaenidae							
Freshwater drum (*Aplodinotus grunniens*)		1	1	1			
TOLERANT SPECIES	9	10	11	10	4	3	1
INTOLERANT SPECIES	6	7	12	6	2	0	0
TOTAL SPECIES	43	48	61	51	23	17	8

[a]Common and scientific names according to the American Fisheries Society (Robins et al. 1991) and Etnier and Starnes (1993).
[b]Numbers represent the number of sites in the watershed that a given species was collected.
[c]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

The fish community at LUK 7.2 was similar to the BBK 12.5 reference. The mean species richness values were similar to those of the reference site and continued to rebound from a low point in fall 1994 (Fig. 5.3). Biomass also reached a record level for this site in September 1996. Unlike conditions in Big Bayou Creek sites, productivity dropped slightly (Fig. 5.4).

The downstream qualitative site, LUK 4.3, did not appear to be affected by plant operations. Species richness was high (Fig. 5.5) and similar to earlier sampling. The community was well represented in all families and significant absences in feeding guilds were not demonstrated. The relative abundance and catch-per-effort data were average for this site (Fig. 5.5). Thus, no evidence for major impacts by PGDP operations on the community at LUK 4.3 was observed.

Monitoring of the fish communities associated with PGDP streams indicated some depressed conditions. The impacts were limited to sites closest to the plant, which suggests that PGDP activities or discharges may be the cause. These activities include nutrient enrichment and elevated temperatures (Roy et al. 1996). The low species richness and lack of sensitive species may be caused by poor water quality or may reflect degraded habitat (e.g., poor riparian cover). The low number of benthic insectivores and the increased proportion of stonerollers at some sites may also reflect enrichment and/or a change in the availability of a benthic macroinvertebrate food supply. The single nutrient analysis indicated enriched conditions at the lower Big Bayou Creek sites as would be expected downstream of wastewater treatment facilities. Biomass and density respond quickly to improvements in degraded conditions and it will be important to follow changes in these parameters, particularly at the most stressed sites. After changes in density, the return of sensitive species or changes in proportions of feeding guilds (e.g., an increase in benthic insectivores) would signal an improvement in water quality.

The qualitative sampling of area streams located in the Coastal Plain Province supported the general conclusion that Little Bayou creeks were impacted by PGDP discharges. Compared to regional standards, the fish communities in Little Bayou Creek and Big Bayou Creek were not the most impacted but they also did not attain the levels of diversity present in some streams within the area.

5.2 BENTHIC MACROINVERTEBRATES (*J. G. Smith*)

5.2.1 Introduction

Benthic macroinvertebrate studies conducted for the PGDP BMP from September 1991 through March 1995 (Smith 1996, Roy et al. 1996) and prior studies (Birge et al. 1990, Birge et al. 1992) have not detected any significant adverse impacts to the existing macroinvertebrate communities in Big Bayou Creek and Little Bayou Creek from operations at PGDP (Smith 1996, Roy et al. 1996). There have, however, been some indications that some subtle impacts may exist. For example, "spikes" in density (i.e., occasional high density) have been observed at BBK 9.1 and BBK 10.0 that suggest nutrient enrichment. However, these apparent spikes have not occurred frequently enough or persisted long enough to make any concrete conclusions about impacts from nutrient enrichment.

This report includes the results of continued monitoring of benthic macroinvertebrate communities in Big Bayou Creek and Little Bayou Creek. Previous reports included all available data, but the most recent report concluded that data from only two sampling periods per year was sufficient for meeting the objectives of the PGDP BMP (Smith 1996). Therefore, this report includes only those data collected during the September and March sampling periods from September 1991 through March 1996. These months were chosen over the June and December sampling periods primarily because having the same sampling periods as the fish community studies maintains a more balanced and integrated BMP, but these months also coincided with periods that typically experience the highest (March) and lowest (September) stream flows. The objectives of the benthic macroinvertebrate monitoring task are to assess the ecological condition of two streams receiving effluents from PGDP, and document temporal changes in the macroinvertebrate community that may result from pollution abatement activities and/or changes in operations at PGDP.

5.2.2 Materials and Methods

Benthic macroinvertebrate samples have been collected annually during March and September since September 1991 from three sites on Big Bayou Creek (BBK 9.1, BBK 10.0 and BBK 12.5) and one site each on Little Bayou Creek (LUK 7.2) and Massac Creek (MAK 13.8) (Figs. 2.1 and 2.2). Sites BBK 12.5 and MAK 13.8 serve as reference sites and receive no industrial discharges. These reference sites were originally selected from 24 sites visited on 13 streams before the BMP was initiated in September 1991 [Memorandum from J.

M. Loar (ORNL) to T. G. Jett (PGDP), January 16, 1991]. Of these 24 sites, MAK 13.8 and BBK 12.5 were considered the most similar to the study sites in Big Bayou Creek and Little Bayou Creek, and they also appeared to be the least affected by anthropogenic stresses. Because of continued concern of the suitability of these two reference sites, an additional 16 sites on 12 streams were assessed for their suitability as references in April 1996 [Memorandum from L. A. Kszos (ORNL) to D. L. Ashburn and V. W. Jones (PGDP), May 31, 1996]. From this assessment, it was again concluded that BBK 12.5 and MAK 13.8, although not pristine were the most suitable reference sites. Since undisturbed communities of different streams are not identical, having and maintaining more than one reference site is necessary to more accurately define the normal range of macroinvertebrate communities.

At each site on each sampling date, three random samples were collected with a Surber sampler (0.09 m^2 or 1 ft^2) equipped with a 363-μm mesh net. Samples were collected from riffles only because this type of habitat often possesses the greatest variety of benthic organisms (e.g., Hynes 1970, Platts et al. 1983), and limiting collections to a single type of habitat reduces inter-sample variability (e.g., Plafkin et al. 1989, Resh and McElravy 1993). Samples were placed in pre-labeled, polyurethane-coated, glass jars and preserved with 95% ethyl alcohol. To prevent sample decomposition due to dilution of the original preservative, the ethanol in each jar was replaced within seven days of collection. Just before sample collection, dissolved oxygen, conductivity, temperature, and pH were measured with a Horiba U-7 Water Quality Checker. Water depth, location within the riffle (distance from permanent head-stakes on the stream bank), visual estimate of the relative current velocity (very slow, slow, moderate, or fast), and substrate types (visual estimate) based on a modified Wentworth particle size scale (Loar et al. 1985) were recorded for each sample. A detailed description of the procedures employed for site evaluation and sample collection, storage, and maintenance can be found in Smith and Smith (1995).

In the laboratory, each sample was first placed in a U. S. Standard No. 60-mesh (250-μm openings) sieve and rinsed with tap water. Small aliquots of a sample were then placed in a white tray partially filled with water, and the organisms were removed from the sample debris with forceps. This process was repeated with the remaining sample until it was entirely sorted. Finally, organisms were identified to the lowest practical taxon and enumerated. Details of laboratory sample processing procedures are available in Wojtowicz and Smith (1992).

Data were analyzed with Statistical Analysis System software and procedures (SAS 1985a, 1985b). Statistical analyses were done on macroinvertebrate community estimates of density, total taxonomic richness, and taxonomic richness of the Ephemeroptera, Plecoptera, and Trichoptera (EPT). Season-specific data (i.e., March and September) for each response were analyzed with a two-way analysis of the variance (ANOVA) with site and year as the main effects; $p \leq 0.05$ was considered statistically significant. When no significant interaction between site and year was detected and a site effect was, site differences were separated with a Tukey's studentized range test; $p < 0.05$ was accepted as statistically significant. Before doing the ANOVAs, values for each response were transformed as recommended by Elliot (1977) (i.e., $\log_{10}(X+1)$ for density values, and square root of $X+0.5$ for richness values, where X = the individual observed values for the responses).

5.2.3 Results

5.2.3.1 Taxonomic composition

A checklist of the benthic macroinvertebrate taxa collected in each year of the PGDP BMP since 1991 is given in Appendix E, Table E.1. No notable differences were obvious in taxonomic composition at any site from previous years. The mayflies (Ephemeroptera) *Baetis* and *Caenis* occurred at all sites in all years, and one or more heptageniid mayfly taxa were present at all sites on Big Bayou Creek years as well. The mayfly, *Tricorythodes*, was usually present at BBK 9.1 and BBK 10.0, but it was collected infrequently or absent at the other three sites. Stoneflies (Plecoptera) continued to be rare or absent at BBK 9.1 and BBK 10.0. Although stoneflies were collected more frequently at LUK 7.2, they have still not been collected as consistently as at BBK 12.5 and MAK 13.8. Even at BBK 12.5 and MAK 13.8, no single stonefly taxon was collected in all years, but except for two years at MAK 13.8, there were usually two or more taxa co-occurring. Filter feeding caddisflies (Trichoptera: *Cheumatopsyche*, *Hydropsyche*, and *Chimarra*) were consistently collected at all sites, but the presence of other caddisflies was sporadic.

Dipterans (true flies), especially the Chironomidae, Empididae, and Simuliidae, were common at all sites (Table E.1). Snails (Gastropoda) and bivalves (Bivalvia) were generally rare at all sites. This was especially noted for bivalves. No bivalves were collected at BBK 12.5 or MAK 13.8, and only the exotic Asiatic clam, *Corbicula fluminea*, was routinely collected at BBK 9.1. The bivalves were represented by several taxa at LUK 7.2, although no taxon was consistently collected.

5.2.3.2 Abundance and community structure

Total density. Mean densities were much higher in March 1996 than in March 1995 at BBK 9.1 and BBK 10.0 (> 5-fold higher), and density at LUK 7.2, which had increased considerably in March 1995 over previous years, remained relatively unchanged in 1996 (Fig. 5.6). Densities at these three sites were also much higher ($\sim \geq 3$X) than densities at the reference sites. Density values for March 1996 for BBK 12.5 and MAK 13.8 were similar and had changed little from previous years. With several large "spikes" in density over the five years of study, a significant interaction between site and year for the March sampling periods was expected (Table 5.8). However, over this period, no major changes persisted for more than two years at any site (Fig. 5.6).

Changes in density between the September 1994 and 1995 sampling periods and differences among sites in September 1995 were generally less than those observed for March (Fig. 5.6). The mean density value for BBK 9.1 was about two times lower in 1995 than in 1994 after exhibiting two consecutive years of increases. Density at BBK 12.5 exhibited its second consecutive increase for the September sampling periods ($\sim$2X in each year), while densities at BBK 10.0, LUK 7.2, and MAK 13.8 changed little compared with previous years. As for the March sampling periods, the patterns of change among the sites have been different (Table 5.8, $p = 0.0003$ for interaction between site and sampling year), but increases or decreases within any site have generally not persisted more than two consecutive years.

Relative abundance. As in past years, the macroinvertebrate community at each of the five study sites has generally been numerically dominated by two or three major taxonomic groups including the Chironomidae, Oligochaeta, and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa (Fig. 5.7). An additional taxon, the planarians (Turbellaria), was regularly collected at the three Big Bayou Creek sites, but they have been virtually absent from LUK 7.2 and MAK 13.8. The contributions of planarians to the total densities at the Big Bayou Creek sites have varied considerably, but they usually accounted for $\leq 10\%$ of the total density.

