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OAK RIDGE
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ENVIRONMENTAL SCIENCES DIVISION

Report on the Biological Monitoring Program at Paducah Gaseous Diffusion Plant January–December 1995

L. Adams Kszos

Environmental Sciences Division
Publication No. 4527

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Report on the Biological Monitoring Program at Paducah Gaseous Diffusion Plant January–December 1995

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ACRONYMS

ANOVA	analysis of variance
BMAP	Biological Monitoring and Abatement Program
BMP	Biological Monitoring Program
BBK	Big Bayou Creek kilometer
DCBP	decachlorobiphenyl
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
NCBP	National Contaminant Biomonitoring Program
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
RCW	recirculating cooling water
SAS	statistical analysis system
SD	standard deviation
SE	standard error
TRC	total residual chlorine
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, (3) document the effects of pollution abatement facilities on stream biota, and (4) recommend any program improvements that would increase effluent treatability. In September 1992, a renewed Kentucky Pollutant Discharge Elimination System (KPDES) permit was issued to PGDP. As of this writing, a new Agreed Order is in draft form. The renewed permit requires toxicity monitoring of continuous and intermittent outfalls on a quarterly basis. A BMP is not required in either the draft Agreed Order or the renewed permit; however, biological monitoring of the U.S. Department of Energy (DOE) facilities at PGDP is required under DOE Order 5400.1. Data collected under BMP will also be used to support two studies proposed in the draft Agreed Order.

The BMP for PGDP consists of three major tasks: (1) effluent and ambient 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 1995 to December 1995, 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 United States Enrichment Corporation (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, which are two small tributaries to the Ohio River. 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 Wildlife Management Area and flows for 10.5 km north toward the Ohio River; 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 (or 011) 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—Big Bayou Creek kilometer (BBK) 12.5, BBK 10.0, and BBK 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 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 is conducted at LUK 4.3. Toxicity monitoring and benthic macroinvertebrate sampling were conducted quarterly, and fish community and bioaccumulation sampling were conducted twice annually in the spring and fall. KPDES outfalls evaluated for effluent toxicity in 1995 included 001, 006, 008, 009, 010, 013, 015, 016, 017, and 018.

Toxicity Monitoring

Ceriodaphnia 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. Fathead minnow toxicity tests of water from ambient sites (BBK 12.5, BBK 10.8, BBK 9.1, LUK 7.2, and MAK 13.8) were conducted concurrently with the continuously flowing outfalls. 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 (TUc=100/IC25) is required as a compliance endpoint in the renewed permit (September 1992 to present). The higher the TUc, the more toxic an effluent. Because Little Bayou and Big Bayou creeks have been determined to have a low flow of zero, a TUc > 1.0 would be considered a noncompliance (for the continuously flowing outfalls) and an indicator of potential instream toxicity.

During 1995, effluent from Outfall 001 exceeded the permit limit of TUc > 1.0 twice. A process change in the RCW System and/or the addition of effluent from the C-612 facility to Outfall 001 during 1995 may account for the toxicity to *Ceriodaphnia* in 1995. Effluent from the C-612 facility will be evaluated for toxicity during 1996 to determine whether it may be contributing to the toxicity at Outfall 001. No toxicity was evident in effluent samples from 006, 008, 009, or 010 during 1995. This is an improvement from the number of permit exceedances in previous years. After ranking the intermittent outfalls using all tests conducted since 1991, Outfalls 013 and 018 were identified as having the greatest frequency of toxicity in comparison with the other intermittent outfalls. During 1995, no toxicity was observed in effluent samples from 013, 015, 016, and 017. Outfall 018 exceeded a TUc > 1 twice in 1995. In previous years, each of the intermittent outfalls exceeded a TUc > 1 on several occasions. The intermittent outfalls are consistently more toxic (as determined by the TUc) to fathead minnow larvae than *Ceriodaphnia*. As a result, in 1996, tests of the intermittent outfalls will be reduced to fathead minnow larvae only.

During 1995, there was no consistent evidence of chronic toxicity to fathead minnows for any of the ambient sites. This is consistent with findings from 1991 to 1994. There has been no consistent evidence of chronic toxicity in water from the ambient locations, no correlation of reductions in fathead minnow survival at the continuously flowing outfalls with reductions in fathead minnow survival at the ambient locations, and no significant change in water chemistry from the ambient sites or outfalls. Ambient toxicity tests will therefore be discontinued in the second quarter of calendar year 1996. The high variability in minnow survival at the reference locations makes it difficult to distinguish normal variability due to the test system from effects on survival that may be due to the presence or absence of a contaminant. Variability among replicates also tends to be high in the full-strength effluent from the intermittently flowing outfalls. In some cases, the variability (expressed as standard deviation) can approach that of the ambient locations and brings in to question the applicability of the TUc as an indicator of toxicity for intermittently flowing outfalls. The KDOW may consider incorporating acute toxicity limits for these outfalls; acute limits and therefore acute toxicity test procedures may eliminate some of the variability associated with the chronic fathead minnow tests.

Bioaccumulation

Bioaccumulation monitoring conducted to date as part of the BMP identified PCB contamination in fish in Big Bayou Creek and Little Bayou Creek as a major concern. 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. The primary objective of the 1994–95 bioaccumulation monitoring was to evaluate spatial and temporal changes in PCB contamination in sunfish from Big Bayou and Little Bayou creeks. Monitoring for mercury in fish was also conducted but at a more limited number of sites and at a decreased frequency than in previous years.

Longear sunfish and spotted bass were collected for PCB and mercury analysis from Big Bayou Creek, Little Bayou Creek, and Massac Creek during October 1994. In April 1995, longear sunfish were again sampled for PCB analysis. Hinds Creek (Anderson County, Tennessee) served as a source of uncontaminated reference fish. Mean PCB concentrations in sunfish from Little Bayou and Big Bayou Creeks were higher than in fish from reference areas. The highest concentrations continued to be in fish from upper Little Bayou Creek, with a sharp decrease in contamination with increasing distance downstream. PCB concentrations in fish from LUK 9.0 exhibited a distinct seasonal pattern with the highest concentrations found in the spring, suggesting greater mobilization of residual sources during this time period. PCB concentrations in sunfish appeared to have decreased over time at all Little Bayou Creek and Big Bayou Creek sites from April 1992 to April 1995, although the extent of the decrease in upper Little Bayou Creek may have resulted in part from habitat changes that affected the size and species of fish available.

In October 1994, mean mercury and PCB concentrations in spotted bass from the two creeks were also elevated. However, PCB concentrations in these bass were not much higher than sunfish collected at the same sites. The highest mercury concentrations in fish from the PGDP vicinity continued to be in spotted bass collected from Big Bayou Creek. The mean mercury concentration in Big Bayou Creek bass in October 1994, if adjusted for the difference in fish weight, was similar to the level of contamination observed in this species in previous years.

The high temporal variability in PCB concentrations in fish indicates that continued routine monitoring of Little Bayou Creek and Big Bayou Creek fish is warranted. Monitoring of similar PCB problems in Oak Ridge (Tennessee) has shown that dramatic year-to-year changes can occur while cleanup activities and construction/excavation activities are ongoing. Sunfish have been shown to be effective integrators of PCB exposure and can be effectively used to evaluate the effects of stream discharges. Future monitoring will 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. All screening evaluations for other contaminants will be discontinued unless there is a demonstrated need as a result of some change in aqueous inputs.

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 and September 1995. Qualitative sampling at one site in Little Bayou Creek was conducted during March 1995. 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 there was only one sensitive species, whereas there were six 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 (e.g., Outfall 008). Although the temperatures may not be lethal, they could produce avoidance of the areas of Big Bayou Creek near the plant outfalls. Density at BBK 10.0 was similar to or higher than that at the reference sites, with a correspondingly high biomass. Density and biomass were dominated by one species, the herbivore stoneroller. This numerical dominance by a herbivorous species, combined with the low numbers of benthic insectivores, suggests possible nutrient enrichment at BBK 10.0, perhaps associated with discharges from Outfall 004. Compared with sampling results from 1993 and 1994, BBK 10.0 experienced a rebound in biomass in September 1995. Despite the increased biomass, a spring to spring production estimate indicated declining productivity at BBK 10.0. If the rebounding density and biomass values observed in the fall 1995 sample continue through 1996, then an increase would be expected in productivity. 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 impact but at less severe levels 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. The tolerant species were common and abundant. 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, productivity estimates have shown a four-fold decline from 1992–93 to 1994–95. This decrease indicates some impacts on recruitment success for the fish community at BBK 9.1. The possible causes for this minor impact could include slight increases in the temperature or nutrient levels resulting from outfall discharges.

The fish community at LUK 7.2 was similar to that at the BBK 12.5 reference site, with perhaps some species deficiencies. The mean species richness values were similar to those of the reference site and had rebounded substantially from a low point in fall 1994. Density and biomass also reached near record levels for this site in September 1995. Unlike conditions in Big Bayou Creek sites, productivity did not show a consistent decline.

The downstream qualitative site, LUK 4.3, did not appear to be affected by plant operations. Species richness was higher than that found in earlier sampling (1992–93), particularly in terms of sensitive species. 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. Thus, the community at LUK 4.3 appeared to be minimally affected by PGDP operations.

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 closest to 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 identify causative agents, a network of temperature recorders will continue to be deployed at sampling sites to evaluate possible thermal impacts. As a further investigative tool, qualitative surveys will be made in Massac Creek and other area streams, such as Humphrey Creek. These surveys will help to determine whether the fauna in Big Bayou Creek watershed is depressed compared with regional levels.

Macroinvertebrate densities at all sites were comparable for the period September 1991–March 1995. The occasional substantial increases in densities at BBK 9.1 may be the result of a sustained period of habitat stability or a short-term increase in nutrient availability. Although BBK 9.1 had substantially higher densities, compared with the reference sites, on four occasions; during the majority of the period covered in this report, no site was consistently different from the other sites. Only BBK 10.0 had a significant negative trend in densities during each sampling season; however, during September 1991–March 1995, BBK 10.0 generally fell within the range exhibited by the reference sites. Data from future collections should determine whether this is a sustained trend or natural variation. Likewise, additional data will be needed to determine whether the positive trend identified in the winter samples at LUK 7.2, in addition to the high densities in March 1995, indicate community improvement or seasonal variation. Total taxonomic richness values were generally similar at all sites, and although total richness values exhibited substantial seasonal variation, regression analysis indicated that neither BBK 9.1, BBK 10.0, or LUK 7.2 was experiencing any significant changes. Regression analysis indicated that BBK 9.1 and LUK 7.2 exhibited significant changes in trends for EPT richness in fall samples, although values were generally within the range exhibited by the reference sites.

There were no consistent spatial or temporal trends evident in mean values or statistical analyses that provided strong evidence of major impacts to the community parameters evaluated at BBK 9.1, BBK 10.0, or LUK 7.2. However, the inability to detect statistically significant trends from the available data does not necessarily indicate that significant differences do not exist between the sites. The considerable spatial and temporal variability present in the data may have masked subtle impacts. Because the addition of the December data provided little additional information, sample collection will be reduced from quarterly to twice annually beginning in 1996. Finally, there were substantial differences between the two sites used as references (BBK 12.5 and MAK 13.8). In an effort to minimize the effects of differences between reference sites, stream sites near the PGDP will be surveyed in April 1996 for potential use as additional references.

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 revealed the accumulation of polychlorinated biphenyls (PCBs) in fish from selected reaches of the Bayou watershed, a finding that prompted issuance of a fish consumption advisory for Little Bayou Creek by the Kentucky Department for Environmental Protection. Continuation of the program will also provide a data base that can be used to determine the adequacy and efficacy of remedial actions that are implemented and to detect any new or unsuspected toxicants that are released in effluents.

In September 1992, a renewed KPDES permit was issued to PGDP. As of this writing, a new Agreed Order is in draft form. The renewed permit requires toxicity monitoring of continuous and intermittent outfalls on a quarterly basis. A BMP is not required in either the draft Agreed Order or the renewed permit. However, biological monitoring of the DOE facilities at PGDP, at Oak Ridge, Tennessee, and at Portsmouth, Ohio, is required under DOE Order 5400.1. The goals of the BMP are to (1) evaluate the acceptability of PGDP effluents under the Kentucky Pollutant Discharge Elimination System (KPDES) regulatory program, (2) characterize the potential environmental impacts of PGDP effluents, and (3) make recommendations on any changes necessary to improve effluent discharges. Data collected under BMP will also be used to support three studies proposed in the draft Agreed Order: (1) temperature variability and instream effects of elevated temperature from Outfalls 001 and 011, (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 and ambient 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 1995. 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 the United States Department of Energy (DOE). In July 1993, DOE leased the plant production operations facilities, which are managed by Lockheed Martin Utility Systems, Inc. (LMUS), to the United States Enrichment Corporation (USEC). Under this lease, USEC has assumed responsibility for compliance activities directly associated with uranium enrichment operations. 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 (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 1385-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% ^{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

*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.

(WKWMA), 2821 ha of natural habitat, state-maintained forage crops, and ponds, used by 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 is two small tributaries of the Ohio River, 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 98 cm in 1995 (82% of normal), with one major

ORNL-DWG 95M-7163

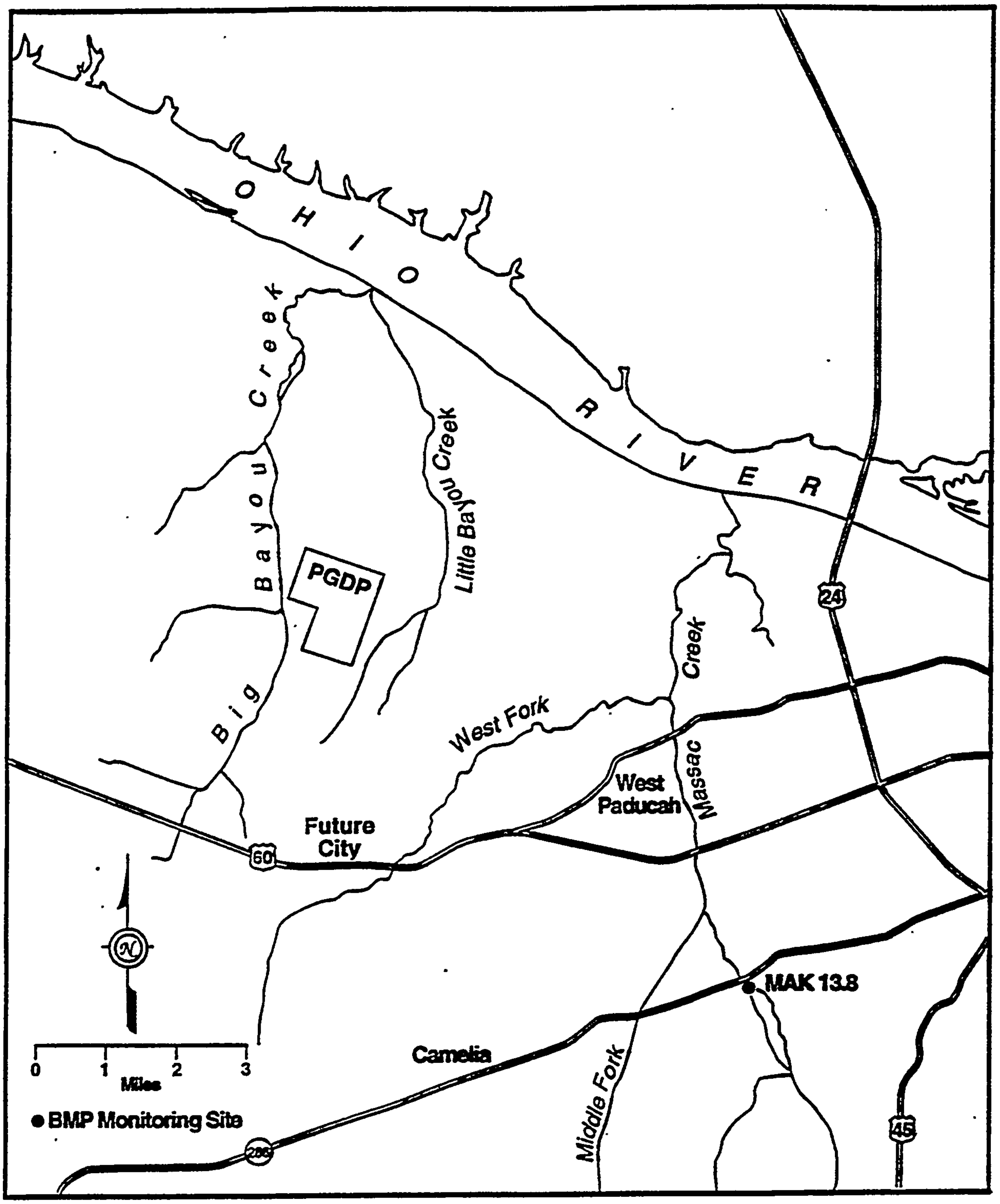
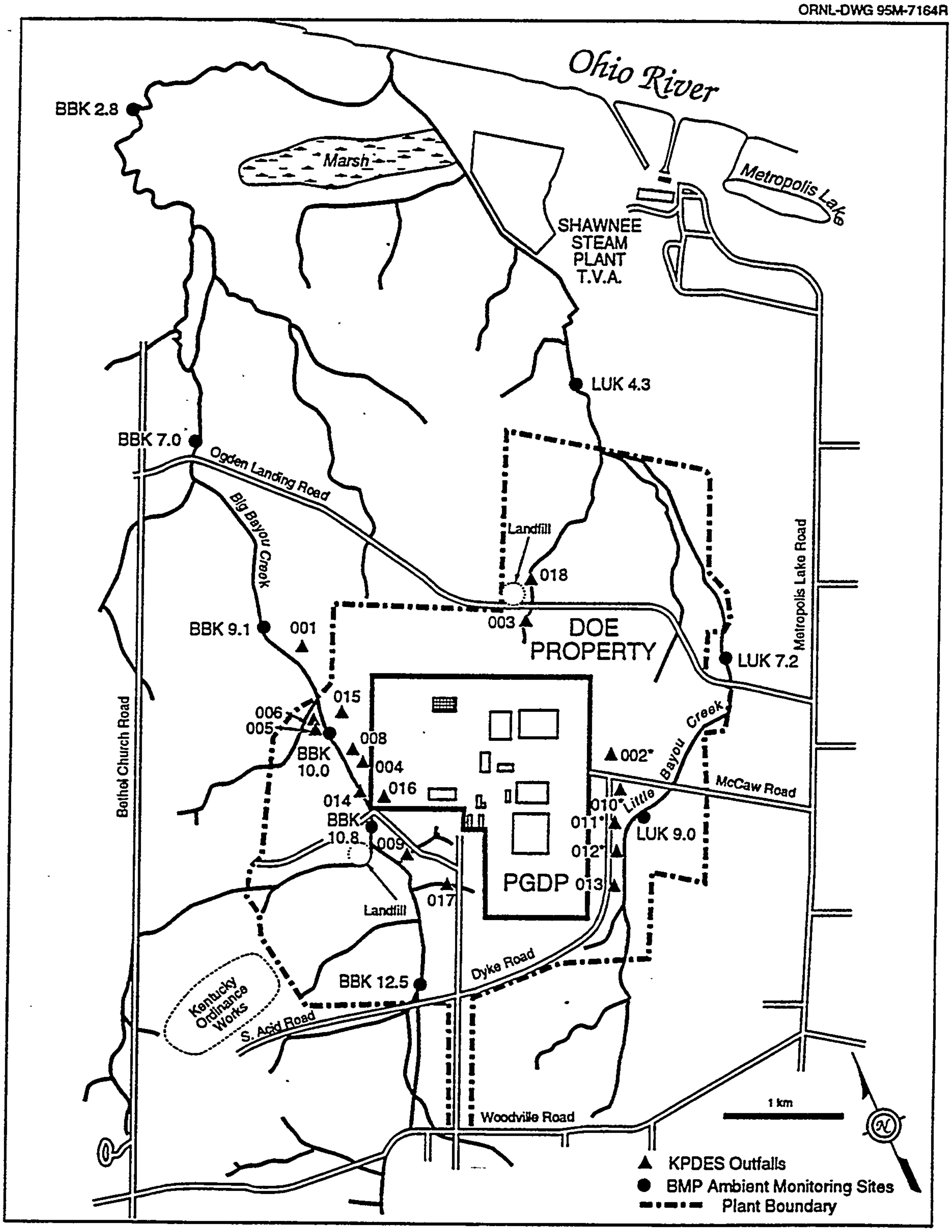


Fig. 2.1. Map of Paducah Gaseous Diffusion Plant (PGDP) in relation to the geographic region. The reference site for PGDP biological monitoring activities is located on Massac Creek at kilometer (MAK) 13.8.

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.

storm (≥5 cm in 24–48 hours) in April. See Kszos et al. (1994b) for information on precipitation during 1992–94. 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. 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 Kentucky Division of Water (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). The KDOW has granted a stay of permit limits for temperature, phosphorus, pH, Cd, Cr, Cu, Pb, Ni, and Zn. PGDP is working with KDOW to negotiate an Agreed Order concerning the establishment of final limits for these parameters.

Monitoring of 17 individual outfalls is conducted in accordance with the KPDES Agreed Order. Table 2.1 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, 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 2.1. 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)

Two exceedances of the chlorine permit limit at Outfall 011 were recorded in 1995 (Table 2.2). On January 17, 1995, low temperature (which reduced chlorine demand) and excessive rainfall (which caused the lift station to overflow) were the main factors in the exceedance of 0.04 mg/L total residual chlorine (TRC). Subsequent to the exceedance, a system was installed to add sodium thiosulfate to the effluent prior to the lift station, during rainfall, to ensure that chlorine is removed. During June 21, 1995, the metering pump used to feed sodium thiosulfate to Outfall 011 developed an airlock and malfunctioned, which resulted in an exceedance of 0.05 mg/L TRC. Operating procedures for the feed station were revised to reduce the potential for future occurrences of airlocks in the pump.

Three exceedances of the PCB limit occurred during 1995 (compared to 11 in 1994). On April 20, 1995, one exceedance was measured for Outfall 011 (0.29 μg/L) and one exceedance was measured for Outfall 012 (0.26 μg/L). One exceedance for Outfall 012 was measured on June 21, 1995; however, this value was reported as an exceedance in error because the sum of two aroclors (1242 and 1260) that were measured below the quantifiable detection limit were summed and reported as a detected value (Milne 1996). The events related to KPDES PCB exceedances and investigative actions that occurred during 1995 are reported in Milne (1996). Activities reported include (1) site mapping; (2) solubility studies; (3) sampling efforts at Outfalls 011 and 012; (4) use of semi-permeable membrane devices (SPMDs) for PCB tracking; and (5) characterization of sediments from Outfall 011, 012, and a sewer east of C-333-A. In addition, the following corrective action activities are summarized: (1) remediation of the C-540-A area; (2) lining of Outfall 011 ditch; (3) inspection and maintenance of lift stations 001, 011, and 012; and (4) the Corps of Engineers risk analysis. The summary of 1995 investigations and corrective actions are as follows (from Milne 1996):

1. The ditch characterization and SPMD data indicated that contamination in ditch 012 appears to be or has been influenced by sources, at least in part, independent of K011;
2. All exceedances for Outfalls 011 and 012 in 1995 were due to Aroclor 1242. Levels of 1260 were detected below the practical quantifiable limit during all three exceedances;
3. PCB Aroclor 1242 was not detected in the K011 ditch sediment survey. Aroclor 1260 was detected in the sediment removed from the K011 lift station;
4. PCB Aroclor 1260 was detected in the grounding vault and shallow boring around the C-540-A area;

5. The SPMD study shows that PCBs are present in the sewer on the south side of C-333 building that flows toward K012;
6. No exceedances occurred in K011 after lining the ditch; and
7. PCB Aroclors 1242 and 1248 were found in the soil and sediment samples on the south side of C-333.

Table 2.2. Exceedances in 1995 for parameters for which permit limits are in effect

Parameter	Outfall	Date	Limit (daily maximum)	Result
Residual chlorine	011	1/17/95	0.019 mg/L	0.04 mg/L
		6/21/95	0.019 mg/L	0.05 mg/L
PCB	011	4/20/95	0.000079 μg/L	0.29 μg/L
	012	4/20/95	0.000079 μg/L	0.26 μg/L
		6/21/95[a]	0.000079 μg/L	0.17 μg/L
Oil and grease	006	12/27/95	15 mg/L	16.9 mg/L

[a]This value was erroneously reported as an exceedance. PCB values for June at Outfall 012 were 0.14 μg/L for Aroclor 1242 and 0.03 μg/L for Aroclor 1260. Both are below the quantifiable detection limit. The summation of the values, 0.17 μg/L is at the quantifiable detection limit and was reported as a detected value.

Note: PCB = polychlorinated biphenyl. Data provided by D. L. Ashburn, Environmental Management Division, Lockheed Martin Energy Systems, Inc.

Summary statistics (mean, maximum, minimum, and the number of observations) for KPDES chemical parameters for 1995 measured for each outfall are given in Appendix A (Tables A.1 to A.14). Water quality in 1995 differed little from water quality in 1993–94. In general, water quality in the outfalls was characterized by occasional increases in concentrations of some metals. Metals of concern included Cd, Cr, Cu, Pb, Ni, and Zn. Currently, KDOW has issued a stay on limits for the aforementioned metals. Maximum values for one or more of these metals have exceeded the stayed permit limits in 1995 (Tables A.1–A.14) with the most exceedances since 1992 being for zinc and copper and primarily in Outfalls 008, 009, and 012 (C. C. Travis, personal communication). The PGDP and KDOW have agreed that PGDP will conduct a study to determine whether alternative metal limits are justified based on concentrations of dissolved metals in the outfalls; current limits are based on concentrations of total metals. The KDOW will review the information developed to determine metal limits. Total suspended solids (TSS) at Outfall 018 were higher in 1995 than in 1994. The TSS mean for Outfall 018 was 717 mg/L with the highest mean values occurring in April (596 mg/L), October (6000 mg/L), and December (916 mg/L). During the remainder of the year, the TSS mean at Outfall 018 ranged from 7–112 mg/L.

High levels of TSS are a result of runoff from the construction of a new landfill near the outfall. The runoff from the outfall will be permitted under a separate KPDES permit which will be final in calendar year 1996. Maximum pH levels exceeded the stayed permit limit (6.0–9.0) at Outfalls 001, 006, and 011 in 1995. The PGDP has met the interim limit for pH (6.0–10.5) in all cases, and instream pH measurements have been within the limits set by the permit (see Sect. 3.2). The KDOW is reviewing the instream pH data collected by PGDP to determine whether instream monitoring of pH would be an acceptable option for PGDP to pursue. The PGDP is exploring engineering controls for temperature at Outfalls 001 and 011; these controls may enable PGDP to meet permit limits for temperature at these sites. In addition, ESD staff are conducting a temperature study to evaluate the effects of elevated temperatures on the biota of Big Bayou and Little Bayou creeks. The results of this study will be available in 1996. A discussion of current instream water quality monitoring occurs in Sect. 3.2 of this report. Discussions of water quality monitoring efforts prior to Fall 1991 can be found in Birge et al. 1992.

Flow from the north/south diversion ditch is normally channeled through Outfall 001 by a lift station that pumps the effluent through the C-616 full-flow lagoon. However, during rainfalls with flows that have maximum daily averages greater than a 10-year occurrence interval, the lift station overflows to Outfall 003. This is the only time that Outfall 003 is monitored. Outfall 005 is not monitored regularly because its effluent flows into the C-611 secondary lagoon. Outfall 006, the C-611 secondary lagoon, is monitored for the same parameters as those required for Outfall 005. Outfall 007, a septic field for the C-611 water treatment plant, is not permitted for discharge. Monitoring of Outfall 014 occurs only when the C-611 sludge lagoon is dredged (i.e., every 2 or 3 years), and the filter backwash is discharged to the outfall. Outfalls 002, 010, 011, and 012 have sumps equipped with pumps (lift stations) that collect process effluent and pump it to the C-617 lagoon. The lagoon can discharge the combined effluent to Outfall 010 or 011, depending on the valve settings The lift stations have the capacity to handle the process wastewater only. During rain events, surface water runoff combines with the process effluent and floods the lift stations. When the water level in the lift stations reaches a predetermined level, the pumps shut down and the stormwater runoff and process wastewater will flow through their respective outfalls.

Two process changes occurred in 1995 which affect the discharge from Outfall 001. In June, 1995, construction of the C-612 facility (Northwest Plume Interim Remedial Action Pilot Plant) was completed. Discharge of treated water from the facility to Outfall 001 began on August 31, 1995. During this same period, a corrosion control inhibitor (Copper-Trol CU-1; Betz Laboratories) was added to the Recirculating Cooling Water (RCW) System. RCW comprises the majority of discharge to Outfall 001. There has not been any noticeable increase or decrease in Cu from Outfall 001 following addition of the Copper-Trol (Chris Travis, LMUS, personal communication).

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 2.3. Two additional sites (LUK 9.0, and LUK 4.3; Fig 2.2) were sampled as part of

Table 2.3. 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.

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 1995 are outlined in Table 2.4; a summary of sampling locations is provided in Table 2.5. Toxicity monitoring and benthic macroinvertebrate sampling were conducted quarterly, and fish community and bioaccumulation sampling were conducted twice annually (in the spring and fall). KPDES outfalls at which effluents were evaluated for toxicity during 1995 included 001, 006, 008, 009, 011, 013, 015, 016, 017, and 018.

Table 2.4. Sampling schedule for the four components of the Biological Monitoring Program at Paducah Gaseous Diffusion Plant, January–December 1995

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

Table 2.5. Summary of sampling locations for tasks of the Biological Monitoring Program 1991–95

Location[a]	Toxicity Monitoring[b]	Bioaccumulation		Invertebrates	Fish	
		PCB[c]	Hg[d]		Quantitative	Qualitative
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. Hinds Creek = reference site located in Anderson Co., Tennessee.

[b]BBK 10.8 during 1995 only; BBK 10.0 water chemistry only 1994–present.

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

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

3. TOXICITY MONITORING

L. A. Kszos and J. R. Sumner

The toxicity monitoring task for BMP consists of two subtasks. The first measures the toxicity of effluents as required by the KPDES permit. The second monitors ambient water toxicity of four sites in Big Bayou Creek, one site in Little Bayou Creek, and one reference site in Massac Creek. The effluent toxicity data are presented in Sect. 3.1; the ambient toxicity data are presented in Sect. 3.2.

3.1 EFFLUENT TOXICITY

3.1.1 Introduction

The EPA supports the use of aquatic test organisms to determine the chronic toxicity of a test water (Weber et al. 1989). Toxicity monitoring at PGDP uses 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; Weber et al. 1989) concurrently to characterize the toxicity of the continuous and intermittent effluents that discharge into Big Bayou and Little Bayou creeks. These two tests are EPA-approved for use to estimate (1) the chronic toxicity of effluents collected at the end of the discharge pipe and tested with a standard dilution water; (2) the toxicity of receiving water downstream from or within the influence of the outfall; and (3) the effects of multiple discharges on the quality of the receiving water (Weber et al. 1989). These tests are also part of the Biological Monitoring and Abatement Programs at ORNL, the Oak Ridge K-25 Site, and the Oak Ridge Y-12 Plant.

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. After May 1995, tests of continuously flowing Outfalls 006, 008, 009, and 010 were reduced to the more sensitive species (fathead minnow larvae), as described in the 1994 BMP report (Kszos et al. 1995). Tests of continuously flowing outfall 001 and the intermittently flowing outfalls (013, 015, 016, 017, and 018) continued with *Ceriodaphnia* and fathead minnow larvae.

3.1.2 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 includes all tests conducted from 1991 to 1995 by ESD. Most of the outfalls have been evaluated at least 17 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. Subsequent tests used seven 24-h composite samples as required by the renewed KPDES permit. Beginning in August 1995, tests of the continuous outfalls used three 24-h composite samples. Samples from the continuously flowing outfalls were collected by personnel from ESD and transported to a nearby offsite laboratory at the Paducah Community College. During one test period, October 1994, samples from the continuously flowing outfalls were collected by personnel from PGDP, refrigerated, and shipped to ESD using 24-h delivery. 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

Table 3.1. Summary of toxicity test dates for continuous outfalls

Outfall	Test Date	Species
001, 006, 008, 009, 011	October 24–31, 1991	*Ceriodaphnia* and Fathead minnow
001, 006, 008, 009, 011	February 13–20, 1992	*Ceriodaphnia* and Fathead minnow
001, 006, 008, 009, 011	May 21–28, 1992	*Ceriodaphnia* and Fathead minnow
001, 006, 008, 009, 011	August 13–20, 1992	*Ceriodaphnia* and Fathead minnow
001, 006, 008, 009, 011	October 22–29, 1992	*Ceriodaphnia* and Fathead minnow
001, 006, 008, 009, 011	February 11–18, 1993	*Ceriodaphnia* and Fathead minnow
001, 006, 008, 009, 011	May 20–27, 1993	*Ceriodaphnia* and Fathead minnow
001, 006, 008, 009, 011	August 19–16, 1993	*Ceriodaphnia* and Fathead minnow
001, 006, 008, 009, 011	October 14–21, 1993	*Ceriodaphnia* and Fathead minnow
008	December 2–9, 1993	Fathead minnow
001, 006, 008, 009, 011	March 10–17, 1994	*Ceriodaphnia* and Fathead minnow
006, 011	March 25–April 1, 1994	Fathead minnow
006, 011	April 28–May 5, 1994	*Ceriodaphnia* and Fathead minnow
001, 008, 009	May 25–June 2, 1994	*Ceriodaphnia* and Fathead minnow
008, 009	June 16–23, 1994	Fathead minnow
001, 006, 008, 009, 010	August 11–18, 1994	*Ceriodaphnia* and Fathead minnow
006	September 8–16, 1994	*Ceriodaphnia*
008, 009	September 8–16, 1994	Fathead minnow
001, 006, 008, 009, 010	October 27–November 4, 1994	*Ceriodaphnia* and Fathead minnow
001	November 16–23, 1994	*Ceriodaphnia*
009	November 16–23, 1994	Fathead minnow
001, 006, 008, 009, 010	March 9–16, 1995	*Ceriodaphnia* and Fathead minnow
001, 006, 008, 009, 010	May 10–17, 1995	*Ceriodaphnia* and Fathead minnow
001	August 9–16, 1995	*Ceriodaphnia*
001, 006, 008, 009, 010	August 9–16, 1995	Fathead minnow
001	October 25–31, 1995	*Ceriodaphnia*
001, 006, 008, 009, 010	October 25–November 1, 1995	Fathead minnow
001	November 15–21, 1995	*Ceriodaphnia*

Table 3.2. Summary of toxicity test dates for intermittent outfalls

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

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

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. 1989).

