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MARTIN MARIETTA

ENVIRONMENTAL SCIENCES DIVISION

Report on the Biological Monitoring Program at Paducah Gaseous Diffusion Plant December 1990 to November 1992

L. Adams Kszos
Editor

Environmental Sciences Division
Publication No. 4059

March 1994

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

ANOVA	analysis of variance
BMP	Biological Monitoring Program
BBK	Big Bayou Creek kilometer
DOE	Department of Energy
ESD	Environmental Sciences Division
EPA	Environmental Protection Agency
FDA	U.S. Department of Agriculture Food and Drug Administration
GC/ECD	gas chromatography/electron capture detection
GLM	general linear model
HC	Humphrey Creek
HINDSCR	Hinds Creek
IC	inhibition concentration
ICP	inductively coupled plasma spectroscopy
IRIS	Integrated Risk Information System
KDOW	Kentucky Division of Water
KPDES	Kentucky Pollutant Discharge Elimination System
LUK	Little Bayou Creek kilometer
MAK	Massac Creek kilometer
NCBP	National Contaminant Biomonitoring Program
NOEC	no-observed-effect concentration
NPDES	National Pollutant Discharge Elimination System
ORNL	Oak Ridge National Laboratory
PCB	polychlorinated biphenyls
PGDP	Paducah Gaseous Diffusion Plant
QA	quality assurance
RGA	regional gravel aquifer
SAS	statistical analysis system
TU	toxicity units
TU_c	chronic toxicity units

UK	University of Kentucky
USGS	U.S. Geological Service
UV	ultraviolet light
WKWMA	West Kentucky Wildlife Management Area
YOY	young of year

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This project was funded by the Department of Air and Water Policy, Paducah Gaseous Diffusion Plant. The Paducah Gaseous Diffusion Plant and Oak Ridge National Laboratory are managed by Martin Marietta Energy Systems, Inc., under contract DE-AC05-84OR21400 with the U.S. Department of Energy.

EXECUTIVE SUMMARY

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 implemented in 1987 by the University of Kentucky. Research staff of the Environmental Sciences Division (ESD) at Oak Ridge National Laboratory (ORNL) served as reviewers and advisers to the University of Kentucky. Beginning in fall 1991, ESD/ORNL added data collection and report preparation to its responsibilities for the PGDP BMP. 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 health and environmental impacts, (3) document the effects on stream biota resulting from operation of pollution abatement facilities, and (4) make recommendations on any necessary improvements for 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 DOE facilities at PGDP is required under draft DOE Order 5400.1. Data collected under BMP will also be used to support three 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 includes ESD/ORNL activities occurring from December 1990 to November 1992.

Study Area

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 011 to Little Bayou Creek. Effluent from Outfalls 013, 015, 016, 017, and 018 regularly discharge to Big Bayou and Little Bayou creeks during rainfall events.

Prior to ORNL's initiation of the instream monitoring task, a site selection study was conducted in early December 1990. This study included visits to 24 potential reference stream sites located outside the boundaries of the PGDP and 5 stream sites adjacent to the PGDP. Based on the site visits, biota surveys, and previous work conducted by the University of Kentucky, five stream sites were included in the Ambient Toxicity monitoring and Instream Monitoring tasks.

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. 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 effluents evaluated for toxicity included 001, 004, 006, 008, 009, 011, 013, 015, 016, 017, and 018.

Toxicity Monitoring

Ceriodaphnia and fathead minnow toxicity tests of effluents from the continuously flowing outfalls (001, 004, 006, 008, 009 and 011), the intermittently flowing outfalls (013, 015, 016, 017, and 018), and ambient sites (BBK 12.5, BBK 10.0, BBK 9.1, LUK 7.2, and MAK 13.8) were conducted quarterly beginning in October 1991. All of the ambient sites and outfalls except 016 were evaluated five times; outfall 016 was evaluated four times. Tests with *Ceriodaphnia* and fathead minnows were typically conducted concurrently. No-observed-effect concentrations (NOEC; that concentration causing no reduction in survival or growth of fathead minnows or survival or reproduction of *Ceriodaphnia*) and the 25% inhibition concentrations (IC25; that concentration causing a 25% reduction in fathead minnow growth or *Ceriodaphnia* survival compared to a control) were determined for each test. The NOEC was used as a compliance endpoint for tests conducted under the draft Agreed Order (prior to September 1992). The lower the NOEC, the more toxic an effluent. The chronic toxicity unit (TU_c=100/IC25) is required as a compliance endpoint in the renewed permit (September 1992 to present). Because Little Bayou and Big Bayou creeks have been determined to have a low flow of zero, an NOEC < 100% effluent or a TU_c of > 1.2 would be considered a noncompliance and an indicator of potential instream toxicity.

Effluent samples from the continuous outfalls were rarely toxic (NOEC < 100% or TU_c > 1.2) to *Ceriodaphnia*, and effluent from the intermittent outfalls was never toxic to *Ceriodaphnia*. When toxicity was observed in the outfalls, no toxicity was observed in the ambient sites. Effluent samples from the continuous and intermittent outfalls were occasionally toxic (NOEC < 100% or TU_c > 1.2) to fathead minnows. Effluents from all of the continuous outfalls except 001 were toxic in February 1992. However, during this same test period, fathead minnow survival was reduced only at BBK 12.5 (above PGDP) and LUK 7.2. It is hypothesized that a pathogenic organism(s) is the cause of low fathead minnow survival at these sites because treatment with ultraviolet light eliminated the toxicity. Likewise it was hypothesized that a natural pathogen was the cause of "toxicity" to fathead minnows at all sites during the October 1991 test. Toxicity observed in the effluent samples from outfalls 004, 006, 008 and

009 was not present at the ambient sites. Effluent from Outfall 009 was also toxic to fathead minnows in October 1992, but no instream toxicity was observed at BBK 9.1. Toxicity of the intermittent outfalls may be due to high levels of suspended solids. Ambient toxicity tests were not conducted concurrently with the intermittent outfalls. Tests with filtered and nonfiltered effluent during 1993–94 will provide additional insight into the toxicity of the intermittent outfalls.

Bioaccumulation

The objectives of the bioaccumulation monitoring were (1) to continue polychlorinated biphenyl (PCB) tracking studies in fish from Big Bayou Creek and Little Bayou Creek; (2) to confirm elevated mercury concentrations in fish in Big Bayou Creek and establish appropriate reference site concentrations; and (3) to conduct screening analyses to detect other contaminants that might be of concern to consumers of fish from these streams.

Longear sunfish were collected for PCB and mercury analysis from Big Bayou Creek, Little Bayou Creek, and Massac Creek during April 1992. Hinds Creek (Anderson County, Tennessee) served as a source of uncontaminated reference fish. PCB contamination was evident in longear sunfish collected from both Big Bayou and Little Bayou creeks. Mean PCB concentrations in sunfish from sites downstream of PGDP discharges exceeded those from the reference sites. The highest mean PCB concentration occurred in fish from the site in Little Bayou Creek immediately downstream from outfall 011. In Big Bayou Creek, the highest mean PCB concentration was found in fish from BBK 9.1, below outfall 001, but fish from BBK 10.0 also contained PCB contamination. For both creeks, there was a strong downstream gradient in PCB contamination in sunfish. Along with a close association between degree of contamination and proximity to outfalls demonstrated to be PCB sources in the past, this 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. Continued regular monitoring of PCB concentrations in fish are needed to detect any consistent trend over time.

Mean concentrations of mercury in redbreast sunfish from the Tennessee reference site (Hinds Creek) were less than 50% of those observed at any local reference site (Big Bayou Creek or Massac Creek). Mercury concentrations in fish from sites in Big Bayou Creek below PGDP were similar and exceeded that in local reference site fish. The slightly 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.

Concentrations of metals measured in filets of longear sunfish from Big Bayou Creek and Little Bayou Creek are typical of those observed in previous monitoring and generally differ little (with several exceptions) from concentrations observed in fish from the Tennessee reference site. Concentrations of As, Cd, Cu, Pb, Se, and Zn were similar to or lower than the national geometric mean concentrations observed for whole body analyses of fish in the USFWS National Contaminant Biomonitoring Program. Concentrations of Sb, Cd, Cr, Ni, Se, and Ag were well below screening levels used in the Environmental

Protection Agency (EPA) Integrated Risk Information System (IRIS). Beryllium and arsenic were not detected in PGDP fish (beryllium detection limit was at the IRIS screening level; arsenic detection limit was 10× screening level). Those metals for which IRIS screening levels are not published (Cu, Pb, Tl, U, and Zn) were found at concentrations similar to or lower than typically occur in food such as marine fish or mammalian muscle (Bowen 1979). Detection of elevated concentrations of uranium in fish from Little Bayou Creek is consistent with the observed elevated concentrations of uranium in this creek.

Ecological Monitoring

Beginning in September 1991, benthic macroinvertebrate samples were collected at quarterly intervals from five stream sites. The services of a subcontractor will be retained during summer 1993 to process invertebrate samples. Samples are currently being stored and maintained at a benthic invertebrate sample chain-of-custody facility at ORNL in Oak Ridge, Tennessee. Processing will involve (1) sorting the invertebrates from the debris in each sample, (2) identifying taxa to the lowest practical level (genus in most cases), and (3) enumerating the individuals within each taxon.

Fish population and community studies can be used to assess the ecological effects of changes in water quality and habitat. The initial 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 Creek and Big Bayou Creek and (2) to document the effects of PGDP operations on fish community structure and function. Quantitative sampling of the fish populations at four sites in the Bayou 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 from September 22 to 25, 1991 and from March 15 to 17, 1992. Data from these samples were used to estimate species richness, population size (numbers and biomass per unit area), length frequency, and condition factors. Qualitative fish sampling was conducted by electrofishing on March 17 and June 9, 1992. Data from these samples were used to determine the species richness and number of specimens (relative abundance) based on sampling a known length of stream.

Data on the fish communities of Big Bayou Creek and Little Bayou Creek downstream of the PGDP were compared to data from reference sites located on Big Bayou above PGDP and on Massac Creek. These comparisons indicated a slight but noticeable degradation in the communities downstream of PGDP. The fish communities at BBK 10.0 and BBK 9.1 showed signs of impact. The fish community at BBK 10.0 had a low mean and total species richness compared to the reference site (MAK 13.8). At both sites, there were few sensitive species at low densities and tolerant species were more common and abundant than at the reference. The presence of hybrid sunfish at both sites indicates that the communities were under some reproductive stress. Finally, condition factors at each site were higher than at MAK 13.8. The high condition factor combined with a large population of central stonerollers at BBK 10.0 indicates that there is some nutrient enrichment at this site.

The fish community at LUK 7.2 was generally in poor condition compared with the BBK 12.5 reference. The mean and total species richness values were low and the community lacked any catostomid species. Sensitive species were absent and several tolerant species were present at considerable densities. Because the site is on a smaller stream, some of these deficiencies might be expected; however, overall the community was poorer than at BBK 9.1 but not as affected as BBK 10.0. The downstream qualitative site, LUK 4.3, did not appear to continue the poor conditions found at LUK 7.2. Species richness was comparable to MAK 13.8, particularly in terms of sensitive species. The community was well represented in all families, except perhaps catostomids, and significant absences in feeding guilds were not demonstrated. The relative abundance and catch per effort data were similar to quantitative data at MAK 13.8 and BBK 9.1.The fish communities associated with PGDP streams indicate depressed conditions. The greatest impacts occurred at sites closest to the plant, which suggests that PGDP effluents may be the cause. The low species richness and few sensitive species can be caused by poor water quality (e.g., high temperatures or chlorine levels) or reflect degraded habitat conditions. Biomass and density respond quickly to improvements in degraded conditions and it will be important to follow changes in these parameters, particularly at the most stressed sites.

1. INTRODUCTION

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 (Birge et al. 1987), 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 for approval. The PGDP BMP was implemented in 1987 and consisted of ecological surveys, toxicity monitoring of effluents and receiving streams, bioaccumulation of trace contaminants in biota and supplemental chemical characterization of effluents. The goals of BMP are to (1) evaluate the acceptability of PGDP effluents under the Kentucky Pollutant Discharge Elimination System (KPDES) regulatory program, (2) characterize their potential health and environmental impacts, and (3) make recommendations on any necessary improvements for effluent treatability. 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 the BMP conducted by the University of Kentucky were presented in a 3-year draft 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/ORNL 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 identifying those effluents with the potential for adversely affecting instream fauna, assessing the ecological health of receiving streams, guiding plans for remediation, and 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 BMP 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. 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) influence of effluent pH on instream pH; and (3) development of site-specific metal limits for outfalls.

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 (e.g., benthic macroinvertebrates and fish). This report includes ESD/ORNL activities occurring from December 1990 to November 1992.

2. DESCRIPTION OF STUDY AREA

2.1 SITE DESCRIPTION

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The PGDP is managed by Martin Marietta Energy Systems, Inc. for DOE. The plant was constructed in 1951 and is an active uranium enrichment facility consisting of a diffusion cascade and extensive support facilities (Kornegay et al. 1992a). 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, maintenance and laboratory facilities, and two active landfills. 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 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 PDGP is mostly rural, with residences and farms surrounding the plant. Immediately adjacent to PGDP is the West Kentucky Wildlife Management Area (WKWMA), a 2821-ha facility made up of natural habitat, state-maintained forage crops, and ponds, which is used by hunters and fishermen. About 20 of the 35 ponds support fishing, and ~ 200 deer are harvested annually.

The population within the 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).

2.1.2 Geohydrology

PGDP is located in the Jackson Purchase region of western Kentucky. It lies in the northern margin of the Mississippi Embayment portion of the Gulf Coastal Plain Province. The Mississippi Embayment was a large sedimentary trough, oriented roughly north-south, which existed during the Cretaceous and Tertiary periods. The sedimentary sequence overlying the Mississippian age bedrock in the vicinity of PGDP consists mainly of fine- to medium-grained clastic materials, including (from youngest to oldest) a basal gravel (i.e., Tuscaloosa Formation) or rubble zone, the McNary Formation, the Porters Creek Clay, and undifferentiated Eocene sands.

Following deposition of the embayment sediments, the embayment was either uplifted and/or sea level lowered, resulting in the development of an erosional surface that truncated the sediments. Subsequently, during the late Tertiary and Quaternary periods, a unit designated as the Continental Deposits was laid down in the region. The Continental

Deposits have been interpreted as originally being deposited in an alluvial fan that covered most of the Jackson Purchase region (Olive 1980). The Continental Deposits have been informally divided into a lower gravel region and an upper silt or clay unit, each unit varies in thickness from 0 to 32 m. The clay facies are believed to consist of discontinuous fine sand lenses enclosed by clay, however, this interpretation is based on limited data and the degree of interconnectedness of the interbedded sand lenses cannot be verified at this time (Kornegay et al. 1992b). Immediately overlying the Continental Deposits, Pleistocene loess (originating as windblown material generated by glacial activity) was deposited in a layer of variable thickness (3–10 m). Recent Ohio River alluvial deposits occur at lower elevations along the river's floodplain.

Current understanding of local groundwater hydrology in the vicinity of PGDP is dominated by the recognized importance of the Continental Deposits. This unit is termed the regional gravel aquifer (RGA) and is the uppermost aquifer underlying most of PGDP and the contiguous area north. This groundwater flow system is primarily developed in Pleistocene sands and gravels of the lower member of the Continental Deposits, ~ 13 to 33 m beneath PGDP. The Continental Deposits rest upon terraces cut by the ancestral Tennessee and Tennessee-Ohio Rivers. Terrace escarpments occurring under the south end of PGDP form the southern limit of the RGA.

Groundwater flow in the loess and the upper member of the Continental Deposits is primarily oriented downward because of the interbedded sand and gravel lenses and the significantly lower potentiometric surface of the RGA. Within the RGA, flow is directed north, discharging into the Ohio River. The hydrology of the RGA was first investigated by the U. S. Geological Service (USGS) in the mid 1960s. Results of these studies indicated that the gravel is saturated over most of its areal extent in the region of the plant, and wells completed within it are reported to be capable of producing yields of up to 3790 L/min. For a more detailed description of the geohydrology of the area, see Kornegay et al. 1992a; CH2M Hill 1991; D'Appolonia 1983; TERRAN 1990; GeoTrans 1990.

2.1.3 Surface Water

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 (Fig. 2.1). Surface drainage from PGDP is two small tributaries of the Ohio River, Big Bayou Creek and Little Bayou Creek. These creeks meet ~ 4.8 km north of the site and discharge to the Ohio River at kilometer 1524, ~ 56 km upstream of the confluence of the Ohio and Mississippi Rivers (Fig. 2.2). PGDP is located on a local drainage divide; surface flow is east-northeast toward Little Bayou Creek and west-northwest towards 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 creeks 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

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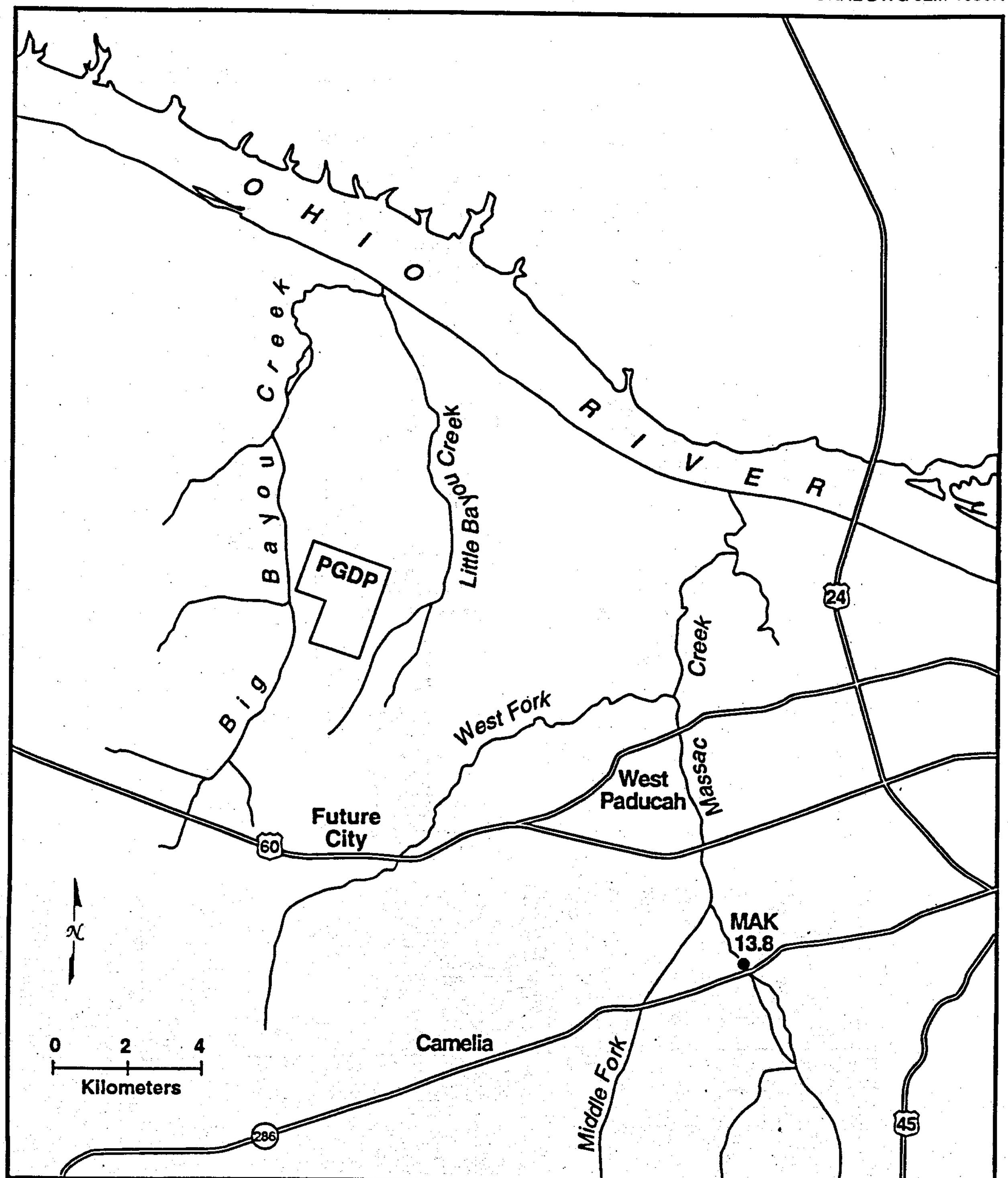

Fig. 2.1. Map showing the location of Paducah Gaseous Diffusion Plant (PGDP) in relation to the geographic region. The reference site for PGDP biological monitoring activities is located on Massac Creek kilometer (MAK) 13.8.

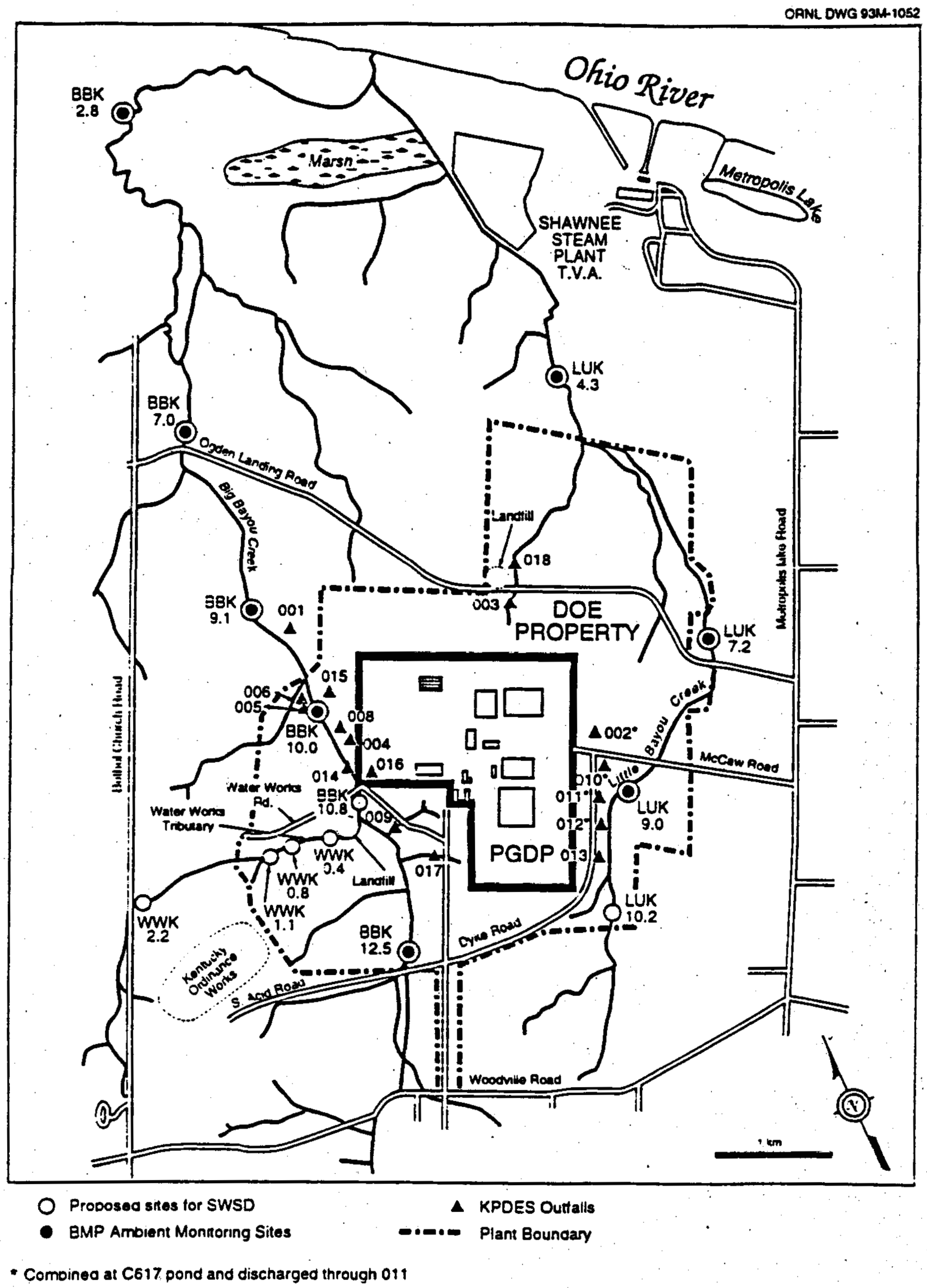

Fig. 2.2. Location of Biological Monitoring Program (BMP) sites and Kentucky Pollutant Discharge Elimination System (KPDES) permitted outfalls for the Paducah Gaseous Diffusion Plant (PGDP). BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; WWK = Water Works Tributary kilometer; TVA = Tennessee Valley Authority.

from PGDP operations can constitute about 85% of the normal flow in Big Bayou Creek and 100% in Little Bayou Creek. During the dry season in 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. 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 liquid effluents at PGDP consist of once-through cooling water, although a variety of liquid 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

R. L. Hinzman and T. G. Jett

The Clean Water Act is currently administered for PGDP by the Kentucky Division of Water (KDOW) through the KPDES Wastewater Discharge Permitting Program. A National Pollutant Discharge Elimination System (NPDES) permit (KY0004049), issued by Region IV of the U. S. Environmental Protection Agency (EPA), became effective February 15, 1975. The NPDES permit was revised February 4, 1977, and expired in 1980. Although PGDP had applied for a new permit, no system was in place at KDOW to replace the NPDES permit and a new permit could not be issued. PGDP operated under the original 1975 NPDES permit until the state of Kentucky issued the KPDES permit (KY0004049). On November 5, 1986, the state permit was adjudicated because the permit limits were not achievable. As part of the negotiations associated with the adjudication process, an Agreed Order was proposed that included interim limits while a biological monitoring study was conducted at PGDP. The KPDES permit expired in October 1991; however, monitoring continues under the KPDES Agreed Order. By submitting permit renewal documents in May 1991, PGDP complied with regulations that allow the continued discharge of wastewater under the auspices of the expired permit.

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 continuously to Little Bayou Creek. These combined discharges averaged ~ 15 × 10^6 L/day and 1.8 × 10^6 L per day to Big Bayou Creek and Little Bayou Creek respectively.

Summary statistics (mean, maximum, and minimum), the number of observations, and the interim limits for KPDES chemical parameters observed at each outfall are given in Appendix A (Tables A.1 to A.15). Water quality in the outfalls was affected by occasional increases in concentrations of some metals (most outfalls), increased concentrations of residual chlorine (outfalls 001, 002, 008, 009, 010, 011), and high pH levels. Mean

Table 2.1. Kentucky Pollutant Elimination System 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	6.2±4.3	Recirculating cooling water blowdown treatment effluent, coal-pile runoff, once-through cooling water, surface runoff, roof and floor drains, treated uranium solutions, sink drains
002	C-360, C-637, C-337-A	0.4±0.6	Once through cooling water, roof and floor drains, sink drains, extended aeration sewage treatment system
003	North edge of plant	2.8	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	1.5±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	2.7±1.1	Water treatment plant sludge, sand filter backwash, laboratory sink drains from outfall 005
007	Outfall eliminated	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	4.5±3.2	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	1.7±4.6	Surface drainage, roof and floor drains, condensate, once-through cooling water, sink drains
010	C-531, C-331	0.3±0.3	Switchyard runoff, roof and floor drains, condensate, sink drains
011	C-340, C-533, C-532, C-315, C-333, C-331	0.5±0.5	Once-through cooling water, roof and floor drains, switchyard runoff, condensate, sink drains
012	C-633, C-533, C-333-A	0.6±1.2	Roof, floor and sink drains, condensate, surface runoff, extended aeration sewage treatment system
013	Southeast corner of the plant	5.3±8.1	Surface runoff
014	C-611 U-shaped sludge lagoon	NM[c]	Sand filter backwash, sanitary water
015	West central plant areas	1.5±3.7	Surface runoff
016	Southwest corner of the plant	4.7±6.3	Surface runoff
017	Extreme south area of the plant	0.8±1.8	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.
[c]NM = Not monitored

Note: This table was taken from Kornegay et al. 1992 (Paducah Gaseous Diffusion Plant Environmental Report for 1991. ES/ESH-22/V3. Oak Ridge National Laboratory, Oak Ridge, Tennessee) and Birge et al. 1992 (Biological Monitoring Program for the Paducah Gaseous Diffusion Plant. Annual Report for Study Period October 1990 through March 31, 1992. University of Kentucky, Lexington, Kentucky).

hardness values at outfall 001 were about twice as high in 1992 than in previous years (Table 5.3 in Birge et al. 1992). A discussion of current water quality monitoring occurs in Sect. 3 of this report. Discussions of previous water quality monitoring efforts 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. No flow occurred at outfall 003 in 1991; therefore, no monitoring data were collected. 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 to experience any discharge. Outfall 014 was not monitored in 1991. Monitoring of this U-shaped lagoon occurs only when the C-611 sludge lagoon is dredged (i.e., every 2 or 3 years), and the filter backwash is discharged to outfall 014.

The number of KDPES noncompliances at PGDP under the Agreed Order has steadily declined over the last 3 years; there were 33, 24 and 16 noncompliances in 1990, 1991 and 1992 respectively. One residual chlorine noncompliance occurred in 1991 (compared with 12 in 1990) due to inadequate sodium thiosulfate feed at outfall 010. There was also one unexplained residual chlorine noncompliance at outfall 001 in 1992; the KPDES limit was exceeded by 0.001 ppm. There were four suspended-solids noncompliances in 1991 and two in 1992; all were the results of heavy rain suspending sediment in effluent waters. The holding time for a turbidity sample was exceeded in 1992, resulting in a noncompliance. One iron and one chromium noncompliance occurred in 1991 due to soil disturbance during construction activities. There were 16 temperature noncompliances and one temperature-related dissolved oxygen noncompliance in 1991. The temperature noncompliances were related to heat in once-through cooling water and steam condensate discharges. Four pH exceedances occurred in 1992; one was the result of a malfunction in the water treatment facility, and the others were attributed to algal blooms in holding lagoons. Three trichloroethylene noncompliances occurred in 1992 when samples were discarded before the results were received from the laboratory. One recirculating cooling water spill and one chilled water spill occurred in 1992 and were attributed to mechanical failures. Three unpermitted discharge violations occurred in 1992.

Corrective measures have been taken to reduce the number of KPDES noncompliances at PGDP. Emphasis has been placed on erosion control at construction sites, effluent ditches, and landfills. A best management practices plan for the control of suspended solids, prepared in 1991, details measures taken to prevent erosion and investigates erosion-related problems and corrective measures. The plan was submitted to and approved by the KDOW. The Plant Effluent Chlorine and Temperature Control Project became operational in October 1991. The project provided a common lagoon (C-617) for outfalls 002, 010, 011, and 012. This lagoon, designed to contain effluent from the outfall except during heavy rainfall, provides sodium thiosulfate feed for chlorine removal and increased holding time for temperature reduction. Sodium thiosulfate feed stations were installed permanently at outfalls 009 and 004. Once-through cooling water that originally flowed through outfall 001 is now routed through the C-616 full-flow lagoon to allow for chlorine dissipation. In response to temperature noncompliances, leaking steam traps in several buildings were repaired or replaced and temperature noncompliances ceased.

2.3 DESCRIPTION OF STUDY SITES

J. G. Smith, M. J. Peterson, and M. G. Ryon

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 and to evaluate ambient toxicity. A summary of the site locations is given in Table 2.2. Three additional sites (BBK 2.8, LUK 9.0, and LUK 4.3; Fig 2.2) were sampled as part of the bioaccumulation monitoring task. Hinds Creek in East Tennessee also served as a reference site for the bioaccumulation monitoring task. A description of the sampling locations for the bioaccumulation monitoring is provided in Sect. 4. Site selection and sampling locations for the ecological monitoring studies are described below. Ambient toxicity monitoring sites were chosen to correspond with those used for ecological monitoring. Biological monitoring activities conducted through December 1992 are outlined in Table 2.3. 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 whose effluents were evaluated for toxicity included 001, 004, 006, 008, 009, 011, 013, 015, 016, 017, and 018.

Prior to ORNL's initiation of the instream monitoring task for the PGDP BMP, a site selection study was conducted in early December 1990. This study included visits to 24 potential reference stream sites located outside the boundaries of PGDP (Table 2.4), and 5 stream sites adjacent to PGDP: LUK 7.2, LUK 4.3, BBK 12.5, BBK 9.1, and the tributary draining Outfall 003. The site selection study also involved the collection of qualitative benthic macroinvertebrate and fish samples at some of the sites to aid in final site selection.

Checklists of invertebrates and fishes collected from selected sites during the site selection survey are presented in Tables 2.5 and 2.6 respectively. Because these samples were qualitative, the results serve primarily to document that these taxa were present at these sites at the time of the survey. However, these qualitative data did provide some minimal information on the relative health of each stream sampled and, thus, helped in making final site selections.

Based on the site visits, biota surveys, and previous work conducted by the University of Kentucky (Birge et al. 1990), five stream sites were included in the instream monitoring task of the BMP. A list of the selected sites and a summary of their locations are given in Table 2.2; their locations in relation to the PGDP are shown in Fig. 2.1 and Fig. 2.2. Final sampling locations within each selected site were made in June 1991 during a habitat characterization study. This study included measurements of vegetative cover, bank structure, channel morphology, substrate and cover variables, and flow conditions. Pertinent results of this study for each site are presented in the sections following. Available water quality data, obtained during the routine collection of benthic

Table 2.2. Locations and names of sampling sites included in Paducah Gaseous Diffusion Plant Biological Monitoring Program for the Instream Monitoring Task

University of Kentucky Stream name/site	Location[a]	Permanent site name[b]
Big Bayou Creek		
BB1	~200 m downstream of bridge on South Acid Road	BBK 12.5
BB4	~50 m upstream of Outfall 006	BBK 10.0
BB7	~25 m upstream of flume at gaging station at Bobo Road	BBK 9.1
Little Bayou Creek		
LB3	~110 m downstream of bridge on Route 358	LUK 7.2
Massac Creek		
Not sampled	~40 m upstream of bridge on Route 62, 10 km SE of PGDP	MAK 13.8

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

[b]Site names are based on stream name and distance of the site from the mouth of the stream. For example, BB7 is designated as Big Bayou Creek Kilometer (BBK) 9.1 and is located 9.1 km upstream of the mouth; LUK = Little Bayou Creek kilometer; and MAK = Massac Creek kilometer.

Table 2.3. Sampling schedule for the four components of the Biological Monitoring Program at Paducah Gaseous Diffusion Plant for September 1991 through December 1992

Month	Toxicity monitoring	Benthic macroinvertebrates	Fishes	Bioaccumulation
1991				
Sept.		X	X	
Oct.	X			X
Nov.				
Dec.		X		
1992				
Jan.				
Feb.	X			
Mar.		X	X	X
Apr.				
May	X			
June		X		
July				
Aug.	X			
Sept.		X	X	X
Oct.				
Nov.	X			
Dec.		X		

Table 2.4. Location of the 24 potential reference sites for Paducah Gaseous Diffusion Plant Biological Monitoring Program that were visited on December 4–6, 1990

Drainage	General location		Specific location		
	Direction from PGDP	County	Stream	Location[a]	USGS[b] quadrangle
Clinton Creek	W	Ballard (N of Route 60)	Clinton Creek	3 km S of Monkey's Eyebrow	Bandana
			Hanley Creek	1 km S of Bandana on Route 358	Bandana
			Hanley Creek	1 km N of Bandana on Route 358	Bandana
Humphrey Creek	SW	Ballard (S of Route 60)[a]	Humphrey Creek	1 km E of Hinkelville	La Center
			Humphrey Creek	Route 60 E of La Center	La Center
			Humphrey Creek	Route 358 N of La Center	La Center
			Humphrey Creek	3 km SE of La Center	La Center
			Little Humphrey Creek	Route 358 N of La Center	La Center
Champion Creek	SE	McCracken	Champion Creek	Route 994	Paducah West
Massac Creek	E	McCracken	Massac Creek	0.2 km E of Maxon on Route 786/305	Paducah West
			Massac Creek	4 km SW of I-25 on Route 60	Paducah West
			Massac Creek	Route 62 at USGS gaging station	Paducah West
			Massac Creek	Route 1322	Paducah West
			Middle Fork	Route 62	Paducah West
Massac Creek	E	McCracken	Middle Fork	Route 1322	Paducah West
			West Fork	Biggs Road and Route 996	Heath
			West Fork	Routes 996 and 726	Heath
			West Fork	0.5 km E of Future City on Route 60	Heath
			West Fork	1.3 km E of Health on Route 724	Heath
			Little Massac Creek	0.5 km E of Lamont on Route 996	Heath
			Black Branch	Route 60	Paducah West
Newton's Creek	NW	McCracken	Newton's Creek	Grief Road	Joppa
			Nasty Creek	Grief Road	Joppa
Big Bayou Creek	NW	McCracken	Brushy Creek	Bethel Church Road 1.4 km S of Route 358	Joppa

[a]All sites were located at road crossings (bridges) except the two sites on Route 358, north of La Center.
[b]USGS = U.S. Geological Service.

Table 2.5. Results of qualitative survey of benthic macroinvertebrates in Little Bayou Creek, Big Bayou Creek, outfall 003, and potential reference sites, including Humphrey Creek and Massac Creek, December 3–6, 1990
"X" = taxon was collected

Taxon	Site[a]						
	LUK 7.2	LUK 4.3	BBK 12.5	BBK 9.1	Outfall 003	HC	MAK 13.8
Bryozoa?	X	–	–	–	–	–	X
Turbellaria							
Planariidae	–	–	X	X	–	–	–
Crustacea							
Cladocera	–	X	X	X	–	–	–
Copepoda	–	–	–	X	–	–	–
Ostracoda	–	–	–	X	–	–	–
Isopoda							
Asellidae							
Caecidotea	–	–	X				
Lireus	–	–	X	–	–	X	X
Amphipoda				–	–	–	–
Gammaridae							
Crangonyx	–	–	X	–	–	X	X
Talitridae							
Hyalella azteca	–	–	X	X	–	–	–
Decapoda							
Cambaridae							
Procambarus	–	–	X	–	–	–	X
Hydracarina	–	–	X	X	–	–	X
Insecta							
Ephemeroptera							
Baetidae							
Baetis	X	X	X	X	–	X	X
Cloeon	–	X	X	X	–	X	X
Caenidae							
Caenis	X	X	X	X	–	X	X
Ephemeridae							
Hexagenia	–	–	X	–	–	–	–
Heptageniidae							
Stenacron	X	X	–	–	–	X	–
Stenonema	X	–	X	X	–	X	X
Leptophlebiidae							
Leptophlebia?	–	–	–	–	–	–	X
Odonata							
Anisoptera							
Corduliidae							
Tetragoneuria	–	–	X	–	–	–	–
Gomphidae							
Gomphus	–	–	–	X	–	–	–
Progomphus	X	–	–	–	–	–	–

Table 2.5 (continued)

Taxon	LUK 7.2	LUK 4.3	BBK 12.5	BBK 9.1	Outfall 003	HC	MAK 13.8
	Site[a]						
Libellulidae							
Plathemis	–	–	–	X	–	–	–
Macromiidae							
Macromia	X	–	–	X	–	–	–
Zygoptera							
Calopterygidae							
Calopteryx	X	X	X	X	–	X	X
Coenagrionidae							
Argia	X	X	X	X	–	–	–
Enallagma	X	–	X	X	–	–	X
Plecoptera							
Capniidae							
Allocapnia	X	X	X	X	X	X	X
Nemouridae?	–	–	–	–	–	X	–
Taeniopterygidae							
Taeniopteryx	–	X	–	–	–	X	X
Hemiptera							
Belostomatidae							
Belostoma	–	–	–	–	–	X	–
Corixidae							
Trichocorixa	–	–	–	–	–	X	–
Nepidae							
Ranatra	–	X	X	–	–	–	–
Megaloptera							
Corydalidae							
Corydalus cornutus	X	X	–	–	–	–	–
Sialidae							
Sialis	–	–	X	X	–	–	–
Trichoptera							
Hydroptilidae							
Hydroptila	–	–	–	X	–	–	–
Hydropsychidae							
Cheumatopsyche	X	X	X	X	–	X	X
Hydropsyche	X	–	X	X	–	–	X
Leptoceridae							
Triaenodes	X	–	–	–	–	–	–
Philopotomidae							
Chimarra	–	X	X	X	–	–	X
Coleoptera							
Dryopidae							
Helichus	X	–	–	–	–	–	–
Dytiscidae							
Deronectes?	–	–	–	–	X	–	–
Laccophilus	X	–	–	–	X	–	–

Table 2.5 (continued)

Taxon	Site[a]						
	LUK 7.2	LUK 4.3	BBK 12.5	BBK 9.1	Outfall 003	HC	MAK 13.8
Elmidae							
Ancyronyx variegatus	–	X	–	–	–	–	–
Dubiraphia	X	X	X	X	–	X	–
Stenelmis	X	–	–	–	–	–	–
Gyrinidae							
Gyrinus	–	–	X	–	–	X	X
Haliplidae							
Peltodytes	–	–	–	X	–	–	–
Hydrophilidae							
Berosus	X	–	X	X	–	X	X
Diptera							
Chironomidae	X	X	X	X	X	X	X
Simuliidae							
Simulium	X	X	X	X	–	X	X
Tabanidae							
Tabanus	X	–	X	X	X	–	–
Tipulidae							
Pseudolimnophila	–	–		–	X	–	–
Tipula	X	X	X	–	X	–	–
Mollusca							
Gastropoda							
Physidae							
Physella	X	X	X	–	–	–	X
Pelecypoda							
Sphaeriidae							
Musculium	X	–	X	–	–	X	–

[a]LUK = Little Bayou Creek kilometer; BBK = Big Bayou Creek kilometer; HC = Humphry Creek; MAK = Massac Creek kilometer.

Table 2.6. Results of qualitative fish surveys in Little Bayou Creek, Big Bayou Creek, 003, and two offsite reference streams, Humphrey Creek and Massac Creek, December 4–6, 1990

X = taxon was collected

Species[b]	Sampling site[a]						
	LUK 7.2	LUK 4.3	BBK 12.5	BBK 9.1	Outfall 003	HC	MAK 13.8
Clupeidae							
Gizzard shad (*Dorosoma cepedianum*)		X					
Cyprinidae							
Stoneroller (*Campostoma anomalum*)	X	X	X	X		X	X
Red shiner (*Cypinella lutrensis*)	X	X	X	X		X	X
Spotfin shiner (*Cyprinella spiloptera*)		X					
Steelcolor shiner (*Cyprinella whipplei*)		X		X			X
Carp (*Cyprinus carpio*)		X				X	
Silvery minnow (*Hybognathus nuchalis*)		X					
Ribbon shiner (*Lythrurus fumeus*)		X		X		X	X
Redfin shiner (*Lythrurus umbratilis*)	X	X	X	X	X	X	X
Golden shiner (*Notemigonus crysoleucas*)			X			X	
Suckermouth minnow (*Phenacobius mirabilis*)	X	X	X	X		X	X
Bluntnose minnow (*Pimephales notatus*)	X	X	X	X		X	X
Creek chub (*Semotilus atromaculatus*)	X	X	X	X		X	X
Catostomidae							
White sucker (*Catostomus commersoni*)	X					X	X
Creek chubsucker (*Erimyzon oblongus*)	X	X	X	X	X	X	X
Spotted sucker (*Minytrema melanops*)		X		X		X	X
Golden redhorse (*Moxostoma erythrurum*)		X					X
Ictaluridae							
Black bullhead (*Ameiurus melas*)		X					
Yellow bullhead (*Ameiurus natalis*)	X	X	X	X		X	X
Esocidae							
Grass pickerel (*Esox americanus vermiculatus*)		X		X			
Aphredoderidae							
Pirate perch (*Aphredoderus sayanus*)	X	X				X	
Cyprinodontidae							
Blackspotted topminnow (*Fundulus olivaceus*)	X	X	X	X	X	X	X
Poecillidae							
Western mosquitofish (*Gambusia affinis*)	X			X		X	
Atherinidae							
Brook silverside (*Labidesthes sicculus*)							X

Table 2.6 (continued)

Species[b]	Sampling site[a]						
	LUK 7.2	LUK 4.3	BBK 12.5	BBK 9.1	Outfall 003	HC	MAK 13.8
Centrarchidae							
Green sunfish (*Lepomis cyanellus*)	X	X	X	X		X	X
Warmouth (*Lepomis gulosus*)	X	X				X	
Bluegill (*Lepomis macrochirus*)	X	X	X	X	X	X	X
Longear sunfish (*Lepomis megalotis*)	X	X	X	X	X	X	X
Redear sunfish (*Lepomis microlophus*)		X		X			
Hybird sunfish (*bluegill x longear?*)	X					X	
Spotted bass (*Micropterus punctulatus*)	X	X	X	X	X	X	X
Largemouth bass (*Micropterus salmoides*)	X	X	X	X			X
White crappie (*Pomoxis annularis*)			X	X			
Percidae							
Slough darter (*Etheostoma gracile*)	X		X				X
Total species	19	27	16	20	6	21	21

[a]Little Bayou Creek kilometer (LUK) 7.2 is located at the Route 358 bridge; LUK 4.3 is located at the Anderson Road bridge; Big Bayou Creek kilometer (BBK) 12.5 is located above Paducah Gaseous Diffusion Plant (PDGP) at South Acid Road bridge; BBK 9.1 is located at an unnamed road crossing about 0.4 km NE of BM 371 (Heath quadrangle); 003 is an unnamed tributary to Little Bayou Creek downstream from outfall 003 at PGDP; Humphrey Creek (HC) is Route 60 bridge on Humphrey Creek; Massac Creek kilometer (MAK) 13.8 is located at Route 62 bridge on Massac Creek.