ORNL-DWG 97-6006

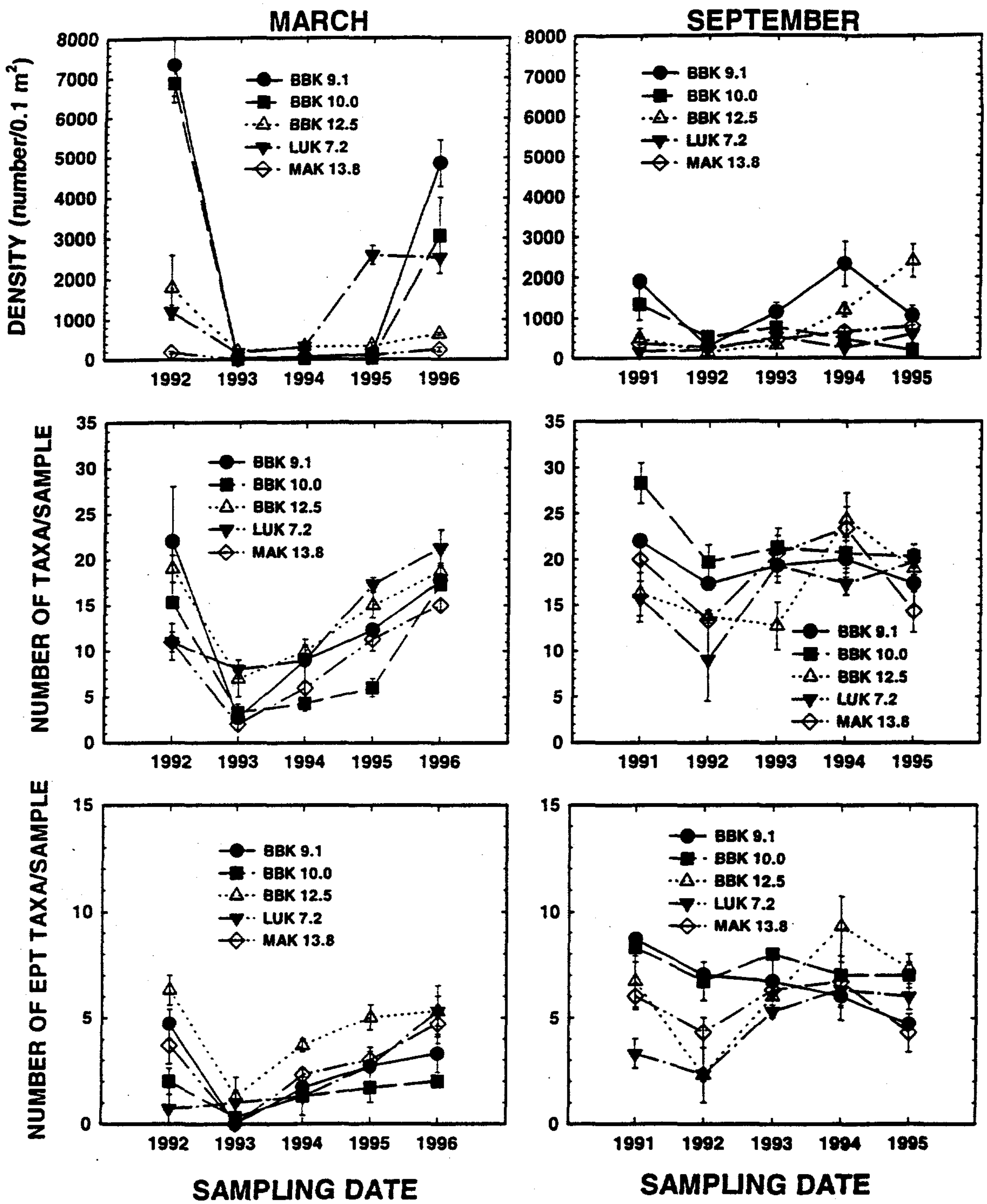

Fig. 5.6. Seasonal means for total density, total taxonomic richness, and richness of the Ephemeroptera, Plecoptera, and Trichoptera (EPT) of the benthic macroinvertebrate communities in Big Bayou Creek, Little Bayou Creek, and Massac Creek in Paducah, Kentucky, September 1991–March 1996. Vertical bars are ± 1 SE. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

Table 5.8. Results of the two-way analysis of variance (ANOVA) on seasonal-specific data for total density, total taxonomic richness, and taxonomic richness of the Ephemeroptera, Plecoptera, and Trichoptera (EPT) of the benthic macroinvertebrate communities in Big Bayou Creek, Little Bayou Creek, and Massac Creek in Paducah, Kentucky, September 1991–March 1996

		Density		Total Richness		EPT richness	
Comparison/Source of Variation	df[a]	*f* - value	*p* - value[b]	*f* - value	*p* - value[b]	*f* - value	*p* - value[b]
March							
Site	450	57.35	0.0001	20.37	0.0001	10	0.0001
Year	450	184.48	0.0001	110.54	0.0001	26.57	0.0001
Site X Year	1,650	20.18	0.0001	5.27	0.0001	1.48	0.1443
September							
Site	450	14.32	0.0001	6.09	0.0004	8.47	0.0001
Year	450	14.67	0.0001	8.61	0.0001	8.19	0.0001
Site X Year	1,650	3.55	0.0003	2.57	0.0057	3.45	0.0004

[a]df = degrees of freedom.
[b]$p \leq 0.05$ considered statistically significant.

ORNL-DWG 97-6007

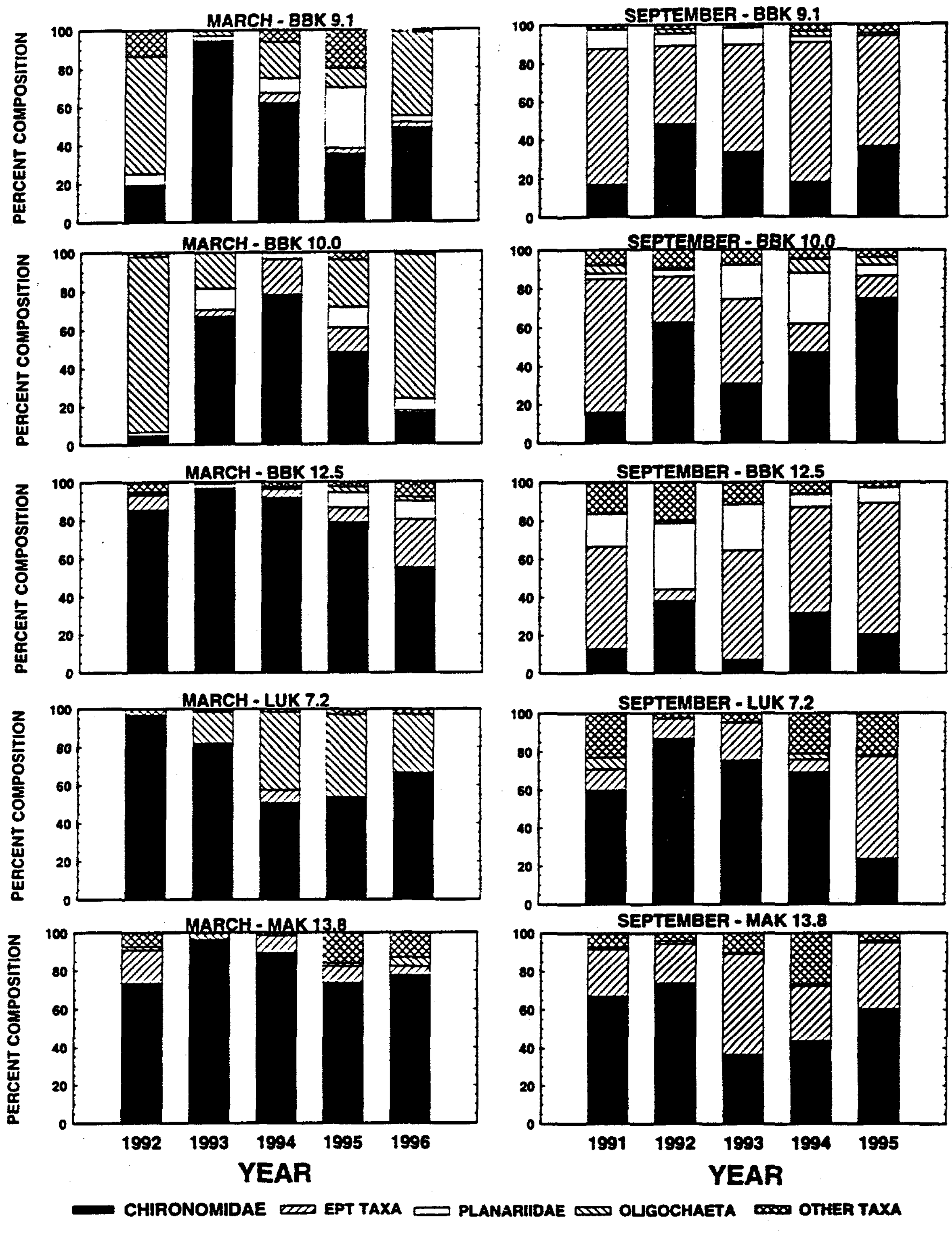

Fig. 5.7. Mean relative abundance (i.e., percent of total community density) by season of selected benthic macroinvertebrate taxa in Big Bayou Creek, Little Bayou Creek, and Massac Creek in Paducah, Kentucky, September 1991–March 1996. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

At BBK 9.1, the oligochaetes and chironomids were generally the most abundant taxa during the March sampling periods, and the relative abundance of the EPT taxa was always <5% (Fig. 5.7). The two years in which oligochaete relative abundance was the highest (1992 and 1996) corresponded closely with the years in which total community density was also highest (Fig. 5.6). During the September sampling periods the chironomids continued to predominate at BBK 9.1 as in previous years. In contrast to March however, the EPT taxa accounted for more than 40% of the total density in each year and the oligochaetes comprised much less than 5%.

As at BBK 9.1, the chironomids and oligochaetes were generally the most abundant taxa at BBK 10.0 during the March sampling periods, with the highest relative abundances of the oligochaetes closely corresponding to the years of highest total density (1992 and 1996) (Figs. 5.6 and 5.7). Also like BBK 9.1, the chironomids and EPT taxa were the predominant taxa during the September sampling periods, but the relative abundance of the EPT taxa was much more variable and usually lower.

At BBK 12.5, the chironomids accounted for ≥80% of the total density in each March sampling period except 1996 (Fig. 5.7). During March 1996, the relative abundance of the EPT taxa increased from <10% of the total density as in previous years to ~25%. The EPT taxa were the most abundant taxa during each of the September sampling periods except in 1992 when they comprised < 10% of the total density. In the other four years however, the percentage of EPT taxa exceeded 50%. The chironomids were also a predominant group in September, but their contribution was generally less than at all other sites.

The chironomids were the numerically dominant taxa at LUK 7.2 during all sampling periods in March and September, accounting for >50% of the total density on each sampling date except September 1995 (Fig. 5.7). In September 1995, the EPT taxa comprised ~50% of the total density, but in all other sampling periods they generally accounted for < 10%, particularly in the March sampling periods. As at BBK 9.1 and BBK 10.0, the oligochaetes were usually one of the most abundant groups at LUK 7.2 during the March sampling periods, but during the September sampling periods, the oligochaetes contributed little to total density.