During tests conducted in January, July, and August 1995 of Outfall 018 and April 1995 of Outfalls 015 and 017, subsamples of effluent were filtered through glass microfiber filters (1.2 μm) to remove suspended solids. Fathead minnow tests were then conducted using nontreated and filtered effluent samples. The amount of suspended solids was measured in all of the intermittent samples by filtering a known volume of effluent through a pre-weighed filter.

A linear interpolation method (Weber et al. 1989) 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 (TUc = 100/IC25) is required as a compliance endpoint in the renewed permit (September 1992 to present). The higher the TUc, the more toxic an effluent. Because Little Bayou and Big Bayou creeks have been determined to have a low flow of zero, a TUc > 1.0 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).

3.1.3 Results

3.1.3.1 Continuously flowing Outfalls 001, 006, 008, 009, and 011

Mean survival and growth of fathead minnows and survival and mean reproduction of *Ceriodaphnia* for each outfall and test during 1995 are provided in Appendixes B.1 and B.2. A summary of the TUcs for all toxicity tests conducted during 1991–95 are provided in Table 3.3. During 1995, only two exceedances of the permit limit (TUc > 1.0) occurred for the outfalls. Both exceedances were for Outfall 001 and occurred for *Ceriodaphnia* in October and November 1995. The resulting TUcs were 9.18 and 1.56.

Water quality measurements (pH, conductivity, alkalinity, and hardness) for each outfall and test during 1995 are provided in Appendix B.3. A summary of water quality parameters for the continuously flowing outfalls during 1991–95 is provided in Table 3.4. In samples collected from 1991 to 1995, the pH ranged from a minimum of 6.8 S.U. (Outfall 006) to a maximum of 9.7 S.U. (Outfall 006). Effluent from Outfall 006 had the highest mean pH (8.78 S.U.). Mean alkalinity ranged from 35 (Outfall 001) to 52 mg/L as $CaCO_3$ (Outfall 009). Mean hardness and conductivity were highest in effluent from Outfall 001 (388 mg/L as $CaCO_3$ and 1244 μS/cm respectively). Mean hardness at the remaining outfalls ranged from 75 to 86 mg/L as $CaCO_3$ and mean conductivity ranged from 223 to 264 μS/cm.

Table 3.3. Results of effluent toxicity tests for continuously flowing Outfalls 001, 006, 008, 009, and 011

Outfall	Test Date	Chronic Toxicity Units (TUc)[a]	
		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[c]	1.5
006	October 1991	ND[b]	< 1
	February 1992	1.39	1.56
	May 1992	ND[b]	<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

Table 3.3 (continued)

		Chronic Toxicity Units (TUc)[a]	
Outfall	Test Date	Fathead Minnow	*Ceriodaphnia*
	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]
008	October 1991	ND[b]	<1
	February 1992	9.77	<1
	May 1992	ND[b]	<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]

Table 3.3 (continued)

		Chronic Toxicity Units (TUc)[a]	
Outfall	Test Date	Fathead Minnow	*Ceriodaphnia*
09	October 1991	ND[b]	< 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]
011	October 1991	ND[b]	<1
	February 1992	7.69	<1
	May 1992	ND[b]	<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

Table 3.3 (continued)

		Chronic Toxicity Units (TUc)[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]

[a]Chronic toxicity unit = 100/IC25; IC25 = the concentration causing a 25% reduction in fathead minnow growth or *Ceriodaphnia* reproduction in comparison to the control. IC = inhibition concentration.
[b]ND = not determined.
[c]NT = not tested.
[d]I = Invalid test due to low reproduction in the control water.
[e]Effluent from the C-617 lagoon was diverted from Outfall 011 to Outfall 010 during June 1994. As a result, effluent from Outfall 010 was tested after June 1994 instead of Outfall 011.

3.1.3.2 Intermittently flowing Outfalls 013, 015, 016, 017, and 018

Mean survival and growth of fathead minnows and survival and mean reproduction of *Ceriodaphnia* for each outfall and test during 1995 are provided in Appendices B.4 and B.5. A summary of the TUcs for all toxicity tests conducted during 1991–95 is provided in Table 3.5. Although PGDP does not have a compliance limit for the intermittent outfalls, TUc > 1.0 was used as a benchmark. Out of the 32 exceedances of TUc > 1.0 for the effluents, toxicity to *Ceriodaphnia* was only observed in 4 tests (January 1993 and February 1994 for Outfall 013 and September 1994 and January 1995 for Outfall 018). In 1995, only two tests exceeded a TUc > 1.0 of the effluents, both occurring for Outfall 018 (January for *Ceriodaphnia* and November for fathead minnows). The resulting TUcs were low (1.01 and 1.87).

Ranking the outfalls provided a means to compare the frequency of toxicity and mean TUcs of the outfalls. Each outfall was ranked in terms of frequency of TUc > 1.0 (5 = highest frequency and 1 = lowest frequency) and by mean TUc (5 = highest mean and 1 = lowest mean) using tests conducted from 1991 to 1995. The ranks were then summed to obtain an overall ranking (Table 3.6). Outfall 017 had the highest overall rank sum (8) and was followed by Outfalls 015 and 018, each with an overall rank sum of 7. Outfalls 013 and

Table 3.4. Summary of water chemistry analyses of full-strength samples from continuously flowing outfalls from 1991 to 1995

Sample	pH (Standard units)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Outfall 001				
Mean (± SD)	8.33 (0.67)	34.6 (9.0)	388.4 (108.8)	1244.4 (300.3)
Range	7.11–9.54	23–85	134–680	489–1867
n	121	121	121	121
Outfall 006				
Mean (± SD)	8.78 (0.51)	49.7 (13.4)	83.9 (21.8)	223.4 (41.6)
Range	6.80–9.72	30–88	50–204	163–329
n	131	131	131	131
Outfall 008				
Mean (± SD)	7.40 (0.21)	35.6 (11.7)	75.4 (15.3)	264.3 (44.8)
Range	6.86–8.20	18–65	44–112	177–461
n	138	138	138	138
Outfall 009				
Mean (± SD)	7.78 (0.38)	51.9 (24.5)	84.9 (23.4)	260.7 (112.2)
Range	7.10–8.95	29–233	44–210	116–1020
n	139	139	139	139
Outfall 010[a]				
Mean (± SD)	7.76 (0.25)	39.2 (13.2)	85.6 (22.1)	263.1 (61.8)
Range	7.27–9.15	21–77	52–158	168–491
n	118	118	118	118

[a]Effluent was discharged from outfall 011 before August 1994.
Note: n = number of samples.

015 had the greatest frequency of TUc > 1.0 (24%); however, they had the lowest mean TUc (3.8 and 5.6, respectively) in comparison to the other outfalls. Outfall 017 had the highest mean TUc (17.4).

Water quality measurements (pH, conductivity, alkalinity, hardness, and TSS) for each outfall and test during 1995 are provided in Appendix B.6. A summary of water quality parameters for each outfall during 1991–95 is provided in Table 3.7. In general, water from the intermittent outfalls had higher alkalinity and hardness than the continuous outfalls.

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

		Chronic toxicity unit (TUc)[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
15	December 1991	<1	<1
	March 1992	7.91	<1
	June 1992	<1	<1
	September 1992	<1	ND[b]
	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)

	Test Date	Chronic toxicity unit (TUc)[a]	
		Fathead minnow	*Ceriodaphnia*
	January 1995	< 1	< 1
	April 1995	< 1	< 1
	July 1995	< 1	< 1
	October 1995	< 1	< 1
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
017	December 1991	ND[b]	<1
	March 1992	4.54	<1
	June 1992	<1	<1
	September 1992	5.01	<1
	November 1992	<1	<1
	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

Table 3.5 (continued)

	Test Date	Chronic toxicity unit (TUc)[a]	
		Fathead minnow	*Ceriodaphnia*
	January 1995	< 1	< 1
	April 1995	< 1	< 1
	July 1995	< 1	< 1
	November 1995	< 1	< 1
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
	July 1995	< 1	< 1
	November 1995	< 1	< 1

[a]Chronic toxicity unit = 100/IC25. IC25 = the concentration causing a 25% reduction in fathead minnow growth or *Ceriodaphnia* reproduction in comparison to the control. IC = inhibition concentration.
[b]ND = not determined.

In samples collected from 1991–95, mean alkalinity ranged from 59 to 115 mg/L $CaCO_3$ and mean hardness ranged from 111 to 171 mg/L $CaCO_3$. Minimum pH ranged from 6.91 to 7.66 S.U. and maximum pH ranged from 7.96 to 8.27 S.U. Mean conductivity ranged from 208 to 374 μS/cm.

Table 3.6. Ranking of intermittent outfalls based upon frequency of chronic toxicity units > 1.0 and mean TUc for 34 tests

Outfall	Frequency (%) of TUc > 1.0	Rank[a] of Frequency (TUc > 1)	Mean TUc	Rank[a] of mean TUc	Sum of ranks
013	24	4.5	3.8	1	6
015	18	2.5	7.3	4	7
016	12	1	7.1	3	4
017	18	2.5	17.4	5	8
018	24	4.5	5.6	2	7

[a]Highest rank = 5; lowest rank = 1.
Note: TUc = Chronic toxicity unit(s)

Filtering effluent samples from Outfall 018 during July 1995 significantly improved minnow survival (Analysis of variance [ANOVA; $p = 0.0120$]); however, minnow survival in filtered effluent from Outfall 018 during January 1995 was significantly lower than the nontreated sample. Minnow survival in filtered effluent from Outfalls 015 and 017 during April 1995 and Outfall 018 during November 1995 was not different than minnow survival in the nontreated samples (ANOVA; $p > 0.1385$). A correlation between the amount of suspended solids in each of the intermittent effluents during 1995 and minnow survival did not exist ($p = 0.7295$).

3.1.4 Discussion

3.1.4.1 Continuously flowing outfalls

During 1995, effluent from Outfall 001 exceeded the permit limit for *Ceriodaphnia* of TUc > 1.0 two times, October and November. Effluent from Outfall 001 has only exceeded the permit limit for *Ceriodaphnia* on two previous occasions, May 1992 and October 1993. A process change in the RCW System and the addition of effluent from the C-612 facility to Outfall 001 during 1995 may account for the toxicity to *Ceriodaphnia* in 1995. A new corrosion inhibitor (Copper-Trol CU-1) was added to the RCW System, which discharges to Outfall 001, in May 1995. In addition, the C-612 facility (Northwest Plume Interim Remedial Action Pilot Plant) began pumping and treating contaminated water that discharges to Outfall 001 on August 31, 1995, prior to the two permit exceedances at Outfall 001. Toxicity

Table 3.7. Summary of water chemistry analyses of full-strength samples from intermittently flowing effluents from 1991 to 1995

Sample	pH (Standard units)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Outfall 013				
Mean (± SD)	7.47 (0.24)	58.8 (15.3)	158.9 (96.0)	323.0 (190.9)
Range	6.91–7.96	28–81	42–360	84–704
n	18	18	18	18
Outfall 015				
Mean (± SD)	7.74 (0.23)	85.6 (25.0)	147.4 (38.3)	322.9 (106.5)
Range	7.20–8.18	42–123	76–244	153–656
n	17	17	17	17
Outfall 016				
Mean (± SD)	7.78 (0.23)	98.5 (22.8)	170.5 (80.9)	374.1 (195.1)
Range	7.35–8.20	60–147	72–446	138–856
n	17	17	17	17
Outfall 017				
Mean (± SD)	7.91 (0.16)	115.4 (25.7)	167.6 (38.6)	342.3 (83.2)
Range	7.66–8.27	70–146	92–230	175–466
n	18	18	18	18
Outfall 018				
Mean (± SD)	7.71 (0.23)	72.4 (57.6)	110.7 (40.5)	208.3 (89.6)
Range	7.23–8.13	36–295	52–162	55–360
n	18	18	18	18

results of the corrosion inhibitor, provided by the manufacturer, indicate that effluent from the RCW System would not be toxic to aquatic life. Effluent from the C-612 facility will be evaluated for toxicity during 1996 to determine whether it may be contributing to the toxicity at Outfall 001.

No toxicity was evident in effluent samples from Outfalls 006, 008, 009, or 010 during 1995. This is an improvement from the number of permit exceedances in previous years. For example, in 1994 Outfall 009 exceeded the permit limit four times during fathead minnow tests. Outfalls 008 and 010 each had two exceedances and Outfall 006 had three exceedances during 1994. If the physical/chemical properties of the effluents remain consistent throughout the year, then this improvement in water quality may be real. However, with changes in the chemistry of the effluent, the small number of samples evaluated for toxicity may not accurately predict an improvement in toxicity from one year to the next. Variability in minnow survival among replicates is often high. Standard deviation in minnow survival ranged from 0 to 31.7% (mean standard deviation = 12.1%) in effluent from the continuous outfalls during 1995. This characteristic of the fathead minnow test could also prevent one from detecting the presence of toxicity (or lack of toxicity) in the effluent discharges.

As noted in Sect. 2, the most frequent permit exceedances for the continuously flowing discharges have been for zinc and copper. The monthly mean and maximum concentration of Cu in the continuously flowing discharges were below those that would be toxic to fathead minnows. Maximum concentrations in the outfalls ranged from 13 to 34 μg Cu/L and the mean concentrations in 1995 were typically <15 μg Cu/L. Schubauer-Berigan et al. (1993) found LC50s (the concentration that kills 50% of the organisms in 96 h) for fathead minnows of 44 μg/L and >200 μg/L at pH values of 7–7.5 and 8–8.5 respectively. Erikson et al. (1996) evaluated the effects of water chemistry on the toxicity of copper to fathead minnows and found at a hardness of approximately 200 mg/L (4 meq/L as added calcium and magnesium), the 96-h LC50 was approximately 180 μg Cu/L. The pH for continuously flowing outfalls typically ranges from 7.5 to 8.5 (Sect. 3.2). The hardness for Outfall 001 (the only outfall with TUc >1 in 1995) was typically 388 mg/L (as $CaCO_3$) from 1991 to 1995.

The monthly mean concentrations of Zn in the continuously flowing outfalls ranged from <13 to 90 μg/L (Appendix A) and were below those that would be toxic to fathead minnows; the maximum concentration of Zn measured in Outfall 002 (460 μg/L) and Outfall 012 (220 μg/L) could affect minnow survival and growth. Norberg and Mount (1985) determined that the 96 h LC50 for fathead minnows was 238 μg/L and in 7 d, growth of the minnows was affected at 125 μg Zn/L. The fact that Outfalls 002 and 012 are composited with, and thus diluted by, Outfalls 010 and 011 in the C-617 lagoon and that the TUcs for Outfall 010 were <1 for all tests in 1995 would indicate that under normal conditions, Zn levels in Outfall 010 are non-toxic to fathead minnows. In addition, measurements of Zn at Outfalls 002 and 012 are only taken during rainfall events; thus Zn is probably associated with suspended particulate matter that would be biologically unavailable to minnows. This hypothesis will be investigated further by the site-specific metals study planned as part of the draft Agreed Order.

3.1.4.2 Intermittently flowing outfalls

After ranking all of the intermittently flowing outfalls, Outfalls 013 and 018 were identified as having the greatest frequency of toxicity in comparison to the other outfalls. Outfall 017 ranked highest for mean TUc and for the overall sum of ranks. During 1995, no toxicity was observed in effluent samples from Outfalls 013, 015, 016, and 017. Outfall 018 exceeded a TUc > 1 during two tests in 1995, January for *Ceriodaphnia* and April for fathead minnow larvae. In previous years, each of the intermittent outfalls exceeded a TUc > 1 on several occasions. Outfall 016 exceeded a TUc > 1 once, Outfalls 013 and 018 twice, and Outfalls 015 and 017 three times in 1994 alone. The intermittent outfalls are consistently more toxic (as determined by the TUc) to fathead minnow larvae than *Ceriodaphnia*. As a result, tests of the intermittent outfalls in 1996 will be reduced to fathead minnow larvae only.

Suspended solids were believed to be the main sources of toxicity in the intermittent effluent samples, resulting in low minnow survival through the deposition of particles on gill surfaces or contaminant desorption from particles (Kszos et al. 1995). To test this hypothesis, the amount of suspended solids in the effluent samples was correlated to minnow survival. Toxicity tests were also conducted on nontreated and filtered effluent from outfalls in 1995. A relationship between the amount of suspended solids and minnow survival was not evident in 1995 toxicity data, and results of filtering of effluent samples were inconclusive. Because the intermittent outfalls were toxic to fathead minnow larvae during only one test in 1995, an improvement in minnow survival through filtering of effluent samples or a correlation in suspended solids to minnow survival may not necessarily be seen. In addition, the variability in minnow survival among replicates may prevent the detection of a difference in minnow survival from nontreated and filtered effluent samples. The influence of suspended solids on minnow survival at the intermittently flowing outfalls will continue to be investigated in 1996.

As with the continuously flowing outfalls, the maximum concentration of copper and zinc in the discharge was at times elevated (Appendix A). Monthly mean and maximum concentrations of Cu ranged from <12 to 17 μg/L and 12 to 40 μg/L. These concentrations would not be expected to affect survival or growth of fathead minnows (see Sect. 3.1.4.1).

The monthly mean concentrations of Zn in the intermittent outfalls ranged from 23–49 μg/L (Appendix A) and were below those that would be toxic to fathead minnows; the maximum concentration of Zn measured in outfall 018 (150 μg/L) could affect minnow growth. Outfall 018 exceeded a TUc > 1 in April 1995, however the concentrations of Zn during this test are not known. Because Outfall 018 has been identified as having the greatest frequency of toxicity in comparison to other outfalls (1991–1995), low levels of Zn may contribute to the toxicity observed. This will be investigated further by the site-specific metals study planned as part of the draft Agreed Order.

3.2 AMBIENT TOXICITY

3.2.1 Introduction

Ambient toxicity monitoring at PGDP employed the fathead minnow test described in Sect. 3.1. Monitoring of ambient sites at PGDP was incorporated into BMP in order to (1) evaluate area source contributions to stream toxicity, (2) characterize patterns of toxicity in Big Bayou and Little Bayou creeks, (3) document changes in water quality attributable to changes in operations at PGDP, and (4) provide data to evaluate whether the effluent limitations established for PGDP protect and maintain the use of Big Bayou and Little Bayou creeks for warmwater aquatic life. The sites chosen for testing on Big Bayou Creek were changed during the past year. Because there was no consistent chronic toxicity to fathead minnows or *Ceriodaphnia* at ambient sites, testing with *Ceriodaphnia* was discontinued at all sites and testing with fathead minnows was discontinued at BBK 10.0; water chemistry continued to be measured at BBK 10.0. Because of the high frequency of TUc > 1.0 at Outfall 009 during 1994, an additional ambient site at BBK 10.8 (below Outfall 009 and above Outfall 008) was included for fathead minnow toxicity tests during 1995. Unless otherwise noted, the discussion below is limited to 1995 data.

3.2.2 Materials and Methods

Ambient toxicity was evaluated using the fathead minnow as described in Sect. 3.1 for continuously flowing outfalls with the following exceptions: (1) no dilutions were tested, and (2) each test used seven consecutive, daily grab samples of stream water. Tests which included evaluating a water sample that had been exposed to ultraviolet light were discontinued in 1994. Three ambient sites on Big Bayou Creek (BBK 12.5, BBK 10.8, and

BBK 9.1; Fig. 2.2), one site on Little Bayou Creek (LUK 7.2, Fig. 2.2), and one site on Massac Creek (MAK 13.8, Fig. 2.1) were evaluated for toxicity. Prior to 1994, an additional site on Big Bayou Creek (BBK 10.0) was also evaluated for toxicity (Kszos et al. 1994). Water chemistry analyses continued on samples from BBK 10.0. These sites are similar to those selected for the ecological monitoring component of BMP (Sect. 5). Toxicity tests with minnows were conducted on a quarterly basis in 1995. See Kszos et al. (1995) for discussion of previous toxicity test results. Water sampling and water chemistry analyses were conducted as described for continuously flowing outfalls in Sect. 3.1.2.

An evaluation of significant differences in fathead minnow survival and growth among sites for each test was made using an analysis of variance procedure (General Linear Models) in SAS (SAS 1985a, 1985b). Means were separated using Tukey's Studentized Range Test for each test period. Unless otherwise noted, statements of significance (probability) are based on $p < 0.05$.

3.2.3 Results

Mean survival and growth of fathead minnows for each site and test in 1995 are provided in Table 3.8. During 1995, survival at the reference sites (BBK 12.5 and MAK 13.8) ranged from 70% to 80% and 77.5% to 95% respectively. Survival in water from Big Bayou Creek sites downstream of discharges from PGDP (BBK 10.8, BBK 9.1) was not significantly different from the reference site (BBK 12.5). Survival in water from LUK 7.2 was only significantly lower than survival in water from MAK 13.8 during the October 1995 test. Reductions in survival at the continuously flowing outfalls (see Section 3.1) were not correlated with any decreases in survival at the ambient sites (including LUK 7.2), but effluent samples only occasionally reduced fathead minnow survival or growth. Minnow growth was quite variable from test to test; growth in the reference sites (BBK 12.5 and MAK 13.8) ranged from 0.38 to 0.61 mg/larvae and 0.39 to 0.55 mg/larvae respectively. The analysis of minnow growth in water from Big Bayou and Little Bayou creek sites showed that growth in sites downstream of PGDP discharges (BBK 10.0, BBK 9.1, and LUK 7.2) was never lower than the reference sites (BBK 12.5 and MAK 13.8).

A summary of water quality measurements (pH, conductivity, alkalinity, hardness, and temperature) for each site and test in 1995 is provided in Appendix B.7. The change in water chemistry (hardness, conductivity, pH, and alkalinity) with distance downstream in Big Bayou

Table 3.8. Summary of fathead minnow survival and growth measured for toxicity tests of ambient sites in 1995

Test Date	Site[a]	Mean survival (%)	Survival SD (%)	Mean growth (mg)	Growth SD (mg)
Mar. 1995	BBK 12.5	80.0	18.3	0.61	0.05
	BBK 10.8	37.5	41.9	0.63	0.11
	BBK 9.1	85.0	17.3	0.59	0.04
	LUK 7.2	75.0	50.0	0.58	0.05
	MAK 13.8	77.5	38.6	0.55	0.05
May 1995	BBK 12.5	70.0	18.3	0.49	0.08
	BBK 10.8	85.0	12.9	0.40	0.08
	BBK 9.1	100.0	0.0	0.48	0.04
	LUK 7.2	87.5	18.9	0.44	0.03
	MAK 13.8	95.0	5.7	0.39	0.06
Aug. 1995	BBK 12.5	97.5	5.0	0.49	0.03
	BBK 10.8	87.5	5.0	0.57	0.06
	BBK 9.1	95.0	5.7	0.56	0.05
	LUK 7.2	92.5	9.5	0.60	0.06
	MAK 13.8	75.0	31.0	0.54	0.05
Oct. 1995	BBK 12.5	75.0	19.1	0.38	0.04
	BBK 10.8	60.0	31.6	0.55	0.12
	BBK 9.1	95.0	10.0	0.43	0.01
	LUK 7.2	55.0	12.9	0.51	0.07
	MAK 13.8	95.0	10.0	0.42	0.02

[a]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer; SD = Standard deviation.

Creek for tests conducted in 1991–95 is illustrated in Figs. 3.1 and 3.2. A summary of water chemistry for MAK 13.8 and LUK 7.2 is also provided in Figs. 3.1 and 3.2. The data is summarized for 1991–95 because a comparison of mean water chemistry values for each year showed that the water quality at the ambient sites and the outfalls has changed very little since

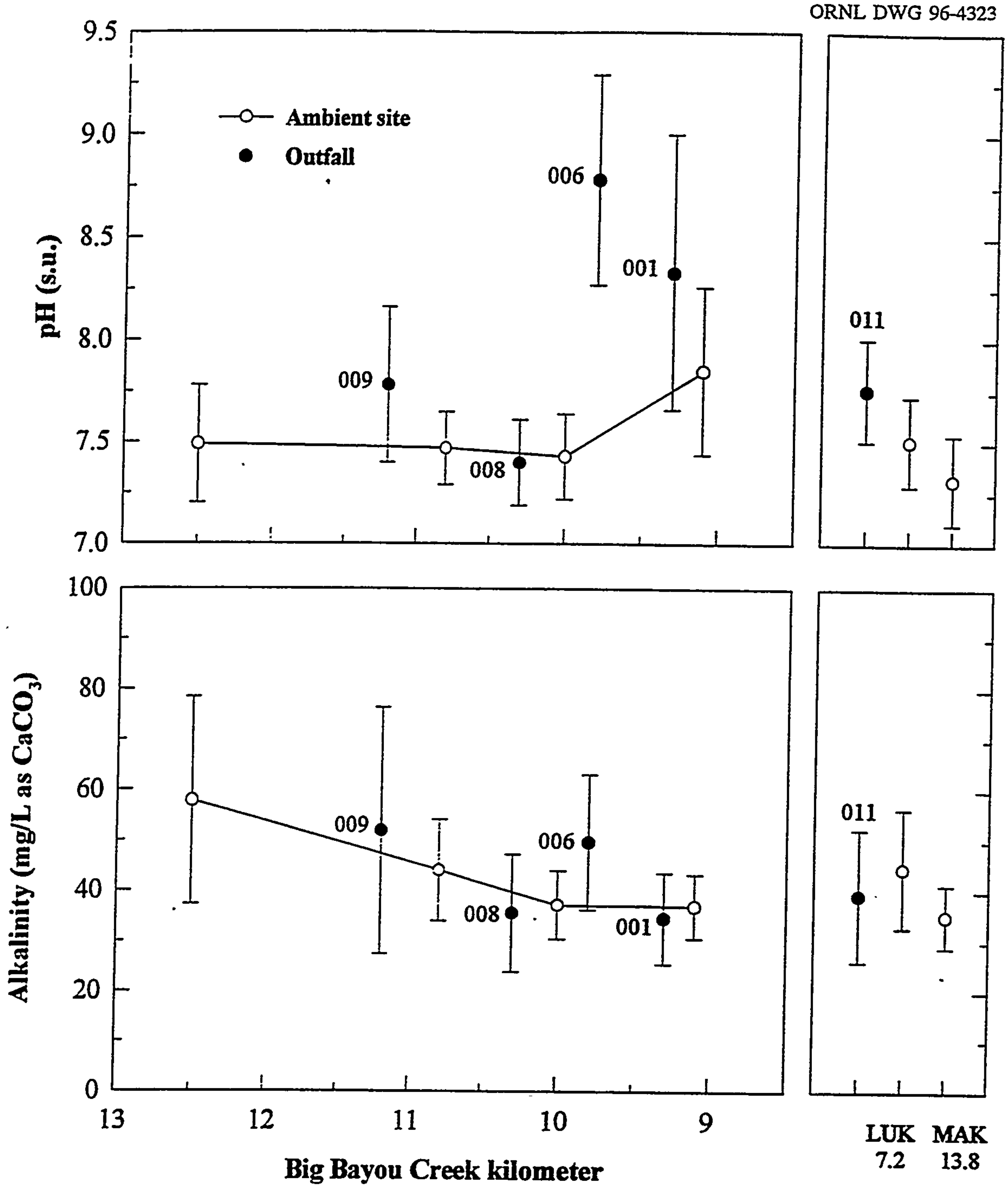


Fig. 3.1. Summary of pH (mean ±SD) and alkalinity (mean ±SD) at Big Bayou Creek, Little Bayou Creek, and Massac Creek sites for 1991–95. Mean (± SD) value of continuously flowing outfalls is also shown. LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

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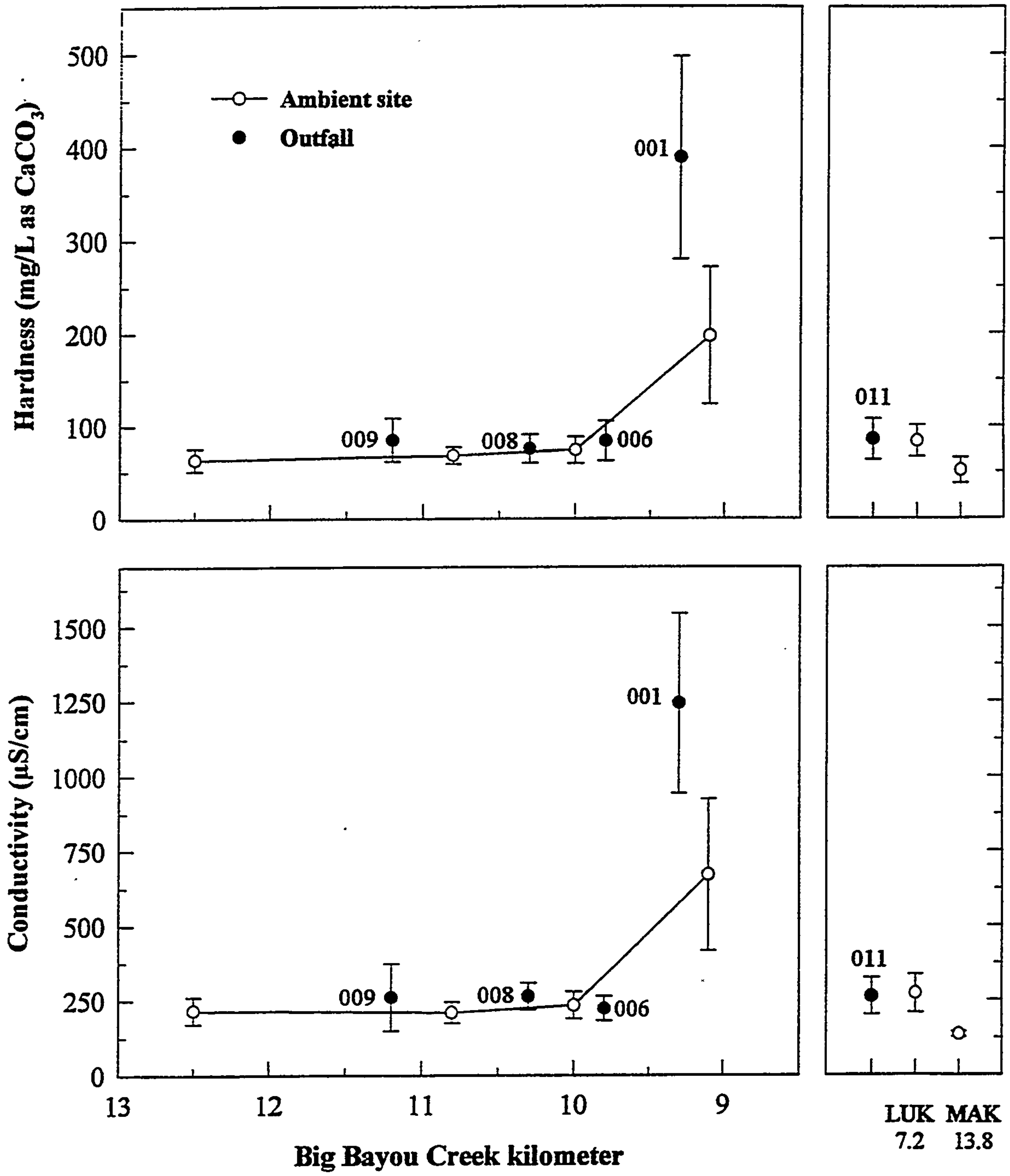

Fig. 3.2. Summary of hardness (mean ±SD) and conductivity (mean ±SD) at Big Bayou Creek, Little Bayou Creek, and Massac Creek sites for 1991–95. Mean (± SD) value of continuously flowing outfalls is also shown. LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

1991. The only significant temporal differences detected were that mean hardness at outfall 006 was significantly lower in 1991–92 (70 mg/L as $CaCO_3$) than in 1993 (103 mg/L as $CaCO_3$) and mean alkalinity at outfall 006 was significantly lower in 1991–92 (37 mg/L as $CaCO_3$) than in 1993 (70 mg/L as $CaCO_3$). Mean hardness and alkalinity at this outfall were not different between 1993, 1994, and 1995 and there was no significant difference reflected between years at BBK 9.1. At the ambient sites, mean pH was significantly higher at MAK 13.8 during 1991–92 as compared with 1993 or 1994, but was not significantly different from mean pH during 1995.

Differences in mean water chemistry at each site followed the same trend during 1995 as seen in previous years. There was little change in conductivity from BBK 12.5 downstream to BBK 10.0, but then mean conductivity increased as much as fourfold from BBK 10.0 downstream to BBK 9.1. The statistical analysis of mean conductivity in 1995 (Table 3.9) showed that BBK 9.1 was consistently distinguishable from all other sites.

The mean pH at BBK 9.1 was also distinguishable from the mean pH at BBK 10.0. For three of the tests in 1995, mean pH at BBK 9.1 was significantly higher (range = 7.91–8.64 S.U.) than the mean pH at all other sites (range = 7.15–7.65 S.U.). As in 1994, pH at BBK 10.0, BBK 10.8, BBK 12.5, and LUK 7.2 was not typically different from pH at the reference site (MAK 13.8; Table 3.10).

Unlike conductivity and pH which increased with distance downstream, alkalinity decreased with distance downstream, although the spatial pattern changed with each test. For two tests in 1995, each site below PGDP discharges in Big Bayou Creek was distinguishable from the reference site (BBK 12.5), but in the other two tests, alkalinity was not so clearly distinguishable between sites (Table 3.11). Alkalinity at LUK 7.2 was similar to that at BBK 9.1 during two tests (Table 3.11). For all tests, mean alkalinity at the reference site (MAK 13.8) was not significantly different from mean alkalinity at BBK 9.1 (Table 3.11).