[b]Common and scientific names according to the American Fisheries Society (C. R. Robins et al. *Common and scientific names of fishes from the United States and Canada*, 5th ed., American Fisheries Society Special Publication 20, Bethesda, MD., 1991.

Note: All surveys were conducted using two Smith-Root backpack electrofishers (Model 15A) to sample a 200- to 4000-m reach of stream at each site except 003 (75 m of stream was sampled with a single unit). Species identifications were performed in the field and confirmed in the laboratory on preserved specimens collected during the surveys.

macroinvertebrate and fish samples, from September 1991 through June 1992 are also presented below.

2.3.1 Big Bayou Creek

Big Bayou Creek originates south-southwest of the PGDP and flows northerly, passing the facility along its western boundary (Fig. 2.2). As the stream flows adjacent to PGDP, it receives effluents from eight separate outfalls. The stream then continues in a northerly direction before draining into the Ohio River just west of the Shawnee Steam Plant.

Three monitoring sites were established on Big Bayou Creek including BBK 12.5, BBK 10.0, and BBK 9.1. All three sites were characterized by relatively steep banks (10–12 ft high), and the stream channel exhibited considerable variability in width and depth over the entire reach of each site. Overall, BBK 9.1 was the deepest and widest site on Big Bayou Creek, whereas BBK 10.0 was generally the shallowest and narrowest site

(Table 2.7). Dissolved oxygen and pH levels were relatively similar among these sites, but conductivity doubled from BBK 12.5 to BBK 9.1 (Table 2.7). Not surprisingly, discharge increased with distance downstream (Table 2.7), probably due in large part to flow augmentation from effluent discharges. Current velocity within the riffles from which benthic macroinvertebrates were collected similarly increased with distance downstream (Table 2.7).

The substrate at all three sites in Big Bayou Creek was dominated by gravel that was mixed with some sand/fine sediment. Clay was found at all sites but was usually restricted to the steeper edges of pools. BBK 12.5 was the only site in Big Bayou Creek that also contained a considerable proportion of rubble-sized rocks (i.e., rocks ranging in size from 64 to 250 mm) in the riffle from which benthos samples were collected.

BBK 9.1 was surrounded on both sides by a narrow band of mature trees, composed predominately of species typical of a bottomland forest. This band of trees provided canopy coverage of about 63% over the stream. Agricultural and early successional fields surrounded the narrow band of trees; thus, the forest's ground cover was heavily influenced by the surrounding disturbance. A variety of lowland tree species were evident along the stream bank, including river birch (*Betula nigra*), walnut (*Juglans nigra*), sycamore (*Plantanus occidentalis*), cottonwood (*Populus deltoides*), slippery

Table 2.7. Physical characteristics and water quality data for benthic macroinvertebrate and fish monitoring sites associated with the Paducah Gaseous Diffusion Plant Biological Monitoring Program

Values are means ± 1 SD in parentheses

Site[c]	Physical Characteristics[a]				Water Quality Data[b]		
	Depth (cm)	Width (m)	Current Velocity[d] (m/sec)	Discharge (m^3/sec)	Conductivity (μS/cm)	D.O.[e] (mg/L)	pH
BBK 9.1	20.4 (28.4)	7.0 (2.2)	0.25 (0.25)	0.086 (0.027)	345 (188)	10.0 (2.0)	7.9 (0.8)
BBK 10.0	8.9 (10.7)	5.6 (2.1)	0.16 (0.23)	0.03 (0.016)	248 (139)	9.9 (1,8)	8.0 (0.7)
BBK 12.5	13.5 (19.4)	6.2 (2.5)	0.02 (0.02)	0.01 (0.012)	170 (43)	10.0 (1.8)	7.5 (0.6)
LUK 7.2	7.9 (7.6)	4.0 (0.4)	0.08 (0.09)	0.014 (0.013)	141 (75)	9.5 (1.5)	7.5 (0.5)
MAK 13.8	14.0 (16.8)	3.6 (1.7)	0.14 (0.13)	0.022 (0.011)	98 (8)	10.1 (3.1)	7.1 (0.7)

[a]Means for physical data are based on measurements obtained in June 1991.
[b]Means for water quality data are based on measurements collected quarterly along with fish and/or invertebrates samples from September 1991 to June 1992.
[c]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.
[d]Current velocities are only for riffles from which benthic macroinvertebrate samples were collected.
[e]D.O. = Dissolved oxygen.

elm (*Ulmus rubra*), and pin oak (*Quercus palustris*). Common disturbance-adapted understory species found in this zone were poison ivy (*Toxicodendron radicans*), honeysuckle (*Lonicera japonica*), multiflora rose (*Rosa multiflora*), grape (*Vitus sp.*), black raspberry (*Rubus occidentalis*), and a number of grasses (including *Panicum*, *Elymus*, and *Festuca spp.*).

Vegetation along the banks of BBK 10.0 exhibited the greatest evidence of disturbance of all study sites. The left side (i.e., facing upstream) of this site was dominated by a young bottomland forest indicative of fairly recent disturbance. Briars and weedy vines were common in the understory, including multiflora rose, trumpet creeper (*Campsis radicans*), poison ivy, common blackberry (*Rubus allegheniensis*), and honeysuckle. The most commonly observed tree species were sycamore, river birch, pin oak, willow (*Salix nigra*), and cottonwood. An agricultural field tightly bordered much of the top of the right bank, with only a narrow band of a few small shrubs and trees lining the upper fourth of the reach. Common plants found on the right bank were common ragweed (*Ambrosia artemissifolia*), milkweed (*Asclepias syriaca*), rye (*Elymus* sp.), fescue (*Festuca sp.*), false nettle (*Boehmeria cylindrica*), water horehound (*Lycopus americanus*), Aster (*Aster sp.*), and smartweed (*Polygonum* sp.). The lack of mature vegetation at this site contributed to the low amount of canopy coverage (~24% coverage). The preponderance of alien and native disturbance-adapted vegetation along much of this reach was probably due, in part, to the encroachment of the agricultural field and the presence of a power line corridor near the head of the reach.

BBK 12.5 was the upstream most site on Big Bayou Creek, and was located upstream of all effluent discharges that originate from PGDP. Because of this site's location above PGDP, it served as a reference site not only for BBK 10.0 and BBK 9.1, but also for LUK 7.2 on Little Bayou Creek, which had no suitable upstream reference area (see explanation following).

The vegetation surrounding BBK 12.5 was characteristic of a relatively undisturbed, mature bottomland forest, which provided canopy coverage over ~ 74% of the stream at this site. The most common tree species were river birch, red maple (*Acer rubrum*), sycamore, and pin oak. Small tree and shrub species comprised the mid canopy, including winged elm (*Ulmus alata*), swamp holly (*Ilex decidua*), black willow (*Salix nigra*), sweet gum (*Liquidambar styraciflua*), and black cherry (*Prunus serotina*). Typical herbs found near the top of the stream banks and in the surrounding forest were virginia creeper (*Parthenocissus quinquefolia*), poison ivy, grape, rye, and panic grass (*Panicum sp.*). Herbaceous vegetation was patchy on the steep streambanks, where species such as cutgrass (*Leersia sp.*), manna grass (*Glyceria striata*), touch-me-not (*Impatiens biflora*), false nettle (*Boehmeria cylindrica*), day flower (*Commelina sp.*), violet (*Viola* sp.), and smartweed were found.

2.3.2 Little Bayou Creek

Little Bayou Creek originates south-southeast of PGDP and flows northerly, passing PGDP along its eastern boundary (Fig. 2.2). The stream continues to flow northerly until just south of the Shawnee Steam Plant, where it turns west and eventually drains into Big Bayou Creek. As the stream flows past PGDP, it receives the effluents from four effluent discharge points (Fig. 2.2).

One monitoring site, LUK 7.2, was established on Little Bayou Creek for the instream monitoring task (Fig. 2.2). Like the Big Bayou Creek sites, LUK 7.2 was characterized by steep banks that were 10–12 ft high. This site was generally shallower and narrower than the other monitoring sites (Table 2.7). Discharge at this site was similar to that at BBK 12.5, although mean current velocity in the benthic macroinvertebrate collection riffle was greater (Table 2.7). Conductivity, dissolved oxygen, and pH readings at LUK 7.2 were similar to those obtained at BBK 12.5 and MAK 13.8 (Table 2.7). The substrate at this site, including the benthos riffle, consisted primarily of extensive areas of clay that were overlain with a shallow layer of gravel. A fine layer of silt was also evident over much of the larger substrate particles.

The vegetation surrounding LUK 7.2 consisted of a mature bottomland forest on the right side of the stream (i.e., facing upstream), and a narrow band of forest with an encroaching field on the left side. The tree species present were similar to those found in the bottomland communities of other sites. The most common species were river birch, red maple (*Acer rubrum*), hackberry (*Celtis laevigata*), and pin oak. Less abundant were sycamore, willow, slippery elm, walnut, cottonwood, and a number of oaks (*Quercus spp.*). Herbaceous vegetation was sparse on the generally steep and muddy stream banks. The most commonly observed understory species found on the stream banks were smartweed, violet, christmas fern (*Polystichum acrostichoides*), false nettle, poison ivy, manna grass, and honeysuckle.

On September 16, 1992, a reconnaissance of the upper reaches of Little Bayou Creek was made to determine if a suitable reference area for LUK 7.2 existed for the instream monitoring task of BMP (Fig. 2.2). Approximately 1.5–2.0 km of the stream was included in the reconnaissance that covered the stream from Outfall 011 upstream to the first bridge crossing the stream channel (Fig. 2.2). The first 1 km of the stream downstream of this bridge was composed of a deep, dry channel. When water was first encountered, it was in a large, deep pool because of the presence of a beaver dam located further downstream. From this point downstream past Outfall 011, the stream flow was restricted by a series of deep pools created by additional beaver dams. Because of the extent of dry stream bed in the upper reaches, and the occurrence of existing water in large pools only, it was decided that upper Little Bayou Creek would not serve as a suitable reference site.

2.3.3 Massac Creek

A single site in Massac Creek, MAK 13.8 (Fig. 2.1), was selected to serve as an offsite reference site for both Big Bayou and Little Bayou creeks. This site was selected from a total of 24 stream sites located near the PGDP, which were visited during the selection of permanent sites in December 1990. Selection of MAK 13.8 was based on the following reasons: (1) it appeared to be one of the least impacted of the potential reference sites visited; (2) it was similar in size to portions of Big Bayou Creek and Little Bayou Creek; and (3) the fish community was relatively rich and diverse.

Massac Creek originates southeast of PGDP in McCracken County, Kentucky, ~2.5 miles northeast of Melber (Fig. 2.1). The stream then generally flows north before draining into the Ohio River approximately halfway between PGDP and the city of Paducah. The site selected for monitoring, MAK 13.8, was located just upstream of a USGS gage that is just upstream of a bridge on State Hwy 62, southwest of Paducah.

As were the other BMP monitoring sites, MAK 13.8 was characterized by steep banks (~10–12 ft high). The stream channel was relatively narrow and, compared to the other sites, moderately deep (Table 2.7). Discharge and current velocity within the benthic invertebrate sampling riffle were comparable to those for BBK 10.0 (Table 2.7). Mean values for dissolved oxygen and pH were similar to those for the other four monitoring sites, while conductivity was lower and less variable (Table 2.7). The substrate throughout the entire site was dominated by gravel that was often mixed with considerable quantities of silt/sand. Clay and large woody debris were also fairly common at this site.

The riparian vegetation at MAK 13.8 was very similar to that at BBK 9.1, consisting of a narrow band of bottomland forest on either side of the stream, with agricultural fields encroaching upon the periphery of the forest. The young to occasionally mature forest was dominated by river birch, slippery elm, sycamore, hackberry, and black cherry (*Prunus serotina*), which provided canopy coverage of > 62% over the stream. A number of alien and native, disturbance-adapted plant species were evident in the riparian zone, particularly near the top of the stream banks. Included in this latter group were poison ivy, honeysuckle, virginia creeper, and ragweeds (*Ambrosia artemissifolia* and *Ambrosia trifida*).

3. TOXICITY MONITORING

L. A. Kszos

The toxicity monitoring task for BMP consists of two subtasks. The first subtask measures the toxicity of effluents as required by the KPDES permit. The second subtask monitors ambient water toxicity of three 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 from outfalls that discharge to Big Bayou and Little Bayou creeks. These two tests are EPA-approved for use in the KPDES program 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 Toxicology Laboratory of ESD 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 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.

3.1.2 Materials and Methods

Toxicity tests of effluents from the continuously flowing outfalls (001, 004, 006, 008, 009, and 011) and the intermittently flowing outfalls (013, 015, 016, 017, and 018) were conducted according to the schedule shown in Table 3.1. This report includes all tests conducted during 1991 and 1992 by ESD. All of the outfalls except 016 were evaluated five times; outfall 016 was evaluated four 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. Under the renewed permit, samples must be composited over 24 hours. Thus, the test conducted during October 1992 used seven 24-h composite samples. Samples from the continuously flowing outfalls were collected by personnel from ESD and transported to an offsite laboratory. The intermittently flowing outfalls are rainfall dependant; thus, tests were conducted using one grab sample. Samples from the intermittently flowing outfalls were collected by

Table 3.1. Summary of toxicity test dates for continuous and intermittent outfalls

Outfall	Test Date	
	Fathead Minnow	*Ceriodaphnia*
001, 004, 006, 008, 009, 011	October 24–31, 1991	October 24–31, 1991
	February 13–20, 1992	February 13–20, 1992
	May 21–28, 1992	May 21–28, 1992
	August 13–20, 1992	August 13–20, 1992
	October 22–29, 1992	October 22–29, 1992
013, 015, 016, 017, 018	December 27, 1991 – January 3, 1992	December 27, 1991 –January 3, 1992
	March 20–27, 1992	March 20–27, 1992
	June 26–July 3, 1992[a]	June 26–July 2, 1992
	September 22–29, 1992	September 29–October 6, 1992
	November 13–20, 1992	November 13–20, 1992

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

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 lab were recorded.

Tests with *Ceriodaphnia* and fathead minnows were typically conducted concurrently following procedures outlined in Weber et al. (1989) and Kszos et al. (1989). These tests are static, renewal tests, meaning that test water is replaced daily for 6 or 7 consecutive days. The fathead minnow test consists of four replicates per test concentration with ten animals per replicate. Each day before the water was replaced, the number of surviving larvae was recorded. At the end of 7 d, the larvae were dried and weighed to obtain an estimate of growth. The *Ceriodaphnia* test consists of ten replicates per test concentration with one animal per replicate. Each day, the animals were transferred from a beaker containing old test solution and placed in a beaker containing fresh test solution. At this time, survival and the number of offspring produced were recorded. A control consisting of dilute mineral water augmented with trace metals was included with each test. On each day of a test, subsamples of each effluent were routinely analyzed for pH, conductivity, alkalinity, water hardness, and total residual and free chlorine (Kszos et al. 1989). A subsample of each sample was also acidified and saved for metal analyses by Inductively Coupled Plasma spectroscopy (ICP).

No-observed-effect concentrations (NOEC, that concentration causing no reduction in survival or growth of fathead minnows or survival or reproduction of *Ceriodaphnia*) were determined using SAS statistical software (Statistical Analysis System for personal computers, release 6.03) and the EPA Dunnett's program (Weber et al. 1989). Flow charts of the statistical analyses of the fathead minnow and *Ceriodaphnia* data are provided in Figs. 3.1 and 3.2. 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* survival compared to a control). A computer program (ICp Calculation Program, release 1.0) distributed by the EPA (Environmental Research Laboratory, Duluth, Minnesota) and provided by KDOW was used for the calculation. The NOEC was used as a compliance endpoint for tests conducted under the draft Agreed

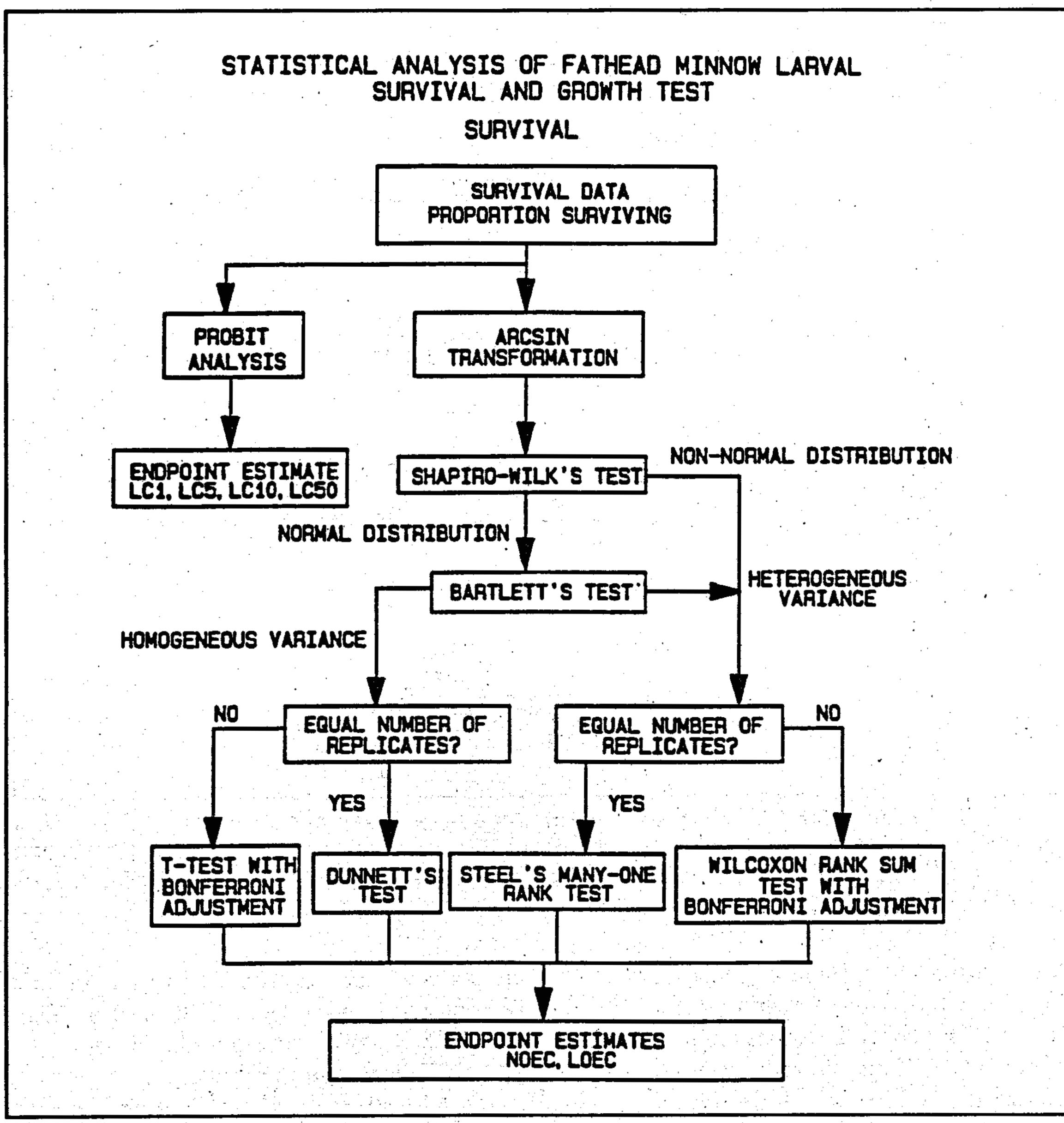

Fig. 3.1. Flow chart for statistical analysis of fathead minnow larval survival data. (From C. I. Weber et al. 1989, Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms, 2nd ed. EPA/600/4-89/001. U.S. Environmental Protection Agency, Cincinnati, Ohio.)

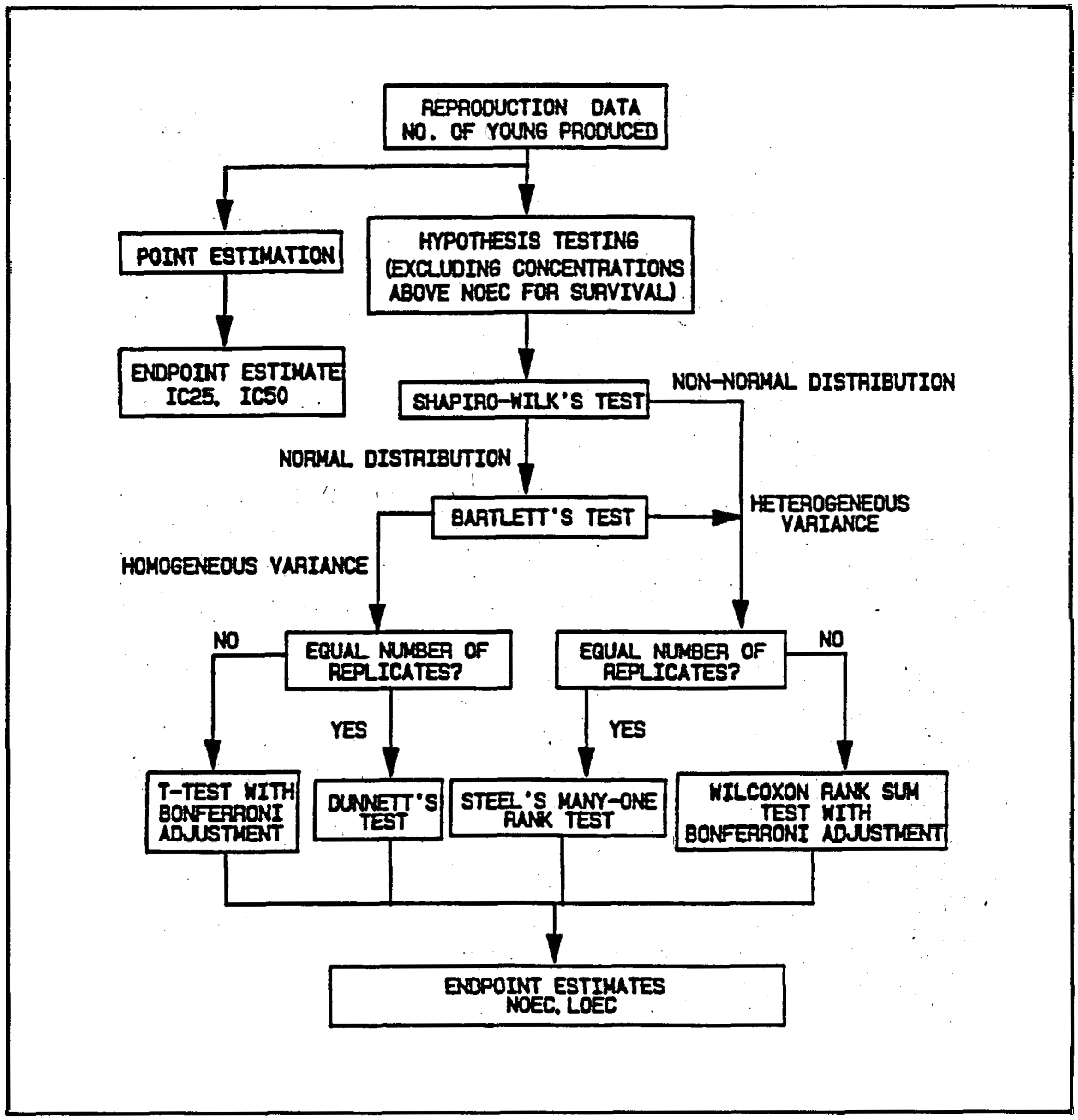

Fig. 3.2. Flow chart for statistical analysis of *Ceriodaphnia* reproduction data. (From C. I. Weber et al. 1989, Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms, 2nd ed. EPA/600/4-89/001. U.S. Environmental Protection Agency, Cincinnati, Ohio.)

Order (prior to September 1992). The lower the NOEC, the more toxic an effluent. The chronic toxicity unit (TU_C=100/IC25) is required as a compliance endpoint in the renewed permit (September 1992 to present). The higher the TU_C, the more toxic an effluent. Because Little Bayou and Big Bayou creeks have been determined to have a low flow of zero, an NOEC < 100% or a TU_C of > 1.2 would be considered a significant non-compliance and an indicator of potential instream toxicity. Survival percentages for fathead minnow larvae were transformed (arcsine square root; Weber et al. 1989) before being analyzed statistically.

3.1.3 Results

3.1.3.1 Continuously flowing outfalls 001, 004, 006, 008, 009, and 011

A summary of the NOECs and TU_cs for all toxicity tests conducted during 1991–92 are provided in Table 3.2. Summaries of fathead minnow and Ceriodaphnia test endpoints are provided in Appendix B. Low fathead minnow growth during the October 1991 (Table B.1) and May 1992 (Table B.9) test periods precluded a determination of TU_cs for fathead minnows. An NOEC was determined based on survival. The *Ceriodaphnia* test outcomes were the same for each outfall using either the NOEC or TU_c approach. Effluent samples from Outfalls 008, 009, and 011 were never toxic to *Ceriodaphnia*. Effluent samples from Outfalls 001, 004, and 006 were toxic (TU_c > 1.2, as defined by the KDOW or NOEC < 100%) to *Ceriodaphnia* during one of five tests. The TU_c and NOEC approaches did not agree as well for the fathead minnow tests. Effluent samples from Outfalls 004, 006, and 008 were toxic during the February 1992 test period using the TU_c approach but were not toxic using the NOEC approach. Two test periods were in agreement: effluent from Outfall 009 during October 1992 and water from Outfall 011 during February 1992 were toxic to fathead minnows using either approach.

A summary of water quality parameters for each outfall is provided in Table 3.3. Water quality summaries for each test are provided in appendix B. The pH of the effluent ranged from a minimum of 7.1 (Outfall 008) to a maximum of 9.7 (outfall 006). Effluent from Outfall 006 had the highest mean pH (9.1). Mean alkalinity ranged from 30.4 (Outfall 001) to 50.4 (Outfall 009). Mean hardness and conductivity were highest in effluent from Outfall 001 (418 mg/L and 1335 μS/cm respectively). Mean hardness at the remaining outfalls ranged from 70 to 85 mg/L and mean conductivity ranged from 222 to 292 μS/cm.

The ICP analyses of total recoverable metals obtained during each day of each test are presented in Tables 3.4 to 3.9. For many of the metals, concentrations were below the detection limit of the ICP. Only those metals that were above the detection limits are presented. KPDES monitoring data is provided in Appendix A. ICP analyses showed that effluent from Outfall 001 contained the highest mean concentrations of Ca (88–120 mg/L), K (7–17 mg/L), Mg (7–15 mg/L), Na (75–159 mg/L), and Si (3–5 mg/L). Potassium was also detected in effluent from outfall 004 during two test periods, but was not detected in any other outfall. Concentrations in effluent from outfalls 004, 006, 008, 009, and 011 were lower than in Outfall 001 and were similar: Ca, 12–26 mg/L; Mg, 1–6 mg/L; Na, 14–40 mg/L; and Si, 1.0–2.9 mg/L. Nickel and Zinc were occasionally detected. KPDES data are available for additional metals that were not detected by ICP analyses. Mean aluminum concentrations in 1992 ranged from 0.69–0.74 mg/L; mean concentrations of Cd, Cr, Cr-6, Cu, Ni, Pb, and Zn were below detection for all outfalls (Appendix A).

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

A summary of the NOECs and TU_cs for all toxicity tests conducted during 1991–92 is provided in Table 3.10. Summaries of fathead minnow and *Ceriodaphnia* test endpoints are provided in Appendix B. Water from the intermittently flowing outfalls was not toxic to *Ceriodaphnia*. Because 50% was the

Table 3.2. Comparison of effluent toxicity test endpoints for Outfalls 001, 004, 006, 008, 009, and 011

Outfall	Test date	Fathead minnow		*Ceriodaphnia*	
		NOEC[a]	TU_c[b]	NOEC[a]	TU_c[b]
001	October 1991	100	ND[c]	100	<1
	February 1992	100	<1	100	<1
	May 1992	100	ND[c]	25	4.5
	August 1992	100	<1	100	<1
	October 1992	100	<1	100	<1
004	October 1991	50	ND[c]	100	<1
	February 1992	100	4.26	100	1.03
	May 1992	100	ND[c]	100	<1
	August 1992	100	<1	25	3.15
	October 1992	100	<1	100	<1
006	October 1991	100	ND[c]	100	<1
	February 1992	100	1.39	50	1.56
	May 1992	50	ND[c]	100	<1
	August 1992	100	<1	100	<1
	October 1992	100	<1	100	<1
008	October 1991	100	ND[c]	100	<1
	February 1992	100	9.77	100	<1
	May 1992	100	ND[c]	100	<1
	August 1992	100	<1	100	<1
	October 1992	100	<1	100	<1
009	October 1991	100	ND[c]	100	<1
	February 1992	100	7.87	100	<1
	May 1992	100	<1	100	<1
	August 1992	100	<1	100	<1
	October 1992	100	2.16	100	1.05
011	October 1991	100	ND[c]	100	<1
	February 1992	<25	7.69	100	<1
	May 1992	100	ND[c]	100	<1
	August 1992	100	<1	100	<1
	October 1992	100	<1	100	<1

[a]NOEC = no-observed-effect concentration; the concentration causing no reduction in fathead minnow survival or growth or *Ceriodaphnia* survival or reproduction.

[b]TU_c = chronic toxicity unit (100/IC25); IC25 = the concentration causing a 25% reduction in fathead minnow growth or *Ceriodaphnia* survival.

[c]ND = not determined.

Table 3.3. Summary (mean ± SD; n = 35) of water chemistry analyses of full-strength samples from continuously flowing effluents taken in conjunction with toxicity tests

Sample	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Outfall 001				
Mean (± SD)	8.3 (0.6)	30.4 (6.2)	418 (132)	1335 (408)
Range	7.4–9.5	23.0–46.0	168–660	586–1867
Outfall 004				
Mean (± SD)	7.5 (0.1)	39.7 (8.4)	85 (39)	292 (46)
Range	7.3–7.9	28.0–59.0	56–298	213–392
Outfall 006				
Mean (± SD)	9.1 (0.4)	37.4 (4.4)	71 (11)	226 (29)
Range	8.3–9.7	31.0–58.0	50–96	185–281
Outfall 008				
Mean (± SD)	7.4 (0.2)	33.2 (8.8)	70 (12)	256 (39)
Range	7.1–7.9	23.0–63.0	50–102	177–350
Outfall 009				
Mean (± SD)	7.7 (0.3)	50.4 (15.8)	76 (15)	222 (39)
Range	7.2–8.3	32.0–110.0	44–120	116–296
Outfall 011				
Mean (± SD)	7.8 (0.2)	36.9 (10.3)	73 (13)	229 (26)
Range	7.5–8.7	23.0–62.0	52–104	168–173

Table 3.4. Mean and range (n = 7) of total recoverable metal concentrations (in milligrams per liter) in effluent from Outfall 001 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date			
		10-27-91	02-13-92	05-21-92	08-13-92
Al	0.05	BD[a]	BD	BD	BD
Ba	0.05	BD	0.06 0.05–0.07	BD	BD
Ca	0.05	119.57 104.03–131.75	87.81 64.93–113.08	97.21 48.17–135.12	100.58 40.64–140.61
Fe	0.05	0.17 0.09–0.31	0.20 0.10–0.25	BD	BD
K	5	15.34 14.73–16.63	7.62 5.22–9.62	10.66 5.72–14.26	12.65 5.99–17.63
Mg	0.01	14.18 11.21–17.48	7.79 6.14–11.43	27.98 15.74–37.64	26.41 12.12–35.44
Mn	0.05	0.40 0.40–0.40	0.91 0.91–0.91	BD	BD
Na	1	159.72 131.86–187.79	75.59 53.33–99.53	112.04 61.57–151.69	103.26 43.11–144.27
Ni	0.1	0.78 0.78–0.78	BD	BD	BD
P	0.05	BD	BD	BD	0.08 0.06–0.09
Si	1	5.47 5.31–5.82	3.44 3.02–4.22	3.32 1.96–4.32	3.72 1.99–4.99
Sr	0.01	0.52 0.50–0.55	0.29 0.22–0.33	0.35 0.17–0.49	0.40 0.16–0.55
Zn	0.05	BD	0.17 0.17–0.17	BD	BD

[a]BD = Below detection limit.

Table 3.5. Mean and range ($n = 7$) of total recoverable metal concentrations (in milligrams per liter) in effluent from Outfall 004 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date			
		10-27-91	02-13-92	05-21-92	08-13-92
Al	0.05	BD[a]	BD	BD	BD
Ba	0.05	BD	BD	BD	BD
Ca	0.05	23.61 17.67–30.08	21.77 18.61–24.26	16.05 15.48–16.40	12.71 11.98–13.18
Fe	0.05	0.06 0.06–0.06	0.13 0.07–0.17	BD	BD
K	5	5.56 5.56–5.56	BD	5.06 5.06–5.06	BD
Mg	0.01	4.45 2.73–5.41	2.94 2.22–3.33	6.96 6.43–7.94	4.63 4.16–5.31
Mn	0.05	1.20 1.20–1.20	0.91 0.91–0.91	BD	BD
Na	1	39.88 36.88–42.54	26.80 24.81–29.51	28.45 26.09–32.12	18.04 16.13–21.84
Ni	0.1	0.78 0.78–0.78	BD	BD	BD
P	0.05	0.32 0.24–0.37	0.29 0.13–0.49	0.29 0.10–0.48	0.42 0.18–0.61
Si	1	1.75 1.22–2.17	1.93 1.61–2.23	1.04 1.00–1.09	1.42 1.23–1.56
Sr	0.01	0.36 0.12–0.57	0.27 0.18–0.42	0.08 0.08–0.08	0.06 0.06–0.07
Zn	0.05	BD	0.05 0.05–0.05	BD	BD

[a]BD = Below detection limit.

Table 3.6. Mean and range (n = 7) of total recoverable metal concentrations (in milligrams per liter) in effluent from Outfall 006 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date			
		10-27-91	02-13-92	05-21-92	08-13-92
Al	0.05	BD[a]	BD	BD	BD
Ba	0.05	BD	BD	BD	BD
Ca	0.05	14.77 13.98–15.75	13.55 12.69–14.63	14.03 13.59–14.25	12.85 12.07–13.93
Fe	0.05	0.11 0.07–0.16	0.13 0.10–0.15	BD	0.06 0.05–0.08
K	5	BD	BD	BD	BD
Mg	0.01	3.65 2.73–4.58	1.21 0.56–2.50	7.37 6.90–7.51	5.87 5.19–6.86
Mn	0.05	1.15 1.15–1.15	0.91 0.91–0.91	BD	BD
Na	1	32.39 30.89–34.42	19.12 18.53–20.07	22.17 21.51–23.01	17.43 13.76–22.04
Ni	0.1	0.78 0.78–0.78	BD	BD	BD
P	0.05	BD	BD	BD	BD
Si	1	1.38 1.19–1.57	1.64 1.55–1.73	1.03 1.00–1.08	1.43 1.33–1.52
Sr	0.01	0.09 0.08–0.11	0.05 0.05–0.06	0.60 0.06–0.06	0.07 0.06–0.08
Zn	0.05	BD	BD	BD	BD

[a]BD = Below detection limit.

Table 3.7. Mean and range ($n = 7$) of total recoverable metal concentrations (in milligrams per liter) in effluent from Outfall 008 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date			
		10-27-91	02-13-92	05-21-92	08-13-92
Al	0.05	BD[a]	0.34 0.34–0.34	BD	BD
Ba	0.05	BD	BD	BD	BD
Ca	0.05	17.98 14.43–22.42	20.25 17.04–22.96	14.37 13.60–15.11	11.96 11.66–12.16
Fe	0.05	BD	0.16 0.06–0.40	BD	BD
K	5	BD	BD	BD	BD
Mg	0.01	4.02 2.73–5.42	2.41 0.63–3.13	6.63 5.92–7.91	4.54 4.08–5.25
Mn	0.05	1.15 1.15–1.15	BD	BD	BD
Na	1	35.93 30.89–40.07	21.31 12.56–27.61	25.82 23.74–29.20	16.76 14.97–20.29
Ni	0.1	0.78 0.78–0.78	BD	BD	BD
P	0.05	BD	BD	0.12 0.07–0.16	0.24 0.16–0.31
Si	1	1.49 1.16–1.90	2.13 1.42–3.87	1.06 1.01–1.13	1.18 1.05–1.31
Sr	0.01	0.20 0.11–0.28	0.18 0.13–0.25	0.07 0.06–0.09	0.06 0.06–0.07
Zn	0.05	BD	BD	BD	BD

[a]BD = Below detection limit.

Table 3.8. Mean and range (n = 7) of total recoverable metal concentrations (in milligrams per liter) in effluent from Outfall 009 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date			
		10-27-91	02-13-92	05-21-92	08-13-92
Al	0.05	0.16 0.10–0.22	0.96 0.96–0.96	BD	BD
Ba	0.05	BD[a]	BD	BD	BD
Ca	0.05	18.01 14.35–19.44	26.49 19.26–31.39	16.30 15.26–17.74	14.46 13.72–15.19
Fe	0.05	0.23 0.16–0.30	0.31 0.11–0.68	0.28 0.07–0.64	0.13 0.07–0.33
K	5	BD	BD	BD	BD
Mg	0.01	2.27 1.82–2.92	1.60 0.59–2.94	5.28 4.64–6.07	4.54 4.20–4.97
Mn	0.05	0.38 0.38–0.38	0.77 0.77–0.77	BD	BD
Na	1	14.30 6.66–20.16	14.37 4.44–21.09	19.30 16.39–21.69	14.82 12.23–18.32
Ni	0.1	BD	BD	BD	BD
P	0.05	BD	BD	BD	0.10 0.10–0.10
Si	1	1.73 1.12–2.01	2.50 1.67–4.57	2.93 1.60–4.53	1.07 1.02–1.11
Sr	0.01	0.14 0.11–0.18	0.21 0.18–0.25	0.06 0.06–0.07	0.07 0.06–0.08
Zn	0.05	0.05 0.05–0.05	BD	BD	BD

[a]BD = Below detection limit.

Table 3.9. Mean and range ($n = 7$) of total recoverable metal concentrations (in milligrams per liter) in effluent from Outfall 011 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date			
		10-27-91	02-13-92	05-21-92	08-13-92
Al	0.05	BD[a]	BD	BD	BD
Ba	0.05	BD	BD	BD	BD
Ca	0.05	22.98 20.93–26.27	22.80 14.04–27.41	15.15 14.23–16.20	12.09 11.23–14.22
Fe	0.05	BD	0.07 0.07–0.07	BD	BD
K	5	BD	BD	BD	BD
Mg	0.01	3.08 2.73–3.33	2.04 0.59–2.94	6.21 5.78–7.27	4.54 4.14–5.20
Mn	0.05	1.20 1.20–1.20	0.77 0.77–0.77	BD	BD
Na	1	23.58 17.21–29.14	14.90 8.87–18.46	22.02 20.71–24.19	16.32 14.43–19.96
Ni	0.1	0.78 0.78–0.78	BD	BD	BD
P	0.05	BD	BD	BD	0.11 0.06–0.17
Si	1	1.68 1.32–1.94	1.94 1.48–2.37	1.15 1.09–1.24	1.21 1.04–1.36
Sr	0.01	0.22 0.18–0.24	0.17 0.11–0.22	0.09 0.08–0.11	0.08 0.07–0.08
Zn	0.05	BD	0.06 0.06–0.06	BD	BD

[a]BD = Below detection limit.

Table 3.10. Comparison of effluent toxicity test endpoints for Outfalls 013, 015, 016, 017, and 018

Outfall	Test date	Fathead minnow		*Ceriodaphnia*	
		NOEC[a]	TU_c[b]	NOEC[a]	TU_c[b]
013	December 1991	100	<1	100	<1
	March 1992	25	5.82	100	<1
	June 1992	100	1.02	100	<1
	September 1992	100	<1	100	<1
	November 1992	50	1.96	100	<1
015	December 1991	100	<1	100	<1
	March 1992	50	7.91	100	<1
	June 1992	100	<1	100	<1
	September 1992	100	<1	50[c]	ND[d]
	November 1992	100	<1	100	<1
016	December 1991	100	<1	100	<1
	March 1992	50	1.74	100	<1
	September 1992	100	<1	100	<1
	November 1992	100	1.32	100	<1
017	December 1991	100	ND	100	<1
	March 1992	25	4.54	100	<1
	June 1992	50	<1	100	<1
	September 1992	50	5.01	100	<1
	November 1992	100	<1	100	<1
018	December 1991	100	<1	100	<1
	March 1992	12	5.27	100	<1
	June 1992	100	<1	100	<1
	September 1992	100	<1	100	<1
	November 1992	50	1.43	100	<1

[a]NOEC = no-observed-effect concentration; the concentration causing no reduction in fathead minnow survival or growth or *Ceriodaphnia* survival or reproduction.

[b]TU_c = chronic toxicity unit (100/IC25); IC25 = the concentration causing a 25% reduction in fathead minnow growth or *Ceriodaphnia* survival.

[c]Highest concentration tested.

[d]ND = not determined.

highest concentration of effluent from Outfall 015 tested during September 1992, the NOEC = 50%. (See discussion.) Using the TU_C approach, effluent from Outfalls 013, 016, 017, and 018 was toxic to fathead minnows in two of five tests. Effluent from Outfall 015 was toxic in one of five tests. Using the NOEC approach, the same results were found for effluent from outfalls 013, 015, and 018. In one case (Outfall 017, June 1992), the NOEC approach indicated toxicity but the TU_C approach did not; and, in another case (Outfall 016, November 1992), the NOEC approach did not indicate toxicity but the TU_C approach did.

A summary of water quality parameters for each outfall is provided in Table 3.11. Water quality summaries for each test are provided in Appendix B. In general, water from the intermittent outfalls had higher alkalinity and hardness than the continuous outfalls. Mean alkalinity ranged from 56 to 114 mg/L and mean hardness ranged from 112 to 176 mg/L. Minimum pH ranged from 7.1 to 7.8 and maximum pH ranged from 8.0 to 8.2. Mean conductivity ranged from 217 to 342 μS/cm.

The ICP analyses of total recoverable metals obtained during each day of each test are presented in Tables 3.12 to 3.16. For many of the metals, concentrations were below the detection limit of the ICP. Only those metals that were present at concentrations above the detection limits are presented. KPDES monitoring data is provided in Appendix A. ICP analyses showed that effluent from the intermittent outfalls had elevated concentrations of aluminum (0.67–4.3 mg/L) and high suspended solids (maximum ranged from 18 to 2980 mg/L) compared with continuous outfalls. Mean concentrations of Cd, Cr, Cr-6, Cu, Ni, Pb, and Zn were below detection for all outfalls (Appendix A).

3.1.4 Discussion

3.1.4.1 Continuously flowing outfalls

Effluent from the continuously flowing outfalls was not consistently toxic to either *Ceriodaphnia* or fathead minnows. Effluent which enters Big Bayou Creek from outfalls 001, 004, and 006 was toxic to *Ceriodaphnia* in only one of five tests. For the 2 valid *Ceriodaphnia* tests (control reproduction > 15 offspring female) conducted by Birge et al. (1992) in 1991, only effluent from Outfall 004 was toxic. Effluent from Outfall 001 was toxic at a concentration of 50% (TU_C = 4.5). Because this outfall contributes the highest flow (Appendix A) to Big Bayou Creek, this level of toxicity indicates there was a potential for instream toxicity during this test period. However, effluent from Outfall 001 was not toxic to fathead minnows or to *Ceriodaphnia* during any other test period. Thus, the toxicity observed was an isolated event. Effluent from outfall 004 was toxic to *Ceriodaphnia* during August 1992. It is unlikely that any instream toxicity occurred, however, because effluent from Outfall 008 tested during the same time period was not toxic; effluent from outfall 004 joins with effluent from outfall 008 before entering Big Bayou Creek. Effluent from Outfall 006 was toxic to *Ceriodaphnia* during February 1992. However, the NOEC (50%) and TU_C (1.56) indicate that under conditions of normal base stream flow this effluent would probably not contribute to instream toxicity. Effluent from Outfall 011 which enters into Little Bayou Creek was never found to be toxic to *Ceriodaphnia*.

Fathead minnows were typically more sensitive than *Ceriodaphnia*. Birge et al. (1992) also found that fathead minnows (embryo-larval survival and teratogenicity test) were more sensitive than *Ceriodaphnia*. The TU_C approach indicates that effluent samples from outfalls 004,

Table 3.11. Summary (mean ± SD; n = 5 unless otherwise noted) of water chemistry analyses of full-strength effluent from intermittently flowing effluents taken in conjunction with toxicity tests

Sample	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Outfall 013				
Mean (± SD)	7.6 (0.3)	55.7 (18.2)	160 (115)	305 (224)
Range	7.1–8.0	28.0–81.0	42–360	84–704
Outfall 015				
Mean (± SD)	7.8 (0.3)	80.2 (18.3)	126 (34)	259 (69)
Range	7.5–8.2	52.0–98.0	76–154	153–314
Outfall 016[a]				
Mean (± SD)	7.8 (0.2)	87.0 (24.7)	111 (33)	217 (59)
Range	7.6–8.1	60.0–119.0	72–146	138–280
Outfall 017				
Mean (± SD)	8.0 (0.1)	113.8 (26.1)	176 (53)	342 (107)
Range	7.8–8.1	70.0–142.0	92–230	175–466
Outfall 018				
Mean (± SD)	7.8 (0.3)	58.7 (17.3)	112 (44)	219 (93)
Range	7.2–8.1	36–79	52–162	98–337

[a]n=4

Table 3.12. Mean and range (n = 7) of total recoverable metal concentrations (in milligrams per liter) in effluent from Outfall 013 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date		
		12-27-91	03-20-92	06-26-92
Al	0.05	2.85	90.67	BD[a]
Ba	0.05	0.06	BD	BD
Ca	0.05	30.10	20.17	100.81
Fe	0.05	1.62	0.63	BD
K	5	BD	BD	BD
Mg	0.01	2.50	3.64	19.46
Mn	0.05	BD	BD	BD
Na	1	1.98	1.43	7.71
Ni	0.1	BD	BD	BD
P	0.05	BD	BD	BD
Si	1	9.55	4.67	1.50
Sr	0.01	2.31	1.29	8.70
Zn	0.05	BD	BD	BD

[a]BD = Below detection limit.