As at BBK 12.5, oligochaetes contributed little to total density in the March sampling periods at MAK 13.8, and the chironomids comprised more than 80% of the total density in every year (Fig. 5.7). Similarities were also seen at these two reference sites during the

September sampling periods with the numerically dominant taxa being the chironomids and EPT taxa. However, at MAK 13.8, the chironomids consistently accounted for a greater proportion and the EPT taxa a smaller proportion of the total density than at BBK 12.5.

Total taxonomic richness. Total richness in September 1995 declined from the previous September at all sites but BBK 10.0 and LUK 7.2 (Fig. 5.6). There was a small increase of three taxa per sample from 1994 at LUK 7.2, while at BBK 10.0 there was no change. In March 1996, total richness exhibited its third consecutive increase for the March periods. The most notable increase occurred at BBK 10.0 where the average number of taxa per sample increased nearly 12; increases at the other four sites ranged from three to five taxa per sample. The ANOVA indicated that the interaction between site and sampling year was significant for both the March and September sampling seasons (Table 5.8). Thus, changes at some or all of the sites differed during the five-year period of study, but Fig. 5.6 clearly shows that changes were not dramatically different among the sites.

EPT richness. Richness of the Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa followed trends that were similar to those of total richness in both March and September (Fig. 5.6). The only exceptions were that during the September sampling periods, LUK 7.2 showed little change from 1994 to 1995 rather than increasing like total richness, and EPT richness decreased in every year at BBK 9.1 in September, although values have always been within or near the range of the reference sites. A significant interaction between site and sampling year for the September sampling periods was revealed by an ANOVA (Table 5.8). For the March sampling periods, the ANOVA detected no significant interaction between site and year, suggesting that changes have been similar among the sites since 1992 (Table 5.8). The Tukey's test on sites for the March data indicated that over all years (i.e., 1992-1996), EPT richness has been significantly higher at BBK 12.5 than at all other sites. The test was unable to detect any additional statistically significant site differences.

5.2.4 Discussion

Differences between stream sites potentially affected by operations at PGDP (BBK 9.1, BBK 10.0, and LUK 7.2) and the reference sites (BBK 12.5 and MAK 13.8) continued to suggest the presence of no major impacts to existing macroinvertebrate communities. Furthermore, no major changes have occurred at any site that have persisted; thus, the marcoinvertebrate communities appear to have been in a "steady state" since the PGDP BMP was initiated in 1991. Subtle differences in benthic communities among sites are consistent with expected effects of changes in water quality below PGDP discharges, but are slight in magnitude.

Densities that are higher than those at reference sites continue to occur periodically at BBK 9.1, BBK 10.0, and LUK 7.2. This was observed in March 1992 at BBK 9.1 and BBK 10.0, March 1995 at LUK 7.2, and March 1996 at BBK 9.1, BBK 10.0, and LUK 7.2. Richness parameters, however, generally showed no such "spikes." With few exceptions, total richness values at BBK 9.1, BBK 10.0, and LUK 7.2 have been within or near the range exhibited by the reference sites. However, the most recent data suggests that EPT richness may have been slightly suppressed at BBK 10.0 during March and may be declining at BBK 9.1 in September. Since differences among sites in March have typically been no more than about three taxa per sample since 1993, it is possible that EPT richness is not suppressed but is within a normal range. Similarly, for the September sampling periods, because EPT richness at BBK 9.1 has been within or near that of the reference sites, the observed decline may be natural. Differences of this magnitude have been observed among small reference streams on the DOE Oak Ridge Reservation in Oak Ridge, Tennessee (e.g., Smith 1994; Smith 1993).

Differences in the relative abundances of some major taxonomic groups were distinct between some sites, particularly in the March sampling periods. During March sampling periods, BBK 9.1, BBK 10.0, and LUK 7.2 were generally dominated numerically by oligochaetes and chironomids, while the reference sites were generally dominated by chironomids and, to a smaller extent, EPT taxa; oligochaetes were generally absent or in very low numbers at the reference sites. Differences in the September sampling periods were more subtle. All sites were typically dominated by chironomids and EPT taxa, although the EPT taxa usually comprised a smaller proportion of the communities at BBK 10.0 and LUK 7.2.

The observed differences between the reference sites and BBK 9.1, BBK 10.0, and LUK 7.2 were not likely the result of a toxicant because the normal response from a toxicant is to reduce density and taxonomic richness (e.g., Wiederholm 1984). This conclusion is supported by the results of ambient toxicity tests at these sites that have shown no consistent evidence of toxicity (see Section 3). Based on a recent study of thermal discharges from the PGDP, elevated temperatures are not thought to be a major impact to the benthic macroinvertebrate communities at each site (Roy et al. 1996). However, the possibility of more subtle, undetectable thermal effects cannot be ruled out, nor can the possibility that the communities that currently exist are the result of selection of thermally tolerant taxa.

The characteristics exhibited at BBK 9.1, BBK 10.0, and LUK 7.2 in composition, density, and community structure are consistent with those associated with nutrient enrichment (e.g., Hynes 1974; Wiederholm 1984). In the presence of excess nutrients a macroinvertebrate community will typically change more to one that consists of a greater abundance of oligochaetes and/or chironomids, and total densities can increase substantially. Taxonomic richness can increase or decline with the latter condition occurring at the higher nutrient concentrations. A one-time analysis for nutrients at the invertebrate sampling sites showed the presence of elevated concentrations of nutrients (Table 5.1). Although these nutrient analyses were conducted about one month after the invertebrate samples were collected, they show that nutrients are at least periodically much higher at BBK 9.1, BBK 10.0, and LUK 7.2 than at the reference sites and, thus, provide support for the hypothesis of nutrient effects on the macroinvertebrate communities. Sites BBK 9.1, BBK 10.0, and LUK 7.2 had the highest nitrate and phosphorus concentrations, and ammonia concentrations were highest at BBK 9.1 and BBK 10.0. These sites were the only sites with large proportions of oligochaetes in the March sampling periods. Oligochaetes are often the most abundant taxa in the presence of enriched conditions and large amounts of organic matter (Hynes 1974).

Physical habitat may also have been another important factor contributing to the greater abundances of oligochaetes since they prefer finer, softer substrates (e.g., Lazim and Learner 1987; Pennak 1989) such as those found at BBK 9.1 and BBK 10.0. However, substrate composition at BBK 9.1, BBK 10.0, and MAK 13.8 was similar (i.e., fine, unstable gravel and silt), and the substrate at LUK 7.2 was more similar to that of BBK 12.5, although more clay exists at LUK 7.2. Thus, substrate cannot account for all of the observed differences in the proportions of oligochaetes. A more frequent sampling program for nutrients with the existing biological sampling program could help resolve this potential relationship between nutrients and macroinvertebrate community composition and structure in Big Bayou Creek and Little Bayou Creek.

5.2.5 Conclusions

Monitoring efforts from 1991 through 1996 continued to provide the benefit of showing that no major adverse impacts are occurring to the benthic macroinvertebrate communities of Big Bayou Creek and Little Bayou Creek from PGDP operations or effluent discharges. However, the long-term, continuous data set compiled to date, in combination with recently collected nutrient data, suggest that the macroinvertebrate communities at BBK 9.1, BBK 10.0, and LUK 7.2 are experiencing some subtle effects that are consistent with nutrient enrichment associated with PGDP effluents. The results of this effort have also shown that no major persistent changes have occurred in the macroinvertebrate communities at these sites during this period, suggesting that the macroinvertebrate communities have remained in a "steady state" since 1991.

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Appendix A

RAINFALL

Table A.1. Daily precipitation for 1996 in Paducah, Kentucky

Note: Only days with measurable precipitation are shown

Month	Day	Precipitation (cm)	Month	Day	Precipitation (cm)
January	1	0.64	June	1	4.65
	2	0.86		6	1.47
	3	0.13		7	1.50
	6	0.53		9	0.38
	11	1.07		10	0.91
	16	0.10		11	2.64
	17	0.10		12	4.50
	18	2.34		18	1.32
	22	0.20		24	2.46
	23	2.16	July	2	0.64
	26	0.46		8	0.51
February	1	0.15		14	3.43
	14	0.18		19	3.94
	15	0.15		20	0.10
	16	0.33		21	1.63
	19	0.71		22	0.13
	27	1.24		29	0.03
March	5	2.13		30	5.13
	6	1.24	August	2	0.25
	7	0.03	September	6	0.43
	14	0.30		8	0.30
	15	0.51		15	2.87
	16	0.05		16	3.00
	18	0.20		20	0.08
	19	1.12		21	5.31
	20	0.05		26	1.73
	24	1.02		27	3.89
	25	0.41		28	0.05
	28	0.53	October	8	0.20
	31	0.66		17	2.67
April	4	0.48		21	0.89
	7	0.18		22	2.13
	8	0.25		25	0.28
	12	0.13		26	0.56
	13	1.47		27	1.47
	15	0.08		28	0.41
	19	1.70		29	0.10
	20	0.79		31	0.56

Table A.1 (continued)

Month	Day	Precipitation (cm)	Month	Day	Precipitation (cm)
	21	0.13	November	1	0.30
	22	0.61		7	12.45
	23	1.73		9	0.05
	25	0.84		10	0.05
	28	1.40		13	0.20
	29	1.96		17	0.48
May	1	0.05		21	0.13
	2	0.03		24	0.10
	5	0.81		25	1.52
	6	3.00		29	0.48
	7	1.50		30	2.29
	10	1.19	December	1	0.05
	11	0.69		5	0.23
	13	0.10		11	1.73
	14	2.77		12	2.24
	15	1.17		15	0.89
	26	0.41		16	1.57
	27	1.55		23	1.91

Source: Midwestern Climate Center, Champaign, IL, Station ID156110.

Appendix B

TOXICITY MONITORING

Table B.1. Results of fathead minnow toxicity tests of continuously flowing effluents at the Paducah Gaseous Diffusion Plant

Tests conducted March–November 1996

Date	Outfall	Concentration	Survival (%)	Growth[a] (mg/larvae)	
			Mean	Mean	SD
March 1996	Control	100	94.9	0.51	0.04
	001	6	95.0	0.59	0.06
		12	100.0	0.63	0.05
		25	92.5	0.62	0.02
		50	85.0	0.55	0.08
		100	95.0	0.60	0.05
	006	6	100.0	0.59	0.03
		12	90.0	0.49	0.04
		25	90.0	0.54	0.03
		50	61.5	0.37	0.13
		100	47.5	0.33	0.07
	008	6	97.5	0.49	0.06
		12	90.0	0.48	0.04
		25	92.5	0.52	0.04
		50	90.0	0.50	0.05
		100	80.0	0.41	0.15
	009	6	86.8	0.46	0.06
		12	100.0	0.55	0.05
		25	95.0	0.52	0.04
		50	100.0	0.55	0.04
		100	100.0	0.56	0.02
	010	6	100.0	0.48	0.02
		12	55.0	0.30	0.23
		25	90.0	0.45	0.04
		50	27.5	0.16	0.12
		100	27.5	0.15	0.12
March 1996	Control	100	87.5	0.42	0.06
(Retest)	006	6	87.5	0.50	0.07
		12	92.5	0.54	0.03
		25	82.5	0.51	0.05
		50	70.0	0.43	0.11
		100	60.0	0.44	0.10
	010	6	82.5	0.51	0.09
		12	85.0	0.58	0.04

Table B.1 (continued)