Trends in hardness were similar to those for conductivity. There was little difference in hardness from BBK 12.5 downstream to BBK 10.0, and then hardness increased two to three fold from BBK 10.0 downstream to BBK 9.1 (Fig. 3.2). For all tests conducted in 1995, mean hardness at BBK 9.1 was significantly higher than hardness at all other sites and ranged from 136 to 218 mg/L (Table 3.12). Hardness at LUK 7.2 was similar to that at all Big Bayou Creek sites for three tests (Table 3.12). In three tests, mean hardness at MAK 13.8

Table 3.9. Mean conductivity measured at each site and comparison of means (Tukey's Studentized Range test)

Units expressed as microseimens per centimeter, 7 samples tested per site

	Site[a]					
Test	BBK 12.5	BBK 10.8	BBK 10.0	BBK 9.1	LUK 7.2	MAK 13.8
Mar. 9–16, 1995						
Mean	180	206	188	689	262	132
Comparison	C,D	B,C	C,D	A	B	D
May 10-17, 1995						
Mean	182	222	182	735	320	136
Comparison	B,C	B,C	B,C	A	B	C
Aug. 9–16, 1995						
Mean	200	224	220	554	290	132
Comparison	C	B,C	C	A	B	D
Oct. 25–Nov. 1, 1995						
Mean	260	282	251	803	336	138
Comparison	B	B	B	A	B	C

Note: Sites with the same letter are not significantly different.
[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

(48–56 mg/L as $CaCO_3$) was not different than at BBK 10.0 (63-76 mg/L as $CaCO_3$; Table 3.12).

3.2.4 Discussion

During 1995, there was not consistent toxicity to fathead minnows in laboratory tests of water from any site in Big Bayou Creek or Little Bayou Creek. This is based on a comparison of survival in the water from each site with survival in water from the reference site (MAK 13.8). Similar results were found during 1991–94: fathead minnow survival and growth in the water from the sites near PGDP were typically equal to or greater than survival or growth in water from the reference site (Kszos et al. 1994, 1995). Survival and growth at BBK 10.8 were not different from the reference site. Reductions in survival or growth would not be expected, however, because effluent samples from Outfall 009 were not toxic in 1995.

Table 3.10. Mean pH measured at each site and comparison of means (Tukey's Studentized Range test)

Expressed in standard units; 7 samples measured at each site

	Site[a]					
Test	BBK 12.5	BBK 10.8	BBK 10.0	BBK 9.1	LUK 7.2	MAK 13.8
Mar. 9–16, 1995						
Mean	7.16	7.42	7.44	7.66	7.50	7.15
Comparison	B	A,B	A,B	A	A,B	B
May 10-17, 1995						
Mean	7.17	7.39	7.56	7.91	7.52	7.23
Comparison	C	B,C	B	A	B	C
Aug. 9–16, 1995						
Mean	7.50	7.41	7.44	7.95	7.63	7.42
Comparison	B,C	C	B,C	A	B	C
Oct. 25–Nov. 1, 1995						
Mean	7.65	7.65	7.59	8.64	7.41	7.35
Comparison	B	B	B	A	B	B

Note: Sites with the same letter are not significantly different.
[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

The influence of discharges from PGDP on the water chemistry of Big Bayou and Little Bayou creeks continues to be shown by the changes in conductivity, hardness, alkalinity, and pH at sites downstream of those discharges. An analysis of mean water chemistry of outfalls or ambient water between years shows that there is very little temporal change in the characteristics of water from the outfalls or from the sites. Each year, the water chemistry data shows the influence of effluent from Outfalls 001 and 006 on the water chemistry of Big Bayou Creek (Fig. 2.2): (1) conductivity and hardness are significantly higher at BBK 9.1 than BBK 10.0, and (2) pH is often higher at BBK 9.1 than BBK 10.0. An immediate decrease in alkalinity occurs in about 50% of the tests at sites below plant operations. Because alkalinity is also highly variable at the site above PGDP discharges (BBK 12.5, Table 3.11), the magnitude of the change in alkalinity with distance downstream in Big Bayou Creek seems to be linked with natural variations in flow (e.g., rainfall).

Table 3.11. Mean alkalinity measured at each site and comparison of means (Tukey's Studentized Range test)

Expressed as mg/L as $CaCO_3$; 7 samples measured per site

Test	Site[a]					
	BBK 12.5	BBK 10.8	BBK 10.0	BBK 9.1	LUK 7.2	MAK 13.8
Mar. 9–16, 1995						
Mean	27	33	27	32	52	24
Comparison	C,D	B,C	B	B,C,D	A	D
May 10-17, 1995						
Mean	37	38	44	42	56	33
Comparison	B,C	B,C	B	B,C	A	C
Aug. 9–16, 1995						
Mean	65	48	37	35	43	37
Comparison	A	B	C,D	D	B,C	C,D
Oct. 25–Nov. 1, 1995						
Mean	80	57	44	40	38	38
Comparison	A	B	C	C	C	C

Note: Sites with the same letter are not significantly different.
[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

In the first quarter following publication of this report, ambient toxicity tests will be discontinued. There has been no consistent evidence of chronic toxicity in water from the ambient locations, no correlation of reductions in fathead minnow survival at the continuously flowing outfalls with reductions in fathead minnow survival at the ambient locations, and no significant change in the water chemistry of the ambient sites or outfalls. In addition, the high variability in minnow survival at the reference locations makes it difficult to distinguish normal variability due to the test system from effects on survival that may be due to a contaminant. The tests may be reinstated if the composition of the discharges change due to process changes at PGDP.

Table 3.12. Mean hardness measured at each site and comparison of means (Tukey's Studentized Range test)

Expressed as mg/L as $CaCO_3$; 7 samples measured per site

	Site[a]					
Test	BBK 12.5	BBK 10.8	BBK 10.0	BBK 9.1	LUK 7.2	MAK 13.8
Mar 9–16, 1995						
Mean	66	67	70	218	86	56
Comparison	B,C	B,C	B,C	A	B	C
May 10-17, 1995						
Mean	65	66	76	175	90	54
Comparison	B	B	B	A	B	B
Aug. 9–16, 1995						
Mean	59	68	63	136	74	48
Comparison	B,C	B	B,C	A	B	C
Oct. 25–Nov. 1, 1995						
Mean	59	71	73	200	96	41
Comparison	C,D	C	B,C	A	B	D

Note: Sites with the same letter are not significantly different.
[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

3.3 SUMMARY

During 1995, effluent from Outfall 001 exceeded the permit limit of TUc > 1.0 twice. A process change in the RCW System and/or the addition of effluent from the C-612 facility to Outfall 001 during 1995 may account for the toxicity to *Ceriodaphnia* in 1995. Effluent from the C-612 facility will be evaluated for toxicity during 1996 to determine whether it may be contributing to the toxicity at Outfall 001. No toxicity was evident in effluent samples from Outfalls 006, 008, 009, or 010 during 1995. This is an improvement from the number of permit exceedances in previous years. After ranking the outfalls using all tests conducted since 1991, Outfalls 013 and 018 were identified as having the greatest frequency of toxicity in comparison to the other intermittent outfalls. During 1995, no toxicity was observed in effluent samples from Outfalls 013, 015, 016, and 017. Outfall 018 exceeded a TUc > 1 twice in 1995. In previous years, each of the intermittent outfalls exceeded a TUc > 1 on several occasions. The intermittent outfalls are consistently more toxic (as determined by the TUc) to fathead minnow larvae than *Ceriodaphnia*. As a result, in 1996, tests of the intermittent outfalls will be reduced to fathead minnow larvae only.

During 1995, there was no consistent evidence of chronic toxicity to fathead minnows for any of the ambient sites. This is consistent with findings from 1991 to 1994 (Kszos et al. 1995). Ambient toxicity tests will therefore be discontinued in the second quarter of calendar year 1996. The high variability in minnow survival at the reference locations makes it difficult to distinguish normal variability due to the test system from effects on survival that may be due to the presence or absence of a contaminant. Variability among replicates also tends to be high in the full-strength effluent from the intermittently flowing outfalls. In some cases, the variability (expressed as standard deviation) can approach that of the ambient locations and brings into question the applicability of the TUc as an indicator of toxicity for intermittently flowing outfalls. The KDOW may consider incorporating acute toxicity limits for these outfalls; acute limits and, therefore, acute toxicity test procedures may eliminate some of the variability associated with the chronic fathead minnow test. The influence of effluent from Outfall 001 and Outfall 006 on the water chemistry of Big Bayou Creek was evident in increases in pH, conductivity, and hardness between BBK 10.0 and BBK 9.1. Water quality of the outfalls and ambient sites, as indicated by pH, conductivity, hardness, and alkalinity, has not changed significantly since 1992.

4. BIOACCUMULATION

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

4.1 INTRODUCTION

Bioaccumulation monitoring conducted to date as part of the Biological Monitoring Plan at PGDP identified PCB contamination in fish in Big Bayou Creek and Little Bayou Creek as major concerns (Birge et al. 1990, 1992; Kszos et al. 1993, 1994, 1995). 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 et al. 1993, 1994, 1995). 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 1994–95 bioaccumulation monitoring was to evaluate spatial and temporal changes in PCB contamination in sunfish from Big Bayou Creek and Little Bayou Creek. Monitoring for mercury contamination in fish was also conducted but at a more limited number of sites and at a decreased frequency than in previous years. To evaluate the maximum concentrations likely to occur in fish from the two creeks, larger fish (i.e., bass) were also analyzed for mercury and PCBs.

4.2 STUDY SITES

In October 1994, longear sunfish (*Lepomis megalotis*) were collected for PCB analysis at BBK 12.5 (the upstream reference site on Big Bayou Creek); BBK 10.0, BBK 9.1, and BBK 2.8 on Big Bayou Creek below PGDP; and LUK 9.0 and LUK 4.3 on Little Bayou Creek (Fig. 2.2). In April 1995, the same sites were monitored for PCBs, except at BBK 2.8 and LUK 7.2. BBK 2.8 will no longer be monitored because sampling was difficult and PCB levels in fish were historically low. LUK 7.2 was added as a routine PCB-monitoring site in April 1995 because, unlike LUK 9.0, sunfish of adequate size were available at this site and may provide a more reliable assessment of long-term changes in contamination in Little Bayou Creek. (This site was monitored for organic contamination in the past.) Spotted bass, *Micropterus punctulatus*, were collected when present from BBK 9.1 and LUK 4.3 in October 1994 for mercury and PCB analysis. 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).

The length of stream sampled at each site varied with the degree of difficulty in obtaining fish but was never more than 1000 meters. The site at BBK 10.0 was constrained to the reach between PGDP Outfalls 008 and 006 (Fig. 2.2). 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. However, changes in aquatic habitat at LUK 9.0, resulting from beaver activity, necessitated that some fish be taken slightly downstream of the reach sampled in previous years. The LUK 9.0 sampling reach in October 1994 and April 1995 extended from Outfall 011 downstream to approximately 250 meters downstream of McCaw Road. (In previous years no fish were collected downstream of the road.) LUK 7.2 encompassed an approximately 250-m reach upstream of Ogden Landing road. The most downstream site included a reach 1000 m long, centered at LUK 4.3.

4.3 MATERIALS AND METHODS

The bioaccumulation task focuses primarily on evaluating contamination in filets of common sport fish such as sunfish and bass. Thus, the bioaccumulation data can be used to assess the potential risk to people who might eat fish from these creeks, but is less useful in evaluating ecological risks. [Whole-body analysis of stream forage organisms are a more appropriate measure of evaluating ecological risk because (1) the whole organism (not just muscle) is eaten by terrestrial predators, (2) organisms such as minnows or clams are more readily eaten by predators than game fish, and (3) lower organisms can have very different bioconcentration potentials.] However, for the two contaminants of most concern, mercury and PCBs, the spatial and temporal pattern observed in sunfish are likely to be observed in lower organisms as well. Because sunfish are short-lived and have small home ranges, they reflect recent contaminant exposure at the site of collection and are thus ideal monitoring tools for evaluating spatial and temporal trends in contamination.

Eight longear sunfish were collected for PCB analysis by backpack electrofishing from each site except at LUK 9.0 in October 1994, where five bluegill and three bullhead were collected, and LUK 7.2, where five fish (three green sunfish and two longear sunfish) were collected. 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 sources. In general, high fish densities enabled the collection of eight specimens of sunfish >30 g at all sites except the upper Little Bayou Creek sites where habitat was limited due to recent beaver activity.

Longear sunfish were collected in Big Bayou Creek and Little Bayou Creek on October 19–20, 1994, and on April 24–25, 1995, as part of routine twice yearly monitoring of PCB concentrations in this species. In previous years sunfish were also tested for mercury contamination in the spring at the same number of sites. However, because it was found that there was very little difference in mean mercury concentrations in sunfish between sites in each stream, the monitoring of one site in each stream was deemed adequate to evaluate any temporal changes in mercury contamination. This effort, along with the metals screening at the same sites, was postponed until October 1995 to coincide with the routine monitoring of mercury in spotted bass at the same locations. Monitoring of sunfish in October instead of April may also provide a better opportunity to collect the preferred species and sizes at these sites.

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 greater 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 20, 1994, in Big Bayou Creek (BBK 9.1) and Little Bayou Creek (LUK 4.3). Eight spotted bass were taken at BBK 9.1; one spotted bass and one largemouth (*Micropterus salmoides*) were taken form LUK 4.3.

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 by passing each sample three times through a hand meat grinder. A 25-g sample of the ground tissue was wrapped in heavy duty aluminum foil, labeled, frozen, and submitted to ORNL Analytical Chemistry Division for PCB 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. 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 maintained 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. Results are summarized in Appendix C. Statistical evaluations of mercury concentrations in bass were made using SAS procedures and software for analysis of variance (ANOVA), linear regression analysis, and analysis of covariance (ANCOVA) (SAS 1985a, 1985b). The level of significance used for all statistical tests was 5% ($p < 0.05$). SAS procedures were used to calculate the mean, standard error (SE), and standard deviation (SD) of mercury and PCB concentrations at each site. Statistical comparison tests were not used to evaluate the 1994–95 PCB data because of the high number of samples in which PCB concentrations were below the limit of detection. (Use of detection limit values provides a misrepresentation of the variation in PCB concentrations at a given site.) At the more contaminated sites, standard statistical comparisons would require the use of multiple assumptions because of the different species and sizes of fish available in 1994-95. In the following section, a series of graphs are provided that effectively illustrate the general spatial and temporal trends in PCB contamination.

4.4 RESULTS AND DISCUSSION

4.4.1 PCBs

4.4.1.1 Spatial trends

Fall 1994. Results of PCB analyses of sunfish collected from Big Bayou Creek and Little Bayou Creek in October 1994 are presented in Table 4.1 and Appendix C. Detectable concentrations of PCBs were found in sunfish at BBK 9.1 and BBK 10.0. The mean PCB concentration in sunfish from BBK 2.8 in October 1994 was only slightly higher than that in the reference stream sites, indicating the PCB contamination in Big Bayou Creek is confined to the reach near the plant. PCB concentrations in sunfish from upper Little Bayou Creek (LUK 9.0) near PGDP were much higher than in Big Bayou Creek, averaging 0.36 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 et al. 1993, 1994, 1995). The mean PCB concentration in Little Bayou Creek fish dropped sharply with distance downstream, averaging only 0.13 μg/g at LUK 4.3. 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) 0.17 ± 0.02 μg/g PCBs, a level not much different from longear sunfish concentrations at the same site. Bass collected in 1994 were smaller than previous years. Although it was expected that bass would contain higher concentrations than sunfish because of its trophic position, the similarity in lipid content of the two species in Big Bayou Creek may partially explain why PCB concentrations in bass were not higher (see Appendix C). Concentrations in the eight fish ranged from 0.11 to 0.32 μg/g; only the highly chlorinated materials similar to Aroclor 1254/1260 were present (Appendix C). PCB concentrations in the two bass collected from Little Bayou Creek were higher, averaging 0.25 ± 0.10 μg/g. The observed difference between PCB levels in bass and sunfish in Little Bayou Creek was closer to that expected.

Spring 1995. In spring 1995, PCB contamination was again evident in longear sunfish collected from both Big Bayou Creek and Little Bayou Creek (Table 4.1 and Appendix C). The constituents of the PCB mixtures extracted from fish resembled Aroclor 1254 and 1260.

Table 4.1. Mean concentrations of PCBs in fish from streams near PGDP and a reference stream, October 1994 and April 1995

Units expressed as micrograms per gram, wet weight

Site[a]	Species[b]	Mean	SE	Range	*n*
October 1994:					
BBK 12.5	LNGEAR	BLD[c]	...	<0.006–<0.012	8
BBK 10.0	LNGEAR	0.19	0.03	0.12– 0.32	8
BBK 9.1	LNGEAR	0.16	0.03	0.09– 0.31	8
	SPOBASS	0.17	0.02	0.11– 0.32	8
BBK 2.8	LNGEAR	0.03	0.006	0.01– 0.07	8
LUK 9.0	BLUGILL (6) YBULL (3)	0.36	0.05	0.11– 0.54	9
LUK 4.3	LNGEAR	0.13	0.02	0.08– 0.22	8
	SPOBASS	0.25	0.1	0.15– 0.35	2
Hinds Creek[d]	REDBRE	BLD	...	<0.004– <0.015	6
April 1995:					
BBK 12.5	LNGEAR	BLD[e]	...	<0.01– 0.02	8
BBK 10.0	LNGEAR	0.08	0.04	0.007– 0.34	8
BBK 9.1	LNGEAR	0.09	0.02	0.02 – 0.25	8
LUK 9.0	LNGEAR (6) GREENSF (2)	0.44	0.06	0.32 – 0.81	8
LUK 7.2	LNGEAR (2) GREENSF (2)	0.19	0.09	0.07–0.45	4
LUK 4.3	LNGEAR	0.09	0.02	0.05 – 0.19	8
Hinds Creek	REDBRE	BLD	...	<0.005–<0.025	10

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

[b]LNGEAR = Longear sunfish (*Lepomis megalotis*); SPOBASS = Spotted bass (*Micropterus punctulatus*); REDBRE = Redbreast sunfish (*Lepomis auritus*); BLUGILL = Bluegill (*Lepomis macrochirus*); YBULL = Yellow bullhead (*Ameiurus natalis*); GREENSF = Green sunfish (*Lepomis cyanellus*).

[c]BLD = below limit of detection

[d]Hinds Creek is an uncontaminated reference stream in east Tennessee.

[e]One of eight fish was higher than the detection limit.

As has been the case since October 1994, lower chlorinated PCBs (such as Aroclor 1248) were not found in any Little Bayou Creek or Big Bayou Creek fish.

The highest mean concentration again occurred in fish from the site in Little Bayou Creek immediately downstream from the 010 and 011 outfalls (LUK 9.0). The level of contamination in sunfish from Little Bayou Creek declined by a factor of 2 less than 2 km downstream at LUK 7.2, and decreased by another factor of 2 at the most downstream site (LUK 4.3; Table 4.1). The pattern of decreasing PCB concentrations in fish with distance downstream of the plant area is most dramatically evident in seasons where all three sites in Little Bayou Creek were monitored (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.

In Big Bayou Creek, the mean PCB concentrations at BBK 9.1 and BBK 10.0 were again higher than the PCB concentrations in reference fish upstream of the plant outfalls (Table 4.1). Mean PCB concentrations at the two sites in April 1995, as well as in previous years, were similar, suggesting that Outfall 001 (located between the two sites) is not a major contributor of PCBs to the system.

4.4.1.2 Temporal trends

Results of the October 1994 and April 1995 sampling 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. At the most contaminated site (LUK 9.0), where PCB concentrations in fish are most responsive to changes in PCB inputs, a distinct seasonal pattern is evident (Fig. 4.2). Mean PCB concentrations in sunfish were highest in the spring of each year, suggesting greater mobilization from residual sources within the plant during winter and early spring. This pattern is consistent with the results from the deployment of semipermeable membrane devices (used to estimate aqueous PCB levels) at storm drain locations inside the

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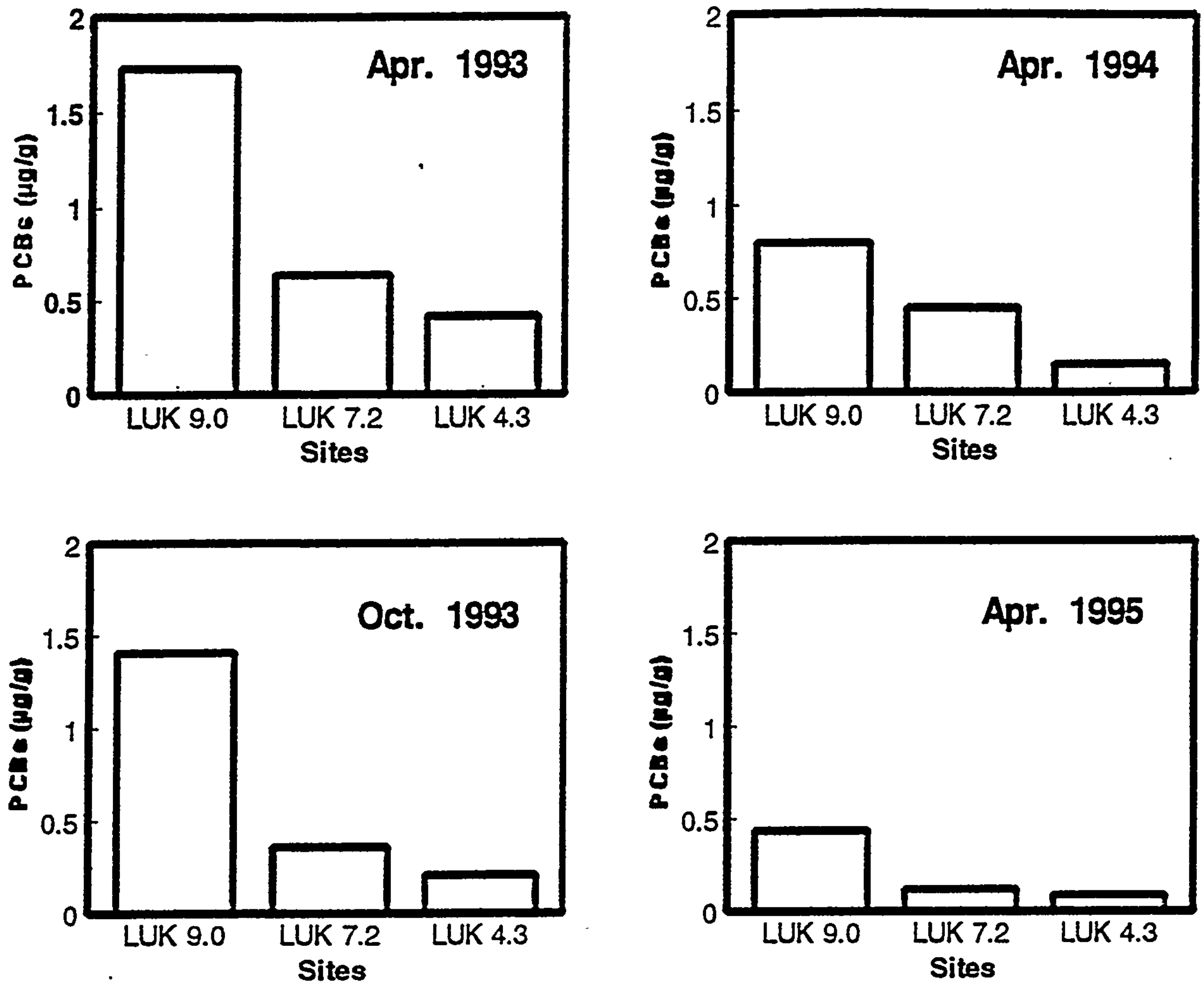

Fig. 4.1. Mean PCB concentrations in Little Bayou Creek sunfish in seasons where all three sites on Little Bayou Creek were monitored. LUK = Little Bayou Creek kilometer.

plant: a 1995 study showed PCB levels were markedly higher in the spring (John McCarthy, Oak Ridge National Laboratory, personal communication).

If the spring and fall fish data from LUK 9.0 are considered separately, mean PCB concentrations have steadily decreased over the 1992–95 period (Fig. 4.2). The much lower PCB concentrations in October 1994 and April 1995 may be the result, in part, of habitat changes that have necessitated sampling smaller-sized fish, sampling different species (bluegill are terrestrial feeders and would be expected to contain lower PCBs than longear), and sampling a larger reach (more downstream) than in previous years. However, the magnitude

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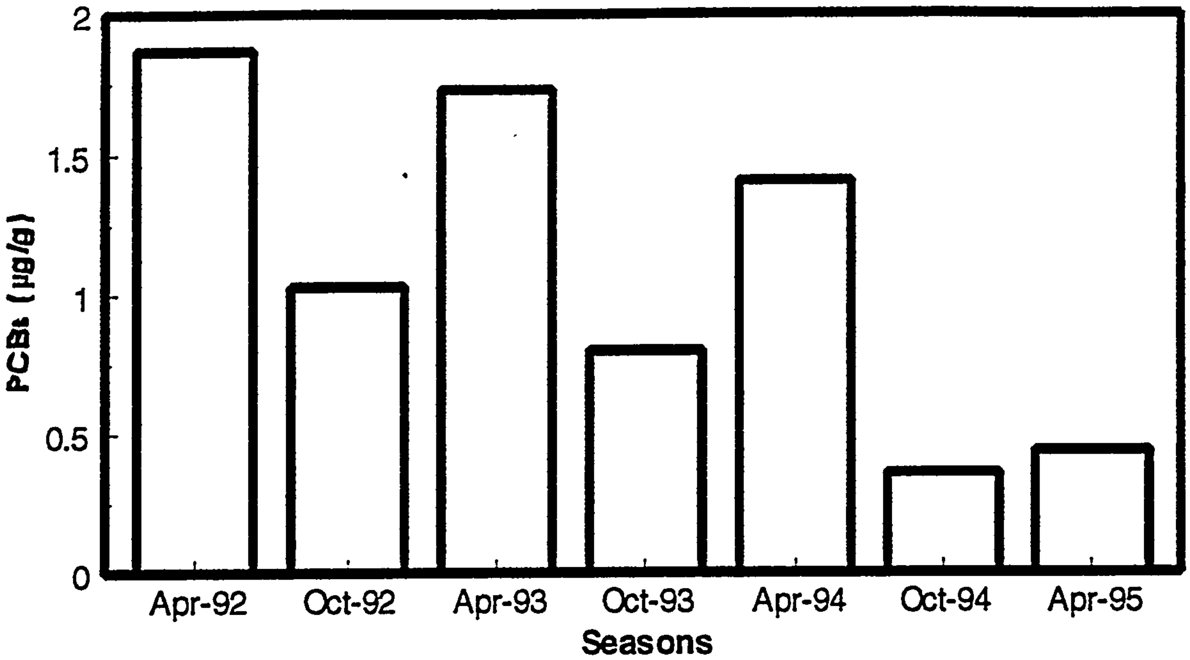

Fig. 4.2. Mean PCB concentrations in fish at Little Bayou Creek kilometer (LUK) 9.0, 1992–95.

of the decrease also suggests that decreases in PCB inputs are a major factor. The same general trend of decreasing PCB concentrations over time is evident at all Little Bayou and Big Bayou Creek sites from April 1992 to April 1995 (Fig 4.3), lending additional support to the premise that the flux of PCBs from PGDP to streams has decreased markedly. The decrease in mean PCB concentrations in fish appears to coincide with similar decreases in PCB exceedances in water over the same time period. The high temporal variability observed in fish at some sites suggests that PCB levels in fish may not remain consistently low. However, the overall decreasing trend and the seasonal pattern of PCB contamination in fish near the plant is encouraging in that it suggests that sunfish are highly responsive to in-plant remedial actions that reduce PCB inputs. The observed pattern does not suggest residual contamination in stream sediments as being a major source of PCBs.

4.4.2 Mercury

Previous monitoring indicated that sunfish from Big Bayou Creek downstream of the PGDP contained mercury concentrations that were elevated over fish from upstream areas and

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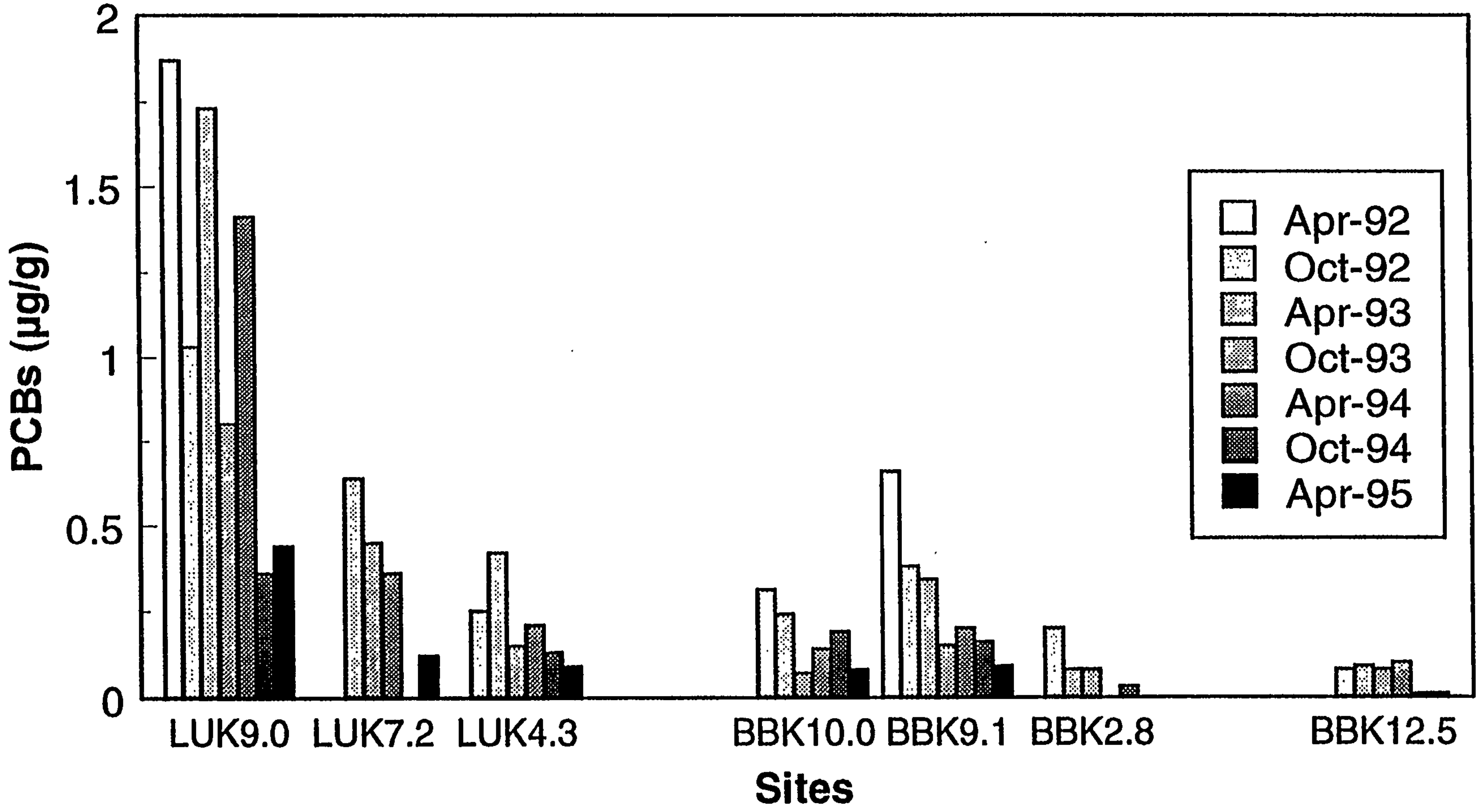

Fig. 4.3. Mean PCB concentrations in sunfish from Little Bayou Creek and Big Bayou Creek, 1992–94. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer.

other reference streams (Fig. 4.4). As noted previously (Kszos et al. 1994, 1995), the elevated concentrations of mercury in fish from Big Bayou Creek below PGDP may be a result of mercury in PGDP effluents, but they may also be a consequence of differences in the biogeochemical processing of mercury downstream from the plant or instream sediment contamination. With the exception of the 1992 results, mean mercury concentrations in sunfish from Little Bayou Creek were similar to reference site concentrations.