Table 3.13. Mean and range (n = 7) of total recoverable metal concentrations (in milligrams per liter) in effluent from Outfall 015 determined by inductively coupled plasma spectroscopy

Metal	Detection Limits	Test Date		
		12-27-91	03-20-92	06-26-92
Al	0.05	0.67	0.14	BD
Ba	0.05	0.05	BD	BD
Ca	0.05	38.57	45.18	44.12
Fe	0.05	0.54	0.06	BD
K	5	BD	BD	5.49
Mg	0.01	2.50	5.67	5.68
Mn	0.05	0.77	BD	BD
Na	1	4.33	4.93	4.77
Ni	0.1	BD	BD	BD
P	0.05	BD	BD	BD
Si	1	6.41	4.03	2.11
Sr	0.01	0.35	0.44	0.62
Zn	0.05	BD	BD	BD

Note: BD = Below Detection.

Table 3.14. Mean and range (n = 7) of total recoverable metal concentrations (in milligrams per liter) in effluent from Outfall 016 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date		
		12-27-91	03-20-92	06-26-92
Al	0.05	2.07	0.13	NT
Ba	0.05	BD[a]	BD	NT
Ca	0.05	34.19	37.98	NT
Fe	0.05	1.31	0.20	NT
K	5	BD	BD	NT
Mg	0.01	0.63	4.51	NT
Mn	0.05	BD	BD	NT
Na	1	3.61	2.79	NT
Ni	0.1	BD	BD	NT
P	0.05	BD	0.32	NT
Si	1	9.96	4.70	NT
Sr	0.01	0.43	0.52	NT
Zn	0.05	BD	BD	NT

[a]BD = Below detection limit.

Table 3.15. Mean and range (n = 7) of total recoverable metal concentrations (in milligrams per liter) in effluent from Outfall 017 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date		
		12-27-91	03-20-92	06-26-92
Al	0.05	BD[a]	BD	BD
Ba	0.05	0.05	BD	BD
Ca	0.05	50.76	46.72	67.41
Fe	0.05	0.17	BD	BD
K	5	BD	BD	BD
Mg	0.01	2.50	6.40	10.28
Mn	0.05	0.77	BD	BD
Na	1	3.90	3.41	7.65
Ni	0.1	BD	BD	BD
P	0.05	BD	BD	BD
Si	1	3.41	2.58	2.86
Sr	0.01	1.02	0.87	1.90
Zn	0.05	BD	BD	BD

[a]BD = Below detection limit.

Table 3.16. Mean and range (n = 7) of total recoverable metal concentrations (milligrams per liter) in effluent from Outfall 018 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date		
		12-27-91	03-20-92	06-26-92
Al	0.05	4.30	0.80	BD[a]
Ba	0.05	0.06	BD	BD
Ca	0.05	27.43	18.67	43.61
Fe	0.05	2.38	0.66	BD
K	5	BD	BD	BD
Mg	0.01	0.63	3.33	6.69
Mn	0.05	0.77	BD	BD
Na	1	3.09	2.08	7.18
Ni	0.1	BD	BD	BD
P	0.05	BD	BD	BD
Si	1	12.74	4.29	2.51
Sr	0.01	0.42	0.24	0.70
Zn	0.05	BD	BD	BD

[a]BD = Below detection limit.

006, 008, 009, and 011 tested in February and effluent from Outfall 009 tested in October 1992 were toxic to fathead minnows. On the other hand, the NOEC approach indicates that none of the effluents (except for 011) were toxic. This difference is due to the fact that the NOEC approach uses growth only for those minnows that survive the test, while the TU_C approach uses growth for the number of fish that were used at the start of the test. In addition, if the mean growth for each concentration does not monotonically decrease (e.g., growth in the 50% effluent is greater than growth in the 100% effluent), the responses are "smoothed" by averaging (pooling) adjacent means (Weber et al. 1989). For example, in full-strength effluent from Outfall 009, mean weight for fish that survived the entire test was 0.38 mg/fish. Mean weight decreased to 0.29 mg/fish when calculated for 40 fish (the number of fish that were used to begin the test) and decreased to 0.24 mg/fish when the means for all concentrations were pooled (growth in the 100% effluent was greater than growth in the 50% effluent). The interpretation of results obtained using the NOEC and TU_C approaches probably lies somewhere in between the two. Full-strength effluent samples from each of the outfalls decreased growth of fish to some extent, thus indicating toxicity. However, for outfalls 004, 006, and 008, the effluent samples were not as toxic as indicated by the TU_Cs, ranging from 4.26 to 9.77. Effluent samples from outfalls 004, 006, and 008 were not toxic to fathead minnows during August and October 1992. Thus, toxicity observed in February was an isolated event. Effluent from Outfall 011 was toxic to minnows in February using either the NOEC or the TU_C approach, indicating there was a potential for instream toxicity during this period.

Effluent from Outfall 011 was not toxic during August and October 1992, again indicating that toxicity during the February test was an isolated event.

The NOEC and TU_C approaches agreed well for the *Ceriodaphnia* test, indicating that either approach could be used as a compliance endpoint. However, the two approaches did not agree for the fathead minnow test. The analysis suggests that the TU_C approach may overestimate the degree of toxicity to the minnows. Results of the fathead minnow test must be interpreted carefully when the TU_C is used as a compliance endpoint.

3.1.4.2 Intermittently flowing outfalls

Effluent samples from the intermittently flowing outfalls (013, 015, 016, 017, and 018) were not consistently toxic to either *Ceriodaphnia* or fathead minnows. None of the effluent samples were toxic to *Ceriodaphnia*. During the September 22–29 test with *Ceriodaphnia*, low survival in the control invalidated the test. Therefore, a second test was conducted during September 29–October 6, 1992, using the same effluent. Because there was an insufficient amount of effluent remaining from Outfall 015 to conduct a full test, 50% was the highest concentration tested. During the first test period with effluent from Outfall 015, *Ceriodaphnia* survival was 100% and mean reproduction was 28 offspring/female after 6 d. This high survival and reproduction indicates that 100% effluent was not toxic to *Ceriodaphnia*. For the two valid tests conducted by Birge et al. (1992) in 1991, none of the intermittent outfall samples were toxic to *Ceriodaphnia*.

Fathead minnows were more sensitive than *Ceriodaphnia* to all of the effluents. As was the case with tests done at the continuously flowing outfalls, there was some disagreement between the NOEC and TU_C approaches. Using the TU_C approach, effluent samples from Outfalls 013, 016, 017, and 018 were toxic (TU_C > 1.2) during two of five tests. Effluent from Outfall 015 was toxic during one test. The NOEC approach was in agreement with the TU_C approach for effluent samples from Outfalls 013, 015, and 018. For effluent from Outfall 016, the TU_C approach indicated toxicity during the November 1992 test, while the NOEC approach did not. For effluent from Outfall 017, the NOEC approach indicated toxicity, while the TU_C approach did not. The intermittent outfalls do not have a compliance endpoint in the draft Agreed Order or the renewed permit. However, the TU_C is reported to the KDOW and can be used to identify those effluents that are "toxic" and may need to be investigated.

Birge et al. (1990, 1992) hypothesized that a remobilization of soil metals may produce measurable toxicity for limited periods of time. Aluminum, in particular, was higher in the intermittent outfalls than in the continuous outfalls. For the intermittent outfalls, maximum aluminum concentrations for 1992 ranged from 1.3 to 119 mg/L. Although the amount of aluminum biologically available as dissolved aluminum is not known, work by Birge et al. (1992) showed that between 20 and 50% of the aluminum in Big Bayou Creek was in the dissolved fraction (0.45 μm filterable fraction). The freshwater criteria for chronic effects (EPA 1988) is 0.087 mg/L. Thus, it is possible that concentrations of aluminum in the effluent were toxic. However, *Ceriodaphnia* are more sensitive to aluminum than fathead minnows (EPA 1988), and effluent from the intermittent outfalls was never found to be toxic to *Ceriodaphnia*. Suspended solids were higher in the intermittent outfalls (Appendix A, maximum in 1992 ranged from 18 to 2980 mg/L), than in the continuously flowing outfalls (Appendix A, maximum in 1992 ranged from 21 to 75 mg/L). Suspended solids may affect fish by either killing them or reducing their growth rate (EPA 1986). The high level of suspended solids in the effluents may therefore cause low growth of minnows in the test beakers. Additional studies are scheduled for 1993–94 which will provide insight into the toxicity of metals and suspended solids. Toxicity tests will be conducted using nontreated and filtered effluent to determine whether suspended solids (or contaminants bound to suspended solids) are toxic to fathead minnows. In addition, the draft Agreed Order contains a requirement for determination of site-specific metal criteria for Big Bayou and Little Bayou creeks. This study will include determination of the concentrations of dissolved and total metals in the effluents.

3.2 AMBIENT TOXICITY

3.2.1 Introduction

Ambient toxicity monitoring at PGDP employed the *Ceriodaphnia* and fathead minnow tests described in Sect. 3.1. Toxicity monitoring 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 demonstrating that the effluent limitations established for PGDP protect and maintain the use of Big Bayou and Little Bayou creeks for growth and propagation of fish and aquatic life. The sites chosen for testing on Big Bayou Creek were selected to bracket area and point source discharges into the creeks and to correspond closely to those selected as instream monitoring study sites. The site chosen on Little Bayou Creek is downstream of all PGDP continuous discharges.

3.2.2 Materials and Methods

Ambient toxicity was evaluated using the fathead minnow test and the *Ceriodaphnia* test 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. For four tests, a subsample of each ambient water sample was exposed to ultraviolet (UV) light for a 15-min period in a Lifeguard® model QL25TH water treatment device. The unit contained a 25-W UV light source (254 nm wavelength) shielded from direct contact with the water by a quartz tube. The water samples were then evaluated for toxicity using fathead minnows.

Three ambient sites on Big Bayou Creek (BBK 12.5, BBK 10.0, and BBK 9.1; Fig. 2.2), one site on Little Bayou Creek (LUK 7.2, Fig. 2.2), and one site on Massac Creek (MAK 13.8, Fig. 2.1) were evaluated for toxicity. These sites are the same as those selected for the ecological monitoring component of BMP (Sect. 5). Five tests were conducted on a quarterly basis from October 1991 to October 1992. Water sampling and water chemistry analyses were conducted as described for continuously flowing outfalls in Sect. 3.1.2. All data analyses were accomplished as in Sect. 3.1.2 with the exception of those described in the following section. Significant differences in fathead minnow survival and growth and *Ceriodaphnia* survival among sites were evaluated using the General Linear Models (GLM) procedure in SAS (SAS 1985a, 1985b). The GLM procedure proved to be inappropriate for separating differences among all sites for *Ceriodaphnia* reproduction. In this case, separate GLM analyses were conducted 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 all tests are provided in Table 3.17. Mean survival and growth for each site and test are provided in Appendix B. Mean survival of minnows for all tests and sites ($n = 20$) ranged from 81.9% to 91.8%; growth ranged from 0.36 to 0.44 mg/fish. There was no significant difference in survival among sites (GLM; $p = 0.99$) or tests (GLM; $p = 0.13$). Likewise there was no difference in growth among sites or tests. A comparison of minnow survival in nontreated water vs UV-treated water ($n = 16$) showed that survival was significantly higher in the UV-treated water from LUK 7.2 (GLM; $p = 0.02$) and MAK 13.8 (GLM; $p = 0.03$). There was no difference in survival or growth based on treatment at the remaining sites.

Mean survival and reproduction of *Ceriodaphnia* for all tests are provided in Table 3.17. Mean survival and reproduction data for each site and test are provided in Appendix B. Mean survival (n=5) of *Ceriodaphnia* was high at all sites (94.1–99.5%). Reproduction among tests ($n = 50$) was significantly different (GLM; $p = 0.0002$); thus, the presence of chronic toxicity (significant reduction in reproduction compared to the control) at each site was determined by separate GLMs conducted for each test. Reproduction at each site was never found to be significantly lower than the control and in many cases was higher than the control (Appendix B).

Conductivity, hardness, and pH increased with distance downstream in Big Bayou Creek (Table 3.18). Mean hardness increased from 65 mg/L above PGDP (BBK 12.5) to 197 mg/L at the site furthest downstream (BBK 9.1). Mean conductivity increased from 225 μS/cm above PGDP (BBK 12.5) to 680 mg/L at BBK 9.1. Mean pH increased from 7.6 (maximum = 8.0) at BBK 12.5 to 7.9 (maximum = 9.0) at BBK 9.1. Mean alkalinity decreased slightly (59.8 to 34.5 mg/L) with distance downstream in Big Bayou Creek. All parameters measured in Little Bayou Creek (LUK 7.2) were higher than in the reference site (MAK 13.8, Table 3.18). Results of ICP analyses obtained concurrently with some of the toxicity tests are summarized in Tables 3.19 to 3.23. In general, concentrations of detected metals were similar between the reference site, MAK 13.8, and BBK 12.5. Concentrations of sodium were higher in BBK 12.5 than in MAK 13.8 (7–30 mg/L and 5–13 mg/L respectively). Metal concentrations decreased slightly or remained the same at BBK 10.0 then increased at BBK 9.1. Between BBK 12.5 and BBK 9.1, calcium increased approximately 3 fold, magnesium increased approximately 4 fold, and sodium increased approximately 2 fold. Metal concentrations in LUK 13.8 were similar to BBK 12.5.

3.2.4 Discussion

Over all tests conducted during October 1991 to October 1992, there was no reduction in fathead minnow survival or growth or *Ceriodaphnia* survival or reproduction. No toxicity to *Ceriodaphnia* was observed for the *Ceriodaphnia* tests conducted by Birge et al. (1992) during 1991. Comparisons with Birge et al. (1992) fathead minnow toxicity test data are not provided because they used a different test method (embryo-larval teratogenicity test). Fathead minnow survival was low at all sites (including MAK 13.8 and BBK 12.5) during the October 1991 test. At this time it is hypothesized that a natural pathogen

Table 3.17. Toxicity test results for ambient sites on Big Bayou, Little Bayou, and Massac creeks

Site	Fathead minnow: Mean Survival[a,b] (%) (CV%)	Fathead minnow: Growth[b] (mg/fish) (SD)	*Ceriodaphnia*: Mean Survival[a,c] (%) (CV%)	*Ceriodaphnia*: Reproduction[d] (offspring/female) (SD)
BBK 12.5	81.9 (33.9)	0.37 (0.18)	99.5 (2.7)	30.8 (8.6)
BBK 12.5 UV[e]	93.5 (23.4)	0.40 (0.11)	NT[f]	NT
BBK 10.0	87.2 (25.8)	0.39 (0.18)	99.5 (2.7)	29.8 (7.7)
BBK 10.0 UV	93.1 (21.1)	0.44 (0.15)	NT	NT
BBK 9.1	91.8 (27.8)	0.44 (0.20)	94.1 (10.2)	31.9 (7.4)
BBK 9.1 UV	99.2 (14.1)	0.52 (0.13)	NT	NT
LUK 7.2	83.7 (45.7)	0.37 (0.17)	99.5 (2.7)	29.7 (5.9)
LUK 7.2 UV	99.8 (12.4)	0.47 (0.13)	NT	NT
MAK 13.8	83.7 (30.9)	0.36 (0.15)	98.3 (4.5)	30.7 (8.0)
MAK 13.8 UV	98.3 (12.2)	0.44 (0.14)	NT	NT

[a]Survival (CV%) values were arcsine transformed for calculation.
[b]$n=20$.
[c]$n=5$.
[d]$n=50$.
[e]UV = sample was exposed to ultraviolet light for 15 min, $n=16$.
[f]NT = not tested.
Note: CV = Coefficient of variation; SD = Standard deviation; BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

Table 3.18. Summary (mean ± SD; n = 35) of water chemistry analyses of water from ambient sites

Sample	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
BBK 12.5				
Mean (± SD)	7.6 (0.2)	59.8 (18.5)	65 (12)	225 (45)
Range	7.0–8.0	20.0–84.0	50–98	112–281
BBK 10.0				
Mean (± SD)	7.5 (0.2)	36.9 (5.1)	73 (191	242 (45)
Range	6.9–7.9	24.0–50.0	54–112	126–319
BBK 9.1				
Mean (± SD)	7.9 (0.4)	34.5 (3.8)	197 (83)	680 (299)
Range	7.2–9.0	26–44	64–346	207–1277
LUK 7.2				
Mean (± SD)	7.7 (0.2)	45.3 (9.1)	79 (14)	255 (52)
Range	7.2–8.0	21–71	50–111	100–333
MAK 13.8[a]				
Mean (± SD)	7.5 (0.2)	36.0 (6.7)	48 (10)	135 (12)
Range	6.8–7.8	21–49	32–88	98–167

[a]Reference site.
Note: BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

Table 3.19. Mean and range (n = 7) of total recoverable metal concentrations (in milligrams per liter) in effluent from Massac Creek kilometer 13.8 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date			
		10-27-91	02-13-92	05-21-92	08-13-92
Al	0.05	0.79	3.22	BD	BD
Ba	0.05	BD	0.08 0.06–0.10	BD	BD
Ca	0.05	12.67 11.67–14.19	13.30 11.32–15.57	10.60 9.82–11.37	8.94 8.08–9.31
Fe	0.05	0.45 0.20–0.80	2.17 0.30–6.65	0.10 0.06–0.23	0.50 0.47–0.55
K	5	5.65 5.65–5.65	5.61 5.61–5.61	BD	BD
Mg	0.01	1.95 1.56–2.08	0.63 0.63–0.63	2.72 2.52–2.93	2.33 2.27–2.38
Mn	0.05	0.48 0.29–0.77	0.77 0.77–0.77	0.07 0.05–0.09	0.08 0.06–0.10
Na	1	13.80 10.88–18.91	5.51 3.36–7.06	12.40 11.92–12.76	9.99 9.60–10.29
Ni	0.1	BD	BD	BD	BD
P	0.05	BD	BD	BD	0.14 0.14–0.14
Si	1	5.92 5.30–7.33	11.55 6.19–25.70	4.80 4.68–4.97	4.18 4.03–4.44
Sr	0.01	0.08 0.07–0.09	0.09 0.08–0.10	0.04 0.04–0.05	0.05 0.04–0.05
Zn	0.05	BD	BD	BD	BD

[a]BD = Below detection limit.

Table 3.20. Mean and range ($n = 7$) of total recoverable metal concentrations (in milligrams per liter) in effluent from Big Bayou Creek kilometer 12.5 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date			
		10-27-91	02-13-92	05-21-92	08-13-92
Al	0.05	BD[a]	2.45 0.89–5.35	BD	BD
Ba	0.05	BD	0.06 0.06–0.07	BD	BD
Ca	0.05	15.03 14.54–16.17	14.59 8.66–18.32	17.25 16.05–19.04	12.97 12.29–13.52
Fe	0.05	BD	1.41 0.63–2.21	BD	0.06 0.05–0.07
K	5	BD	5.27 5.05–5.53	BD	5.32 5.06–5.56
Mg	0.01	1.95 1.56–2.08	0.57 0.47–0.63	4.45 4.33–4.57	3.45 3.39–3.51
Mn	0.05	1.15 1.15–1.15	0.77 0.77–0.77	BD	BD
Na	1	30.86 26.14–39.17	6.99 2.20–10.10	27.76 27.17–28.31	27.28 26.24–28.30
Ni	0.1	0.78 0.78–0.78	BD	BD	BD
P	0.05	BD	BD	BD	BD
Si	1	4.63 4.01–4.96	8.73 6.74–10.94	2.41 2.14–2.66	2.52 2.14–2.78
Sr	0.01	0.07 0.07–0.07	0.07 0.04–0.09	0.06 0.05–0.08	0.06 0.05–0.07
Zn	0.05	BD	BD	BD	BD

[a]BD = Below detection limit.

Table 3.21. Mean and range ($n = 7$) total recoverable metal concentrations (in milligrams per liter) in effluent from Big Bayou Creek kilometer 10.1 determined by inductively coupled plasma spectroscopy

Metal	Detection Limits	Test Date			
		10-27-91	02-13-92	05-21-92	08-13-92
Al	0.05	BD[a]	2.40 0.24–6.77	BD	BD
Ba	0.05	BD	0.06 0.05–0.09	BD	0.09 0.09–0.09
Ca	0.05	19.75 17.17–22.57	16.83 13.46–20.00	16.62 15.67–17.94	13.37 12.64–13.64
Fe	0.05	0.08 0.06–0.09	1.58 0.32–4.00	BD	BD
K	5	5.01 5.01–5.01	5.14 5.14–5.14	BD	5.23 5.07–5.51
Mg	0.01	3.12 2.50–3.33	1.96 0.63–3.13	5.92 2.99–7.11	4.77 4.51–5.26
Mn	0.05	0.38 0.38–0.38	0.54 0.09–0.77	BD	BD
Na	1	28.61 22.25–32.99	9.43 4.14–13.48	24.54 22.66–26.68	16.98 15.25–20.43
Ni	0.1	BD	BD	BD	BD
P	0.05	BD	BD	BD	0.22 0.15–0.31
Si	1	1.69 1.26–2.19	8.90 4.23–18.63	1.01 1.01–1.01	1.14 1.01–1.29
Sr	0.01	0.18 0.11–0.24	0.10 0.08–0.12	.07 0.06–0.08	0.08 0.07–0.08
Zn	0.05	BD	BD	BD	BD

[a]BD = Below detection limit.

Table 3.22. Mean and range (n = 7) of total recoverable metal concentrations (in milligrams per liter) in effluent from Big Bayou Creek kilometer 9.1 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date			
		10-27-91	02-13-92	05-21-92	08-13-92
Al	0.05	BD[a]	1.84 0.15–5.24	BD	BD
Ba	0.05	BD	0.06 0.05–0.08	BD	BD
Ca	0.05	50.61 43.62–62.00	31.68 20.38–40.00	49.76 23.03–75.44	47.48 20.86–69.95
Fe	0.05	0.09 0.07–0.12	1.13 0.13–3.14	BD	BD
K	5	7.06 5.89–8.37	BD	7.76 5.79–9.22	7.86 5.31–9.07
Mg	0.01	8.22 7.50–8.74	3.66 2.50–5.00	16.04 8.98–22.75	14.09 7.30–19.50
Mn	0.05	1.20 1.20–1.20	0.77 0.77–0.77	BD	BD
Na	1	73.08 64.21–92.99	23.45 11.73–35.38	59.51 31.66–86.58	47.62 20.56–68.84
Ni	0.1	0.78 0.78–0.78	BD	BD	BD
P	0.05	BD	BD	BD	0.08 0.06–0.11
Si	1	2.77 2.40–3.19	7.35 3.98–15.68	1.78 1.20–2.35	2.12 1.46–2.75
Sr	0.01	0.27 0.24–0.31	0.14 0.09–0.16	0.17 0.09–0.26	0.19 0.09–0.28
Zn	0.05	BD	BD	BD	BD

[a]BD = Below detection limit.

Table 3.23. Mean and range (n = 7) of total recoverable metal concentrations (in milligrams per liter) in effluent from outfall at Little Bayou Creek kilometer 7.2 determined by inductively coupled plasma spectroscopy

Metal	Detection limits	Test date			
		10-27-91	02-13-92	05-21-92	08-13-92
Al	0.05	BD[a]	3.35 0.59–7.18	BD	0.05 0.05–0.05
Ba	0.05	0.07 0.07–0.07	0.07 0.05–0.10	BD	BD
Ca	0.05	30.94 26.72–33.51	18.40 11.25–28.94	17.60 16.59–19.17	14.79 12.96–16.14
Fe	0.05	0.15 0.09–0.21	1.93 0.47–3.94	0.17 0.06–0.27	0.07 0.07–0.07
K	5	BD	BD	BD	BD
Mg	0.01	3.20 2.81–3.33	1.94 1.12–2.86	6.94 6.47–7.69	5.15 4.76–5.87
Mn	0.05	1.20 1.20–1.20	BD	BD	BD
Na	1	22.78 15.57–28.04	13.04 4.83–20.03	30.43 28.21–32.79	17.29 14.87–21.14
Ni	0.1	BD	BD	BD	BD
P	0.05	BD	BD	BD	0.15 0.07–0.26
Si	1	2.72 2.29–3.09	10.86 5.07–18.98	3.74 3.10–4.91	1.47 1.27–1.75
Sr	0.01	0.61 0.46–0.72	0.41 0.18–1.38	0.14 0.12–0.17	0.10 0.09–0.12
Zn	0.05	BD	BD	BD	BD

[a]BD = Below detection limit.

in the water might have been the cause. An analysis of ambient fathead minnow tests conducted at ORNL (Kszos and Stewart 1992) examined survival among replicates in effluents and ambient waters and found, when mean survival of minnows was between 40% and 70%, among-replicate variation for ambient tests was significantly greater than it was for the effluent tests. A large variation in survival makes it more difficult to use the minnow test to distinguish among ambient sites and may falsely indicate toxicity. The unusual minnow mortality in tests with ambient water appeared to be due to a pathogenic bacteria or fungi, for exposing the water to UV light before testing nearly eliminated minnow mortality. Ambient tests of Big Bayou, Little Bayou, and Massac creeks using UV treated water showed that in UV treatment significantly improved survival in MAK 13.8 and LUK 7.2 ($p = 0.03$ and $p = 0.02$ respectively). The toxicity observed for the ambient sites in October 1991 was not repeated during the remaining tests.

3.3 SUMMARY

Effluent from the continuous outfalls was rarely toxic to *Ceriodaphnia* and effluent from the intermittent outfalls was never toxic to *Ceriodaphnia*. Effluent from Outfall 001 was toxic during May 1992, but no instream toxicity was observed at the Big Bayou Creek site (BBK 9.1) immediately downstream of Outfall 001. Effluent from Outfall 004 was toxic in August 1992, but the toxicity did not "carry through" to Outfall 008. Thus, toxicity of the effluents to *Ceriodaphnia* was not present at the ambient sites.

Effluent from the continuous and intermittent outfalls was occasionally toxic to fathead minnows. Effluent from all of the continuous outfalls except 001 was toxic in February 1992. However, during this same test period, fathead minnow survival was only reduced at BBK 12.5 (above PGDP) and LUK 7.2. For both sites, treatment with UV light eliminated the toxicity. Thus, toxicity observed in the effluent from Outfalls 004, 006, 008, and 009 was not present at the ambient sites. Effluent from Outfall 009 was also toxic to fathead minnows in October 1992. No instream toxicity was observed at BBK 9.1, but this site is also below Outfall 008. If toxicity persists in effluent from Outfall 009 during 1993, we may want to consider an additional monitoring site in Big Bayou Creek below Outfall 009. Ambient toxicity tests were not conducted concurrently with the intermittent outfalls. Tests with filtered and nonfiltered effluent during 1993–94 will provide additional insight into the toxicity of the intermittent outfalls.

4. BIOACCUMULATION

G. R. Southworth

4.1 INTRODUCTION

Bioaccumulation monitoring conducted to date as part of BMP at PGDP identified PCB contamination in fish in Big Bayou Creek and Little Bayou Creek as major concerns (Birge et al. 1990, 1992). Mercury concentrations in fish from Big Bayou Creek were found to be higher in fish collected downstream from PGDP discharges than in fish from an upstream site (Birge et al. 1992), but the difference was not large and mercury concentrations in fish were well below both the U.S. Department of Agriculture Food and Drug Administration (FDA) limit (FDA 1984a) and the EPA human health risk assessment guidelines. Concentrations of various metals in fish from Big Bayou Creek and Little Bayou Creek were well below levels of concern for human consumption.*

The objectives of the 1992 bioaccumulation monitoring were (1) to continue PCB tracking studies in fish from Big Bayou Creek and Little Bayou Creek, (2) to confirm elevated mercury concentrations in fish in Big Bayou Creek and establish appropriate reference site concentrations, and (3) to conduct screening analyses to detect other contaminants that may be of concern to consumers in fish from these streams.

4.2 STUDY SITES

Longear sunfish (*Lepomis megalotis*) were collected for PCB analysis at BBK 12.5 (the upstream reference site on Big Bayou Creek), BBK 10.0, 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). Longear sunfish were also taken for mercury analysis at BBK 12.5, BBK 10.0, BBK 9.1, BBK 2.8, and MAK 13.8 (local reference site, Fig. 2.1). Hinds Creek in Anderson County, Tennessee, served as a 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. Longear sunfish were also sampled from LUK 7.2 and BBK 9.1 for contaminant screening analyses. Larger fish (spotted bass, *Micropterus punctulatus*, and carp, *Cyprinus carpio*) were collected, when present, from BBK 9.1 and LUK 4.3. The length of stream sampled at each site varied with the degree of difficulty in obtaining fish but was held to $\leq$1000 m. The site at BBK 10.0 was restricted to the reach between PGDP outfalls 008 and 001 (Fig. 2.3). The BBK 9.1 site encompassed the reach from BBK 9.1 up to outfall 001 (Fig. 2.3). Larger fish (carp, 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

*U.S. Environmental Protection Agency, Region IV Toxic Substances Spreadsheet, U.S. Environmental Protection Agency, Region IV, Atlanta, Georgia. Unpublished mimeo. July 1990.

LB3 in Birge et al. 1990, 1992) required that collections be confined to a relatively short reach near LUK 9.0 at the expense of expanding the reach downstream in order to obtain larger fish of a single species. This site was restricted to ~ 250 m from outfall 011 downstream to LUK 9.0. The downstream site included 1000 m centered at LUK 4.3. Fish for contaminant screening analyses were collected from BBK 9.1 and from LUK 7.2 in order to detect any contribution from outfall 003.

4.3 MATERIALS AND METHODS

PCB concentrations in sunfish provide an effective monitor of temporal and spatial changes in PCB contamination within stream fishes but do not provide a direct estimate of the highest PCB concentrations that may be present in stream biota. Larger, older, fattier fish, such as carp or channel catfish, accumulate 3 to 10 times higher PCB 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 indicator.

Fish were collected by backpack electrofishing. Eight fish were taken from each site for PCB and mercury analysis, and four fish taken for screening analyses. Collections of larger fish (spotted bass, carp) for PCB monitoring were made on October 18, 1991, in Big Bayou Creek (BBK 9.1) and Little Bayou Creek (LUK 4.3). Eight carp were collected at BBK 9.1, but only three small carp were found at LUK 4.3. Eight spotted bass were therefore taken at this site as a substitute.

Longear sunfish (*Lepomis megalotis*) were collected in Big Bayou Creek and Little Bayou Creek on April 6–7, 1992, as part of routine twice yearly monitoring of PCB concentrations in this species. 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. High fish densities at most sites enabled the collection of eight specimens of sunfish ≥35 g at all sites except LUK 9.0 (the site closest to PGDP where habitat is extremely limited). Fish were also taken for mercury analysis at BBK 12.5, BBK 10.0, BBK 9.1, BBK 2.8, and MAK 13.8 (local reference site) on April 6–7, 1992, and Hinds Creek in Tennessee on April 15, 1992. 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 the next day. Each fish was weighed and measured, then fileted, skinned or scaled, and rinsed in process tap water. The October samples were skinned; however all subsequent samples were scaled and the skin left on the filet. Samples of sunfish for specific analyses were excised, wrapped in heavy duty aluminum foil, labeled, and frozen on dry ice (if processed on site) or in a standard freezer at −15° C. For larger fish (carp, 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 determinations in carp and bass collected in October 1991 were analyzed by capillary column gas chromatography–electron capture detection (GC/ECD) using a method based on EPA procedure PPB 12/83 (EPA 1984), which involves homogenizing the sample in anhydrous sodium sulfate, extraction with methylene chloride, cleanup using column chromatography, and GC/ECD. Subsequent PCB analyses were conducted using a modification to this method in which sulfuric acid partitioning is used as a cleanup step to destroy lipids.* Screening analyses for chlorinated pesticides utilized PPB 12/83. 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), for As, Cd, Cr, Cu, Pb, Ni, Se, Ag, V and U by inductively coupled plasma/mass spectrometry (EPA 1991, procedures 200.3, 200.8) and for zinc by inductively coupled plasma/optical emission spectrometry (EPA 1991, procedure 200.11). Radionuclides were detected by gamma scintillation spectrometry.

Quality assurance was maintained by a combination of blind duplicate analyses, analysis of biological reference standards and wild fish from uncontaminated sites, and determination of recoveries of analyte spikes to uncontaminated fish. Results are summarized in Appendix A.

Statistical evaluations of data were made using SAS procedures and software (SAS 1985a, 1985b) for ANOVA, Tukey's Multiple Comparison Test, and the calculation of mean, standard error, and standard deviation. Tests for homogeneity of variance among various data groups were conducted using Levene's test on untransformed and $\log_e$-transformed variables (Sokal and Rohlf 1981). Dunnett's Test was used to compare means of various groups with controls (Zar 1984). All comparisons were conducted using $p = 0.05$.

4.4. RESULTS AND DISCUSSION

4.4.1. PCBs

4.4.1.1 Fall 1991

Results of PCB analyses of carp (*Cyprinus carpio*) and spotted bass (*Micropterus punctulatus*) collected from Big Bayou Creek and Little Bayou Creek on October 18, 1991, are presented in Table 4.1. Carp filets from BBK 9.1 contained an average (± SE) PCB concentration of 2.3 ± 1.2 μg/g wet weight. This average was heavily influenced by two fish that contained 7.8 and 5.6 μg/g; no other fish contained in excess of 2 μg/g. The range of concentrations was from 0.42 to 7.8 μg/g. Residues similar to Aroclor 1254 predominated in the fish from Big Bayou Creek, but materials quantified as Aroclor 1248 and 1260 were also present. The highest PCB concentrations generally occurred in fish having the highest concentrations of intramuscular lipids (Table 4.1), a common finding in PCB monitoring; although exceptions are common place. Monitoring by University of Kentucky researchers in July 1991 (Birge et al. 1992) reported an average PCB concentration of 0.27 μg/g in sunfish collected at this site. Data from biological monitoring programs in PCB-contaminated creeks on the DOE Oak Ridge Reservation, Oak Ridge, Tennessee, indicate that large carp typically contain

*Mid-America Fish Contaminants Group, *Extraction and Analysis of Acid Stable Organochlorine Pesticides/PCBs in Biological Tissue*, Unpublished mimeo, 1989.

Table 4.1. Concentrations of polychlorinated biphenyls (in micrograms per gram wet weight) and lipid content (percentage wet weight) in filets of carp and spotted bass from Big Bayou Creek and Little Bayou Creek, October 1991

Site[a]	Sample type[b]	Date	Species[c]	Sex	Number[d]	Weight (g)	Length (cm)	ΣPCB[e]	Arochlor 1248 (μg/g wet wt)	Arochlor 1254 (μg/g wet wt)	Archlor 1260 (μg/g wet wt)	Lipid
BBK 9.1	R	10/17/91	COCARP	F	3021	1782	52.4	0.51	0.17	0.24	0.11	20.7
BBK 9.1	R	10/17/91	COCARP	M	3022	2060	54.1	0.58	0.13	0.30	0.15	1.34
BBK 9.1	R	10/17/91	COCARP	M	3023	1688	49.8	0.42	0.15	0.21	0.06	1.10
BBK 9.1	R	10/17/91	COCARP	M	3024	3527	61.8	0.78	0.36	0.31	0.11	0.92
BBK 9.1	R	10/17/91	COCARP	F	3025	2325	52.9	0.48	0.25	0.13	0.10	0.69
BBK 9.1	R	10/17/91	COCARP	M	3026	2432	55.5	7.80	0.97	2.12	4.72	3.89
BBK 9.1	R	10/17/91	COCARP	F	3027	3767	63.2	5.58	0.41	1.72	3.45	3.87
LUK 4.3	R	10/17/91	SPBASS	F	3030	274	27.5	0.28	<0.01	0.16	0.12	0.43
LUK 4.3	R	10/17/91	SPBASS	F	3031	232	26.6	0.24	<0.01	0.12	0.12	0.48
LUK 4.3	R	10/17/91	SPBASS	F	3032	243	26.6	0.40	<0.01	0.19	0.20	0.39
LUK 4.3	R	10/17/91	SPBASS	M	3033	369	28.8	0.44	<0.01	0.20	0.24	0.52
LUK 4.3	R	10/17/91	SPBASS	M	3034	324	28.6	0.49	<0.01	0.21	0.28	0.36
LUK 4.3	R	10/17/91	SPBASS	M	3035	200	24.8	0.37	<0.01	0.16	0.21	0.49
LUK 4.3	R	10/17/91	SPBASS	M	3036	336	29.2	0.28	<0.01	0.10	0.18	0.57
LUK 4.3	R	10/17/91	SPBASS	F	3037	524	32.8	0.27	<0.01	0.13	0.14	0.67
LUK 4.3	R	10/17/91	COCARP	F	3038	582	36.0	1.39	0.70	0.51	0.18	1.20
LUK 4.3	R	10/17/91	COCARP	M	3039	554	33.7	0.40	<0.06	0.29	0.12	0.68
LUK 4.3	R	10/17/91	COCARP	F	3013	469	33.1	0.77	0.57	0.20	<0.10	0.78
HINDSCR	C	11/14/90	COCARP	M	5792	1560	49.8	<0.01	<0.01	<0.02	<0.02	1.61
HINDSCR	C	11/14/90	COCARP	M	5793	1763	50.3	<0.10	<0.05	<0.10	<0.10	0.93
BBK 9.1	D	10/17/91	COCARP	M	3024	3527	61.8	0.94	0.47	0.36	0.11	1.18
LUK 4.3	D	10/17/91	SPBASS	F	3037	524	32.8	0.44	<0.07	0.25	0.19	0.80

[a]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; HINDSCR = Hinds Creek, an uncontaminated reference stream in Anderson County, Tennessee.
[b]R = regular, C = control or reference site, D = duplicate.
[c]COCARP = carp (*Cyprinus carpio*), SPBASS = spotted bass (*Micropterus punctulatus*).
[d]Tag number.
[e]Sum of PCBs quantified against commercial mixtures, in micrograms per gram wet wt.

about five-fold higher concentrations of PCBs than sunfish in small streams. Thus, the results from carp in Big Bayou Creek approximate concentrations that would have been predicted from the July 1991 sunfish data (Birge et al. 1992).

Carp were uncommon at LUK 4.3, and only three small specimens were collected. PCB concentrations averaged 0.85 ± 0.28 μg/g wet weight, with a range of 0.40 to 1.39 μg/g. Residues were predominantly similar to Aroclor 1248 and 1254, with some Aroclor 1260. Spotted bass were more abundant at this site, and eight were collected for analysis. PCBs in bass averaged 0.35 ± 0.03 μg/g wet weight, with a range of 0.24 to 0.49 μg/g. Residues were predominantly mixtures resembling Aroclor 1254 and 1260. Sunfish from LUK 4.3 averaged 0.28 μg/g PCBs in July 1991 (Birge et al. 1992). As was the case in Big Bayou Creek, PCB concentrations found in carp were within expectations predicted by the Birge et al. (1992) data, especially considering that the small carp comprising the collections in Little Bayou Creek would not be expected to differ as greatly from sunfish in their bioaccumulation potential as would larger carp. Similarly, spotted bass contained PCB concentrations similar to those observed in sunfish, as would be expected from previous monitoring (Birge et al. 1992).

4.1.1.2 Spring 1992

PCB contamination was evident in longear sunfish collected from both Big Bayou and Little Bayou creeks (Table 4.2, Fig. 4.1, Table C.1). Statistical comparison (Dunnett's test) of mean concentrations in fish from sites downstream from PGDP discharges with the mean concentration in fish from reference sites [Hinds Creek in Tennessee, Big Bayou Creek above all PGDP discharges (BBK 12.5)] indicated that mean PCB concentrations in sunfish exceeded the reference site mean at all sites in Big Bayou Creek and Little Bayou Creek downstream from PGDP (Table 4.2). The constituents of the PCB mixtures extracted from fish most closely resembled commercial mixtures Aroclor 1260 and 1254, with 1260 being more abundant.

The highest mean concentration occurred in fish from the site in Little Bayou Creek immediately downstream from outfall 011 (LUK 9.0), as was the case in previous monitoring (Birge et al. 1992). The level of contamination in sunfish from Little Bayou Creek declined substantially farther downstream at LUK 4.3, a pattern also observed consistently in previous monitoring (Birge et al. 1992). In Big Bayou Creek, the highest mean PCB concentration was found in fish from BBK 9.1, below outfall 001, but fish from BBK 10.0 also contained PCB contamination (Table 4.2, Fig. 4.1). As was the case in Little Bayou Creek, PCB concentrations in sunfish were much lower farther downstream (BBK 2.8). Statistical comparisons of differences in mean PCB concentrations among sites (Tukey's test) discriminated the sites having the highest PCB contamination in each stream from the other sites in that stream (Table 4.2). Thus, PCB contamination at BBK 9.1 exceeded that at BBK 10.0 or BBK 2.8, and LUK 9.0 exceeded LUK 4.3.

Although concentrations of PCBs were similar between BBK 9.1 and LUK 9.0, the fish from Little Bayou Creek were both smaller and in nutritionally poorer condition (reflected as lower intramuscular lipid content, Table C.1). Both factors would tend to make Little Bayou Creek fish less effective bioconcentrators of PCBs than Big Bayou Creek fish. Thus, the actual difference in these two creeks is probably greater than

Table 4.2. Mean concentrations of polychlorinated biphenyls (in micrograms per gram wet wt) in longear sunfish from streams near Paducah Gaseous Diffusion Plant, April 1992

Site	Mean	SE	n	Tukey group[a]	Dunnett's test[b]
BBK 12.5	0.02	0.004	8	D	ref
BBK 10.0	0.08	0.002	8	C	S
BBK 9.1	0.23	0.050	8	A,B	S
BBK 2.8	0.04	0.009	8	C,D	S
LUK 9.0	0.46	0.103	8	A	S
LUK 4.3	0.08	0.005	8	B,C	S
HindsCr[c]	0.02	0.001	6	D	ref

[a]Groups separated by results of Tukey's Multiple Comparison Test on $\log_e$-transformed data. Mean concentrations are similar at sites having the same letter grouping, $p < 0.05$.

[b]Results of one-tailed Dunnett's Test for comparing group means with a reference site mean using $\log_e$-transformed data. Data from Hinds Creek and BBK 12.5 were pooled to compute the reference site mean (ref). S indicates statistically significant difference, $p < 0.05$.

[c]At this site only, Redbreast sunfish, *Lepomis auritus* were tested.

Note: BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; Hinds Cr = Hinds Creek.

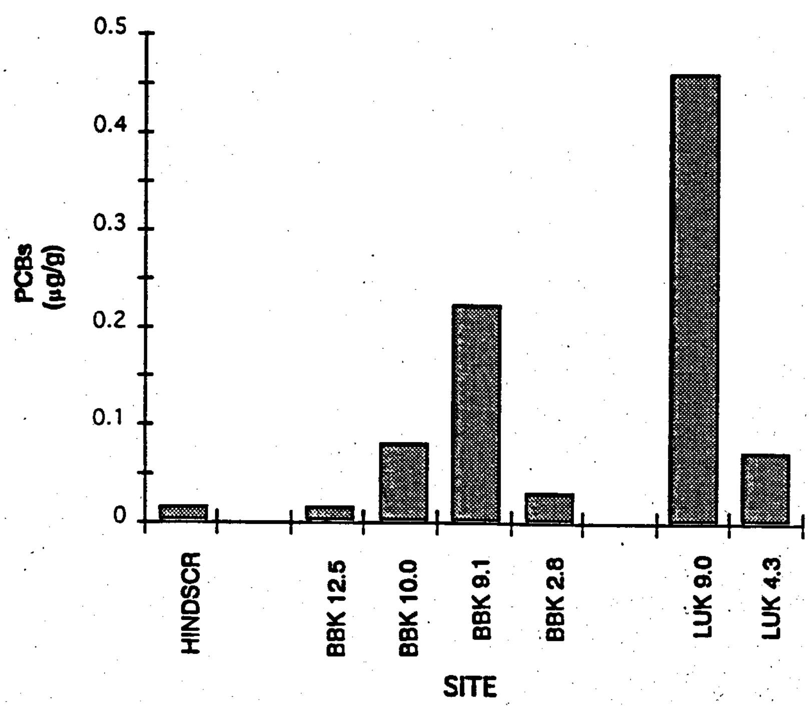

Fig. 4.1. Concentrations of PCBs (in micrograms per gram wet wt) in filets of longear sunfish from Big Bayou Creek and Little Bayou Creek near Paducah Gaseous Diffusion Plant, April 1992. Hinds Creek (HINDSCR) and Big Bayou Creek kilometer (BBK) 12.5 are reference sites. LUK = Little Bayou Creek kilometer.

the difference in mean concentrations of PCBs in sunfish indicates.

Mean concentrations of PCBs in sunfish varied considerably among sampling periods in previous monitoring in Big Bayou Creek and Litle Bayou Creek, with no apparent temporal trend or pattern (Birge et al. 1992). Generally, when higher PCB concentrations were observed in sunfish, lower chlorinated constituents (Aroclor 1248) were present in substantial proportions, and PCBs were detected in aqueous effluent samples. The concentrations reported in this study are lower than those reported previously. Although it would be tempting to interpret this as partial remediation of the problem, the apparent short-term variability in PCB contamination in sunfish from this system makes such an interpretation unwarranted. Also, lower-than-desired recoveries of matrix spikes in quality assurance (QA) samples raises concerns that the concentrations reported may have underestimated actual concentrations (Appendix C). Continued regular monitoring of PCB concentrations in fish is needed to detect any consistent trend over time.