Date	Outfall	Concentration	Survival (%)	Growth[a] (mg/larvae)	
			Mean	Mean	SD
		25	92.5	0.60	0.10
		50	90.0	0.57	0.07
		100	85.0	0.64	0.06
May 1996	Control	100	87.2	0.44	0.08
	001	6	92.5	0.54	0.06
		12	95.0	0.50	0.03
		25	76.9	0.46	0.08
		50	82.5	0.44	0.10
		100	87.5	0.48	0.02
	006	6	80.0	0.45	0.06
		12	95.0	0.56	0.05
		25	92.5	0.54	0.05
		50	70.0	0.40	0.09
		100	72.5	0.44	0.10
	008	6	97.5	0.55	0.02
		12	72.5	0.46	0.12
		25	82.5	0.46	0.07
		50	90.0	0.53	0.07
		100	89.7	0.51	0.05
	009	6	100.0	0.57	0.03
		12	85.0	0.54	0.08
		25	80.0	0.50	0.10
		50	62.5	0.39	0.16
		100	95.0	0.57	0.05
	010	6	97.5	0.61	0.07
		12	100.0	0.65	0.05
		25	90.0	0.60	0.07
		50	100.0	0.67	0.04
		100	97.4	0.63	0.03
August 1996	Control	100	90.0	0.52	0.06
	001	6	100.0	0.65	0.02
		12	92.5	0.65	0.03
		25	89.7	0.57	0.04
		50	97.5	0.52	0.08
		100	95.0	0.58	0.03
	006	6	87.5	0.50	0.08

Table B.1 (continued)

Date	Outfall	Concentration	Survival (%) Mean	Growth[a] (mg/larvae) Mean	SD
		12	92.5	0.51	0.04
		25	92.3	0.54	0.06
		50	97.5	0.63	0.02
		100	95.0	0.64	0.08
	008	6	95.0	0.56	0.02
		12	87.5	0.55	0.04
		25	100.0	0.58	0.05
		50	92.5	0.51	0.06
		100	72.5	0.38	0.11
	009	6	90.0	0.57	0.04
		12	92.5	0.63	0.04
		25	90.0	0.64	0.06
		50	87.5	0.61	0.13
		100	92.5	0.60	0.08
	010	6	72.5	0.35	0.06
		12	85.0	0.57	0.10
		25	72.5	0.40	0.10
		50	67.5	0.35	0.03
		100	62.5	0.30	0.07
September 1996	Control	100	97.5	0.65	0.01
(Retest)	010	6	95.0	0.68	0.04
		12	95.0	0.73	0.05
		25	95.0	0.68	0.04
		50	92.5	0.71	0.09
		100	95.0	0.73	0.05
November 1996	Control	100	95.0	0.51	0.04
	001	6	100.0	0.57	0.01
		12	100.0	0.62	0.02
		25	100.0	0.62	0.04
		50	92.5	0.50	0.02
		100	97.5	0.59	0.04
	Control	100	90.0	0.49	0.03
	006	6	82.1	0.43	0.11
		12	85.0	0.47	0.07
		25	90.0	0.55	0.07
		50	90.0	0.54	0.05
		100	94.9	0.55	0.04

Table B.1 (continued)

Date	Outfall	Concentration	Survival (%)	Growth[a] (mg/larvae)	
			Mean	Mean	SD
	Control	100	95.0	0.51	0.03
	008	6	92.5	0.50	0.05
		12	85.0	0.48	0.02
		25	80.0	0.42	0.05
		50	80.0	0.39	0.02
		100	77.5	0.38	0.11
	Control	100	100.0	0.57	0.02
	009	6	100.0	0.55	0.05
		12	97.5	0.49	0.06
		25	90.0	0.52	0.05
		50	95.0	0.53	0.06
		100	85.0	0.52	0.05
	Control	100	95.0	0.50	0.06
	010	6	97.4	0.61	0.04
		12	90.0	0.56	0.04
		25	100.0	0.55	0.02
		50	80.0	0.46	0.09
		100	92.5	0.56	0.05

[a]Growth reported as total weight of surviving larvae per number of initial larvae.

Table B.2. Results of *Ceriodaphnia* toxicity tests of continuously flowing effluents at the Paducah Gaseous Diffusion Plant

Tests conducted March–November 1996

Date	Outfall	Concentration	Survival (%)	Offspring per female	
				Mean	SD
March 1996	Control	100	100	33.6	3.0
	001	6	100	33.6	8.1
		12	90	34.9	9.2
		25	100	35.9	13.1
		50	89	30.2	14.4
		100	100	37.1	2.9
May 1996	Control	100	89	25.7	11.0
	001	6	90	28.1	10.1
		12	100	25.6	11.5
		25	100	28.7	8.1
		50	90	31.9	7.4
		100	100	31.1	2.0
August 1996	Control	100	100	34.2	3.7
	001	6	100	32.9	2.9
		12	90	30.0	10.9
		25	90	32.5	12.3
		50	90	34.6	12.9
		100	100	35.9	4.3
November 1996	Control	100	100	33.0	4.5
	001	6	100	36.0	1.8
		12	100	35.0	2.8
		25	100	37.4	4.0
		50	100	36.5	11.1
		100	100	41.9	3.3

Table B.3. Summary of water chemistry analyses conducted during toxicity tests of continuously flowing effluents at the Paducah Gaseous Diffusion Plant

Analyses conducted March–November 1996

Water Quality Parameter	Date	Outfall	Mean	SD	Min	Max
pH (S.U.)	March 1996	001	8.29	0.09	8.20	8.38
		006	8.99	0.18	8.87	9.20
		008	7.50	0.05	7.46	7.55
		009	7.98	0.10	7.92	8.09
		010	7.81	0.14	7.70	7.97
		006	8.42	0.24	8.28	8.70
		010	7.48	0.05	7.43	7.52
	May 1996	001	8.97	0.36	8.60	9.32
		006	9.05	0.39	8.61	9.36
		008	7.54	0.11	7.43	7.64
		009	7.99	0.11	7.91	8.12
		010	7.82	0.08	7.73	7.88
	August 1996	001	9.31	0.09	9.23	9.41
		006	8.96	0.27	8.65	9.16
		008	7.27	0.01	7.26	7.27
		009	7.80	0.12	7.69	7.92
		010	7.66	0.23	7.40	7.80
	September 1996	010	7.25	0.07	7.21	7.33
	November 1996	001	8.72	0.09	8.64	8.81
		006	8.95	0.21	8.81	9.20
		008	7.37	0.17	7.20	7.53
		009	7.95	0.13	7.86	8.10
		010	7.87	0.12	7.74	7.98
Alkalinity (mg/L as $CaCO^3$)	March 1996	001	36.0	1.7	35	38
		006	53.6	1.1	53	55
		008	40.6	6.4	36	48
		009	64.0	6.5	58	71
		010	35.6	5.0	31	41
		006	53.3	1.1	52	54
		010	35.6	2.0	34	38
	May 1996	001	39.6	5.8	33	44
		006	49.6	1.1	49	51
		008	48.0	6.2	43	55
		009	77.0	19.9	60	99
		010	46.6	10.9	38	59
	August 1996	001	35.6	1.1	35	37
		006	45.6	1.1	45	47

Table B.3 (continued)

Water Quality Parameter	Date	Outfall	Mean	SD	Min	Max
	August 1996	001	35.6	1.1	35	37
		006	45.6	1.1	45	47
		008	25.3	0.5	25	26
		009	31.3	3.7	27	34
		010	26.0	3.6	22	29
	September 1996	010	27.3	1.5	26	29
	November 1996	001	47.6	8.3	41	57
		006	56.3	5.0	51	61
		008	27.0	6.0	23	34
		009	57.0	17.0	38	71
		010	46.3	12.3	36	60
Hardness (mg/L as $CaCO^3$)	March 1996	001	308.6	9.8	302	320
		006	74.0	5.2	70	80
		008	69.3	11.3	60	82
		009	120.0	10.3	108	126
		010	76.0	7.2	70	84
		006	72.6	6.4	68	80
		010	84.0	3.4	82	88
	May 1996	001	312.0	24.2	290	338
		006	70.6	7.5	62	76
		008	83.3	7.5	78	92
		009	107.3	22.0	86	130
		010	88.6	2.3	86	90
	August 1996	006	72.6	6.4	68	80
		008	76.0	12.0	64	88
		009	65.3	9.4	58	76
		010	72.0	5.2	66	76
	September 1996	010	68.6	3.0	66	72
	November 1996	001	226.0	38.5	182	254
		006	78.6	1.1	78	80
		008	64.0	8.7	54	70
		009	82.6	13.6	72	98
		010	90.0	10.0	80	100
Conductivity (μS/Cm)	March 1996	001	1158.0	10.4	1151	1170
		006	188.0	2.5	186	191
		008	324.0	94.3	258	432
		009	994.6	237.8	810	1263
		010	270.6	40.6	241	317
		006	192.6	5.8	186	197
	March 1996	010	271.0	12.5	258	283

Table B.3 (continued)

Water Quality Parameter	Date	Outfall	Mean	SD	Min	Max
	May 1996	001	1074.0	78.7	992	1149
		006	212.3	4.0	208	216
		008	321.0	42.0	278	362
		009	391.3	65.8	322	453
		010	314.0	17.5	294	327
	August 1996	001	1095.6	66.3	1046	1171
		006	217.3	5.6	211	222
		008	229.3	18.1	210	246
		009	212.0	17.7	192	226
		010	261.6	33.2	240	300
	September 1996	010	266.3	7.6	258	273
	November 1996	001	867.6	122.8	726	945
		006	223.3	10.1	217	235
		008	245.6	26.7	215	264
		009	256.0	73.7	209	341
		010	287.6	10.1	276	294

Table B.4. Results of fathead minnow toxicity tests of intermittently flowing effluents at the Paducah Gaseous Diffusion Plant

Tests conducted January–October 1996

Date	Outfall	Concentration	Survival (%)	Growth[a] (mg/larvae)	
			Mean	Mean	SD
January 1996	Control	100	97.4	0.59	0.04
	013	6	100.0	0.66	0.04
		12	97.5	0.69	0.07
		25	100.0	0.64	0.11
		50	100.0	0.73	0.06
		100	100.0	0.68	0.09
	015	6	97.3	0.67	0.07
		12	100.0	0.70	0.04
		25	100.0	0.70	0.03
		50	100.0	0.73	0.04
		100	100.0	0.70	0.04
	016	6	97.5	0.60	0.06
		12	97.5	0.66	0.08
		25	100.0	0.63	0.03
		50	97.5	0.70	0.09
		100	85.0	0.55	0.05
	017	6	100.0	0.62	0.04
		12	80.0	0.57	0.15
		25	87.2	0.61	0.06
		50	92.3	0.72	0.07
		100	89.7	0.67	0.09
	018	6	97.5	0.68	0.05
		12	95.0	0.70	0.06
		25	87.2	0.66	0.05
		50	100.0	0.76	0.02
		100	100.0	0.73	0.06
April 1996	Control	100	97.5	0.60	0.09
	013	6	97.5	0.69	0.06
		12	100.0	0.70	0.02
		25	92.5	0.69	0.08
		50	92.5	0.74	0.09
		100	90.0	0.67	0.05

Table B.4 (continued)