Spotted bass in streams near PGDP occupy the role of terminal predator and have contained mercury concentrations approximately double those in sunfish. Some bass collected previously have exceeded routinely cited human health threshold limits. The mean mercury concentrations (± SE) in bass sampled from BBK 9.1 and LUK 4.2 in October 1994 were 0.43 ± 0.05 and 0.26 ± 0.03 $\mu g/g$ respectively. At BBK 9.1, concentrations in individual fish ranged from 0.22 $\mu g/g$ to 0.63 $\mu g/g$. Of the eight fish sampled, only one exceeded the

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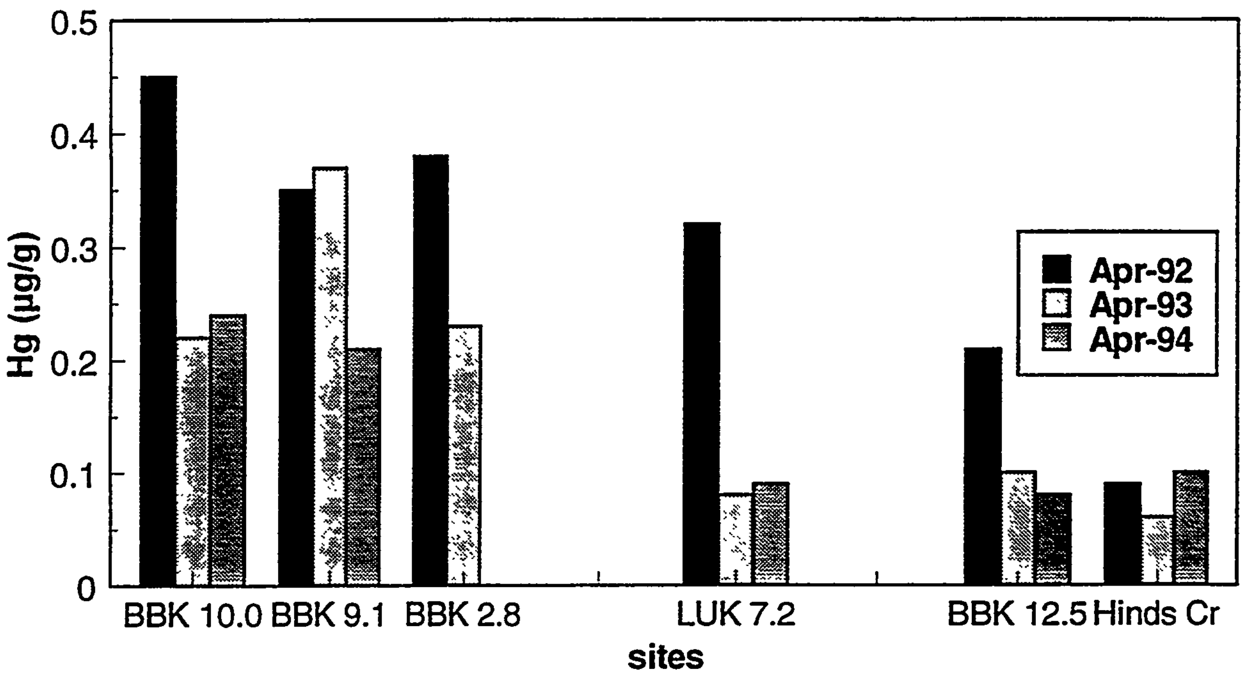

Fig. 4.4. Mean Hg concentrations in Little Bayou and Big Bayou Creek sunfish. BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer; HindsCr = Hinds Creek, a reference stream in east Tennessee.

EPA screening level of 0.60 $\mu g/g$ (EPA 1995) and none exceeded the FDA threshold limit of 1.00 $\mu g/g$ (FDA 1984). The mean concentration in 1994 was less than the mean concentrations reported for the previous two sampling periods (0.72 $\pm$ 0.08 $\mu g/g$ and 0.61 $\pm$ 0.06 $\mu g/g$ in 1992 and 1993 respectively) (Fig. 4.5).

The sharp decrease in mean mercury concentrations in 1994 was not likely the result entirely of a decrease in mercury exposure. Mercury concentrations in fish are generally correlated with fish size, and the size of bass available in 1994 was substantially smaller (mean weight 281 g) than the previous 2 years (mean weight 475 g). Linear regression analysis indicated that for each season there was a positive correlation between weight and mercury levels. A comparison of mean mercury concentrations adjusted for variation in mercury with weight using ANCOVA indicated no statistical differences between seasons. Mean weight-adjusted mercury concentrations in sunfish collected from Big Bayou Creek were 0.66, 0.59, and 0.50 $\mu g/g$ in 1992, 1993, and 1994 respectively.

4.5 SUMMARY

Mean PCB concentrations in sunfish from Little Bayou and Big Bayou Creeks were higher than in fish from reference areas. The highest concentrations continued to be in fish from upper Little Bayou Creek, with a sharp decrease in contamination with increasing distance downstream. PCB concentrations in fish from LUK 9.0 exhibited a distinct seasonal pattern with the highest concentrations found in the spring, suggesting greater mobilization of residual sources during this time period. PCB concentrations in sunfish appeared to have decreased over time at all Little Bayou and Big Bayou sites from April 1992 to April 1995, although the extent of the decrease in upper Little Bayou Creek may have been caused in part by habitat changes that affected the size and species of fish available.

In October 1994, mean mercury and PCB concentrations in spotted bass from the two creeks were also elevated. However, PCB concentrations in these bass were not much higher than sunfish collected at the same sites. The highest mercury concentrations in fish from the PGDP vicinity continued to be in spotted bass collected from Big Bayou Creek. The mean mercury concentration in Big Bayou Creek bass in October 1994, if adjusted for the difference in fish weight, was similar to the level of contamination observed in this species in previous years.

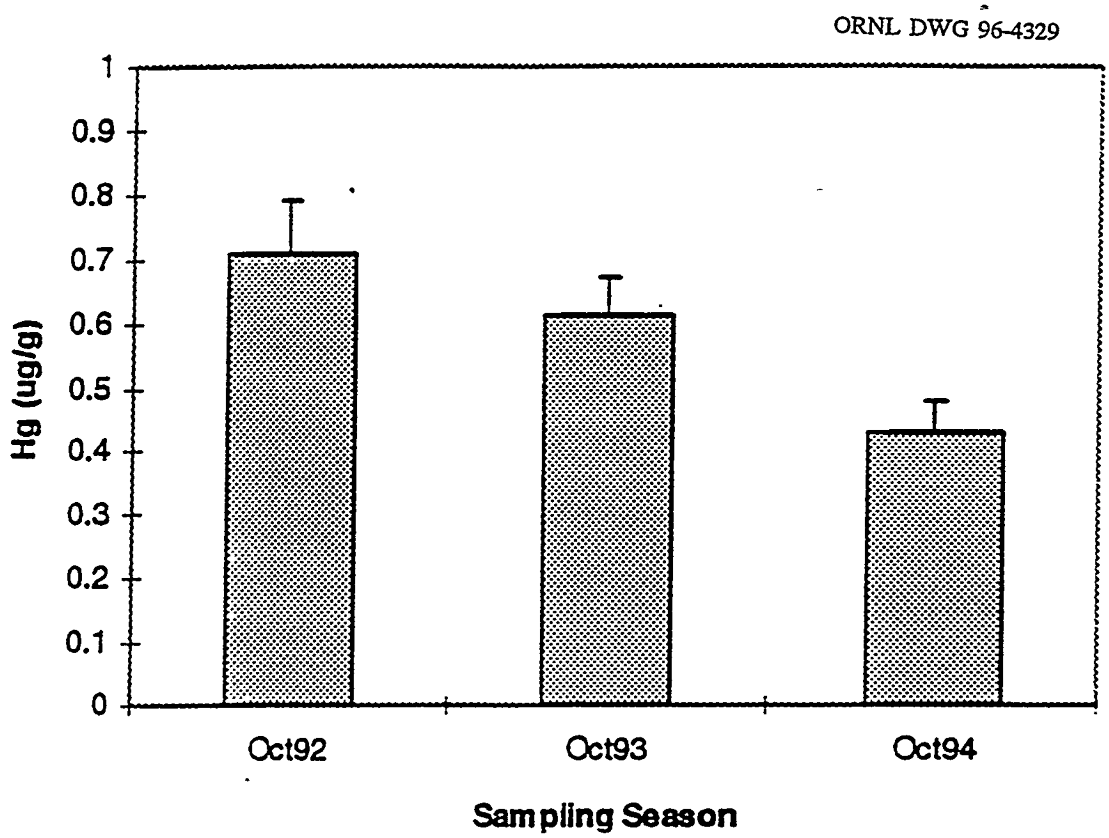

Fig. 4.5. Mean mercury concentrations for spotted bass (*Micropterus punctulatus*) collected at Big Bayou Creek kilometer (BBK) 9.1 in October 1992, October 1993, and October 1994 (Error bars indicate standard error of the mean).

The high temporal variability in PCB concentrations in fish indicates that continued routine monitoring of Little Bayou and Big Bayou Creek 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 construction/excavation activities are ongoing. Sunfish have shown to be effective integrators of PCB exposure and can be effectively used to evaluate the effects of stream discharges. Future monitoring will 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. All screening evaluations for other contaminants will be discontinued unless there is a demonstrated need as a result of some change in aqueous inputs.

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, Ohio, facility (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 documented impacts (Ryon 1993b, 1994c) as well as indicated recovery (Ryon 1994b, 1994d).

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 are located on Big Bayou Creek (BBK 12.5, BBK 10.0, and BBK 9.1; Fig. 2.2), one on Little Bayou Creek (LUK 7.2, Fig. 2.2), and one offsite reference station is located on Massac Creek (MAK 13.8, Fig. 2.1). MAK 13.8 was chosen as a larger 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 and lower Big Bayou Creek sites. 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).

5.1.3 Materials and Methods

Quantitative sampling of the fish populations at four sites in the Bayou Creek watershed (BBK 12.5, BBK 10.0, BBK 9.1, and LUK 7.2) and at one site in a reference stream, Massac Creek (MAK 13.8), was conducted by electrofishing on March 13–15 and September 11–14, 1995. Data from these samples were used to estimate species richness and population size (numbers and biomass per unit area), and to calculate annual production. Fish sampling sites either overlapped or were within 100 m of the sites included in the benthic macroinvertebrate monitoring task. Qualitative fish sampling was conducted by electrofishing on September 13, 1995. Data from this sample were used to determine the species richness and number of specimens (relative abundance) based on sampling a known length of stream. All field sampling was conducted according to standard operating procedures (Ryon 1992b).

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 species-size class were measured and weighed, additional members of that size class were only measured. Length-weight regressions based on the weighed individuals were used to estimate missing weight data.

After processing fish from all passes, the fish were allowed to fully recover from the anesthesia and 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.

5.1.3.2 Qualitative field sampling procedures

Qualitative sampling involved electrofishing a limited length of stream for one pass and collecting all stunned fish. A five-person sampling team electrofished upstream for approximately 1 h using two Smith-Root backpack electrofishers. The sample reach began at a consistent 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- to three-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 (in meters) sampled were recorded.

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 (in square meters) 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 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 1994 and spring 1995 sampling dates.

5.1.4 Results

The physical parameters of the sample sites showed only minor differences between the March (spring) and September (fall) samples (Table 5.1). There was no pattern of sites being deeper or wider in fall than in spring, contrary to previous sampling (Ryon 1994a,e). A

Table 5.1. Lengths, mean width, mean depth, surface area, and pool:riffle ratio of fish sampling sites in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, for March and September 1995

Site[a]	Length (m)	Mean width (m)	Mean depth (cm)	Surface area (m^2)	Pool:riffle ratio
March 1995					
BBK 9.1	100	7.2	23.8	720	0.8
BBK 10.0	100	4.8	10.8	480	1.0
BBK 12.5	98	6.0	9.2	588	2.1
LUK 7.2	110	3.1	6.7	341	1.7
MAK 13.8	100	6.0	19.0	600	0.7
September 1995					
BBK 9.1	115	6.1	20.8	702	0.9
BBK 10.0	104	4.9	10.4	510	2.2
BBK 12.5	103	6.2	11.5	639	6.4
LUK 7.2	118	2.9	7.9	342	1.3
MAK 13.8	94	4.9	21.9	461	10.8

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

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 habitat is a faster water velocity, a high pool:riffle ratio suggests generally slower flow in the fall sample period.

5.1.4.1 Quantitative sampling

Species richness and composition. A total of 33 fish species were found at the 5 sites on Big Bayou Creek, Little Bayou Creek, and Massac Creek (Table 5.2) for the March and September 1995 samples. BBK 9.1 and BBK 10.0 had 25 and 15 species, respectively, for the 2 sampling seasons, compared to 27 species at the reference stream, MAK 13.8. The number of species at BBK 9.1 represents an increase of seven from 1994 sampling (Ryon 1995). The LUK 7.2 site had 20 species during the year, while the smaller reference site, BBK 12.5 had 18 species. Mean species richness for MAK 13.8, BBK 9.1, and BBK 10.0 was 21.0, 16.5, and 11.0, respectively (Table 5.3). At LUK 7.2 and BBK 12.5, the mean richness was 16.0 and 12.5 respectively. At all sites, species richness was higher in the September samples than in March. The core species assemblage at all sites included central stoneroller (*Campostoma anomalum*), creek chub (*Semotilus atromaculatus*), blackspotted topminnow (*Fundulus olivaceus*), creek chubsucker (*Erimyzon oblongus*), green sunfish (*Lepomis cyanellus*), bluegill (*L. macrochirus*), and longear sunfish (*L. megalotis*). Another species, the pirate perch (*Aphredoderus sayanus*) expanded its range to include Big Bayou Creek sites. Six species were judged 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). Piscivores or top carnivores included two species, largemouth bass (*Micropterus salmoides*), and spotted bass (*M. punctulatus*). Other important groups include benthic insectivores, a feeding guild that can reflect impacts on the benthic macroinvertebrate community (Miller et al. 1988), and generalist feeders, which 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). The lowest site on Big Bayou, BBK 9.1, had several species which are more common in larger streams, such as bigmouth buffalo (*Ictiobus cyprinellus*), white crappie (*Pomoxis annularus*), and common carp (*Cyprinus carpio*). These species were not taken at upstream Big Bayou sites.

Table 5.2. Species composition of quantitative samples in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March and September 1995

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	1	0	1
Cyprinidae					
Central stoneroller (*Campostoma anomalum*)	2	2	2	2	2
Red shiner (*Cyprinella lutrensis*)	1	0	1	2	0
Steelcolor shiner (*Cyprinella whipplei*)[d]	0	0	1	0	2
Common carp (*Cyprinus carpio*)	1	0	0	0	1
Mississippi silvery minnow (*Hybognathus nuchalis*)	1	1	0	1	1
Ribbon shiner (*Lythrurus fumeus*)[d]	0	0	0	1	1
Redfin shiner (*Lythrurus umbratilis*)[d]	1	1	2	2	2
Golden shiner (*Notemigonus crysoleucas*)	1	0	0	2	0
Suckermouth minnow (*Phenacobius mirabilis*)	0	0	0	1	0
Bluntnose minnow (*Pimephales notatus*)	1	1	2	2	2
Fathead minnow (*Pimephales promelas*)	0	0	1	0	0
Creek chub (*Semotilus atromaculatus*)	1	2	2	2	2
Catostomidae					
White sucker (*Catostomus commersoni*)	1	0	1	0	2
Creek chubsucker (*Erimyzon oblongus*)	1	1	2	0	2
Bigmouth buffalo (*Ictiobus cyprinellus*)	1	0	0	0	0
Spotted sucker (*Minytrema melanops*)	2	0	0	0	1
Golden redhorse (*Moxostoma erythrurum*)	1	0	0	0	1
Ictaluridae					
Yellow bullhead (*Ameiurus natalis*)	2	1	2	1	2
Aphredoderidae					
Pirate perch (*Aphredoderus sayanus*)	1	0	1	1	2
Cyprinodontidae					
Blackspotted topminnow (*Fundulus olivaceus*)	2	2	2	2	2
Poeciliidae					
Western mosquitofish (*Gambusia affinis*)	1	1	1	2	1
Centrarchidae					
Green sunfish (*Lepomis cyanellus*)	2	2	2	2	2
Warmouth (*Lepomis gulosus*)	0	0	0	1	1
Bluegill (*Lepomis macrochirus*)	2	2	2	2	2
Longear sunfish (*Lepomis megalotis*)	2	2	2	2	2
Hybrid sunfish	2	0	1	0	1
Redspotted sunfish (*Lepomis miniatus*)[d]	0	0	0	1	0
Spotted bass (*Micropterus punctulatus*)	2	1	0	0	2
Largemouth bass (*Micropterus salmoides*)	1	1	1	1	1
White crappie (*Pomoxis annularus*)	1	0	0	0	0
Percidae					
Slough darter (*Etheostoma gracile*)	0	0	0	2	2
Logperch (*Percina caprodes*)	0	1	0	0	2
Blackside darter (*Percina maculata*)[d]	0	0	0	0	2
TOTAL SPECIES	25	15	18	20	27

[a]BBK = Big Bayou kilometer, LUK = Little Bayou kilometer, MAK = Massac Creek kilometer.
[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991) and Etnier an d 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 and September 1995 and means for 1994–95 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 1995					
Density	0.27	0.83	3.79	2.23	0.63
Biomass	6.52	6.4	11.16	2.31	5
Species richness	11	8	11	13	18
September 1995					
Density	3.45	8.44	3.21	5.09	5.14
Biomass	22.21	28.65	15.19	9.32	19.5
Species richness	22	14	14	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

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

A logperch (*Percina caprodes*) was found in the fall sample at BBK 10.0, which represents the first time this sensitive species has been observed in ORNL sampling of Big Bayou Creek.

The community composition of the Big Bayou Creek watershed shows less diversity than the community at the Massac Creek reference site. There are noticeably fewer benthic insectivores, sensitive species, and percids at the Big Bayou Creek sites than at MAK 13.8 (Table 5.4). Within Big Bayou Creek, BBK 10.0 has lower numbers of catostomids, cyprinids, and rarely has percids or sensitive species, compared to BBK 9.1 or BBK 12.5. Although one might expect to have some of these species groups disappear as the watershed diminishes in size, there is a noticeable dip in many categories at the BBK 10.0 site. Whether the overall lower diversity in Big Bayou Creek as compared with Massac Creek represents a

Table 5.4. Fish community composition based on quantitative samples of Big Bayou Creek, Little Bayou Creek, and Massac Creek, March and September 1995

Species numbers	BBK 9.1	BBK 10.0	BBK 12.5	MAK 13.8	LUK 7.2
Tolerant species	7	3	7	6	4
Intolerant species	2	1	1	6	1
Piscivores	2	2	1	2	1
Generalist feeders	8	4	7	9	5
Benthic insectivores	3	2	2	6	4
Cyprinids	8	5	7	8	9
Catostomids	5	1	2	4	0
Centrarchids	6	5	5	7	6
Percids	0	1	0	3	1

Note BBK = Big Bayou Creek kilometer; MAK = Massac Creek kilometer; LUK = Little Bayou Creek kilometer.

watershed effect will need to be investigated further. One would expect the upper site to have more percids and sensitive species because of the absence of discharges affecting the site. Their absence or low numbers at BBK 12.5 may reflect isolation, by plant activities, of the upper sections from recolonization sources downstream, or may reflect a naturally lower watershed carrying capacity. The low number of catostomids and intolerant species is also noticeable at LUK 7.2; however this site is more intermediate between the two reference sites in terms of percids, cyprinids, and benthic insectivores. This intermediate ranking may reflect the absence of a barrier between the site and downstream sources of species.

Density. Quantitative estimates of density were higher at all sites during the September samples than during the March samples (Table 5.3). This was the pattern in previous PGDP samples (Ryon 1994a, 1984e, 1995) 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 1992c; Southworth et al. 1992). The higher fall density reflects recruitment of fish into the community and normally occurs at all sites, unless a substantial impact has occurred.

The highest total density values were at MAK 13.8 and at BBK 10.0 during September sampling. The densities at BBK 9.1 were about one-third to one-half of the levels at

BBK 10.0 (Table 5.3). Overall, the densities at BBK 9.1 and BBK 10.0 were at or near the highest levels observed since 1990 (Fig 5.1).

Densities of individual species varied slightly between sites, with less variation among the two species with the highest values (Appendix D, Tables D.2 and D.4). During most sampling 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. At BBK 10.0, stonerollers comprised more than 80% of the total fish numbers, far exceeding the proportion of the fish community at MAK 13.8 or BBK 9.1. The high densities of central stoneroller (a scraping herbivore) in Big Bayou Creek probably reflected greater algal growth resulting from nutrient enrichment by PGDP discharges. The longear sunfish is a generalist feeder and the primary centrarchid in the PGDP area streams.

At LUK 7.2, the density increased in September 1995 (Table 5.3) but remained within the range of previous sampling (Fig 5.2). The species with the highest densities were bluntnose minnow (*Pimephales notatus*), red shiner (*Cyprinella lutrensis*), and western mosquitofish (*Gambusia affinis*) (Tables D.2 and D.4). The BBK 12.5 reference site was similar to downstream Big Bayou Creek sites with highest densities for longear sunfish and central stoneroller.

Biomass. Like the density estimates, quantitative estimates of total fish biomass were consistently higher in September samples than in March samples (Table 5.3). The highest biomass levels were at BBK 9.1 and BBK 10.0. Like the previous years, mean fish biomass at MAK 13.8 was similar to the biomass 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 (Tables D.3 and D.5). Other fish species that were among the two highest biomass contributors included central stoneroller, or spotted bass at BBK 9.1 and central stoneroller at BBK 10.0, MAK 13.8, and BBK 12.5. At LUK 7.2, the two highest biomass contributors varied among the creek chub, bluntnose minnow, or central stoneroller.

Production. Production values were calculated for the spring 1994 to spring 1995 period at all sites. Total production (in grams per square meter per year) was highest in Big Bayou Creek, increasing upstream (Table 5.5). The production at BBK 10.0 was more than

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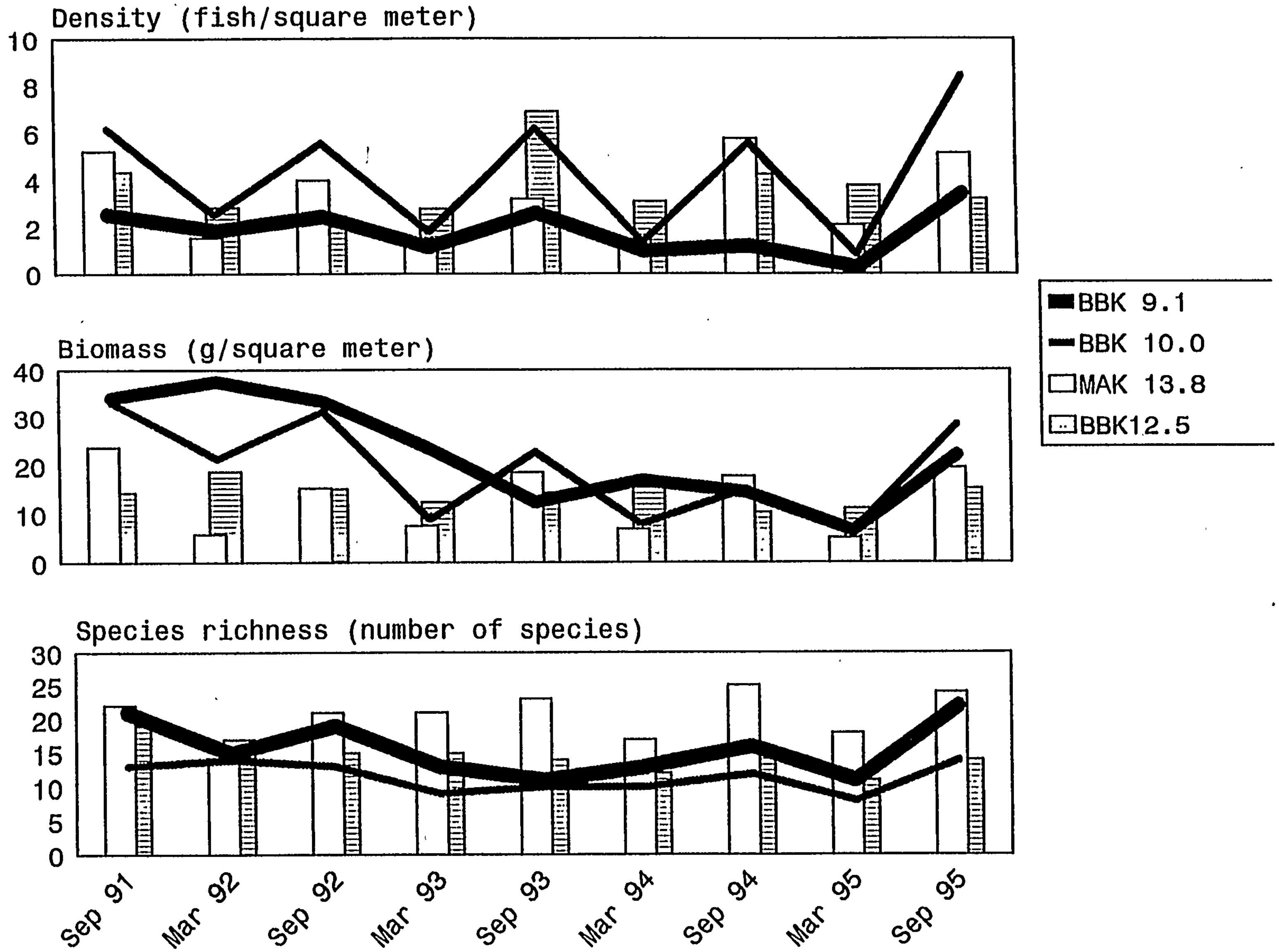

Fig. 5.1. Species richness, biomass, and density of fish at two Big Bayou Creek at kilometer (BBK) 10.0 and 9.1 sites and two reference sites, Massac Creek at kilometer (MAK) 13.8 and BBK 12.5

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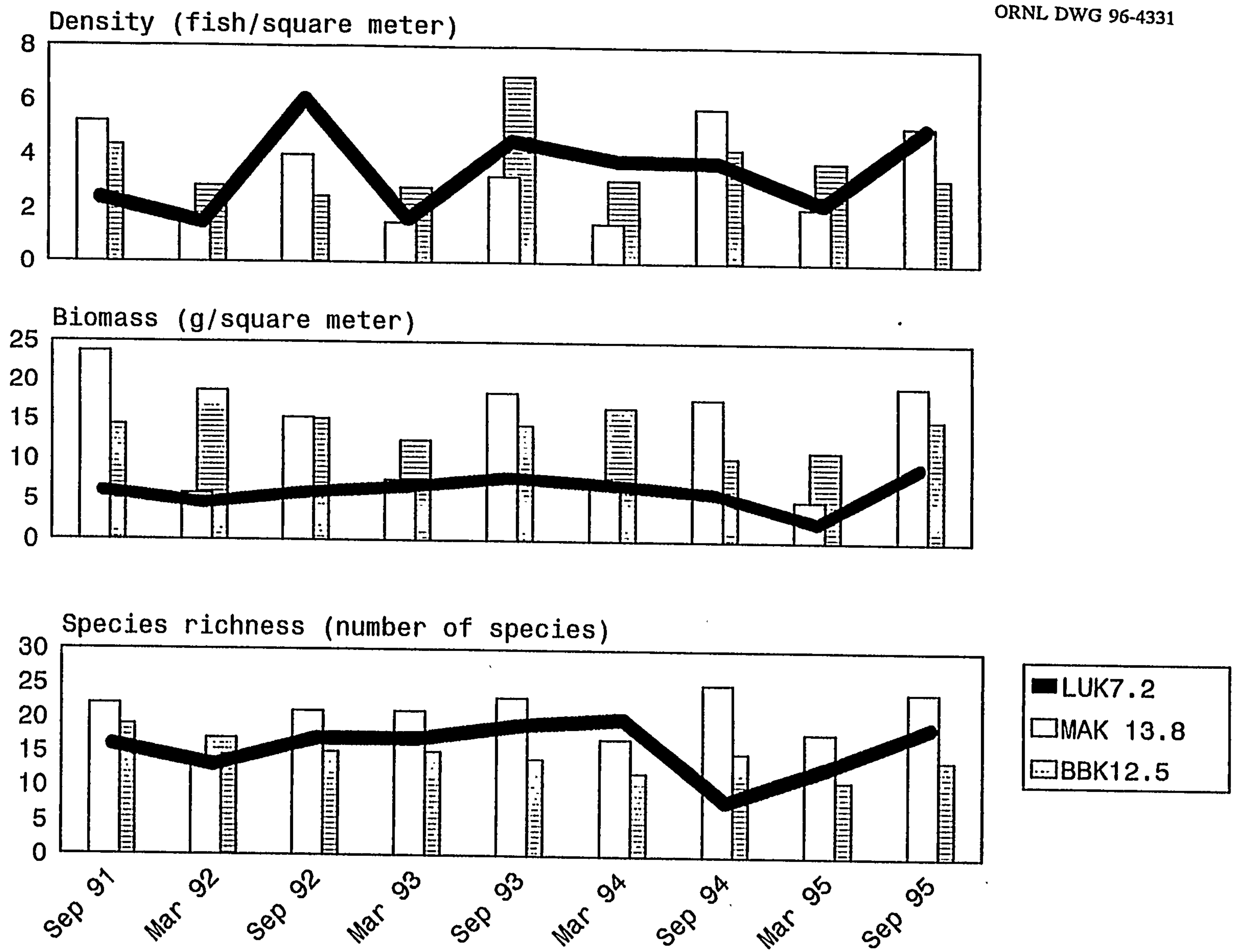

Fig. 5.2. Species richness, biomass, and density of fish at Little Bayou Creek site at kilometer (LUK) 7.2 and two reference sites, Big Bayou Creek at kilometer (BBK) 12.5 and Massac Creek at kilometer (MAK) 13.8.

Table 5.5. Fish annual production in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March 1994 to March 1995

Values expressed as grams per square meter per year

Species[b]	Sites[a]				
	BBK9.1	BBK10.0	BBK12.5	LUK7.2	MAK13.8
Stoneroller	0.94	8.34	8.99	0.42	1.59
Red shiner	-	0	0.02	0.35	-
Steelcolor shiner	-<0.01	-	-	-	0.02
Ribbon shiner	-	-	-	-0.01	0
Redfin shiner	-<0.01	-<0.01	0.02	0.03	0.03
Golden shiner	-	-	-	-<0.01	-
Suckermouth minnow	-	-<0.01	0.01	0.11	-
Bluntnose minnow	-	0	0.24	3.13	0.39
White sucker	-0.15	-	-0.01	-	0.01
Creek chubsucker	-0.04	0	0.13	-0.02	0
Golden redhorse	-0.19	-	-	-	-
Yellow bullhead	-<0.01	-	0.95	-0.01	0.06
Pirate perch	-	-	-	-0.19	-0.01
Blackspotted topminnow	0.01	<0.01	0.12	0.08	0.19
Western mosquitofish	-	-	-	0.02	-
Green sunfish	0.03	-0.02	0.41	0.06	0.14
Warmouth	-0.01	-	-	<0.01	-<0.01
Bluegill	0.01	-<0.01	0.07	0	-<0.01
Longear sunfish	2.72	-0.10	3.42	0.14	1.87
Spotted bass	-0.26	-	-0.01	-<0.01	-<0.01
Largemouth bass	-0.01	-	-	-	-
Bluntnose darter	-	-	-	0.02	-
Slough darter	-	-	-	0.06	-<0.01
Log perch	-	-	-	-	-0.04
Blackside darter	-	-	-	-	-0.01
Total production	2.93	8.20	15.52	4.63	4.34

[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).

twice that at the reference site, MAK 13.8. At BBK 10.0, the higher production was dominated by the contribution of the central stoneroller. However, production at BBK 9.1 decreased to levels below that in Massac Creek. Further, the productivity declined at both lower Big Bayou Creek sites compared to earlier levels continuing a trend covering the past 3 sampling years (Fig 5.3). Productivity at the reference sites did not show such a declining trend. Production at LUK 7.2 was only a third of that found at BBK 12.5 (Table 5.5). A ten-fold difference in production of central stoneroller, longear sunfish, and yellow bullhead accounted for the majority of the disparity. The high level of production at BBK 10.0 might be expected given the other signs of enrichment; however, the overall high production throughout the Big Bayou Creek system was unexpected.

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 Oak Ridge monitoring sites (Table 5.5 in Ryon 1994e). Estimates of production in southeastern reference streams varied from 2.02 to 27.1 $g \cdot m^{-2} \cdot year^{-1}$ compared to 4.34 to 15.5 $g \cdot m^{-2} \cdot year^{-1}$ at PGDP area reference streams. Similarly, production at sites downstream of plant discharges ranged from 3.06 to 27.4 $g \cdot m^{-2} \cdot year^{-1}$ in the southeast vs 2.93 to 8.20 $g \cdot m^{-2} \cdot year^{-1}$ in Big Bayou Creek watershed.

5.1.4.2 Qualitative sampling

During qualitative sampling conducted on lower Little Bayou Creek (LUK 4.3) in September, totals of 26 species and 441 specimens were taken (Table 5.6). The numbers of species and specimens were similar to most previous samples (Fig 5.4). The survey found one new species not taken in previous qualitative surveys of LUK 4.3, the redspotted sunfish (*Lepomis miniatus*). Also, the abundance of the pirate perch increased tremendously in this survey. The increase was also mirrored by a wider distribution of the pirate perch in Big Bayou Creek. The Little Bayou Creek community represented by this sample included seven cyprinid, two catostomid, seven centrarchid, and two percid species. When the sample was analyzed for the sensitivity of species to pollution and/or environmental degradation (Karr et al. 1986), there were four species intolerant of such changes and five tolerant species.