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 as 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. PCB concentrations of ~ 0.3 μg/g in fish having 1% lipids would imply aqueous phase PCB concentrations of roughly 0.03 μg/L (using concentration factor =10,000 from EPA 1990).

4.4.2 Mercury

In previous monitoring (Birge et al. 1992), mercury concentrations in fish from Big Bayou Creek were found to be somewhat higher downstream from PGDP than upstream. Fish from all sites contained concentrations of mercury that appeared to be elevated relative to reference sites in East Tennessee.

The results of mercury monitoring in longear sunfish confirmed the findings of previous studies (Birge et al. 1992) that concentrations in fish from Big Bayou Creek were somewhat higher downstream from PGDP than upstream (Table 4.3, Fig. 4.2 , Table C.2). Mean mercury concentrations in sunfish were similar to those observed by Birge et al. (1992), ranging from a maximum of 0.45 μg/g at BBK 10.0 to 0.21 μg/g at BBK 12.5, upstream from PGDP. Because previous sampling (Birge et al. 1992) suggested that background or reference site concentrations of mercury in streams near PGDP were elevated relative to concentrations of mercury typical of fish from uncontaminated streams in East Tennessee, a second local reference site, Massac Creek, was sampled to help determine the appropriate reference concentration. Mean concentrations of mercury in redbreast sunfish from Hinds Creek (Oak Ridge, Tennessee) were less than 50% of those observed at any site in

Table 4.3. Mean concentrations of total mercury (in micrograms per gram wet wt) in longear sunfish from streams near PGDP, April 1992

Site	Mean	SE	*n*	Tukey group[a]	Dunnett's test[b]
BBK 12.5	0.21	0.02	8	C	ref
BBK 10.0	0.45	0.03	8	A	S
BBK 9.1	0.35	0.04	8	A,B,C	S
BBK 2.8	0.38	0.06	8	A,B	S
LUK 7.2	0.32	0.14	4	excluded	excluded
Massac Cr	0.23	0.02	8	B,C	ref
HindsCr[c]	0.09	0.01	6	D	excluded

[a]Groups separated by results of Tukey's Multiple Comparison Test on $\log_e$-transformed data. Mean concentrations are similar at sites having the same letter grouping, $p < 0.05$.

[b]Results of one-tailed Dunnett's Test for comparing group means with a local reference site mean (ref) using $\log_e$-transformed data. Data from Massac Creek and BBK 12.5 were pooled to compute the reference site mean. S indicates statistically significant difference, $p < 0.05$.

[c]At this site only, Redbreast sunfish, *Lepomis auritus*, were used for testing.

Note: BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; Massac Cr = Massac Creek; Hinds Cr = Hinds Creek (reference site in Oak Ridge, Tenn.).

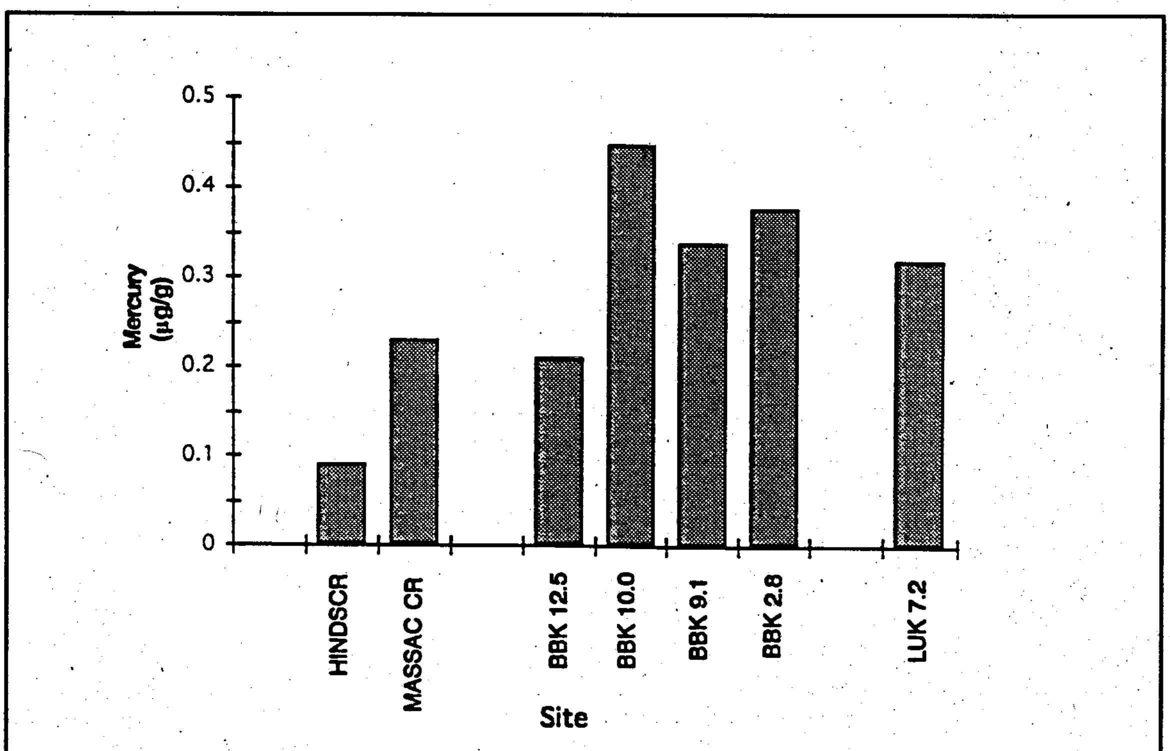

Fig. 4.2. Mean concentrations of total mercury (in micrograms per gram wet wt) in filets of longear sunfish from Big Bayou Creek and Little Bayou Creek near Paducah Gaseous Diffusion Plant. Hinds Creek is a reference site in Anderson County, Tennessee; Massac Creek and Big Bayou Creek kilometer 12.5 are reference sites near Paducah, Kentucky. BBK = Big Bayou Creek kilometer; HINDSCR = Hinds Creek; LUK = Little Bayou Creek kilometer.

Big Bayou Creek or in Massac Creek (Table 4.3). Statistical comparison of mean mercury concentrations in fish from Big Bayou Creek, Massac Creek, and Hinds Creek (Tukey's Test) indicated that the Hinds Creek fish differed significantly from all the other sites (Table 4.3). Mercury concentrations in fish from the three Big Bayou Creek sites below PGDP were similar. Because mercury concentrations in both Kentucky reference sites were similar—and much higher than the Tennessee reference site—data from the two Kentucky sites (BBK 12.5 and Massac Creek) were combined as a local reference collection for comparison with Big Bayou Creek sites below PGDP. Dunnett's test indicated that mean mercury concentrations in fish from all sites in Big Bayou Creek downstream from PGDP exceeded that in local reference site fish.

Previous monitoring (Birge et al. 1992) indicated that mercury was not elevated in fish from Little Bayou Creek. Therefore, mercury was analyzed in a limited number of longear sunfish from LUK 7.2 as part of contaminant screening analyses. Results of these analyses varied considerably, with two fish containing low concentrations and two containing concentrations typical of Big Bayou Creek fish. A more extensive collection of fish will be analyzed from Little Bayou Creek in 1993 to more conclusively evaluate mercury levels in fish there.

Mercury concentrations in fish cannot be closely correlated with mercury concentrations in ambient water. For example, East Fork Poplar Creek in Oak Ridge, Tenessee, is highly contaminated, with aqueous total mercury concentrations exceeding 1 μg/L in its headwaters (Kornegay et al. 1992b). However, mercury concentrations in redbreast sunfish from that creek average close to 1 mg/kg (Kornegay et al. 1992b), only a little more than twice that typical of Big Bayou Creek sunfish. Fish from relatively pristine lakes in Canada and the upper midwest United States can have fish that exceed 1 mg/kg mercury despite very low (<10 ng/L) concentrations of mercury in water. The slightly 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 natural biogeochemical processing of mercury downstream from the plant. The bioaccumulation of mercury is a complex process in which inorganic mercury is converted to methylmercury by microorganisms, and the methylmercury is then accumulated via food chain processes. Mercury concentrations in fish would be affected by factors that alter the rate at which naturally occurring mercury is converted to methyl mercury or by changes in food chain structure that induce fish at some locations to feed on more highly contaminated prey. Naturally occurring mercury appears to be more bioavailable in streams near PGDP than in some other parts of the country (Lowe et al. 1985). Thus, it is possible that elevated mercury concentrations in fish in Big Bayou Creek are a consequence of changes in water chemistry or invertebrate community structure downstream from PGDP.

Resolution of questions about the source of elevated mercury in Big Bayou Creek fish is likely to be difficult and expensive, involving ultra-trace analyses of parts per trillion concentrations of methylmercury in water. The concentrations found in longear sunfish are well below the FDA limit of 1 mg/kg. However, although limited sampling of bass (*Micropterus* spp.) in Big Bayou Creek did not suggest a large difference in concentrations between this species and sunfish, a larger collection (eight fish from

BBK 9.1 collected in fall 1992) will be analyzed for mercury to more accurately establish the correspondence in mercury concentrations between longear sunfish and spotted bass and provide additional data to evaluate the risk posed by elevated mercury concentrations in Big Bayou Creek fish.

4.4.3 Screening studies

4.4.3.1 Metals

Concentrations of metals measured in filets of longear sunfish from Big Bayou and Little Bayou creeks are listed in Tables 4.4 and C.2. Levels are typical of those observed in previous monitoring (Birge et al. 1990) and generally differ little (with several exceptions) from concentrations observed in fish from the Hinds Creek (Oak Ridge, Tennessee) reference site. Concentrations of As, Cd, Cu, Pb, Se, and Zn were similar to or lower than the national geometric mean concentrations (Table 4.4) observed for whole body analyses of fish in the U.S. Fish and Wildlife Service National Contaminant Biomonitoring Program (Lowe et al. 1985). Concentrations of Sb, Cd, Cr, Ni, Se, and Ag were well below screening levels used in the EPA Integrated Risk Information System (IRIS) (EPA 1990). Beryllium and arsenic were not detected in PGDP fish. (Beryllium detection limit was at the IRIS

Table 4.4. Mean metal concentrations (μg/g wet wt) ± SE in longear sunfish from streams at PGDP, April 1992
n = 4 except where noted

Metal	Site				
	BBK 9.1	LUK 7.2	HindsCr[a]	NCBP[b]	EPA[c]
Antimony	<0.1	<0.1	<0.1	NS	43.1
Arsenic	<0.05	<0.05	<0.05	0.16	0.006
Beryllium	<0.003	<0.003	0.004	NS	0.0025
Cadmium	<0.1	<0.1	<0.1	0.04	10.8
Chromium	<0.1 – 0.12	0.22 ± 0.09	<0.1 – 0.21	NS	10,800
Copper	0.24 ±0.02	0.20 ±0.02	0.15 ± 0.02	0.86	ND
Lead	<0.1	<0.1	<0.1	0.19	ND
Nickel	<0.1	<0.1	<0.1	NS	2.15
Selenium	0.64 ± 0.02	0.47 ± 0.01	0.26 ± 0.19	0.46	5.4
Silver	<0.1	<0.1	<0.1	NS	2.48
Thallium	<0.02	<0.02	<0.02	NS	ND
Uranium	<0.003	0.009 ± 0.004	<0.003	NS	ND
Zinc	13.5 ± 0.9	9.3 ± 1.0	6.1 ± 0.3	25.6	ND

[a]Reference stream, Anderson County, Tennessee; n = 2.
[b]Mean concentration of metals collected for the National Contaminant Biomonitoring Program (NCBP) (T. P. Lowe, T. W. May, W. G. Brumbaugh, and D. A. Kane, National Contaminant Biomonitoring Program: Concentrations of seven elements in freshwater fish, 1978–1981. Arch Environ. Contam. Toxicol. 14:363–388. 1985.)
[c]U.S. Environmental Protection Agency (EPA) Integrated Risk Information System screening levels (U.S. Environmental Protection Agency, 1990, Region IV Toxic Substances Spreadsheet, Unpublished mimeo, U.S. Environmental Protection Agency, Region IV, Atlanta, Ga. July 1990.)
Note: If ≥50% of results are below detection limit, range is given. NS = not sampled, ND = not determined. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer.

screening level, arsenic detection limit was 10× screening level.) Those metals for which IRIS screening levels are not published (Cu, Pb, Tl, U and Zn were found at concentrations similar to or lower than typically occur in food such as marine fish or mammalian muscle (Bowen 1979).

Selenium appeared to be higher in PGDP fish than in Hinds Creek fish, but this difference is a result of an anomalously low selenium concentration measured in one Hinds Creek fish. Fish from this site have averaged virtually the same as PGDP fish (~ 0.5 μg/g) in monitoring conducted since 1985 in Tennessee (Loar 1992a, 1992b, Southworth and Peterson, unpublished data). Concentrations of zinc were somewhat higher in PGDP fish than in Hinds Creek fish, but were not atypical of many sites (Lowe et al. 1985).

Detection of elevated concentrations of uranium (Table 4.4) in fish from Little Bayou Creek is consistent with the observed elevated concentrations of uranium in this creek (Kornegay et al. 1992a). Uranium concentrations in Little Bayou Creek in 1991 ranged from 0.008 to 0.032 mg/L. Such ambient concentrations would predict [using a bioconcentration factor of 2× (NCRP 1984)] uranium concentrations of 0.016 to 0.064 μg/g in fish. This range is similar to the concentrations observed in sunfish from Little Bayou Creek in 1992 (Table 4.4, C.2). The lower uranium concentrations observed in Big Bayou Creek in 1991 (<0.001–0.04 mg/L) are also consistent with the lower concentrations of uranium found in fish from Big Bayou Creek.

Substances with low bioaccumulation factors, such as uranium, are rapidly excreted by fish. Therefore, concentrations of these substances measured in fish do not represent the effects of time-integrated exposure to the contaminant over a period of weeks or months but rather reflect only the short-term exposure history (hours to days). Thus, measured uranium levels in fish are likely to be as variable as uranium concentrations in water. The data presented in this report suggest that uranium concentrations in fish at PGDP are similar to concentrations in ambient water. Using a large number of water samples taken at many different times to estimate the concentrations of uranium in fish would provide a better basis for preliminary risk evaluations than using a small number of actual analyses of fish taken on a limited number of occasions. If such preliminary evaluations indicate an issue of concern, *in situ* calibration of uranium concentrations in fish versus concentrations in water would provide a more precise basis for modeling the temporal variation of uranium concentrations in fish. At the present time, increased surveillance of uranium in fish is not warranted, but carrying out a preliminary risk evaluation is deemed advisable.

4.4.3.2 Chlorinated pesticides

Very low concentrations of several chlorinated pesticides were tentatively identified in longear sunfish from Big Bayou Creek and Little Bayou Creek (Table C.3). All pesticides were below practical quantitation limits and were reported as estimated concentrations. The presence of PCBs in these samples makes it possible that some PCB congeners may have been quantified as trace amounts of pesticides, thus the low levels reported are likely overestimates of what may be present. Because the concentrations of pesticides were low and exhibited no clear association with any site, neither more extensive tracking studies nor more eliminating PCB interferences are needed.

4.4.3.3 Radionuclides

The only radionuclide detected by gamma spectrometry in samples of fish from Big Bayou Creek and Little Bayou Creek was naturally occurring ^{40}P, which was found at concentrations typical of aquatic life in all samples (Bowen 1979). Other radioisotopes found at PGDP (^{237}Np) or associated with nuclear fallout/ reactor waste (^{60}Co, ^{137}Cs, ^{241}Am) did not exceed detection limits (Table 4.5).

Table 4.5. Concentrations of radionuclides (in picocuries per gram) wet weight in individual longear sunfish collected from Big Bayou Creek and Little Bayou Creek near Paducah Gaseous Diffusion Plant

Site	Type	Date	Spp	Sex	No.	Wgt	Lgth	^{40}K	^{137}Cs	^{237}Np	^{241}Am	^{60}Co
BBK 9.1	R	04/06/92	LNGEAR	M	3029	50.9	13.2	2.8	<0.1	<0.2	<0.4	<0.1
BBK 9.1	R	04/06/92	LNGEAR	M	3264	64.5	13.8	3.0	<0.1	<0.1	<0.3	<0.1
BBK 9.1	R	04/06/92	LNGEAR	M	3628	42.7	13.3	2.8	<0.1	<0.2	<0.4	<0.1
BBK 9.1	R	04/06/92	LNGEAR	M	3608	56.0	13.9	4.1	<0.1	<0.1	<0.4	<0.1
LUK 7.2	R	04/07/92	LNGEAR	M	3663	61.6	14.5	4.2	<0.1	<0.1	<0.3	<0.1
LUK 7.2	R	04/07/92	LNGEAR	M	3664	43.5	12.4	4.0	<0.1	<0.2	<0.5	<0.1
LUK 7.2	R	04/07/92	LNGEAR	M	3667	30.4	11.5	4.9	<0.2	<0.2	<0.7	<0.2
LUK 7.2	R	04/07/92	LNGEAR	M	3669	31.0	11.2	3.6	<0.2	<0.2	<0.7	<0.2
HINDSCR	R	06/03/92	REDBRE	M	3905	84.4	15.5	3.3	<0.1	<0.2	<0.4	<0.1
HINDSCR	R	06/03/92	REDBRE	F	3906	115.3	18.2	3.3	<0.1	<0.1	<0.4	<0.1

Note: Spp = species; LNGEAR = longear sunfish (*Lepomis megalotus*); REDBRE = redbreast sunfish (*Lepomis auritus*); No. = fish identification tag number; Wgt = weight (grams); Lgth = total length (centimeters); BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; HINDSCR = Hinds Creek.

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. For example, piscivorous fish integrate the direct effects of water quality and habitat changes on primary producers (periphyton) and consumers (benthic invertebrates) that are utilized for food by forage fish. Moreover, statements about the condition of the fish community are better understood by the general public (Karr 1981).

The initial 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 and (2) to document the effects of PGDP operations on fish community structure and function.

5.1.2 Study Sites

Initially, five sites were selected for quantitative sampling of the fish community. These sites were chosen based on previous work done by the University of Kentucky (Birge et al. 1990) and qualitative fish surveys conducted in December 1990 (Table 2.6). 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). Massac Creek was selected after an extensive survey of potential reference streams (Table 2.4). MAK 13.8 was chosen as a reference site for BBK 9.1 and BBK 10.0. The upper site on Big Bayou Creek (BBK 12.5) was selected as a smaller reference site to be comparable to LUK 7.2. Specific sampling locations at these sites were chosen during preliminary studies in mid-June 1991, during which time a quantitative characterization of habitat was conducted (see Sect. 2.3). Finally, Birge et al. (1990) concluded that the fish community of lower Little Bayou Creek was impacted, but qualitative sampling conducted by ORNL staff in December 1990 suggested otherwise (Memorandum from J. M. Loar, ESD, Oak Ridge National Laboratory, to T. G. Jett, Paducah Gaseous Diffusion Plant, January 16, 1991). Therefore, a qualitative sampling site (LUK 4.3) was established to evaluate the fish community in this area.

5.1.3 Materials and Methods

Quantitative sampling of the fish populations at four sites in the Bayou 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 September 22–25, 1991, and March 15–17, 1992. Data from these samples were used to estimate species richness, population size (numbers and biomass per unit area), length frequency, and condition factors. These data can be used to estimate annual production; however, calculation of annual production requires a spring to spring sample and will be included in the report for calendar year 1993. 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 March 17 and June 9, 1992. Data from these samples were used to determine the species richness and number of specimens (relative abundance) based on sampling a known length of stream. Sampling was conducted according to standard operating procedures (Ryon 1992a).

5.1.3.1 Quantitative field sampling procedures

All stream sampling was conducted using two or three Smith-Root Model 15A backpack electrofishers, depending on stream size. Each unit can deliver up to 1200 V of pulsed direct current in order to stun fish.

After a 0.64-cm-mesh seine was 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 with mechanical aeration 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 one or two Smith-Root Model 15A backpack electrofishers. Sampling always started at the same stream location and proceeded through a known length of stream. 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. 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. 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 individual. 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. The species relative abundance was rated as follows: one specimen = rare, 2 to 20 specimens = uncommon, 21 to 100 specimens = common, and >100 specimens = abundant.

Length-Frequency and Condition Factor. The population structure of the more abundant species was examined by length frequencies created by the Fortran program. These frequencies indicate whether the population includes young and adult individuals and if any unusual mortality has affected a size class.

Condition factor (K) was calculated for individual fish by site and species using the formula:

$$K = 100\ (\text{weight}/\text{length}^3),$$

with weight in grams and total length in centimeters (Hile 1936). The condition factor measures the degree of plumpness of individual fish as an indication of relative health (Bennett 1970). Fish without measured weights were not used in calculations. Comparisons of condition factors between sites and between sampling periods were made using an analysis of variance procedure (GLM) on untransformed data (SAS 1985b), because the condition factors exhibited homogeneity of variance as estimated with the UNIVARIATE procedure (SAS 1985a). If the GLM procedure indicated significant differences in condition factors between groups, the Tukey test was performed to identify those groups that were significantly different.

Annual Production. Annual production will be estimated at each site using a size-frequency method (Garman and Waters 1983) as modified by Railsback et al. (1989). Production will be calculated for the period between the spring 1992 and spring 1993 sampling dates; therefore, no production values were included in this report.

5.1.4 Results

The physical parameters of the sample sites showed some differences between the September 1991 (fall) and March 1992 (spring) samples (Table 5.1). The lower Big Bayou Creek sites (BBK 9.1 and 10.0) and Massac Creek were deeper and wider in spring than in fall samples. LUK 7.2 showed the opposite pattern, being shallower and narrower in the spring. Due to a slight shortening of the sample reach, BBK 12.5 was shallower but wider in the spring sample. The pool:riffle ratios indicated a faster flow with less available pool habitat in the spring sample versus the fall sample at all sites except LUK 7.2

The reference sites were comparable in size, depth, and pool structure to their appropriate study sites. MAK 13.8 was slightly narrower than BBK 9.1 and 10.0, deeper than BBK 10.0, and shallower than BBK 9.1. The pool:riffle ratios were very similar between BBK 10.0 and MAK 13.8, but BBK 9.1 had much more pool habitat. LUK 7.2 was narrower and shallower than BBK 12.5, and BBK 12.5 had more pool habitat.

5.1.4.1 Quantitative Sampling

Species Richness and Composition. A total of 32 fish species were found at the 5 sites on Big Bayou Creek, Little Bayou Creek, and Massac Creek (Table 5.2) for the September 1991 and March 1992

Table 5.1. Length, mean width, mean depth, surface area, and pool:riffle ratio of fish sampling sites in Big Bayou, Little Bayou, and a reference stream, Massac Creek for September 1991 (Fall) and March 1992 (Spring)

Site[a]	Length (m)		Mean width (m)		Mean depth (cm)		Surface area (m^2)		Pool:riffle ratio	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
BBK 9.1	110	104	6.8	7.2	22.4	25.1	748	749	1.0	1.0
BBK 10.0	96	95	5.4	5.8	12.3	13.2	518	551	2.1	1.3
BBK 12.5	106	98	5.9	6.1	15.9	15.5	625	598	4.6	2.5
LUK 7.2	107	103	4.3	3.7	8.2	5.6	460	381	1.7	1.9
MAK 13.8	111	107	3.9	4.5	16.0	17.5	433	482	2.7	1.1

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

Table 5.2. Species composition of quantitative samples in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, September 1991 and March 1992

Species[b]	Sites[a]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Amiidae					
Bowfin (*Amia calva*)	1[c]	0	0	0	0
Cyprinidae					
Stoneroller (*Campostoma anomalum*)	2	2	2	2	2
Red shiner (*Cyprinella lutrensis*)	1	1	2	2	1
Steelcolor shiner (*Cyprinella whipplei*)[d]	1	1	1	0	2
Ribbon shiner (*Lythrurus fumeus*)[d]	0	0	1	0	1
Redfin shiner (*Lythrurus umbratilis*)[d]	1	0	2	2	2
Suckermouth minnow (*Phenacobius mirabilis*)	2	1	0	2	0
Bluntnose minnow (*Pimephales notatus*)	0	0	2	2	2
Fathead minnow (*Pimephales promelas*)	0	1	2	0	0
Creek chub (*Semotilus atromaculatus*)	2	2	2	2	2
Catostomidae					
White sucker (*Catostomus commersoni*)	1	0	1	0	1
Creek chubsucker (*Erimyzon oblongus*)	1	2	2	0	2
Spotted sucker (*Minytrema melanops*)	1	0	0	0	0
Black redhorse (*Moxostoma duquesnei*)	0	0	0	0	1
Golden redhorse (*Moxostoma erythrurum*)	1	0	0	0	1
Ictaluridae					
Black bullhead (*Ameiurus melas*)	1	0	1	0	0
Yellow bullhead (*Ameiurus natalis*)	2	2	2	2	2
Aphredoderidae					
Pirate perch (*Aphredoderus sayanus*)	0	0	0	2	2
Cyprinodontidae					
Blackspotted topminnow (*Fundulus olivaceus*)	2	2	2	2	2
Poeciliidae					
Western mosquitofish (*Gambusia affinis*)	2	2	0	2	2

Table 5.2. (continued)

Species[b]	Sites[a]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Centrarchidae					
Flier (*Centrarchus macropterus*)	0	0	0	1	0
Green sunfish (*Lepomis cyanellus*)	2	2	2	2	2
Warmouth (*Lepomis gulosus*)	0	1	2	0	0
Bluegill (*Lepomis macrochirus*)	2	2	2	0	2
Longear sunfish (*Lepomis megalotis*)	2	2	2	2	2
Redear sunfish (*Lepomis microlophus*)	2	0	0	0	0
Hybrid sunfish	2	2	2	0	0
Spotted bass (*Micropterus punctulatus*)	2	2	2	1	2
Largemouth bass (*Micropterus salmoides*)	2	1	2	1	1
White crappie (*Pomoxis annularis*)	2	0	0	0	0
Percidae					
Slough darter (*Etheostoma gracile*)	1	1	2	2	0
Logperch (*Percina caprodes*)	0	0	0	0	1
Blackside darter (*Percina maculata*)	0	0	0	0	1
Total species	23	17	20	16	22

[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 (C. R. Robins et al. 1991. Common and scientific names of fishes from the United States and Canada. 5th Edition. American Fisheries Society Special Publication 20. Bethesda, Maryland).

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

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

samples. BBK 9.1 and BBK 10.0 had 23 and 17 species for the 2 sampling seasons, compared to the 22 species at the reference stream, MAK 13.8. The LUK 7.2 site had 16 species during the 2 sampling seasons, while the comparable reference site, BBK 12.5 had 20 species. Mean species richness for MAK 13.8, BBK 9.1, and 10.0 was 18, 18, and 13.5 respectively (Table 5.3). At LUK 7.2 and BBK 12.5, the mean richness was 14.5 and 18 respectively. For all five sites, species richness was higher in the September 1991 sample than in March 1992. The core species assemblage at all sites included central stoneroller (*Campostoma anomalum*), creek chub (*Semotilus atromaculatus*), yellow bullhead (*Ameiurus natalis*), blackspotted topminnow (*Fundulus olivaceus*), green sunfish (*Lepomis cyanellus*), and longear sunfish (*L. megalotis*). Eleven species were judged to be sensitive to water quality and/or habitat degradation (see Karr et al. 1986;

Table 5.3. Total fish density (individuals per square meter), biomass (grams per square meter), and species richness for September 1991 and March 1992 at sampling sites in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek

	Site[a]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
		September 1991			
Density	2.55	6.17	4.35	2.40	5.21
Biomass	34.12	33.17	14.32	6.03	23.71
Species richness	21	13	19	16	22
		March 1992			
Density	1.84	2.55	2.85	1.49	1.55
Biomass	37.55	21.19	18.72	4.51	5.77
Species richness	15	14	17	13	14

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

Ohio EPA 1987, 1988) and eight were rated as tolerant to such conditions (Appendix D, Table D.1).

The lowest site on Big Bayou Creek, BBK 9.1, had several species which are more common in larger streams including bowfin (*Amia calva*), white crappie (*Pomoxis annularis*), and redear sunfish (*Lepomis microlophus*). These species were not taken at other quantitative sites. BBK 9.1 had high numbers of cyprinid (six), catostomid (four), and centrarchid (seven) species. The number of sensitive species (three) was half the number of species tolerant (six) of habitat degradation and/or pollution. Hybrid sunfish were also found during both surveys. The fish community composition at BBK 9.1 included representatives for all trophic levels. Piscivores or top carnivores included three species, the bowfin, largemouth bass (*Micropterus salmoides*), and spotted bass (*M. punctulatus*). Benthic insectivores, a feeding guild that can reflect impacts on the benthic macroinvertebrate community (Miller et al. 1988), were represented by three species. Generalist feeders, 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), included a total of five species.

BBK 10.0 had fair numbers of cyprinid (six) and centrarchid (six) species, but had fewer catostomids (one) than at BBK 9.1. There were also fewer sensitive species (one) than tolerant (five) species. Hybrid sunfish were taken during both sampling seasons. The trophic composition of the community at BBK 10.0 included two piscivores (the bass species), only two benthic insectivores, and four generalist feeders.

Compared to the MAK 13.8 reference, the two lower Big Bayou Creek sites showed some degradation. The reference site had high numbers of cyprinid (seven), catostomid (four), and percid (two) species, with moderate levels of centrarchid species (five). MAK 13.8 also had more sensitive (seven) than tolerant (five) species and did not have any hybrid sunfish in either sample season. Trophically, MAK 13.8 had similar numbers of piscivores (two) and generalist feeders (four) as the Big Bayou sites but had a higher number (four) of benthic insectivores.

The LUK 7.2 site maintained moderate levels of cyprinid (six) and centrarchid (five) species but lacked any catostomids. LUK 7.2 had four tolerant species, but no sensitive species. Hybrid sunfish were not found at the site. The trophic composition of the fish community at LUK 7.2 included two piscivores, two benthic insectivores, and three generalist feeders. By comparison, the BBK 12.5 reference had more cyprinid (eight), catostomid (two) and centrarchid (six) species. The number of sensitive species increased to two, but the number of tolerant species also increased to seven. Hybrid sunfish were found during both sampling seasons. Trophically, the fish community at BBK 12.5 reflected the headwater influence, with six generalist feeders, two piscivores, and only one benthic insectivore. In headwater situations, generalist feeders have a decided advantage because they can utilize terrestrial sources of food much easier than can benthic insectivores.

Density. Quantitative estimates of density were higher at all sites during the September 1991 than during the March 1992 samples (Table 5.3). This has been the dominant pattern for the Biological Monitoring and Abatement Program sampling conducted at the approximately 50 sites in the Oak Ridge, Tennessee, area since 1985 (Loar 1992a, 1992b; Southworth et al. 1992; Ryon 1992b). 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 BBK 10.0 during both sampling seasons, with the September sample more than twice as large as the March sample. The densities at BBK 9.1 were about one-half to two-thirds of the levels at BBK 10.0 but showed less variation between sampling seasons. The MAK 13.8 reference had levels similar to BBK 10.0 in September (5.21 versus 6.17, respectively) but were proportionally lower in March (1.55 versus 2.55 respectively). Density values at LUK 7.2 were about half those at BBK 12.5 in both the September and March samples (Table 5.3).

Densities of individual species varied among sites, especially between the three species with the highest values (Tables D.2 and D.3). During both sampling seasons at BBK 9.1 and 10.0, the species present in highest or next highest numbers were the central stoneroller or longear sunfish, with a variety of species having the third highest numbers. The MAK 13.8 reference was more consistent with the highest densities for longear sunfish, bluntnose minnow (*Pimephales notatus*), and redfin shiner (*Lythurus umbratilus*) during both samples. The high densities of central stoneroller (a scraping herbivore) in Big Bayou Creek probably reflects greater algal growth resulting from nutrient enrichment by PGDP discharges. Comparisons of the densities of sensitive to tolerant species indicate that sites on lower Big Bayou Creek had extremely low densities for sensitive species and higher densities for tolerant species. At MAK 13.8, the densities of sensitive species were always higher than densities of tolerant species.

At LUK 7.2, the species with the highest densities were blackspotted topminnow, central stoneroller, creek chub, and bluntnose minnow (Tables D.2 and D.3). The BBK 12.5 reference site had longear sunfish, blackspotted topminnow, green sunfish, and bluntnose minnow with the highest densities. Although the densities of sensitive species were low at BBK 12.5, no sensitive species were found at LUK 7.2. The density of tolerant species was slightly higher at BBK 12.5 as compared with LUK 7.2.

Biomass. Unlike the density estimates, quantitative estimates of total biomass were not consistently higher in September samples than in March samples (Table 5.3); biomass was higher in March at BBK 9.1 and BBK 12.5. The highest biomass levels were at BBK 9.1, and there was a downstream increase in biomass. Compared with MAK 13.8, mean biomass was greater by 1.8- to 2.4-fold at the lower Big Bayou Creek sites. Mean biomass at LUK 7.2 was lower by 3-fold compared with the mean biomass at the BBK 12.5 reference.

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 at LUK 7.2 in March (Tables D.4 and D.5). Other fish species that were among the two highest biomass contributors included white sucker (*Catostomus commersoni*), or spotted sucker (*Minytrema melanops*) at BBK 9.1, central stoneroller at BBK 10.0, spotted bass and bluntnose minnow at MAK 13.8, and yellow bullhead at BBK 12.5. At LUK 7.2, the two highest biomass contributors were the longear sunfish and green sunfish in September and the central stoneroller and blackspotted topminnow in March.

Length-frequency. Length-frequency distributions were made for the five most widespread species including longear sunfish, green sunfish, central stoneroller, blackspotted topminnow, and creek chub (Figs. D.1 to D.12). Populations of longear sunfish generally displayed normal size structure (Figs. D.1 to D.4). For example, at the reference streams (MAK 13.8 and BBK 12.5) the population in the fall was dominated by high young-of-year (YOY) size classes (2.0–6.0 cm) with older size classes progressively smaller numerically. In contrast, the longear population in the fall at BBK 10.0 had a high number of 8.0- to 9.9-cm fish without correspondingly high YOY size classes (Fig. D.1). Green sunfish populations (Figs. D.5 and D.6) were obviously very successful in the small-size streams, LUK 7.2 and especially BBK 12.5. At the larger stream sites, the numbers were low but did span the entire size range. For the blackspotted topminnow, the basic population structure appeared more bell shaped, with the dominate size class of 4.0–5.9 cm in both fall and spring samples (Figs. D.7 and D.8). This may be a result of their live-bearing reproductive strategy or represent sampling error in capturing the small sizes of this slender fish. Length frequencies of central stoneroller populations (Figs. D.9 and D.10) demonstrated substantially large populations, particularly in the 4.0- to 7.9-cm classes at BBK 9.1 and 10.0. These plots also detailed the transition of the YOY class in the fall sample to the reproductive size classes in the following spring sample. The creek chub length frequencies (Figs. D.11 and D.12) reflected large fall YOY size classes, particularly at small stream sites, and the less numerous surviving adult size classes in the spring. The length-frequency data did not indicate noticeable stress upon these major species in the Big Bayou Creek and Little Bayou Creek study sites.

Condition Factor. Condition factors were calculated for all species and compared between the September and March samples and between sites. In studies of fish populations in the area of Oak Ridge, Tennessee, condition factors do not usually show a trend in site comparisons, but a noticeable pattern of higher condition factors in spring versus fall samples has been documented (Loar 1992a, 1992b; Southworth et al. 1992; Ryon 1992b).

The majority of fish species did not have significant differences in condition factors between sampling seasons. Twenty-one species did not show a statistically significant difference between the September and the March samples in 40 species-site combinations. Where differences were statistically significant, the March sample usually had higher condition factors. In 14 species, the March sample was greater than the September sample in 24 species-site combinations. However, the September condition factors were significantly higher than the March condition factors for five species at five sites. It could be expected that condition factors would be higher in spring samples if the sample included individuals showing an increase in weight as a result of preparations for spawning.

Condition factors were also compared between sites within a season. Significant differences were not seen for 17 species in 25 species-site combinations. Only 10 species had a significant difference in 16 species-site combinations (Table 5.4). The condition factors at BBK 9.1 and/or BBK 10.0 were significantly greater than at MAK 13.8 for nine species-site comparisons. In two comparisons, condition factors at BBK 9.1 and MAK 13.8 were significantly greater than at BBK 10.0, while the condition factors at BBK 9.1 were significantly greater than at BBK 10.0 and MAK 13.8 in two other comparisons. Generally, condition factors were significantly higher at the lower Big Bayou Creek sites, particularly BBK 9.1, than at the MAK 13.8 reference. This trend also applied to the Little Bayou Creek/upper Big Bayou Creek reference comparison where condition factors at LUK 7.2 were significantly greater than at BBK 12.5 in seven species-site combinations. These trends indicate that fish residing in areas downstream from PGDP discharges were not necessarily in poor condition. Species such as green sunfish, yellow bullhead, or longear sunfish apparently could take advantage of an increased food supply to generate high condition factors, as compared to reference sites where enrichment may not be substantial.

5.1.4.2 Qualitative Sampling

Qualitative sampling was conducted on lower Little Bayou at LUK 4.3 in March and June 1992. A total of 28 species were collected, with 23 and 22 species in the March and June samples respectively (Table 5.5). These totals were similar to species richness values generated by the quantitative samples. For example, 12 and 14 species were found on the first pass of the quantitative samples at BBK 9.1 and MAK 13.8, respectively, in March 1992. Species found only during the qualitative sampling included spotfin shiner (*Cyprinella spiloptera*), sand shiner (*Notropis stramineus*), Mississippi silvery minnow (*Hybognathus nuchalis*), tadpole madtom (*Noturus gyrinus*), and bluntnose darter (*Etheostoma chlorosomum*). Although these species were usually found only in small numbers (except Mississippi silvery minnow), they do suggest favorable site conditions. The surveys found a considerable number of cyprinid (11) and centrarchid (8) species, although the number of catostomids (2) seemed low for the stream size and available habitat.

The qualitative samples were also evaluated for relative abundance of the species based on sampling a known area (176–186 m). The most abundant species were Mississippi silvery minnow, longear sunfish, and bluntnose minnow. Species rated as common included green sunfish and blackspotted topminnow. Species rarely encountered (one specimen per sample) included sand shiner, spotted

Table 5.4. Comparison between sampling sites[a] on Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, of mean condition factors of fish collected in September 1991 and March 1992

Species	Tukey comp[b]	September 1991 site (condition factor[c])	Tukey comp	March 1992 site (condition factor)
Bluegill		BBK 10.0 (1.700)		BBK 9.1 (1.724)
		BBK 9.1 (1.686)		MAK 13.8 (1.606)
		BBK 12.5 (1.565)		BBK 12.5 (1.514)
		MAK 13.8 (1.391)		BBK 10.0 (1.477)
Bluntnose minnow		LUK 7.2 (0.937)		LUK 7.2 (0.991)
		MAK 13.8 (0.835)		MAK 13.8 (0.963)
		BBK 12.5 (0.799)		BBK 12.5 (0.885)
Green sunfish		BBK 9.1 (1.662)		BBK 9.1 (1.760)
		BBK 10.0 (1.633)		LUK 7.2 (1.681)
		LUK 7.2 (1.608)		BBK 10.0 (1.661)
		MAK 13.8 (1.573)		BBK 12.5 (1.579)
		BBK 12.5 (1.548)		MAK 13.8 (1.510)
Longear sunfish		BBK 9.1 (1.813)		LUK 7.2 (1.899)
		BBK 10.0 (1.780)		BBK 9.1 (1.838)
		LUK 7.2 (1.779)		BBK 10.0 (1.809)
		BBK 12.5 (1.678)		MAK 13.8 (1.665)
		MAK 13.8 (1.654)		BBK 12.5 (1.634)
Steelcolor minnow		BBK 9.1 (0.899)		BBK 10.0 (0.917)
		MAK 13.8 (0.753)		MAK 13.8 (0.780)
				BBK 12.5 (0.719)
Yellow bullhead		BBK 9.1 (1.257)		LUK 7.2 (1.366)
		LUK 7.2 (1.217)		BBK 9.1 (1.312)
		BBK 10.0 (1.160)		BBK 10.0 (1.230)
		BBK 12.5 (1.160)		MAK 13.8 (1.148)
		MAK 13.8 (1.135)		BBK 12.5 (1.110)

Table 5.4. (continued)

Species	Tukey comp[b]	September 1991 site (condition factor[c])	Tukey comp	March 1992 site (condition factor)
Creek chub		BBK 9.1 (1.024)		
		LUK 7.2 (1.005)		
		BBK 10.0 (0.965)		
		MAK 13.8 (0.964)		
		BBK 12.5 (0.944)		
Central stoneroller		BBK 9.1 (1.039)		
		MAK 13.8 (1.037)		
		LUK 7.2 (1.011)		
		BBK 12.5 (0.989)		
		BBK 10.0 (0.954)		
Spotted bass		BBK 10.0 (1.399)		
		BBK 9.1 (1.211)		
		MAK 13.8 (1.024)		
		BBK 12.5 (0.855)		
Blackspotted minnow		BBK 9.1 (0.929)		
		LUK 7.2 (0.918)		
		BBK 10.0 (0.882)		
		MAK 13.8 (0.864)		
		BBK 12.5 (0.839)		

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, and MAK = Massac Creek kilometer.
[b]Sites connected by the same vertical line are not significantly different ($p < 0.05$), based on Tukey's studentized range test.
[c]Values in parenthesis are mean condition factors.

Table 5.5. Species composition, number of specimens, relative abundance[a] and catch per unit effort of the qualitative fish sampling conducted on Little Bayou Creek, March 17 and June 9, 1992

Species[b]	March 17, 1992[c]	June 9, 1992[d]
Cyprinidae		
Stoneroller (*Campostoma anomalum*)	2 (UC)	19 (UC)
Red shiner (*Cyprinella lutrensis*)	12 (UC)	12 (UC)
Spotfin shiner (*Cyprinella spiloptera*)[e]	36 (C)	10 (UC)
Steelcolor shiner (Cyprinella whipplei)[e]	6 (UC)	4 (UC)
Mississippi silvery minnow (Hybognathus nuchalis)	241 (A)	128 (A)
Ribbon shiner (*Lythrurus fumeus*)[e]	24 (C)	14 (UC)
Redfin shiner (Lythrurus umbratilis)[e]	40 (C)	7 (UC)
Sand shiner (Notropis stramineus)[e]	1 (R)	0
Suckermouth minnow (Phenacobius mirabilis)	6 (UC)	1 (R)
Bluntnose minnow (*Pimephales notatus*)	107 (A)	58 (C)
Creek chub (*Semotilus atromaculatus*)	3 (UC)	16 (UC)
Catostomidae		
Creek chubsucker (*Erimyzon oblongus*)	2 (UC)	0
Spotted sucker (*Minytrema melanops*)	1 (R)	0
Ictaluridae		
Yellow bullhead (*Ameiurus natalis*)	6 (UC)	7 (UC)
Tadpole madtom (*Noturus gyrinus*)	1 (R)	0
Aphredoderidae		
Pirate perch (*Aphredoderus sayanus*)	3 (UC)	3 (UC)
Cyprinodontidae		
Blackspotted topminnow (*Fundulus olivaceus*)	46 (C)	69 (C)
Poeciliidae		
Western mosquitofish (*Gambusia affinis*)	0	1 (R)
Centrarchidae		
Flier (*Centrarchus macropterus*)	0	1 (R)
Green sunfish (*Lepomis cyanellus*)	27 (C)	39 (C)
Warmouth (*Lepomis gulosus*)	15 (UC)	17 (UC)
Bluegill (*Lepomis macrochirus*)	26 (C)	18 (UC)
Longear sunfish (*Lepomis megalotis*)	121 (A)	179 (A)
Spotted bass (*Micropterus punctulatus*)	4 (UC)	5 (UC)
Largemouth bass (*Micropterus salmoides*)	0	2 (UC)
White crappie (*Pomoxis annularis*)	0	1 (R)
Percidae		
Bluntnose darter (*Etheostoma chlorosomum*)	0	1 (R)
Slough darter (*Etheostoma gracile*)	1 (R)	0
Total specimens	731	612
Total species	23	22
Catch/unit effort[f]	7.2	4.2

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

[b]Species identifications were performed in the field and/or confirmed in the laboratory on preserved specimens collected during the surveys. Common and scientific names according to the American Fisheries Society (C. R. Robins et al. Common and scientific names of fishes from the United States and Canada, 5th edition, American Fisheries Society Special Publication 20, Bethesda, Maryland. 1991).

[c]One electrofisher used for 73 m and 25 min, and two electrofishers used for 103 m and 38 min.

[d]Two electrofishers used for 186 m and 73 min.

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

[f]Catch per unit effort is number of fish per minute of electrofishing.

sucker, tadpole madtom, western mosquitofish (*Gambusia affinis*), flier (*Centrarchus macropterus*), white crappie, bluntnose darter, and slough darter (*Etheostoma gracile*).

The total catch for each sample was 731 fish for March and 612 fish for June. The catch per unit effort (number fish per minute electrofished) was 7.2 in March and 4.2 in June. Although these numbers are lower than numbers found in quantitative estimates, they do suggest that there was a resident fish community at the LUK 4.3 site. A stronger influence from PGDP was not indicated at this site than was indicated further upstream. For example, on the first pass of the sample at MAK 13.8 during March 1992, 512 fish were collected with a catch per unit effort of 6.8. Similarly, at the most downstream site on Big Bayou Creek (BBK 9.1) which is closest in size and habitat structure to LUK 4.3 of all the PGDP-influenced sites, the total catch in the March quantitative sample was 1100 fish and the catch per unit effort was 8.2. These comparisons of quantitative data would be expected to produce higher total numbers and catch per effort, because blocknets were used to prevent the escape of fish from the sample area.