Date	Outfall	Concentration	Survival (%)	Growth[a] (mg/larvae)	
			Mean	Mean	SD
	015	6	90.0	0.65	0.07
		12	97.5	0.72	0.04
		25	95.0	0.71	0.06
		50	95.0	0.80	0.04
		100	87.5	0.70	0.13
	016	6	87.5	0.59	0.03
		12	92.5	0.67	0.09
		25	97.5	0.70	0.08
		50	77.5	0.60	0.11
		100	72.5	0.56	0.13
	017	6	90.0	0.60	0.04
		12	92.5	0.58	0.06
		25	90.0	0.56	0.05
		50	72.5	0.46	0.29
		100	82.5	0.57	0.14
	018	6	95.0	0.65	0.06
		12	95.0	0.72	0.06
		25	85.0	0.70	0.04
		50	92.5	0.67	0.04
		100	90.0	0.65	0.10
July 1996	Control	100	90.0	0.46	0.06
	013	6	97.5	0.49	0.08
		12	90.0	0.49	0.10
		25	95.0	0.63	0.04
		50	90.0	0.62	0.11
		100	97.5	0.67	0.07
	015	6	95.0	0.59	0.04
		12	90.0	0.57	0.04
		25	100.0	0.69	0.07
		50	97.5	0.63	0.09
		100	95.0	0.67	0.11
	016	6	100.0	0.55	0.07
		12	87.5	0.56	0.07
		25	90.0	0.57	0.04
		50	90.0	0.64	0.05
		100	100.0	0.67	0.04
	017	6	84.6	0.47	0.08
		12	100.0	0.61	0.04

Table B.4 (continued)

Date	Outfall	Concentration	Survival (%)	Growth[a] (mg/larvae)	
			Mean	Mean	SD
		25	90.0	0.62	0.06
		50	100.0	0.65	0.05
		100	95.0	0.65	0.06
	018	6	97.4	0.50	0.06
		12	97.5	0.57	0.02
		25	94.7	0.56	0.10
		50	95.0	0.65	0.05
		100	97.5	0.69	0.04
October 1996	Control	100	95.0	0.43	0.03
	013	6	97.5	0.48	0.03
		12	100.0	0.47	0.03
		25	95.0	0.46	0.05
		50	95.0	0.51	0.07
		100	77.5	0.40	0.11
	Control	100	97.5	0.44	0.02
	015	6	92.5	0.44	0.02
		12	97.5	0.47	0.05
		25	92.5	0.48	0.05
		50	85.0	0.41	0.05
		100	92.5	0.46	0.04
	Control	100	90.0	0.45	0.03
	016	6	95.0	0.49	0.04
		12	100.0	0.50	0.04
		25	95.0	0.50	0.05
		50	95.0	0.51	0.09
		100	76.9	0.42	0.06
	Control	100	97.5	0.47	0.05
	017	6	100.0	0.55	0.02
		12	95.0	0.54	0.01
		25	97.4	0.54	0.04
		50	95.0	0.50	0.05
		100	90.0	0.49	0.10
	Control	100	90.0	0.42	0.02
	018	6	87.5	0.43	0.04
		12	87.5	0.44	0.05
		25	85.0	0.41	0.02
		50	72.5	0.35	0.10
		100	82.5	0.37	0.05

[a]Growth reported as total weight of surviving larvae per number of initial larvae.

Table B.5. Results of *Ceriodaphnia* toxicity tests of intermittently flowing effluents at the Paducah Gaseous Diffusion Plant

Tests conducted January 1996

Date	Outfall	Concentration	Survival (%)	Offspring per female	
				Mean	SD
January 1996	Control	100	100	28.3	3.7
	013	6	100	12.3	11.6
		12	100	13.9	10.5
		25	100	14.3	6.9
		50	90	10.2	6.3
		100	100	2.7	3.5
	Control	100	100	30.4	2.5
	015	6	100	27.0	4.2
		12	100	29.1	4.9
		25	100	29.5	3.3
		50	100	26.6	4.5
		100	100	27.3	3.3
	Control	100	90	27.1	3.5
	016	6	100	27.5	2.9
		12	100	23.9	10.6
		25	100	29.2	6.5
		50	100	22.5	10.1
		100	100	25.3	5.7
	Control	100	100	25.3	4.0
	017	6	100	15.5	13.1
		12	90	14.0	11.3
		25	100	14.3	11.0
		50	100	12.4	12.0
		100	100	9.2	8.1
	Control	100	100	28.3	11.1
	018	6	100	23.4	10.0
		12	100	22.2	6.9
		25	90	17.6	10.3
		50	100	17.6	5.3
		100	100	10.4	2.9

Table B.6. Summary of water chemistry analyses conducted during toxicity tests of intermittently flowing effluents at the Paducah Gaseous Diffusion Plant

Analyses conducted January–October 1996

Date	Outfall	pH (S.U.)	Alkalinity (mg/L $CaCO_3$)	Hardness (mg/L $CaCO_3$)	Conductivity (μS/cm)	Total Suspended Solids (mg/L)
January 1996	013	7.71	71	166	389	181.2
	015	7.61	67	116	272	424.0
	016	7.81	154	246	589	8.2
	017	7.85	80	112	269	159.5
	018	7.67	58	152	326	253.0
April 1996	013	7.48	47	86	204	60.0
	015	7.97	81	100	258	25.3
	016	7.95	72	92	251	21.8
	017	8.05	86	104	239	35.3
	018	7.65	46	84	126	56.5
July 1996	013	7.86	106	288	556	5.7
	015	7.81	75	84	392	22.8
	016	7.77	85	114	272	8.3
	017	7.98	130	180	359	60.0
	018	7.70	76	106	227	11.7
October 1996	013	7.78	76	240	472	4.0
	015	7.86	74	196	504	60.4
	016	7.69	80	168	410	6.4
	017	8.10	99	152	322	39.8
	018	7.65	62	114	230	6.0

Appendix C

RESULTS OF ANALYSES OF INDIVIDUAL FISH SAMPLES

Appendix C

RESULTS OF ANALYSES OF INDIVIDUAL FISH SAMPLES

PCB concentrations in sunfish from uncontaminated areas are generally below routine detection limits. As expected, PCB concentrations in fish from the two reference sites (Hinds Creek and BBK 12.5) were below the limit of detection in both October 1994 and April 1995. Mean recoveries (±SD) of PCBs spiked into reference stream fish were good, averaging 69.7% ± 5.89 for the October 1994 sampling season and 68.6% ± 9.36 for the April 1995 season.

The average absolute difference in PCB concentrations between duplicate fish samples was extremely small, in part due to the low concentrations in these set of analyses. In October 1994, the average absolute difference was 0.045 μg/g for PCB-1254 and 0.052 μg/g for PCB-1260. For the April 1995 samples, the average absolute difference between duplicates was 0.015 μg/g for PCB-1254 and 0.044 μg/g for PCB-1260.

Table C.1. Concentrations of mercury and PCBs in individual fish collected from Little Bayou Creek and Big Bayou Creek

Site[a]	Date[b]	Spp.[c]	Sex	Sample	Type[d]	Wt.[e]	Lgt.[f]	Hg[g]	1248[h]	Qual[i]	1254[j]	Qual	1260[k]	Qual	Lipids[l]
BBK10.0	10/24/95	LONEAR	M	8930	R	40.0	12.4	.	0.082	U	0.082	U	0.082	U	0.43
BBK10.0	10/24/95	LONEAR	M	8931	R	35.3	11.5	.	0.087	U	0.087	U	0.087	U	0.84
BBK10.0	10/24/95	LONEAR	F	8932	R	52.9	14.1	.	0.058	U	0.049	J	0.064	.	0.44
BBK10.0	10/24/95	LONEAR	M	8933	R	25.8	10.9	.	0.059	U	0.059	U	0.050	JP	0.46
BBK10.0	10/24/95	LONEAR	M	8934	R	39.1	12.0	.	0.077	U	0.077	U	0.077	U	0.59
BBK10.0	10/24/95	LONEAR	M	8935	R	33.5	11.7	.	0.086	U	0.086	U	0.086	U	0.62
BBK10.0	10/24/95	LONEAR	M	8936	R	30.6	11.6	.	0.094	U	0.094	U	0.094	U	0.62
BBK10.0	10/24/95	LONEAR	M	8937	R	34.7	12.2	.	0.105	U	0.105	U	0.105	U	0.44
BBK10.0	10/24/95	LONEAR	M	8930	D	40.0	12.4	.	0.072	U	0.025	.	0.051	.	0.49
BBK9.1	10/24/95	LONEAR	M	8940	R	58.8	13.9	0.23	0.083	U	0.083	U	0.083	.	0.33
BBK9.1	10/24/95	LONEAR	M	8941	R	43.7	13.9	0.44	.	.	.	.	.	.	.
BBK9.1	10/24/95	LONEAR	M	8942	R	54.5	13.6	0.29	0.094	U	0.094	U	0.094	U	0.45
BBK9.1	10/24/95	LONEAR	M	8943	R	41.7	12.6	0.25	0.017	P	0.044	.	0.106	.	0.75
BBK9.1	10/24/95	LONEAR	M	8944	R	39.1	12.1	0.21	0.083	U	0.083	U	0.083	U	0.63
BBK9.1	10/24/95	LONEAR	F	8945	R	41.5	13.1	.	0.082	U	0.082	U	0.082	U	0.39
BBK9.1	10/24/95	LONEAR	M	8946	R	48.5	13.1	0.26	.	.	.	.	.	.	.
BBK9.1	10/24/95	LONEAR	F	8948	R	43.6	13.1	0.42	.	.	.	.	.	.	.
BBK9.1	10/24/95	LONEAR	F	8949	R	59.5	14.6	0.45	0.055	U	0.055	U	0.055	U	0.22
BBK9.1	10/24/95	LONEAR	M	8958	R	38.4	12.5	.	0.084	U	0.084	U	0.084	U	.
BBK9.1	10/24/95	LONEAR	M	8959	R	49.0	13.3	.	0.064	U	0.064	U	0.064	U	0.38
BBK9.1	10/24/95	LONEAR	M	8941	D	43.7	13.9	0.43	.	.	.	.	.	.	.
BBK9.1	10/24/95	LONEAR	M	8959	D	49.0	13.3	.	0.061	U	0.061	U	0.061	U	0.38
BBK12.5	10/24/95	LONEAR	M	8960	R	62.2	14.7	.	0.057	U	0.057	U	0.057	U	0.35
BBK12.5	10/24/95	LONEAR	M	8961	R	43.2	13.5	.	0.083	U	0.083	U	0.083	U	0.22
BBK12.5	10/24/95	LONEAR	M	8962	R	36.3	12.5	0.51	0.043	JP	0.094	U	0.094	U	0.36
BBK12.5	10/24/95	LONEAR	M	8963	R	40.2	12.8	0.28	0.037	JP	0.074	U	0.074	U	0.59
BBK12.5	10/24/95	LONEAR	M	8964	R	36.3	12.1	.	0.100	U	0.100	U	0.100	U	0.46
BBK12.5	10/24/95	LONEAR	M	8965	R	61.7	14.3	.	0.023	JP	0.061	U	0.061	U	0.34
BBK12.5	10/24/95	LONEAR	M	8966	R	35.6	11.9	.	0.088	U	0.088	U	0.088	U	0.26
BBK12.5	10/24/95	LONEAR	M	8967	R	41.1	13.2	.	.	.	.	.	.	.	.
BBK12.5	10/24/95	LONEAR	M	8968	R	39.1	13.0	0.30	0.088	U	0.088	U	0.088	U	0.28
BBK12.5	10/24/95	LONEAR	M	8960	D	62.2	14.7	.	.	.	.	.	.	.	.
BBK12.5	10/24/95	LONEAR	M	8961	D	43.2	13.5	0.20	.	.	.	.	.	.	.
LUK4.3	10/25/95	LONEAR	M	8970	R	45.6	13.0	.	0.006	JP	0.113	.	0.069	U	0.48
LUK4.3	10/25/95	LONEAR	M	8971	R	38.4	12.9	.	0.009	J	0.097	P	0.089	.	0.32
LUK4.3	10/25/95	LONEAR	M	8972	R	29.7	11.1	.	0.020	P	0.048	P	0.028	.	0.31
LUK4.3	10/25/95	LONEAR	M	8973	R	34.0	12.0	.	0.010	J	0.050	JP	0.073	JP	0.34
LUK4.3	10/25/95	LONEAR	M	8974	R	42.2	13.0	.	0.063	JP	0.071	P	0.054	J	0.40
LUK4.3	10/25/95	LONEAR	M	8975	R	41.4	13.0	.	0.078	U	0.078	P	0.054	JP	0.27
LUK4.3	10/25/95	LONEAR	M	8976	R	34.5	11.6	.	0.033	J	0.028	J	0.035	JP	0.29
LUK4.3	10/25/95	LONEAR	M	8977	R	32.2	11.6	.	0.078	J	0.082	J	0.045	J	0.22
LUK4.3	10/25/95	LONEAR	M	8970	D	45.6	13.0	.	0.045	JP	0.033	JP	0.077	U	0.35
LUK7.2	10/25/95	LONEAR	M	8980	R	27.9	11.3	0.16	0.287	.	0.210	.	0.101	J	0.42
LUK7.2	10/25/95	LONEAR	M	8981	R	29.6	11.9	0.24	0.422	.	0.255	.	0.138	J	0.69
LUK7.2	10/25/95	LONEAR	M	8982	R	30.6	11.7	0.17	0.242	P	0.215	.	0.161	.	0.43
LUK7.2	10/25/95	LONEAR	M	8983	R	27.8	11.1	0.14	0.200	U	0.179	J	0.210	P	0.32
LUK7.2	10/25/95	LONEAR	M	8984	R	41.7	12.2	0.19	0.092	.	0.053	JP	0.039	J	0.47