This latest survey at LUK 4.3 represents a return to sampling at this site following a fall 1994 and spring 1995 hiatus. Although previous surveys suggested no impacts from PGDP operations (Ryon 1994a, 1994e, 1995), sampling was renewed at this locale because of

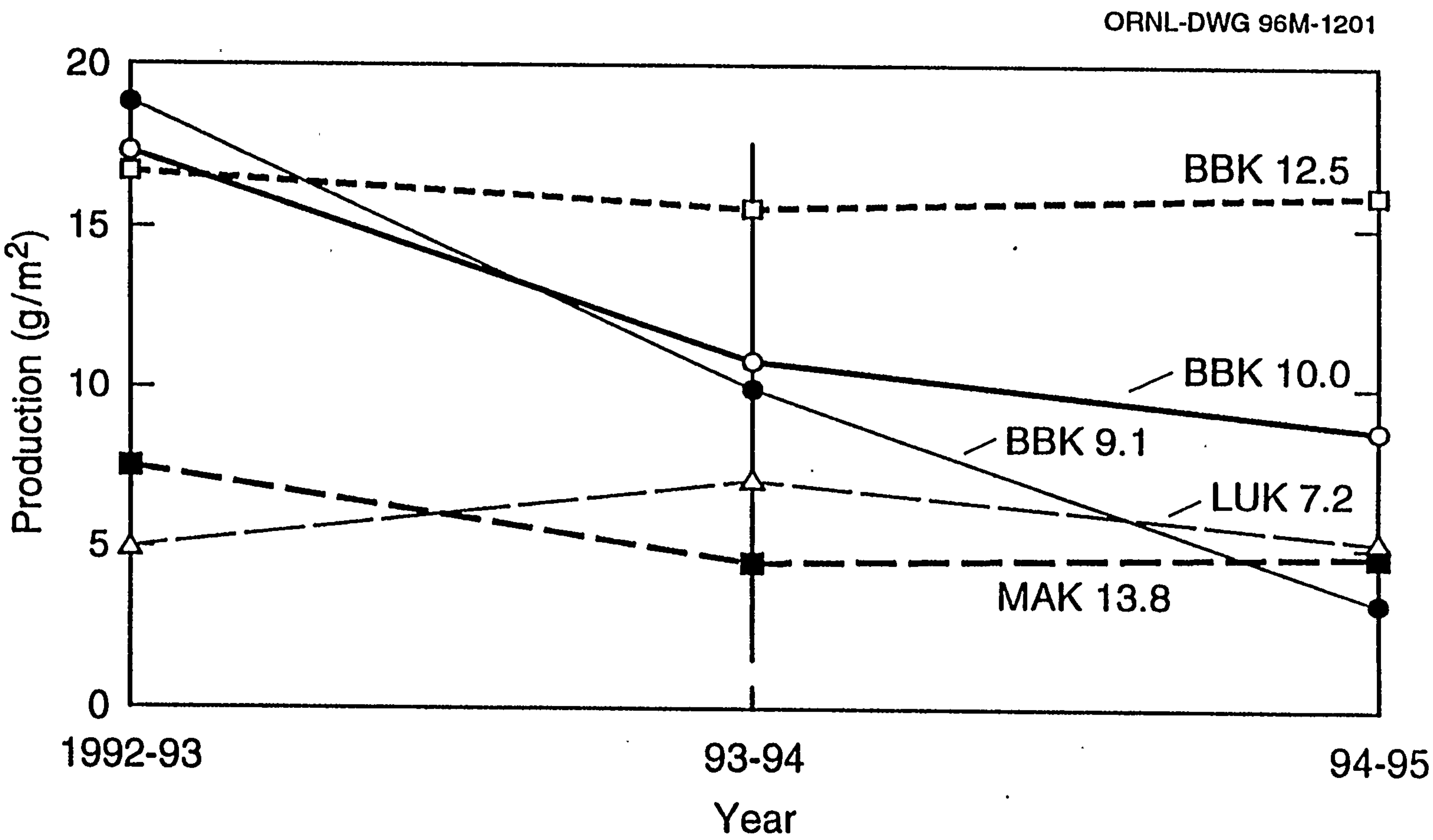

Fig. 5.3. Total production (g/m^2) for Big Bayou Creek kilometer (BBK) sites, Little Bayou Creek kilometer (LUK) site, and Massac Creek kilometer (MAK) site for 1992 to 1995.

Table 5.6. Species composition of the qualitative fish sampling conducted on Little Bayou Creek, September 13, 1995

Species[a]	Number of specimens	Relative abundance[b]
Cyprinidae		
Red shiner (*Cyprinella lutrensis*)[c]	5	UC
Spotfin shiner (*Cyprinella spiloptera*)[c]	5	UC
Common carp (*Cyprinus carpio*)	2	UC
Mississippi silvery minnow (*Hybognathus nuchalis*)[c]	19	UC
Ribbon shiner (*Lythrurus fumeus*)[c]	50	C
Redfin shiner (*Lythrurus umbratilis*)[c]	24	C
Bluntnose minnow (*Pimephales notatus*)	37	C
Catostomidae		
Creek chubsucker (*Erimyzon oblongus*)	3	UC
Spotted sucker (*Minytrema melanops*)	1	R
Ictaluridae		
Yellow bullhead (*Ameiurus natalis*)	9	UC
Tadpole madtom (*Noturus gyrinus*)[c]	1	R
Esocidae		
Grass pickerel (*Esox americanus vermiculatus*)	14	UC
Aphredoderidae		
Pirate perch (*Aphredoderus sayanus*)	43	C
Cyprinodontidae		
Blackspotted topminnow (*Fundulus olivaceus*)	40	C
Poeciliidae		
Western mosquitofish (*Gambusia affinis*)	22	C
Centrarchidae		
Flier (*Centrarchus macropterus*)	8	UC
Green sunfish (*Lepomis cyanellus*)	23	C
Warmouth (*Lepomis gulosus*)	8	UC
Bluegill (*Lepomis macrochirus*)	14	UC
Longear sunfish (*Lepomis megalotis*)	59	C
Redear sunfish (*Lepomis microlophus*)	13	UC
Redpotted sunfish (*Lepomis* miniatus)[c]	1	R
Spotted bass (*Micropterus punctulatus*)	7	UC
White crappie (*Pomoxis annularis*)	1	R

Table 5.6 (continued)

Species[a]	Number of specimens	Relative abundance[b]
Percidae		
Bluntnose darter (*Etheostoma chlorosomum*)	4	UC
Slough darter (*Etheostoma gracile*)	1	UC
TOTAL SPECIES	26	
TOTAL SPECIMENS	414	
CATCH PER EFFORT (FISH/MIN)	3.4	

[a]Common and scientific names according to the American Fisheries Society (Robins et al. 1991) and Etnier and Starnes (1993). Please refer to Sect. 6 of this document for full references.

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

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

Note: Two electroshockers used for 194 m and 123 min. Species identifications were performed in the field and/or confirmed in the laboratory on preserved specimens collected during the surveys

construction activity and beaver control actions upstream in the watershed. This survey revealed the continued presence of a diverse fish community, with good representation of intolerant species and a range of trophic levels and feeding guilds. In order to monitor the possible impacts (e.g., from excess siltation associated with construction) on the fish communities, qualitative sampling will resume on a regular basis at LUK 4.3.

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 a low mean and total species richness in comparison with MAK 13.8 and BBK 12.5 (Fig. 5.1). There was only one sensitive species compared to six sensitive species at the Massac Creek reference site. The number of benthic insectivores were low, although other feeding guilds were similar to levels seen at MAK 13.8. The lower species richness, compared to reference sites, may be a result of thermal impacts associated with outfalls (e.g., K008). Although the temperatures may not

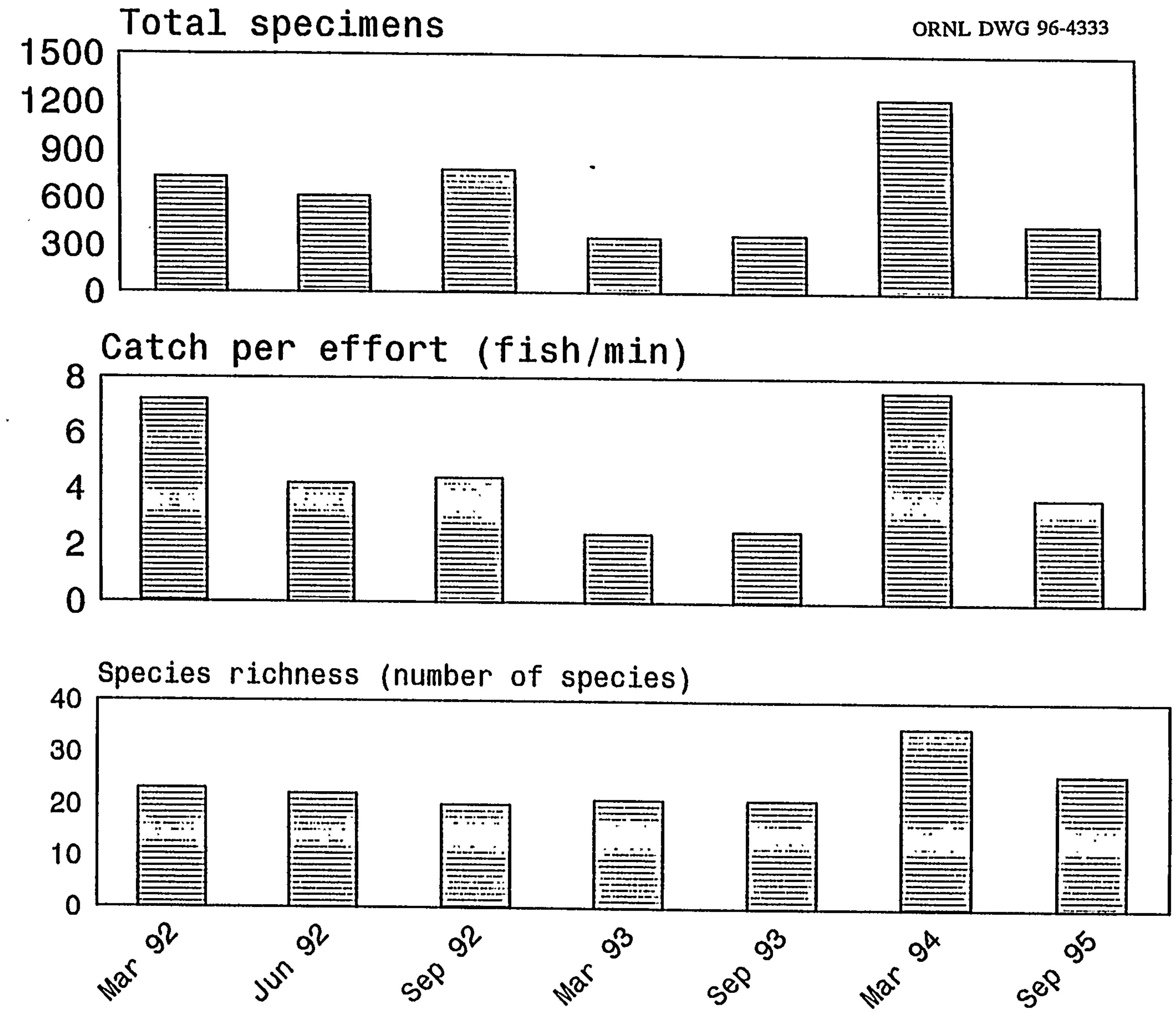

Fig. 5.4 Species richness, catch per effort, and total specimens at Little Bayou Creek qualitative site at kilometer (LUK) 4.3.

be lethal, they could produce avoidance of the areas of Big Bayou Creek near the plant outfalls (Roy et al. 1996). Density at BBK 10.0 was similar to or higher than that at the reference sites, with a correspondingly high biomass. Density and biomass were dominated (>80%) by one species, the herbivore stoneroller. This numerical dominance by a herbivorous species, combined with the low numbers of benthic insectivores, suggests possible nutrient enrichment at BBK 10.0 perhaps associated with discharges from Outfall K004. Compared to sampling results from 1993 and 1994, BBK 10.0 has experienced a rebound in biomass in September 1995 (Fig 5.1). Despite the increased biomass, a spring to spring production estimate indicated declining productivity at BBK 10.0 (Fig 5.3). If the rebounding density and biomass values observed in the fall 1995 sample continue through 1996, then an increase would be expected in productivity. The influence of other contaminants (e.g., heavy metals) from upstream outfalls may account for a small part of the impact. A few exceedances for zinc, copper, and/or cadmium were noted for the nearest upstream outfalls (C. C. Travis, LMES, personal communication) for 1992 through 1995. The extent of metal impacts would be extremely hard to separate from other possible factors. Toxicity tests showed only 4 possible toxic episodes out of 33 tests at the nearest outfall, K008 (Table 3.3). 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 impact but at less severe levels 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. The tolerant species were common and abundant. Density was less than or equal to that at MAK 13.8, and species richness was slightly increased (Fig 5.1) from 1993. As with BBK 10.0, productivity estimates have shown a substantial decline from 1992–93 to 1994–95 (Fig. 5.3). This four-fold decrease indicates some impacts on recruitment success for the fish community at BBK 9.1. The possible causes for this minor impact could include slight increases in the temperature or nutrient levels resulting from outfall discharges. The influence of other contaminants (e.g., heavy metals) from upstream outfalls may not account for much of the impact. No exceedances for heavy metals were noted for the nearest upstream outfalls (C. C. Travis, LMES, personal communication) for 1992 through 1995. Also, toxicity tests showed only 4 possible toxic episodes out of 33 tests at the nearest outfall, K001 (Table 3.3).

The fish community at LUK 7.2 was similar to the BBK 12.5 reference, with perhaps some species deficiencies. The mean species richness values were similar to those of the reference site and had rebounded substantially from a low point in fall 1994 (Fig 5.2). Density and biomass also reached near record levels for this site in September 1995. Unlike conditions in Big Bayou Creek sites, productivity did not show a consistent decline (Fig 5.3).

The downstream qualitative site, LUK 4.3, did not appear to be affected by plant operations. Species richness was higher (Fig 5.4) than that found in earlier sampling (1992–93), particularly in terms of sensitive species. 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 5.4). Thus, the community at LUK 4.3 appeared to be minimally affected by PGDP operations.

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 closest to 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 identify causative agents, a network of temperature recorders will continue to be deployed at sampling sites to evaluate possible thermal impacts. As a further investigative tool, qualitative surveys will be made in Massac Creek and other area streams, such as Humphrey Creek. These surveys will help to determine whether the fauna in Big Bayou Creek watershed is depressed compared with regional levels.

5.2 BENTHIC MACROINVERTEBRATES (*M.R. Smith*)

5.2.1 Introduction

Analysis of benthic macroinvertebrate data collected from March and September sampling periods from September 1991 through March 1994 indicated substantial temporal variation present at most sites (Smith 1995). While there was no strong evidence of impact at the two Big Bayou Creek sites (BBK 9.1 and BBK 10.0), some evidence suggested an impoverished benthic community at the Little Bayou Creek site (LUK 7.2), when compared with the reference sites.

This report includes the results from an additional year of samples from the September 1994 and March 1995 sampling periods. Additionally, December samples collected from 1992 to 1994, which were not processed for the previous reports, are included in the present analyses to help distinguish between natural variations present in benthic communities and any influence from the PGDP.

The objectives of the benthic macroinvertebrate monitoring task are to assess the ecological condition of two streams receiving effluents from the PGDP and document any temporal changes in macroinvertebrate community composition that may result from pollution abatement programs and/or changes in operations at the PGDP.

5.2.2 Materials and Methods

Benthic macroinvertebrate samples have been collected quarterly (March, June, September, and December) 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). Samples from each quarter were processed during the first sample year (September 1991–March 1992) to provide baseline information, while only samples taken during September and March of the following years were processed for the previous report (Kszos et al. 1995). In addition to processing the September 1994 and March 1995 samples for inclusion in this report, samples taken during December from 1992 to 1994 were processed to determine whether data from this additional sampling period would provide further resolution of spatial differences. Thus, sample year two included data from September and December 1992 and March 1993, sample year three included September and December 1993 and March 1994, and sample year four included data from September and December 1994 and March 1995. Samples from June remain archived and are being maintained according to proscribed procedures (Smith 1992), and will not be processed unless further resolution of results is needed.

Because riffle areas of streams generally possess the greatest variety of benthic organisms, including those considered to be sensitive to stress (Platts et al. 1983), samples were collected from riffles only. The locations of sampling sites were based not only on their proximity to major effluent discharges but also on the presence, similarity, and quality of riffle habitat.

At each site, three random samples were taken with a Surber sampler (0.09 m^2) equipped with a 363-μm mesh net. Samples were placed in pre-labeled, polyurethane-coated, glass jars and preserved with ~80% ethyl alcohol (ETOH). To prevent sample decomposition, the ETOH in each jar was replaced within 7 days of collection. Immediately prior to sample collection, dissolved oxygen, conductivity, temperature, and pH were measured with a Horiba U-7 Water Quality Checker. Qualitative measurements of selected physical attributes (distance from a permanent headstake at the base of the riffle, substrate size and embeddedness, flow rate, and water depth) were visually determined for each sample before collection. A detailed description of procedures employed for site evaluation and sample collection, storage, and maintenance can be found in Wojtowicz and Smith (1992).

Laboratory processing consisted of washing the samples in a U.S. Standard No. 60-mesh (250-μm openings) sieve, placing a small portion of the sample in a white, water-filled tray, and then removing organisms from the debris. This process was repeated with the remaining sample until all organisms were removed. Organisms were then identified to the lowest practical taxon and enumerated. Details of laboratory sample processing are available in Wojtowicz and Smith (1992).

Data analysis was performed with the aid of Statistical Analysis System software and procedures (SAS 1985a, 1985b). Density, total taxonomic richness, and EPT richness (the total number of Ephemeroptera, Plecoptera, and Trichoptera) were statistically analyzed by two-way ANOVA with site and date as the main effects, and $p < 0.05$ being considered statistically significant. Prior to performing the ANOVAs, values for each metric were transformed (i.e. $\log_{10}[X+1]$) for density values, and square root of $X+0.5$ for both total and EPT richness values, where X = the individual observed values for density, taxonomic richness, and EPT richness; Elliot 1977). Linear regressions to estimate site-specific seasonal trends were performed for each metric, and slopes were analyzed to look for significant ($p <$ 0.05) differences from a zero slope. The general model used was $y = a + mx$; where y = metric analyzed, a = constant, m = slope, and x = time. Regression analysis is useful in identifying changes in trends over time; however, unusual values at the beginning or end of the period considered may affect the results.

5.2.3 Results

5.2.3.1 Taxonomic composition

A list of benthic macroinvertebrate taxa collected at each site from September 1991 through March 1995 is presented in Appendix E, Table E.1. Taxonomic composition continued to be similar at all sites through March 1995, with few changes in composition resulting from the inclusion of the December sampling periods. As was the case in the previous 3 sampling years, oligochaetes (aquatic worms) continued to be collected at all sites during sampling year 4. There were generally more Ephemeroptera taxa at the Big Bayou Creek sites than at LUK 7.2 or MAK 13.8, and those taxa (*Caenis* and *Baetis*) that were present at all sites in sampling years 1–3 were also present at all sites in sampling year 4.

LUK 7.2 had four additional Plecoptera taxa present (*Allocapnia*; *Haploperla*; *Isoperla*; and an unidentified taxon of Perlodidae) with the inclusion of the additional data; three of the four Plecoptera taxa were collected during the December 1992 sampling date only, while the fourth taxon, *Allocapnia*, was present in both December 1992 and March 1995 sampling periods. The new data resulted in the addition of only one additional plecopteran to the list for each remaining site.

Composition of Trichoptera (caddisflies) taxa was generally similar at all sites, with Hydropsychidae and Philopotamidae taxa being present at all sites throughout most of the study period.

Two Coleoptera (beetle) taxa, *Berosus* and *Stenelmis* were common at all sites, while other taxa within this order had more disparate temporal and/or spatial distributions.

The order Diptera (true flies) had several taxa that were fairly ubiquitous. The four major groups representing the midge family Chironomidae (Chironomini, Orthocladiinae, Tanypodinae, and Tanytarsini) were present at all sites over all sampling years, and *Simulium* and *Hemerodromia* were common at all sites during most sampling years. The other dipteran taxa were more irregular in their occurrence.

Other taxonomic groups were present at some or all sites, with taxa such as Nemertea, Planariidae, and Hydracarina being occasionally present at most sites, whereas Nematomorpha, *Hyallela azteca*, and Odonata were rarely collected.

5.2.3.2 Abundance

Total density. Mean densities (number of organisms/0.1 m^2) for each site and sampling period from September 1991 through March 1995 are presented in Fig. 5.5. BBK 9.1 exhibited the highest macroinvertebrate densities on 7 of the 13 sampling dates, although densities were significantly ($p < 0.05$) higher at BBK 9.1 than one or both reference sites (BBK 12.5 and MAK 13.8) on only 5 occasions, 4 of which were in the first 2 sampling years. BBK 9.1 exhibited substantial increases in densities from December 1991 to March 1992 and again from March 1994 to December 1994, primarily from large numbers of *Simulium* (Simuliidae: Diptera) and Orthocladiinae (Chironomidae: Diptera) in March 1992, and Tanytarsini and Chironomini (Chironomidae: Diptera) in December 1994. However, unlike the March 1992 event, a similar peak was not observed at BBK 10.0 in December 1994. Although BBK 10.0 and LUK 7.2 generally fell within the range of densities exhibited by the reference sites, total density at LUK 7.2 increased substantially in March 1995 and was significantly higher than both BBK 12.5 and MAK 13.8.

Results of two-way ANOVA on densities are presented in Table 5.7, and indicate that the patterns of change were significantly different among two or more sites across years in each of the three sampling seasons (spring=March, fall=September, and winter=December).

The results of a regression analysis performed on densities are presented in Table 5.8. BBK 10.0 was the only site where the slope of density vs time differed significantly ($p < 0.05$) from zero during each sampling season. Densities declined at BBK 10.0 from 1336.9 organisms/0.1 m^2 in September 1991 to 19.76 organisms/0.1 m^2 in March 1995. BBK 9.1 and BBK 12.5 exhibited no detectable significant trends during any season, whereas LUK 7.2 and MAK 13.8 both exhibited significant trends only across the winter sampling periods. The positive slope at LUK 7.2 across the winter sampling periods suggests that the abundances of one or more populations comprising the community at this site was increasing during this season, while the negative slope at BBK 10.0 suggests the opposite.

Relative abundance. The percent composition of five selected major categories of benthic macroinvertebrates at each of the five study sites is presented in Fig. 5.6. Because EPT taxa are generally considered to be intolerant to pollutants (e.g., Lenat 1988), comparing the relative abundance of these organisms to relatively tolerant taxa (e.g., Chironomidae and oligocheates) may aid in determining the ecological condition of a site, when compared to an appropriate reference. The three sites on Big Bayou Creek exhibited substantial temporal

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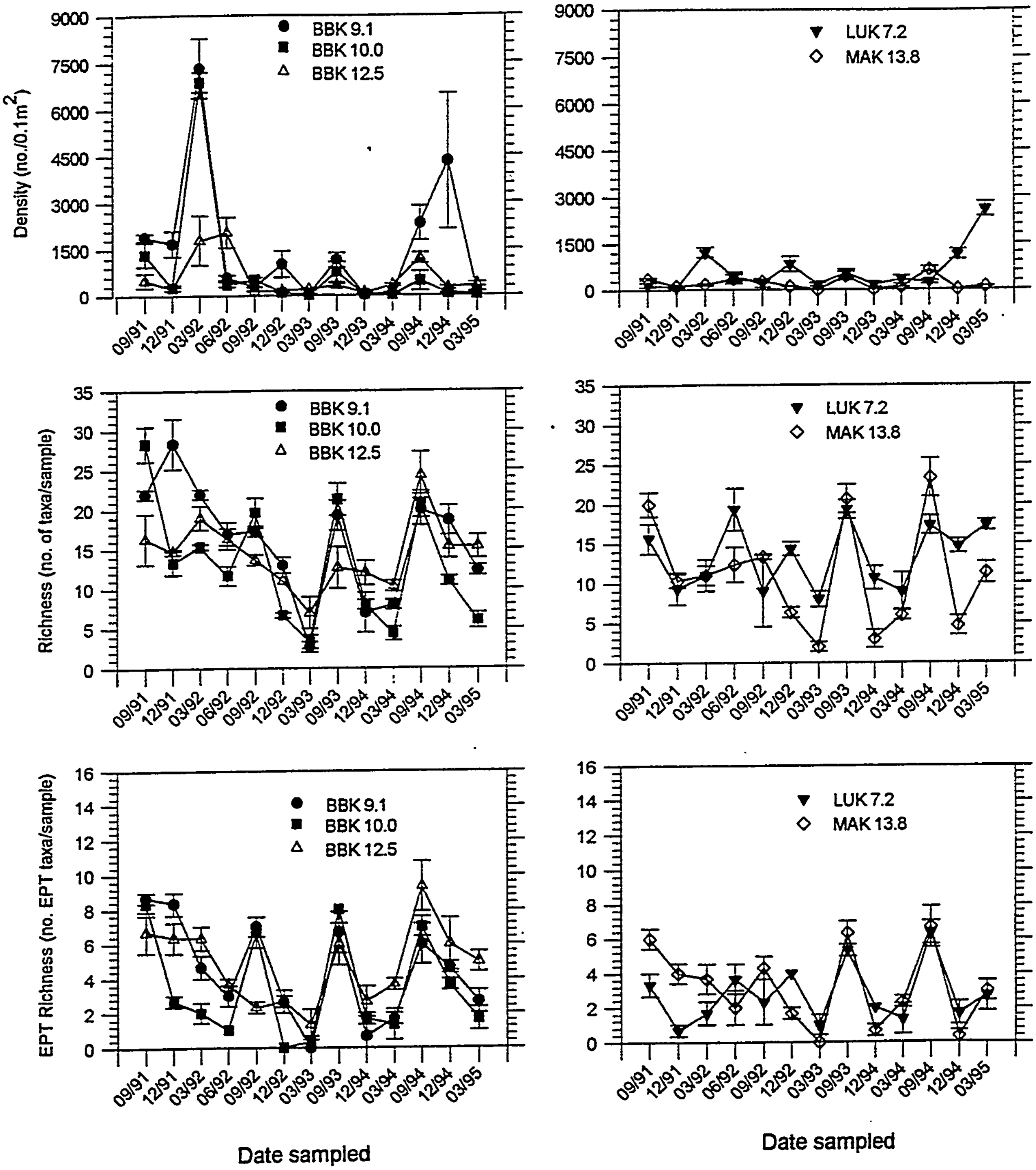

Fig. 5.5. Mean total density, mean total taxonomic richness, and mean richness of the Ephemeroptera, Plecoptera, and Trichoptera (EPT richness) of the benthic macroinvertebrate communities in Big Bayou Creek, Little Bayou Creek, and Massac Creek, September 1991 to March 1995. Vertical bars are ± 1 SE. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

Table 5.7. Two-way ANOVA statistics for 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 from September 1991 to March 1995

$p < 0.05$ is considered statistically significant

Comparison/Source of variation	df[a]	Density		Total Richness		EPT Richness	
		f - value	*p* - value	*f* - value	*p* - value	*f* - value	*p* - value
ALL SITES[b]							
Spring							
Site	4,40	51.43	0.0001	17.54	0.0001	8.52	0.0001
Sample Year	3,40	160.33	0.0001	82.56	0.0001	25.13	0.0001
Site X Sample Year	12,40	18.88	0.0001	5.64	0.0001	1.33	0.2401
Fall							
Site	4,40	13.50	0.0001	6.97	0.0002	8.95	0.0001
Sample Year	3,40	9.56	0.0001	9.76	0.0001	9.85	0.0001
Site X Sample Year	12,40	3.42	0.0017	2.31	0.0238	2.96	0.0050
Winter							
Site	4,40	29.93	0.0001	31.38	0.0001	16.98	0.0001
Sample Year	3,40	33.43	0.0001	22.13	0.0001	18.63	0.0001
Site X Sample Year	12,40	9.10	0.0001	6.63	0.0001	11.17	0.0001

[a]df = degrees of freedom.
[b]Spring = March; fall = September; winter = December.

Table 5.8. Results of regression analyses for density, total richness, and richness of the Ephemeroptera, Plecoptera, and Trichoptera (EPT) for the benthic macroinvertebrate communities in Big Bayou Creek, Little Bayou Creek, and Massac Creek from September 1991 to March 1995

Season[a,b]	Density				Total richness				EPT richness			
Spring	df	r^2	Slope	p -value	df	r^2	Slope	p -value	df	r^2	Slope	p -value
BBK 9.1	110	0.31	-2.1	0.0619	110	0.06	-0.779	0.4541	110	0.02	-0.45	0.6597
BBK 10.0	110	0.48	-3.06	0.012	110	0.3	-2.074	0.0649	110	0	0.03	0.9795
BBK 12.5	110	0.29	-2	0.0732	110	0.01	-0.353	0.7313	110	0	-0.02	0.9826
LUK 7.2	110	0.06	0.824	0.4293	110	0.24	1.763	0.1084	110	0.06	0.82	0.4296
MAK 13.8	110	0.01	0.303	0.7682	110	0.03	0.522	0.6131	110	0.01	0.32	0.7549
Fall												
BBK 9.1	110	0.05	0.757	0.4666	110	0.03	-0.562	0.5867	110	0.34	-2.26	0.0472
BBK 10.0	110	0.34	-2.249	0.0483	110	0.28	-1.963	0.078	110	0.06	-0.8	0.4403
BBK 12.5	110	0.29	2.027	0.0701	110	0.17	1.427	0.184	110	0.18	1.46	0.1744
LUK 7.2	110	0.17	1.424	0.1848	110	0.09	1.01	0.3362	110	0.39	2.53	0.0298
MAK 13.8	110	0.3	2.052	0.0673	110	0.19	1.518	0.16	110	0.08	0.96	0.3579
Winter												
BBK 9.1	110	0.03	-0.505	0.6242	110	0.17	-1.445	0.1791	110	0.18	-1.48	0.1699
BBK 10.0	110	0.5	-3.143	0.0105	110	0.03	-0.595	0.5654	110	0.11	1.13	0.2849
BBK 12.5	110	0.01	-0.285	0.7814	110	0.02	0.41	0.6905	110	0	-0.21	0.8414
LUK 7.2	110	0.37	2.43	0.0354	110	0.21	1.624	0.1354	110	0.03	0.52	0.6147
MAK 13.8	110	0.49	-3.101	0.0112	110	0.49	-3.08	0.0116	110	0.78	-5.91	0.0001

[a]Spring = March; fall = September; winter = December.
[b]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.
Note: p- value indicates the probability that the slope is different from zero with $p < 0.05$ being significant.

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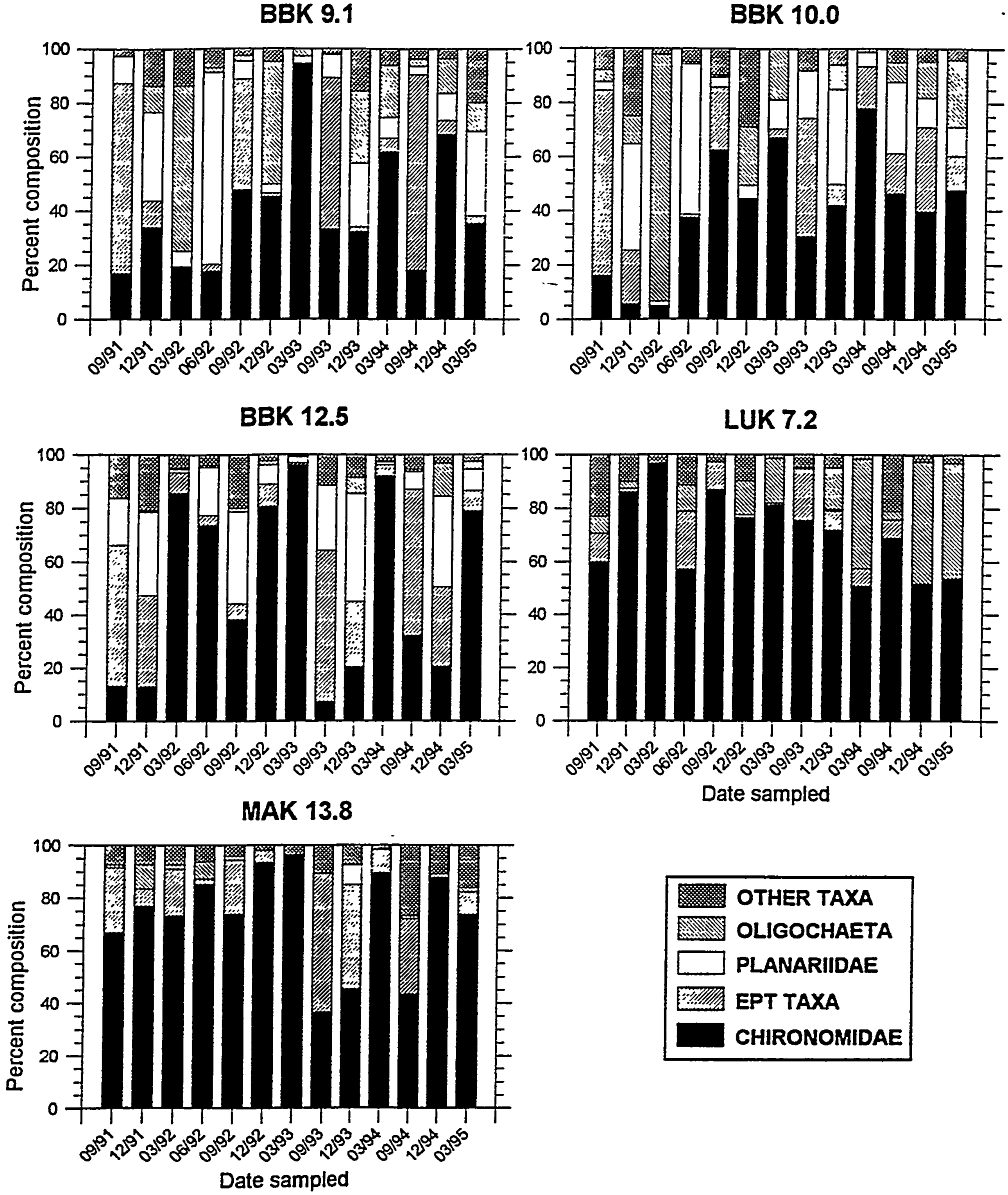

Fig. 5.6. Mean relative abundance (i.e., percent density) of selected benthic macroinvertebrate taxa in Big Bayou Creek, Little Bayou Creek, and Massac Creek, September 1991 to March 1995. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

variations in relative abundances of the major taxa. EPT taxa were generally at their highest relative abundances during September and December, and at their lowest during March. Conversely, Chironomidae taxa were generally at their greatest abundance during the March sampling period, and lowest in September and December.

At both BBK 9.1 and BBK 10.0, Chironomidae taxa were the most abundant organisms on 8 of the 13 dates sampled, with EPT taxa being most abundant on 3 and 2 sampling dates, respectively. Planariidae and oligocheates each made considerable contributions to total densities at both BBK 9.1 and BBK 10.0 on several dates. Planariidae were most abundant at BBK 10.0 during December 1991 and at both BBK 9.1 and BBK 10.0 during June 1992, while oligocheates were most abundant at both BBK 9.1 and BBK 10.0 during March 1992. Chironomidae were the most abundant on the majority of sampling dates at BBK 12.5, with EPT taxa being the most abundant taxa on four dates. As was the case with the other BBK sites, Planariidae made substantial contributions to total densities at BBK 12.5, being most abundant on two sampling dates. Oligocheates, on the other hand, were a relatively minor portion of the total number of organisms at BBK 12.5, never exceeding more than 13% of the total density.