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 from PGDP were greatest at BBK 10.0. The fish community at this site had a low mean and total species richness in comparison with MAK 13.8. There were few sensitive species at very low densities. Tolerant species were more common and abundant here than at the reference site. The number of benthic insectivores were low, although other feeding guilds were similar to levels seen at MAK 13.8. During both sampling seasons, hybrid sunfish were found which indicated some reproductive stress. Density at BBK 10.0 was similar to or higher than that at the reference site, with a correspondingly high biomass. Condition factors were significantly higher than at MAK 13.8. The large population of central stoneroller and the high condition factors indicate some enrichment at the site. Overall the fish community at BBK 10.0 has demonstrated shortcomings.

The fish community at BBK 9.1 showed signs of impact but not at the levels seen at BBK 10.0. Mean and total species richness were similar to MAK 13.8, but there were few sensitive species at low densities. The tolerant species were more common and abundant. Similar to findings from BBK 10.0, hybrid sunfish were found during both sampling seasons. Density was less than or equal to that at MAK 13.8, and the biomass values were high. Condition factors were significantly higher than at MAK 13.8.

The fish community at LUK 7.2 was generally in poor condition in comparison to the BBK 12.5 reference. The mean and total species richness values were low, and the community lacked any catostomid species. Sensitive species were absent, and several tolerant species were present at considerable densities. Density and biomass were lower than at BBK 12.5, but condition factors for selected species were significantly higher than at the reference site. Because the site is on a smaller stream, some of these deficiencies might be expected; however, the community was poorer overall than at BBK 9.1 but not as affected as BBK 10.0.

The downstream qualitative site, LUK 4.3, did not appear to continue the poor conditions found at LUK 7.2. Species richness was comparable to that found at MAK 13.8, particularly in terms of sensitive species. The community was well represented in all families, except perhaps catostomids, and significant absences in feeding guilds were not demonstrated. The relative abundance and catch-per-effort data were similar to quantitative data at MAK 13.8 and BBK 9.1. Thus, the community at LUK 4.3 appeared to be no more stressed than BBK 9.1 at its worst.

The fish communities associated with PGDP streams indicate depressed conditions but are not specific on causative agents. The greatest impacts occurred at sites closest to the plant, which suggests that PGDP effluents may be the cause. The low species richness and few sensitive species may be caused by poor water quality (e.g., high temperatures or chlorine levels) or reflect degraded habitat conditions (e.g. lack of instream cover). Biomass and density respond quickly to improvements in degraded conditions and it will be important to follow changes in these parameters, particularly at the most stressed sites. After changes in density, the return of sensitive species or changes in proportions of feeding guilds (e.g., an increase in benthic insectivores) would signal an improvement in water quality.

5.2 BENTHIC MACROINVERTEBRATES

J. G. Smith

5.2.1 Introduction

Benthic macroinvertebrates are those animals which are large enough to be seen without the aid of magnification and which live on or in the substrate of flowing and nonflowing bodies of water. The limited mobility and relatively long life spans (a few months to more than a year) of most taxa make them ideal for use in evaluating the ecological effects of effluent discharges to streams (Platts et al. 1983). Thus, the composition and structure of the benthic macroinvertebrate community reflects the relatively recent past and can be considerably more informative than methods that rely solely on water quality analyses but ignore the potential synergistic effects often associated with complex effluents.

The initial objectives of the benthic macroinvertebrate monitoring task are to characterize and evaluate the "health" of the benthic macroinvertebrate communities of Big Bayou and Little Bayou creeks adjacent to and downstream of PGDP. Following this initial characterization and evaluation, any changes that occur in the benthic macroinvertebrate community, which may be associated with operations and remedial actions at the PGDP, will be documented. The data from the first year will also be used as a baseline from which the effectiveness of remedial actions at PGDP can be assessed.

5.2.2 Materials and Methods

Beginning in September 1991, benthic macroinvertebrate samples were collected at quarterly intervals from five stream sites (Table 2.3) as part of the PGDP BMP. Three random, quantitative samples were collected from a permanently marked riffle at each site with a Surber bottom sampler (0.09 m^2) fitted with a 363-micron-mesh collection net. All samples were placed in prelabeled, polyurethane-coated, glass jars and preserved in 80% ethanol; the ethanol was replaced with fresh ethanol within 7 d of collection. All samples were collected, transported, stored, and maintained in accordance to established QA procedures (Smith 1992).

Supplemental information on water quality and stream characteristics was recorded at the time of sampling. Temperature, conductivity, dissolved oxygen, and pH were measured with an Horiba Model U-7 Water Quality Checker. Water depth, location within the riffle area (distance from permanent headstakes on the stream bank), visual determination of relative stream velocity (very slow, slow, moderate, or fast), and substrate type (visual determination) based on a modified Wentworth particle size scale (Loar et al. 1985) were recorded for each sample. All measurements/data for water quality and stream characteristics were obtained in accordance to established QA procedures (Smith 1992).

The services of a subcontractor will be retained in mid-1993 to process invertebrate samples. Samples are currently being stored and maintained at a benthic invertebrate sample chain-of-custody facility at ORNL in Oak Ridge, Tennessee. Processing will involve (1) sorting the invertebrates from the debris in each sample, (2) identifying taxa to the lowest practical level (genus in most cases), and (3) enumerating the individuals within each taxon. Established written procedures (Wojtowicz and Smith 1992) will be followed in processing the samples. A reference collection will be made for each site, and duplicate collections will be retained by the processing subcontractor and ORNL.

Data management and analysis will be accomplished on computer with the Statistical Analysis System (SAS 1985a, 1985b). Analyses of the data will include, but not necessarily be limited to, calculation of mean values for parameters such as total density (number of individuals per 0.1 m^2), taxonomic richness (number of taxa per sample), and combined richness of the Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa per sample. Analyses will also include appropriate statistical techniques (e.g., analysis of variance of density and various richness parameters) to help identify site differences and changes associated with activities at PGDP. Where possible, water quality data and data from other tasks will be used to aid in data interpretations.

5.2.3 Results

As stated in the Materials and Methods section (5.1.2), a subcontractor will be retained in mid-1993 to process benthic macroinvertebrate samples collected to date. Available results will be presented in FY94.

Results of the benthic macroinvertebrate studies will be used not only to help evaluate the "health" of the streams adjacent to PGDP, the results will also be used to periodically evaluate the status and needs of the sampling program. For example, benthic macroinvertebrate studies of streams located in the Oak Ridge, Tennessee, area have shown that a large data base obtained from a quarterly sampling regime is not always needed to demonstrate the existence of impacts (J. G. Smith, unpublished data, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee). Therefore, while a quarterly sampling schedule continues for all sites associated with the BMPs in Oak Ridge; when appropriate, only samples collected during the spring and fall are being processed; whereas samples collected during the winter and summer are being backlogged and will be processed only if further resolution of the data are necessary. This decreases the potential for delays in data acquisition without compromising the ability to identify impacts/changes associated with operations and/or remedial actions at each facility. Thus, for the PGDP BMP, data obtained during at least the first year will be used not only to characterize and evaluate the health of the benthic communities of each study stream, but they will also be used to evaluate the need or potential for modifications in the monitoring program that will allow the most efficient and cost-effective means for monitoring the benthos without compromising our ability to detect changes should they occur.

6. REFERENCES

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

Birge, W. J., T. M. Short, and J. E. Lauth. 1990. Biological monitoring program for the Paducah Gaseious Diffusion Plant: Three-year draft report. University of Kentucky, Lexington, Kentucky.

Birge, W. J., D. P. Price, D. P. Keogh, J. A. Zuiderveen, and M. D. Kercher. 1992. Biological Monitoring Program for the Paducah Gaseous Diffusion Plant. Annual Report for Study Period October 1990 through March 31, 1992. University of Kentucky, Lexington, Kentucky.

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

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

CH2M Hill. 1991. Results of the Site Investigation, Phase I, at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, KY/ER-4, Paducah Gaseous Diffusion Plant, Paducah, Kentucky.

D'Appolonia, June 1983. Final Report, Groundwater Monitoring Program, PGDP, Paducah, Kentucky. Project 82-1397. ESO 15603. Paducah Gaseous Diffusion Plant, Paducah, Kentucky.

EPA (U.S. Environmental Protection Agency). 1980. Interim methods for the sampling and analysis of priority pollutants in sediments and fish tissues. EPA 600/4-81-055. Environmental Monitoring and Support Laboratory, U. S. Environmental Protection Agency, Cincinnati, Ohio.

EPA (U.S. Environmental Protection Agency). 1984. Extraction and analysis of priority pollutants in biological tissue, method PPB 12/83. EPA 600/4-81-055. Environmental Services Division, Region IV, U. S. Environmental Protection Agency, Athens,Georgia. Mimeo.

EPA (U.S. Environmental Protection Agency). 1986. Quality Criteria for Water. Office of Water Regulations and Standards, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1988. Ambient water qualtiy criteria for aluminum. EPA 440/5-86-008. Washington, D.C.

EPA (U.S. Environmental Protection Agency) 1991. Methods for the Determination of Metals in Environmental Samples. EPA-600/4-91-010. Environmental Monitoring Systems Laboratory, U.S.EPA, Cincinnati, Ohio.

FDA (U.S. Department of Agriculture Food and Drug Administration). 1984a. Polychlorinated biphenyls in fish and shellfish: reduction of tolerances, Final Decision. Fed. Regist. 49: 21514–21520.

FDA (U.S. Department of Agriculture Food and Drug Administration). 1984b. Action level for methylmercury in fish. Fed. Regist. 49: 45663.

Garman, G. C. and T. F. Waters. 1983. Use of the size-frequency (Hynes) method to estimate annual production of a stream fish population. Can. J. Fish. Manag. 6:176–182.

GeoTrans, Inc. 1990. Numerical Modeling of Groundwater Flow at the Paducah Gaseous Diffusion Plant, Phase I and II. Sterling, Kentucky.

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

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

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

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

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

Kornegay, F.C., D.C. West, T.G. Jett and M.F. Williams. 1992a. Paducah Gaseous Diffusion Plant Environmental Report for 1991. ES/ESH-22/V3. Environmental, Safety, and Health Compliance and Environmental Management Staffs, Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee and Paducah, Kentucky.

Kornegay, F.C., D.C. West, R.A. Evans, M.F. Tardiff, F.D. Adams, and P.C. Mucke. 1992b. Oak Ridge Reservation Environmental Report for 1991. ES/ESH-22/V1, V2. Environmental, Safety, and Health Compliance and Environmental Management staff, Oak Ridge Y-12 Plant, Oak Ridge National Laboratory, and Oak Ridge K-25 Site. Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee.

Kszos, L. A., A. J. Stewart, L. F. Wicker, L. E. Roberson, and T. L. Phipps. 1989. Environmental Sciences Division Toxicology Laboratory Quality Assurance Program. QAP-X-89-ES-002. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Kszos, L. A. and A. J. Stewart. 1992. Artifacts in ambient toxicity testing. Proceedings of the Water Environment Federation, 65th Annual Conference and Exposition, New Orleans, Louisiana, September 20–24, 1992 (Paper AC92-020-005).

Kszos, L. A., A. J. Stewart, and P. A. Taylor. 1992. An evaluation of nickel toxicity to *Ceriodaphnia dubia* and *Daphnia magna* in a contaminated stream and in laboratory tests. Env. Tox. Chem. 11:1001–1012.

Kszos, L. A. et al. 1993. Biological Monitoring and Abatement Program for the Oak Ridge K-25 Site. K/EM-24/R2. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

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

Loar, J. M., M. J. Sale, G. F. Cada, D. K. Cox, R. M. Cushman, G. K. Eddlemon, J. L. Elmore, A. J. Gatz, Jr., P. Kanciruk, J. A. Solomon, and D. S. Vaughn. 1985. Application of habitat evaluation models in southern Appalachian trout streams. ORNL/TM-9323. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Loar, J. M. et al. 1989. The Oak Ridge Y-12 Plant Biological Monitoring and Abatement Program for East Fork Poplar Creek. ORNL/TM-10265. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Loar, J. M. et al. 1991. Oak Ridge National Laboratory Biological Monitoring and Abatement Program for White Oak Creek Watershed and the Clinch River. ORNL/TM-10370. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Loar, J. M. et al. 1992a. First annual report on the Biological Monitoring and Abatement Program at Oak Ridge National Laboratory. ORNL/TM-10399. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Loar, J. M. et al. 1992b. Second annual report on the Biological Monitoring and Abatement Program for White Oak Creek Watershed and the Clinch River. ORNL/TM-10804. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Loar, J. M. et al. 1994. Third report on the Oak Ridge National Laboratory Biological Monitoring Program for White Oak Creek Watershed and the Clinch River. ORNL/TM-11358 Report. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

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

Miller, D. L., P. M. Leonard, R. M. Hughes, J. R. Karr, P. B. Moyle, L. H. Schrader, B. A. Thompson, R. A. Daniels, K. D. Fausch, G. A. Fitzhugh, J. R. Gammon, D. b. Halliwell, P. L. Angermeier, and D. J. Orth. 1988. Regional application of an Index of Biotic Integrity for use in water resource management. Fisheries 13(5):12–20.

National Council on Radiation Protection and Measurements (NCRP). 1984. Radiological Assessment: Predicting the Transport, Bioaccumulation, and Uptake by Man of Radionuclides Released to the Environment. National Council on Radiation Protection and Measurements, Bethesda, Maryland.

Oakes, T. W., D. L. Ashburn, and F. M. O'Hara. 1987. Environmental Surveillance of the U.S. Department of Energy Paducah Reservation and Surrounding Environs During 1986. ES/E3H-1/V3, Paducah, Kentucky.

Ohio EPA (Environmental Protection Agency). 1987. Biological Criteria for the Protection of Aquatic Life: Volume III. Standardized Biological Field Sampling and Laboratory Methods for Assessing Fish and Microinvertebrate Communities. Ohio Environmental Protection Agency, Division of Water Quality Monitoring and Assessment, Columbus, Ohio.

Ohio EPA (Environmental Protection Agency). 1988. Biological Criteria for the Protection of Aquatic Life: Volume II. Users Manual for Biological Field Assessment of Ohio Surface Streams. Ohio Environmental Protection Agency, Division of Water Quality Monitoring and Assessment, Columbus, Ohio.

Olive, W. W. 1980. Geologic Maps of the Jackson Purchase Region, Kentucky. U.S. Geological Survey Miscellaneous Investigations Series, Map I-1217. U.S. Geological Survey, Reston, Virginia

Omerik, J. J. 1987. Annuals of the Association of American Geographers. Ecoregions of the Conterminous United States. 77:118–125.

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

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

Ryon, M. G. 1992a. Biological Monitoring and Abatement Programs: Fish community studies project, Quality Assurance Plan and Standard Operating Procedures. ORNL/FPO-QAP-X-90-ES-067. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Ryon, M. G. (ed.) 1992b. Ecological effects of contaminants in McCoy Branch, 1989–1990. ORNL/TM-11926. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

SAS Institute, Inc. 1985a. SAS User's Guide: Basics, 1985 ed., SAS Institute, Inc., Cary, North Carolina.

SAS Institute, Inc. 1985b. SAS User's Guide: Statistics, Version 5 ed. SAS Institute, Inc., Cary, North Carolina.

Smith, J. G. 1992. Biological Monitoring and Abatement Program (BMAP) Benthic Macroinvertebrate Monitoring Project Sample Collection and Storage QA Plan. QAP-X-90-ES-068. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Sokal, R. R. and F. J. Rohlf. 1981. Biometry. W. H. Freman and Company, San Francisco, CA.

Southworth, G. R. 1990. PCB concentrations in stream sunfish (*Lepomis auritus*) in relation to proximity to chronic point sources. Water, Air and Soil Pollution 51: 287–296.

Southworth, G. R., J. M. Loar, M. G. Ryon, J. G. Smith, A. J. Stewart, and J. A. Burris. 1992. Ecological effects of contaminants and remedial actions in Bear Creek. ORNL/TM-11977. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

TERRAN. 1990. Aquifer Assessment Report-Groundwater Monitoring Phase II. C-404 Aquifer Testing Program. ESO 16749. Kettering, Ohio.

U.S. Department of Commerce, Bureau of the Census. April 1991. 1990 Census of Population and Housing Public Law 94-171 Data. Washington, D.C.

Weber, C. I., W. H. Peltier, T. J. Norberg-King, W. B. Horning II, F. A. Kessler, J. R. Menkedick, T. W. Neiheisel, P. A. Lewis, D. J. Klemm, Q. H. Pickering, E. L. Robinson, J. M. Lazorchak, L. J. Wymer and R. W. Freyberg. 1989. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms, 2nd ed. EPA/600/4-89/001. U.S. Environmental Protection Agency, Cincinnati, Ohio.

Wojtowicz, J. A., and J. G. Smith. 1992. Biological Monitoring and Abatement Program (BMAP) Benthic Macroinvertebrate Monitoring Project Sample Processing QA Plan. QAP-X-91-ES-068. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Zar, J. H. 1984. Biostatistical Analysis. Prentice Hall, Inc., Englewood Cliffs, New Jersey.

Appendix A

SUMMARY STATISTICS AND INTERIM LIMITS FOR WATER QUALITY PARAMETERS AT KPDES-PERMITTED OUTFALLS

Table A.1. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 001 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)		42	0.59 (0.4–0.9)	47	0.50 (0.0–1.21)
Acetone		24	<0.67 (0.01–1.0)	21	<1.19 (1.0–<5.0)
Aluminum	M	30	0.70 (0.2–1.6)	25	0.69 (0.2–2.3)
Arsenic				1	<0.005
Cadmium				6	<0.008 (<0.005–<0.01)
Carbon tetrachloride (μg/L)		3	<5 (<5–<5)		
Chromium	0.15	62	<0.05 (<0.05–0.05)	44	<0.05 (<0.05–0.09)
Chromium-6				6	<0.12 (<0.01–0.02)
Copper	0.17	31	<0.01 (<0.01–<0.01)	25	<0.01 (<0.01–0.04)
Dichloroethylene (μg/L)		3	<5.0 (<5.0–<5.0)		
Dissolved alpha (pCi/L)	M	51	8.26 (−10.7–61.0)	52	10.98 (−14.8–112.6)
Dissolved beta (pCi/L)	M	51	40.69 (−11.0–185.0)	52	43.72 (−17.0–116.0)
Disolved oxygen		31	9.01 (6.5–18.4)	21	8.74 (6.7–10.9)
Fecal coliform (Co/100ml)		1	66.0 (66.0–66.0)	4	48.5 (6.0–115.0)
Flow (MLD)	M	31	6.62 (1.1–63.9)	52	6.28 (1.4–13.0)
Fluorine		31	0.47 (0.13–0.95)	21	0.51 (0.3–0.9)
Gross Alpha (pCi/L)				2	3.75 (−0.6–8.1)
Gross Beta (pCi/L)				2	48.0 (39.0–57.0)
Hardness, as $CaCO_3$		1	95.0 (95.0–95.0)	14	419.4 (194.0–10009.0)
Iron	34.3	60	0.47 (0.13–1.17)	25	0.45 (0.1–2.1)
Isopropanol		24	<0.68 (<0.03–<1.0)	21	<1.19 (<1.0–<5.0)
Lead				6	<0.11 (<0.03–<0.2)
Nickel		31	<0.06 (<0.05–0.2)	25	<0.05 (<0.05–<0.05)
^{237}Neptunium (pCi/L)		4	<2.30 (<0.2–3.0)	4	−0.05 (−0.3–0.1)
Oil and grease		33	<5.09 (<5.0–8.0)	31	<5.0 (<5.0–<5.0)
Perchloroethylene (μg/L)		3	<5.0 (<5.0–<5.0)		
pH (SU)		60	8.45 (7.0–9.8)	53	8.42 (6.9–10.1)
^{239}Plutonium (pCi/L)		4	<3.0 (<3.0–<3.0)	4	0.11 (0.1–0.1)
PO_4-P		1	0.06 (0.06–0.06)	8	0.16 (0.08–0.3)
Polychlorinated biphenyl (μg/L)	0.1	21	<0.11 (<0.1–0.3)	14	<0.10 (<0.1–<0.1)
Residual Chlorine	0.1	53	<0.017 (<0.01–0.06)	53	<0.01 (<0.01–0.04)
Suspended alpha (pCi/L)	M	51	0.22 (−7.9–13.5)	52	−0.38 (−4.5–9.2)
Suspended beta (pCi/L)	M	51	−0.22 (−19.0–17.0)	52	1.70 (−15.0–24.0)
Suspended solids		31	<19.16 (<4.0–56.0)	30	16.70 (4.0–42.0)
^{99}Technetium (pCi/L)		60	20.5 (0.0–105)	54	22.75 (0–77.0)
Temperature (°C)	33.8	60	21.98 (6.7–34.40)	52	20.28 (6.7–33.3)
Trichloroethylene		31	<0.001	22	<0.001
Total phosphorus		1	0.15 (0.15–0.15)	11	0.17 (0.1–0.2)
Uranium		60	<0.26 (<0.001–0.18)	52	0.02 (0.001–0.2)
Zinc	0.93	60	<0.02 (<0.005–0.03)	47	<0.01 (<0.005–0.08)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; *n*=number of observations.

Table A.2. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 002 for 1991-1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)		5	0.63 (0.5-0.8)	2	0.66 (0.6-0.7)
Aluminum	M	13	1.07 (0.5-2.6)	9	1.57 (0.7-2.8)
Cadmium				3	<0.008 (<0.005-<0.01)
Chromium	0.31	44	<0.05 (<0.05-0.12)	9	<0.06 (<0.05-0.09)
Chromium-6		3	0.08 (0.03-0.11)	1	0.05 (0.05-0.05)
Copper	M	13	<0.01 (<0.10-0.02)	9	<0.01 (<0.01-0.01)
Dissolved alpha (pCi/L)	M	5	2.74 (−0.3-6.0)	4	3.58 (−1.9-9.3)
Dissolved beta (pCi/L)	M	5	6.60 (−7.0-21.0)	4	10.25 (1.0-32.0)
Disolved oxygen	5.0	22	8.84 (7.5-10.7)	8	8.43 (6.0-11.2)
Fecal coliform (Co/100ml)		3	242.7 (10.0->600.0)		
Flow (MLD)	M	43	<0.91 (<0.004-10.2)	10	2.61 (0.08-9.8)
Fluorine	5.0	22	<0.16 (<0.10-0.3)	8	0.22 (0.1-0.5)
Hardness, as $CaCO_3$		1	38.0 (38.0-38.0)	2	74.5 (72.0-77.0)
Iron	6.55	22	0.86 (0.2-2.5)	9	1.48 (0.5-2.8)
Lead				3	<0.11 (<0.07-<0.2)
^{237}Neptunium (pCi/L)		5	<1.81 (<0.0-3.0)	3	−0.03 (−0.4-0.2)
Nickel	M	13	<0.05 (<0.05-<0.05)	9	<0.05 (<0.05-<0.05)
Oil and grease	M	13	<5.00 (<5.0-<5.0)	9	<5.0 (<5.0-<5.0)
pH (SU)	6-10	42	8.02 (6.3-8.9)	10	7.27 (6.5-8.0)
^{239}Plutonium (pCi/L)		5	<2.40 (<0.0-3.0)	3	0.03 (0.0-0.1)
PO_4-P				1	0.23 (0.23-0.23)
Polychlorinated biphenyl (μg/L)	100.0	10	<0.11 (<0.1-0.2)	8	<0.10 (<0.1-<0.1)
Residual Chlorine	0.15	43	<0.02 (<0.01-0.09)	10	<0.01 (<0.01-<0.01)
Suspended alpha (pCi/L)	M	5	−0.80 (−2.5-0.4)	4	−0.18 (−2.3-2.3)
Suspended beta (pCi/L)	M	5	4.80 (−2.0-18.0)	4	0.45 (−3.2-4.0)
Suspended solids	M	13	21.69 (8.0-54.0)	9	34.22 (11.0-75.0)
^{99}Technetium (pCi/L)				1	8.00 (8.0-8.0)
Temperature (°C)	89	42	20.21 (3.9-32.8)	10	17.06 (6.1-25.6)
Trichloroethylene	0.0807	13	<0.001	9	<0.001
Total phosphorus				2	0.16 (0.09-0.2)
Uranium	M	6	<0.004 (0.001-0.01)	4	0.004 (0.003-0.006)
Zinc	0.17	43	0.03 (0.01-0.07)	9	0.05 (0.02-0.08)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; *n*=number of observations.

Table A.3. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 004 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
Aluminum		1	<0.10 (<0.1–<0.1)		
Barium		1	0.012 (0.012–0.012)		
Biological oxygen demand	45	24	8.7 (<5.0–15.0)	24	10.38 (5.0–16.0)
Boron (μg/L)		1	<0.10 (<0.1–<0.1)		
Chloride		1	18.0 (18.0–18.0)		
Chromium		1	<0.05		
Copper		1	<0.01		
Fecal coliform (Co/100ml)	400	24	<11.46	25	<5.56 (<1.0–38.0)
Fluorine		1	0.16 (0.16–0.16)		
Flow (MLD)	M	24	1.25 (1.1–1.9)	24	1.28 (1.1–1.9)
Gross Alpha (pCi/L)		1	7.5 (7.5–7.5)		
Gross Beta (pCi/L)		1	60.0 (60.0–60.0)		
Hardness, as $CaCO_3$		1	40.0 (40.0–40.0)	1	120.0
Iron		1	0.43 (0.43–0.43)		
Magnesium		1	5.0 (5.0–5.0)		
Manganese		1	0.03 (0.03–0.03)		
Nickel		1	<0.05		
NO_3		1	2.6 (2.6–2.6)		
Oil and grease		2	<5.9 (<5.0–6.9)		
pH (SU)	6–9	24	7.8 (6.6–9.0)	25	7.42 (6.7–8.4)
PO_4-P		1	1.44 (1.44–1.44)		
Residual Chlorine		1	<0.01		
SO_4		1	44.0 (44.0–44.0)		
Suspended solids	45	24	<6.13 (<4.0–12.0)	21	<6.48 (<4.0–14.0)
Titanium		1	<0.005		
Trichloroethylene		1	<0.001		
Zinc		1	0.07 (0.07–0.07)		

Note: If any value was below the detection limit, a less than value appears with the means value. M = Monitored only; MLD=millions of liters per day; *n*=number of observations.

Table A.4. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 006 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
Aluminum		1	0.38 (0.38–0.38)	4	0.54 (0.2–1.0)
Cadmium				6	<0.008 (<0.005–<0.01)
COD		53	<11.08 (<5.0–22.0)	43	<12.33 (<5.0–25.0)
Chromium				4	<0.05 (<0.05–<0.05)
Chromium-6				2	<0.01 (<0.01–<0.01)
Conductivity (μmhos/cm)				37	258.3 (192.0–316.0)
Copper		1	<0.01	4	<0.01 (<0.01–0.02)
Disolved oxygen				1	14.9 (14.9–14.9)
Flow (MLD)	M	53	4.88 (3.0–11.7)	82	5.15 (0.04–10.8)
Hardness, as $CaCO_3$		1	38.0 (38.0–38.0)	14	73.1 (48.0–133.0)
Iron		1	0.49 (0.49–0.49)	4	0.82 (0.2–20.0)
Lead				6	<0.10 (<0.03–<0.2)
Nickel		1	<0.05	4	<0.05 (<0.05–<0.05)
Oil and grease				9	<5.0 (<5.0–<5.0)
Polychlorinated biphenyl (μg/L)		6	<0.1 (<0.1–<0.1)	12	<0.10 (<0.1–<0.1)
pH (SU)	6–10.4	53	9.42 (8.8–10.1)	88	9.52 (7.5–10.7)
PO_4-P				4	0.11 (0.08–0.2)
Residual Chlorine				10	<0.01 (<0.01–<0.02)
Suspended solids	50	53	<13.59 (<4.0–27.0)	52	<12.79 (<4.0–47.0)
Total phosphorus				11	0.10 (0.08–0.14)
Turbidity (NTU)	M	53	7.41 (1.0–12.0)	43	7.88 (0.0–49.0)
Zinc		1	0.006 (0.006–0.006)	4	<0.01 (<0.005–0.03)

Note: If any value was below the detection limit, a less than value appears with the means value. M = Monitored only; MLD=millions of liters per day; *n*=number of observations; NTU = nephelometric turbidity unit.

Table A.5. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 008 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)		5	0.61 (0.5–0.8)	4	0.65 (0.6–0.7)
Aluminum	M	14	<0.18 (<0.1–0.5)	25	<0.21 (<0.1–0.6)
Cadmium				6	<0.008 (<0.005–<0.01)
Chromium	0.1	54	<0.05 (<0.05–0.15)	63	<0.05 (<0.05–0.08)
Chromium-6				3	<0.01 (<0.01–0.01)
Copper	M	14	<0.01 (<0.01–0.01)	25	<0.01 (<0.01–0.02)
Dissolved alpha (pCi/L)	M	4	0.90 (−5.8–8.7)	12	1.45 (−5.2–6.2)
Dissolved beta (pCi/L)	M	4	61.25 (−6.0–244.0)	12	13.50 (0.0–27.0)
Disolved oxygen	5	24	7.77 (4.9–9.7)	29	7.96 (5.3–11.2)
Fluoride	5	24	0.18 (0.1–0.3)	29	0.17 (0.1–0.2)
Flow (MLD)	M	23	3.86 (1.5–26.1)	60	2.84 (1.1–4.5)
Gross Alpha (pCi/L)				1	0.20 (0.2–0.2)
Gross Beta (pCi/L)				1	1.00 (1.0–1.0)
Hardness, as $CaCO_3$		1	32.00 (32.0–32.0)	14	67.43 (35.0–127.0)
Iron	9.42	25	<0.21 (<0.01–0.96)	34	<0.29 (<0.01–1.0)
Molybdenum				1	<0.05 (<0.05–<0.05)
Nickel	M	14	<0.05 (<0.05–<0.05)	25	<0.05 (<0.05–<0.05)
^{237}Neptunium (pCi/L)		4	<2.25 (<0.0–3.0)	5	−0.14 (−0.4–0.3)
Oil and grease	M	18	<5.16 (<5.0–7.9)	29	<5.00 (<5.0–<5.0)
Lead				6	<0.11 (<0.03–<0.2)
Polychlorinated biphenyl (μg/L)	100.0	12	<0.10 (<0.1–<0.1)	18	<0.10 (<0.1–<0.1)
pH (SU)	6–9	54	7.62 (6.5–8.6)	61	7.35 (6.5–9.0)
^{239}Plutonium (pCi/L)		4	<3.0 (<3.0–<3.0)	5	0.12 (0.0–0.5)
PO_4-P		1	0.31 (0.31–0.31)	4	0.59 (0.5–0.6)
Residual Chlorine	0.33	54	<0.06 (<0.01–0.32)	56	<0.01 (<0.01–0.2)
Suspended alpha (pCi/L)	M	4	1.58 (−4.3–8.6)	12	−0.53 (−3.6–2.0)
Suspended beta (pCi/L)	M	4	11.25 (−5.0–43.0)	12	1.88 (−4.5–15.0)
Suspended solids	M	13	<5.85 (<4.0–14.0)	29	<7.56 (<4.0–21.0)
^{99}Technetium (pCi/L)		31	8.45 (0.0–24.0)	13	14.08 (0.0–25.0)
Trichloroethylene	0.027	13	<0.001 (<0.001–0.001)	20	<0.01 (<0.001–0.09)
Temperature (°C)	31.7	54	22.10 (9.4–32.8)	56	20.86 (9.4–30.0)
Total phosphorus		1	0.57 (0.57–0.57)	11	0.62 (0.5–0.7)
Uranium	M	22	0.007 (0.001–0.029)	15	<0.002 (<0.001–0.005)
Zinc	0.34	54	<0.03 (<0.005–0.044)	57	<0.03 (<0.005–0.12)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; *n*=number of observations

Table A.6. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 009 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)		4	0.55 (0.5–0.6)	4	0.56 (0.0–0.8)
Aluminum	M	12	0.64 (0.2–1.5)	15	0.74 (0.3–2.2)
Cadmium				6	<0.008 (<0.003–<0.01)
Chromium	0.23	54	<0.05 (<0.05–0.12)	47	<0.05 (<0.05–0.08)
Chromium-6				2	<0.02 (<0.01–0.02)
Copper	M	12	<0.01 (<0.01–0.01)	15	<0.01 (<0.01–0.03)
Dissolved alpha (pCi/L)	M	4	3.6 (−2.8–11.5)	4	2.80 (0.90–5.8)
Dissolved beta (pCi/L)	M	4	8.0 (−8.0–20.0)	4	8.25 (3.0–15.0)
Disolved oxygen	5	24	8.98 (5.7–12.0)	21	8.80 (5.0–14.1)
Fluoride	5	24	0.16 (0.1–0.3)	21	<0.15 (<0.1–0.2)
Flow (MLD)	M	52	0.87 (0.4–14.0)	52	0.76 (0.2–4.5)
Hardness, as $CaCO_3$		1	49.0 (49.0–49.0)	14	70.4 (19.0–132.0)
Iron	8.41	24	0.81 (0.2–2.5)	25	0.75 (0.3–1.6)
Lead				7	<0.12 (<0.03–<0.20)
Mercury				1	<0.0 (<0.0–<0.0)
Molybdenum				1	<0.05 (<0.05–<0.05)
Nickel	M	12	<0.05 (<0.05–<0.05)	15	<0.05 (<0.05–<0.05)
^{237}Neptunium (pCi/L)		4	<2.25 (<0.0–3.0)	4	−0.13 (−0.4–0.0)
Oil and grease	M	13	<5.55 (<5.0–12.1)	20	<5.0 (<5.0–<5.0)
pH (SU)	6–10	53	8.09 (6.2–9.7)	52	7.90 (6.2–9.7)
^{239}Plutonium (pCi/L)		4	<3.00 (<3.0–<3.0)	4	0.03 (−0.3–0.4)
PO_4-P		1	0.09 (0.09–0.09)	4	0.17 (0.1–0.2)
Polychlorinated biphenyl (μg/L)	100	10	<0.10 (<0.1–<0.1)	13	<0.10 (<0.1–<0.1)
Residual Chlorine	0.01	54	<0.01 (<0.01–0.01)	52	<0.01 (<0.01–<0.02)
Suspended alpha (pCi/L)	M	4	−0.65 (−4.7–2.0)	4	0.08 (−3.4–2.3)
Suspended beta (pCi/L)	M	4	3.25 (−5.0–19.0)	4	0.50 (−2.0–5.0)
Suspended solids	M	12	10.25 (4.0–19.0)	20	<13.2 (<4.0–29.0)
^{99}Technetium (pCi/L)				4	8.25 (0.0–12.0)
Temperature (°C)	31.7	53	18.48 (5.0–32.8)	52	17.28 (5.0–28.9)
Total phosphorus		1	0.20 (0.2–0.2)	11	0.18 (0.1–0.2)
Trichloroethylene	M	12	<0.001 (<0.001–0.001)	12	<0.001 (<0.001–<0.001)
Uranium	M	4	<0.003 (<0.001–0.006)	6	<0.002 (<0.001–0.003)
Zinc	1.15	53	0.03 (0.006–0.103)	47	<0.05 (<0.005–0.152)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; *n*=number of observations.

Table A.7. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 010 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)		30	0.47 (0.3–0.9)	9	0.38 (0.2–0.7)
Aluminum	M	13	2.69 (0.6–8.8)	9	1.66 (0.6–3.0)
Cadmium				3	<0.008 (<0.005–<0.01)
Chromium	0.5	43	<0.06 (<0.05–0.29)	9	<0.05 (<0.05–<0.05)
Chromium-6				1	<0.01 (<0.01–<0.01)
Copper	M	13	<0.01 (<0.01–0.03)	9	<0.01 (<0.01–0.03)
Dissolved alpha (pCi/L)	M	33	4.65 (−7.0–20.1)	9	8.10 (0.5–19.0)
Dissolved beta (pCi/L)	M	33	18.12 (−23.0–78.0)	9	21.44 (−14.0–65.0)
Disolved oxygen	5	22	8.61 (6.5–11.3)	8	7.74 (5.2–11.3)
Fecal coliform (Co/100ml)		1	60.00 (60.0–>60.0)		
Fluoride	5	22	0.23 (0.1–0.4)	8	0.28 (0.1–0.4)
Flow (MLD)	M	44	<0.38 (<0.004–3.1)	10	2.01 (0.004–5.7)
Hardness, as $CaCO_3$		1	45.0 (45.0–45.0)	2	79.5 (63.0–96.0)
Iron	8.32	22	2.17 (0.3–7.8)	9	<1.40 (<0.01–2.7)
Lead				3	<0.11 (<0.07–<0.2)
^{237}Neptunium (pCi/L)		4	<2.25 (<0.0–3.0)	4	0.03 (−0.3–0.5)
Nickel	M	13	<0.05 (<0.05–<0.05)	9	<0.05 (<0.05–<0.05)
Oil and grease	M	13	<5.32 (<5.0–9.1)	9	<5.0 (<5.0–<5.0)
pH (SU)	6–9	43	7.82 (6.9–8.6)	9	7.72 (6.8–9.8)
^{239}Plutonium (pCi/L)		4	<2.25 (<0.0–3.0)	4	0.00 (0.0–0.0)
PO_4-P				1	0.17 (0.17–0.17)
Polychlorinated biphenyl (μg/L)	100	10	<0.10 (<0.1–<0.1)	8	<0.10 (<0.1–<0.1)
Residual Chlorine	0.01	44	<0.01 (<0.01–0.02)	12	<0.01 (<0.01–0.01)
Suspended alpha (pCi/L)	M	33	2.17 (−5.9–13.3)	9	1.82 (−0.6–3.8)
Suspended beta (pCi/L)	M	33	−0.39 (−19.0–19.0)	9	4.11 (−2.0–18.0)
Suspended solids	M	13	41.69 (7.0–106.0)	9	26.00 (10.0–45.0)
^{99}Technetium (pCi/L)		21	11.38 (0.0–66.0)	4	40.50 (13.0–93.0)
Temperature (°C)	31.7	43	19.52 (3.9–31.1)	9	19.44 (8.9–25.0)
Trichloroethylene	M	13	<0.001 (<0.001–0.001)	9	<0.001 (<0.001–<0.001)
Total phosphorus				2	0.19 (0.17–0.22)
Uranium	M	34	<0.02 (<0.001–0.072)	8	0.02 (0.006–0.027)
Zinc	0.26	43	0.03 (0.01–0.09)	9	<0.04 (<0.005–0.073)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; *n*=number of observations.

Table A.8. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 011 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)	M	42	0.30 (0.2–0.7)	50	0.29 (0.2–0.5)
Aluminum	M	13	<0.37 (<0.1–1.3)	15	0.33 (0.2–0.6)
Cadmium				6	<0.01 (<0.005–0.02)
Chromium	0.85	52	<0.05 (<0.05–<0.05)	47	<0.05 (<0.006–0.16)
Chromium-6				2	<0.01 (<0.01–<0.01)
Copper	M	13	<0.01 (<0.01–0.01)	15	<0.01 (<0.005–0.01)
Dissolved alpha (pCi/L)	M	43	45.87 (−9.3–1325.5)	51	8.86 (−8.1–30.3)
Dissolved beta (pCi/L)	M	43	30.35 (−13.0–782.0)	51	10.57 (−.0–36.0)
Disolved oxygen	5	24	7.44 (4.4–10.3)	20	8.72 (6.6–10.6)
Fecal coliform (Co/100ml)		2	45.50 (24.0–67.0)	3	<58.67 (<1.0–144.0)
Fluoride	5	24	0.15 (0.1–0.3)	20	0.14 (0.1–0.2)
Flow (MLD)		52	0.87 (0.08–3.7)	50	1.55 (0.4–4.2)
Gross Alpha (pCi/L)				2	12.40 (6.8–18.0)
Gross Beta (pCi/L)				2	19.50 (8.0–31.0)
Hardness, as $CaCO_3$		1	33.0 (33.0–33.0)	14	65.64 (44.0–128.0)
Iron	5.94	24	0.62 (0.04–7.8)	24	<0.31 (<0.01–0.8)
Lead				6	<0.11 (<0.03–0.2)
Nickel	M	13	<0.05 (<0.05–<0.05)	15	<0.05 (<0.02–0.05)
^{237}Neptunium (pCi/L)		4	<2.25 (<0.0–3.0)	4	0.05 (−0.2–0.2)
Oil and grease	M	15	<5.00 (<5.0–<5.0)	18	<5.0 (<5.0–<5.0)
pH (SU)	6–10	52	7.94 (7.0–9.3)	51	8.17 (6.5–9.4)
^{239}Plutonium (pCi/L)		4	<3.0 (<3.0–<3.0)	4	0.08 (0.0–0.2)
PO_4-P				4	0.28 (0.2–0.3)
Polychlorinated biphenyl (μg/L)	100	12	<0.12 (<0.1–0.3)	12	<0.10 (<0.1–<0.1)
Residual Chlorine	0.14	53	<0.01 (<0.01–0.03)	52	<0.01 (<0.01–0.02)
Suspended alpha (pCi/L)	M	43	−0.022 (−7.9–15.8)	51	0.12 (−5.5–17.7)
Suspended beta (pCi/L)	M	43	1.18 (−20.0–20.0)	51	0.32 (−13.0–40.0)
Suspended solids	M	13	<10.69 (<4.0–38.0)	19	<10.42 (<4.0–38.0)
^{99}Technetium (pCi/L)		52	6.64 (0.0–34.0)	53	7.72 (−7.0–37.0)
Temperature (°C)	35	52	26.03 (11.7–37.8)	51	22.28 (8.9–33.9)
Trichloroethylene	M	12	<0.007 (<0.001–0.029)	11	<0.002 (<0.001–0.004)
Total phosphorus				11	0.30 (0.2–0.4)
Uranium	M	53	<0.15 (<0.001–4.4)	52	0.03 (0.002–0.06)
Zinc	0.16	52	<0.03 (<0.005–0.119)	46	<0.02 (<0.002–0.1)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; *n*=number of observations

Table A.9. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 012 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)	M	30	0.47 (0.2–0.8)	9	0.39 (0.0–0.6)
Aluminum	M	12	0.95 (0.2–2.6)	8	1.04 (0.4–1.7)
Cadmium				3	<0.008 (<0.005–<0.01)
Chromium	0.76	41	<0.05 (<0.05–0.06)	9	<0.05 (<0.05–0.09)
Chromium-6				1	<0.01 (<0.01–<0.01)
Copper	M	12	<0.01 (<0.01–0.02)	8	<0.01 (<0.01–0.01)
Dissolved alpha (pCi/L)	M	32	1.83 (−9.0–11.6)	9	2.50 (−2.1–8.1)
Dissolved beta (pCi/L)	M	32	6.18 (−23.0–51.0)	9	8.91 (−2.8–21.0)
Disolved oxygen	5	21	8.69 (6.5–11.2)	7	8.26 (6.3–11.3)
Fecal coliform (Co/100ml)		3	516.7 (350.0–>600.0)		
Fluoride	5	21	0.27 (0.1–0.4)	7	0.41 (0.3–0.5)
Iron	18.22	21	0.72 (0.3–1.9)	8	0.99 (0.3–1.7)
Flow (MLD)		43	0.57 (0.08–3.9)	10	3.14 (0.08–11.0)
Hardness, as $CaCO_3$		1	61.0 (61.0–61.0)	2	94.50 (73.0–116.0)
Nickel	M	12	<0.05 (<0.05–0.05)	8	<0.05 (<0.05–<0.05)
^{237}Neptunium (pCi/L)		5	<2.20 (<0.0–3.0)	3	−0.10 (−0.4–0.1)
Oil and grease	M	17	<5.00 (<5.0–<5.0)	8	<5.00 (<5.0–<5.0)
Lead				3	<0.11 (<0.07–<0.20)
pH (SU)	6–10	42	7.59 (6.4–8.2)	9	7.32 (6.3–8.0)
^{239}Plutonium (pCi/L)		5	<2.40 (<0.0–3.0)	3	0.03 (0.0–0.1)
PO_4-P				1	0.26 (0.26–0.26)
Polychlorinated biphenyl (μg/L)	100	12	<0.10 (<0.1–<0.1)	7	<0.09 (<0.0–0.1)
Residual Chlorine	0.01	43	<0.01 (<0.01–0.01)	11	<0.01 (<0.01–<0.01)
Suspended alpha (pCi/L)	M	32	0.77 (−9.0–14.7)	9	1.30 (−2.0–3.3)
Suspended beta (pCi/L)	M	32	−1.22 (−21.0–19.0)	9	2.00 (−3.0–23.0)
Suspended solids	M	12	<18.92 (<4.0–50.0)	8	27.38 (8.0–71.0)
^{99}Technetium (pCi/L)		31	5.58 (0.0–31.0)	3	5.67 (0.0–14.0)
Temperature (°C)	35	42	21.88 (6.1–32.8)	9	20.06 (10.0–29.4)
Trichloroethylene	M	13	<0.001	8	<0.001 (<0.001–<0.001)
Total phosphorus				2	0.22 (0.2–0.3)
Uranium	M	33	<0.006 (<0.001–0.017)	8	<0.007 (<0.001–0.02)
Zinc	0.4	41	<0.04 (<0.005–0.102)	9	0.05 (0.02–0.08)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; n=number of observations.