Table C.1 (continued)

Site[a]	Date[b]	Spp.[c]	Sex	Sample	Type[d]	Wt.[e]	Lgt.[f]	Hg[g]	1248[h]	Qual[i]	1254[j]	Qual	1260[k]	Qual	Lipids[l]
LUK7.2	10/25/95	LONEAR	M	8985	R	20.8	10.5	0.11	0.168	.	0.203	.	0.103	J	0.47
LUK7.2	10/25/95	LONEAR	M	8986	R	25.4	10.9	0.27	0.088	J	0.106	J	0.122	J	0.03
LUK7.2	10/25/95	LONEAR	M	8987	R	26.7	10.9	0.16	0.255	P	0.199	.	0.124	.	0.44
LUK7.2	10/25/95	LONEAR	M	8981	D	29.6	11.9	0.20	.	.	.	.	.	.	.
LUK7.2	10/25/95	LONEAR	M	8983	D	27.8	11.1	.	0.230	P	0.206	.	0.168	.	0.35
LUK9.0	10/25/95	LONEAR	F	2271	R	21.3	10.3	.	0.067	JP	0.175	.	0.086	J	0.61
LUK9.0	10/25/95	LONEAR	M	2273	R	17.7	9.9	.	0.124	P	0.763	.	0.467	.	0.42
LUK9.0	10/25/95	LONEAR	M	2274	R	28.0	11.2	.	0.104	P	0.260	.	0.229	P	0.59
LUK9.0	10/25/95	LONEAR	M	2275	R	35.2	11.6	.	0.049	JP	0.464	.	0.359	.	0.46
LUK9.0	10/25/95	LONEAR	M	2276	R	27.7	11.1	.	0.068	JP	0.406	.	0.338	P	0.42
LUK9.0	10/25/95	LONEAR	M	2277	R	24.9	10.9	.	0.140	U	0.149	.	0.545	.	0.33
LUK9.0	10/25/95	LONEAR	M	2266	R	23.6	11.0	.	0.142	P	0.374	.	0.265	.	0.46
LUK9.0	10/25/95	LONEAR	M	2267	R	25.1	10.5	.	0.095	JP	0.290	.	0.221	P	0.37
LUK9.0	10/25/95	LONEAR	F	2271	D	21.3	10.3	.	0.089	JP	0.114	JP	0.120	JP	0.40
BBK9.1	10/24/95	SPOBAS	F	8950	R	680.7	38.6	1.20	0.048	U	0.215	.	0.246	P	0.13
BBK9.1	10/24/95	SPOBAS	M	8951	R	316.4	28.5	0.44	0.034	U	0.016	P	0.098	.	0.31
BBK9.1	10/24/95	SPOBAS	F	8952	R	400.2	31.6	0.79	0.036	U	0.042	.	0.095	.	0.25
BBK9.1	10/24/95	SPOBAS	M	8953	R	230.5	27.0	0.29	0.035	U	0.057	P	0.103	P	0.22
BBK9.1	10/24/95	SPOBAS	F	8954	R	206.6	25.4	0.56	0.027	U	0.013	P	0.045	.	0.39
BBK9.1	10/24/95	SPOBAS	M	8955	R	173.7	23.8	0.29	0.031	U	0.022	P	0.051	.	0.25
BBK9.1	10/24/95	SPOBAS	M	8956	R	182.8	23.7	0.27	0.041	U	0.062	P	0.148	.	0.78
BBK9.1	10/24/95	SPOBAS	M	8957	R	147.6	23.3	0.33	0.042	U	0.023	P	0.040	JP	0.51
BBK9.1	10/24/95	SPOBAS	M	8953	D	230.5	27.0	0.35	0.038	U	0.079	.	0.177	P	0.23
LUK7.2	10/25/95	SPOBAS	F	8998	R	201.3	24.1	.	0.034	U	0.400	.	0.514	.	0.63
MAK13.8	10/25/95	SPOBAS	M	2260	R	126.2	22.0	0.36	.	.	.	.	.	.	.
MAK13.8	10/25/95	SPOBAS	M	2261	R	211.7	25.9	0.39	.	.	.	.	.	.	.
MAK13.8	10/25/95	SPOBAS	M	2262	R	305.7	28.0	0.29	.	.	.	.	.	.	.
MAK13.8	10/25/95	SPOBAS	F	2263	R	112.5	20.5	0.31	.	.	.	.	.	.	.
MAK13.8	10/25/95	SPOBAS	M	2261	D	211.7	25.9	0.28	.	.	.	.	.	.	.
BBK12.5	4/24/96	LONEAR	M	2503	R	41.8	12.0	.	0.085	U	0.028	U	0.20	U	0.39
BBK12.5	4/24/96	LONEAR	M	2504	R	45.7	12.3	.	0.076	U	0.02	U	0.30	U	0.53
BBK12.5	4/24/96	LONEAR	M	2505	R	45.9	11.9	.	0.072	U	0.015	U	0.20	U	0.29
BBK12.5	4/24/96	LONEAR	M	2506	R	31.7	11.1	.	0.115	U	0.031	U	0.67	U	0.39
BBK9.1	4/24/96	LONEAR	M	2630	R	71.8	14.5	.	0.046	U	0.038	JBP	0.16	P	0.31
BBK9.1	4/24/96	LONEAR	M	2631	R	69.6	13.9	.	0.051	U	0.047	JBP	0.18	P	0.66
BBK9.1	4/24/96	LONEAR	M	2632	R	50.5	12.6	.	0.071	U	0.035	UB	0.46	U	0.39
BBK9.1	4/24/96	LONEAR	M	2633	R	59.7	13.4	.	0.051	U	0.12	BP	0.31		1.67
BBK9.1	4/24/96	LONEAR	M	2634	R	85.0	14.8	.	0.034	U	0.11	B	0.23		1.95
BBK9.1	4/24/96	LONEAR	M	2635	R	42.0	11.8	.	0.082	U	0.10	BP	0.22		1.23
BBK9.1	4/24/96	LONEAR	M	2636	R	60.3	13.0	.	0.055	U	0.074	B	0.15		1.45
BBK9.1	4/24/96	LONEAR	M	2637	R	48.1	12.3	.	0.063	U	0.074	B	0.21		0.81
BBK9.1	4/24/96	LONEAR	M	2630	D	71.8	14.5	.	0.042	U	0.064		0.15		0.79
LUK4.3	4/24/96	LONEAR	M	2640	R	49.8	12.9	.	0.068	U	0.032	U	0.29	U	0.12
LUK4.3	4/24/96	LONEAR	M	2641	R	46.5	12.2	.	0.033	U	0.089		0.063	P	0.91
LUK4.3	4/24/96	LONEAR	M	2642	R	42.3	11.8	.	0.044	U	0.074		0.059		0.61
LUK4.3	4/24/96	LONEAR	M	2643	R	37.2	11.0	.	0.043	U	0.069		0.103	P	0.28

Table C.1 (continued)

Site[a]	Date[b]	Spp.[c]	Sex	Sample	Type[d]	Wt.[e]	Lgt.[f]	Hg[g]	1248[h]	Qual[i]	1254[j]	Qual	1260[k]	Qual	Lipids[l]
LUK4.3	4/24/96	LONEAR	M	2644	R	35.5	11.8	.	0.052	U	0.080		0.18		0.42
LUK4.3	4/24/96	LONEAR	M	2645	R	37.4	12.0	.	0.044	U	0.080		0.14		0.34
LUK4.3	4/24/96	LONEAR	M	2646	R	42.5	12.0	.	0.044	U	0.063	P	0.15		0.45
LUK4.3	4/24/96	LONEAR	M	2647	R	40.7	12.6	.	0.037	U	0.046		0.12		0.21
LUK4.3	4/24/96	LONEAR	M	2640	D	49.8	12.9	.	0.058	U	0.061	J	0.23		0.36
LUK7.2	4/24/96	LONEAR	M	2650	R	38.5	11.7	.	0.108	U	0.046	U	0.21	P	0.02
LUK7.2	4/24/96	LONEAR	M	2651	R	40.7	12.1	.	0.041	U	0.41		0.33	P	1.13
LUK7.2	4/24/96	LONEAR	M	2652	R	28.2	10.3	.	0.061	U	0.12	P	0.22		0.66
LUK7.2	4/24/96	LONEAR	M	2653	R	30.7	10.9	.	0.056	U	0.19		0.25		0.40
LUK7.2	4/24/96	LONEAR	F	2654	R	31.8	11.0	.	0.05	U	0.11	P	0.25		1.05
LUK7.2	4/24/96	LONEAR	M	2655	R	29.3	10.3	.	0.064	U	0.13	P	0.27		0.49
LUK7.2	4/24/96	LONEAR	M	2656	R	35.4	11.7	.	0.044	U	0.12		0.24		0.51
LUK7.2	4/24/96	LONEAR	M	2657	R	35.2	11.1	.	0.042	U	0.14		0.25		0.47
LUK7.2	4/24/96	LONEAR	M	2650	D	38.5	11.7	.	0.094	U	0.059	U	0.45	U	0.38
LUK9.0	4/24/96	LONEAR	M	2660	R	47.7	12.0	.	0.066	U	0.22		0.28	P	0.13
LUK9.0	4/24/96	LONEAR	M	2661	R	44.1	12.3	.	0.076	U	0.30		0.34		0.15
LUK9.0	4/24/96	LONEAR	M	2662	R	37.4	11.7	.	0.041	U	0.27	P	0.38		0.29
LUK9.0	4/24/96	LONEAR	M	2663	R	26.6	10.6	.	0.066	U	0.20	P	0.30		0.19
LUK9.0	4/24/96	LONEAR	M	2664	R	44.2	12.3	.	0.071	U	0.26		0.42		0.17
LUK9.0	4/24/96	LONEAR	M	2665	R	44.7	12.5	.	0.083	U	0.13	P	0.27		0.49
LUK9.0	4/24/96	LONEAR	M	2666	R	27.9	11.4	.	0.062	U	0.19		0.25		0.19
LUK9.0	4/24/96	LONEAR	M	2667	R	32.7	11.4	.	0.049	U	0.17		0.24		0.17
LUK9.0	4/24/96	LONEAR	M	2660	D	47.7	12.0	.	0.065	U	0.30		0.46		0.23