Chironomidae were the most abundant taxa at LUK 7.2 on all dates, contributing at least 50% of the total densities. EPT taxa contributed from less than 1% to ~22% of the total densities, exceeding 5% on seven dates, while Planariidae never contributed over 0.2% of the total densities. Oligocheate contributions ranged from 0% to over 45% of total densities.

As was the case at the other sites, Chironomidae were the most abundant taxa at the reference site on Massac Creek (MAK 13.8) on the majority of sampling dates (>50% 10 of 13 dates). EPT taxa contributions ranged from 0% to ~ 53% of the total densities, exceeding 5% on 9 of 13 sampling dates, and was the most abundant taxa on one date. Planariidae were only collected on two dates, with contributions of ~0.1% and ~7.5% of the total, while oligocheates were collected on seven sampling dates , and never contributed over 10% of the total densities.

5.2.3.3 Taxonomic richness

Total Richness. Total richness values for BBK 9.1, BBK 10.0, and LUK 7.2 generally fell within the range exhibited by the reference sites (Fig. 5.5). No site consistently had the highest total richness value, with BBK 9.1, BBK 10.0, and BBK 12.5 each having the highest total richness level on three dates. Similarly, LUK 7.2 had the highest total richness level on four dates and the lowest values on four sampling dates. Total richness values at MAK 13.8 never exceeded those of the other sites on any sampling date, while total richness at this site was the lowest of all sites on 5 of the 13 sampling dates. Two-way ANOVA results indicated that the patterns of change at some or all sites were significantly different when all sites were analyzed together (Table 5.7). Except for MAK 13.8, the regression analysis was unable to detect any significant departures from a zero slope in any season (Table 5.8). MAK 13.8 experienced a significant negative slope during the winter sampling dates suggesting that total richness at this site during December may have declined some during the study.

EPT Richness. Mean EPT richness values from September 1991 to March 1995 are presented in Fig. 5.5. Values at BBK 9.1 fell within the range of the reference sites, or were higher, on 9 of 13 sampling dates, and BBK 9.1 had the lowest EPT richness values of any site on 2 sampling dates. Although BBK 10.0 had the highest EPT richness value on only one sampling date, values were generally within the range exhibited by the reference sites or exceeded them on seven sampling dates. BBK 10.0 had the lowest EPT richness values on 4 of the 13 sampling dates.

Over entire study period, EPT richness at LUK 7.2 either fell within the range of the reference sites' values or had higher values on five occasions. Two-way ANOVA results indicated that the pattern of change in EPT richness among sites was significantly different at some sites in both fall and winter, but was not significant during the spring (Table 5.7). Regression analysis indicated that no site changed significantly during spring, while in the fall, EPT richness declined at BBK 9.1 and increased at LUK 7.2 (Table 5.8). MAK 13.8 was the only site to change over the winter sampling dates, where it exhibited a significant decline in EPT richness.

5.2.4 Discussion

The occasional substantial increases in densities at BBK 9.1 may be the result of a sustained period of habitat stability or a short-term increase in nutrient availability. Although BBK 9.1 had substantially higher densities compared to the reference sites on four occasions, during the majority of the period covered in this report, no site was consistently different from the other sites. Regression analyses indicated that only BBK 10.0 had a significant negative trend in densities during each sampling season. However, during the period covered in this report BBK 10.0 generally fell within the range exhibited by the reference sites. Data from future collections should determine whether this is a sustained trend or natural variation. Likewise, additional data will be needed to determine whether the positive trend in densities identified in the Winter samples at LUK 7.2 by regression analysis, in addition to the high densities in March 1995, indicate community improvement or seasonal variation. Total taxonomic richness values were generally similar at all sites, and although total richness values exhibited substantial seasonal variation, regression analysis indicated that neither BBK 9.1, BBK 10.0, or LUK 7.2 was experiencing any significant changes over the period of time analyzed. Regression analysis indicated that BBK 9.1 and LUK 7.2 exhibited significant changes in trends for EPT richness in fall samples, although values were generally within the range exhibited by the reference sites.

There were no consistent spatial or temporal trends evident in mean values or statistical analyses that provided strong evidence of major impacts to the community parameters evaluated at BBK 9.1, BBK 10.0, or LUK 7.2. However, the inability to detect statistically significant trends from the available data does not necessarily indicate that significant differences do not exist between the sites. The considerable spatial and temporal variability present in the data may have masked subtle impacts. However, the lack of measurable impacts to the benthic macroinvertebrate communities combined with the results of the ambient toxicity monitoring (Sect. 3) tend to suggest that the effluents from PGDP are causing no negative impacts to the benthic macroinvertebrate communities.

It should also be noted that, although exceedances for metals such as zinc and copper have been reported (Sect. 2), there appears to have been no measurable impact on those benthic macroinvertebrate taxa generally considered to be most sensitive to these substances (i.e., EPT taxa). Because the addition of the December data provided little additional information, sample collection will be reduced from quarterly to twice annually (March and September) beginning in 1996.

Finally, there were substantial differences between the two sites used as references (BBK 12.5 and MAK 13.8). When reference sites for this project were initially selected, 24 sites on 13 separate streams were considered (Loar 1991, unpublished data). Of these 24 sites, MAK 13.8 and BBK 12.5 were considered to be the most similar to the sites receiving PGDP effluents. Because relatively undisturbed stream communities are seldom identical, having more than one reference site is necessary for more realistic comparisons with potentially impacted sites. In an effort to minimize the effects of differences between reference sites, a survey of streams near the PGDP will be conducted in April 1996 in an effort to identify additional reference sites.

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Appendix A

SUMMARY STATISTICS FOR WATER QUALITY PARAMETERS AT KPDES PERMITTED OUTFALLS

Table A.1 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 001 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K001	ANION	Total Residual Chlorine	mg/L	12		0.0000	0.0000	0.0000
K001	MICP	Aluminum	mg/L	12		0.6850	0.3120	1.5890
K001	MICP	Cadmium	mg/L	12	<	0.0010	0.0010	0.0010
K001	MICP	Copper	mg/L	12	<	0.0130	0.0060	0.0250
K001	MICP	Hexavalent Chromium	mg/L	12	<	0.0100	0.0100	0.0100
K001	MICP	Iron	mg/L	12		0.4390	0.2400	1.0890
K001	MICP	Lead	mg/L	12	<	0.0030	0.0030	0.0060
K001	MICP	Nickel	mg/L	12	<	0.0460	0.0250	0.1000
K001	MICP	Phosphorus (P)	mg/L	12		0.2510	0.1960	0.3130
K001	MICP	Uranium	mg/L	12		0.0170	0.0020	0.0500
K001	MICP	Zinc	mg/L	12	<	0.0140	0.0080	0.0200
K001	PHYSC	Flow	MLD	12		8.7850	6.2982	12.8122
K001	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	12		313.1170	211.5000	412.8000
K001	PHYSC	pH	SU	12		8.3083	7.4000	9.4000
K001	PHYSC	Temperature	Deg. F	12		66.8750	48.2000	87.8000
K001	PHYSC	Total Suspended Solids	mg/L	12		20.1290	8.0000	39.6000
K001	PPCB	PCB	µg/L	12		0.0000	0.0000	0.0000
K001	RADS	Suspended Alpha[c]	pCi/L	6		5.6400	-3.0000	34.6400
K001	RADS	Suspended Beta	pCi/L	6		5.2170	1.0000	19.5000
K001	RADSD	Dissolved Alpha[c]	pCi/L	6		8.6800	-1.2000	32.6300
K001	RADSD	Dissolved Beta	pCi/L	6		36.6970	17.0000	64.1800
K001	SVOA	Acetone	mg/L	12	<	1.0000	1.0000	1.0000
K001	SVOA	Isopropanol	mg/L	12	<	1.0000	1.0000	1.0000
K001	SVOA	Oil and Grease	mg/L	12	<	4.4330	1.2000	5.0000
K001	VOA	Trichloroethene	mg/L	12	<	0.0010	0.0010	0.0010

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

[c]Sample result less than backgkround.

Table A.2 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 002 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K002	ANION	Total Residual Chlorine	mg/L	12		0.0000	0.0000	0.0000
K002	MICP	Aluminum	mg/L	12		2.0810	0.3900	5.9500
K002	MICP	Cadmium	mg/L	12	<	0.0010	0.0010	0.0010
K002	MICP	Chromium	mg/L	12	<	0.0100	0.0060	0.0110
K002	MICP	Copper	mg/L	12	<	0.0160	0.0120	0.0340
K002	MICP	Iron	mg/L	12		1.5710	0.4240	3.6000
K002	MICP	Lead	mg/L	12	<	0.0040	0.0030	0.0150
K002	MICP	Nickel	mg/L	12	<	0.0500	0.0500	0.0500
K002	MICP	Phosphorus (P)	mg/L	12		0.2690	0.1400	0.4400
K002	MICP	Uranium	mg/L	4		0.0080	0.0020	0.0210
K002	MICP	Zinc	mg/L	12		0.0630	0.0150	0.4600
K002	PHYSC	Flow	MLD	12		1.5821	0.0114	13.5882
K002	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	12		97.0830	44.0000	131.0000
K002	PHYSC	pH	SU	12		7.9333	7.1000	8.9000
K002	PHYSC	Temperature	Deg. F	12		66.4170	45.0000	92.0000
K002	PHYSC	Total Suspended Solids	mg/L	12		26.9170	4.0000	72.0000
K002	PPCB	PCB	µg/L	12		0.0000	0.0000	0.0000
K002	RADS	Suspended Alpha[c]	pCi/L	4		0.6750	-1.0000	1.6000
K002	RADS	Suspended Beta[c]	pCi/L	4		0.5000	-3.0000	3.0000
K002	RADSD	Dissolved Alpha	pCi/L	4		2.9250	0.0000	8.1000
K002	RADSD	Dissolved Beta	pCi/L	4		5.7500	0.0000	12.0000
K002	SVOA	Oil and Grease	mg/L	12	<	5.2750	5.0000	8.3000
K002	VOA	Trichloroethene	mg/L	12	<	0.0010	0.0010	0.0010

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

[c]Sample results less than background.

Table A.3 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 004 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K004	PHYSC	BOD	mg/L	12		9.2920	2.5000	15.5000
K004	PHYSC	Fecal Coliform	#/100mL	12		12.7020	0.0000	30.9350
K004	PHYSC	Flow	MLD	12		1.1696	0.8819	1.6162
K004	PHYSC	pH	SU	12		6.9000	6.3000	7.3000

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

Table A.4 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 006 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K006	ANION	Total Residual Chlorine	mg/L	12		0.0000	0.0000	0.0000
K006	MICP	Aluminum	mg/L	12		0.5400	0.3100	0.8330
K006	MICP	Cadmium	mg/L	12	<	0.0009	0.0005	0.0010
K006	MICP	Chromium	mg/L	12	<	0.0092	0.0060	0.0110
K006	MICP	Copper	mg/L	12	<	0.0123	0.0060	0.0250
K006	MICP	Iron	mg/L	12		0.7381	0.3370	1.1450
K006	MICP	Lead	mg/L	12	<	0.0029	0.0016	0.0040
K006	MICP	Nickel	mg/L	12	<	0.0437	0.0250	0.1000
K006	MICP	Phosphorus (P)	mg/L	12		0.0869	0.0340	0.1680
K006	MICP	Zinc	mg/L	12	<	0.0131	0.0080	0.0300
K006	PHYSC	Flow	MLD	12		3.3104	2.2521	4.5382
K006	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	12		61.0417	54.5000	71.0000
K006	PHYSC	pH	SU	12		8.9917	8.6000	9.4000
K006	PHYSC	Total Suspended Solids	mg/L	12		15.6333	5.0000	25.5000
K006	PPCB	PCB	μg/L	12		0.0000	0.0000	0.0000
K006	SVOA	Oil and Grease	mg/L	12	<	4.4665	1.0600	6.1630

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

Table A.5 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 008 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K008	ANION	Total Residual Chlorine	mg/L	12		0.0000	0.0000	0.0000
K008	MICP	Aluminum	mg/L	12	<	0.3313	0.1560	0.7000
K008	MICP	Cadmium	mg/L	12	<	0.0009	0.0005	0.0010
K008	MICP	Chromium	mg/L	12	<	0.0092	0.0060	0.0110
K008	MICP	Copper	mg/L	12	<	0.0107	0.0000	0.0200
K008	MICP	Iron	mg/L	12		0.2888	0.1800	0.8050
K008	MICP	Lead	mg/L	12	<	0.0039	0.0030	0.0130
K008	MICP	Nickel	mg/L	12	<	0.0437	0.0250	0.1000
K008	MICP	Phosphorus (P)	mg/L	12		0.4895	0.3800	0.6050
K008	MICP	Uranium	mg/L	12		0.0098	0.0020	0.0220
K008	MICP	Zinc	mg/L	12		0.0310	0.0170	0.0540
K008	PHYSC	Flow	MLD	12		2.8191	2.0704	4.2846
K008	PHYSC	pH	SU	12		7.0000	6.6000	7.3000
K008	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	12		60.3000	52.0000	69.2000
K008	PHYSC	Temperature	Deg. F	12		70.1833	54.2000	87.8000
K008	PHYSC	Total Suspended Solids	mg/L	12		5.2667	2.4000	12.5000
K008	PPCB	PCB	µg/L	12		0.0000	0.0000	0.0000
K008	RADS	Suspended Alpha[c]	pCi/L	5		7.7540	-3.0000	39.4700
K008	RADS	Suspended Beta	pCi/L	5		6.7220	0.0000	13.6100
K008	RADSD	Dissolved Alpha[c]	pCi/L	5		8.7860	-0.6000	29.2300
K008	RADSD	Dissolved Beta	pCi/L	5		35.2740	9.0000	117.0000
K008	SVOA	Oil and Grease	mg/L	12	<	5.0000	5.0000	5.0000
K008	VOA	Trichloroethene	mg/L	12	<	0.0010	0.0010	0.0010

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

[c]Sample results less than background.

Table A.6 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 009 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K009	ANION	Total Residual Chlorine	mg/L	12		0.0000	0.0000	0.0000
K009	MICP	Aluminum	mg/L	12		0.4627	0.2650	1.0800
K009	MICP	Cadmium	mg/L	12	<	0.0010	0.0005	0.0020
K009	MICP	Chromium	mg/L	12	<	0.0092	0.0060	0.0110
K009	MICP	Copper	mg/L	12	<	0.0105	0.0000	0.0170
K009	MICP	Iron	mg/L	12		0.5729	0.3200	0.7990
K009	MICP	Lead	mg/L	12	<	0.0024	0.0000	0.0040
K009	MICP	Nickel	mg/L	12	<	0.0444	0.0250	0.1000
K009	MICP	Phosphorus (P)	mg/L	12		0.1508	0.1000	0.2180
K009	MICP	Uranium	mg/L	12	<	0.0017	0.0010	0.0040
K009	MICP	Zinc	mg/L	12		0.0268	0.0120	0.0440
K009	PHYSC	Flow	MLD	12		1.4917	0.5034	9.4474
K009	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	12		62.6917	54.0000	79.6000
K009	PHYSC	pH	SU	12		7.3375	6.8000	7.9000
K009	PHYSC	Temperature	Deg. F	12		63.1500	42.8000	81.6000
K009	PHYSC	Total Suspended Solids	mg/L	12		6.2917	2.5000	10.6000
K009	PPCB	PCB	µg/L	12		0.0000	0.0000	0.0000
K009	RADS	Suspended Alpha[c]	pCi/L	5		0.1660	-3.0700	2.1000
K009	RADS	Suspended Beta	pCi/L	5		2.9860	0.0000	7.0000
K009	RADSD	Dissolved Alpha	pCi/L	5		2.3180	0.3000	5.0000
K009	RADSD	Dissolved Beta[c]	pCi/L	5		9.0200	-1.0000	22.0000
K009	SVOA	Oil and Grease	mg/L	12	<	5.0000	5.0000	5.0000
K009	VOA	Trichloroethene	mg/L	12	<	0.0010	0.0010	0.0010

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

[c]Sample results less than background.

Table A.7 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 010 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K010	ANION	Total Residual Chlorine	mg/L	12		0.0000	0.0000	0.0000
K010	MICP	Aluminum	mg/L	12		0.6306	0.3110	1.4600
K010	MICP	Cadmium	mg/L	12	<	0.0009	0.0005	0.0010
K010	MICP	Chromium	mg/L	12	<	0.0092	0.0060	0.0110
K010	MICP	Copper	mg/L	12	<	0.0103	0.0000	0.0130
K010	MICP	Iron	mg/L	12		0.6195	0.2650	1.1780
K010	MICP	Lead	mg/L	12	<	0.0029	0.0015	0.0030
K010	MICP	Nickel	mg/L	12	<	0.0421	0.0250	0.1000
K010	MICP	Phosphorus (P)	mg/L	12		0.3368	0.1980	0.4960
K010	MICP	Uranium	mg/L	12		0.0095	0.0030	0.0210
K010	MICP	Zinc	mg/L	12		0.0320	0.0080	0.0570
K010	PHYSC	Flow	MLD	12		2.3032	1.6124	3.8683
K010	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	12		71.6917	58.0000	97.5000
K010	PHYSC	pH	SU	12		7.6250	6.6000	9.0000
K010	PHYSC	Temperature	Deg. F	12		75.8417	59.4000	92.8000
K010	PHYSC	Total Suspended Solids	mg/L	12		15.2208	7.0000	30.7500
K010	PPCB	PCB	μg/L	12		0.0000	0.0000	0.0000
K010	RADS	Suspended Alpha[c]	pCi/L	5		1.2640	-2.5000	6.7200
K010	RADS	Suspended Beta[c]	pCi/L	5		5.8460	-2.0000	29.2300
K010	RADSD	Dissolved Alpha	pCi/L	5		17.1980	1.0000	75.5900
K010	RADSD	Dissolved Beta	pCi/L	5		18.8280	3.0000	40.1400
K010	SVOA	Oil and Grease	mg/L	12	<	5.0000	5.0000	5.0000
K010	VOA	Trichloroethene	mg/L	12	<	0.0010	0.0010	0.0010

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

[c]Sample results less than background.

Table A.8 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 011 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K011	ANION	Total Residual Chlorine	mg/L	12		0.0019	0.0000	0.0130
K011	MICP	Aluminum	mg/L	12		0.7413	0.3120	2.3000
K011	MICP	Cadmium	mg/L	12	<	0.0009	0.0005	0.0010
K011	MICP	Chromium	mg/L	12	<	0.0092	0.0060	0.0110
K011	MICP	Copper	mg/L	12	<	0.0126	0.0060	0.0260
K011	MICP	Iron	mg/L	12		0.6409	0.1780	1.9000
K011	MICP	Lead	mg/L	12	<	0.0040	0.0030	0.0110
K011	MICP	Nickel	mg/L	12	<	0.0465	0.0250	0.0500
K011	MICP	Phosphorus (P)	mg/L	12		0.1555	0.1000	0.2200
K011	MICP	Uranium	mg/L	12		0.1320	0.0150	0.3400
K011	MICP	Zinc	mg/L	12		0.0240	0.0150	0.0500
K011	PHYSC	Flow	MLD	12		0.3054	0.0076	1.2718
K011	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	12		85.6333	50.0000	160.0000
K011	PHYSC	pH	SU	12		8.0500	7.2000	9.9000
K011	PHYSC	Temperature	Deg. F	12		65.9750	43.0000	88.2000
K011	PHYSC	Total Suspended Solids	mg/L	12		9.8167	4.0000	23.0000
K011	PPCB	PCB	μg/L	12		0.0242	0.0000	0.2900
K011	RADS	Suspended Alpha[c]	pCi/L	4		1.6000	-1.6000	3.2000
K011	RADS	Suspended Beta	pCi/L	4		5.2500	2.0000	10.0000
K011	RADSD	Dissolved Alpha	pCi/L	4		48.7750	2.3000	137.8000
K011	RADSD	Dissolved Beta	pCi/L	4		24.5000	15.0000	32.0000
K011	SVOA	Oil and Grease	mg/L	12	<	5.2292	5.0000	7.7500
K011	VOA	Trichloroethene	mg/L	12		0.0098	0.0010	0.0650

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

[c]Sample results less than background.

Table A.9 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 012 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K012	ANION	Total Residual Chlorine	mg/L	11		0.0000	0.0000	0.0000
K012	MICP	Aluminum	mg/L	11		1.1830	0.3120	5.9000
K012	MICP	Cadmium	mg/L	11	<	0.0010	0.0005	0.0010
K012	MICP	Chromium	mg/L	11	<	0.0110	0.0060	0.0240
K012	MICP	Copper	mg/L	11	<	0.0140	0.0100	0.0260
K012	MICP	Iron	mg/L	11		1.3950	0.3400	6.6000
K012	MICP	Lead	mg/L	11	<	0.0030	0.0030	0.0070
K012	MICP	Nickel	mg/L	11	<	0.0470	0.0150	0.0500
K012	MICP	Phosphorus (P)	mg/L	11		0.2450	0.0900	1.0700
K012	MICP	Uranium	mg/L	4		0.0070	0.0040	0.0080
K012	MICP	Zinc	mg/L	11		0.0900	0.0160	0.2200
K012	PHYSC	Flow	MLD	11		4.0802	0.0643	40.6131
K012	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	11		127.2730	80.0000	270.0000
K012	PHYSC	pH	SU	11		7.4000	7.1000	7.7000
K012	PHYSC	Temperature	Deg. F	11		63.0910	44.0000	83.0000
K012	PHYSC	Total Suspended Solids	mg/L	11		32.6360	6.0000	248.0000
K012	PPCB	PCB	µg/L	12		0.0360	0.0000	0.2600
K012	RADS	Suspended Alpha[c]	pCi/L	4		1.3000	-0.3000	4.2000
K012	RADS	Suspended Beta[c]	pCi/L	4		3.2500	-3.0000	10.0000
K012	RADSD	Dissolved Alpha	pCi/L	4		4.7500	3.5000	5.5000
K012	RADSD	Dissolved Beta	pCi/L	4		10.7500	2.0000	34.0000
K012	SVOA	Oil and Grease	mg/L	11	<	5.0000	5.0000	5.0000
K012	VOA	Trichloroethene	mg/L	11	<	0.0010	0.0010	0.0010

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

[c]Sample results less than background.

Table A.10 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 013 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K013	MICP	Aluminum	mg/L	11		1.7910	0.3120	4.6200
K013	MICP	Cadmium	mg/L	11	<	0,0010	0.0005	0.0010
K013	MICP	Chromium	mg/L	11	<	0.0090	0.0060	0.0110
K013	MICP	Copper	mg/L	11	<	0.0130	0.0100	0.0190
K013	MICP	Iron	mg/L	11		1.4870	0.1860	3.6800
K013	MICP	Lead	mg/L	11	<	0.0030	0.0030	0.0030
K013	MICP	Nickel	mg/L	11	<	0.0910	0.0500	0.5000
K013	MICP	Uranium	mg/L	4		0.0030	0.0020	0.0030
K013	MICP	Zinc	mg/L	11		0.0270	0.0150	0.0790
K013	PHYSC	Flow	MLD	11		3.4444	0.0984	23.3913
K013	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	11		185.5450	50.0000	378.0000
K013	PHYSC	pH	SU	11		7.4546	7.1000	7.8000
K013	PHYSC	Total Suspended Solids	mg/L	11		21.1820	4.0000	77.0000
K013	PPCB	PCB	μg/L	11		0.0000	0.0000	0.0000
K013	RADS	Suspended Alpha[c]	pCi/L	4		0.1250	-3.0000	1.8000
K013	RADS	Suspended Beta	pCi/L	4		1.2500	0.0000	4.0000
K013	RADSD	Dissolved Alpha[c]	pCi/L	4		-0.6250	-8.7000	2.4000
K013	RADSD	Dissolved Beta	pCi/L	4		7.0000	0.0000	13.0000
K013	SVOA	Oil and Grease	mg/L	11	<	5.0450	5.0000	5.5000
K013	VOA	Trichloroethene	mg/L	11	<	0.0010	0.0010	0.0010

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

[c]Sample results less than background.

Table A.11 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 015 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K015	MICP	Aluminum	mg/L	10		1.1410	0.4140	2.2900
K015	MICP	Cadmium	mg/L	10	<	0.0010	0.0005	0.0010
K015	MICP	Chromium	mg/L	10	<	0.0090	0.0060	0.0110
K015	MICP	Copper	mg/L	10	<	0.0120	0.0100	0.0130
K015	MICP	Iron	mg/L	10		0.9620	0.4370	1.8600
K015	MICP	Lead	mg/L	10	<	0.0030	0.0030	0.0040
K015	MICP	Nickel	mg/L	10	<	0.0500	0.0500	0.0500
K015	MICP	Uranium	mg/L	10		0.1330	0.0300	0.3300
K015	MICP	Zinc	mg/L	10		0.0250	0.0150	0.0410
K015	PHYSC	Flow	MLD	10		1.0295	0.0265	3.4254
K015	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	10		146.4000	88.0000	190.0000
K015	PHYSC	pH	SU	10		7.6200	7.2000	8.0000
K015	PHYSC	Total Suspended Solids	mg/L	10		16.9000	4.0000	29.0000
K015	PPCB	PCB	μg/L	10		0.0000	0.0000	0.0000
K015	RADS	Suspended Alpha	pCi/L	4		3.6500	0.9000	6.5000
K015	RADS	Suspended Beta	pCi/L	4		5.2500	2.0000	9.0000
K015	RADSD	Dissolved Alpha	pCi/L	4		31.6000	2.9000	112.2000
K015	RADSD	Dissolved Beta	pCi/L	4		38.7500	25.0000	45.0000
K015	SVOA	Oil and Grease	mg/L	10	<	5.0000	5.0000	5.0000
K015	VOA	Trichloroethene	mg/L	10	<	0.0010	0.0010	0.0010

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

Table A.12 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 016 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K016	MICP	Aluminum	mg/L	10		0.8640	0.3120	2.3600
K016	MICP	Cadmium	mg/L	10	<	0.0010	0.0010	0.0010
K016	MICP	Chromium	mg/L	10	<	0.0090	0.0060	0.0110
K016	MICP	Copper	mg/L	10	<	0.0130	0.0100	0.0170
K016	MICP	Iron	mg/L	10		0.6010	0.2030	1.4600
K016	MICP	Lead	mg/L	10	<	0.0030	0.0030	0.0030
K016	MICP	Nickel	mg/L	10	<	0.0500	0.0500	0.0500
K016	MICP	Uranium	mg/L	4		0.0030	0.0020	0.0050
K016	MICP	Zinc	mg/L	10		0.0380	0.0170	0.0720
K016	PHYSC	Flow	MLD	10		0.1930	0.0189	1.0825
K016	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	10		171.2000	100.0000	272.0000
K016	PHYSC	pH	SU	10		7.6600	7.1000	8.2000
K016	PHYSC	Total Suspended Solids	mg/L	10		8.9000	4.0000	24.0000
K016	PPCB	PCB	µg/L	10		0.0000	0.0000	0.0000
K016	RADS	Suspended Alpha[c]	pCi/L	4		-0.7500	-4.2000	1.2000
K016	RADS	Suspended Beta[c]	pCi/L	4		-0.5000	-3.0000	3.0000
K016	RADSD	Dissolved Alpha[c]	pCi/L	4		-0.7750	-10.1000	2.8000
K016	RADSD	Dissolved Beta	pCi/L	4		12.0000	1.0000	32.0000
K016	SVOA	Oil and Grease	mg/L	10	<	5.0000	5.0000	5.0000
K016	VOA	Trichloroethene	mg/L	10	<	0.0010	0.0010	0.0010

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

[c]Sample results less than background.

Table A.13 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 017 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K017	MICP	Aluminum	mg/L	11		0.9690	0.3940	3.1000
K017	MICP	Cadmium	mg/L	11	<	0.0010	0.0010	0.0010
K017	MICP	Chromium	mg/L	11	<	0.0090	0.0060	0.0110
K017	MICP	Copper	mg/L	11	<	0.0120	0.0100	0.0120
K017	MICP	Iron	mg/L	11		0.8620	0.2570	2.8600
K017	MICP	Lead	mg/L	11	<	0.0030	0.0030	0.0030
K017	MICP	Nickel	mg/L	11	<	0.0500	0.0500	0.0500
K017	MICP	Uranium	mg/L	4		0.0040	0.0020	0.0060
K017	MICP	Zinc	mg/L	11		0.0230	0.0150	0.0420
K017	PHYSC	Flow	MLD	11		1.4269	0.0076	10.8251
K017	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	11		147.8180	68.0000	198.0000
K017	PHYSC	pH	SU	11		7.7636	7.5000	8.1000
K017	PHYSC	Total Suspended Solids	mg/L	11		13.3640	4.0000	35.0000
K017	PPCB	PCB	µg/L	11		0.0000	0.0000	0.0000
K017	RADS	Suspended Alpha[c]	pCi/L	4		-0.4500	-2.9000	0.9000
K017	RADS	Suspended Beta[c]	pCi/L	4		1.2500	-1.0000	4.0000
K017	RADSD	Dissolved Alpha[c]	pCi/L	4		1.4500	-4.2000	5.5000
K017	RADSD	Dissolved Beta	pCi/L	4		10.2500	3.0000	24.0000
K017	SVOA	Oil and Grease	mg/L	11	<	5.0000	5.0000	5.0000
K017	VOA	Trichloroethene	mg/L	11	<	0.0010	0.0010	0.0010

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

[c]Sample results less than background.

Table A.14 Water quality parameters measured at Kentucky Pollutant Discharge Elimination System Permitted Outfall 018 in 1995

Station	Anatype[a]	Analysis	Units	No. Observations	Qualifer[b]	Mean	Minimum	Maximum
K018	MICP	Aluminum	mg/L	11		55.5080	0.9050	530.0000
K018	MICP	Cadmium	mg/L	11	<	0.0010	0.0005	0.0000
K018	MICP	Chromium	mg/L	11	<	0.0120	0.0060	0.0300
K018	MICP	Copper	mg/L	11	<	0.0170	0.0000	0.0400
K018	MICP	Iron	mg/L	11		53.9990	0.7900	520.0000
K018	MICP	Lead	mg/L	11	<	0.0180	0.0030	0.1500
K018	MICP	Nickel	mg/L	11	<	0.0730	0.0500	0.3100
K018	MICP	Uranium	mg/L	11		0.0070	0.0020	0.0200
K018	MICP	Zinc	mg/L	11		0.0490	0.0200	0.1500
K018	PHYSC	Flow	MLD	11		6.4194	0.1211	35.9575
K018	PHYSC	Hardness as $CaCO_3$	mg/L $CaCO_3$	11		93.8180	44.0000	180.0000
K018	PHYSC	pH	SU	11		7.3909	5.8000	7.8000
K018	PHYSC	Total Suspended Solids	mg/L	11		717.4550	7.0000	6000.0000
K018	PPCB	PCB	µg/L	11		0.0000	0.0000	0.0000
K018	RADS	Suspended Alpha[c]	pCi/L	4		2.5750	-2.8000	9.3000
K018	RADS	Suspended Beta[c]	pCi/L	4		4.2500	-2.0000	14.0000
K018	RADSD	Dissolved Alpha[c]	pCi/L	4		6.1500	-2.7000	15.7000
K018	RADSD	Dissolved Beta	pCi/L	4		18.5000	12.0000	33.0000
K018	SVOA	Oil and Grease	mg/L	11	<	5.0000	5.0000	5.0000
K018	VOA	Trichloroethene	mg/L	11	<	0.0010	0.0010	0.0000

Note: Data provided by T. Brindley, Environmental Management, Paducah Gaseous Diffusion Plant.

[a]ANION = a negatively charged ion; MICP = metals by inductively coupled plasma/mass spectroscopy; PHYSC = physical and field measurements; PPCB = pesticides/polychlorinated biphenyls; RADS = radiochemical analysis; RADSD = radiochemical analysis, dissolved; SVOA = semivolatile organics; VOA = volatile organics.

[b]A "<" qualifier was added to the mean when ≥50% of the observations had "<" qualifiers.

[c]Sample results less than background.