Table A.10. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 013 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)		4	0.62 (0.5–0.9)	4	0.44 (0.0–0.7)
Aluminum		10	1.99 (0.4–5.3)	12	1.77 (0.2–3.9)
Cadmium				5	<0.01 (<0.005–0.03)
Chromium				5	<2.65 (<0.05–7.0)
Chromium-6				4	<3.70 (<0.0–7.9)
Copper		10	<0.01 (<0.01–0.01)	12	<0.01 (<0.01–<0.01)
Dissolved alpha (pCi/L)		4	3.25 (−0.9–6.8)	4	1.70 (−2.5–3.5)
Dissolved beta (pCi/L)		4	13.00 (4.0–23.0)	4	15.50 (−24.0–54.0)
Fluoride	M	10	0.58 (0.2–1.1)	10	0.58 (0.3–1.1)
Flow (MLD)	M	11	<3.71 (<0.004–9.7)	13	2.69 (0.08–14.5)
Hardness, as $CaCO_3$		1	139.0 (139.0–139.0)	2	109.0 (60.0–158.0)
Iron		10	1.84 (0.1–5.6)	12	1.64 (0.1–4.0)
Lead				5	<0.14 (<0.03–<0.20)
Nickel		10	<0.05 (<0.05–<0.05)	12	<0.05 (<0.05–<0.05)
^{237}Neptunium (pCi/L)		4	<2.25 (<0.0–3.0)	4	−0.08 (−0.4–0.3)
Oil and grease	M	10	<5.00 (<5.0–<5.0)	12	<5.0 (<5.0–<5.0)
pH (SU)	6–9	10	7.71 (6.6–8.6)	12	7.46 (6.9–7.8)
^{239}Plutonium (pCi/L)		4	<2.27 (<0.07–3.0)	4	0.04 (0.0–0.1)
Polychlorinated biphenyl (μg/L)		8	<0.11 (<0.1–0.2)	12	<0.10 (<0.1–<0.1)
Suspended alpha (pCi/L)		4	−2.58 (−6.7–0.5)	4	−2.15 (−4.9–0.0)
Suspended beta (pCi/L)		4	−3.00 (−8.0–3.0)	4	−0.50 (−6.0–8.0)
Suspended solids	271	10	<42.70 (<4.0–229.0)	12	<31.08 (<4.0–81.0)
Trichloroethylene				2	<0.001 (<0.001–<0.001)
Uranium		4	0.003 (0.001–0.004)	4	<0.002 (<0.001–0.005)
Zinc				2	0.019 (0.016–0.021)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; *n*=number of observations.

Table A.11. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 014 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
COD		NM	NM	1	7.00
Flow (MLD)	M	NM	NM	1	0.02
pH (SU)	6–9	NM	NM	1	9.50
Polychlorinated biphenyl (μg/L)		NM	NM	1	<0.10
Residual Chlorine		NM	NM	1	<0.01
Suspended solids	50	NM	NM	1	9.00
Turbidity (NTU)	M	NM	NM	1	1.40

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; NM=Not Monitored; MLD=millions of liters per day; *n*=number of observations; NTU = nephelometric turbidity unit.

Table A.12. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 015 for 1991-1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)	M	4	0.46 (0.3–0.9)	4	0.43 (0.3–0.6)
Aluminum	M	10	3.06 (0.6–8.9)	12	2.77 (0.3–7.6)
Cadmium				4	<0.01 (<0.005–0.03)
Chromium				3	<0.05 (<0.05–<0.05)
Chromium-6				1	<0.01 (<0.01–<0.01)
Copper	M	10	<0.01 (<0.01–0.03)	12	<0.01 (<0.01–0.02)
Dissolved alpha (pCi/L)	M	4	48.93 (3.6–109.0)	4	45.63 (4.2–111.0)
Dissolved beta (pCi/L)	M	4	84.50 (32.0–154.0)	4	71.25 (0.0–218.0)
Fluoride	5	10	0.40 (0.3–0.6)	9	0.47 (0.3–0.6)
Flow (MLD)		11	<1.78 (<0.004–10.2)	11	<4.32 (<0.004–17.4)
Hardness, as $CaCO_3$		1	133.0 (133.0–133.0)	2	63.50 (58.0–69.0)
Iron		10	3.38 (0.4–10.9)	12	2.27 (0.08–6.3)
Lead				4	<0.16 (<0.03–<0.2)
Nickel	M	10	<0.05 (<0.05–<0.05)	12	<0.06 (<0.05–0.16)
^{237}Neptunium (pCi/L)		4	<2.30 (<0.2–3.0)	4	−0.38 (−1.0–0.0)
Oil and grease	M	10	<5.00 (<5.0–<5.0)	11	<5.00 (<5.0–<5.0)
pH (SU)	6–10	10	7.93 (6.2–8.9)	12	7.64 (6.9–8.1)
^{239}Plutonium (pCi/L)		4	<2.26 (<0.02–3.0)	4	0.09 (0.04–0.1)
PO_4-P		1	<0.05 (<0.05–<0.05)		
Polychlorinated biphenyl (μg/L)	100	8	<0.10 (<0.1–<0.1)	10	<0.10 (<0.1–0.1)
Suspended alpha (pCi/L)	M	4	−1.18 (−5.6–1.1)	4	−0.43 (−4.9–1.6)
Suspended beta (pCi/L)	M	4	4.75 (−13.0–16.0)	4	11.58 (−0.7–26.0)
Suspended solids	427	10	134.4 (5.0–636.0)	12	<103.3 (4.0–698.0)
Trichloroethylene	M			2	<0.001 (<0.001–<0.001)
Total phosphorus		1	0.14 (0.14–0.14)		
Uranium	M	4	0.13 (0.02–0.25)	4	0.16 (0.01–0.3)
Zinc				3	<0.01 (<0.005–0.02)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; *n*=number of observations

Table A.13. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 016 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)	M	4	0.64 (0.5–0.9)	3	0.39 (0.0–0.6)
Aluminum	M	10	1.30 (0.3–3.2)	10	0.53 (0.2–1.3)
Cadmium				2	<0.008 (<0.005–<0.01)
Chromium				2	<0.05 (<0.05–<0.05)
Copper	M	10	<0.01 (<0.01–0.02)	10	<0.01 (<0.01–<0.01)
Dissolved alpha (pCi/L)	M	4	2.25 (−2.9–9.0)	4	0.60 (−3.8–2.3)
Dissolved beta (pCi/L)	M	4	18.75 (11.0–35.0)	4	9.00 (−30.0–43.0)
Fluoride	5	10	0.21 (0.2–0.3)	8	0.21 (0.2–0.3)
Flow (MLD)		10	<0.30 (<0.004–1.5)	10	<0.64 (<0.004–3.8)
Hardness, as $CaCO_3$		1	103.0 (10.3.0–103.0)	2	144.0 (62.0–226.0)
Iron		10	1.29 (0.2–3.2)	10	0.43 (0.1–1.1)
Lead				2	<0.12 (<0.03–<0.2)
Nickel	M	10	<0.05 (<0.05–<0.05)	10	<0.05 (<0.05–<0.05)
^{237}Neptunium (pCi/L)		4	<2.25 (<0.0–3.0)	4	0.11 (−0.6–0.6)
Oil and grease	M	10	<5.0 (<5.0–<5.0)	10	<5.00 (<5.0–<5.0)
pH (SU)	6–10	10	7.68 (7.0–8.4)	10	7.64 (6.9–8.5)
^{239}Plutonium (pCi/L)		4	<2.28 (<0.1–3.0)	4	0.11 (0.0–0.2)
PO_4-P		1	0.14 (0.14–0.14)		
Polychlorinated biphenyl (μg/L)	100	8	<0.10 (<0.1–0.1)	10	<0.10 (<0.1–<0.1)
Suspended alpha (pCi/L)	M	4	0.68 (−2.9–7.1)	4	−0.25 (−2.5–2.3)
Suspended beta (pCi/L)	M	4	0.70 (−8.0–5.8)	4	−1.00 (−7.0–6.0)
Suspended solids	45	10	<27.80 (<4.0–91.0)	10	<10.60 (<4.0–19.0)
^{99}Technetium (pCi/L)				1	12.00 (12.0–12.0)
Total phosphorus		1	0.27 (0.27–0.27)		
Trichloroethylene	M			2	<0.001 (<0.001–<0.001)
Uranium	M	4	0.004 (0.001–0.009)	4	<0.004 (<0.001–0.008)
Zinc				2	0.013 (0.011–0.014)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; *n*=number of observations.

Table A.14. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 017 for 1991–1992

Parameter (mg/L unless otherwise noted)	Interim limit	1991		1992	
		n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)		4	0.62 (0.4–0.9)	4	0.41 (0.0–0.7)
Aluminum	M	10	0.59 (0.2–1.3)	12	1.83 (0.2–14.6)
Cadmium				5	<0.02 (<0.005–0.03)
Chromium				2	<0.05 (<0.05–<0.05)
Chromium-6				2	<0.005 (<0.0–0.01)
Copper	M	10	<0.01 (<0.01–0.02)	12	<0.01 (<0.01–0.03)
Dissolved alpha (pCi/L)	M	4	3.03 (−0.9–5.4)	4	2.80 (−0.5–5.1)
Dissolved beta (pCi/L)	M	4	12.25 (0.0–19.0)	4	3.15 (−6.0–17.0)
Fluoride		10	0.49 (0.3–0.6)	10	0.47 (0.4–0.6)
Flow (MLD)		11	<1.70 (<0.004–6.1)	12	<0.95 (<0.004–6.1)
Hardness, as $CaCO_3$		1	120.0 (120.0–120.0)	2	138.5 (91.0–186.0)
Iron		10	0.68 (0.08–2.4)	12	2.39 (0.2–21.5)
Lead				5	<0.14 (<0.03–<0.20)
Nickel	M	10	<0.05 (<0.05–0.06)	12	<0.06 (<0.05–0.14)
^{237}Neptunium (pCi/L)		4	<2.25 (<0.0–3.0)	4	−0.25 (−0.7–0.1)
Oil and grease		10	<5.06 (<5.0–5.6)	12	<5.00 (<5.0–<5.0)
pH (SU)	6–10	10	7.72 (6.5–8.4)	12	7.69 (7.1–8.2)
^{239}Plutonium (pCi/L)		4	<2.25 (<0.0–3.0)	4	0.05 (0.0–0.1)
PO_4-P		1	<0.05 (<0.05–<0.05)		
Polychlorinated biphenyl (μg/L)	100	8	<0.10 (<0.1–<0.1)	12	<0.10 (<0.1–<0.1)
Suspended alpha (pCi/L)	M	4	−1.20 (−7.2–6.5)	4	−0.73 (−2.7–1.1)
Suspended beta (pCi/L)	M	4	−3.25 (−16.0–7.0)	4	3.25 (−1.0–10.0)
Suspended solids	M	10	<30.20 (<4.0–140.0)	12	182.2 (4.0–1930.0)
Total phosphorus		1	0.06 (0.06–0.06)		
Trichloroethylene				2	<0.001 (<0.001–<0.001)
Uranium	M	4	0.006 (0.002–0.012)	4	0.006 (0.001–0.012)
Zinc				2	0.02 (0.008–0.022)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; *n*=number of observations

Table A.15. Interim limits and summary statistics for Kentucky Pollutant Discharge Elimination System Permit water quality parameters at Outfall 018 for 1991–1992

Parameter (mg/L unless otherwise noted)	1991		1992	
	n	Mean (range)	*n*	Mean (range)
^{235}U (% by wt)	3	0.71 (0.5–0.8)	4	0.31 (0.0–0.7)
Aluminum	7	6.02 (0.5–14.1)	11	20.78 (0.4–119.0)
Cadmium			4	<0.02 (<0.005–0.031)
Chromium			2	<0.05 (<0.05–<0.05)
Chromium-6			1	<0.01 (<0.01–<0.01)
Copper	7	<0.01 (<0.01–0.03)	11	<0.03 (<0.01–0.14)
Dissolved alpha (pCi/L)	3	11.50 (3.4–16.5)	4	9.05 (0.0–24.2)
Dissolved beta (pCi/L)	3	53.00 (30.0–82.0)	4	29.25 (7.0–45.0)
Fluoride	7	0.55 (0.3–0.7)	9	0.49 (0.3–0.7)
Flow (MLD)	8	<3.33	11	<6.05 (<0.004–38.6)
Hardness, as $CaCO_3$	1	92.00 (92.0–92.0)	2	103.5 (89.0–118.0)
Iron	7	5.21 (0.3–12.5)	11	24.53 (0.1–163.0)
Lead			4	<0.16 (<0.03–<0.2)
Nickel	7	<0.05	11	<0.06 (<0.05–0.1)
^{237}Neptunium (pCi/L)	3	<2.00 (<0.0–3.0)	4	0.13 (−0.3–0.6)
Oil and grease	7	<5.03 (<5.0–5.2)	11	<5.32 (<5.0–8.5)
pH (SU)	7	7.73 (6.9–8.2)	11	7.68 (7.2–8.2)
^{239}Plutonium (pCi/L)	3	<2.06 (<0.2–3.0)	4	0.10 (0.0–0.2)
Polychlorinated biphenyl (μg/L)	8	<0.09 (<0.0–0.1)	11	<0.10 (<0.1–<0.1)
Suspended alpha (pCi/L)	3	−1.53 (−5.9–3.6)	4	1.10 (−1.4–4.1)
Suspended beta (pCi/L)	3	3.33 (−10.0–23.0)	4	12.50 (4.0–29.0)
Suspended solids	7	177.14 (5.0–614.0)	11	<369.2 (<4.0–2980.0)
Trichloroethylene			2	<0.001 (<0.001–<0.001)
Uranium	3	0.01 (0.004–0.017)	4	0.02 (0.002–0.065)
Zinc			2	0.03 (0.2–0.05)

Note: If any value was below the detection limit, a less than value appears with the means value. M=Monitored only; MLD=millions of liters per day; *n*=number of observations.

Appendix B

TOXICITY TEST RESULTS AND WATER CHEMISTRY ANALYSES

Table B.1. Results of toxicity tests of continuously flowing effluents and ambient samples at the Paducah Gaseous Diffusion Plant
Tests conducted October 24–31, 1991

Site[a]	Concentration (%)	Fathead minnow: Mean survival (SD) (%)	Fathead minnow: Mean growth (SD) (mg/fish)	*Ceriodaphnia dubia*: Survival (%)	*Ceriodaphnia dubia*: Mean offspring/surviving female (SD)
Control	100	97.5 (5.0)	0.15 (0.03)	100	19.9 (9.9)
Outfall 001	100	92.5 (5.0)	0.22 (0.03)	80	27.0 (13.5)
	50	82.5 (5.0)	0.12 (0.03)	90	25.3 (13.2)
	25	97.5 (5.0)	0.18 (0.01)	90	34.3 (5.1)
	12	95.0 (10.0)	0.20 (0.03)	100	21.6 (11.1)
	6	100.0 (0.0)	0.17 (0.01)	90	28.0 (8.2)
Outfall 004	100	65.0 (5.8)	0.12 (0.04)	80	30.4 (10.1)
	50	87.5 (12.6)	0.18 (0.01)	90	25.2 (9.2)
	25	92.5 (9.6)	0.13 (0.04)	70	29.4 (11.7)
	12	97.5 (5.0)	0.18 (0.04)	70	33.4 (8.8)
	6	85.0 (19.2)	0.17 (0.03)	100	34.9 (5.9)
Outfall 006	100	92.5 (9.6)	0.16 (0.04)	90	29.8 (8.7)
	50	96.7 (5.8)	0.20 (0.01)	70	29.6 (14.8)
	25	97.5 (5.0)	0.22 (0.03)	90	25.8 (12.7)
	12	97.5 (5.0)	0.20 (0.05)	80	22.8 (11.7)
	6	100.0 (0.0)	0.22 (0.04)	90	31.1 (4.9)
Outfall 008	100	72.5 (26.3)	0.15 (0.05)	100	36.9 (6.2)
	50	90.0 (14.1)	0.16 (0.04)	70	27.4 (9.3)
	25	76.7 (25.2)	0.20 (0.07)	100	29.0 (8.2)
	12	77.5 (15.0)	0.13 (0.03)	70	22.9 (14.8)
	6	95.0 (10.0)	0.14 (0.02)	60	14.8 (5.9)
Outfall 009	100	95.0 (5.8)	0.13 (0.03)	100	32.3 (5.5)
	50	95.0 (5.8)	0.11 (0.03)	90	25.1 (8.7)
	25	82.5 (9.6)	0.13 (0.06)	100	27.3 (7.3)
	12	77.5 (18.0)	0.13 (0.01)	80	22.6 (7.2)
	6	87.5 (12.6)	0.16 (0.03)	100	27.2 (10.2)
Outfall 011	100	97.5 (5.0)	0.10 (0.03)	90	38.9 (8.6)
	50	90.0 (8.2)	0.18 (0.01)	100	33.9 (7.2)

Table B.1 (continued)

Site[a]	Concentration (%)	Fathead minnow		*Ceriodaphnia dubia*	
		Mean survival (SD) (%)	Mean growth (SD) (mg/fish)	Survival (%)	Mean offspring/surviving female (SD)
	25	90.0 (14.1)	0.17 (0.05)	100	39.7 (3.9)
	12	95.0 (5.8)	0.12 (0.06)	80	22.1 (12.4)
	6	92.5 (5.0)	0.19 (0.07)	100	28.2 (10.8)
BBK 12.5	100	42.5 (33.0)	0.15 (0.05)	100	38.1 (10.8)
BBK 10.0	100	57.5 (33.0)	0.16 (0.04)	100	31.7 (9.5)
BBK 9.5	100	52.5 (33.0)	0.20 (0.07)	70	32.4 (14.4)
LUK 7.2	100	95.0 (5.0)	0.13 (0.03)	90	27.3 (6.4)
MAK 13.8	100	62.5 (27.5)	0.14 (0.02)	90	43.1 (2.6)

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

Table B.2. Summary (mean ± SD; n = 7) of water chemistry analyses conducted during toxicity tests of continuously flowing effluents and ambient waters at the Paducah Gaseous Diffusion Plant
Analyses conducted October 24–31, 1991

Site[a]	Concentration (%)	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Control	100	7.7 (0.6)	64 (1.3)	77 (3)	168 (5.8)
Outfall 001	100	9.2 (0.3)	32 (4.0)	445 (42)	1563 (158)
	25	8.3 (0.3)	54 (1.5)	173 (18)	549 (44)
	6	8.0 (0.4)	60 (2.2)	103 (10)	265 (13)
Outfall 004	100	7.5 (0.1)	43 (4.7)	86 (14)	356 (30)
	25	7.9 (0.4)	57 (1.3)	81 (6)	216 (10)
	6	7.9 (0.4)	60 (1.6)	81 (5)	181 (4)
Outfall 006	100	9.4 (0.7)	39 (0.8)	75 (8)	273 (7)
	25	8.3 (0.6)	57 (1.0)	74 (6)	193 (3)
	6	7.9 (0.5)	59 (3.7)	79 (5)	174 (3)
Outfall 008	100	7.5 (0.1)	36 (3.8)	77 (11)	313 (19)
	25	7.9 (0.4)	56 (1.2)	82 (10)	206 (6)
	6	7.9 (0.4)	60 (2.1)	79 (5)	177 (4)
Outfall 009	100	7.5 (0.2)	43 (9.0)	64 (14)	194 (46)
	25	7.8 (0.3)	57 (2.4)	74 (5)	176 (10)
	6	7.9 (0.4)	62 (1.6)	79 (6)	171 (3)
Outfall 011	100	7.8 (0.1)	42 (6.4)	77 (9)	258 (12)
	25	7.9 (0.3)	57 (2.4)	78 (4)	192 (2)
	6	7.9 (0.4)	64 (0.9)	75 (6)	175 (1)
BBK 12.5	100	7.6 (0.2)	76 (8.1)	63 (16)	250 (26)
BBK 10.0	100	7.6 (0.1)	43 (4.2)	76 (16)	286 (24)
BBK 9.5	100	8.4 (0.5)	39 (5.1)	257 (75)	907 (289)
LUK 7.2	100	7.6 (0.1)	50 (5.7)	93 (16)	302 (21)
MAK 13.8	100	7.4 (0.2)	43 (4.4)	50 (17)	145 (13)

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

Table B.3. Results of toxicity test of intermittently flowing effluents at the Paducah Gaseous Diffusion Plant
Tests conducted December 27, 1991–January 3, 1992

Sample source	Concentration (%)	Fathead minnow		*Ceriodaphnia dubia*	
		Mean survival (SD) (%)	Mean growth (SD) (mg/fish)	Survival (%)	Mean offspring/surviving female (SD)
Control	100	97.5 (5.0)	0.59 (0.04)	90	28.3 (9.7)
Outfall 013	100	97.5 (5.0)	0.61 (0.04)	100	36.0 (4.8)
	50	95.0 (10.0)	0.60 (0.09)	100	34.8 (3.4)
	25	92.5 (15.0)	0.57 (0.08)	100	36.1 (4.1)
	12	95.0 (5.8)	0.65 (0.06)	90	36.0 (3.6)
Outfall 015	100	95.0 (5.8)	0.67 (0.03)	100	34.7 (5.3)
	50	95.0 (5.8)	0.60 (0.06)	90	33.7 (5.2)
	25	97.5 (5.0)	0.65 (0.11)	60	37.3 (3.1)
	12	95.0 (5.8)	0.66 (0.03)	90	34.2 (5.8)
Outfall 016	100	100.0 (0.0)	0.68 (0.09)	100	33.5 (3.4)
	50	97.5 (5.0)	0.58 (0.02)	100	33.3 (6.4)
	25	100.0 (0.0)	0.57 (0.05)	80	36.0 (5.8)
	12	97.5 (5.0)	0.55 (0.06)	70	36.1 (4.1)
Outfall 017	100	95.0 (5.8)	0.68 (0.05)	100	33.2 (4.9)
	50	100.0 (0.0)	0.93 (0.05)	70	33.0 (5.2)
	25	92.5 (5.0)	0.62 (0.08)	90	32.2 (3.5)
	12	97.5 (5.0)	0.57 (0.02)	90	28.6 (4.6)
Outfall 018	100	80.0 (18.3)	0.67 (0.13)	90	32.7 (3.3)
	50	97.5 (5.0)	0.65 (0.07)	100	31.4 (2.6)
	25	97.5 (5.0)	0.64 (0.04)	90	33.1 (4.1)
	12	87.5 (12.6)	0.64 (0.03)	90	34.4 (5.7)

Table B.4. Summary of water chemistry analyses conducted on December 27, 1991, in association with toxicity tests of intermittent effluents at the Paducah Gaseous Diffusion Plant

Sample	Concentration (%)	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Outfall 013	100	7.60	57	86	191
	25	8.14	65	84	177
Outfall 015	100	7.79	77	106	231
	25	8.23	69	88	192
Outfall 016	100	7.73	79	96	212
	25	8.16	70	90	181
Outfall 017	100	8.01	104	144	295
	25	8.27	78	96	206
Outfall 018	100	7.79	57	84	180
	25	8.23	64	82	175

Table B.5. Results of toxicity tests of continuously flowing effluents and ambient samples at the Paducah Gaseous Diffusion Plant
Tests conducted February 13–20, 1992

Site[a]	Concentration (%)	Fathead minnow		*Ceriodaphnia dubia*	
		Mean survival (SD) (%)	Mean growth (SD) (mg/fish)	Survival (%)	Mean offspring/surviving female (SD)
Control	100	97.5 (5.0)	0.48 (0.05)	90	19.4 (3.0)
Outfall 001	100	87.5 (12.6)	0.63 (0.07)	100	30.0 (5.9)
	50	100.0 (0.0)	0.49 (0.10)	100	29.9 (3.1)
	25	97.5 (5.0)	0.50 (0.07)	90	29.0 (6.6)
	12	NT[b]	NT	70	24.7 (6.6)
Outfall 004	100	95.0 (5.8)	0.38 (0.09)	100	15.0 (7.6)
	50	97.5 (5.0)	0.36 (0.03)	100	18.5 (6.4)
	25	100.0 (0.0)	0.33 (0.08)	80	24.1 (3.5)
	12	NT	NT	80	24.4 (3.2)
Outfall 006	100	97.5 (5.0)	0.35 (0.07)	80	3.5 (3.0)
	50	97.5 (5.0)	0.39 (0.09)	100	35.8 (5.7)
	25	97.5 (5.0)	0.33 (0.09)	100	32.6 (6.4)
	12	NT	NT	90	34.0 (3.0)
Outfall 008	100	60.0 (21.6)	0.36 (0.11)	100	29.0 (5.3)
	50	80.0 (21.6)	0.44 (0.03)	100	32.4 (9.1)
	25	87.5 (25.0)	0.44 (0.05)	70	35.0 (5.5)
	12	60.0 (42.4)	0.47 (0.05)	80	33.1 (10.1)
Outfall 009	100	82.5 (17.1)	0.38 (0.06)	90	27.9 (4.3)
	50	80.0 (8.2)	0.32 (0.05)	90	27.8 (5.8)
	25	60.0 (33.7)	0.36 (0.03)	90	29.1 (9.8)
	12	NT	NT	70	25.9 (4.5)
Outfall 011	100	80.0 (16.3)	0.31 (0.04)	100	29.1 (9.7)
	50	65.0 (5.8)	0.29 (0.08)	90	31.6 (9.5)
	25	65.0 (28.9)	0.42 (0.08)	90	28.2 (6.6)
	12	NT	NT	60	23.3 (4.8)
BBK 12.5	100	62.5 (26.3)	0.47 (0.11)	100	30.9 (3.1)
BBK 12.5 UV[c]	100	87.5 (12.6)	0.46 (0.05)	NT	NT
BBK 10.0	100	80.0 (18.3)	0.47 (0.04)	90	33.0 (3.2)

Table B.5 (continued)

Site[a]	Concentration (%)	Fathead minnow Mean survival (SD) (%)	Fathead minnow Mean growth (SD) (mg/fish)	*Ceriodaphnia dubia* Survival (%)	*Ceriodaphnia dubia* Mean offspring/surviving female (SD)
BBK 10.0 UV	100	95.0 (5.8)	0.52 (0.04)	NT	NT
BBK 9.5	100	75.0 (17.3)	0.62 (0.06)	100	32.8 (3.8)
BBK 9.5 UV	100	85.0 (19.2)	0.56 (0.07)	NT	NT
LUK 7.2	100	20.0 (24.5)	0.46 (0.14)	100	30.2 (2.3)
LUK 7.2 UV	100	90.0 (14.1)	0.52 (0.03)	NT	NT
MAK 13.8	100	75.0 (37.9)	0.37 (0.08)	90	27.3 (4.8)
MAK 13.8 UV	100	97.5 (5.0)	0.43 (0.03)	NT	NT

[a]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.
[b]NT = not tested.
[c]Sample was exposed to ultraviolet light for 15 min.

Table B.6. Summary (mean ± SD; n = 7) of water chemistry analyses conducted during toxicity tests of continuously flowing effluents and ambient waters at the Paducah Gaseous Diffusion Plant
Analyses conducted February 13–20, 1992

Site[a]	Concentration (%)	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Control	100	8.1 (0.4)	64 (2.6)	72 (13)	166 (8.4)
Outfall 001	100	7.9 (0.2)	39 (4.8)	397 (40)	901 (104)
	25	8.1 (0.1)	58 (2.1)	126 (21)	367 (17)
Outfall 004	100	7.7 (0.1)	53 (4.6)	81 (7)	287 (18)
	25	8.0 (0.1)	62 (2.1)	80 (4)	198 (8)
Outfall 006	100	9.5 (0.2)	41 (7.7)	63 (16)	195 (6)
	25	8.6 (0.2)	58 (1.2)	76 (5)	172 (7)
Outfall 008	100	7.6 (0.1)	46 (9.1)	75 (14)	233 (32)
	25	8.0 (0.2)	59 (2.4)	77 (4)	187 (8)
Outfall 009	100	7.9 (0.2)	69 (22.0)	87 (11)	211 (49)
	25	8.1 (0.1)	64 (3.8)	81 (3)	185 (13)
Outfall 011	100	8.0 (0.1)	53 (5.4)	82 (11)	229 (25)
	25	8.1 (0.2)	61 (2.1)	83 (4)	184 (10)
BBK 12.5	100	7.5 (0.2)	29 (5.8)	57 (7)	145 (22)
BBK 10.0	100	7.6 (0.3)	34 (5.0)	67 (6)	174 (27)
BBK 9.5	100	7.8 (0.3)	34 (4.6)	101 (22)	318 (71)
LUK 7.2	100	7.7 (0.3)	40 (10.7)	66 (13)	177 (43)
MAK 13.8	100	7.6 (0.3)	25 (2.8)	47 (5)	124 (15)

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

Table B.7. Results of toxicity test of intermittently flowing effluents at the Paducah Gaseous Diffusion Plant

Tests conducted March 20–27, 1992

Sample source	Concentration (%)	Fathead minnow		*Ceriodaphnia dubia*	
		Mean survival (SD) (%)	Mean growth (SD) (mg/fish)	Survival (%)	Mean offspring/surviving female (SD)
Control	100	100.0 (0.0)	0.30 (0.04)	100	23.4 (2.1)
Outfall 013	100	37.5 (33.0)	0.35 (0.11)	80	26.3 (5.3)
	50	65.0 (44.4)	0.26 (0.02)	90	26.4 (5.2)
	25	82.5 (9.6)	0.24 (0.02)	80	20.1 (9.5)
	12	100.0 (0.0)	0.25 (0.03)	90	27.9 (6.4)
Outfall 015	100	25.0 (30.0)	0.44 (0.07)	100	25.2 (3.4)
	50	67.5 (45.7)	0.29 (0.03)	100	22.7 (5.6)
	25	20.0 (33.7)	0.50 (0.11)	70	24.7 (5.3)
	12	95.0 (5.8)	0.24 (0.04)	70	25.6 (8.3)
Outfall 016	100	67.5 (32.0)	0.26 (0.03)	100	25.3 (3.8)
	50	95.0 (5.8)	0.26 (0.03)	100	24.8 (5.2)
	25	87.5 (15.0)	0.31 (0.03)	100	25.8 (2.9)
	12	97.5 (5.0)	0.29 (0.03)	90	23.8 (1.5)
Outfall 017	100	20.0 (18.3)	0.53 (0.05)	80	27.6 (3.3)
	50	57.5 (40.3)	0.23 (0.08)	100	21.8 (8.8)
	25	87.5 (9.6)	0.25 (0.03)	90	24.1 (4.3)
	12	87.5 (9.6)	0.33 (0.07)	100	22.3 (5.7)
Outfall 018	100	5.0 (5.8)	0.22 (0.26)	100	20.1 (2.7)
	50	7.5 (9.6)	0.61 (0.28)	100	24.4 (3.7)
	25	45.0 (35.1)	0.50 (0.06)	90	22.4 (3.4)
	12	92.5 (15.0)	0.35 (0.03)	100	23.3 (9.9)

Table B.8. Summary of water chemistry analyses conducted on March 20, 1992, in association with toxicity tests of intermittent effluents at the Paducah Gaseous Diffusion Plant

Sample source	Concentration (%)	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Outfall 013	100	7.65	43	88	146
	25	7.81	59	92	166
Outfall 015	100	8.16	98	150	287
	25	8.06	104	104	204
Outfall 016	100	8.12	90	128	236
	25	8.09	70	96	190
Outfall 017	100	8.12	114	160	292
	25	8.08	88	108	207
Outfall 018	100	7.79	42	84	140
	25	8.01	59	76	164

Table B.9. Results of toxicity tests of continuously flowing effluents and ambient samples at the Paducah Gaseous Diffusion Plant
Tests conducted May 21–28, 1992

Site[a]	Concentration (%)	Fathead Minnow: Mean survival (SD) (%)	Fathead Minnow: Mean growth (SD) (mg/fish)	*Ceriodaphnia dubia*: Survival (%)	*Ceriodaphnia dubia*: Mean offspring/surviving female (SD)
Control	100	97.5 (5.0)	0.17 (0.02)	90	31.1 (4.7)
Outfall 001	100	100.0 (0.0)	0.23 (0.02)	90	19.1 (7.3)
	50	92.5 (9.6)	0.23 (0.04)	100	21.3 (6.1)
	25	100.0 (0.0)	0.19 (0.04)	90	23.6 (7.7)
	12	100.0 (0.0)	0.19 (0.04)	80	31.3 (5.7)
Outfall 004	100	97.5 (5.0)	0.15 (0.02)	100	31.6 (9.2)
	50	97.5 (5.0)	0.17 (0.02)	100	32.8 (8.9)
	25	85.0 (10.0)	0.17 (0.05)	100	24.9 (2.1)
	12	85.0 (5.8)	0.20 (0.02)	90	31.7 (4.4)
Outfall 006	100	65.0 (37.9)	0.26 (0.17)	100	30.6 (4.9)
	50	97.5 (5.0)	0.16 (0.02)	100	27.6 (10.5)
	25	85.0 (17.3)	0.17 (0.03)	90	29.4 (5.6)
	12	72.5 (22.2)	0.26 (0.06)	90	29.4 (5.2)
Outfall 008	100	80.0 (14.1)	0.21 (0.07)	100	29.2 (7.9)
	50	75.0 (12.9)	0.23 (0.04)	100	25.6 (7.8)
	25	72.5 (22.2)	0.23 (0.05)	90	26.7 (6.8)
	12	87.5 (12.6)	0.21 (0.06)	100	30.4 (1.7)
Outfall 009	100	67.5 (28.7)	0.24 (0.02)	100	31.3 (3.5)
	50	60.0 (39.2)	0.30 (0.08)	100	32.2 (3.2)
	25	75.0 (31.1)	0.27 (0.05)	100	33.5 (3.0)
	12	92.5 (5.0)	0.24 (0.02)	100	33.4 (5.0)
Outfall 011	100	97.5 (5.0)	0.20 (0.03)	100	31.0 (6.5)
	50	95.0 (10.0)	0.27 (0.03)	100	29.6 (10.3)
	25	100.0 (0.0)	0.23 (0.02)	90	33.1 (5.7)
	12	100.0 (0.0)	0.22 (0.02)	100	31.0 (3.7)
BBK 12.5	100	90.0 (8.2)	0.25 (0.02)	90	32.6 (2.3)
BBK 12.5 UV[b]	100	97.5 (5.0)	0.24 (0.03)	NT[c]	NT
BBK 10.0	100	90.0 (11.5)	0.20 (0.01)	100	30.1 (8.1)

Table B.9 (continued)

Site[a]	Concentration (%)	Fathead Minnow		*Ceriodaphnia dubia*	
		Mean survival (SD) (%)	Mean growth (SD) (mg/fish)	Survival (%)	Mean offspring/surviving female (SD)
BBK 10.0 UV	100	95.0 (5.8)	0.20 (0.03)	NT	NT
BBK 9.1	100	95.0 (5.8)	0.21 (0.04)	90	29.0 (7.7)
BBK 9.1 UV	100	97.5 (5.0)	0.33 (0.02)	NT	NT
LUK 7.2	100	67.5 (35.9)	0.33 (0.04)	100	31.0 (9.8)
LUK 7.2 UV	100	97.5 (5.0)	0.28 (0.01)	NT	NT
MAK 13.8	100	65.0 (26.5)	0.36 (0.12)	100	29.2 (5.8)
MAK 13.8 UV	100	95.0 (10.0)	0.25 (0.04)	NT	NT

[a]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.
[b]Sample was exposed to ultraviolet light for 15 min.
[c]NT = not tested.

Table B.10. Summary (mean ± SD; $n = 7$) of water chemistry analyses conducted during toxicity tests of continuously flowing effluents and ambient waters at the Paducah Gaseous Diffusion Plant
Analyses conducted during May 21–28, 1992

Site[a]	Concentration (%)	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Control	100	8.1 (0.5)	65 (2.1)	80 (6)	171 (5.3)
Outfall 001	100	8.0 (0.4)	26 (2.1)	417 (166)	1169 (376)
	25	8.1 (0.1)	56 (4.8)	163 (37)	441 (110)
Outfall 004	100	7.4 (0.1)	35 (3.3)	82 (11)	287 (12)
	25	7.9 (0.1)	58 (0.7)	84 (8)	196 (3)
Outfall 006	100	9.1 (0.1)	35 (1.1)	73 (3)	236 (4)
	25	8.3 (0.1)	60 (4.0)	82 (6)	182 (2)
Outfall 008	100	7.2 (0.1)	30 (3.6)	67 (7)	260 (15)
	25	7.9 (0.1)	56 (1.1)	85 (23)	189 (4)
Outfall 009	100	7.4 (0.2)	40 (2.2)	73 (5)	223 (9)
	25	8.0 (0.1)	59 (3.6)	80 (7)	182 (2)
Outfall 011	100	7.7 (0.1)	31 (2.3)	74 (8)	240 (12)
	25	8.0 (0.1)	56 (0.7)	80 (8)	183 (3)
BBK 12.5	100	7.8 (0.2)	73 (2.6)	74 (9)	258 (5)
BBK 10.0	100	7.5 (0.6)	39 (3.7)	80 (9)	269 (13)
BBK 9.1	100	7.7 (0.6)	34 (1.2)	198 (78)	658 (248)
LUK 7.2	100	7.8 (0.7)	56 (7.4)	88 (8)	297 (14)
MAK 13.8	100	7.5 (0.1)	40 (2.2)	52 (6)	138 (6)

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

Table B.11. Results of toxicity tests of intermittently flowing effluents at the Paducah Gaseous Diffusion Plant
Tests conducted June 26, 1992–July 2, 1992

Site[a]	Concentration (%)	Fathead minnow		*Ceriodaphnia dubia*	
		Mean survival (SD) (%)	Mean growth (SD) (mg/fish)	Survival (%)	Mean offspring/surviving female (SD)
Control	100	97.5 (5.0)	0.47 (0.02)	80	31.9 (3.7)
Outfall 013	100	82.5 (17.1)	0.43 (0.03)	100	34.1 (7.9)
	50	82.5 (23.6)	0.46 (0.04)	100	32.6 (6.8)
	25	97.5 (5.0)	0.47 (0.02)	100	31.7 (7.4)
	12	95.0 (10.0)	0.43 (0.02)	80	36.9 (2.3)
Outfall 015	100	97.5 (5.0)	0.47 (0.05)	90	28.3 (6.7)
	50	100.0 (0.0)	0.42 (0.03)	100	31.1 (11.3)
	25	100.0 (0.0)	0.47 (0.04)	90	31.2 (3.2)
	12	100.0 (0.0)	0.42 (0.01)	90	32.4 (6.5)
Outfall 017	100	72.5 (15.0)	0.53 (0.03)	100	28.5 (6.6)
	50	95.0 (10.0)	0.50 (0.05)	100	27.7 (9.1)
	25	87.5 (15.0)	0.48 (0.04)	100	27.5 (8.7)
	12	97.5 (5.0)	0.45 (0.04)	100	28.6 (7.5)
Outfall 018	100	97.5 (5.0)	0.48 (0.08)	90	37.4 (8.0)
	50	92.5 (9.6)	0.47 (0.02)	100	32.6 (6.2)
	25	95.0 (10.0)	0.51 (0.03)	100	32.6 (3.8)
	12	97.5 (5.0)	0.52 (0.02)	100	33.3 (5.9)

Table B.12. Summary of water chemistry analyses conducted on June 26, 1992, in association with toxicity tests of intermittent effluents at the Paducah Gaseous Diffusion Plant

Sample source	Concentration (%)	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Outfall 013	100	7.6	81	360	704
	25	8.1	70	168	339
Outfall 015	100	7.7	79	154	314
	25	8.1	66	106	216
Outfall 017	100	7.9	115	230	466
	25	8.1	79	130	253
Outfall 018	100	7.7	63	162	337
	25	8.1	65	106	222

Table B.13. Results of toxicity tests of continuously flowing effluents and ambient samples at the Paducah Gaseous Diffusion Plant.
Tests conducted August 13–20, 1992.

Site[a]	Concentration (%)	Fathead minnow		*Ceriodaphnia dubia*	
		Mean survival (SD) (%)	Mean growth (SD) (mg/fish)	Survival (%)	Mean offspring/surviving female (SD)
Control	100	100.0 (0.0)	0.68 (0.11)	100	26.0 (6.7)
Outfall 001	100	100.0 (0.0)	0.68 (0.07)	100	32.4 (2.5)
	50	100.0 (0.0)	0.70 (0.14)	100	32.8 (3.8)
	25	90.0 (8.2)	0.67 (0.10)	100	34.9 (4.6)
	12	97.5 (5.0)	0.62 (0.03)	100	29.9 (4.5)
Outfall 004	100	97.5 (5.0)	0.59 (0.03)	0	---- (---)
	50	100.0 (0.0)	0.56 (0.11)	10	14.0 (---)
	25	97.5 (5.0)	0.58 (0.13)	100	29.9 (6.2)
	12	100.0 (0.0)	0.60 (0.11)	100	32.2 (8.2)
Outfall 006	100	100.0 (0.0)	0.61 (0.10)	100	34.3 (3.5)
	50	97.5 (5.0)	0.63 (0.09)	100	36.4 (4.0)
	25	100.0 (0.0)	0.66 (0.03)	100	35.3 (4.7)
	12	100.0 (0.0)	0.67 (0.15)	100	35.0 (4.3)
Outfall 008	100	92.5 (9.6)	0.60 (0.06)	100	26.3 (7.7)
	50	100.0 (0.0)	0.65 (0.06)	100	21.6 (10.1)
	25	97.5 (5.0)	0.65 (0.05)	90	26.4 (5.8)
	12	97.5 (5.0)	0.69 (0.09)	90	27.0 (9.7)
Outfall 009	100	100.0 (0.0)	0.65 (0.05)	100	30.8 (5.9)
	50	100.0 (0.0)	0.55 (0.08)	100	28.8 (5.5)
	25	97.5 (5.0)	0.61 (0.11)	90	24.4 (5.2)
	12	95.0 (10.0)	0.68 (0.06)	100	25.5 (5.0)
Outfall 011	100	95.0 (10.0)	0.56 (0.10)	90	25.6 (3.6)
	50	100.0 (0.0)	0.59 (0.03)	80	28.0 (8.4)
	25	100.0 (0.0)	0.63 (0.03)	100	23.6 (8.7)
	12	100 (0.0)	0.64 (0.11)	100	27.6 (4.3)
BBK 12.5	100	97.5 (5.0)	0.62 (0.07)	100	23.7 (10.1)

Table B.13 (continued)

Site[a]	Concentration (%)	Fathead minnow		*Ceriodaphnia dubia*	
		Mean survival (SD) (%)	Mean growth (SD) (mg/fish)	Survival (%)	Mean offspring/surviving female (SD)
BBK 12.5 UV[b]	100	62.5 (20.6)	0.46 (0.07)	NT[c]	NT
BBK 10.0	100	97.5 (5.0)	0.60 (0.06)	100	25.6 (7.7)
BBK 10.0 UV	100	62.5 (5.0)	0.50 (0.08)	NT	NT
BBK 9.1	100	100.0 (0.0)	0.61 (0.08)	100	32.4 (3.3)
BBK 9.1 UV	100	100.0 (0.0)	0.66 (0.05)	NT	NT
LUK 7.2	100	100.0 (0.0)	0.57 (0.10)	100	29.2 (3.6)
LUK 7.2 UV	100	97.5 (5.0)	0.61 (0.04)	NT	NT
MAK 13.8	100	92.5 (9.6)	0.55 (0.07)	100	30.8 (4.7)
MAK 13.8 UV	100	95.0 (10.0)	0.63 (0.03)	NT	NT

[a]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.
[b]UV = Ultra violet light treatment.
[c]NT = not tested.

Table B.14. Summary (mean ± SD; n = 7) of water chemistry analyses conducted during toxicity tests of continuously flowing effluents and ambient waters at the Paducah Gaseous Diffusion Plant
Analyses conducted August 13–20, 1992

Site[a]	Concentration (%)	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Control	100	8.3 (0.2)	64 (3.0)	80 (6)	176 (5.5)
Outfall 001	100	8.2 (0.7)	30 (2.0)	379 (149)	1262 (450)
	25	8.3 (0.2)	56 (0.8)	162 (39)	480 (147)
Outfall 004	100	7.5 (0.2)	31 (1.6)	64 (6)	235 (17)
	25	8.1 (0.1)	57 (1.5)	93 (37)	195 (8)
Outfall 006	100	9.0 (0.2)	35 (2.1)	65 (7)	219 (20)
	25	8.4 (0.1)	58 (1.0)	81 (6)	187 (8)
Outfall 008	100	7.4 (0.1)	26 (2.1)	57 (8)	207 (23)
	25	8.1 (0.2)	56 (0.8)	82 (9)	185 (9)
Outfall 009	100	7.7 (0.2)	42 (2.3)	68 (7)	209 (19)
	25	8.0 (0.1)	60 (1.4)	77 (6)	180 (12)
Outfall 011	100	7.6 (0.1)	28 (3.7)	59 (8)	201 (18)
	25	8.1 (0.1)	58 (4.8)	73 (8)	185 (4)
BBK 12.5	100	7.8 (0.2)	68 (1.1)	59 (6)	242 (4)
BBK 10.0	100	7.7 (0.1)	34 (2.6)	65 (9)	222 (16)
BBK 9.1	100	7.9 (0.2)	34 (1.4)	167 (67)	625 (239)
LUK 7.2	100	7.7 (0.1)	37 (2.8)	72 (5)	238 (25)
MAK 13.8	100	7.6 (0.1)	36 (0.8)	40 (5)	131 (7)

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

Table B.15. Results of toxicity tests of intermittently flowing effluents at the Paducah Gaseous Diffusion Plant

Site	Concentration (%)	Fathead minnow		*Ceriodaphnia dubia*	
		Mean survival (SD) (%)	Mean growth (SD) (mg/fish)	Survival (%)	Mean offspring/surviving female (SD)
Control	100	95.0 (5.8)	0.49 (0.04)	90	29.1 (9.7)
Outfall 013	100	87.5 (5.0)	0.49 (0.05)	100	33.9 (2.6)
	50	92.5 (5.0)	0.44 (0.04)	90	36.3 (9.8)
	25	97.5 (5.0)	0.39 (0.02)	100	43.0 (6.9)
	12	95.0 (10.0)	0.34 (0.06)	100	33.0 (9.9)
Outfall 015	100	87.5 (15.0)	0.47 (0.09)	NT[a]	---- (---)
	100 UV[b]	90.0 (8.2)	0.47 (0.07)	NT	---- (---)
	50	90.0 (8.2)	0.44 (0.01)	90	32.4 (11.7)
	25	90.0 (20.0)	0.47 (0.08)	100	41.4 (6.0)
	12	95.0 (5.8)	0.51 (0.07)	100	36.4 (12.1)
Outfall 016	100	92.5 (9.6)	0.54 (0.09)	100	38.9 (8.5)
	50	72.5 (5.0)	0.45 (0.03)	100	32.8 (5.5)
	25	97.5 (5.0)	0.44 (0.05)	100	35.1 (12.1)
	12	90.0 (8.2)	0.42 (0.02)	100	36.4 (11.2)
Outfall 017	100	55.0 (12.9)	0.53 (0.13)	100	38.8 (3.6)
	50	57.5 (15.0)	0.61 (0.04)	100	39.0 (10.7)
	25	62.5 (32.0)	0.59 (0.09)	80	32.5 (5.6)
	12	72.5 (35.9)	0.57 (0.09)	100	39.8 (6.8)
Outfall 018	100	92.5 (5.0)	0.54 (0.05)	100	36.8 (5.3)
	50	90.0 (14.1)	0.46 (0.05)	100	38.1 (4.5)
	25	92.5 (5.0)	0.54 (0.02)	100	35.9 (3.8)
	12	90.0 (8.2)	0.58 (0.07)	100	35.7 (6.1)

[a]NT = not tested.
[b]Sample was exposed to ultraviolet light for 15 min.
Note: Tests conducted September 22–29, 1992 (fathead minnows) and September 29–October 6, 1992 (*Ceriodaphnia*).