[a]Site designations are as follows: BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.
[b]Collection date.
[c]Species designations are as follows: LONEAR - Longear sunfish; SPBASS - Spotted bass.
[d]Type designations are as follows: R - regular sample; D - duplicate sample.
[e]Weight of fish measured in grams.
[f]Total length of fish measured in centimeters.
[g]Concentrations of Hg reported as μg/g wet wt.
[h]Concentrations in fish filets of Aroclor 1248 in μg/g wet wt.
[i]Data qualifiers for the three Aroclors. "U" indicates compound was analyzed for but not detected. The sample quantitation limit is listed. *(detection limits are estimated by using one tenth the quantitation limit).* "J" indicates an estimated value that is below the quantitation limit. "P" indicates greater than a 25% difference between the primary and secondary column results.
[j]Concentrations in fish filets of Aroclor 1254 in μg/g wet wt.
[k]Concentrations in fish filets of Aroclor 1260 in μg/g wet wt.
[l]Percent lipids reported for that sample.

Appendix D

FISH COMMUNITY DATA: SPECIES CHARACTERISTICS, DENSITY, AND BIOMASS FOR BIG BAYOU CREEK, LITTLE BAYOU CREEK, AND MASSAC CREEK DURING MARCH-APRIL AND SEPTEMBER 1996

Table D.1. Tolerance, feeding guilds and lithophilic spawners for species found in and near the drainages of Big Bayou Creek, Little Bayou Creek, and Massac Creek

Species	Tolerance[a]	Feeding guild[b]	Lithophilic spawner[c]
Spotted gar (*Lepisosteus oculatus*)[c]		PIS	
Longnose gar (*Lepisosteus osseus*)		PIS	
Shortnose gar (*Lepisosteus platostomus*)[c]		PIS	
Bowfin (*Amia calva*)		PIS	
Gizzard shad (*Dorosoma cepedianum*)	TOL	GEN	
Goldfish (*Carassius auratus*)	TOL	GEN	
Red shiner (*Cyprinella lutrensis*)	TOL		
Spotfin shiner (*Cyprinella spiloptera*)	TOL		
Steelcolor shiner (*Cyprinella whipplei*)	INTOL		
Common carp (*Cyprinus carpio*)	TOL	GEN	
Ribbon shiner (*Lythrurus fumeus*)	INTOL		
Silver chub (*Macrhybopsis storeiana*)		BIN	
Emerald shiner (*Notropis atherinoides*)			LITH
River shiner (*Notropis blennius*)			LITH
Sand shiner (*Notropis stramineus*)	INTOL		
Mimic shiner (*Notropis volucellus*)	INTOL		
Suckermouth minnow (*Phenacobius mirabilis*)		BIN	LITH
Fathead minnow (*Pimephales promelas*)	TOL	GEN	
Creek chub (*Semotilus atromaculatus*)	TOL	GEN	
White sucker (*Catostomus commersoni*)	TOL	GEN	LITH
Creek chubsucker (*Erimyzon oblongus*)		BIN	
Smallmouth buffalo (*Ictiobus bubalus*)		BIN	
Bigmouth buffalo (*Ictiobus cyprinellus*)		BIN	
Black buffalo (*Ictiobus niger*)		BIN	
Spotted sucker (*Minytrema melanops*)	INTOL	GEN	LITH
Black redhorse (*Moxostoma duquesnei*)	INTOL	BIN	LITH
Golden redhorse (*Moxostoma erythrurum*)	INTOL	BIN	LITH
Black bullhead (*Ameiurus melas*)	TOL	GEN	
Yellow bullhead (*Ameiurus natalis*)	TOL	GEN	
Brown bullhead (*Ameiurus nebulosus*)	TOL	GEN	
Tadpole madtom (*Noturus gyrinus*)	INTOL	BIN	
Freckled madtom (*Noturus nocturnus*)	INTOL	BIN	

Table D.1 (continued)

Species	Tolerance[a]	Feeding guild[b]	Lithophilic spawner[c]
Grass pickerel (*Esox americanus vermiculatus*)		PIS	
Pirate perch (*Aphredoderus sayanus*)		BIN	
Brook silversides (*Labidesthers sicculus*)	INTOL		
Green sunfish (*Lepomis cyanellus*)	TOL		
Warmouth (*Lepomis gulosus*)		GEN	
Bluegill (*Lepomis macrochirus*)		GEN	
Longear sunfish (*Lepomis megalotis*)		GEN	
Redspotted sunfish (*Lepomis miniatus*)		BIN	
Spotted bass (*Micropterus punctulatus*)		PIS	
Largemouth bass (*Micropterus salmoides*)		PIS	
Mud darter (*Etheostoma asprigene*)		BIN	LITH
Bluntnose darter (*Etheostoma chlorosomum*)	INTOL	BIN	
Slough darter (*Etheostoma gracile*)		BIN	
Logperch (*Percina caprodes*)	INTOL	BIN	LITH
Blackside darter (*Percina maculata*)	INTOL	BIN	LITH

[a]Tolerant (TOL) and sensitive (INTOL) species were tentatively identified for the Paducah area using collection records and text discussions in Becker 1983, Burr and Warren 1986, Cross and Collins 1975, Etnier and Starnes 1993, Karr et al. 1986, Lee et al. 1980, Ohio EPA 1987, Ohio EPA 1988, Plfieger 1975, Robison and Buchanan 1988, Smith 1979, and Trautman 1981. Complete citations for references listed in this table may be found in Section 6 of this report.

[b]Feeding guilds are assigned to categories of interest in assessing impacts. Guilds include species that are primarily *generalists* (GEN), fish that feed on many types of food items and from many areas of the stream; *benthic insectivores* (BIN), those that eat macroinvertebrates associated with bottom substrates; and *piscivores* (PIS), fish that eat other fish.

[c]Lithophilic spawners (LITH) are species that release eggs randomly or without parental care in or onto gravel substrates. These species are especially vulnerable to siltation or low dissolved oxygen.

Table D.2. Fish densities (number/m^2) in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March–April 1996

	Sites[a]				
Species[b]	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Stoneroller	0.24	1.03	2.22	0.20	0.83
Red shiner	-	-	<0.01	0.34	<0.01
Steelcolor shiner	-	-	-	-	0.06[c]
Common carp	0.01	-	-	-	-
Ribbon shiner	-	-	-	-	0.02[c]
Redfin shiner	-	0.03	0.02	-	0.09
Golden shiner	-	-	<0.01	<0.01	-
Bluntnose minnow	-	0.03	0.08	0.13	0.08
Creek chub	0.01	0.11	0.43	0.11	0.10
White sucker	-	-	-	-	<0.01
Creek chubsucker	0.01	-	-	-	0.02
Spotted sucker	<0.01	-	-	-	-
Yellow bullhead	0.01	<0.01	0.06	<0.01	0.01
Pirate perch	-	-	-	-	<0.01
Blackspotted topminnow	0.04	0.11	0.33	0.25	0.22
Western mosquitofish	0.01	0.32	-	0.47	0.01
Green sunfish	0.06	0.03	0.11	0.01	0.06
Bluegill	0.21	0.01	0.01	-	0.02
Longear sunfish	0.62	0.12	0.33	0.02	0.34
Redear sunfish	0.01	-	-	-	-
Hybrid sunfish	-	-	<0.01	-	-
Spotted bass	0.01	-	<0.01	-	-
Largemouth bass	0.02	-	0.01[c]	-	-
Slough darter	<0.01	-	-	0.25	<0.01[c]
Logperch	-	-	-	-	0.01
Blackside darter	-	-	-	-	0.01
Total density	1.26	1.79	3.6	1.78	1.88

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991).

[c]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

Table D.3. Fish biomass (g/m²) in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March–April 1996

	Sites[a]				
Species[b]	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Stoneroller	0.87	5.89	8.01	0.65	2.06
Red shiner	-	-	<0.01	0.25	<0.01
Steelcolor shiner	-	-	-	-	0.11[c]
Common carp	1.39	-	-	-	-
Ribbon shiner	-	-	-	-	0.02[c]
Redfin shiner	-	0.04	0.05	-	0.12
Golden shiner	-	-	0.01	0.01	-
Bluntnose minnow	-	0.08	0.23	0.17	0.17
Creek chub	0.29	1.07	2.52	0.36	0.57
White sucker	-	-	-	-	0.16
Creek chubsucker	0.92	-	-	-	0.26
Spotted sucker	1.06	-	-	-	-
Yellow bullhead	0.63	0.05	0.8	0.01	0.15
Pirate perch	-	-	-	-	0.01
Blackspotted topminnow	0.1	0.14	0.45	0.21	0.32
Western mosquitofish	<0.01	0.09	-	0.15	<0.01
Green sunfish	0.58	0.22	0.52	0.01	0.31
Bluegill	4.82	0.18	0.15	-	0.05
Longear sunfish	13.28	1.57	2.11	0.02	1.57
Redear sunfish	0.15	-	-	-	-
Hybrid sunfish	-	-	<0.01	-	-
Spotted bass	1.79	-	0.02	-	-
Largemouth bass	0.71	-	0.21[c]	-	-
Slough darter	<0.01	-	-	0.34	<0.01[c]
Logperch	-	-	-	-	0.05
Blackside darter	-	-	-	-	0.01
Total biomass	26.59	9.33	15.08	2.18	5.94

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991).