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–October 1995

Date	Outfall	Concentration	Survival (%)		Growth (mg/larvae)	
			Mean	SD	Mean	SD
March 1995	Control	100	100.0	0.0	0.45	0.04
	001	6	95.0	10.0	0.56	0.06
		12	95.0	10.0	0.59	0.02
		25	97.5	5.0	0.56	0.02
		50	97.5	5.0	0.66	0.04
		100	97.5	5.0	0.67	0.05
	006	6	95.0	5.8	0.48	0.06
		12	100.0	0.0	0.57	0.03
		25	100.0	0.0	0.57	0.02
		50	100.0	0.0	0.57	0.01
		100	100.0	0.0	0.63	0.06
	008	6	70.0	46.9	0.56	0.03
		12	97.5	5.0	0.59	0.02
		25	97.5	5.0	0.53	0.04
		50	92.5	9.6	0.53	0.03
		100	90.0	14.1	0.51	0.03
	009	6	100.0	0.0	0.55	0.06
		12	100.0	0.0	0.59	0.02
		25	100.0	0.0	0.63	0.06
		50	100.0	0.0	0.66	0.03
		100	97.5	5.0	0.67	0.06
	010	6	77.5	45.0	0.53	0.06
		12	97.5	5.0	0.53	0.04
		25	90.0	14.1	0.61	0.08
		50	72.5	22.2	0.58	0.05
		100	67.5	27.5	0.63	0.05
May 1995	Control	100	97.5	5.0	0.41	0.01
	001	6	97.5	5.0	0.51	0.05
		12	97.5	5.0	0.50	0.04
		25	100.0	0.0	0.48	0.02
		50	92.5	5.0	0.50	0.06
		100	95.0	10.0	0.54	0.04
	006	6	87.5	9.6	0.44	0.02
		12	90.0	20.0	0.47	0.06
		25	90.0	20.0	0.48	0.04
		50	95.0	5.8	0.51	0.04
		100	82.5	23.6	0.50	0.05

Table B.1 (continued)

Date	Outfall	Concentration	Survival (%)		Growth (mg/larvae)	
			Mean	SD	Mean	SD
	008	6	92.5	5.0	0.46	0.05
		12	92.5	5.0	0.47	0.03
		25	82.5	22.2	0.52	0.07
		50	82.5	23.6	0.50	0.08
		100	77.5	33.0	0.53	0.06
	009	6	90.0	14.1	0.51	0.10
		12	92.5	9.6	0.50	0.07
		25	80.0	21.6	0.55	0.04
		50	72.5	27.5	0.58	0.05
		100	80.0	40.0	0.53	0.12
	010	6	95.0	5.8	0.55	0.05
		12	85.0	5.8	0.62	0.04
		25	72.5	15.0	0.59	0.05
		50	75.0	19.2	0.66	0.08
		100	77.5	12.6	0.62	0.10
August 1995	Control	100	92.5	9.8	0.45	0.05
	001	6	92.5	9.6	0.58	0.05
		12	100.0	0.0	0.61	0.03
		25	90.0	14.1	0.61	0.04
		50	92.5	9.6	0.61	0.08
		100	87.5	5.0	0.64	0.05
	006	6	97.5	5.0	0.53	0.04
		12	92.5	5.0	0.61	0.06
		25	100.0	0.0	0.67	0.06
		50	92.5	15.0	0.59	0.09
		100	95.0	5.8	0.67	0.06
	008	6	97.5	5.0	0.58	0.08
		12	95.0	5.8	0.61	0.08
		25	90.0	0.0	0.65	0.06
		50	97.5	5.0	0.67	0.06
		100	97.5	5.0	0.60	0.01
	009	6	85.0	10.0	0.52	0.07
		12	92.5	9.6	0.63	0.04
		25	90.0	20.0	0.68	0.06
		50	85.0	5.8	0.61	0.07
		100	95.0	5.8	0.67	0.04
	010	6	92.5	9.6	0.63	0.08
		12	97.5	5.0	0.64	0.03
		25	95.0	5.8	0.71	0.07
		50	87.5	5.0	0.66	0.06
		100	85.0	10.0	0.66	0.06

Table B.1 (continued)

Date	Outfall	Concentration	Survival (%)		Growth (mg/larvae)	
			Mean	SD	Mean	SD
October 1995	Control	100	100.0	0.0	0.36	0.03
	001	6	100.0	0.0	0.49	0.04
		12	97.5	5.0	0.49	0.04
		25	97.5	5.0	0.48	0.01
		50	100.0	0.0	0.47	0.04
	006	6	97.5	5.0	0.43	0.04
		12	100.0	0.0	0.47	0.01
		25	100.0	0.0	0.48	0.03
		50	100.0	0.0	0.48	0.02
		100	100.0	0.0	0.50	0.03
	008	6	97.5	5.0	0.41	0.02
		12	100.0	0.0	0.43	0.05
		25	97.5	5.0	0.44	0.03
		50	82.5	23.6	0.49	0.03
		100	95.0	5.8	0.43	0.03
	009	6	95.0	5.8	0.41	0.06
		12	95.0	5.8	0.48	0.03
		25	95.0	5.8	0.52	0.02
		50	95.0	5.8	0.48	0.04
		100	90.0	14.1	0.50	0.04
	010	6	100.0	0.0	0.43	0.03
		12	97.5	5.0	0.47	0.04
		25	97.5	5.0	0.53	0.03
		50	100.0	0.0	0.50	0.03
		100	100.0	0.0	0.50	0.02

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

Tests conducted March–November 1995

Date	Outfall	Concentration	Survival (%)	Offspring/surviving female	
				Mean	SD
March 1995	Control	100	100	21.3	10.3
	001	6	100	23.3	10.6
		12	100	20.7	11.3
		25	100	21.9	10.9
		50	90	24.6	13.3
		100	100	29.9	10.1
	Control	100	100	21.4	7.0
	006	6	100	26.6	10.2
		12	100	29.9	9.6
		25	100	29.9	11.3
		50	100	30.5	9.2
		100	100	31.7	7.6
	Control	100	100	21.6	8.4
	008	6	100	22.5	9.2
		12	100	27.0	7.0
		25	90	23.0	7.0
		50	90	24.2	8.7
		100	100	25.7	6.4
	Control	100	100	20.0	8.9
	009	6	100	18.1	8.5
		12	100	21.4	5.9
		25	90	26.9	7.9
		50	100	31.2	4.5
		100	100	30.8	4.7
	Control	100	100	20.4	7.6
	010	6	100	25.3	9.8
		12	100	29.9	7.3
		25	100	29.8	9.4
		50	100	26.4	10.9
		100	100	28.7	5.3
May 1995	Control	100	90	18.8	12.0
	001	6	100	26.8	18.9
		12	100	26.5	14.4
		25	100	37.7	13.7
		50	100	31.7	14.4
		100	90	38.8	21.6

Table B.2 (continued)

Date	Outfall	Concentration	Survival (%)	Offspring/surviving female	
				Mean	SD
	Control	100	90	20.1	4.8
	006	6	100	22.0	11.5
		12	100	23.5	8.1
		25	100	25.2	7.4
		50	90	26.6	8.8
		100	100	29.6	10.4
	Control	100	100	23.2	9.3
	008	6	100	23.0	9.9
		12	100	18.3	10.5
		25	100	19.9	8.7
		50	100	19.4	11.1
		100	100	25.0	7.1
	Control	100	100	18.6	9.7
	009	6	100	15.9	7.9
		12	80	20.1	8.1
		25	100	24.6	10.5
		50	100	26.5	8.3
		100	90	23.7	11.6
	Control	100	100	21.5	9.5
	010	6	100	23.9	9.9
		12	100	27.9	6.0
		25	100	26.7	5.6
		50	100	25.6	8.5
		100	100	32.4	4.5
August 1995	Control	100	100	31.6	6.3
	001	6	100	29.0	3.7
		12	90	30.3	3.7
		25	90	32.8	4.7
		50	100	33.4	6.0
		100	90	35.4	4.3
October 1995	Control	100	100	22.7	8.6
	001	6	100	22.7	6.1
		12	70	18.3	4.4
		25	100	16.7	7.9
		50	100	17.1	2.9
		100	100	15.4	3.8
November 1995	Control	100	100	25.8	6.3
	001	6	90	25.7	8.5
		12	100	23.5	8.4
		25	100	24.1	7.7
		50	90	22.2	9.1
		100	100	14.9	7.6

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 1995

Water Quality Parameter	Date	Outfall	Mean	SD	Min	Max
pH (S.U.)	March 1995	001	7.57	0.12	7.40	7.77
		006	9.06	0.38	8.26	9.41
		008	7.42	0.08	7.27	7.51
		009	8.45	0.22	8.09	8.66
		010	7.71	0.14	7.53	7.93
	May 1995	001	9.13	0.23	8.71	9.37
		006	8.90	0.11	8.72	9.06
		008	7.52	0.08	7.43	7.66
		009	8.51	0.35	7.98	8.95
		010	7.87	0.09	7.77	8.00
	August 1995	001	8.54	0.80	7.94	9.45
		006	8.78	0.12	8.69	8.91
		008	7.50	0.06	7.44	7.55
		009	7.81	0.07	7.73	7.86
		010	7.63	0.11	7.55	7.75
	October 1995	001	8.99	0.05	8.96	9.04
		006	8.75	0.30	8.41	8.97
		008	7.37	0.22	7.11	7.51
		009	7.53	0.05	7.48	7.58
		010	7.56	0.10	7.49	7.68
	November 1995	001	7.35	0.25	7.11	7.60
Alkalinity (mg/L as $CaCO_3$)	March 1995	001	32.3	2.4	30	36
		006	45.0	1.0	43	46
		008	43.3	7.6	33	55
		009	70.6	13.4	53	84
		010	42.0	7.4	35	54
	May 1995	001	38.4	3.8	35	45
		006	49.0	1.2	47	50
		008	52.4	4.6	46	58
		009	60.3	7.2	51	70
		010	46.9	3.9	42	52
	August 1995	001	31.3	5.8	28	38
		006	48.0	0.0	48	48
		008	30.0	2.7	28	33
		009	38.3	3.2	36	42
		010	26.7	5.5	23	33

Table B.3 (continued)

Water Quality Parameter	Date	Outfall	Mean	SD	Min	Max
	October 1995	001	36.7	2.3	34	38
		006	39.0	1.7	38	41
		008	31.0	5.3	27	37
		009	32.3	3.1	29	35
		010	25.0	2.7	22	27
	November 1995	001	35.7	2.5	33	38
Hardness (mg/L as $CaCO_3$)	March 1995	001	417.4	19.0	388	444
		006	70.6	6.7	62	80
		008	69.3	8.0	60	78
		009	105.4	6.7	100	120
		010	94.9	25.1	76	148
	May 1995	001	336.0	56.2	264	410
		006	88.9	13.2	76	108
		008	92.0	8.8	80	102
		009	88.9	10.8	70	102
		010	111.4	11.3	96	124
	August 1995	001	184.7	15.3	168	198
		006	76.7	5.8	70	80
		008	59.3	7.0	52	66
		009	69.3	16.2	60	88
		010	70.7	13.6	60	86
	October 1995	001	271.3	47.4	242	326
		006	62.0	5.3	58	68
		008	66.7	4.2	62	70
		009	58.0	3.5	54	60
		010	75.3	2.3	74	78
	November 1995	001	309.3	23.9	282	326
Conductivity (μS/cm)	March 1995	001	1295.4	35.6	1217	1321
		006	175.3	1.5	172	176
		008	245.6	21.2	215	274
		009	340.7	46.7	278	395
		010	249.3	23.8	222	283
	May 1995	001	1315.3	127.6	1128	1488
		006	270.7	3.5	265	276
		008	333.0	33.0	280	373
		009	278.0	42.1	203	322
		010	394.3	48.7	322	451
	August 1995	001	753.7	72.2	672	809
		006	233.7	1.5	232	235
		008	229.3	22.2	209	253
		009	230.7	27.2	214	262
		010	261.3	18.8	250	283
	October 1995	001	1078.7	180.3	935	1281

Table B.3 (continued)

Water Quality Parameter	Date	Outfall	Mean	SD	Min	Max
		006	211.0	9.5	200	217
		008	282.7	27.8	251	303
		009	198.7	42.9	151	234
		010	300.3	36.7	259	329
	November 1995	001	1232.0	81.5	1143	1303

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

Tests conducted January–November 1995

Date	Outfall	Concentration	Survival (%)		Growth (mg/larvae)	
			Mean	SD	Mean	SD
January 1995	Control	100	95.0	10.0	0.44	0.09
	13	6	97.5	5.0	0.53	0.07
		12	90.0	14.1	0.55	0.02
		25	77.5	12.6	0.70	0.12
		50	90.0	20.0	0.59	0.05
		100	85.0	17.3	0.73	0.10
	15	6	97.5	5.0	0.56	0.08
		12	87.5	18.9	0.58	0.10
		25	92.5	5.0	0.65	0.02
		50	95.0	10.0	0.65	0.05
		100	75.0	19.2	0.72	0.12
	16	6	97.5	5.0	0.46	0.05
		12	90.0	11.6	0.60	0.03
		25	97.5	5.0	0.67	0.06
		50	85.0	12.9	0.68	0.09
		100	80.0	14.1	0.56	0.13
	17	6	92.5	5.0	0.62	0.05
		12	92.5	9.6	0.63	0.02
		25	87.5	9.6	0.73	0.05
		50	85.0	12.9	0.73	0.05
		100	87.5	12.6	0.74	0.09
	18	6	85.0	10.0	0.61	0.03
		12	92.5	9.6	0.71	0.11
		25	97.5	5.0	0.53	0.12
		50	87.5	12.6	0.56	0.03
		100	95.0	5.8	0.67	0.05
	018 Filtered	100	75.0	5.8	0.77	0.08
April 1995	Control	100	97.5	5.0	0.46	0.02
	13	6	97.5	5.0	0.57	0.11
		12	95.0	5.8	0.61	0.04
		25	72.5	17.1	0.65	0.03
		50	72.5	27.5	0.64	0.09
		100	75.0	25.2	0.59	0.08
	15	6	97.5	5.0	0.55	0.05
		12	97.5	5.0	0.63	0.04
		25	97.5	5.0	0.61	0.04

Table B.4 (continued)

Date	Outfall	Concentration	Survival (%)		Growth (mg/larvae)	
			Mean	SD	Mean	SD
		50	85.0	10.0	0.60	0.07
		100	87.5	9.6	0.70	0.03
	015 Filtered	100	97.5	5.0	0.76	0.06
	16	6	90.0	8.2	0.63	0.16
		12	90.0	11.6	0.59	0.09
		25	100.0	0.0	0.62	0.07
		50	90.0	8.2	0.51	0.05
		100	80.0	14.1	0.59	0.06
	17	6	80.0	14.1	0.54	0.05
		12	97.5	5.0	0.57	0.02
		25	82.5	17.1	0.57	0.11
		50	85.0	12.9	0.61	0.12
		100	85.0	23.8	0.64	0.06
	017 Filtered	100	100.0	0.0	0.62	0.04
	18	6	95.0	5.8	0.58	0.03
		12	97.5	5.0	0.61	0.12
		25	95.0	10.0	0.61	0.06
		50	72.5	15.0	0.59	0.10
		100	52.5	27.5	0.58	0.14
July 1995	Control	100	100.0	0.0	0.40	0.05
	13	6	100.0	0.0	0.44	0.03
		12	90.0	0.0	0.49	0.06
		25	85.0	5.8	0.50	0.06
		50	87.5	15.0	0.53	0.09
		100	97.5	5.0	0.48	0.08
	15	6	90.0	8.2	0.44	0.03
		12	82.5	17.1	0.51	0.07
		25	92.5	9.6	0.51	0.08
		50	100.0	0.0	0.45	0.06
		100	90.0	8.2	0.48	0.08
	16	6	97.5	5.0	0.45	0.04
		12	90.0	14.1	0.56	0.07
		25	87.5	5.0	0.59	0.07
		50	92.5	9.6	0.60	0.01
		100	97.5	5.0	0.55	0.03
	17	6	100.0	0.0	0.49	0.02
		12	97.5	5.0	0.52	0.04
		25	92.5	5.0	0.57	0.08
		50	75.0	10.0	0.68	0.07
		100	75.0	19.2	0.66	0.15

Table B.4 (continued)

Date	Outfall	Concentration	Survival (%)		Growth (mg/larvae)	
			Mean	SD	Mean	SD
	18	6	92.5	9.6	0.55	0.05
		12	95.0	5.8	0.56	0.06
		25	77.5	26.3	0.59	0.03
		50	90.0	8.2	0.49	0.09
		100	67.5	15.0	0.66	0.13
	018 Filtered	100	95.0	5.8	0.66	0.06
November 1995	Control	100	100.0	0.0	0.46	0.02
	13	6	97.5	5.0	0.53	0.02
		12	95.0	10.0	0.53	0.05
		25	95.0	10.0	0.55	0.05
		50	90.0	14.1	0.56	0.07
		100	80.0	23.1	0.54	0.07
	15	6	97.5	5.0	0.52	0.04
		12	92.5	9.6	0.53	0.12
		25	97.5	5.0	0.54	0.09
		50	92.5	15.0	0.57	0.04
		100	92.5	9.6	0.57	0.09
	16	6	95.0	5.8	0.55	0.07
		12	92.5	9.6	0.54	0.06
		25	100.0	0.0	0.57	0.07
		50	82.5	17.1	0.50	0.10
		100	87.5	12.6	0.64	0.08
	17	6	92.5	5.0	0.61	0.03
		12	97.5	5.0	0.64	0.03
		25	92.5	9.6	0.62	0.05
		50	70.0	24.5	0.64	0.07
		100	80.0	18.3	0.67	0.09
	18	6	100.0	0.0	0.61	0.05
		12	100.0	0.0	0.65	0.04
		25	95.0	5.8	0.61	0.05
		50	90.0	11.6	0.58	0.06
		100	92.5	9.6	0.50	0.20
	018 Filtered	100	90.0	0.0	0.65	0.10

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

Tests conducted January–November 1995

Date	Outfall	Concentration	Survival (%)	Offspring/surviving female	
				Mean	SD
January 1995	Control	100	100	24.0	5.3
	013	6	100	23.8	1.5
		12	100	22.9	3.5
		25	100	21.3	3.1
		50	100	22.7	4.5
		100	100	19.0	4.1
	Control	100	100	23.3	4.0
	015	6	100	23.2	2.5
		12	100	24.2	2.7
		25	100	23.1	4.6
		50	100	25.8	2.9
		100	100	21.7	3.0
	Control	100	100	22.9	2.9
	016	6	100	22.0	3.3
		12	100	25.2	3.2
		25	100	24.9	3.1
		50	100	21.3	5.4
		100	100	21.8	5.1
	Control	100	90	22.8	5.5
	017	6	100	22.1	4.5
		12	90	19.9	5.7
		25	100	21.7	4.8
		50	100	22.9	1.9
		100	100	19.1	4.5
	Control	100	100	18.5	8.7
	018	6	100	19.8	4.1
		12	100	23.6	5.1
		25	100	23.3	2.6
		50	90	22.1	3.3
		100	100	15.9	4.7
April 1995	Control	100	100	28.9	2.3
	013	6	100	24.8	2.0
		12	100	25.7	2.5
		25	100	27.1	2.5
		50	100	27.4	2.9
		100	100	25.5	3.0

Table B.5 (continued)

Date	Outfall	Concentration	Survival (%)	Offspring/surviving female	
				Mean	SD
	Control	100	100	28.7	3.2
	015	6	100	29.0	3.1
		12	100	29.8	6.0
		25	90	30.7	5.6
		50	100	33.8	5.1
		100	100	29.0	3.9
	Control	100	90	26.1	5.4
	016	6	100	25.3	4.6
		12	100	29.2	1.5
		25	100	25.1	9.4
		50	90	28.8	4.0
		100	90	25.0	5.6
	Control	100	100	23.5	5.2
	017	6	100	21.0	4.7
		12	100	23.8	4.4
		25	100	22.4	7.4
		50	100	23.8	3.8
		100	90	20.9	5.6
	Control	100	90	27.6	4.1
	018	6	90	24.3	4.1
		12	100	26.4	3.7
		25	100	27.2	2.7
		50	100	25.7	4.9
		100	100	24.1	4.3
July 1995	Control	100	90	24.0	6.3
	013	6	90	19.4	6.0
		12	100	24.9	3.1
		25	100	20.5	4.2
		50	100	23.7	2.5
		100	90	19.2	5.0
	Control	100	100	24.2	5.5
	015	6	100	22.8	6.0
		12	100	21.3	6.8
		25	100	24.1	6.0
		50	100	27.2	4.2
		100	100	25.9	6.8
	Control	100	100	22.0	4.9
	016	6	100	21.7	6.2
		12	90	20.9	6.2
		25	100	23.0	7.6
		50	100	26.2	4.7
		100	100	24.7	7.7

Table B.5 (continued)

Date	Outfall	Concentration	Survival (%)	Offspring/surviving female	
				Mean	SD
	Control	100	100	22.9	9.8
	017	6	100	18.9	5.0
		12	100	22.4	5.5
		25	100	23.6	5.9
		50	100	23.8	3.9
		100	90	19.0	5.2
	Control	100	100	18.6	2.4
	018	6	100	20.3	2.5
		12	100	21.3	2.7
		25	100	22.9	2.5
		50	100	22.4	2.2
		100	100	19.2	6.3
November 1995	Control	100	80	23.3	9.5
	013	6	100	22.7	2.2
		12	87.5	22.4	4.2
		25	100	22.3	5.4
		50	100	23.7	3.6
		100	100	26.0	1.9
	Control	100	90	25.5	3.3
	015	6	100	25.7	8.7
		12	100	23.8	7.6
		25	100	27.2	6.8
		50	100	25.8	7.5
		100	100	23.0	8.2
	Control	100	100	21.6	8.2
	016	6	100	29.0	2.8
		12	100	26.7	7.6
		25	100	28.0	4.2
		50	100	23.4	9.2
		100	100	26.0	6.0
	Control	100	100	20.4	7.8
	017	6	100	20.1	2.1
		12	100	19.0	6.5
		25	100	20.3	4.0
		50	90	24.0	4.0
		100	100	22.5	2.1

Table B.5 (continued)

Date	Outfall	Concentration	Survival (%)	Offspring/surviving female	
				Mean	SD
	Control	100	100	25.1	5.3
	018	6	90	18.9	9.8
		12	100	25.1	5.7
		25	100	25.7	4.8
		50	100	25.4	4.7
		100	100	26.4	4.1

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–November 1995

Date	Outfall	pH (S.U.)	Alkalinity (mg/L $CaCO_3$)	Hardness (mg/L $CaCO_3$)	Conductivity (μS/cm)	Total Suspended Solids (mg/L)
January 1995	013	7.31	44	82	205	NM[a]
	015	7.75	72	98	260	NM[a]
	016	7.73	79	120	324	NM[a]
	017	7.84	76	94	215	NM[a]
	018	7.58	48	62	144	39.3
April 1995	013	7.52	54	160	328	28.2
	015	7.76	65	162	369	33.6
	016	7.75	78	120	272	24.8
	017	7.91	71	124	241	52.6
	018	7.69	51	88	188	21.8
July 1995	013	7.46	80	160	314	30.4
	015	7.69	123	190	348	12.4
	016	7.6	147	196	393	4.0
	017	7.66	140	172	350	20.4
	018	7.79	87	144	256	22.0
November 1995	013	7.42	80	310	667	2.2
	015	7.52	74	158	392	34.4
	016	7.55	102	182	438	8.0
	017	7.76	110	180	409	8.2
	018	7.66	74	156	360	15.0

[a]NM = not measured.

Table B.7. Summary of water chemistry analyses conducted during toxicity tests of ambient samples from Big Bayou Creek, Little Bayou Creek, and Massac Creek

Analyses conducted March–November 1995

Water Quality Parameter	Date	Outfall	Mean	SD	Min	Max
pH (S.U.)	March 1995	BBK 9.1	7.66	0.35	7.39	8.37
		BBK 10.0	7.44	0.18	7.23	7.66
		BBK 10.8	7.42	0.22	7.12	7.71
		BBK 12.5	7.16	0.25	6.92	7.54
		LUK 7.2	7.50	0.24	7.10	7.81
		MAK 13.8	7.15	0.09	7.03	7.28
	May 1995	BBK 9.1	7.91	0.15	7.67	8.10
		BBK 10.0	7.56	0.26	7.36	8.02
		BBK 10.8	7.39	0.13	7.26	7.62
		BBK 12.5	7.17	0.17	6.87	7.40
		LUK 7.2	7.52	0.05	7.42	7.58
		MAK 13.8	7.23	0.04	7.17	7.27
	August 1995	BBK 9.1	7.95	0.20	7.66	8.21
		BBK 10.0	7.44	0.07	7.31	7.55
		BBK 10.8	7.41	0.07	7.32	7.52
		BBK 12.5	7.50	0.12	7.32	7.72
		LUK 7.2	7.63	0.08	7.47	7.72
		MAK 13.8	7.42	0.14	7.30	7.72
	October 1995	BBK 9.1	8.64	0.27	8.15	8.86
		BBK 10.0	7.59	0.15	7.41	7.79
		BBK 10.8	7.65	0.12	7.53	7.85
		BBK 12.5	7.65	0.22	7.37	8.01
		LUK 7.2	7.41	0.19	7.21	7.77
		MAK 13.8	7.35	0.21	7.18	7.72
Alkalinity (mg/L as $CaCO_3$)	March 1995	BBK 9.1	31.6	3.2	26	34
		BBK 10.0	36.6	4.4	29	42
		BBK 10.8	33.4	3.8	27	39
		BBK 12.5	27.3	4.2	23	36
		LUK 7.2	51.7	10.3	35	64
		MAK 13.8	24.4	2.2	20	26
	May 1995	BBK 9.1	41.1	2.8	39	47
		BBK 10.0	43.9	7.0	34	52
		BBK 10.8	38.0	6.1	27	44
		BBK 12.5	36.6	5.9	29	46
		LUK 7.2	56.0	5.9	46	65

Table B.7 (continued)

Water Quality Parameter	Date	Outfall	Mean	SD	Min	Max
		MAK 13.8	33.1	2.9	30	39
	August 1995	BBK 9.1	34.6	2.8	31	39
		BBK 10.0	36.9	1.9	33	38
		BBK 10.8	48.1	1.6	46	50
		BBK 12.5	65.4	8.4	52	75
		LUK 7.2	42.6	3.5	36	47
		MAK 13.8	37.0	1.0	35	38
	October 1995	BBK 9.1	39.9	2.0	38	44
		BBK 10.0	43.6	6.3	37	52
		BBK 10.8	56.6	5.2	53	67
		BBK 12.5	80.4	3.9	75	87
		LUK 7.2	38.1	6.8	31	49
		MAK 13.8	38.0	2.0	34	40
Hardness	March 1995	BBK 9.1	218.3	31.5	160	254
(mg/L as $CaCO_3$)		BBK 10.0	70.0	8.9	62	86
		BBK 10.8	67.1	6.9	60	78
		BBK 12.5	66.0	5.9	58	72
		LUK 7.2	85.7	16.6	58	110
		MAK 13.8	55.7	9.6	44	70
	May 1995	BBK 9.1	174.6	69.8	68	266
		BBK 10.0	76.0	20.8	44	100
		BBK 10.8	66.0	16.9	38	82
		BBK 12.5	64.9	10.6	54	84
		LUK 7.2	90.3	13.8	68	102
		MAK 13.8	53.7	16.8	40	88
	August 1995	BBK 9.1	135.7	21.5	112	170
		BBK 10.0	62.6	4.9	58	72
		BBK 10.8	68.0	2.3	66	72
		BBK 12.5	59.4	4.3	52	66
		LUK 7.2	73.7	6.6	66	86
		MAK 13.8	48.3	6.8	40	60
	October 1995	BBK 9.1	200.0	31.3	154	234
		BBK 10.0	73.1	4.9	64	78
		BBK 10.8	71.4	4.9	64	78
		BBK 12.5	59.1	4.9	54	66
		LUK 7.2	96.0	15.9	76	122
		MAK 13.8	41.1	4.3	36	46

Table B.7 (continued)

Water Quality Parameter	Date	Outfall	Mean	SD	Min	Max
Conductivity (μS/cm)	March 1995	BBK 9.1	688.9	82.7	528	769
		BBK 10.0	205.6	22.7	168	238
		BBK 10.8	187.9	22.0	148	212
		BBK 12.5	180.4	22.3	143	201
		LUK 7.2	262.4	43.9	170	292
		MAK 13.8	134.7	2.7	130	137
	May 1995	BBK 9.1	734.7	262.3	226	1002
		BBK 10.0	222.0	50.2	132	280
		BBK 10.8	181.7	35.8	112	215
		BBK 12.5	182.4	11.6	163	194
		LUK 7.2	319.9	64.5	222	406
		MAK 13.8	135.9	3.4	131	140
	August 1995	BBK 9.1	554.1	98.4	443	693
		BBK 10.0	224.9	4.3	219	233
		BBK 10.8	219.9	4.2	213	226
		BBK 12.5	199.6	24.2	166	231
		LUK 7.2	289.9	8.3	282	304
		MAK 13.8	132.3	3.6	125	135
	October 1995	BBK 9.1	803.3	143.9	545	959
		BBK 10.0	282.1	25.4	225	294
		BBK 10.8	250.6	19.9	206	262
		BBK 12.5	259.6	10.7	249	277
		LUK 7.2	336.3	40.4	250	373
		MAK 13.8	138.0	4.8	131	146

Note: BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

Appendix C

RESULTS OF QUALITY ASSURANCE/QUALITY CONTROL ANALYSES OF FISH SAMPLES

Appendix C

RESULTS OF QUALITY ASSURANCE/QUALITY CONTROL ANALYSES OF 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 ($\pm$SD) of PCBs spiked into reference stream fish were good, averaging 69.7% $\pm$ 5.89 for the October 1994 sampling season and 68.6% $\pm$ 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]	Species[c]	Sex	Tag	Type[d]	Wgt[e]	Lgt[f]	Hg[g]	1248[h]	Qual[i]	1254[j]	Qual	1260[k]	Qual	Lipids[l]	% Recovery[m]
BBK 10.0	10/19/94	LNGEAR	M	8670	R	38.2	12.6	.	0.097	U	0.063	JP	0.084	J	0.840	.
BBK 10.0	10/19/94	LNGEAR	M	8671	R	43.4	13.1	.	0.100	U	0.039	JP	0.110	.	0.440	.
BBK 10.0	10/19/94	LNGEAR	M	8672	R	44.3	13.7	.	0.078	U	0.056	JP	0.087	P	0.470	.
BBK 10.0	10/19/94	LNGEAR	M	8673	R	45.9	13.4	.	0.071	U	0.052	JP	0.067	J	0.510	.
BBK 10.0	10/19/94	LNGEAR	M	8674	R	37.9	13.0	.	0.102	U	0.120	P	0.170	P	1.130	.
BBK 10.0	10/19/94	LNGEAR	M	8675	R	43.6	12.8	.	0.080	U	0.063	JP	0.098	P	0.770	.
BBK 10.0	10/19/94	LNGEAR	M	8676	R	53.2	13.8	.	0.069	U	0.084	P	0.122	P	0.590	.
BBK 10.0	10/19/94	LNGEAR	M	8677	R	47.4	13.2	.	0.090	U	0.120	P	0.200	P	0.930	.
BBK 10.0	10/19/94	LNGEAR	M	5768	D	43.6	12.8	.	0.079	U	0.056	JP	0.097	.	0.770	.
BBK 12.5	10/19/94	LNGEAR	F	8590	R	54.4	14.1	.	0.071	U	0.071	U	0.071	U	0.410	.
BBK 12.5	10/19/94	LNGEAR	M	8591	R	36.6	12.8	.	0.081	U	0.081	U	0.081	U	0.310	.
BBK 12.5	10/19/94	LNGEAR	M	8592	R	33.8	12.6	.	0.094	U	0.094	U	0.094	U	0.210	.
BBK 12.5	10/19/94	LNGEAR	M	8593	R	35.1	12.1	.	0.061	U	0.061	U	0.061	U	0.430	.
BBK 12.5	10/19/94	LNGEAR	M	8594	R	41.9	13.1	.	0.120	U	0.120	U	0.120	U	0.410	.
BBK 12.5	10/19/94	LNGEAR	M	8595	R	33.2	12.4	.	0.115	U	0.115	U	0.115	U	0.440	.
BBK 12.5	10/19/94	LNGEAR	M	8596	R	39.2	12.4	.	0.058	U	0.058	U	0.058	U	0.410	.
BBK 12.5	10/19/94	LNGEAR	M	8597	R	32.7	12.6	.	0.099	U	0.099	U	0.099	U	0.530	.
BBK 12.5	10/19/94	LNGEAR	M	3958	D	35.1	12.1	.	0.077	U	0.077	U	0.077	U	0.340	.
BBK 2.8	10/20/94	LNGEAR	F	2040	R	40.4	13.5	.	0.091	U	0.010	JP	0.014	JP	0.510	.
BBK 2.8	10/20/94	LNGEAR	M	2041	R	54.4	14.0	.	0.066	U	0.017	JP	0.012	JP	0.250	.
BBK 2.8	10/20/94	LNGEAR	M	2042	R	40.1	13.4	.	0.100	U	0.039	U	0.011	JP	0.300	.
BBK 2.8	10/20/94	LNGEAR	M	2043	R	52.0	14.7	.	0.089	U	0.039	U	0.070	JP	0.180	.
BBK 2.8	10/20/94	LNGEAR	M	2044	R	43.3	13.2	.	0.080	U	0.007	JP	0.011	J	0.770	.
BBK 2.8	10/20/94	LNGEAR	M	2045	R	37.3	12.4	.	0.090	U	0.009	JP	0.009	JP	0.360	.
BBK 2.8	10/20/94	LNGEAR	M	2046	R	53.3	14.5	.	0.089	U	0.009	JP	0.013	JP	0.070	.
BBK 2.8	10/20/94	LNGEAR	M	2047	R	53.2	13.7	.	0.069	U	0.004	JP	0.017	JP	0.110	.
BBK 2.8	10/20/94	LNGEAR	M	4402	D	43.3	13.2	.	0.090	U	0.012	JP	0.074	U	0.360	.
BBK 9.1	10/20/94	LNGEAR	M	8640	R	54.3	14.4	.	0.052	U	0.033	JP	0.061	.	0.280	.
BBK 9.1	10/20/94	LNGEAR	M	8641	R	50.1	14.5	.	0.071	U	0.070	J	0.102	.	0.240	.
BBK 9.1	10/20/94	LNGEAR	M	8642	R	48.1	13.7	.	0.067	U	0.110	P	0.130	P	0.470	.
BBK 9.1	10/20/94	LNGEAR	M	8643	R	49.6	13.7	.	0.072	U	0.120	P	0.190	.	0.210	.
BBK 9.1	10/20/94	LNGEAR	M	8644	R	69.2	15.1	.	0.046	U	0.055	.	0.088	.	0.260	.
BBK 9.1	10/20/94	LNGEAR	M	8645	R	57.7	14.3	.	0.055	U	0.058	.	0.076	.	0.580	.
BBK 9.1	10/20/94	LNGEAR	M	8646	R	41.7	13.1	.	0.076	U	0.037	JP	0.062	J	0.350	.
BBK 9.1	10/20/94	LNGEAR	M	8647	R	50.3	13.8	.	0.067	U	0.040	JP	0.050	JP	0.350	.
BBK 9.1	10/20/94	LNGEAR	M	1468	D	50.1	14.5	.	0.063	U	0.066	P	0.092	P	0.089	.
BBK 9.1	10/20/94	SPBASS	M	8660	R	240.0	26.0	0.49	0.032	U	0.064	P	0.071	.	0.150	.
BBK 9.1	10/20/94	SPBASS	M	8661	R	523.0	32.5	0.45	0.048	U	0.045	J	0.140	.	0.140	.
BBK 9.1	10/20/94	SPBASS	F	8662	R	460.0	32.4	0.59	0.038	U	0.076	.	0.240	.	0.290	.
BBK 9.1	10/20/94	SPBASS	M	8663	R	244.0	26.7	0.63	0.039	U	0.030	J	0.120	.	0.050	.
BBK 9.1	10/20/94	SPBASS	M	8664	R	183.0	24.8	0.22	0.043	U	0.030	JP	0.137	.	0.190	.
BBK 9.1	10/20/94	SPBASS	F	8665	R	228.0	26.2	0.31	0.052	U	0.038	PJ	0.077	P	0.147	.
BBK 9.1	10/20/94	SPBASS	M	8666	R	217.0	27.3	0.46	0.050	U	0.055	P	0.135	.	0.119	.
BBK 9.1	10/20/94	SPBASS	M	8667	R	155.0	23.0	0.30	0.058	U	0.041	J	0.068	.	0.104	.
BBK 9.1	10/20/94	SPBASS	F	2668	D	460.0	32.4	0.64	.	.	.	.	.	.	.	.
BBK 9.1	10/20/94	SPBASS	M	1668	D	523.0	32.5	.	0.061	U	0.061	P	0.146	P	0.254	.
LUK 4.3	10/20/94	LNGEAR	M	8690	R	33.4	12.5	.	0.156	U	0.156	U	0.078	JP	0.060	.
LUK 4.3	10/20/94	LNGEAR	M	8691	R	44.7	13.1	.	0.096	U	0.041	JP	0.052	JP	0.120	.
LUK 4.3	10/20/94	LNGEAR	M	8692	R	51.1	13.6	.	0.074	U	0.070	JP	0.058	JP	0.280	.
LUK 4.3	10/20/94	LNGEAR	F	8693	R	33.1	12.8	.	0.118	U	0.070	JP	0.058	JP	0.210	.
LUK 4.3	10/20/94	LNGEAR	M	8694	R	33.5	12.2	.	0.102	U	0.080	JP	0.080	JP	0.240	.
LUK 4.3	10/20/94	LNGEAR	M	8695	R	46.3	14.0	.	0.068	U	0.056	JP	0.050	JP	0.390	.
LUK 4.3	10/20/94	LNGEAR	M	8696	R	27.8	11.7	.	0.128	U	0.096	JP	0.120	JP	0.330	.
LUK 4.3	10/20/94	LNGEAR	M	8697	R	38.0	12.6	.	0.090	U	0.066	JP	0.092	P	0.270	.
LUK 4.3	10/20/94	LNGEAR	M	1968	D	44.7	13.1	.	0.083	U	0.110	P	0.120	P	3.500	.