Table B.16. Summary of water chemistry analyses conducted on September 22, 1992, in association with toxicity tests of intermittent effluents at the Paducah Gaseous Diffusion Plant

Sample	Concentration (%)	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Outfall 013	100	7.51	63	186	365
	25	7.99	66	110	226
Outfall 015	100	7.70	95	144	314
	25	8.08	75	98	212
Outfall 016	100	7.83	119	146	280
	25	8.04	82	100	201
Outfall 017	100	8.09	142	216	401
	25	8.23	84	118	226
Outfall 018	100	7.94	79	144	287
	25	8.16	71	102	202

Table B.17. Results of toxicity tests of continuously flowing effluents and ambient samples at the Paducah Gaseous Diffusion Plant
Tests conducted October 22–29, 1992

Site[a]	Concentration (%)	Fathead minnow		*Ceriodaphnia dubia*	
		Mean survival (SD) (%)	Mean growth (SD) (mg/fish)	Survival (%)	Mean offspring/surviving female (SD)
Control	100	100.0 (0.0)	0.47 (0.02)	90	26.6 (8.3)
Outfall 001	100	97.5 (5.0)	0.63 (0.03)	100	25.7 (9.9)
	50	97.5 (5.0)	0.51 (0.06)	100	32.1 (6.8)
	25	97.5 (5.0)	0.55 (0.03)	80	23.0 (10.0)
	12	92.5 (5.0)	0.56 (0.05)	100	28.8 (5.2)
Outfall 004	100	100.0 (0.0)	0.48 (0.02)	90	31.3 (5.6)
	50	100.0 (0.0)	0.51 (0.03)	100	27.4 (8.2)
	25	100.0 (0.0)	0.48 (0.04)	100	28.3 (6.1)
	12	97.5 (5.0)	0.44 (0.08)	100	29.2 (8.6)
Outfall 006	100	95.0 (10.0)	0.47 (0.05)	100	29.4 (8.1)
	50	100.0 (0.0)	0.62 (0.03)	100	29.3 (10.9)
	25	97.5 (5.0)	0.57 (0.02)	100	31.0 (7.6)
	12	100.0 (0.0)	0.53 (0.05)	100	19.3 (7.8)
Outfall 008	100	97.5 (5.0)	0.45 (0.07)	100	21.2 (9.3)
	50	100.0 (0.0)	0.52 (0.07)	100	23.5 (8.6)
	25	92.5 (9.6)	0.49 (0.07)	100	21.6 (9.5)
	12	100.0 (0.0)	0.49 (0.04)	100	29.8 (5.1)
Outfall 009	100	82.5 (9.6)	0.47 (0.08)	100	20.6 (13.2)
	50	70.0 (25.8)	0.50 (0.05)	100	24.9 (7.3)
	25	82.5 (28.7)	0.55 (0.07)	100	30.4 (8.0)
	12	95.0 (5.8)	0.53 (0.08)	100	28.5 (8.6)
Outfall 011	100	90.0 (14.1)	0.45 (0.04)	100	31.1 (7.1)
	50	97.5 (5.0)	0.49 (0.02)	100	27.6 (7.4)
	25	95.0 (5.8)	0.54 (0.09)	90	34.5 (4.3)
	12	90.0 (8.2)	0.51 (0.05)	100	27.2 (6.7)
BBK 12.5	100	68.8 (15.8)	0.37 (0.09)	100	28.8 (6.1)
BBK 12.5 UV[b]	100	90.0 (0.00	0.46 (0.03)	NT[c]	NT
BBK 10.0	100	65.5 (4.1)	0.50 (0.03)	100	28.7 (7.6)

Table B.17. (continued)

Site[a]	Concentration (%)	Fathead minnow: Mean survival (SD) (%)	Fathead minnow: Mean growth (SD) (mg/fish)	*Ceriodaphnia dubia*: Survival (%)	*Ceriodaphnia dubia*: Mean offspring/surviving female (SD)
BBK 10.0	100	65.5 (4.1)	0.50 (0.03)	100	28.7 (7.6)
BBK 10.0 UV	100	85.4 (9.2)	0.52 (0.06)	NT	NT
BBK 9.5	100	85.4 (9.2)	0.54 (0.08)	90	32.7 (6.9)
BBK 9.5 UV	100	90.0 (0.0)	0.53 (0.04)	NT	NT
LUK 7.2	100	80.0 (10.6)	0.42 (0.05)	100	30.6 (5.2)
LUK 7.2 UV	100	90.0 (0.0)	0.47 (0.06)	NT	NT
MAK 13.8	100	76.7 (15.3)	0.41 (0.02)	100	24.0 (6.4)
MAK 13.8 UV	100	80.8 (10.6)	0.45 (0.02)	NT	NT

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

[b]Sample was exposed to ultraviolet light for 15 min.

[c]NT = not tested.

Table B.18. Summary (mean ± SD; n = 7) of water chemistry analyses conducted during toxicity tests of continuously flowing effluents and ambient waters at the Paducah Gaseous Diffusion Plant
Analyses conducted October 22–29, 1992

Site[a]	Concentration (%)	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Control	100	8.1 (0.5)	65 (2.1)	80 (6)	171 (5.3)
Outfall 001	100	8.1 (0.2)	24 (1.0)	552 (70)	1782 (95)
	25	8.1 (0.1)	55 (3.2)	217 (9)	640 (31)
Outfall 004	100	7.5 (0.1)	37 (3.0)	80 (11)	297 (38)
	25	8.0 (0.1)	59 (2.2)	83 (7)	212 (10)
Outfall 006	100	8.6 (0.2)	36 (2.6)	78 (10)	208 (7)
	25	8.2 (0.1)	62 (8.6)	85 (9)	188 (4)
Outfall 008	100	7.4 (0.1)	27 (2.1)	74 (12)	251 (22)
	25	7.9 (0.1)	57 (1.1)	85 (7)	198 (9)
Outfall 009	100	7.8 (0.1)	57 (12.1)	88 (19)	259 (25)
	25	8.0 (0.1)	64 (3.4)	86 (7)	200 (7)
Outfall 011	100	8.0 (0.3)	30 (1.5)	75 (15)	218 (20)
	25	8.1 (0.1)	57 (2.4)	82 (6)	191 (5)
BBK 12.5	100	7.5 (0.3)	53 (11.7)	74 (9)	229 (23)
BBK 10.0	100	7.3 (0.2)	34 (1.4)	78 (6)	257 (17)
BBK 9.5	100	7.5 (0.1)	32 (1.5)	261 (36)	893 (173)
LUK 7.2	100	7.5 (0.2)	43 (1.5)	75 (6)	259 (16)
MAK 13.8	100	7.3 (0.1)	36 (1.6)	49 (6)	138 (2)

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

Table B.19. Results of toxicity tests of intermittently flowing effluents at the Paducah Gaseous Diffusion Plant
Tests conducted November 13–20, 1992

Sample	Concentration (%)	Fathead minnow: Mean survival (SD) (%)	Fathead minnow: Mean growth (SD) (mg/fish)	*Ceriodaphnia dubia*: Survival (%)	*Ceriodaphnia dubia*: Mean offspring/surviving female (SD)
Control	100	95.0 (5.8)	0.40 (0.04)	100	31.6 (5.7)
Outfall 013	100	42.5 (26.3)	0.42 (0.25)	100	34.7 (6.6)
	50	77.5 (33.0)	0.45 (0.12)	100	35.4 (5.2)
	25	90.0 (0.0)	0.44 (0.05)	100	30.7 (7.2)
	12	82.5 (15.0)	0.53 (0.08)	90	30.9 (5.6)
Control	100	NT[a]	NT	100	26.9 (4.1)
Outfall 015	100	92.5 (5.0)	0.36 (0.04)	100	32.7 (5.6)
	50	100.0 (0.0)	0.42 (0.11)	100	32.5 (4.0)
	25	90.0 (8.2)	0.43 (0.06)	100	31.1 (4.4)
	12	95.0 (5.8)	0.40 (0.06)	100	30.8 (4.6)
Control	100	NT	NT	100	31.5 (3.7)
Outfall 016	100	75.0 (20.8)	0.37 (0.04)	90	31.6 (5.9)
	50	95.0 (10.0)	0.43 (0.06)	100	35.7 (4.1)
	25	82.5 (17.1)	0.42 (0.10)	100	34.9 (3.6)
	12	97.5 (5.0)	0.43 (0.01)	100	32.8 (6.4)
Control	100	NT	NT	100	33.6 (6.4)
Outfall 017	100	85.0 (12.9)	0.49 (0.03)	100	33.8 (2.6)
	50	92.5 (9.6)	0.49 (0.09)	80	32.1 (5.1)
	25	87.5 (12.6)	0.54 (0.05)	100	33.3 (7.0)
	12	97.5 (5.0)	0.39 (0.12)	100	31.1 (6.4)
Control	100	NT	NT	80	34.4 (2.5)
Outfall 018	100	72.5 (22.2)	0.34 (0.08)	100	34.3 (5.0)
	50	100.0 (0.0)	0.36 (0.07)	90	31.3 (5.8)
	25	100.0 (0.0)	0.39 (0.05)	90	31.9 (6.4)
	12	97.5 (5.0)	0.45 (0.06)	90	33.9 (5.6)

[a]NT = not tested.

Table B.20. Summary of water chemistry analyses conducted November 13–20, 1992, in association with toxicity tests of intermittent effluents at the Paducah Gaseous Diffusion Plant

Sample	Concentration (%)	pH	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Conductivity (μS/cm)
Outfall 013	100	7.10	28	42	84
	25	7.25	56	76	151
Outfall 015	100	7.48	52	76	153
	25	6.97	67	86	176
Outfall 016	100	7.62	60	72	138
	25	7.95	63	80	159
Outfall 017	100	7.78	70	92	175
	25	6.98	71	86	179
Outfall 018	100	7.23	36	52	98
	25	6.78	62	84	158

Appendix C

CONCENTRATIONS OF CONTAMINANTS IN INDIVIDUAL FISH AND QUALITY ASSURANCE SUMMARY FOR PCB ANALYSES

Table C.1. Concentrations of mercury and PCBs in individual longear sunfish collected from Big Bayou and Little Bayou creeks near the Paducah Gaseous Diffusion Plant
Concentrations in micrograms per gram unless otherwise stated

Site[a]	Type[b]	Date	Spp[c]	Sex[d]	Tag no.[e]	Weight[f]	Length[g]	Hg[h]	ΣPCB[i]	1248[j]	1254[k]	1260[l]	Lipid[m]
BBK 12.5	C	04/06/92	LNGEAR	M	3690	58.0	14.0	0.23	0.04	<0.01	0.04	<0.01	0.99
BBK 12.5	C	04/06/92	LNGEAR	M	3691	80.9	15.0	0.17	0.03	<0.01	0.03	<0.01	0.66
BBK 12.5	C	04/06/92	LNGEAR	M	3692	36.2	12.1	0.24	<0.02	<0.02	<0.02	<0.02	0.75
BBK 12.5	C	04/06/92	LNGEAR	M	3693	75.2	15.4	0.32	<0.02	<0.02	<0.02	<0.02	0.45
BBK 12.5	C	04/06/92	LNGEAR	M	3694	41.7	12.6	0.16	<0.03	<0.03	<0.03	<0.03	1.08
BBK 12.5	C	04/06/92	LNGEAR	M	3695	51.6	13.7	0.17	<0.02	<0.02	<0.02	<0.02	0.55
BBK 12.5	C	04/06/92	LNGEAR	M	3697	70.7	15.7	0.23	<0.02	<0.02	<0.02	<0.02	0.21
BBK 12.5	C	04/06/92	LNGEAR	M	3699	42.4	13.0	0.19	<0.02	<0.02	<0.02	<0.02	0.46
BBK 10.0	R	04/06/92	LNGEAR	M	3640	42.4	13.0	0.46	<0.02	<0.02	<0.02	<0.02	0.29
BBK 10.0	R	04/06/92	LNGEAR	M	3641	53.7	14.3	0.52	0.04	<0.02	<0.02	0.04	0.28
BBK 10.0	R	04/06/92	LNGEAR	M	3542	43.1	12.8	0.47	0.14	<0.02	<0.02	0.14	0.74
BBK 10.0	R	04/06/92	LNGEAR	M	3642	62.9	13.6	0.26	0.12	<0.02	0.12	<0.02	1.00
BBK 10.0	R	04/06/92	LNGEAR	M	3644	52.2	14.4	0.41	<0.02	<0.02	<0.02	<0.02	0.44
BBK 10.0	R	04/06/92	LNGEAR	M	3646	52.8	13.5	0.52	0.18	<0.02	<0.02	0.18	0.25
BBK 10.0	R	04/06/92	LNGEAR	M	3647	55.6	14.5	0.54	0.07	<0.02	<0.02	0.07	0.38
BBK 10.0	R	04/06/92	LNGEAR	M	3648	40.6	12.8	0.44	0.08	<0.02	<0.02	0.08	0.57
BBK 9.1	R	04/06/92	LNGEAR	M	3620	57.8	13.7	0.37	0.25	<0.02	0.07	0.18	0.82
BBK 9.1	R	04/06/92	LNGEAR	M	3621	69.9	14.2	0.27	0.24	0.01	0.08	0.16	1.23
BBK 9.1	R	04/06/92	LNGEAR	M	3622	61.3	14.5	0.40	0.15	<0.03	<0.03	0.15	0.43
BBK 9.1	R	04/06/92	LNGEAR	M	3623	59.0	13.8	0.27	0.53	<0.02	0.31	0.22	0.91
BBK 9.1	R	04/06/92	LNGEAR	M	3624	60.4	13.5	0.23	0.27	<0.02	0.08	0.19	0.67
BBK 9.1	R	04/06/92	LNGEAR	M	3625	56.9	14.5	0.36	0.16	<0.02	0.06	0.10	1.21
BBK 9.1	R	04/06/92	LNGEAR	M	3626	55.0	14.5	0.59	0.08	<0.02	<0.02	0.08	0.32
BBK 9.1	R	04/06/92	LNGEAR	M	3627	51.6	13.3	0.29	0.12	<0.02	0.04	0.08	0.43
BBK 2.8	R	04/06/92	LNGEAR	M	3650	46.8	13.0	0.24	<0.03	<0.03	<0.03	<0.03	0.88
BBK 2.8	R	04/06/92	LNGEAR	M	3651	65.4	14.9	0.37	<0.02	<0.02	<0.02	<0.02	0.30
BBK 2.8	R	04/06/92	LNGEAR	M	3652	64.1	14.0	0.26	<0.02	<0.02	<0.02	<0.02	0.30
BBK 2.8	R	04/06/92	LNGEAR	M	3653	55.5	13.2	0.37	0.06	<0.03	<0.03	0.06	1.06
BBK 2.8	R	04/06/92	LNGEAR	M	3654	62.2	14.1	0.28	<0.03	<0.03	<0.03	<0.03	0.64
BBK 2.8	R	04/06/92	LNGEAR	M	3655	52.2	13.5	0.27	0.06	<0.02	<0.02	0.06	2.01
BBK 2.8	R	04/06/92	LNGEAR	M	3656	70.9	15.6	0.51	0.06	<0.02	<0.02	0.06	1.33
BBK 2.8	R	04/06/92	LNGEAR	M	3657	54.8	14.8	0.70	0.05	<0.03	<0.03	0.05	0.44

Table C.1 (continued)

Site[a]	Type[b]	Date	Spp[c]	Sex[d]	Tag no.[e]	Weight[f]	Length[g]	Hg[h]	ΣPCB[i]	1248[j]	1254[k]	1260[l]	Lipid[m]
LUK 9.0	R	04/07/92	LNGEAR	M	3631	36.1	12.8	.	0.35	<0.03	0.16	0.19	0.16
LUK 9.0	R	04/07/92	LNGEAR	M	3632	32.5	11.7	.	0.94	<0.03	0.26	0.68	0.40
LUK 9.0	R	04/07/92	LNGEAR	M	3633	36.8	12.3	.	0.53	<0.02	0.15	0.38	0.32
LUK 9.0	R	04/07/92	LNGEAR	M	3634	31.6	11.9	.	0.78	<0.04	0.20	0.58	0.34
LUK 9.0	R	04/07/92	LNGEAR	M	3635	36.8	12.2	.	0.23	<0.03	0.09	0.14	0.27
LUK 9.0	R	04/07/92	LNGEAR	M	3636	30.4	11.5	.	0.55	<0.03	0.27	0.28	0.58
LUK 9.0	R	04/07/92	LNGEAR	M	3637	35.1	12.0	.	0.10	<0.03	<0.03	0.10	0.12
LUK 9.0	R	04/07/92	LNGEAR	M	3638	39.0	12.5	.	0.22	<0.03	0.09	0.13	0.27
LUK 7.2	R	04/07/92	LNGEAR	M	3663	61.6	14.5	0.08	.	.	.	.	.
LUK 7.2	R	04/07/92	LNGEAR	M	3665	39.2	12.5	0.08	.	.	.	.	.
LUK 7.2	R	04/07/92	LNGEAR	M	3666	32.0	11.8	0.56	.	.	.	.	.
LUK 7.2	R	04/07/92	LNGEAR	M	3668	28.3	11.2	0.56	.	.	.	.	.
LUK 4.3	R	04/06/92	LNGEAR	M	3670	37.7	12.6	.	0.09	<0.03	<0.03	0.09	0.21
LUK 4.3	R	04/06/92	LNGEAR	M	3671	40.3	12.5	.	0.07	<0.03	<0.03	0.07	0.05
LUK 4.3	R	04/06/92	LNGEAR	M	3672	42.0	12.9	.	0.06	<0.03	<0.03	0.06	0.02
LUK 4.3	R	04/06/92	LNGEAR	M	3673	46.5	13.0	.	0.08	<0.02	<0.02	0.08	0.05
LUK 4.3	R	04/06/92	LNGEAR	M	3674	45.0	12.5	.	0.09	<0.02	<0.02	0.09	0.06
LUK 4.3	R	04/06/92	LNGEAR	M	3675	50.0	14.2	.	0.09	<0.02	<0.02	0.09	0.01
LUK 4.3	R	04/06/92	LNGEAR	M	3676	41.2	13.0	.	0.05	<0.03	<0.03	0.05	0.02
LUK 4.3	R	04/06/92	LNGEAR	M	3677	36.8	11.4	.	0.07	<0.03	<0.03	0.07	0.03
MAK 13.8	C	04/07/92	LNGEAR	M	3610	67.7	14.8	0.33	.	.	.	.	
MAK 13.8	C	04/07/92	LNGEAR	M	3611	84.5	15.2	0.29	.	.	.	.	
MAK 13.8	C	04/07/92	LNGEAR	M	3612	53.5	14.0	0.22	.	.	.	.	
MAK 13.8	C	04/07/92	LNGEAR	M	3613	45.2	13.5	0.18	.	.	.	.	
MAK 13.8	C	04/07/92	LNGEAR	M	3614	47.5	13.6	0.24	.	.	.	.	
MAK 13.8	C	04/07/92	LNGEAR	M	3615	54.2	13.0	0.20	.	.	.	.	
MAK 13.8	C	04/07/92	LNGEAR	M	3616	62.9	14.1	0.12	.	.	.	.	
MAK 13.8	C	04/07/92	LNGEAR	M	3617	40.6	12.5	0.24	.	.	.	.	
HINDSCR	C	04/15/92	REDBRE	M	33680	126.2	17.9	0.07	<0.03	<0.03	<0.03	<0.03	0.16
HINDSCR	C	04/15/92	REDBRE	F	3681	66.66	15.2	0.11	<0.03	<0.03	<0.03	<0.03	0.21
HINDSCR	C	04/15/92	REDBRE	M	3682	40.0	13.5	0.04	<0.04	<0.04	<0.04	<0.04	0.78
HINDSCR	C	04/15/92	REDBRE	F	3683	36.4	12.8	.	<0.03	<0.03	<0.03	<0.03	0.39
HINDSCR	C	04/15/92	REDBRE	F	3684	50.8	13.9	0.12	<0.03	<0.03	<0.03	<0.03	0.01

Table C.1 (continued)

Site[a]	Type[b]	Date	Spp[c]	Sex[d]	Tag no.[e]	Weight[f]	Length[g]	Hg[h]	ΣPCB[i]	1248[j]	1254[k]	1260[l]	Lipid[m]
HINDSCR	C	04/15/92	REDBRE	F	3685	36.9	12.5	0.07	<0.02	<0.02	<0.02	<0.02	0.03
HINDSCR	C	04/15/92	REDBRE	F	3686	47.7	14.8	0.10	.	.	.	.	.
BBK 12.5	D	04/06/92	LNGEAR	M	3693	75.2	15.4	0.32	.	.	.	.	.
BBK 12.5	D	04/06/92	LNGEAR	M	3691	80.9	15.0	.	<0.02	<0.02	<0.02	<0.02	
BBK 10.0	D	04/06/92	LNGEAR	M	3644	52.2	14.4	0.43	.	.	.	.	
BBK 10.0	D	04/06/92	LNGEAR	M	3641	53.7	14.3	.	0.07	<0.02	<0.02	0.07	
BBK 9.1	D	04/06/92	LNGEAR	M	3622	61.3	14.5	0.39	0.09	<0.03	<0.03	0.09	
BBK 2.8	D	04/06/92	LNGEAR	M	3656	70.9	15.6	.	<0.03	<0.03	<0.03	<0.03	
BBK 2.8	D	04/06/92	LNGEAR	M	3654	62.2	14.1	0.30	.	.	.	.	
LUK 9.0	D	04/07/92	LNGEAR	M	3637	35.1	12.0	.	0.43	<0.03	0.15	0.28	
LUK 4.3	D	04/06/92	LNGEAR	M	3673	46.5	13.0	.	0.08	<0.02	<0.02	0.08	

[a]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer; HINDSCR = Hinds Creek.
[b]R = regular; C = reference site; D = duplicate.
[c]Spp = species, LNGEAR = Longear sunfish, *Lepomis megalotus*; REDBRE = redbreast sunfish, *Lepomis auritus*.
[d]Sex: M = male; F = female.
[e]Fish identification tag number.
[f]Weight in grams.
[g]Length = total length, in centimeters.
[h]Hg = total mercury concentration, micrograms per gram wet wt.
[i]ΣPCB = sum of PCBs quantified as specific Aroclor mixtures, micrograms per gram wet wt
[j]1248 = PCBs quantified as similar to Aroclor 1248, micrograms per gram wet wt.
[k]1254 = PCBs quantified as similar to Aroclor 1254, micrograms per gram wet wt.
[l]1260 = PCBs quantified as similar to Aroclor 1260, micrograms per gram wet wt.
[m]Lipid = Lipid content of fish fillet, percentage wet weight.

Table C.2. Concentrations of metals (in micrograms per gram wet wt) in longear sunfish from Little Bayou and Big Bayou creeks, April 1992

Site[a]	Date	Spp[b]	Tag No.	Sex	Wgt (g)	Lgth (cm)	Ag	As	Be	Cd	Cr	Cu	Ni	Pb	Sb	Se	Ti	U	Zn
LUK 7.2	4/7/92	LNGEAR	3663	M	61.6	14.5	<0.1	<0.05	<0.003	<0.1	<0.10	0.24	<0.10	<0.1	<0.1	0.48	<0.02	0.022	11.7
	4/7/92	LNGEAR	3665	M	39.2	12.5	<0.1	<0.05	<0.003	<0.1	<0.10	0.20	<0.10	<0.1	<0.1	0.48	<0.02	0.005	9.4
	4/7/92	LNGEAR	3666	M	32.0	11.8	<0.1	<0.05	<0.003	<0.1	0.46	0.21	<0.10	<0.1	<0.1	0.44	<0.02	<0.003	8.8
	4/7/92	LNGEAR	3668	M	28.3	11.2	<0.1	<0.05	<0.003	<0.1	0.20	0.14	0.16	<0.1	<0.1	0.46	<0.02	0.005	7.1
BBK 9.1	4/6/92	LNGEAR	3029	M	50.9	13.2	<0.1	<0.05	<0.003	<0.1	0.12	0.29	<0.10	<0.1	<0.1	0.62	<0.02	<0.003	13.4
	4/6/92	LNGEAR	3263	M	51.9	14.0	<0.1	<0.05	<0.003	<0.1	0.10	0.27	<0.10	<0.1	<0.1	0.61	<0.02	0.003	15.1
	4/6/92	LNGEAR	3609	M	40.8	13.8	<0.1	<0.05	<0.003	<0.1	0.10	0.20	<0.10	<0.1	<0.1	0.68	<0.02	<0.003	11.1
	4/6/92	LNGEAR	3629	M	61.9	14.0	<0.1	<0.05	<0.003	<0.1	0.10	0.20	<0.10	<0.1	<0.1	0.65	<0.02	<0.003	14.5
HINDSCR	4/15/92	BLUGIL	3689	M	28.5	11.8	<0.1	<0.05	<0.003	<0.1	<0.21	0.13	<0.10	<0.1	<0.1	0.12	<0.02	<0.003	5.9
	4/15/92	BLUGIL	3619	M	27.4	10.5	<0.1	<0.05	0.004	<0.1	<0.10	0.16	<0.10	<0.1	<0.1	0.39	<0.02	<0.003	6.3

[a]LUK = Little Bayou Creek kilometer; BBK = Big Bayou Creek kilometer; HINDSCR = Hinds Creek.
[b]Spp = species, LNGEAR = Longear sunfish; *Lepomis megalotus*; BLUGIL = Bluegill sunfish, *Lepomis macrochirus*.

Table C.3. Concentrations of chlorinated pesticides (in micrograms per gram wet wt) in longear sunfish from Big Bayou Creek and Little Bayou Creek, April 1992

Site[a]	Date	Spp[b]	Tag No.	Sex	Wgt (g)	Lgth (cm)	Dieldrin	DDE	Endosulfan I	Endosulfan II	Heptachlor epoxide	Alpha chlordane	Gamma chlordane	Methoxychlor	PCB 1248[c]	PCB 1254[d]	PCB 1260[e]
BBK9.1	4/6/92	LNGEAR	3028	M	48.2	13.4	ND	ND	ND	0.006	ND	0.009	0.005	ND	0.69	ND	0.25
BBK9.1	4/6/92	LNGEAR	3264	M	64.5	13.8	ND	ND	ND	0.006	0.01	ND	ND	ND	ND	0.35	0.37
BBK9.1	4/6/92	LNGEAR	3609	M	40.8	13.8	ND	ND	ND	ND	ND	ND	0.003	ND	ND	ND	0.09
BBK9.1	4/6/92	LNGEAR	3628	M	48.2	13.4	ND	ND	ND	0.003	ND	ND	0.005	ND	ND	ND	0.11
LUK7.2	4/7/92	LNGEAR	3662	M	40.1	12.5	ND	ND	ND	0.006	ND	ND	0.009	0.031	ND	ND	0.16
LUK7.2	4/7/92	LNGEAR	3664	M	43.5	12.4	ND	ND	ND	0.006	ND	ND	0.009	0.022	ND	0.1	0.12
LUK7.2	4/7/92	LNGEAR	3667	M	30.4	11.5	0.009	0.008	0.013	0.007	0.025	ND	0.014	ND	ND	0.3	0.21
LUK7.2	4/7/92	LNGEAR	3669	M	31.0	11.2	ND	0.008	0.013	0.007	0.027	ND	0.015	ND	ND	0.13	0.12
HNDSCR	4/15/92	BLUGIL	3687	M	57.4	14.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HNDSCR	4/15/92	BLUGIL	3253	F	36.5	12.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; HINDSCR = Hinds Creek.
[b]Spp = species, LNGEAR = Longear sunfish; *Lepomis megalotus*; BLUGIL = Bluegill sunfish, *Lepomis macrochirus*.
[c]1248 = PCBs quantified as similar to Aroclor 1248, micrograms per gram wet wt.
[d]1254 = PCBs quantified as similar to Aroclor 1254, micrograms per gram wet wt.
[e]1260 = PCBs quantified as similar to Aroclor 1260, micrograms per gram wet wt.

Note: Detection limit for a 5-g sample estimated as 10% of quantitation limit. Reported estimated concentrations may be lower in some cases (see below).

Compound	Detection Limit µg/g wet wt	Compound	Detection Limit µg/g wet wt	Compound	Detection Limit µg/g wet wt
ALPHA-BHC	0.005	DDE	0.01	GAMMA CHLORDANE	0.05
BETA-BHC	0.005	ENDRN	0.01	TOXAPHENE	0.1
DELTA-BHC	0.005	ENDOSULFAN II	0.01	PCB-1016	0.05
GAMMA-BHC	0.005	DDD	0.01	PCB-1221	0.05
HEPTACHLOR	0.005	ENDOSULFAN		PCB-1232	0.05
ALDRIN	0.005	SULFATE		PCB-1242	0.05
HEPTACHLOR	0.005	DDT	0.01	PCB-1248	0.05
EXPOXIDE	0.005	METHOXYCHLOR	0.05	PBC-1254	0.1
ENDOSULFAN I	0.01	ENDRIN KETONE	0.01	PCB-1260	0.1
DIELDRIN	0.01	ALPHA CHLORDANE	0.05		

C.1 QUALITY ASSURANCE SUMMARY FOR PCB ANALYSES

Results of analyses of uncontaminated fish that were spiked with known concentrations of PCB standards were more variable and average a lower percentage of recoveries than desired. Matrix spike recoveries averaged (±SD) 53 ± 24 % (n = 8). Recoveries of decachlorobiphenyl (DCBP) internal recovery standards added to each sample prior to extraction were substantially better, averaging 82 ± 22 % (n = 89). The mean absolute difference between duplicate samples was small, 0.10 ± 0.11 µg/g (n=8), in part because of the low concentrations of PCBs found in most samples. The mean coefficient of variation among duplicates was 36%. PCBs were not found in fish from uncontaminated reference sites (mean concentration <0.04 µg/g, n=8).

Overall, the PCB results display a pattern expected from previous studies at Big Bayou and Little Bayou creeks and would not lead to any conclusions different from those made previously. Because of the need to use the sunfish data to detect temporal trends (hopefully demonstrating a PCB-decrease in response to successful remedial actions), and the uncertainty associated with low matrix spike recoveries, archived fish tissues from key sites (LUK 9.0 and BBK 9.1) will be reanalyzed for PCBs. If reanalysis yields substantially higher concentrations than the initial analyses, and higher matrix spike recoveries continue, all remaining archived sunfish samples will reanalyzed.

In pesticide screening studies, matrix spike recoveries were 125% for Aroclor 1260, 47% for alpha chlordane, and 75 % for gamma chlordane. DCBP internal standard recoveries averaged 68 ± 6%, n=10.

Analyses of standard reference mercury-contaminated fish yielded results close to the published true value of 2.52 µg/g, averaging 2.68 ± 0.08 µg/g (n = 12). Mean absolute difference between duplicate samples was very small, 0.01 ± 0.01 µg/g (n = 4), with a mean coefficient of variation of 4%. Analyses of reference site samples averaged 0.09 ± 0.03, (n = 6), a value typical of the long term average at the Hinds Creek reference site. In screening analyses, recoveries of matrix spike additions of metals to reference site fish all approximated 100%, ranging from a low of 95% for silver to a high of 115% for selenium.

Appendix D

FISH SENSITIVITY, DENSITY, BIOMASS, AND LENGTH-FREQUENCY DATA COLLECTED FROM BIG BAYOU CREEK, LITTLE BAYOU CREEK, AND MASSAC CREEK DURING SEPTEMBER 1991 AND MARCH 1992

Table D.1. Species identified as tolerant or sensitive to water quality and habitat degradation in the Big Bayou Creek, Little Bayou Creek and Massac Creek drainages

Tolerant[a]

Red shiner (*Cyprinella lutrensis*)
Spotfin shiner (*Cyprinella spiloptera*)
Fathead minnow (*Pimephales promelas*)
Creek chub (*Semotilus atromaculatus*)
White sucker (*Catostomus commersoni*)
Black bullhead (*Ameiurus melas*)
Yellow bullhead (*Ameiurus natalis*)
Green sunfish (*Lepomis cyanellus*)

Sensitive

Steelcolor shiner (*Cyprinella whipplei*)
Ribbon shiner (*Lythrurus fumeus*)
Sand shiner (*Notropis strammineus*)
Spotted sucker (*Minytrema melanops*)
Black redhorse (*Moxostoma duquesnei*)
Golden redhorse (*Moxostoma erythrurum*)
Tadpole madtom (*Noturus gyrinus*)
Freckled madtom (*Noturus nocturnus*)
Logperch (*Percina caprodes*)
Blackside darter (*Percina maculata*)
Bluntnose darter (*Etheostoma chlorosomum*)

[a]Tolerant and sensitive species were tentatively identified for the Paducah area using collection records and text discussions in the following texts:

Becker, G. C. 1983. *Fishes of Wisconsin*. University of Wisconsin Press, Madison, Wisconsin.

Burr, B. M. and M. L. Warren. 1986. *A Distributional Atlas of Kentucky Fishes*. Kentucky Nature Preserves Commission, Scientific and Technical Series Number 4.

Cross, F. B. and J. T. Collins. 1975. *Fishes in Kansas*. The University of Kansas Museum of Natural History and State Biological Survey, Lawrence, Kansas.

Etnier, D. A. 1987. *Keys to the Fishes of Tennessee*. Unpublished memo. Department of Zoology, The University of Tennessee, Knoxville, Tenn.

Karr, J. R. et al. 1986. *Assessing Biological Integrity in Running Waters—A Method and its Rationale*. Illinois Natural History Survey Special Publication 5.

Lee, D. S. et al. 1980. *Atlas of North American Freshwater Fishes*. North Carolina Biological Survey Publication 1980-12. North Carolina State Museum of Natural History.

Ohio EPA (Environmental Protection Agency). 1987. *Standardized Biological Field Sampling and Laboratory Methods for Assessing Fish and Microinvertebrate Protection Agency, Division for the Protection of Aquatic Life, Vol. III)*, Ohio Environmental Protection Agency, Division of Water Quality Monitoring and Assessment, Columbus, Ohio.

Ohio EPA. 1988. *Users Manual for Biological Field Assessment of Ohio Surface Streams, (Biological Criteria for the Protection of Aquatic Life, Vol. II)*, Ohio Environmental Protection Agency, Division of Water Quality Monitoring and Assessment, Columbus, Ohio.

Pflieger, W. L. 1975. *The Fishes of Missouri*, Missouri Department of Conservation, Western Publishing Co.

Robison, H. W. and T. M. Buchanan. 1988. *Fishes of Arkansas*. University of Arkansas Press.

Smith, J. G. 1979. *The Fishes of Illinois*. University of Illinois Press, Urbana, Illinois.

Trautman, M. B. 1981. *The Fishes of Ohio*. Ohio State University Press, Columbus, Ohio.

Table D.2. Fish densities (number per square meter) in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, September 1991

Species[b]	Sites[a]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Bowfin	<0.01	-	-	-	-
Stoneroller	1.53	3.81	0.41	0.41	0.06
Red shiner	0.01	-	0.25	0.08	0.01
Steelcolor shiner[c]	0.02	-	-	-	0.14
Ribbon shiner[c]	-	-	<0.01	-	0.01
Redfin shiner[c]	0.01	-	0.01	0.02	0.38
Suckermouth minnow	0.04	-	-	0.08	-
Bluntnose minnow	-	-	0.63	0.38	1.66
Fathead minnow	-	0.01	0.01	-	-
Creek chub	0.17	0.16	0.41	0.31	0.04
White sucker	-	-	0.01	-	<0.01
Creek chubsucker	<0.01	0.01	0.01	-	0.02
Spotted sucker	0.04	-	-	-	-
Black redhorse	-	-	-	-	0.01
Golden redhorse	<0.01	-	-	-	0.01
Black bullhead	<0.01	-	<0.01	-	-
Yellow bullhead	0.02	0.05	0.15	0.06	0.01
Pirate perch	-	-	-	0.01	0.01
Blackspotted topminnow	0.13	0.66	1.02	0.40	0.46
Western mosquitofish	0.04	0.15	-	0.32	<0.01
Flier	-	-	-	<0.01	-
Green sunfish	0.03	0.17	0.32	0.17	0.06
Warmouth	-	0.01	0.01	-	-
Bluegill	0.04	0.09	0.10	-	0.03
Longear sunfish	0.44	0.99	0.97	0.14	2.21
Redear sunfish	<0.01	-	-	-	-
Hybrid sunfish	<0.01	0.04	0.01	-	-
Spotted bass	0.02	0.01	0.02	<0.01	0.05
Largemouth bass	<0.01	0.01	0.01	<0.01	0.01
White crappie	<0.01	-	-	-	-
Slough darter	-	-	<0.01	0.03	-
Logperch	-	-	-	-	<0.01
Blackside darter	-	-	-	-	0.01
Total Density	2.55	6.17	4.35	2.40	5.21

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

[b]Common names according to the American Fisheries Society (C. R. Robins et al. 1991. *Common and Scientific names of fishes from the United States and Canada*. 5th Edition. American Fisheries Society Special Publication 20. Bethesda, Maryland.).

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

Table D.3. Fish densities (number per square meter) in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March 1992

Species[b]	Sites[a]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Stoneroller	0.69	1.78	0.10	0.16	<0.01
Red shiner	-	<0.01	0.03	0.10	-
Steelcolor shiner[c]	-	0.01	0.01	-	0.06
Redfin shiner[c]	-	-	<0.01	0.01	0.15
Suckermouth minnow	0.02	0.02	-	0.01	-
Bluntnose minnow	-	-	0.04	0.17	0.45
Fathead minnow	-	-	<0.01	-	-
Creek chub	0.02	0.06	0.17	0.18	<0.01
White sucker	0.02	-	-	-	-
Creek chubsucker	-	<0.01	0.01	-	<0.01
Yellow bullhead	0.01	0.01	0.17	0.03	0.01
Pirate perch		-	-	0.02	<0.01
Blackspotted topminnow	0.03	0.06	0.92	0.44	0.14
Western mosquitofish	0.06	0.04	-	0.16	0.01
Green sunfish	0.04	0.07	0.21	0.10	0.01
Warmouth	-	-	<0.01	-	-
Bluegill	0.08	0.03	0.15	-	0.04
Longear sunfish	0.83	0.45	0.99	0.08	0.65
Redear sunfish	0.01	-	-	-	-
Hybrid sunfish	0.01	0.01	0.01	-	-
Spotted bass	0.01	<0.01	0.01	-	0.03
Largemouth bass	<0.01	-	0.03	-	-
White crappie	<0.01	-	-	-	-
Slough darter	0.01	0.01	<0.01	0.03	-
Total density	1.84	2.55	2.85	1.49	1.55

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

[b]Common names according to the American Fisheries Society (C. R. Robins et al. 1991. *Common and Scientific names of fishes from the United States and Canada*. 5th Edition. American Fisheries Society Special Publication 20. Bethesda, Maryland.).

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

Table D.4. Fish biomass (in grams per square meter) in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, September 1991

Species[b]	Sites[a]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Bowfin	0.57	-	-	-	-
Stoneroller	3.01	9.39	0.71	0.80	0.09
Red shiner	0.01	-	0.07	0.08	<0.01
Steelcolor shiner[c]	0.12	-	-	-	0.34
Ribbon shiner[c]	-	-	<0.01	-	<0.01
Redfin shiner[c]	<0.01	-	0.01	0.02	0.28
Suckermouth minnow	0.21	-	-	0.29	-
Bluntnose minnow	-	-	0.31	0.65	1.71
Fathead minnow	-	0.01	0.01	-	-
Creek chub	0.48	0.35	0.60	0.72	0.05
White sucker	-	-	0.63	-	0.39
Creek chubsucker	0.02	0.85	0.64	-	0.56
Spotted sucker	15.06	-	-	-	-
Black redhorse	-	-	-	-	2.58
Golden redhorse	0.61	-	-	-	1.40
Black bullhead	0.17	-	0.08	-	-
Yellow bullhead	1.14	1.31	2.00	0.46	0.45
Pirate perch	-	-	-	0.03	0.04
Blackspotted topminnow	0.18	0.86	1.14	0.79	0.75
Western mosquitofish	0.01	0.05	-	0.10	<0.01
Flier	-	-	-	0.03	-
Green sunfish	0.69	3.13	1.86	0.94	0.78
Warmouth	-	0.08	0.07	-	-
Bluegill	1.41	2.42	1.52	-	0.23
Longear sunfish	6.94	11.86	4.01	1.05	11.05
Redear sunfish	0.11	-	-	-	-
Hybrid sunfish	0.30	0.58	0.13	-	-
Spotted bass	0.95	0.90	0.12	0.01	2.62
Largemouth bass	1.97	1.38	0.41	0.04	0.37
White crappie	0.16	-	-	-	-
Slough darter	-	-	<0.01	0.02	-
Logperch	-	-	-	-	0.01
Blackside darter	-	-	-	-	0.01
Total Biomass	34.12	33.17	14.32	6.03	23.71

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

[b]Common names according to the American Fisheries Society (C. R. Robins et al. 1991. *Common and Scientific names of fishes from the United States and Canada*. 5th Edition. American Fisheries Society Special Publication 20. Bethesda, Maryland.).

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

Table D.5. Fish biomass (in grams of fish per square meter) in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March 1992

Species[b]	Sites[a]				
	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Stoneroller	4.23	10.67	0.35	0.75	<0.01
Red shiner	-	0.01	0.02	0.08	-
Steelcolor shiner[c]	-	0.06	0.03	-	0.15
Redfin shiner[c]	-	-	<0.01	<0.01	0.11
Suckermouth minnow	0.13	0.16	-	0.06	-
Bluntnose minnow	-	-	0.05	0.26	0.75
Fathead minnow	-	-	<0.01	-	-
Creek chub	0.10	0.32	0.50	0.62	<0.01
White sucker	7.88	-	-	-	-
Creek chubsucker	-	0.07	0.45	-	0.01
Yellow bullhead	1.79	0.25	3.08	0.44	0.04
Pirate perch		-	-	0.17	0.02
Blackspotted topminnow	0.05	0.09	1.13	0.71	0.19
Western mosquitofish	0.02	0.01	-	0.04	<0.01
Green sunfish	1.18	1.47	1.60	0.67	0.13
Warmouth	-	-	0.03	-	-
Bluegill	2.71	0.46	2.07	-	0.16
Longear sunfish	17.14	6.50	7.14	0.67	3.84
Redear sunfish	0.47	-	-	-	-
Hybrid sunfish	0.31	0.25	0.30	-	-
Spotted bass	0.92	0.86	0.04	-	0.37
Largemouth bass	0.53	-	1.93	-	-
White crappie	0.08	-	-	-	-
Slough darter	0.01	0.01	<0.01	0.04	-
Total biomass	37.55	21.19	18.72	4.51	5.77

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

[b]Common names according to the American Fisheries Society (C. R. Robins et al. 1991. *Common and Scientific names of fishes from the United States and Canada*. 5th Edition. American Fisheries Society Special Publication 20. Bethesda, Maryland.).