[c]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

Table D.4 Fish densities (number/m^2) in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, September 1996

Species[b]	Sites[a]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Gizzard shad	<0.01	-	-	-	0.02
Stoneroller	0.34	1.48	0.63	0.07	0.43
Red shiner	-	-	-	0.12	<001[c]
Steelcolor shiner	<0.01[c]	-	-	<0.01[c]	0.08[c]
Miss. silvery minnow	<0.01	<0.01	1.59	0.71	0.81
Ribbon shiner	-	-	-	-	0.03[c]
Redfin shiner	-	-	0.02	<0.01	0.01
Golden shiner	-	-	-	<0.01	-
Bluntnose minnow	<0.01	-	0.02	0.49	0.03
Fathead minnow	-	-	-	-	<0.01
Creek chub	<0.01	<0.01	0.39	0.23	0.19
Creek chubsucker	-	-	<0.01	-	0.06
Spotted sucker	0.01	-	-	-	-
Yellow bullhead	0.01	<0.01	0.07	0.06	0.01
Grass pickerel	-	<0.01	-	-	-
Pirate perch	-	-	-	0.03	0.01
Blackspotted topminnow	0.09	0.34	0.39	0.36	0.23
Western mosquitofish	0.07	0.23	0.02	0.21	0.06
Flier	<0.01	-	-	<0.01	-
Green sunfish	0.09	0.16	0.10	0.10	0.09
Warmouth	-	-	-	<0.01	<0.01
Bluegill	0.08	0.11	0.06	-	0.04
Longear sunfish	0.11	0.30	0.34	0.07	0.25
Hybrid sunfish	-	-	<0.01	0.01	<0.01
Spotted bass	0.01	0.01	0.01	<0.01	<0.01
Largemouth bass	0.01	0.06	0.04	0.01	0.01
White crappie	<0.01	-	-	-	<0.01
Slough darter	-	-	<0.01	0.01	-
Logperch	-	-	-	-	0.05
Blackside darter	-	-	-	-	0.01
Total density	0.82	2.69	3.68	2.49	2.42

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991).

[c]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

Table D.5. Fish biomass (g/m²) in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, September 1996

	Sites[a]				
Species[b]	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Gizzard shad	0.17	-	-	-	0.23
Stoneroller	1.29	7.57	2.14	0.15	2.04[c]
Red shiner	-	-	-	0.18	<0.01
Steelcolor shiner[c]	0.01[c]	-	-	0.02[c]	0.16[c]
Miss. silvery minnow	0.01	0.01	2.69	4.95	1.13
Ribbon shiner	-	-	-	-	0.04
Redfin shiner[c]	-	-	0.05	<0.01	0.01
Golden shiner	-	-	-	<0.01	-
Bluntnose minnow	0.01	-	0.05	0.88	0.07
Fathead minnow	-	-	-	-	0.01
Creek chub	<0.01	0.08	3.50	2.85	1.91
Creek chubsucker	-	-	0.11	-	0.80
Spotted sucker	2.48	-	-	-	-
Yellow bullhead	0.39	0.07	0.53	0.6	0.04
Grass pickerel	-	0.12	-	-	-
Pirate perch	-	-	-	0.11	0.03
Blackspotted topminnow	0.14	0.63	0.77	0.78	0.47
Western mosquitofish	0.03	0.11	0.01	0.11	0.02
Flier	0.06	-	-	0.02	-
Green sunfish	0.66	1.53	0.68	0.48	0.76
Warmouth	-	-	-	0.02	0.01
Bluegill	0.89	0.68	0.34	-	0.11
Longear sunfish	2.64	5.97	2.40	0.25	2.06
Hybrid sunfish	-	-	0.03	0.04	0.05
Spotted bass	0.25	0.25	0.03	0.02	0.01
Largemouth bass	0.45	0.50	0.25	0.05	0.12
White crappie	0.10	-	-	-	0.06
Slough darter	-	-	<0.01	<0.01	-
Logperch	-	-	-	-	0.19
Blackside darter	-	-	-	-	0.02
Total biomass	9.58	17.52	13.58	11.51	10.34

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991).

[c]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

Appendix E

CHECKLIST OF BENTHIC MACROINVERTEBRATE TAXA COLLECTED FROM BIG BAYOU CREEK, LITTLE BAYOU CREEK, AND MASSAC CREEK IN PADUCAH, KENTUCKY, SEPTEMBER 1991 TO MARCH 1996

Table E.1. Checklist of benthic macroinvertebrate taxa collected from Big Bayou Creek, Little Bayou Creek, and Massac Creek in Paducah, Kentucky, September 1991–March 1996[a]

	Site[b,c]				
Taxon	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Turbellaria	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	4	4
Nemertea	1,3,5	1,2,3,5	1,2,3,4,5	1,2,3,5	1,3,4,5
Nematomorpha					
Gordiidae					
Gordius	-	-	5	-	4
Nematoda	1,4,5	1,5	1,4,5	1,2,4,5	1,2,4
Annelida					
Hirudinea	-	2,3	3	-	-
Oligochaeta	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
Branchiura sowerbyi	2,3,4	-	-	-	-
Crustacea					
Amphipoda					
Talitridae					
Hyalella azteca	-	2	-	-	5
Isopoda					
Asellidae					
Caecidotea	-	-	5	-	-
Lirceus	-	-	5	-	-
Decapoda	-	-	-	-	1
Hydrachnidia	1,2,3,4,5	1,2,3,4,5	1,3,4,5	1,2,3,4,5	1,2,3,4,5
Insecta					
Ephemeroptera	-	-	-	3	-
Retracheata	-	-	-	-	5
Baetidae	1,2	1,2,4,5	1,4	3,4	1,2,3
Baetis	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
Centroptilum	4	-	4	4	-
Paracloeodes	-	4,5	-	-	-
Pseudocloeon	-	-	1	-	-
Caenidae					
Caenis	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
Ephemeridae	-	-	4	-	-
Ephemera	-	-	-	-	5
Hexagenia	4	-	-	-	-

Table E.1 (continued)

Taxon	Site[b,c]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Ephemeroptera (cont.)					
Heptageniidae	1	1,2,3,4	1,4	1,5	1
Nixe	-	5	-	-	-
Stenacron	-	2,4,5	3,4,5	4,5	5
Stenonema	1,2,3,4,5	1,2,3,4,5	1,3,4,5	4	1,2
Isonychiidae					
Isonychia	3	-	-	-	-
Trichorythidae					
Tricorythodes	1,2,3,4,5	1,2,3,5	3	-	4
Odonata	-	1,2	2	-	-
Anisoptera	-	-	4	-	-
Gomphidae	-	-	-	3	-
Progomphus obscurus	-	-	-	1,3,4,5	1
Libellulidae					
Erythemis simplicicollis	-	1	-	-	-
Libellula	-	1	-	-	-
Macromiidae					
Macromia	-	1	4	3,4	-
Zygoptera	-	1	-	-	-
Calopterygidae	-	-	-	-	5
Calopteryx	-	-	1	1	1
Hetaerina	-	1,5	-	1	5
Coenagrionidae	-	1	-	-	-
Argia	3,4	1,2,5	4	3,5	2
Ischnura	-	1	-	-	-
Plecoptera	1	1	1,3	1,2	-
Euholognatha					
Capniidae	-	3	3,5	-	3
Allocapnia	-	3	2,4,5	4,5	3,4,5
Leuctridae	-	-	3	-	-
Nemouridae	3	-	2	-	3
Amphinemura	-	-	1,4	1	1,4,5
Systellognatha	-	-	4	-	-
Perlidae	-	4	5	-	-
Perlodidae	-	-	5	4	5
Isoperla	-	-	1,4	-	4,5

Table E.1 (continued)

Taxon	Site[b,c] BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Megaloptera					
Corydalidae					
Corydalus cornutus	3,4,5	1,3,5	1,3,5	1,2,3,5	4,5
Sialidae					
Sialis	-	-	4	-	-
Trichoptera	1	1,2,3	1,2,3	1	1,2,3
Hydropsychidae	1,2,3,4	1,2,3	3	1,2,3	1,2,3,4
Cheumatopsyche	1,2,3,4,5	1,2,3,4,5	1,3,4,5	1,2,3,4,5	1,2,3,4,5
Hydropsyche	1,2,4,5	4	1,2,3,4,5	2,3,4	1,3,4,5
Hydroptilidae	4	-	2	-	-
Hydroptila	1	4	1,2,4,5	1,3,4,5	4
Leptoceridae	-	-	-	4	4
Oecetis	1,4	1,5	4,5	1,3,4,5	1
Molannidae					
Molanna	-	-	-	5	4
Philopotamidae	3	-	-	-	-
Chimarra	1,2,3,5	1,2,3,4,5	1,2,3,4,5	1,4,5	1,3,4,5
Polycentropodidae	3	-	-	-	-
Polycentropus	-	-	1	-	-
Coleoptera	-	4	-	-	-
Elmidae	1	-	-	-	-
Dubiraphia	1,4,5	-	2	1,2,3,4,5	-
Optioservus	-	-	-	-	1
Stenelmis	1,2,3,4,5	1,3,4,5	1,3,5	1,2,3,4,5	1,3,4,5
Hydrophilidae	-	2	-	-	-
Berosus	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4
Enochrus	-	1	-	-	-
Psephenidae					
Ectopria	-	4	-	-	-
Diptera	-	-	3	-	1
Ceratopogonidae	1,4,5	4,5	1,4,5	4,5	4,5
Atrichopogon	-	2	2	-	-
Bezzia	1	1	1,2	-	1,2,3
Culicoides	1	2	2	1,3	-
Dashyhelea	-	4	4	-	-
Monohelea	-	1	-	-	-
Palpomyia	-	-	1	-	-
Probezzia	1	-	-	1	-

Table E.1 (continued)

Taxon	Site[b,c]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Diptera (cont.)					
Chironomidae	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
Chironomini	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
Orthocladiinae	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
Tanypodinae	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
Tanytarsini	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
Culicidae					
Anopheles	-	-	-	-	5
Dolichopodidae	-	4,5	-	-	-
Empididae					
Chelifera	1	1	1	-	-
Hemerodromia	1,2,4,5	1,2,3,4,5	2,4,5	2,4,5	3,4
Simuliidae	1	-	2,3	2	-
Prosimulium	-	-	-	-	4,5
Simulium	1,2,3,4,5	1,4,5	1,2,4,5	1,2,4,5	1,2,3,4,5
Stegopterna	-	-	2,4,5	-	4,5
Tabanidae					
Chrysops	4	-	-	-	-
Tabanus	1	1	-	1	-
Tipulidae	-	1,2	2	4,5	3
Erioptera	-	1	-	-	5
Helius	-	1	-	-	-
Limonia	-	-	-	2	-
Tipula	-	2	1,2,4	-	-
Mollusca					
Gastropoda	4,5	4	-	-	-
Ancylidae	-	-	-	3	1,3
Ferrissia	1	1,5	1,4	1,3,4,5	3,4
Lymnaeidae	-	-	-	1	-
Pseudosuccinea columella	-	-	-	3	1
Physidae					
Physella	4	1,3,5	-	4,5	1,2,4,5
Planorbidae	-	3,5	-	-	4
Gyraulus	-	3,5	-	-	-
Menetus	1,3	1,3,5	5	1,5	1,4
Bivalvia					
Corbiculidae					
Corbicula fluminea	1,2,3,5	-	-	4,5	-

Table E.1 (continued)

Taxon	Site[b,c]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Bivalvia (cont.)					
Sphaeriidae	2	-	-	2,3	-
Musculium	-	-	-	3,4,5	-
Pisidium	-	-	-	1,3	-
Sphaerium	-	5	-	5	-

[a]For March and September sampling periods only.

[b]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

[c]The numbers associated with each taxon and site indicate the sampling years (i.e., the one year cycle beginning with the first collection date) that the taxon was collected at least once, with 1 = September 1991–June 1992, 2 = September 1992–March 1993, 3 = September 1993–March 1994, 4 = September 1994–March 1995, and 5 = September 1995–March 1996. A blank indicates that a lower level of classification (e.g., family, genus, or species) was possible at one or more sites, and a dash (-) indicates that the taxon was not collected or that all collected taxa within the group were identifiable to a lower level of classification at one or more sites.

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