Table C.1 (continued)

Site[a]	Date[b]	Species[c]	Sex	Tag	Type[d]	Wgt[e]	Lgt[f]	Hg[g]	1248[h]	Qual[i]	1254[j]	Qual	1260[k]	Qual	Lipids[l]	% Recovery[m]
LUK 4.3	10/20/94	LMBASS	F	8698	R	142.0	22.7	0.23	0.063	U	0.053	PJ	0.098	P	0.543	.
LUK 4.3	10/20/94	SPBASS	M	8699	R	219.0	25.0	0.28	0.045	U	0.190	.	0.160	.	0.234	.
LUK 9.0	10/20/94	BLUGIL	M	8680	R	17.2	10.5	.	0.141	U	0.350	.	0.190	P	0.590	.
LUK 9.0	10/20/94	BLUGIL	M	8681	R	35.9	13.0	.	0.057	U	0.180	.	0.120	P	0.150	.
LUK 9.0	10/20/94	BLUGIL	M	8682	R	15.0	9.9	.	0.076	U	0.190	.	0.100	P	0.360	.
LUK 9.0	10/20/94	BLUGIL	M	8683	R	45.0	13.8	.	0.031	U	0.050	.	0.060	P	0.160	.
LUK 9.0	10/20/94	BLUGIL	F	8684	R	15.8	10.2	.	0.093	U	0.220	.	0.130	P	0.260	.
LUK 9.0	10/20/94	BLUGIL	F	8685	R	14.6	9.9	.	0.090	U	0.160	.	0.092	.	0.340	.
LUK 9.0	10/20/94	YBULLHD	F	8686	R	63.1	17.9	.	0.041	U	0.190	P	0.320	P	0.110	.
LUK 9.0	10/20/94	YBULLHD	M	8687	R	33.0	13.2	.	0.118	U	0.270	P	0.220	P	0.560	.
LUK 9.0	10/20/94	YBULLHD	M	8688	R	41.2	15.0	.	0.028	U	0.190	.	0.190	P	0.140	.
LUK 9.0	10/20/94	YBULLHD	F	6868	D	63.1	17.9	.	0.069	U	0.360	P	0.540	P	0.220	.
BBK 10.0	04/24/95	LNGEAR	M	8750	R	62.4	13.7	.	0.058	U	0.152	P	0.183	.	0.590	.
BBK 10.0	04/24/95	LNGEAR	M	8751	R	48.2	13.0	.	0.081	U	0.079	U	0.007	JP	0.260	.
BBK 10.0	04/24/95	LNGEAR	M	8752	R	36.9	12.2	.	0.089	U	0.031	JP	0.038	JP	0.250	.
BBK 10.0	04/24/95	LNGEAR	M	8753	R	36.4	12.0	.	0.088	U	0.079	U	0.038	JP	0.350	.
BBK 10.0	04/24/95	LNGEAR	M	8754	R	76.3	14.2	.	0.048	U	0.079	U	0.031	JP	0.150	.
BBK 10.0	04/24/95	LNGEAR	M	8755	R	38.5	12.0	.	0.084	U	0.025	JP	0.079	U	0.280	.
BBK 10.0	04/24/95	LNGEAR	M	8756	R	46.8	12.8	.	0.061	U	0.079	U	0.090	P	0.820	.
BBK 10.0	04/24/95	LNGEAR	M	8757	R	49.9	14.0	.	0.148	U	0.047	JP	0.079	U	0.150	.
BBK 10.0	04/24/95	LNGEAR	M	7578	D	49.9	14.0	.	0.064	U	0.056	J	0.110	P	0.485	.
BBK 10.0	04/24/95	LNGEAR	M	2578	D	36.9	12.2	.	0.095	U	0.055	JP	0.044	JP	0.152	.
BBK 12.5	04/25/95	LNGEAR	M	8830	R	58.9	13.1	.	0.104	U	0.208	U	0.208	U	0.300	.
BBK 12.5	04/25/95	LNGEAR	M	8831	R	62.8	13.1	.	0.068	U	0.135	U	0.135	U	0.216	.
BBK 12.5	04/25/95	LNGEAR	M	8832	R	36.6	11.7	.	0.114	U	0.228	U	0.228	U	1.000	.
BBK 12.5	04/25/95	LNGEAR	M	8833	R	48.4	13.0	.	0.082	U	0.163	U	0.163	U	0.163	.
BBK 12.5	04/25/95	LNGEAR	M	8834	R	45.3	12.8	.	0.080	U	0.160	U	0.160	U	0.305	.
BBK 12.5	04/25/95	LNGEAR	M	8835	R	46.2	13.0	.	0.112	U	0.224	U	0.224	U	0.359	.
BBK 12.5	04/25/95	LNGEAR	M	8836	R	43.6	12.6	.	0.071	U	0.013	J	0.018	J	0.595	.
BBK 12.5	04/25/95	LNGEAR	M	8837	R	60.4	14.2	.	0.055	U	0.109	U	0.109	U	0.175	.
BBK 12.5	04/25/95	LNGEAR	M	0388	D	58.9	13.1	.	0.058	U	0.116	U	0.116	U	0.266	.
BBK 9.1	04/24/95	LNGEAR	M	8840	R	39.7	11.5	.	0.083	U	0.050	J	0.061	J	1.954	.
BBK 9.1	04/24/95	LNGEAR	M	8841	R	73.6	14.2	.	0.090	U	0.135	.	0.110	.	1.477	.
BBK 9.1	04/24/95	LNGEAR	F	8842	R	40.2	11.5	.	0.078	U	0.038	J	0.031	JP	0.832	.
BBK 9.1	04/24/95	LNGEAR	F	8843	R	39.9	11.8	.	0.093	U	0.014	J	0.010	JP	0.690	.
BBK 9.1	04/24/95	LNGEAR	M	8844	R	53.1	13.0	.	0.057	U	0.018	J	0.027	J	1.220	.
BBK 9.1	04/24/95	LNGEAR	M	8845	R	80.0	15.1	.	0.041	U	0.018	JP	0.056	J	0.620	.
BBK 9.1	04/24/95	LNGEAR	M	8846	R	65.2	14.2	.	0.089	U	0.041	JP	0.083	J	0.430	.
BBK 9.1	04/24/95	LNGEAR	M	8847	R	73.8	14.8	.	0.048	U	0.028	JP	0.027	J	0.240	.
BBK 9.1	04/24/95	LNGEAR	M	6488	D	65.2	14.2	.	0.106	U	0.213	U	0.074	JP	0.260	.
LUK 4.3	04/25/95	LNGEAR	M	8820	R	30.9	11.3	.	0.066	U	0.055	J	0.134	.	0.380	.
LUK 4.3	04/25/95	LNGEAR	M	8821	R	30.1	11.7	.	0.057	U	0.043	J	0.081	P	0.317	.
LUK 4.3	04/25/95	LNGEAR	M	8822	R	27.1	10.8	.	0.075	U	0.027	JP	0.039	JP	0.315	.
LUK 4.3	04/25/95	LNGEAR	F	8823	R	37.5	11.6	.	0.052	U	0.016	JP	0.032	JP	0.219	.
LUK 4.3	04/25/95	LNGEAR	F	8824	R	26.3	10.5	.	0.082	U	0.031	JP	0.056	J	0.246	.
LUK 4.3	04/25/95	LNGEAR	F	8825	R	28.7	10.6	.	0.072	U	0.023	J	0.033	JP	0.715	.
LUK 4.3	04/25/95	LNGEAR	M	8826	R	42.8	12.1	.	0.084	U	0.124	U	0.086	P	0.268	.
LUK 4.3	04/25/95	LNGEAR	M	8827	R	40.1	12.1	.	0.107	U	0.031	J	0.071	JP	0.577	.
LUK 4.3	04/25/95	LNGEAR	M	6288	D	42.8	12.1	.	0.098	U	0.124	U	0.047	J	0.117	.
LUK 7.2	04/25/95	LNGEAR	F	8748	R	19.4	9.7	.	0.103	U	0.233	.	0.217	P	0.890	.
LUK 7.2	04/25/95	LNGEAR	M	8749	R	23.9	10.1	.	0.072	U	0.032	JP	0.076	P	0.770	.
LUK 7.2	04/25/95	GREENSF	F	8718	R	37.2	12.1	.	0.103	U	0.013	JP	0.061	J	0.310	.
LUK 7.2	04/25/95	GREENSF	M	8719	R	107.6	16.1	.	0.063	U	0.042	J	0.083	.	0.200	.
LUK 7.2	04/25/95	GREENSF	M	9178	D	107.6	16.1	.	0.079	U	0.020	JP	0.144	.	0.330	.
LUK 9.0	04/24/95	LNGEAR	M	8740	R	12.4	8.5	.	0.129	U	0.240	P	0.200	.	0.540	.
LUK 9.0	04/24/95	LNGEAR	F	8741	R	14.2	8.5	.	0.114	U	0.253	P	0.171	P	0.230	.

Table C.1 (continued)

Site[a]	Date[b]	Species[c]	Sex	Tag	Type[d]	Wgt[e]	Lgt[f]	Hg[g]	1248[h]	Qual[i]	1254[j]	Qual	1260[k]	Qual	Lipids[l]	% Recovery[m]
LUK 9.0	04/24/95	LNGEAR	F	8742	R	19.0	9.7	.	0.090	U	0.173	P	0.150	P	0.390	.
LUK 9.0	04/24/95	LNGEAR	F	8743	R	17.3	9.2	.	0.097	U	0.241	P	0.167	P	0.620	.
LUK 9.0	04/24/95	LNGEAR	M	8744	R	12.5	8.6	.	0.143	U	0.210	P	0.117	JP	0.320	.
LUK 9.0	04/24/95	LNGEAR	F	8745	R	14.0	9.0	.	0.116	U	0.510	P	0.300	P	0.830	.
LUK 9.0	04/24/95	GREENSF	F	8746	R	29.6	12.0	.	0.063	U	0.184	P	0.152	.	0.080	.
LUK 9.0	04/24/95	GREENSF	M	8747	R	14.5	9.0	.	0.124	U	0.277	P	0.172	P	0.740	.
HINDSCR	12/16/93	COCARP	F	8097	R	2449.0	54.6	.	0.101	U	1.010	U	1.010	U	0.626	.
HINDSCR	05/18/94	REDBRE	F	8474	R	97.2	17.1	.	0.102	U	0.102	U	0.102	U	1.300	.
HINDSCR	05/18/94	REDBRE	F	8478	R	79.7	16.3	.	0.073	U	0.073	U	0.073	U	0.670	.
HINDSCR	05/18/94	REDBRE	M	8483	R	49.4	13.5	.	0.074	U	0.074	U	0.074	U	0.570	.
HINDSCR	05/18/94	REDBRE	F	8487	R	83.3	16.4	.	0.039	U	0.039	U	0.039	U	0.320	.
HINDSCR	05/18/94	REDBRE	F	8488	R	104.9	16.4	.	0.047	U	0.047	U	0.047	U	0.790	.
HINDSCR	05/18/94	REDBRE	M	8492	R	54.1	14.0	.	0.148	U	0.148	U	0.148	U	1.600	.
HINDSCR	05/03/95	REDBRE	M	8800	R	136.3	18.6	.	0.062	U	0.062	U	0.062	U	0.140	.
HINDSCR	05/03/95	REDBRE	M	8801	R	102.3	17.8	.	0.089	U	0.179	U	0.179	U	0.210	.
HINDSCR	05/03/95	REDBRE	M	8802	R	58.5	14.5	.	0.125	U	0.249	U	0.249	U	0.274	.
HINDSCR	05/03/95	REDBRE	F	8803	R	49.5	13.4	.	0.063	U	0.127	U	0.127	U	0.317	.
HINDSCR	05/03/95	REDBRE	M	8804	R	46.5	13.6	.	0.079	U	0.079	U	0.079	U	0.318	.
HINDSCR	05/03/95	REDBRE	M	8805	R	44.1	12.7	.	0.037	U	0.085	U	0.170	U	0.730	.
HINDSCR	05/03/95	REDBRE	F	8806	R	42.4	12.4	.	0.090	U	0.090	U	0.090	U	0.880	.
HINDSCR	05/03/95	REDBRE	M	8807	R	31.0	12.4	.	0.054	U	0.054	U	0.054	U	0.220	.
HINDSCR	05/03/95	REDBRE	M	8808	R	29.9	10.2	.	0.057	U	0.057	U	0.057	U	0.430	.
HINDSCR	05/03/95	REDBRE	F	8809	R	33.5	12.0	.	0.053	U	0.056	U	0.056	U	0.530	.
HINDSCR	12/16/93	COCARP	F	8097A	S	2449.0	54.6	.	.	.	1.010	.	1.030	.	0.826	66.50
HINDSCR	05/18/94	REDBRE	F	8474A	S	97.2	17.1	.	.	.	1.480	.	1.320	.	.	75.00
HINDSCR	05/18/94	REDBRE	F	8478A	S	79.7	16.3	.	.	.	0.780	.	0.830	.	.	75.00
HINDSCR	05/18/94	REDBRE	M	8483A	S	49.4	13.5	.	.	.	1.340	.	1.780	.	0.325	74.00
HINDSCR	05/18/94	REDBRE	F	8487A	S	83.3	16.4	.	.	.	1.600	.	1.430	.	0.580	73.00
HINDSCR	05/18/94	REDBRE	F	8488A	S	104.9	16.4	.	.	.	0.890	.	0.860	.	0.105	63.00
HINDSCR	05/18/94	REDBRE	M	8492A	S	54.1	14.0	.	.	.	3.730	.	2.350	.	0.205	61.50
HINDSCR	05/03/95	REDBRE	M	8800A	S	136.3	18.6	.	.	.	1.120	.	1.126	P	0.920	87.00
HINDSCR	05/03/95	REDBRE	M	8801A	S	102.3	17.8	.	.	.	0.939	J	0.970	.	0.134	64.50
HINDSCR	05/03/95	REDBRE	M	8802A	S	58.5	14.5	.	.	.	1.247	.	1.176	.	0.393	67.50
HINDSCR	05/03/95	REDBRE	F	8803A	S	49.5	13.4	.	.	.	0.846	.	0.890	.	0.458	60.50
HINDSCR	05/03/95	REDBRE	M	8804A	S	46.5	13.6	.	.	.	0.850	.	0.980	.	0.173	67.00
HINDSCR	05/03/95	REDBRE	M	8805A	S	44.1	12.7	.	.	.	0.220	.	0.250	.	0.305	65.00

[a]Site designations are as follows: BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer; HINDSCR = Hinds Creek, Anderson County, Tennessee.

[b]Collection date.

[c]Species designations are as follows: LNGEAR - Longear sunfish; REDBRE - Redbreast sunfish; COCARP - Common carp; SPBASS - Spotted bass; LMBASS - Largemouth bass; BLUGIL - Bluegill; YBULLHD - Yellow bullhead.

[d]Type designations are as follows: R - regular sample; D - duplicate sample; S - spike sample.

[e]Weight of fish measured in grams.

[f]Total length of fish measured in centimeters.

[g]Concentrations of Hg reported as μg/g.

[h]Concentrations in fish filets of Aroclor 1248 in μg/g.

[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.

[k]Concentrations in fish filets of Aroclor 1260 in μg/g.

[l]Percent lipids reported for that sample.

[m]Percent recovery represents the percent difference between the quantity of Aroclors added to spike samples and the quantity reported as recovered.

Appendix D

SPECIES CHARACTERISTICS, DENSITY, AND BIOMASS FOR FISH COMMUNITY DATA COLLECTED FROM BIG BAYOU CREEK, LITTLE BAYOU CREEK, AND MASSAC CREEK DURING MARCH AND SEPTEMBER 1995

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]
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		
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	
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	
Tadpole madtom (*Noturus gyrinus*)	INTOL	BIN	
Freckled madtom (*Noturus nocturnus*)	INTOL	BIN	
Grass pickerel (*Esox americanus vermiculatus*)		PIS	
Pirate perch (*Aphredoderus sayanus*)		BIN	
Green sunfish (*Lepomis cyanellus*)	TOL		
Warmouth (*Lepomis gulosus*)		GEN	
Bluegill (*Lepomis macrochirus*)		GEN	

Table D.1 (continued)

Species	Tolerance[a]	Feeding guild[b]	Lithophilic spawner[c]
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 conditions.

Table D.2. Fish densities in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March 1995

Measurement expressed as number per square meter

	Sites[a]				
Species[b]	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Stoneroller	0.07	0.73	1.85	0.21	0.63
Red shiner	-	-	0.05	1.26	-
Steelcolor shiner[c]	-	-	-	-	0.01
Redfin shiner[c]	<0.01	0.02	0.13	0.10	0.25
Golden shiner	-	-	-	0.01	-
Bluntnose minnow	-		0.24	0.27	0.24
Creek chub	-	0.01	0.50	0.14	0.15
White sucker	<0.01	-	-	-	<0.01
Creek chubsucker	-	-	0.02	-	0.02
Spotted sucker	<0.01	-	-	-	-
Golden redhorse	<0.01	-	-	-	-
Yellow bullhead	<0.01	-	0.07	-	0.01
Pirate perch	-	-	-	-	<0.01
Blackspotted topminnow	0.02	0.03	0.15	0.13	0.18
Western mosquitofish	-	-	-	0.08	-
Green sunfish	0.02	<0.01	0.04	0.01	0.06
Warmouth	-	-	-	<0.01	<0.01
Bluegill	0.01	<0.01	0.02	<0.01	0.01
Longear sunfish	0.13	0.04	0.72	0.01	0.52
Hybrid sunfish	<0.01	-	-	-	-
Spotted bass	0.01	-	-	-	<0.01
Slough darter	-	-	-	0.01	<0.01
Logperch	-	-	-	-	<0.01
Blackside darter	-	-	-	-	<0.01
Total density	0.27	0.83	3.79	2.23	2.09

[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 in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March 1995

Values expressed as grams of fish per square meter

Species[b]	Sites[a]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Stoneroller	0.31	5.40	5.74	0.83	0.90
Red shiner	-	-	0.07	0.37	-
Steelcolor shiner[c]	-	-	-	-	0.01
Redfin shiner[c]	<0.01	0.03	0.09	0.11	0.14
Golden shiner	-	-	-	0.01	-
Bluntnose minnow	-	0.20	0.20	0.40	0.25
Creek chub	-	0.09	1.12	0.47	0.25
White sucker	0.72	-	-	-	0.53
Creek chubsucker	-	-	0.17	-	0.04
Spotted sucker	0.51	-	-	-	-
Golden redhorse	0.75	-	-	-	-
Yellow bullhead	0.03	-	1.06	-	0.17
Pirate perch	-	-	-	-	0.03
Blackspotted topminnow	0.01	0.05	0.16	0.08	0.23
Western mosquitofish	-	-	-	0.03	-
Green sunfish	0.62	<0.01	0.24	<0.01	0.46
Warmouth	-	-	-	<0.01	0.02
Bluegill	0.06	0.03	0.11	<0.01	0.11
Longear sunfish	1.86	0.60	2.20	<0.01	1.58
Hybrid sunfish	0.10	-	-	-	-
Spotted bass	1.55	-	-	-	0.23
Slough darter	-	-	-	0.01	<0.01
Logperch	-	-	-	-	0.04
Blackside darter	-	-	-	-	0.01
Total biomass	6.52	6.4	11.16	2.31	5.00

[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 in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, September 1995

Measurement expressed in number per square meter

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	-	<0.01
Stoneroller	2.25	7.12	1.21	0.46	1.89
Red shiner	<0.01	-	-	0.64	-
Steelcolor shiner[c]	-	-	-	-	0.07
Common carp	<0.01	-	-	-	0.01
Miss. silvery minnow	0.05	<0.01	-	0.01	0.43
Ribbon shiner	-	-	-	0.02	0.07
Redfin shiner[c]	0.02	-	0.03	0.04	0.09
Golden shiner	<0.01	-	-	0.01	-
Suckermouth minnow	-	-	-	0.02	-
Bluntnose minnow	0.03	<0.01	0.21	1.68	0.22
Fathead minnow	-	-	<0.01	-	-
Creek chub	0.14	0.11	0.38	0.74	0.13
White sucker	-	-	0.01	-0.23	0.01
Creek chubsucker	0.01	<0.01	0.02		0.25
Bigmouth buffalo	<0.01	-	-		-
Spotted sucker	0.01	-	-		<0.01
Golden redhorse	-	-	-		0.01
Yellow bullhead	0.02	0.02	0.12		0.02
Pirate perch	<0.01	-	<0.01	0.01	0.02
Blackspotted topminnow	0.23	0.33	0.36	0.24	0.34
Western mosquitofish	0.08	0.31	0.08	0.83	0.04
Green sunfish	0.04	0.08	0.27	0.06	0.19
Bluegill	0.04	0.03	0.04	0.01	0.07
Longear sunfish	0.50	0.40	0.46	0.02	0.80
Redspotted sunfish[c]	-	-	-	<0.01	-
Hybrid sunfish	<0.01	-	<0.01	-	<0.01
Spotted bass	0.01	0.01	-	-	<0.01
Largemouth bass	<0.01	0.03	0.03	0.01	0.01
White crappie	<0.01	-	-	-	-
Slough darter	-	-	-	0.06	-
Logperch	-	<0.01	-	-	0.06
Blackside darter	-	-	-	-	0.02
Total density	3.45	8.44	3.21	5.09	5.14

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

Table D.5. Fish biomass (g fish/m²) in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, September 1995

Values expressed as grams of fish per square meter

Species[b]	Sites[a]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Gizzard shad	0.82	-	1.12	-	0.37
Stoneroller	3.29	19.43	3.32	0.66	5.53
Red shiner	<0.01	-	-	0.49	-
Steelcolor shiner[c]	-	-	-	-	0.17
Common carp	0.96	-	-	-	0.30
Miss. silvery minnow	0.16	0.01	-	0.07	1.40
Ribbon shiner	-	-	-	0.03	0.04
Redfin shiner[c]	0.01	-	0.04	0.06	0.13
Golden shiner	0.02	-	-	0.04	-
Suckermouth minnow	-	-	-	0.09	-
Bluntnose minnow	0.05	<0.01	0.56	2.23	0.33
Fathead minnow	-	-	0.01	-	-
Creek chub	0.54	0.58	2.10	3.19	0.64
White sucker	-	-	0.15	-	0.21
Creek chubsucker	0.08	0.05	0.54	-	2.56
Bigmouth buffalo	0.77	-	-	-	-
Spotted sucker	1.81	-	-	-	0.02
Golden redhorse	-	-	-	-	0.13
Yellow bullhead	0.18	0.53	1.68	1.34	0.24
Pirate perch	0.01	-	0.01	0.02	0.05
Blackspotted topminnow	0.29	0.43	0.37	0.32	0.48
Western mosquitofish	0.02	0.13	0.02	0.24	0.02
Green sunfish	0.35	0.58	1.07	0.25	1.13
Bluegill	1.45	0.55	0.51	0.01	0.32
Longear sunfish	9.85	5.70	3.19	0.04	4.93
Redspotted sunfish[c]	-	-	-	0.10	-
Hybrid sunfish	0.03	-	0.06	-	0.09
Spotted bass	1.02	0.09	-	-	0.02
Largemouth bass	0.41	0.57	0.44	0.10	0.18
White crappie	0.09	-	-	-	-
Slough darter	-	-	-	0.04	0.01
Logperch	-	<0.01	-	-	0.17
Blackside darter	-	-	-	-	0.03
Total biomass	22.21	28.65	15.19	9.32	19.50

[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]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 1995

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 1995

Taxon	Site[a,b]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Coelenterata					
Hydrozoa				-	-
Hydridae				-	-
Hydra	1	1,2	2	-	-
Turbellaria					
Planariidae	1,2,3,4	1,2,3,4	1,2,3,4	1,3,4	3,4
Nemertea	1,2,3,4	1,2,3	1,2,3,4	1,2,3	1,3,4
Nemertea?	-	-	2	-	-
Nematomorpha	-	-		-	
Gordiidae	-	-		-	
Gordius	-	-	4	-	4
Nematoda	1,4	1	1,2,4	1,2,3,4	1,2,4
Annelida					
Hirudinea					
Glossiphoniidae					
Helobdella	-	2,3	3	-	-
Oligochaeta	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Branchiura	-	-	-		
sowerbyi	2,3,4	-	-	1	-
Crustacea					
Amphipoda			-	-	-
Talitridae			-	-	-
Hyalella azteca	1	1,2	-	-	-
Decapoda					1
Hydracarina	1,4	1,4	4	2,3,4	2,4
Hydrachnidae	-	-	1	1,3	1,3
Hygrobatidae					
Atractides	1	-	1	-	1
Hygrobates	1,2,3	1,2,3	1	1	-
Lebertiidae	-	-	-	-	-
Lebertia	-	-	-	3	1
Limnesiidae	-	-	-	-	
Limnesia	-	2	-	-	-
Pionidae		-	-	-	-
Piona	1	-	-	-	-
Torrenticolidae					
Torrenticola	1,3	1,2,3	3	1,2,3	1,2,3

Table E.1 (continued)

Taxon	Site[a,b] BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Insecta					
Ephemeroptera				3	
Baetidae	1,3	1,2,4	1,4	1,3,4	1,2,3
Baetis	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Centroptilum	4	4	4	4	-
Paracloeodes	-	4	-	-	-
Pseudocloeon	--		1	-	-
Caenidae					
Caenis	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Ephemerellidae		-	-	-	-
Eurylophella	2	-	-	-	-
Ephemeridae		-	4	-	-
Hexagenia	4	-	-	-	-
Heptageniidae	1	1,2,3,4	1,4	1	1
Stenacron	-	2,4	3,4	4	-
Stenonema	1,2,3,4	1,2,3,4	1,3,4	4	1,2
Oligoneuridae			-	-	-
Isonychia	1,3	1	-	-	-
Tricorythidae				-	
Tricorythodes	1,2,3,4	1,2,3	3	-	4
Odonata		1,2	2		
Anisoptera					
Corduliidae/Libellulidae	-	-	4	-	-
Gomphidae		-	-	3	-
Dromogomphus	1	-	-	-	-
Progomphus	-	-	-	1,3,4	1
Libellulidae	-		-	-	-
Erythemis simplicicollis	-	1	-	-	-
Libellula	-	1	-	-	-
Macromiidae	-				-
Macromia	-	1	4	3,4	-
Zygoptera	1	1			
Calopterygidae	-				
Calopteryx	-	-	1	1	1
Hetaerina	-	1	-	1	-
Coenagrionidae		1			
Argia	1,3,4	1,2,4	4	2,3	2
Enallagma	-	1	-	-	-
Ischnura	-	1	1	-	-
Plecoptera	1	1	1,3	1,2	1
Capniidae		3	1,3	1	1,3
Allocapnia	3	3	2,3,4	2,4	2,3,4

Table E.1 (continued)

Taxon	Site[a,b] BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Chloroperlidae	-	-	-		-
Haploperla	-	-	-	2	-
Leuctridae	-	-	3	-	-
Nemourida	3	-	2		3
Amphinemura	-	-	1,2,4	1	1,4
Perlidae	-		-	-	-
Eccoptura?	-	4	-	-	-
Perlidae/Perlodidae	-	-	4	-	-
Perlodidae	-	-		2,4	
Isoperla	-	-	1,4	2	4
Megaloptera					
Corydalidae					
Corydalus					
cornutus	3,4	1,3	1,3	1,2,3	4
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	1,2,3,4	1,3,4	1,2,3,4	1,2,3,4
Hydropsyche	1,2,4	4	1,2,3,4	1,2,3,4	1,3,4
Hydroptilidae	4	4	2		
Hydroptila	1,4	1,4	1,2,4	1,2,3,4	4
Leptoceridae					4
Oecetis	1,4	1	1,4	1,3,4	1
Oecetis?	-	-	-	4	-
Molannidae	-	-	-	-	
Molanna	-	-	-	-	4
Philopotamidae	3				
Chimarra	1,2,3	1,2,3,4	1,2,3,4	1,2,4	1,3,4
Polycentropodidae	3	-		-	-
Polycentropus	-	-	1	-	-
Coleoptera		4			
Elmidae	1				
Dubiraphia	1,4	3	1,2,3	1,2,3,4	-
Optioservus	-	-	2	-	1
Stenelmis	1,2,3,4	1,3,4	1,3	1,2,3,4	1,3,4
Gyrinidae	-	-	-		
Dineutus	-	-	-	1	1
Haliplidae	-		-	-	-
Peltodytes	-	1	-	-	-
Hydrophilidae		2			
Berosus	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Enochrus	-	1	-	-	-

Table E.1 (continued)

Taxon	Site[a,b] BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Hydrobius	-	-	-	1	-
Psephenidae	-		-	-	
Ectopria	-	4	-	-	-
Diptera			3	1	1
Ceratopogonidae	1,4	3,4	1,2,3,4	3,4	2,3,4
Atrichopogon	-	1,2	1,2	-	-
Bezzia	1	1	1,2	1	1,2,3
Culicoides	1	1	1	1,3	-
Dasyhelea	-	4	4	4	-
Monohelea	1	1	-	-	-
Palpomyia	-	-	1	-	1
Probezzia	1	-	-	1	-
Chaoboridae		-	-	-	
Chaoborus	3	-	-	-	3
Chironomidae	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Chironomini	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Orthocladiinae	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Tanypodinae	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Tanytarsini	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Dolichopodidae	-	4	-	-	-
Empididae					
Chelifera	1	1	1	-	-
Hemerodromia	1,2,4	1,2,3,4	1,2,3,4	1,2,4	3,4
Phoridae	3	-	-	-	-
Simuliidae	1		2,3	2	
Prosimulium	-	-	-	-	4
Simulium	1,2,3,4	1,2,3,4	1,2,4	1,2,4	1,2,3,4
Stegopterna	-	-	2,4	-	4
Tabanidae					-
Chrysops	4	-	3	-	-
Tabanus	1	1	-	1	-
Tipulidae	-	1,2	2	-	3
Erioptera	-	1	3	-	1
Erioptera?	-	-	-	4	-
Helius	-	1	-	-	-
Limonia	-	-	-	2	-
Tipula	-	2	1,2,4	1	-
Mollusca					
Gastropoda	4	4			
Ancylidae				1,3	1,3
Ferrissia fragilis	1	1	1,4	1,3,4	3,4
Hydrobiidae	-	-	-	1	-
Lymnaeidae	-	-	-	1	
Fossaria	-	-	-	1	-

Table E.1 (continued)

Taxon	Site[a,b] BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Pseudosuccinea					
collumella	-	-	-	3	1
Physidae			-		
Physella	4	1,3		1,2,4	1,2,4
Planorbidae		1,3			4
Gyraulus			-	-	-
deflectus	1	-	-	-	-
parvus	1	3	-	-	-
Menetus			-		
dilatatus	1,3	1,3	-	1,4	1,4
Bivalvia		-	-		
Corbiculidae		-	-		-
Corbicula					
fluminea	1,2,3	-	-	4	-
Sphaeriidae	2	-	-	2,3	-
Musculium	1,2	-	-	3,4	-
Pisidium	-	-	-	1,3	3
Sphaerium	1	-	-	-	-

[a]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.
[b]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, and 4 = September 1994–March 1995. A blank indicates that a lower level of classification (e.g., family, genus, or species) was possible, and a dash (-) indicates that the taxon was not collected.

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