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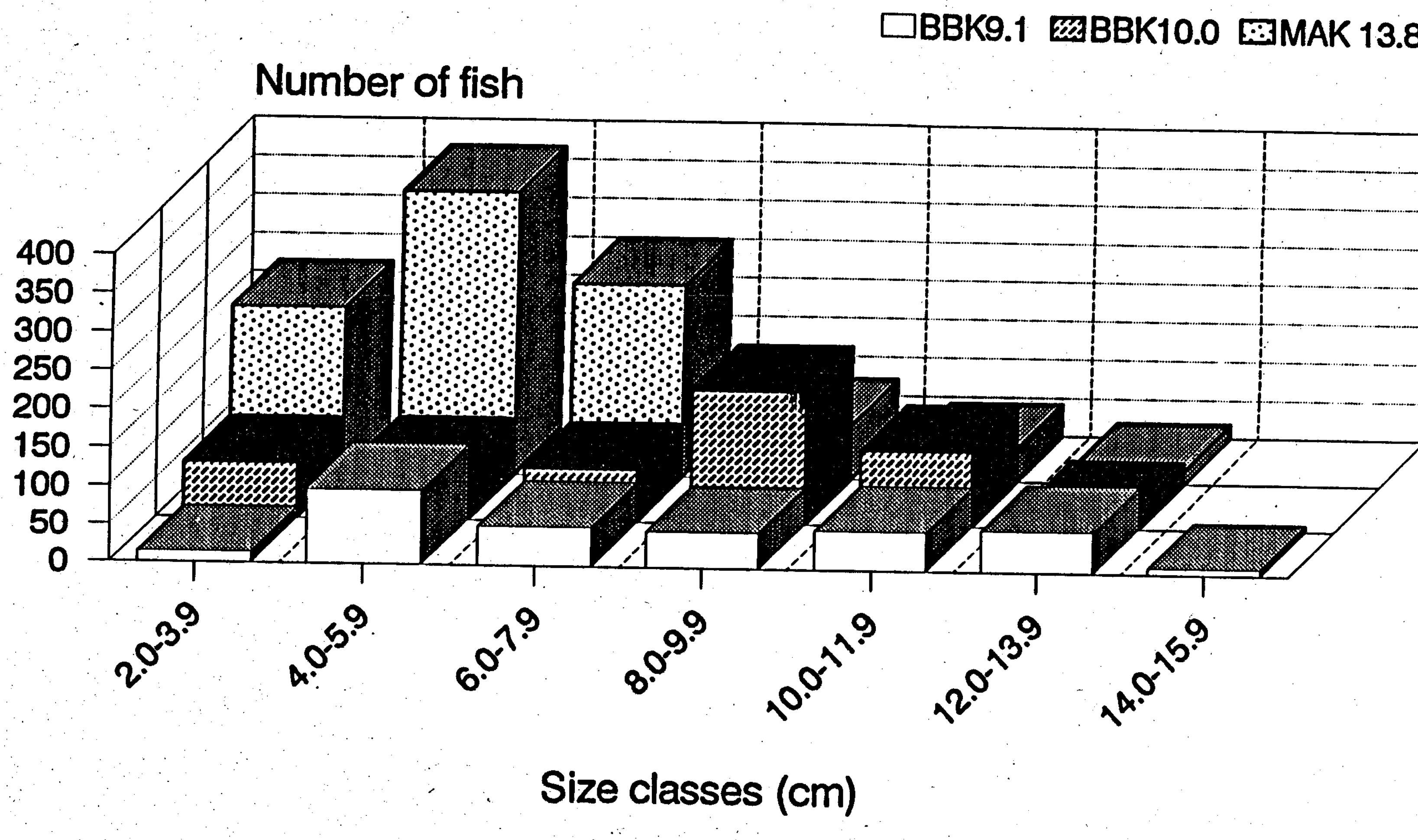

Fig. D.1. Length frequency of longear sunfish populations at Big Bayou Creek and Massac Creek during September 1991. BBK = Big Bayou Creek kilometer; MAK = Massac Creek kilometer.

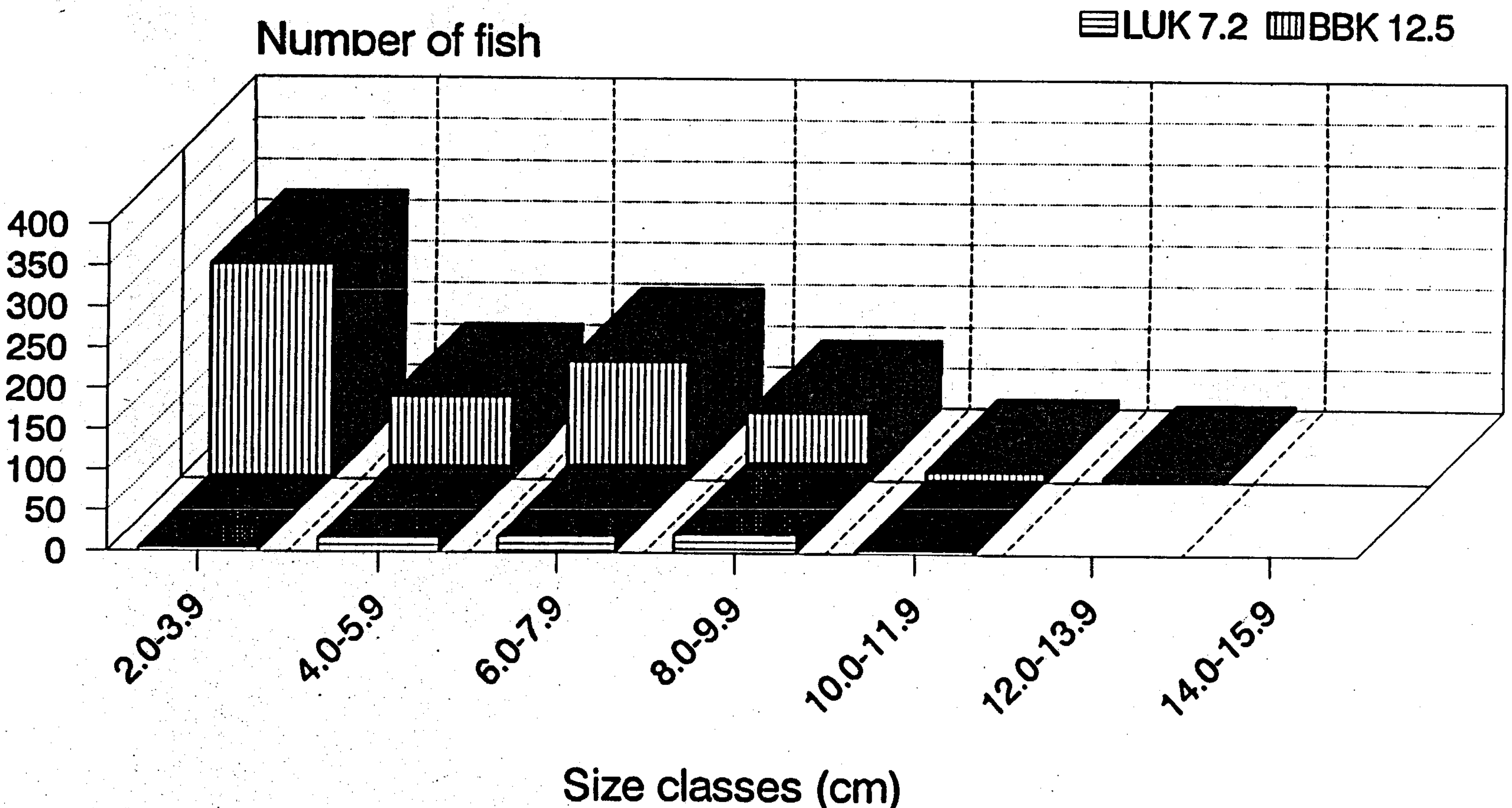

Fig. D.2. Length frequency of longear sunfish populations at Little Bayou Creek and Big Bayou Creek during September 1991. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer.

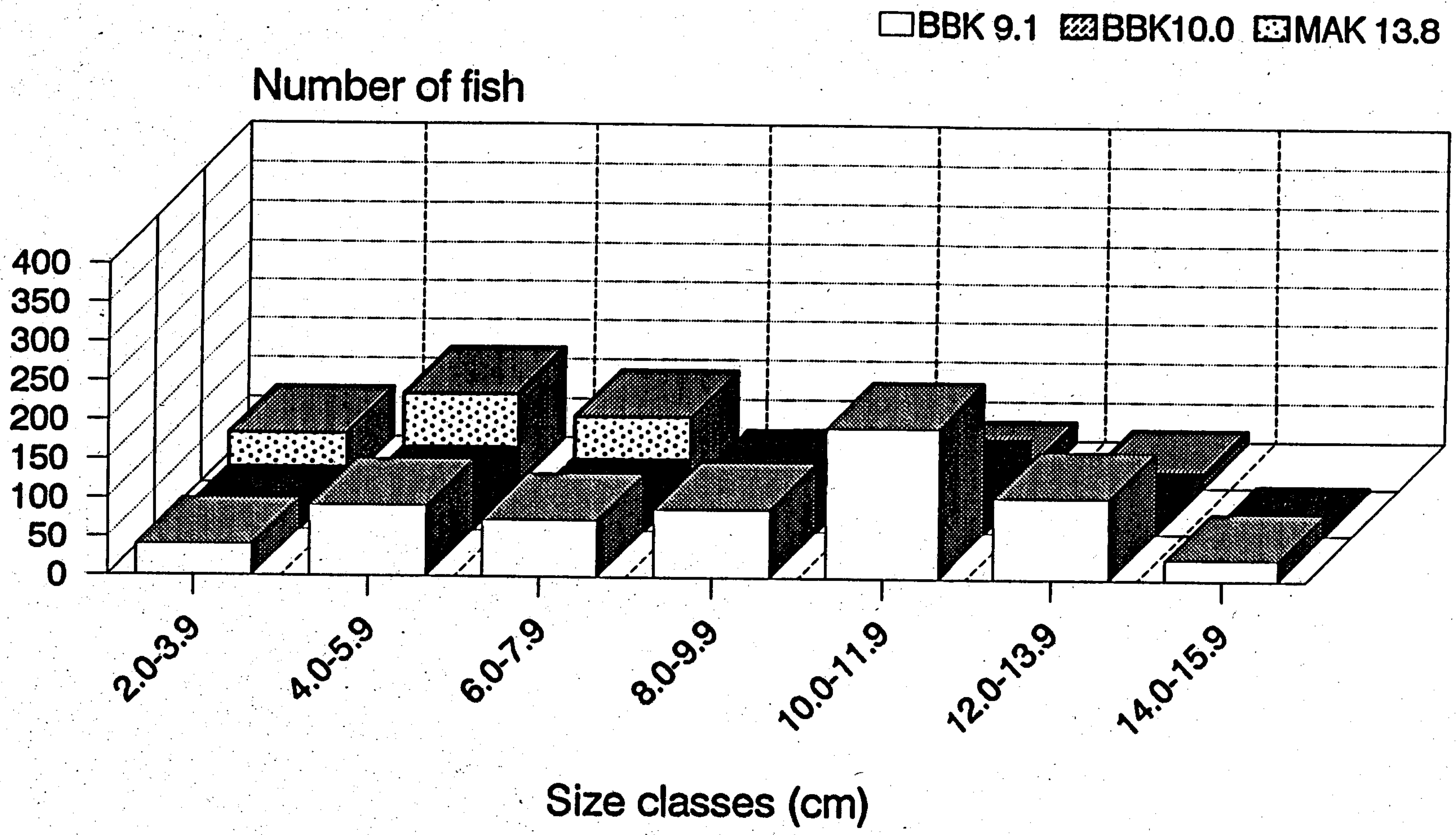

Fig. D.3. Length frequency of longear sunfish populations at Big Bayou Creek and Massac Creek during March 1992. BBK = Big Bayou Creek kilometer; MAK = Massac Creek kilometer.

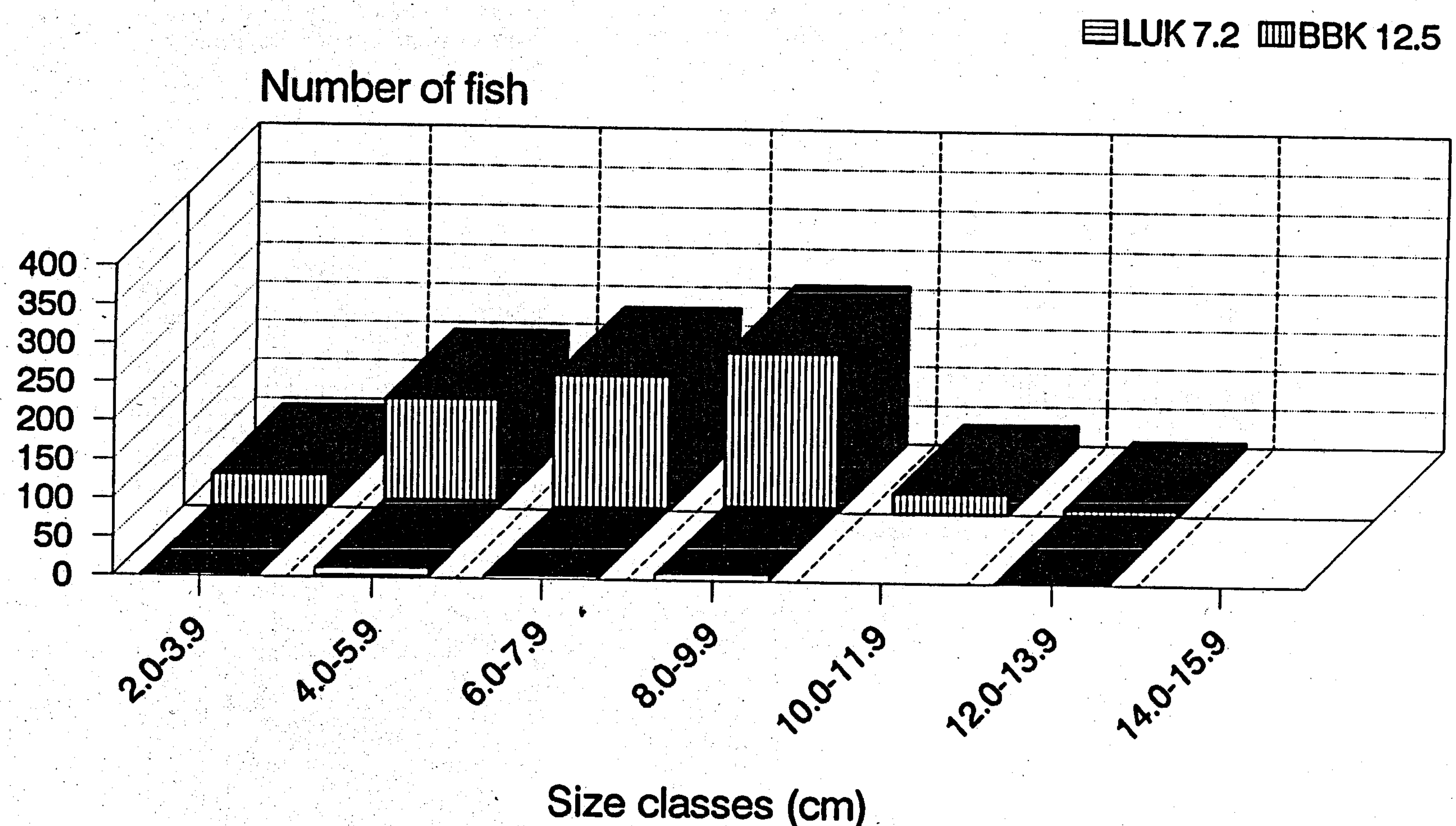

Fig. D.4. Length frequency of longear sunfish populations at Little Bayou Creek and Big Bayou Creek during March 1992. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer.

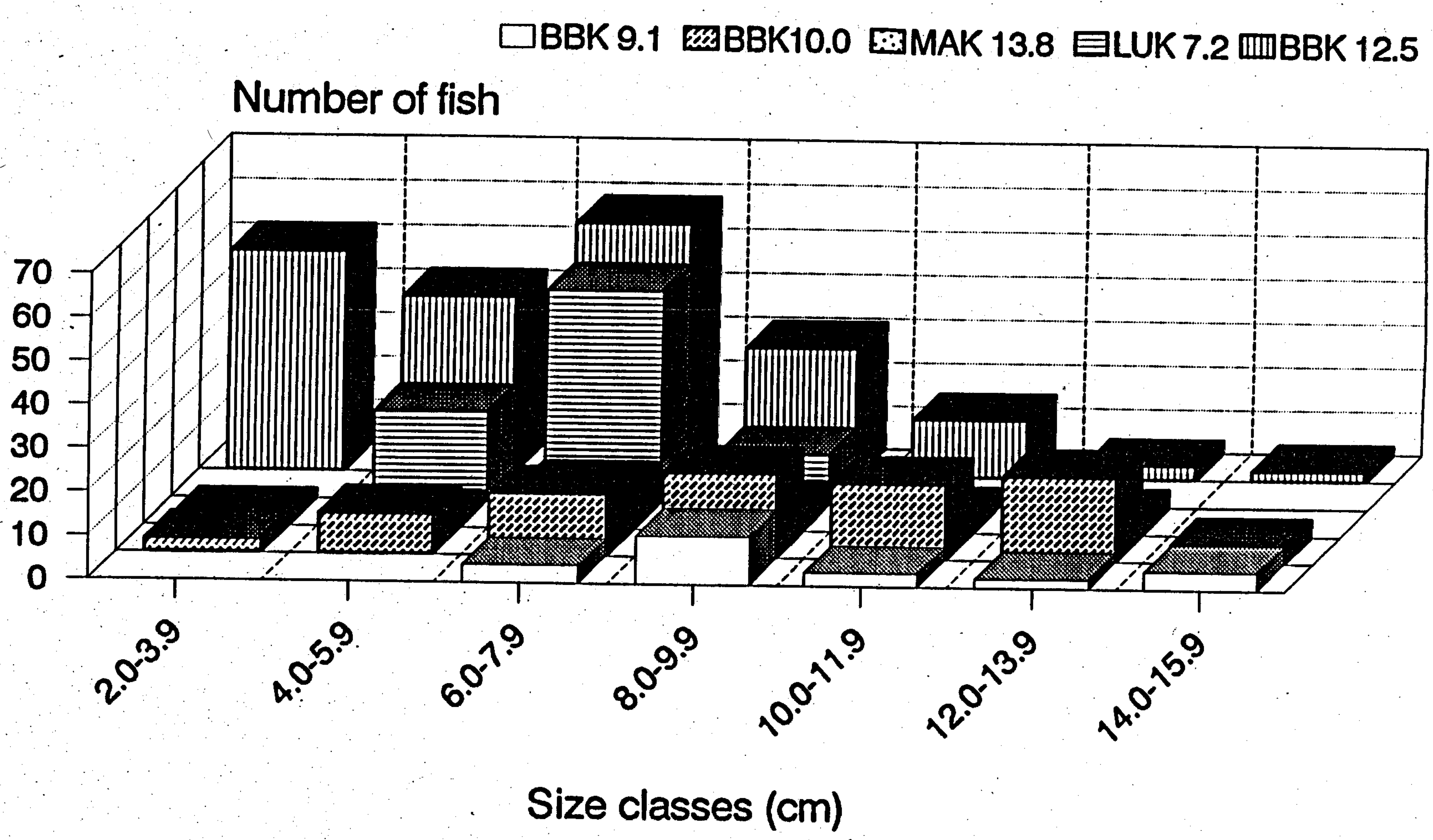

Fig. D.5. Length frequency of green sunfish populations at Little Bayou Creek, Big Bayou Creek, and Massac Creek during September 1991. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

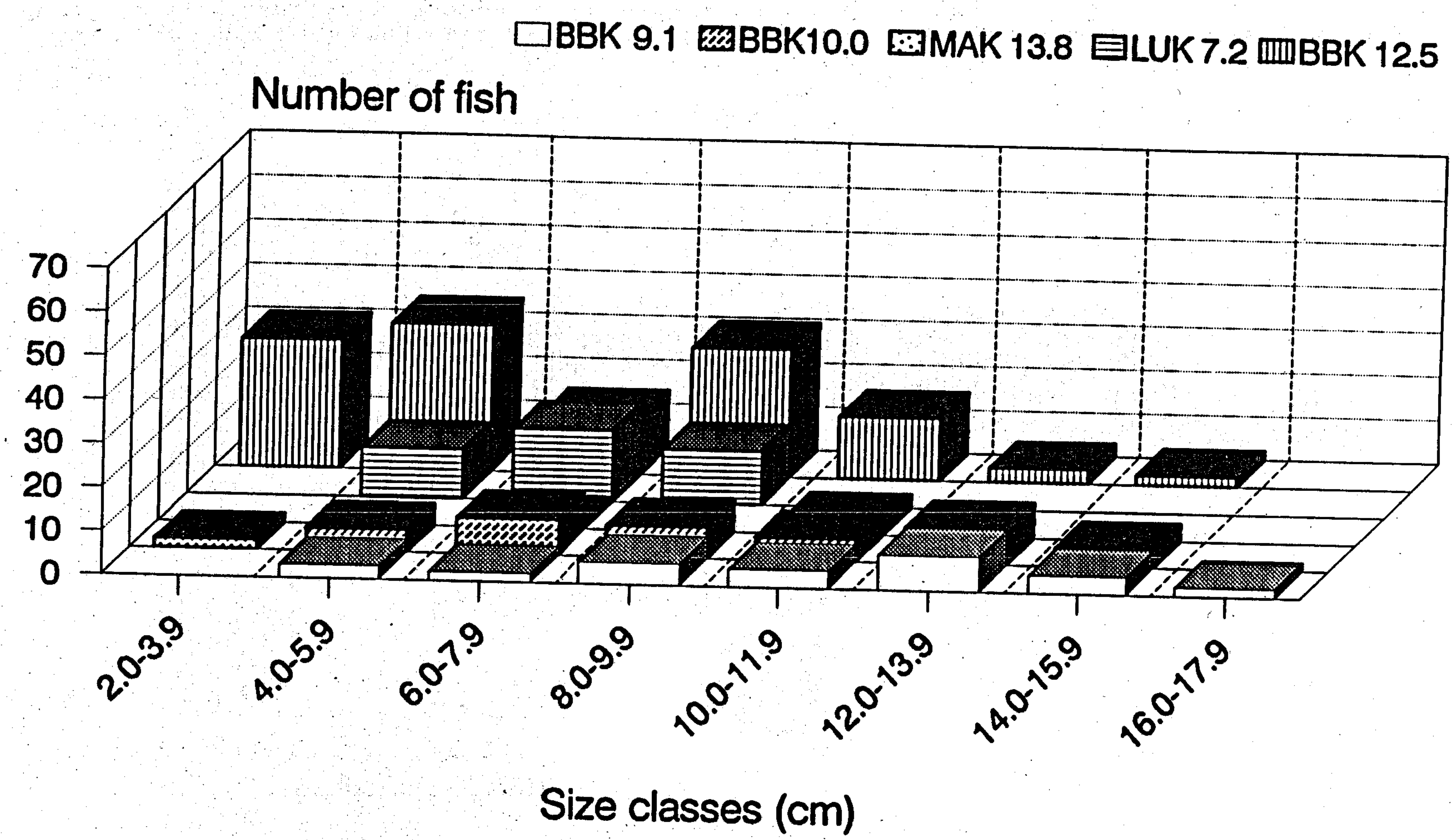

Fig. D.6. Length frequency of green sunfish populations at Little Bayou Creek, Big Bayou Creek, and Massac Creek during March 1992. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

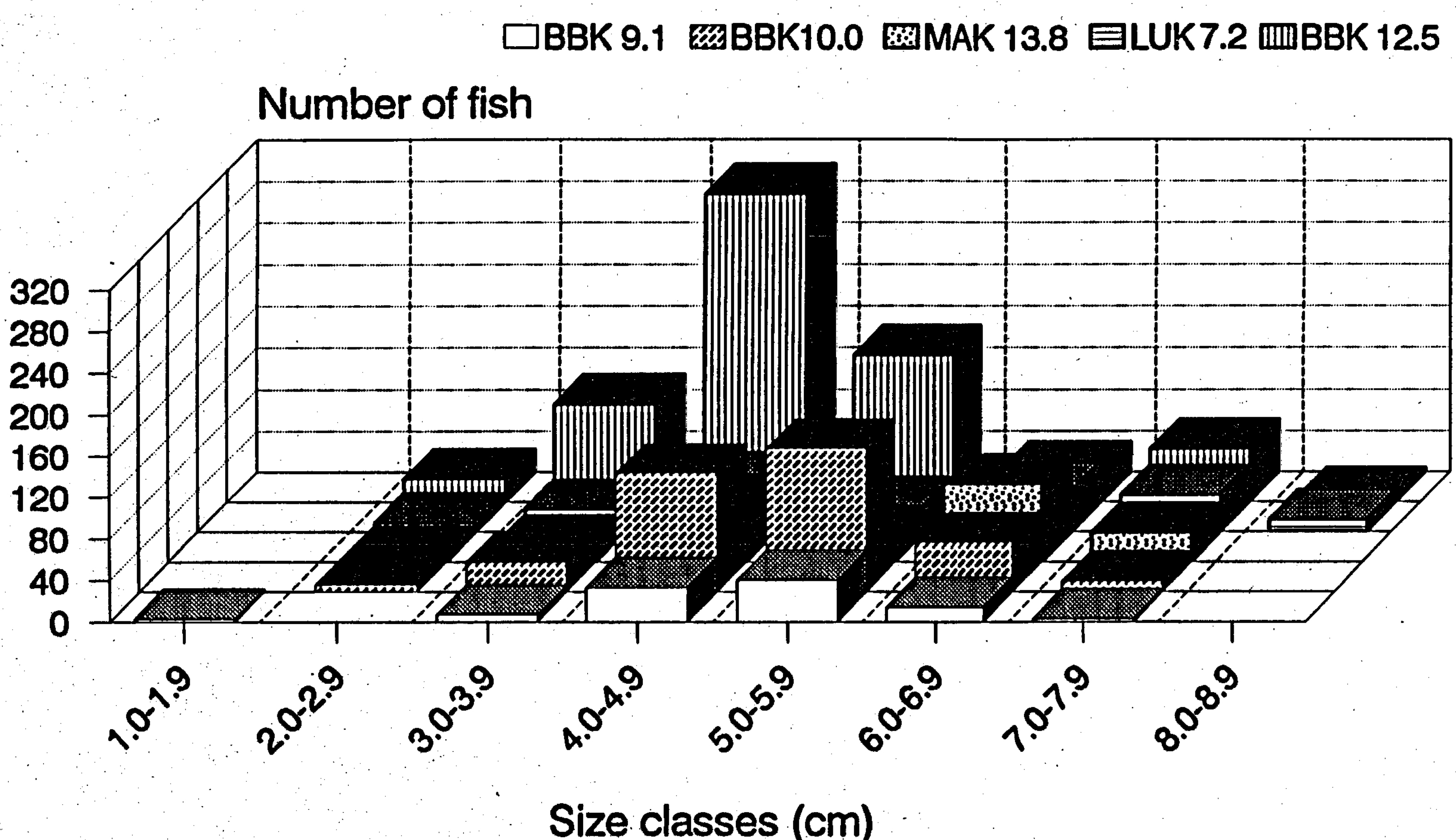

Fig. D.7. Length frequency of blackspotted topminnow populations at Little Bayou Creek, Big Bayou Creek, and Massac Creek during September 1991. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

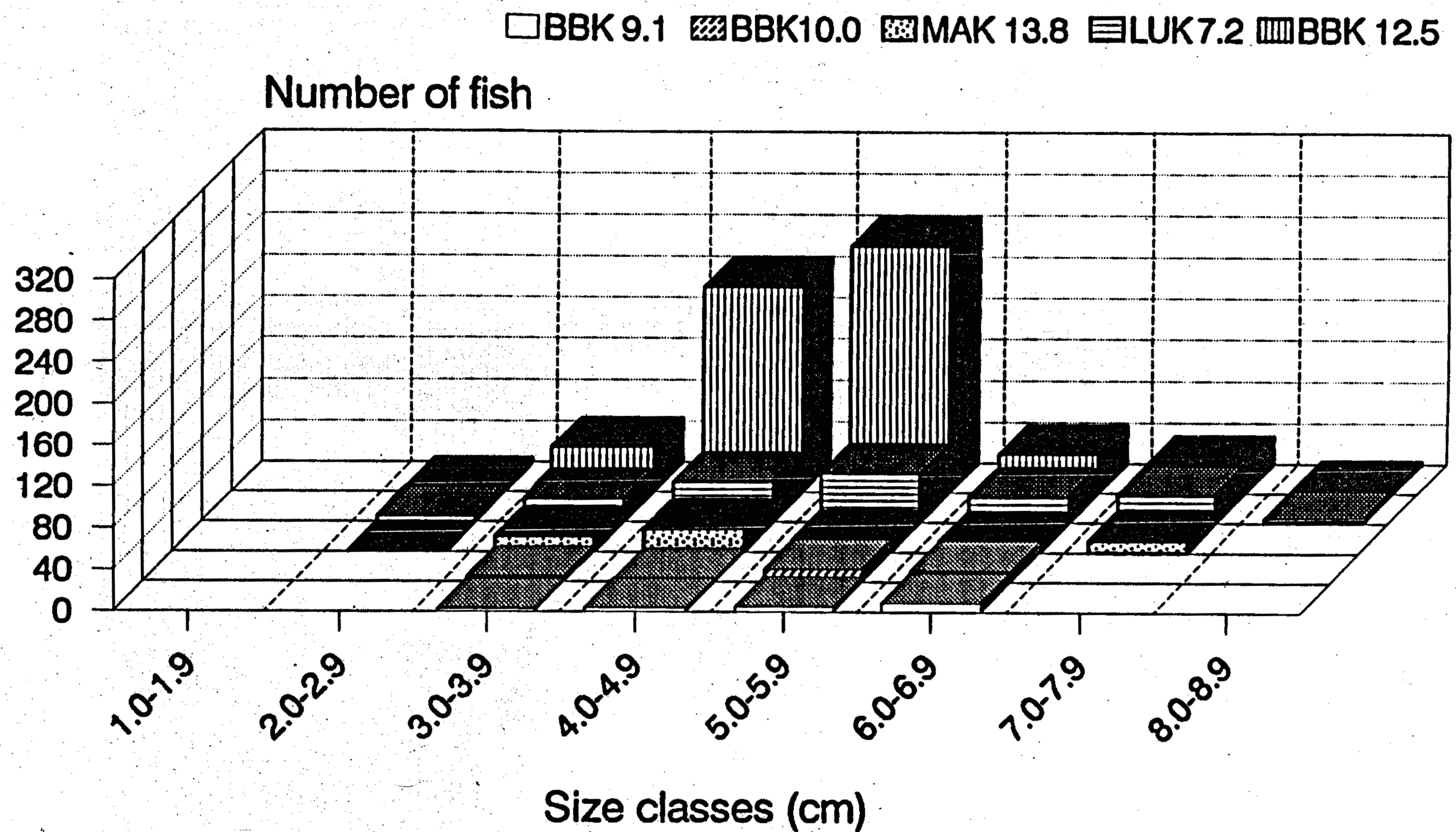

Fig. D.8. Length frequency of blackspotted topminnow populations at Little Bayou Creek, Big Bayou Creek, and Massac Creek during March 1992. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

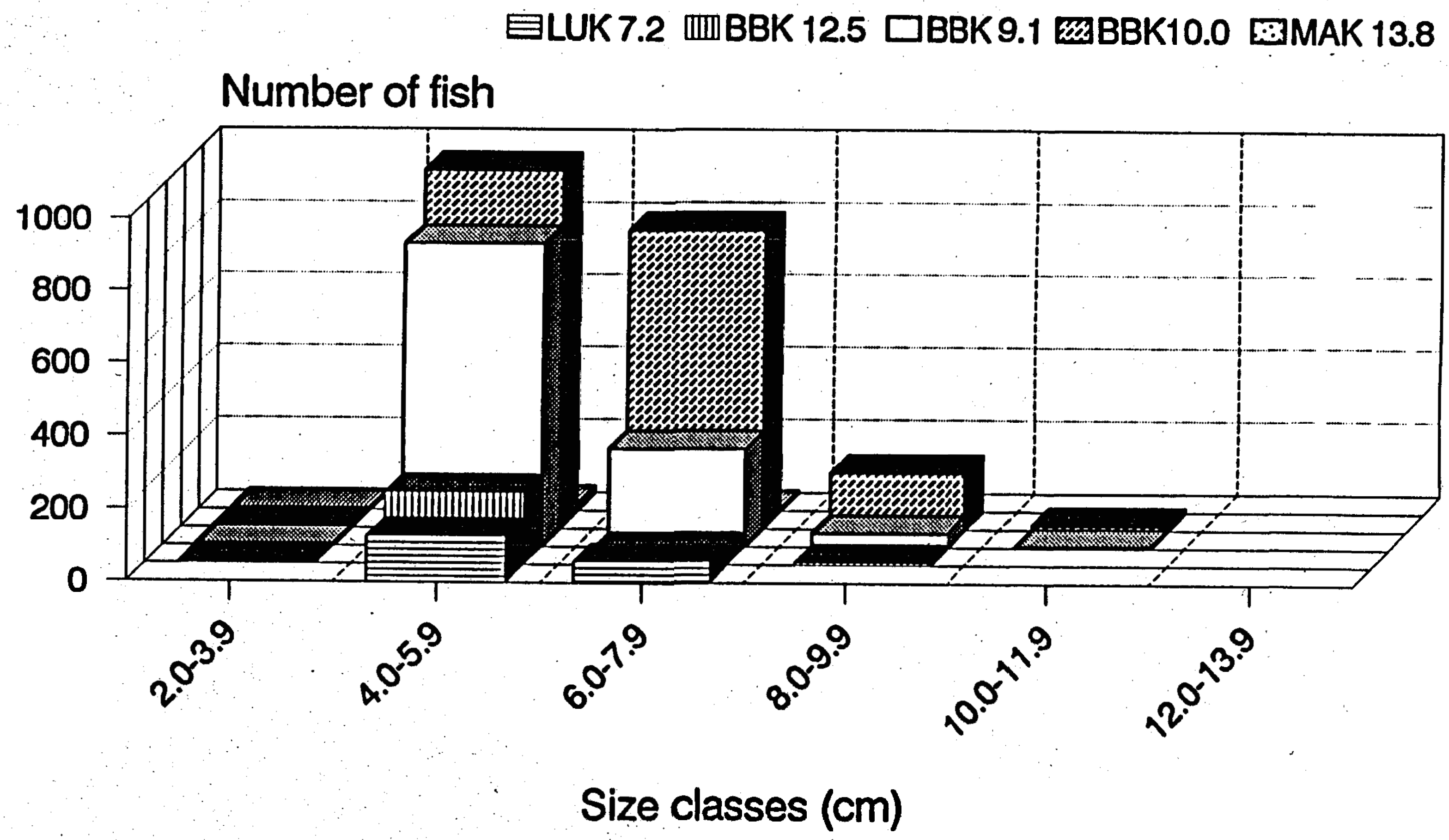

Fig. D.9. Length frequency of stoneroller populations at Little Bayou Creek, Big Bayou Creek, and Massac Creek during September 1991. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

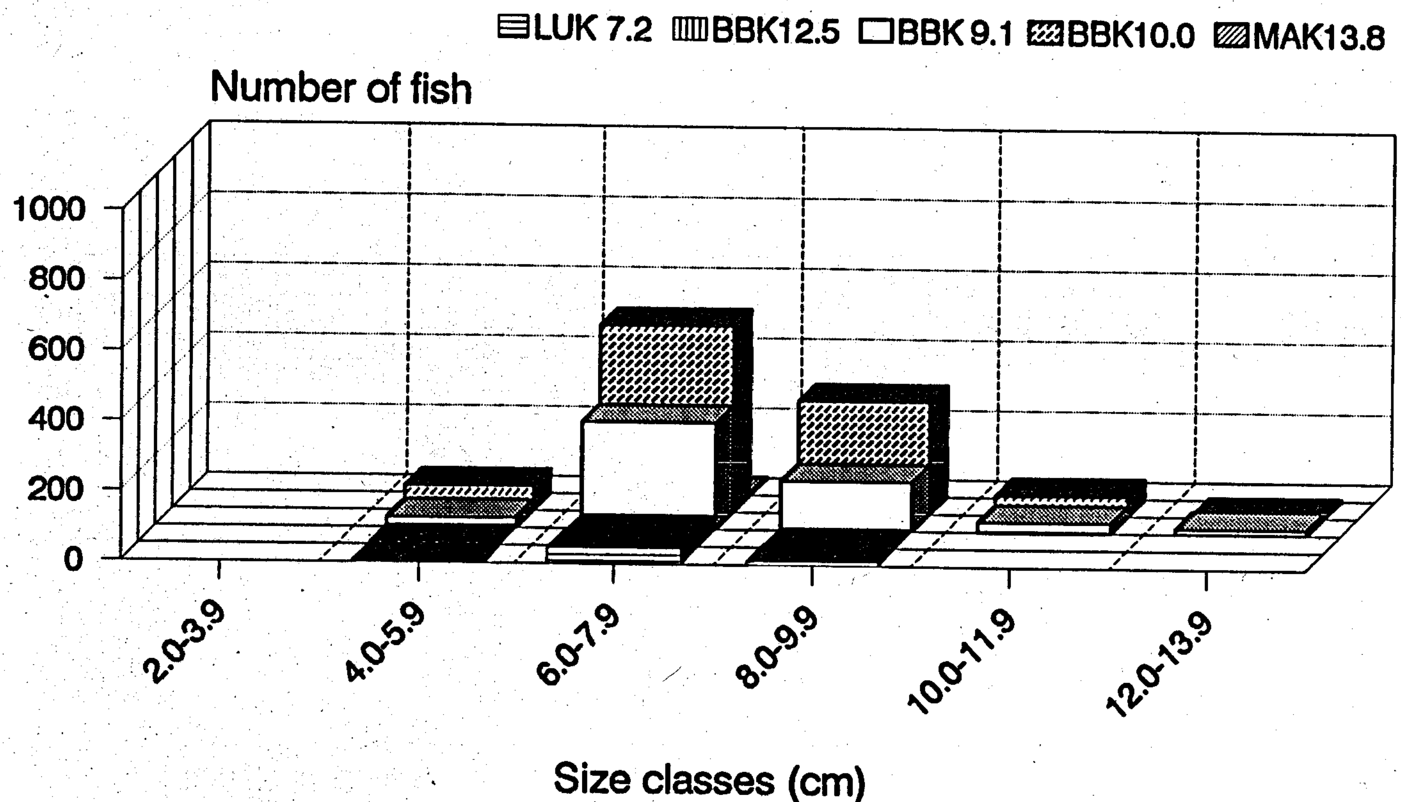

Fig. D.10. Length frequency of stoneroller populations at Little Bayou Creek, Big Bayou Creek, and Massac Creek during March 1992. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

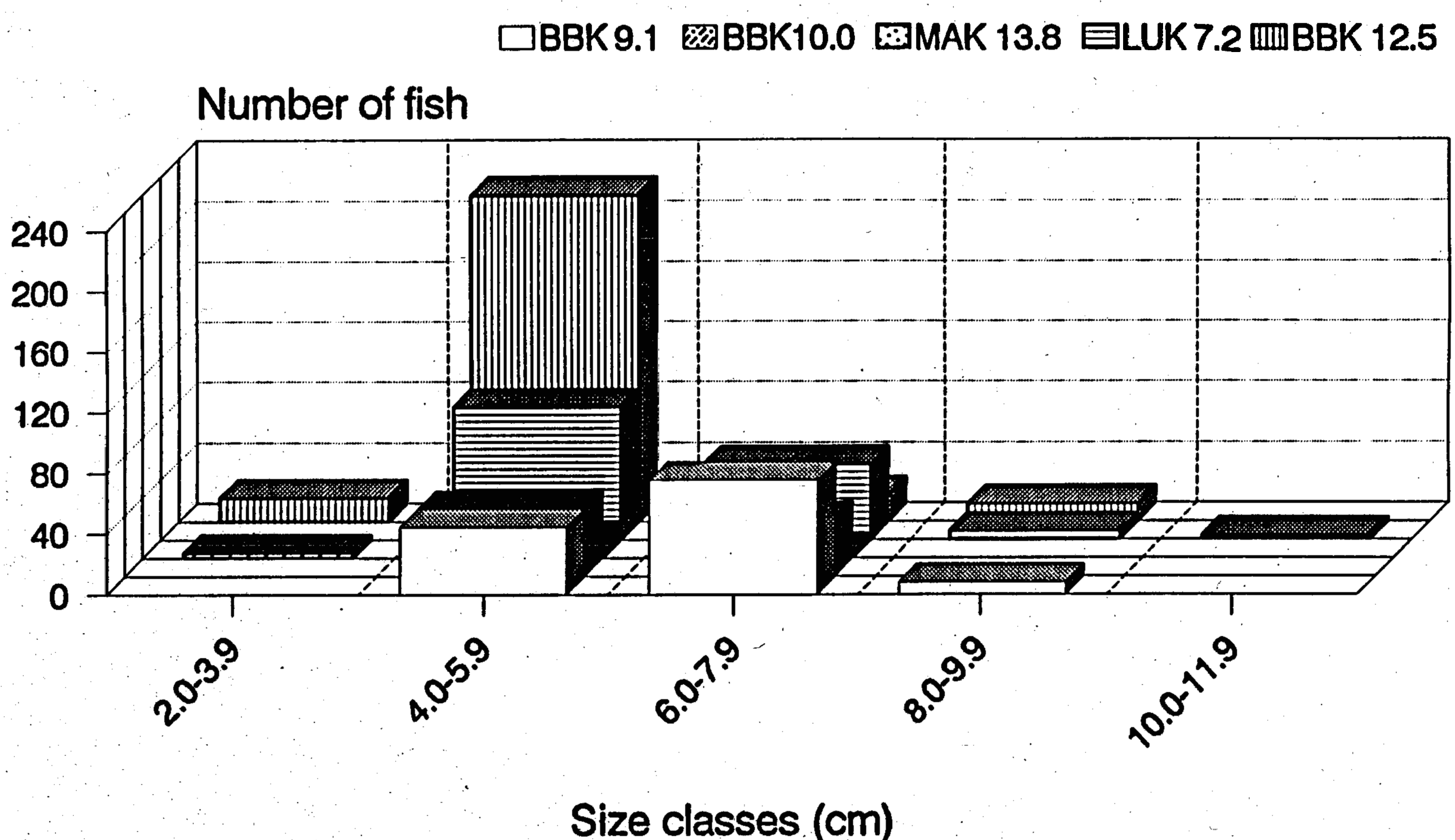

Fig. D.11. Length frequency of creek chub populations at Little Bayou Creek, Big Bayou Creek, and Massac Creek during September 1991. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

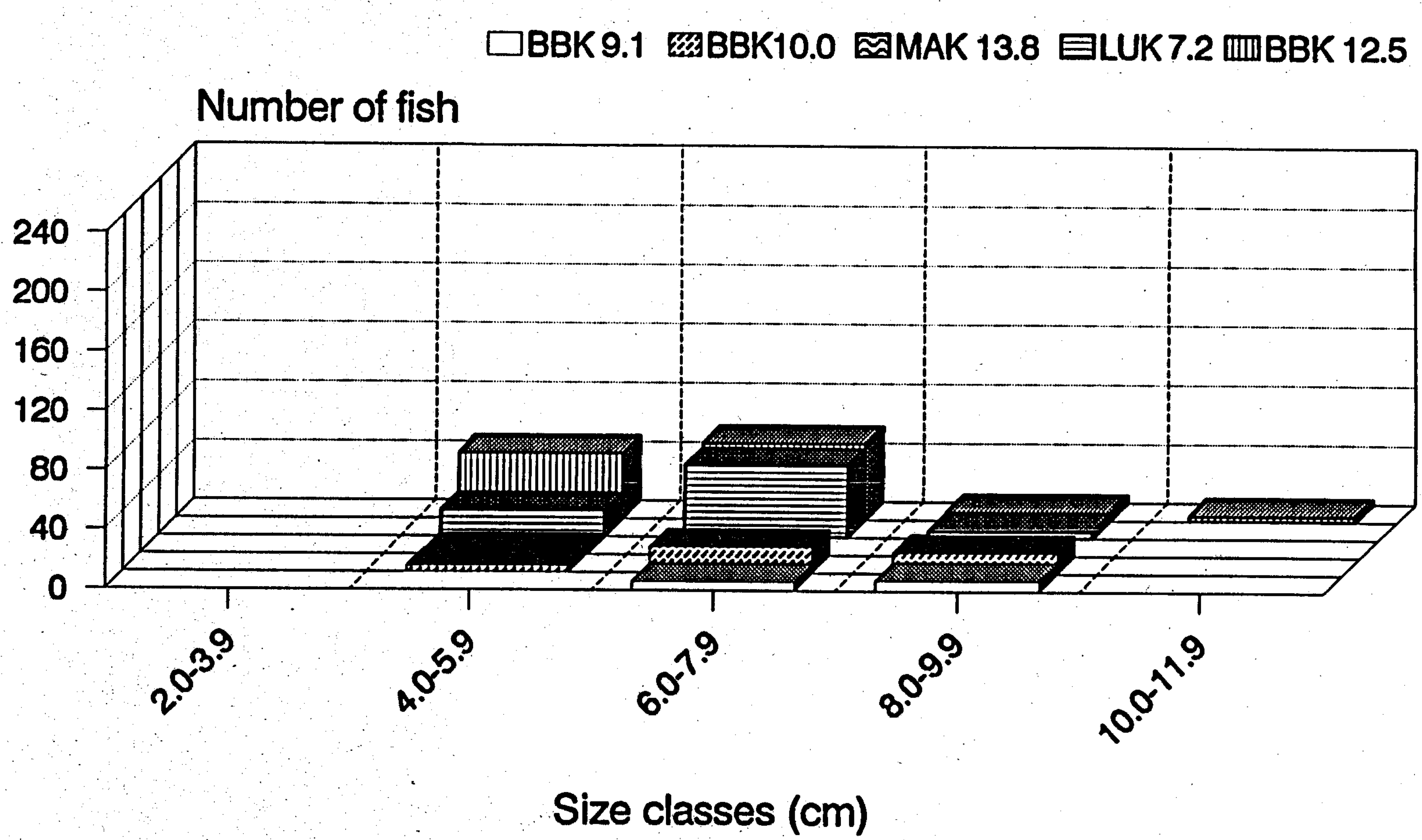

Fig. D.12. Length frequency of creek chub populations at Little Bayou Creek, Big Bayou Creek, and Massac Creek during March 1992. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

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